LOCAL AREA NETWORK ARCHITECTURES USING SPREAD SPECTRUM WITH MESH TOPOLOGIES

MAJOR THEODOROS N. MASTICHIADIS

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DEPARTMENT OF ELECTRICAL ELECTRONIC AND
INFORMATION ENGINEERING
SCHOOL OF ENGINEERING
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ABBREVIATIONS

ASK	Amplitude shift keying
AWGN	Additive white gaussian noise
BEP	Bit error probability
BER	Bit error rate
BITE	Built in test equipment
BPSK	Binary phase shift keying
CDMA	Code division multiple access
CR	Chip rate
CSMA/CD	Carrier sense multiple access, collision detection
C^3i	Command control communication information
DAPRA	Defence Advanced Research Project Agency
DS	Direct sequence
DSP	Digital Signal Processing
FCC	Federal Communication Commission
FH	Frequency hopping
FDMA	Frequency division multiple access
HDD	Hard disk drive
ID	Identification
IMP	Interface message processor
ISI	Inter-symbol interference
ISO	International standardisation organisation
LFSR	Linear feedback shift register
LAN	Local area network
MS	Maximal length sequence
OSI	Open system interconnection
PCB	Printed circuit board
PG	Processing gain

PR	Pseudorandom
QPSK	Quadrature phase shift keying
RAM	Random access memory
SIU	Sub-LAN interconnecting unit
SPSC	Spread spectrum
SPSCIU	Spread spectrum interface unit
SN	Serial number
SNR	Signal to noise ratio
TDM	Time division multiplexing
TDMA	Time division multiple access
TS	Time Slot
TSC	Topology spreading coefficient
VLSI	Very large scale integration

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a	Spread spectrum bandwidth efficiency coefficient
b	Attenuation factor introduced by the physical link
B_d	Subscriber's information bit rate
B_c	Transmitted chip rate
c	The attenuation introduced from the input of a node of a sub-LAN up to the input of the next node
$C_{(t)}$	The pseudorandom code sequence representation in the time domain
$D_{(t)}$	The data representation in the time domain
D_i	Coefficient of port usage
d	The degree of a node
e	The length in chips of a code member of the sequence used
E_s	Average energy of the SPSC signal (ensemble value)
F_c	Central carrier frequency of the SPSC sub-LAN
f_{B_d}	Bandwidth of a data bit at the frequency domain
f_{B_c}	Bandwidth of a chip at the frequency domain
$f_{(n)}$	Frequency shifting that corresponds to the subscriber n of a sub-LAN for signal transmission at the analogue modulation scheme
$Ftr_{(n)}$	Frequency used in the analogue modulation scheme for the transmission of the shifted signal
g	Total number of subscribers that are served by a sub-LAN
h	Number of nodes that form the shortest virtual path between any two nodes
$H_{(f)}$	The Fourier transform of a matched filter impulse response
L or l	Maximum number of subscribers that a node can support
$I_{(t)}$	Interference signals representation in the time domain
j	Number of sub-LANs of a LAN
k	Total number of nodes of the sub-LAN
$K_{n_i m_j}$	Coefficient of preference - The preferability of calling a subscriber 'i' of node 'n' any other one 'j' of node 'm' is defined by this coefficient of preference

$n_{(t)}$	AWGN representation in the time domain
$N_{(f)}$	AWGN representation in the frequency domain (spectral density)
N_o	AWGN power
O_{n_i}	The total traffic generated by subscriber 'i' of node 'n'
p	The percentage of power that results after the appliance on the signal of any type of absorption (all types of losses that are introduced during the implementation of the transmission on a physical link and of the flooding) and matching attenuation from the output of the node up to the input of the next one
PG	Processing gain
$P_{r_{echoes}}$	Probability of echoes generation
$R_{(t)}$	The incoming signal at the receiver representation in the time domain
$S_{(t)}$	Representation in the time domain of the spread spectrum signal
SNR	Signal to noise ratio
T_c	The period of a chip
T_d	The period of a data bit
$T_{rd(i,j)}$	Signal transmission delay from node i to j
T_e	Time after which the power of a packet is extinguished
T_n	The mean time between any two succeeding transmissions of a packet into the network, independently of its source (from any user)
T_p	The duration of a packet
T_r	The mean transmission delay from the output of a node to the input of the next one
T_{rn}	The mean transmission delay of the SPSC signal from the moment it comes into a node untill its output from it
T_1	Period of the timing burst during the initial synchronisation procedure
T_{pr}	Required processing time for one bit into a node (from the time of reception till the time of transmission) during the initial synchronisation procedure
T_{tr}	The average normalised time that the traffic created by any user occupies a virtual communication channel.

T_s	The time interval between two successive transmissions of a timing burst during the initial synchronisation procedure
TSC	Topology spreading coefficient
W	Initial transmitted power of the spread spectrum signal

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This work is dedicated to my wife Zinobia and to my children Nikos and Tina. I want to thank them for their patience over a long period of time, not only without complaint, but also encouraging me.

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DECLARATION

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ABSTRACT

This thesis describes a novel type of family of LANs, that is characterised by high performance, security and survivability. These qualities are of great importance for a lot of applications, especially in environments where uninterrupted operation and low overall time delay for message delivery are required. Such environments can be the military one, airports, crucial industrial areas, etc.

For this family of LANs a mesh topology with physical separation of the subscribers into intercommunicating groups, according to their properties and security demands, in combination with a modular structure is suggested. On this mesh topology a continuous retransmission of any received signal in any direction (flooding routing), together with the spread spectrum techniques, as a media multiple access method (Code Division Multiple Access) are used. This architecture guarantees survivability, offers security, gives possibility of simultaneous communication and similar performance to all the communication channels. The synchronisation and signalling problem of the LAN and the selection of the family of the spreading codes is solved through the use of known protocols, methods and technology. Many different architectures can be designed according to the above principles. Among them the idea of using a separate signalling and timing channel (e.g. a TDM channel) in a universal timing system improves the reliability, without affecting the performance.

A survivable and secure LAN topology, a member of this family, is described. The architecture and operation of two spread spectrum mesh topology LANs that use a signalling TDM channel and the maximal length binary sequences are examined and analysed.

The distributed design of the system in combination with the used code division multiple access method reduces greatly the collision probability and consequently the created delays. The statistical properties of the used packet switching method improves considerably the overall performance of the system. The selection of the spreading code bit rate defines the final bit error rate. Performance estimates for the flooding idea regarding the bit error rate and the collision probabilities have been evaluated. These estimates have been taken through the solution of a simplified mathematical model and verified from simulation tools that have been developed. These simulation tools compose an environment for the study of mesh topology networks.

A. INTRODUCTION

During recent years the revolutionary development of the technology, in any field and the dependence of the every day life upon it, for any type of human activity, enhanced the already imposed need for advanced communications and new services. The improvement in this area is continuous and is mainly coming through the following means of realisation of these requirements:

- the massive and revolutionary use of computers for the development of communications,
- the introduction of the ISDN (integrated services digital network) and
- the use of fibre optic and VLSI technology.

The idea of communication is not involved any more only with the idea of the long distance interconnection but it has been spread out up to the level of the intercommunication of users, machines, instruments or appliances that are next to each other. Looking towards the solution of these problems interest has arisen in the installation and exploitation of Local Area Networks (LAN). A variety of LANs has been introduced and used up to now. Each one has its own individual features and properties, that cover particular requirements. Some of them have already been standardised, like the CSMA/CD, the Token Passing bus and the Token ring (J1,J2,J3).

So during the construction of any campus it can be accepted that there are four utilities (E1) that have to be taken into account and need to be provided. These are the traditional utilities of :

- electricity (wiring),
- water (plumbing)
- air (HVAC)
- and now the most recent one, the communication networks.

Through these communication networks the equipment should be interconnected and integrated services should be provided. Such equipment and services are:

- telephone, paging, video phone,
- data, management data base, word processing, photocopying, image filing (videodisk),

- electronic mail, telex, fax, message service, public address, high speed data,
- lock monitoring, access control,
- computer terminal, personal computer, computer mainframe,
- temperature sensing, thermostat, heating control, climate control, air conditioning, fire detection,
- lighting control, elevator control, energy management,
- pay TV, cable TV,
- loan management,
- etc.

It is imperative for such a network to be cost effective and to have the following desirable features (E1) :

- low cost per channel,
- large number of channels per desk,
- 10 or more digital channels,
- broad-band channel,
- transparency,
- ISDN/OSI compatibility,
- TTL level connection option,
- freedom of choice of equipment,
- freedom of choice of bit rate,
- reliability,
- simple circuitry,
- low component count.

There are environments where in addition to the above features there is also an increased need for:

- high quality of communications with efficient utilisation of the available bandwidth and elimination of any type of time delays,
- secure communications,
- survivable and uninterrupted communications.

Survivability means fault tolerance due to hardware redundancy, decentralisation, alternative routing between any two nodes and dynamic reconfiguration through communication signalling and synchronisation protocols, that guarantee uninterrupted operation. Security is the protection of the data against unauthorised reception. High performance is mainly characterised by low delays, low BER, high throughput, low blocking and collision probabilities. Cases with such requirements can be found in :

- A defence C^3I (Command Control Communication Information) system where any delay, interruption, leakage of information to unauthorised person or even loss of information can be crucial.
- An airport where any abnormality in the interconnection of the control tower with the radar, the aeroplanes and the other facilities can create a calamity.
- An industrial facility where any mistake to the production line command and control system can result to huge problems for the company.
- Etc.

Ongoing research in the field of office automation, trying to fulfil some of these requirements for environments like the above mentioned, has stimulated interest in the following areas:

- The exploitation of the spread spectrum (SPSC) properties (A1, A2, A4, A5, A6, A7, A8) for the design of high quality and secure networks or
- The use of topologies based on various types of connected graphs (mesh topologies) for the design of survivable networks (H1, H2, H3, H4).

Also in the field of network security recent trends demand the isolation of users with similar security characteristics into groups that intercommunicate through trusted bridges.

The current work aims to fulfil all the above referred requirements (security, survivability and high performance) in a new family of LANs, combining these areas (SPSC techniques and mesh topologies). So the architecture of this LAN is based (D25) at the use of :

- interconnected mesh topology sub-LANs,
- the Code Division Multiple Access (CDMA) method,

- the flooding routing protocols (continuous retransmission of the received signal in all directions) and

- a separate signalling channel.

For this architecture :

- The mesh topology in combination with the flooding and signalling protocols offers survivability.

- The SPSC techniques in combination with the user's separation into sub-LANs offers security.

- The SPSC techniques in combination with the distributed nature of the flooding and signalling protocols offers high quality services.

The LAN's users are physically separated into groups (sub-LANs), according to the security requirements. The sub-LANs are interconnected with trusted "Sub-LAN Interconnecting Units" (SIU). This creates a cellular structure with modular features. These LAN's qualities allow for easy expansion and give to the system a high degree of security. The flow of information outside a sub-LAN is always controlled by the intelligence of the SIU.

In the past, SPSC techniques have been used in the design of military networks and of commercial satellite networks. Today packet radio networks using CDMA methods (A9, A10, A11, G1, G2) are the state of the art in the field of the wireless communications, for integrated traffic. Up to now a lot of work in SPSC techniques has been described in the existing literature on individual subfields of the area, such as: synchronisation, pseudorandom (PR) sequences, CDMA, design of wireless networks, etc., but not many have been reported on the exploitation and integration of them for the creation of wired systems. Of course since the most of this work was oriented only towards military applications, it is possible that information about developed protocols and systems has not been published in the open literature. In existing published research results, in the area of local communications, the LAN was mainly examined as an application of a token or of the CSMA methods. It was only after 1982 that references about the use of the CDMA techniques in LANs started appearing. Since then the SPSC LAN is examined only under the topologies of bus and star. These topologies do not offer survivability. At section B.3 a quick overview of this work is given. These SPSC LANs offer good performance but from a security point of view have a drawback, they cannot be used in environments where users with various clearances classifications coexist. In 1985 the idea of designing wireless (radio) SPSC LANs for indoor (within buildings) use (G3, G4) was firstly introduced. Since then a lot of publications in this area appeared (A12, G5, G6, G7). LANs of this type are convenient from an installation point of view, but they do not cover the above security requirements, since they have the advantages and disadvantages of the radio SPSC networks.

The implementation of a LAN with the above qualities and characteristics needs rather complicated and expensive software and hardware compared with the conventional ones. However this cost is traded against the offered services and since its use is oriented toward special applications, it can be consider as cost effective. In addition to this the continuous development of VLSI, fiber optics and bandwidth availability, continue to reduce the cost and the complexity of the implementation.

The rest of this thesis is organised as follows :

- Part B is an overview of the theory of the SPSC techniques and the existing work in the field of LANs. It contains three chapters. The first one gives a short tutorial of the SPSC communication techniques. An attempt has been made to focus this tutorial on the basic principles of SPSC theory. The points that are highlighted are the SPSC definitions and qualities, the direct sequence (DS) communication method, the properties of the correlation method, the basic theory on the use of spreading codes and the processing gain. The second chapter describes the basic aspects and definitions of the theory of LANs. The third chapter refers to existing work in the field of SPSC LANs.

- Part C is a high level description of the architecture of the proposed family of mesh topology SPSC LANs. It consists of four chapters. In these chapters an analytical description of the philosophy and the design aspects and principles used by :

    - the topology and,

    - the communication and signalling protocols

  involved is presented.

- Part D consists of five chapters. At them :

- A LAN member of this family of SPSC LANs as far as its structure and operation concerns is analysed.

- The LAN topology used is examined in greater detail.

- A description of the offered services and of the particular communication and signalling protocols that support them, is given.

- The compatibility and the relationship with the OSI model are examined.

- Two different protocols (a synchronous and an asynchronous one) are developed. An in depth discussion of their operation is done.

- In Part E a mathematical model of the suggested network is built. Through this model :

  - An analysis of the distributed power in the LAN as a function of the topology and in relation with the traffic supported is given.

  - The congestion probability, the probability of having various power values distributed over the sub-LAN and the probabilities of the worst case power status are calculated. It is proved that when the optimum value of the chip rate is used, independently of the use of signalling information, a theoretically null BER can be achieved and that the congestion probability is negligible.

- Part F deals with the simulation tools that were developed for the study of the behaviour of the flooding idea of the SPSC signals on mesh topologies at the physical layer. These tools can be consider as a basis for the creation of a performance evaluation simulation environment, for mesh topology LANs. The software is described. Through these tools performance estimates of the flooding idea, for this family of LANs, are evaluated. The influence of the traffic distribution in the LAN to the power distribution in it is discussed.

- Part G is the conclusion. There the advantages and disadvantages regarding the current presentation are mentioned and recommendations for further research are given.

B. THEORY AND EXISTING WORK ON SPSC SYSTEMS AND LANs

B.1. SPSC TECHNIQUES IN COMMUNICATIONS

B.1.1. SPSC TECHNIQUES DEFINITIONS

SPSC techniques are an implementation of Shannon's information-rate theorem (Appendix A). They can be defined as following (A1) :

> "SPSC is a mean of transmission in which the signal occupies a bandwidth in excess of the minimum necessary to send the information. The band spread is accomplished by means of a code that is independent of the data. A synchronised regeneration of the code at the receiver is used for the despreading and subsequent data recovery."

A more practical approach to this definition is given by the FCC (A12). FCC defines two types of SPSC forms, the frequency hopping (FH) and the DS :

- FH systems transmit narrow band signals with varying forms of data modulation on varying carrier frequencies. The carrier is then hopped from one frequency to another, over a wide bandwidth, at relatively rapid rates. While the signal's peak power is not changed its average power is spread over a wide bandwidth (e.g. 50 hopping frequencies separated by minimum 25 kHz each, with no one frequency to be occupied for more than 0.4 seconds, within any 30 sec period). Figure B.1.1.1 gives a sample of frequency changes over a period of time.
- In DS systems the wideband signal is created by mixing a narrowband signal with a PR data sequence at a much higher data rate than the information being transmitted. The effect of this mixing will be to spread the original signal over a new bandwidth whose shape is dependent on the spreading modulation, the length of the PR sequence and the data rate at which the sequence is mixed. The degree to which this spreading is done is defined as processing gain (PG). According to the FCC definition of SPSC systems of

1985, the original narrowband signal is to be spread over a bandwidth of at least 500 kHz. With the most recent release of this definition (1990), the demand of a minimum performance of 10 dB PG at the correlator receiver has been added.

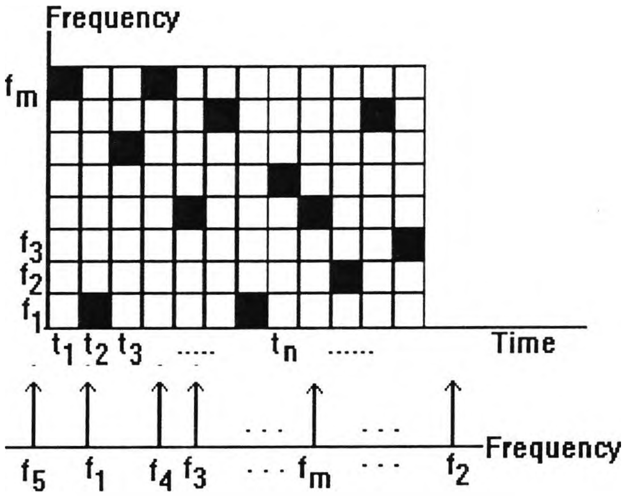


FIG. B.1.1.1 **The frequency changes over a period of time in a frequency hoping communication system.**

Multiple access DS SPSC communication systems can be created via the use of families of codes, for the spreading action, that are highly orthogonal each other (high auto-correlation values and low cross-correlation). This allows many signals to be transmitted simultaneously, over the same channel and in the same frequency bandwidth (fig. B.1.1.2). The involved code is usually a PR digital sequence of a much higher bit rate (named chip rate) than the data. Each data bit is replaced by such a sequence or by a part of it. This type of multiple access system is named a CDMA system (A2, A3).

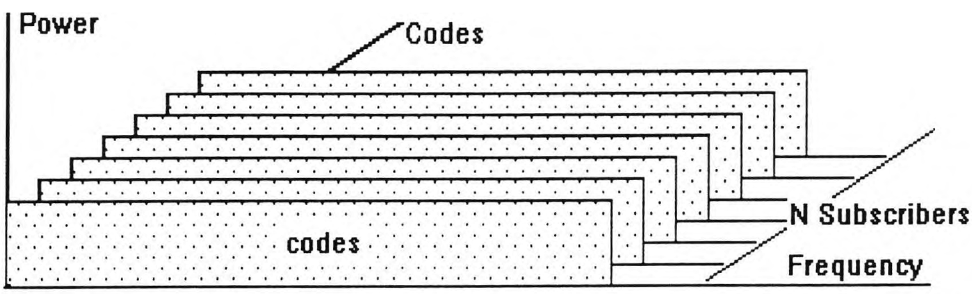


FIG. B.1.1.2 **Principles of operation of CDMA systems.**

The key terms that are met in these techniques are (A5):

- A. PG : Is the bandwidth expansion factor. It is equal to the ratio of the PR code bandwidth used for the spreading action over the bandwidth of the information. It can be seen that the higher the code bandwidth, the better are the interference rejection possibilities of the SPSC system. The increase in the spreading of the signal is achieved by the use of higher rate PR codes.

- B. orthogonality : This term describes the mutual transparency between two signals or the degree of interference the one to the other.

- C. correlation : It expresses the degree of agreement between a pair of signals $g_{(x)}$ and $f_{(x)}$ (autocorrelation if $g_{(x)}=f_{(x)}$ or crosscorrelation otherwise). It is described by the integral :

$$\int_0^{Td} g_{(t)} f_{(t)} \, dt$$

- D. codes : They are used in order to spread the information all over the required bandwidth for successful SPSC transmission. There are a lot of categories of codes that are used. Some of them are : Prime, Gold, JPL, linear, maximal, non-linear, etc. (A5).

- E. chip : It is the bit of the spreading code.

As has already been mentioned, the SPSC techniques have their own properties. These qualities attracted research interest for the creation of robust communication systems with improved performance. The penalty that has to be paid for obtaining these qualities is a higher hardware complexity and the occupancy of a channel with wider frequency bandwidth. These in the past were real problems and restricted the use of these techniques to military projects mainly, where the satisfaction of the requirements for improved quality compensated the increased cost. The recent advances in VLSI technology and the fiber optics applications, have largely eliminated these problems and have provided to the user wide bandwidths and complicated integrated circuits at very low cost. The main qualities of the SPSC techniques are (A1, A2, A4, A5, A6, A7, A8):

- A. The SPSC transmission is ideal for operation in a noisy environment. Through the despreading technique of the receiver any additive noise is spread even more, and consequently its power spectral density is reduced. This does not hold for AWGN, as it has infinite bandwidth and power.

- B. The SPSC transmission is not affected by other transmissions that operate in the same bandwidth and does not also affect them, since each one of them considers the rest as noise. Important preconditions are :

    - that the power level of all the transmissions is lower than a threshold that depends upon the design of the system.

    - that existing signals appear a low mutual interference (highly orthogonal signals) according to the specifications and to the design of the system.

- C. The SPSC techniques can provide low BER. Assuming a well-designed communication channel, then the BER theoretically can be reduced to 0.

- D. Because of the low power spectral density combined with the wide bandwidth that is transmitted, the SPSC signal is difficult to detect or to jam. It is difficult to detect because it is hidden under the noise, and an unauthorised user would need to know of its existence in order to find it. The signal is also difficult to jam, because of its wide bandwidth and the PG obtained through the despreading process.

- E. The SPSC techniques provide protection against unauthorised reception or transmission because of the use of dedicated, private, spreading codes. The degree of security offered is a function of the used code.

- F. The SPSC techniques provide a high anti-multi-path capability. The multi-path interfering signals are not synchronised in time or in phase with the PR code that is generated at the receiver.

- G. The SPSC methods allow multiple user communications with selective addressing capability. Every user has its own private code for transmission or reception, according to the protocol used.

- H. The SPSC techniques have embedded an accurate universal timing. The accurate synchronisation is essential for successful communications through these methods.

- I. The SPSC multiple access systems (CDMA) offer the possibility for concurrent communication capabilities.

- J. In SPSC multiple access systems the performance is similar for all the concurrently operating communication channels. In a CDMA system as the number of users increases, the quality deteriorates gradually and in the same way for every one of them.

B.1.2. DS SPSC SYSTEMS AND PR SEQUENCES

As already mentioned, in a DS SPSC communication link, the spreading of the digital signal $D_{(t)}$ over a wider bandwidth is achieved through the multiplication of it with a higher bit rate PR sequence $C_{(t)}$. Suppose

- that $C_{(t)}$ consists of 'e' chips of period T_C,
- that the period of a data bit is T_d,
- that the bandwidth occupied by the data is f_{B_d} and
- that the bandwidth of $C_{(t)}$ and of the spread signal $S_{(t)}$ is f_{B_C}.

Then $S_{(t)}$ should be (A1, A5):

$$S_{(t)} = D_{(t)} * C_{(t)} \qquad .1.$$

$$S_{(t)} = D_{(t)} \oplus C_{(t)} \qquad .2.$$

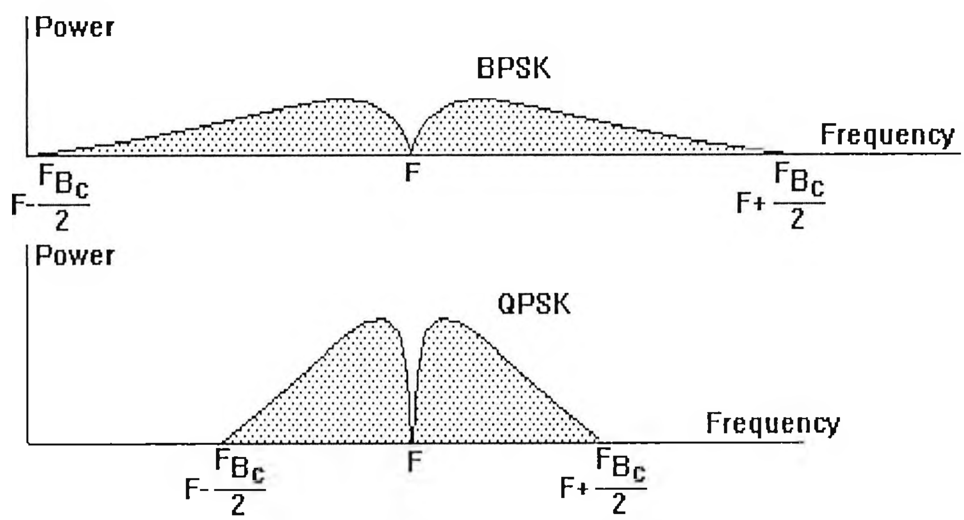


FIG. B.1.2.1 **Frequency bandwidth of a SPSC signal it use QPSK and BPSK analogue modulation.**

The use of equation (1) or (2) depends upon the type of signals that are involved. If they are bipolar (+V corresponds to 1 and -V corresponds to 0), then the first equation is in force. For pure digital signals where +V corresponds to 1 and 0 corresponds to 0, the other one is used. Both of them have the same effect, that is the spreading of the spectrum of the signal. The resultant chip stream can be transmitted either as a multi-level digital signal, or as an analogue one. In the case of analogue transmission, the spread signal is modulated and then is transmitted.

$$S_{(t)} = D_{(t)} * C_{(t)} * \cos(2\omega t) \qquad .3.$$

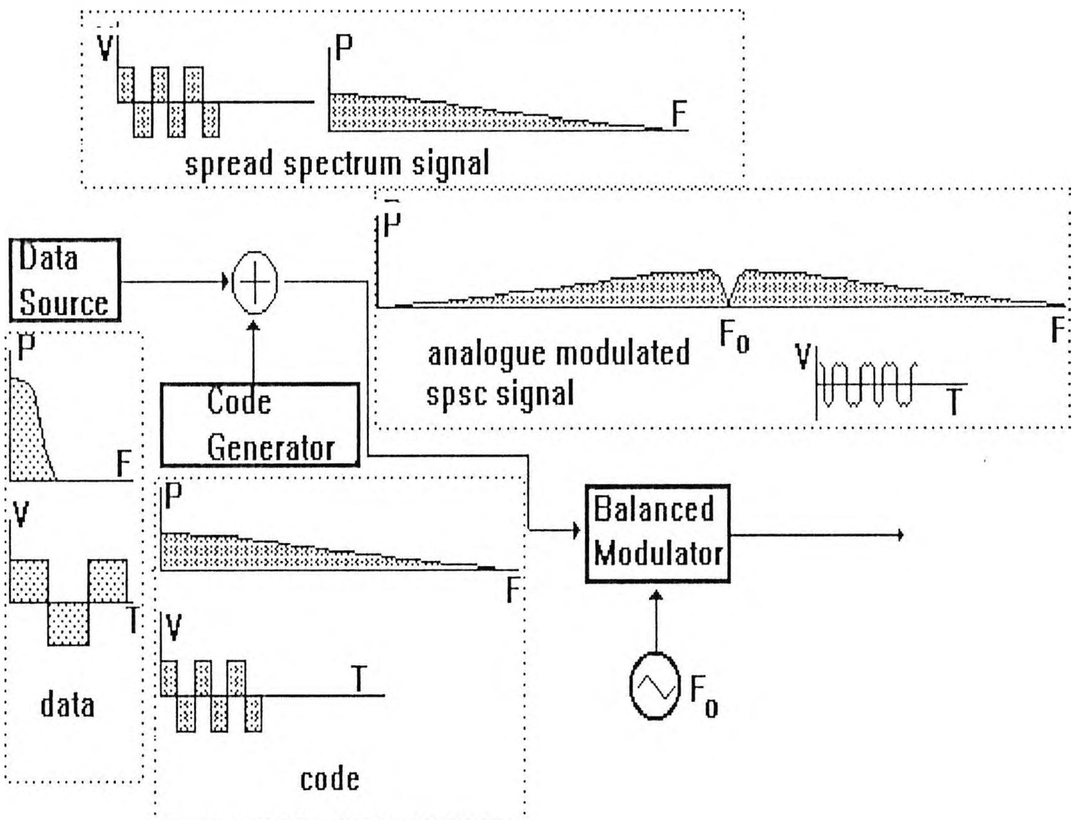


FIG. B.1.2.2 A generic form of a simplified SPSC transmitter.

Any type of modulation (amplitude, phase, etc.) can be used. Usually the BPSK scheme is preferred, since the balanced modulation produces a suppressed carrier component that helps in hiding the signal under the noise. The BPSK occupies a bandwidth, whose every main side lobe is equal to the value of the chip rate. QPSK or more than four phases shift keying can also be used. In these cases the occupied bandwidth is smaller (fig. B.1.2.1) and since the PG is a function of it, the PG is consequently lower (A3, A4, A5).

Figure B.1.2.2 illustrates a generic simplified SPSC transmitter, with the signals represented in both the time and frequency domains. The power of the message is spread over the wider bandwidth that is occupied by the code (fig. B.1.2.3).

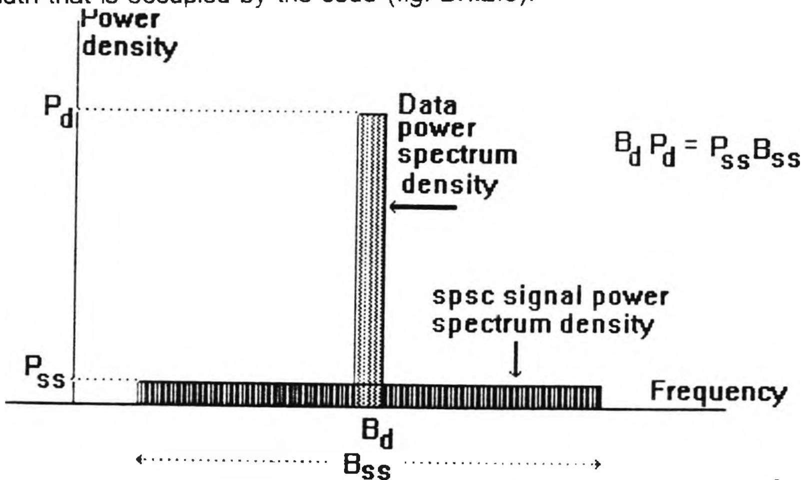


FIG. B.1.2.3 **Frequency occupancy and power spectral density in a SPSC communication system in contrast to the conventional ones.**

If it is accepted that the yielded power spectrum density of the signal is lower than the already existing power in the channel (noise plus other signals), then a SNR lower than one is created and the transmitted signal is hidden under the noise. So when the transmitted signal $S_{(t)}$ arrives at the receiver is :

$$R_{(t)} = \beta * D_{(t)} * C_{(t)} * \cos(2\omega t) + n_{(t)} + I_{(t)} \qquad .4.$$

where :

β is the transmission attenuation factor,

$R_{(t)}$ is the received signal,

$n_{(t)}$ is the additive white gaussian noise (AWGN) and

$I_{(t)}$ is any kind of interference signals.

The multiplication of the received signal with a synchronised replica of the spreading code and consequently the implementation of the correlation function reveals the initially transmitted message. At the receiver $R_{(t)}$ is amplified.

$$R_{1(t)} = D_{(t)} * C_{(t)} * \cos(2\omega t) + n_{(t)} + I_{(t)} \qquad .5.$$

The amplified signal is multiplied with a synchronised replica of the used code at the transmitter, during the implementation of the spreading function (A1, A3, A5). The produced signal is integrated over the period of one data bit (correlation procedure). If we assume that the received signal is synchronous with the used replica of the spreading code, then through this procedure the spread signal collapses to the original modulated one. After the analogue demodulation and the rejection of any unnecessary side-band lobes, the initial data bit D_i reappears. Figure B.1.2.4 illustrates a generic simplified DS SPSC receiver, with the used signals represented in both the time and frequency domains.

$$D_i = \sum_{k=1}^{e} \left[\int_0^{T_c} D_{(t)} * C_{K_{(t)}} * C_{K_{(t)}} * dt \right] \Bigg| 0 \leqslant t \leqslant T_d$$

where

$$\int_0^{T_c} C_{l_{(t)}} * C_{m_{(t)}} * dt = \delta_{ml} \quad \Bigg| \quad \begin{array}{l} \delta_{ml} = 1 \text{ if } m = l \\ \delta_{ml} = 0 \text{ if } m \neq l \end{array}$$

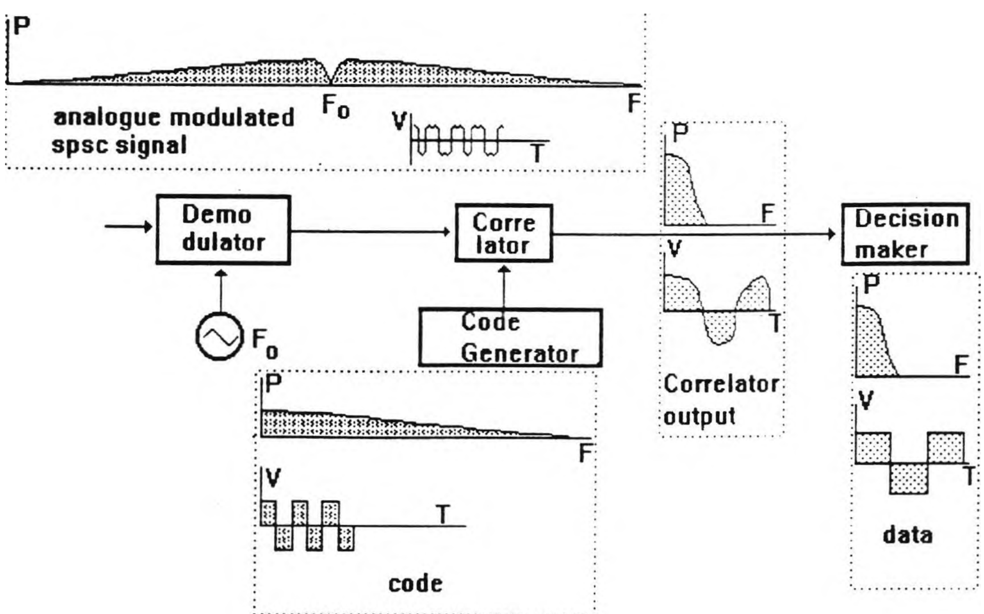


FIG. B.1.2.4 A generic form of a simplified SPSC receiver.

Any incoming signal follows the same process. Noise and interferences that are wider than the narrow band signal $D_{(t)}$ are also rejected. The undesired signals after the multiplication with the replica of the spreading code, are mapped into a bandwidth much wider than the original one. Any signal not synchronous with this code, through this multiplication procedure is spread, resulting in an enhancement of its bandwidth. In the above way the receiver will mostly reject any undesired signal.

$$X_{(t)} = R_{1(t)}C_{(t)} =$$
$$= D_{(t)}C_{(t)}^{2}\cos(2\omega t)+[n_{(t)}+I_{(t)}]C_{(t)} =$$
$$= D_{(t)}\cos(2\omega t)+[n_{(t)}+I_{(t)}]C_{(t)} \ / \text{ since } C_{(t)}^{2}=1$$

The demodulation procedure contributes further to this rejection.

$$X_{1(t)} = X_{(t)}\cos(2\omega t) =$$
$$= D_{(t)}[\cos(2\omega t)]^{2}+[n_{(t)}+I_{(t)}]C_{(t)}\cos(2\omega t) =$$
$$= D_{(t)}+[n_{(t)}+I_{(t)}]C_{(t)}\cos(2\omega t)+(1/2)D_{(t)}[\cos(4\omega t)]^{2}$$

Figure B.1.2.5 illustrates a simplified block diagram of a SPSC transmitter and of a receiver (A3).

As it was referred at section B.1.1 the amount of noise and interfering signals power that allows the demodulation depends upon the PG=f_{B_c}/f_{B_d}. At the following the PG for a matched filter detector and for AWGN (A1, A2, A5) will be estimated.

The average energy E_S(ensemble value) of a SPSC signal is (A2):

$$S_K = \int_0^{T_c} D_{(t)} * C_{K_{(t)}} * dt \quad \Big| \; 1 \ll K \ll e$$

$$\int_0^{Td} D_{(t)}^{2}\, dt = \sum_{k=1}^{e} S_K^{2} = \int_{-\infty}^{\infty} \left|\overline{H_{(f)}}\right|^{2} df = E_S$$

where $H_{(f)}$ is the Fourier transform of a matched filter impulse response. Consequently for AWGN with spectral density $N_{(f)} = N_0/2$ the SNR at the output of a matched filter detector should be :

$$SNR_{out} = \frac{E_s^2}{\int_{-\infty}^{\infty} N_{(f)} \left| \overline{H_{(f)}} \right|^2 df} = \frac{2E_s}{N_0}$$

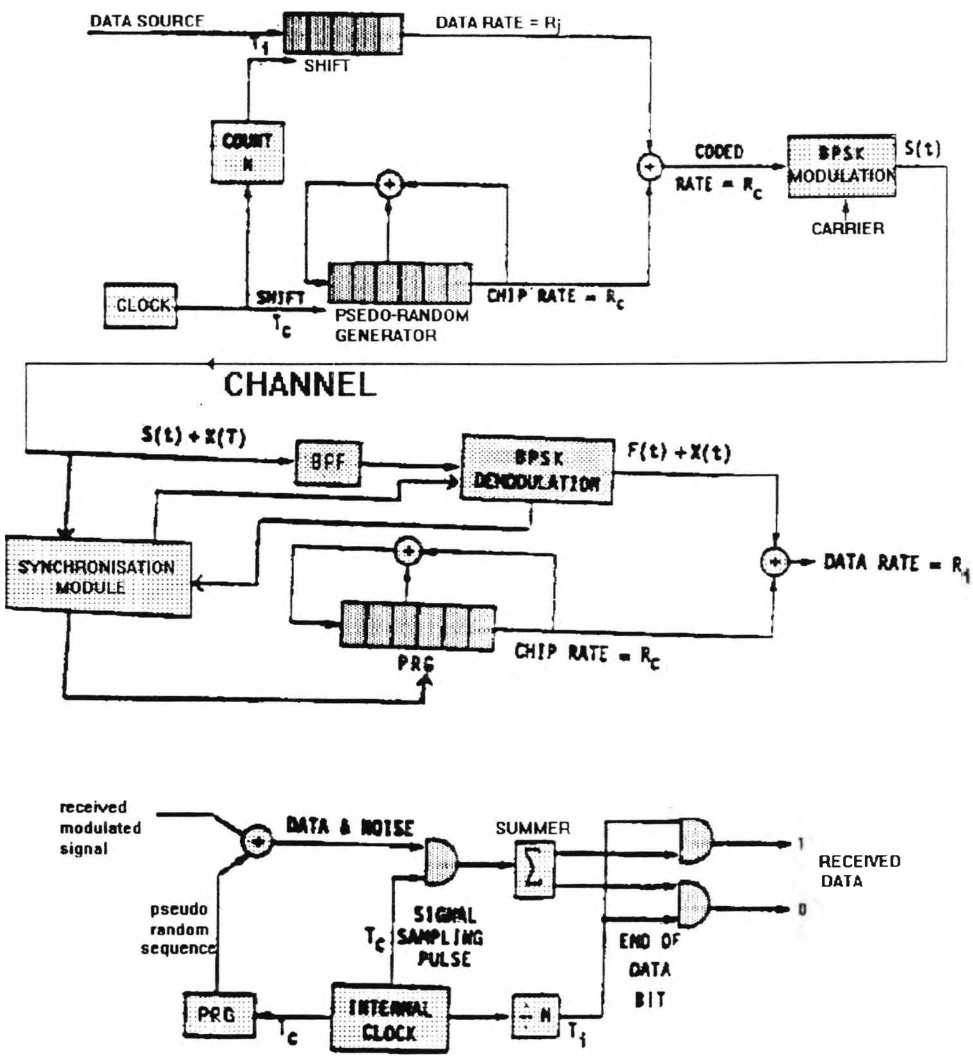


FIG. B.1.2.5 Simplified block diagram of a DS transmitter and a receiver.

This means that the SNR at the output of the matched filter depends only upon the energy of a data bit and not at all upon the shape of the filter. So the power W_{in} at the input of the receiver should be :

$$E_s = W_{in} T_d \Rightarrow W_{in} = \frac{E_s}{T_d}$$

Since the bandwidth of that matched filter should be f_{B_c}, then the noise power should be $2*(N_o/2)*f_{B_c}$ and so the SNR at the input of the filter should be :

$$SNR_{in} = \frac{\frac{E_s}{T_d}}{N_0 f_{B_c}} = \frac{1}{T_d f_{B_c}} * \frac{E_s}{N_0} = \frac{1}{2T_d f_{B_c}} SNR_{out} \quad .12.$$

$$SNR_{out} = 2 T_d f_{B_c} SNR_{in}$$

$$SNR_{out} = 2 (f_{B_c}/f_{B_d}) SNR_{in}$$

CDMA systems operate under the same principles and processes with DS SPSC techniques. Figure B.1.2.6 gives a simplified generic form of a CDMA communication system. Some preconditions of major importance for their successful operation are :

- The code members of the used spreading family of codes, should be highly uncorrelated with each other (orthogonal codes).
- The locally regenerated replica of the spreading code should be fully synchronised with the received signal, otherwise the resulting signal, after the demodulation, has lower power than the resulting signal from a fully synchronised code. This consequently reduces the final SNR.

A common problem often met at wireless DS SPSC networks and CDMA systems, is the "near far problem" as it is known. This is created from echoes or interfering signals that arrive at the receiver with high power due to a short distance from it. Some other interfering signals that are also creating a problem are echoes that due to multipath differences, arrive at the receiver synchronised with the main signal. These also result in interference.

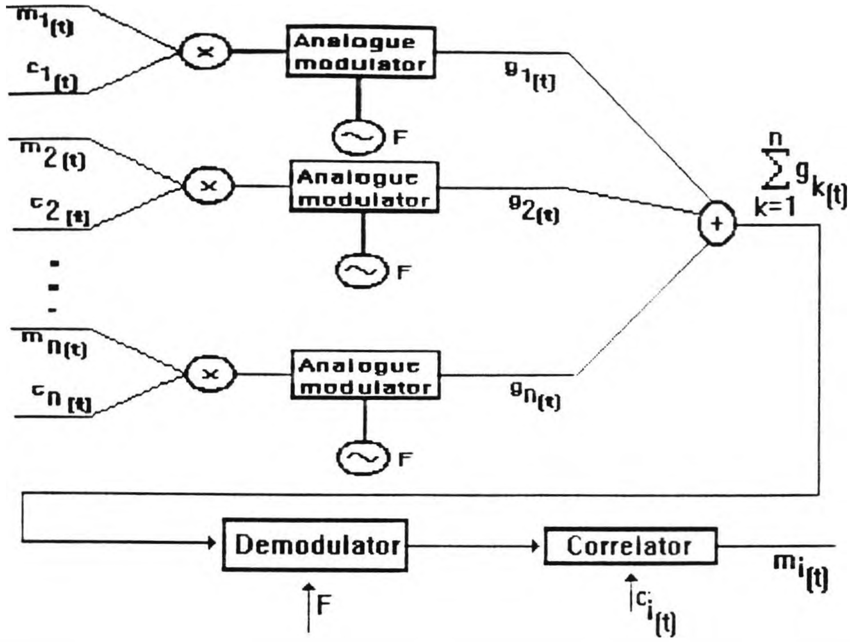


FIG. B.1.2.6 **Simplified generic form of a SPSC CDMA communication system.**

The synchronisation of the receiver with the transmitter is one of the major problems during the design of the SPSC systems. Good synchronisation means that the arrived at the destination coded signal is exactly timed, in respect of the carrier wave, the internal clocks and the PR sequence, with the locally generated one. The synchronisation procedure is performed in two steps :

- A search is executed by the receiver. It tries to synchronise the locally generated code form with the incoming one (acquisition).
- Once the acquisition has been completed the tracking procedure starts. This operates continuously, as long as the communication channel is activated. It aims to achieve and maintain accurate synchronisation of the incoming chips with the locally generated ones.

The codes used for the implementation of the spreading action at SPSC systems should have the following qualities (A1) :

- Existence of a large number of codes (it should be at least equal with the number of users).
- From a security point of view they must offer the required security classification demanded by the system specifications.
- Simple required hardware for their generation.
- Be easy to generate.

- Randomness properties.

- Long periods.

- Be difficult to reconstruct from a short segment.

- High autocorrelation while the crosscorrelation and the partial correlation should be very low.

Such PR sequences can be generated in several ways, exploiting the properties of linear shift registers (LSRs) combinations (fig. B.1.2.7) (A5). The created in this way PR sequences mostly follow the above requirements, although they are rather easily reconstructed from short segments. The use of non-linear logic overcomes this problem. Special optical codes are often created and used for optical SPSC systems (D1, D2, I1).

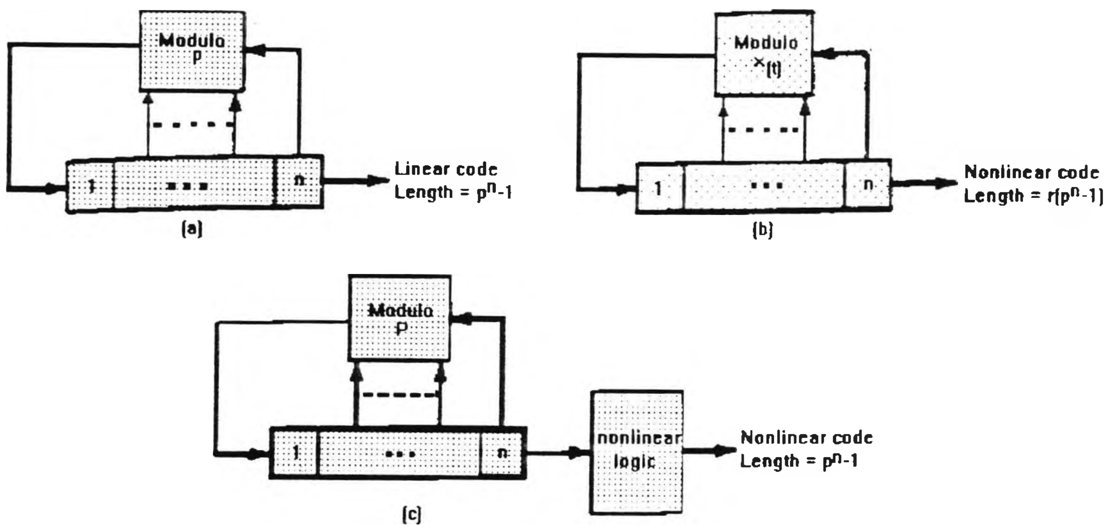


FIG. B.1.2.7 **Linear and nonlinear pseudorandom sequence generator configurations.**

The general equation that produces a PR sequence from a LSR is (A1):

$$C_n = \sum_{k=1}^{r} a_K C_{n-K} \, [\mathrm{mod}2]$$

where c_K represents the output of the 'k' stage of the LSR and a_K={0,1} the feedback coefficient (taps). Between the various families of codes that can be produced by the LSR is the family of

Maximal Length Sequences (MS). Its codes have the maximum length of a sequence that can be produced by a LSR of r stages : $L=2^r-1$. They can be used as the basis for the composition of other types of codes (A5).

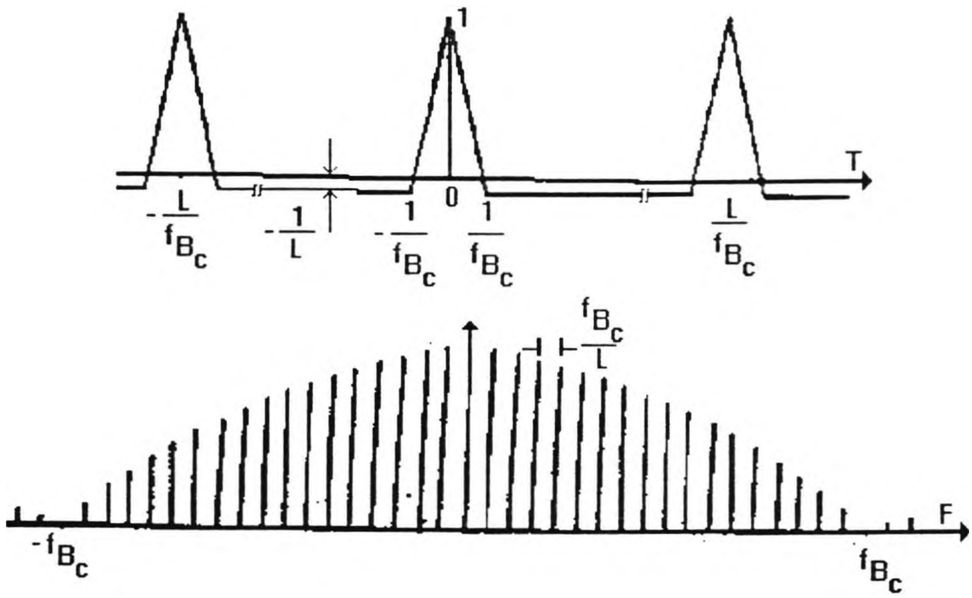


FIG. B.1.2.8 **The autocorrelation function and the power spectral density of a maximal length sequence.**

The main qualities of the MS are as following (A1, A5):

- There is a balance in the number of zeros and ones (2^{r-1} ones and $2^{r-1}-1$ zeros) that the MS consists of.
- In any period of n cycles, the number of cycles where the values of the consecutive stages are zeros or ones are
  - half of n of length one,
  - one-forth of n of length two,
  - one-eighth of n of length three,
  - etc.

- Consider a bipolar MS (the values of its bits are +1 or -1) then the autocorrelation function $R_{c(t)}$ gives :

$$R_{c(t)} = \frac{1}{L} \sum_{k=1}^{L} C_k C_{k+r} = 1 \text{ if } r=0, L, 2L, \dots \text{ or with } -\frac{1}{L} \text{ otherwise}$$

- In the frequency domain the MS occupy a spectrum $F_{c(f)}$ that is defined by the following equation :

$$F_c(f) = \left[\sum_{m=-\infty}^{\infty} \delta(f - mf_0) \right] \frac{L+1}{L} \operatorname{sinc}^2(\pi f T_c) + \frac{1}{L^2} \delta(f) \Bigg| f_0 = \frac{1}{T_c L}$$

Figure B.1.2.8 shows the power at the output of the correlator as a function of the synchronisation of the incoming signal with the locally generated code at the receiver. In the case of a synchronous signal the power is maximum. As the synchronisation deteriorates the power is decreased. At the same figure is also given the frequency bandwidth occupied by the MS.

- A modulo-2 addition of a MS with a phase shifted replica of itself, results in another replica with another phase shift different from the two originals.

$$C = C_n + C_{n+r} = \sum_{k=1}^{L} a_k \left[C_{n-k} + C_{n+r-k} \right] \bmod 2$$

B.2. LOCAL AREA NETWORKS

B.2.1. MILESTONES IN LOCAL AREA NETWORKS

During recent years computer hardware and software have been under a continuous development. So remarkable declines in the size of equivalent memory, increases in the processing speed and reductions in computing cost have been achieved. The result of these, especially after the explosion of personal computing, is that the availability of computers and the variety of their applications have been increased. For a lot of these applications the need for inter-computer data communications has arisen. The satisfaction of this requirement led to the design of computer networks. For the local environment the LANs developed. Although LANs were initially pure data networks, current research aims to the integration of their traffic (C1, C2) with voice and image.

Data communications have different requirements from voice communications (C3). Data communications :

- need high bit rates,
- have a burst nature,
- are not time critical,
- are not tolerant to errors and
- usually appear needs for local communication.

On the other hand voice appears the following characteristics

- has a high redundancy, around 50%,
- occupies the channel long periods of time (100sec on average for the circuit switching PCM systems) and
- is sensitive to delays (it cannot afford more than 250 msec of total delay).

A computer network is a communication system that allows a number of autonomous computer systems to exchange information in a meaningful way in order to do a job. Every one of the computers of the network, in order to communicate with any other machine, must obey particular protocols during the exchanging of information with the computer with which it is 'conversing' (C3, C4).

The LANs are resources sharing data communications networks that

- are spread over limited areas of 0.1 to 10 km with various interconnection patterns,
- use high bandwidths (over 1 Mbit/sec) and
- are usually privately owned.

They are met in Universities, companies, factories, etc. LAN's main characteristics are the topology and the medium access method. Although it is difficult to separate the topology from the transmission medium access method, as their combination gives the LAN's architecture, this will be tried here.

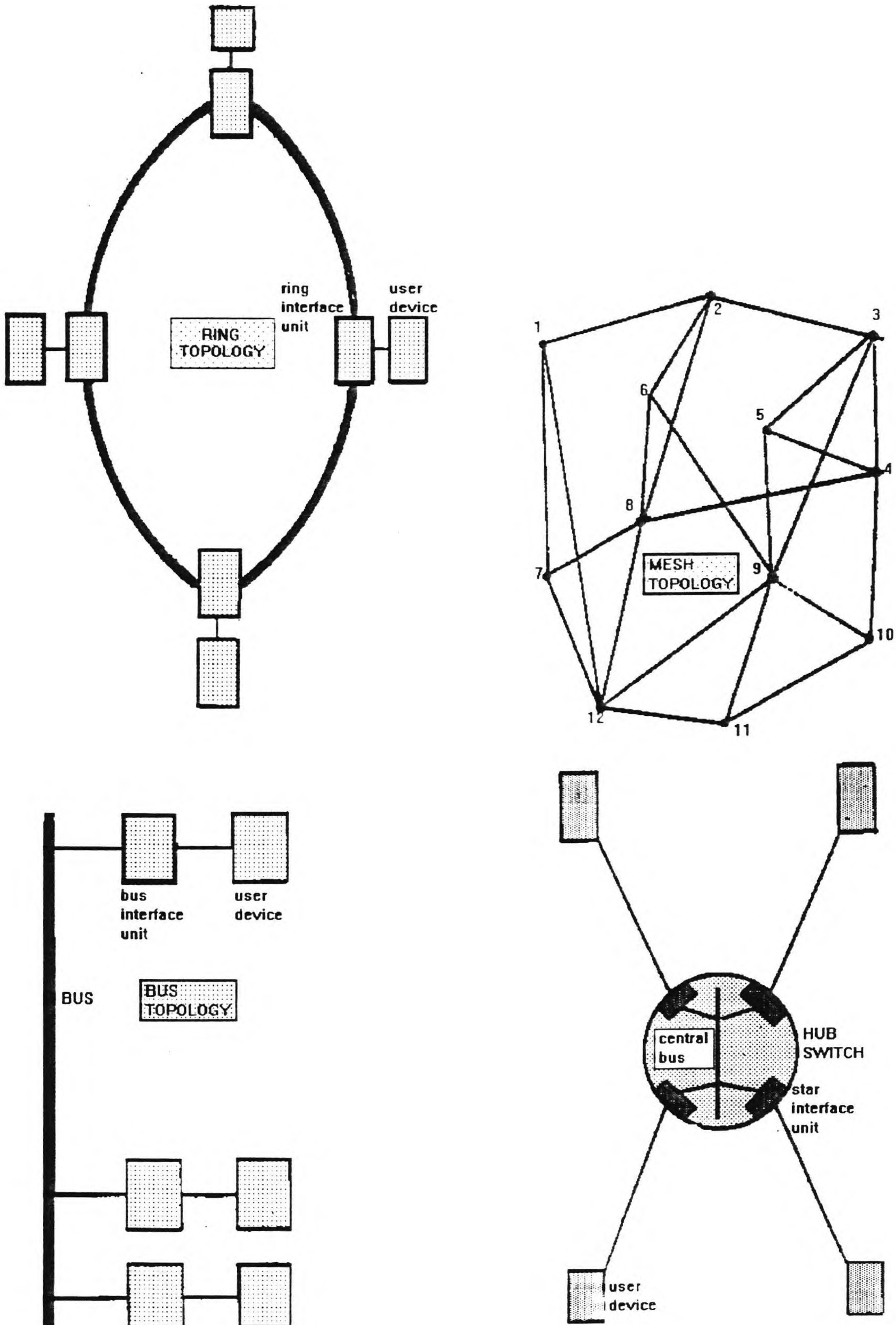
The interconnection pattern used among the various users and nodes of the network is named the topology. The most widely met topologies in LANs are the star, the ring the bus, and the mesh (C3) (fig. B.2.1.1).

The star topology has a hub switch (central) from where point to point links with peripheral units start. The main disadvantage of this topology is its centralised nature. This topology can support a number of terminals communicating with a time sharing system. In this case the hub node might be the time sharing machine itself.

The ring topology is a decentralised structure, where each one of the nodes carries its own intelligence. Usually the required hardware per node is not complex. In such a LAN the message is passed from node to node untill it reaches its destination. The large advantages of the ring over other connecting methods are the guaranteed response time and the possibility to provide the user with a powerful network management system. Its main disadvantage is that the failure of a single node can result in the failure of the whole network.

Another decentralised topology is the bus. It is internationally accepted. It is a passive network where the signal is not regenerated at each node, but is broadcasted along the whole network.

FIG. B.2.1.1 The main types of used topologies for LANs.



The destination node reads the message as it passes through. This LAN uses passive nodes whose failure do not affect its operation. Another characteristic of this LAN is the possibility of easy expansion.

Finally a topology that covers any requirement and that does not belong to the above mentioned cases, is the mesh one. It does no follow special laws like the above, but it is designed according to the specifications of the application. This topology is very often served by communications and medium access protocols that have been developed especially for this particular application. Its main advantage is the high degree of redundancy that results in a more survivable network. The penalty that is usually paid in that case, is the required complexity of the used software and hardware and a high cost.

A variety of medium access strategies have been used. They give a common protocol to gain the user the control of the medium and they provide a means for resolving contention, when more than one subscriber requires access to the channel concurrently. The most common of these are the Carrier Sense Multiple Access / Collision Detection (CSMA/CD) and the Token Passing protocols. Both of them are used for decentralised structures.

The CSMA/CD is usually met with the bus topology (C6). It is based on the ALOHA transmission method. The user, before his transmission attempt, listens (senses) to the channel to determine if it is idle. If it is sensed empty then the data are transmitted. If it is sensed busy the user waits a random period of time and then attempts again. However because of the propagation delays of the bus, and of the non zero carrier detection time, a collision may occur when the user senses an idle channel and begins to transmit his data, while another user has already transmitted his packet, but it has not yet propagated to this subscriber. When a collision occurs all parties involved immediately cease their transmission and they wait a random amount of time before initiating a retransmission.

Token passing provides controlled access to the transmission medium. This results in no collisions when two or more users require access to the channel simultaneously. When a user wants to transmit a packet he seizes the free token. He changes it to a busy one and he appends his data packet to the busy token. The packet goes around the ring from node to node. When it arrives at the destination it is copied and then is retransmitted. Finally returns back to the sending station that removes the packet from the ring. After the removal of the packet the station generates a new free token and passes it to the neighbouring station. So the user is granted the channel access right when he gets the free token.

The main task to be succeeded from the combination of the media access protocol and the topology is the improvement of the survivability and of the performance. Good performance characteristics mean :

- low delays,
- low BER,
- high throughput,
- low blocking and collision probabilities,
- etc.

Regarding survivable networks a lot of work has been done in the field. The design philosophy of this work is usually based on mesh networks with active nodes that retransmit the received signals (E2, E3, S1, S2), according to the used protocols.

ISO has issued the general principles that the computer networks have to follow (OSI model) (C2, C5). On the basis of this model the IEEE 802 committee (J1, J2, J3) has standardised the above topologies (not the mesh and the star one), their medium access methods and their intercommunication methods.

LANs are an area under a dynamic development. A lot of research is taking place towards the improvement and estimation of the performance of LANs, the design of new routing, synchronisation and media access contention free protocols, the design of new topologies, the use of fiber optics, the traffic integration etc.

B.2.2. THE OSI MODEL

The complexity and the variety of computer systems together with the need for their interconnection, created the requirement for the establishment of common rules and models, according to which computers should be designed. These rules and models define the architecture of the communication systems, so that standardisation can be achieved. It is well known that the architectures of the communication systems have been standardised mainly via ISO and IEEE.

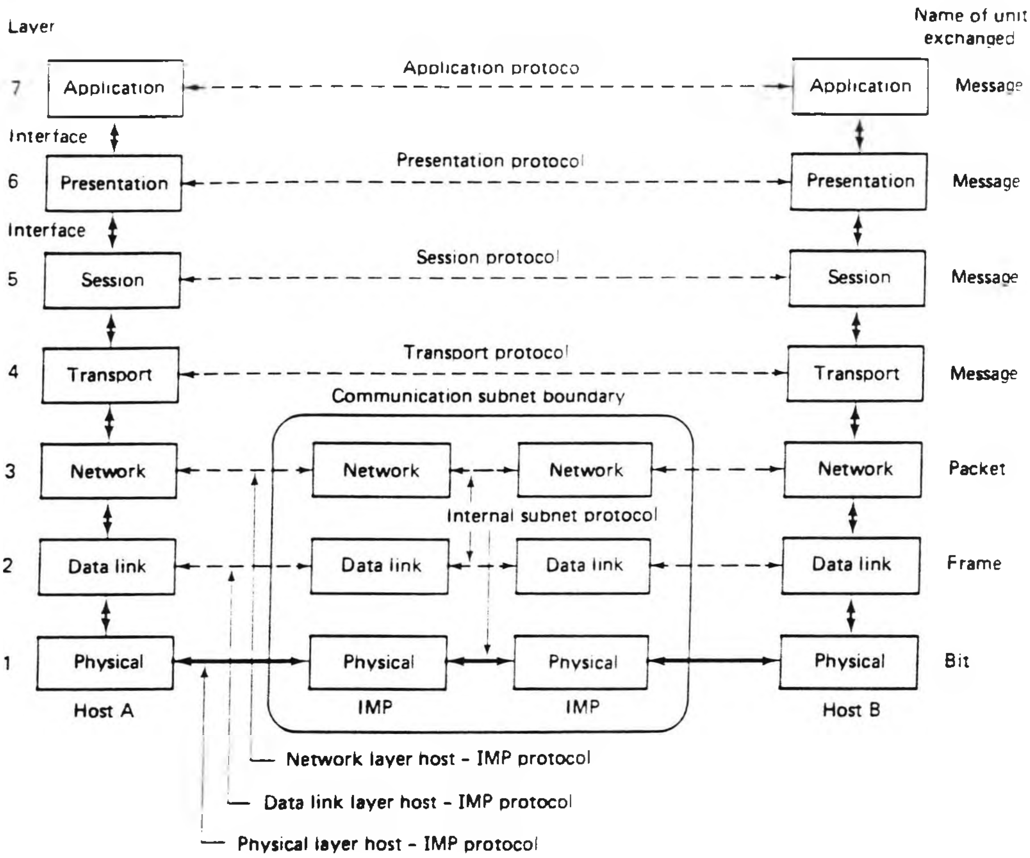


FIG. B.2.2.1 **The seven layers OSI reference model of ISO**

Standardisation is very well organised and is fully implemented in telephone networks. It is followed by all the manufacturers and the service provider companies. Computer networks are still in their early days. The achievement of inter-network communication for the user is a complicated work, that needs different procedures, according to the particular manufacturer, the network and the protocols used. The trend is toward the creation of a universal communication environment with standard procedures and interfaces for the set up of communication links. In this section a brief report of the existing international standards, that the system architectures should follow, will be given.

For the standardisation of computer communication systems the International Standards Organisation (ISO) developed the "seven layers" "open system interconnection" (OSI) (C2) reference model (fig. B.2.2.1). This is an abstract and general model that covers any kind of application. However the further need for specialisation in machines, networks and services, forced the development of specialised models, based on OSI, dedicated to particular purposes and services, such as Government OSI Profiles (GOSIP) and the NATO model for C^3i systems (J4) (fig. B.2.2.2). GOSIP addresses the needs of Government administrative and tactical office environments.

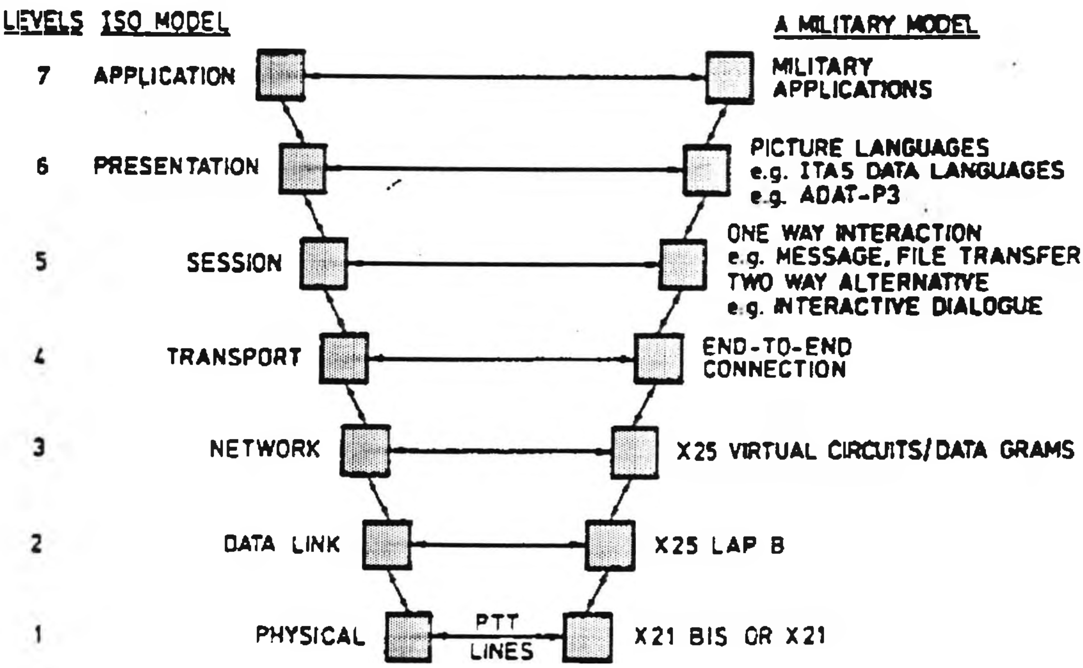


FIG. B.2.2.2 A seven layer military reference model.

According to the OSI model the communication among the modern computers is based upon a series of protocols (C2). These protocols are hierarchical and built in layers (levels). Each one of them has been developed on its processor. For inter-communication between two particular machines, every layer of each one of them, has a conversation with the corresponding layer of the other machine. At every one of the computers, each layer offers particular services to the higher ones, shielding them from the actual way that these services are implemented. Between any two successive layers, interfaces exist. In real life, for the implementation of the conversation of any two computers at a particular layer, the information that has to be exchanged, is transferred from the higher to the lower layer, where the physical connection takes place.

The philosophy that describes the development of a layer is given by Zimmerman in 1980 (C2):

- 1. A layer should be created when a different level of abstraction is needed.
- 2. Each layer should perform a well defined function.
- 3. The layer boundaries should be chosen, in such a way that the information flow across the interfaces is minimised.
- 4. The number of functions should be large enough that distinct functions need not be thrown together in the same layer out of necessity, and small enough that the architecture does not become unwieldy.
- 5. The function of each layer should be chosen with an eye towards the internationally standardised protocols.

CCITT has recognised layers, 1-3, of OSI/ISO reference model. Now attempts are being made to be defined standards for all the forms of network services. Layers 4-5 are the difficult layers of the model and have traditionally been prerogative of computer manufacturers to implement their own standards within their own architecture (C2, C5). Layers 6-7 are more diversified because technology has just come into the areas of colour graphics and voice and data processing. Within the two higher layers no one standard will apply, but groups of standards, through which the interested parties will try either to provide or receive a service. Layers 1-3 are characterised as 'lower layers', while layers 5-7 are named 'higher layers'.

A short description of the OSI model has as follows (C2) :

- **LAYER 1 : The physical layer**. It provides characteristics to set up, maintain and release physical connections between data links entities.

- **LAYER 2 : The data link layer**. It aims at the implementation of the required procedures for the correct transmission of the data. This is done through:

  - the appropriate processing of the data that are to be transmitted and
  - the acknowledgement procedure.

- **LAYER 3 : The network layer**. It determines the characteristics of the interfaces between the hosts and the IMPs, the packets exchange protocol and also the routing protocol.

- **LAYER 4 : The transport protocol**. It is an end to end protocol. The program on the source machine carries a conversation with the program in the destination machine, using signalling messages. It ensures that the data arrive correctly at the other end. It connects the lower with the higher layers.

- **LAYER 5 : The session layer**. It is the user's interface into the network. Through this layer the user asks for a particular service or connection with another machine.

- **LAYER 6 : The presentation layer**. It performs general functions and provides services that apply to all users. Such functions are the message compression, the data encryption, file conversion for cooperation with incompatible machines, etc.

- **LAYER 7 : The application layer**. This layer provides user services, some general (e.g. electronic mail) and some specific. The user application programs run above this layer.

B.3. SHORT REVIEW OF THE EXISTING SPSC LANs

Up to now SPSC techniques have been mainly used in radio networks. Today packet switching radio networks with integrated traffic (voice and data) are the state of the art (A2, A9, A10, A11, A12, G1, G2, G9). DARPA (Defence Advanced Research Project Agency) of the USA has done a lot of research towards this direction (G1). Recently, in addition to the above mentioned work, recommendations for use of SPSC with wireless indoor LANs were published (A12, G3, G4, G5, G6, G7, G16).

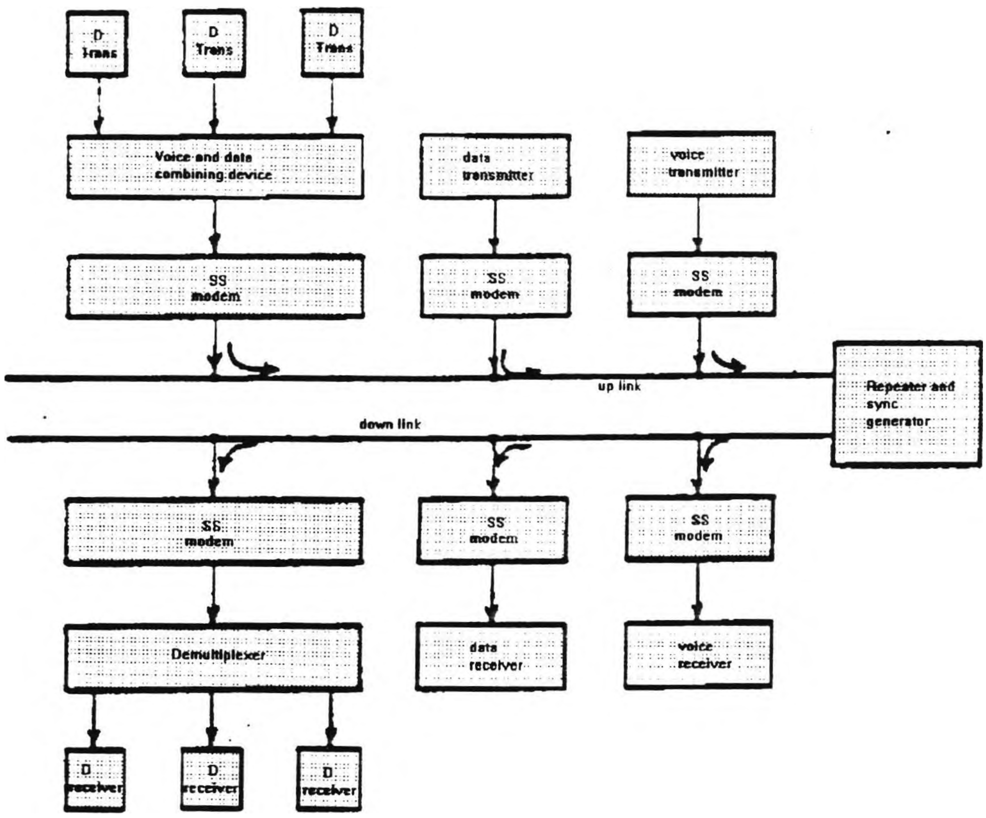


FIG. B.3.1 The architecture that was designed at Concordia University.

These wireless LANs usually consists of base stations and portable small size transmitters and receivers. Experimental and analytical work done by Dr. M. Kavehrad (G4, G5, G7) and by Dr. Pahlavan (G3, G6) have shown that a system with the following characteristics :

- star connection
- chip rate of 255 chips/bit
- MS codes
- bit rates of 100 Kbits/sec
- carrier of 1.2-1.5 GHz
- BPSK modulation

can support up to 50 users in a building. The major advantage of these LANs, due to the radio propagation used are :

- the relative independence from the distance or the position of the receiver, that allows the mobility of the subscribers,
- the easy installation that is very important in cases of buildings, and
- the independence from a faulted or cut line.

On the other hand these types of LANs are subject to the usual 'radio networks' limitations. However the advantages and qualities of the SPSC techniques help in overcoming some of the constraints of the radio propagation such as :

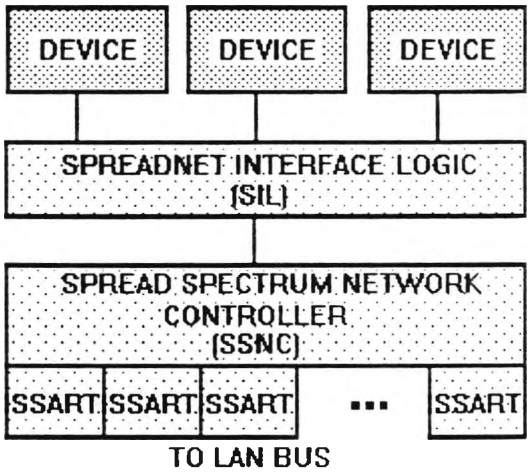
- the multipath propagation delays and fadings,
- the existence of interferences from other transmissions,
- the vulnerability to jamming

while others like :

- the lack of privacy and security (since anybody can listen to a radio transmission broadcast),
- the synchronisation difficulty,
- the occupancy of the frequency spectrum,
- the dependence on the atmospheric conditions and from the morphology of the area,
- the bandwidth restrictions

still exist.

Except of the design of radio SPSC LANs, SPSC were also used in the field of wired communications during the last years. Several different groups, all over the world, have been working in this direction. Up to now, between them, only the University of Aberdeen has presented a complete system architecture, while there are several publications in the individual areas that are involved with a SPSC wired system design, such as hardware, codes design, performance analysis, building of experimental links, etc.

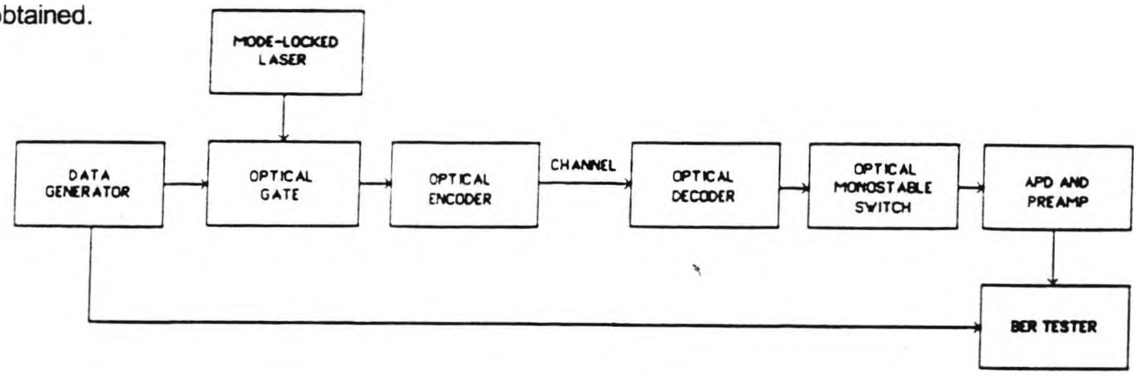


SSART : SPREAD SPECTRUM ASYNCHRONOUS RECEIVER AND TRANSMITTER

FIG. B.3.2 The logical and modular construction of Spreadnet.

The first reference is from Canada (D4). Figure B.3.1 illustrates the main idea of the architecture that was proposed. It is a broadcast SPSC bus LAN. It consists of an uplink (transmission) and a downlink (reception) cable and of a synchronisation and wide band amplification unit. This unit receives the incoming SPSC uplink signal, amplifies it and retransmits it to the downlink cable. All the nodes transmit to the uplink cable and receive from the downlink one, analogously modulated signals. The problem of synchronisation has been solved through the periodical use of a SPSC sync, carrying the codes of different users, (one at a time). This is transmitted to the downlink cable by the synchronisation and wide band amplification unit. This proposal aims to serve integrated traffic (voice and data packets). Performance results obtained from mathematical analysis show that this LAN can support 8 voice users if a PG=167 exists and 12 data users if a PG=512 exists. This idea was further developed at the Korea Advanced Institute of Science and

Technology (D5, D21), where further performance results, through analytical estimations, were obtained.



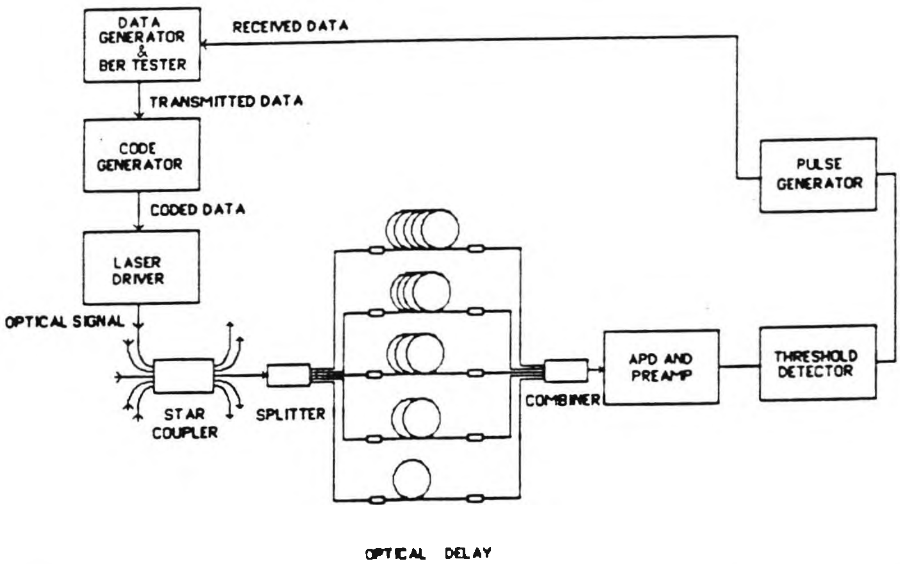


FIG. B.3.3 **The block diagram of an optical SPSC system that was designed in Colombia University / USA.**

Another architecture, named 'spreadnet', based on the bus topology and developed in the UK, is described in D3. The hardware and the protocols of a complete LAN were designed. According to this proposal the LAN can support 150 nodes on a bus of up to 2 Km length, using a transmission rate of 100 Mbits/sec. The transmitted signals are baseband. The synchronisation problem (initial signal acquisition and tracking) is solved through the use of digital correlation techniques and continuous data acquisition. The signalling and network management are achieved through the use of separate virtual management channels. These channels are selected from the data channels. Fig. B.3.2 illustrates the logical and modular construction of a workstation. This hardware structure is similar with the one described in D4. It differs from it in the synchronisation and signalling methods used. The wide band amplification unit is not also required. Further research and development on 'spreadnet' (D23) examines the use of fiber optics techniques in various topologies such as the active bus, the passive bus and the star.

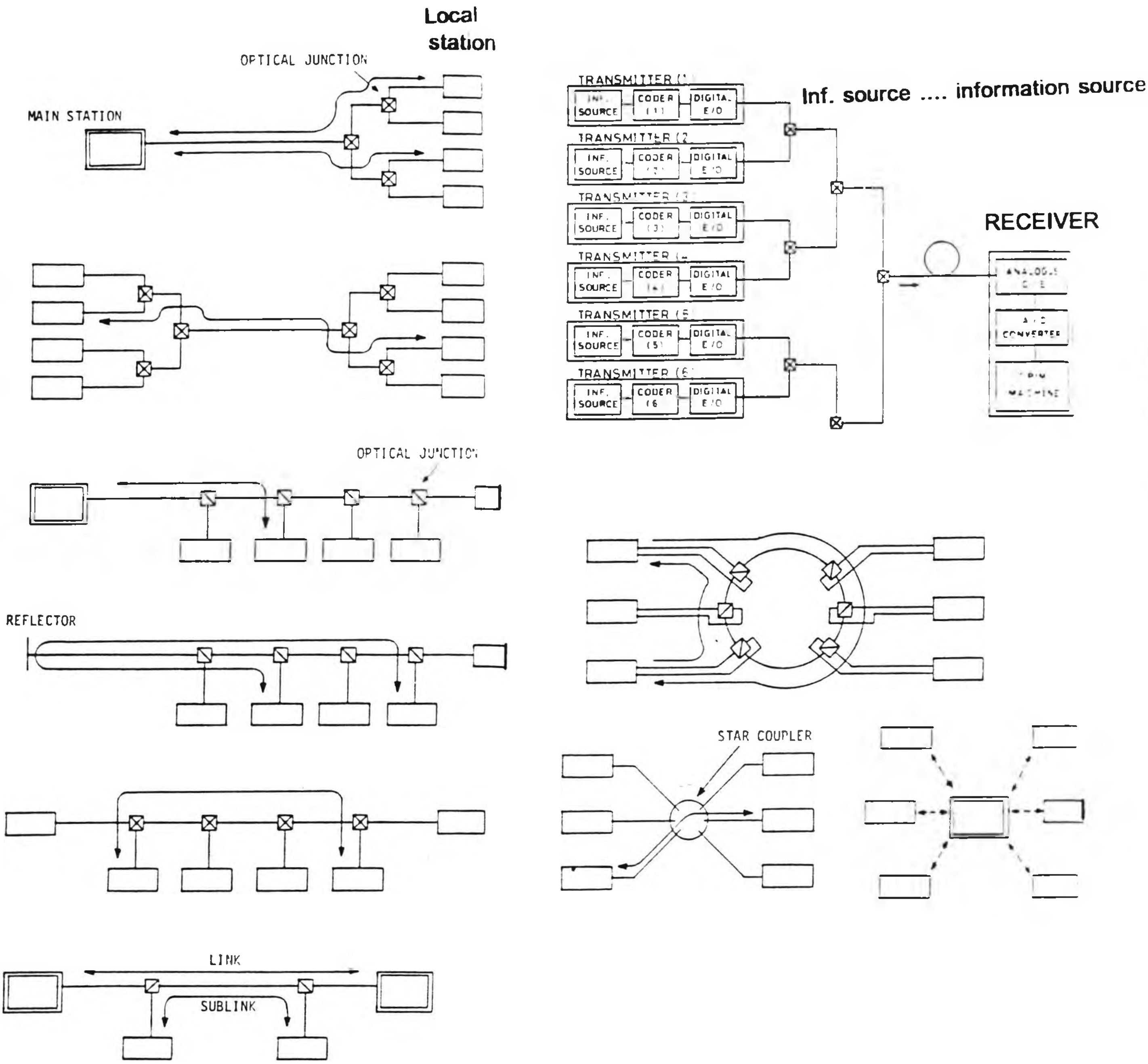


FIG. B.3.4 An optical SPSC link that was designed in Japan.

In Japan research has been carried out on fiber optics SPSC LANs. Various topologies (figure B.3.4) have been examined for the design of transmission systems that use passive optical multiplexing with gold sequences (D12). Experimental, theoretical and simulation results were obtained for a multipoint-to-point network. According to them 12 users can be supported by a PR MS of 511 chips/bit.

In Columbia University an optical SPSC bus is suggested (D1,D13,D15,D16). A new type of optical prime codes were derived from a set of prime sequences obtained from the 'galois fields'. Two protocols were suggested and analysed (a synchronous and an asynchronous one). Experimental links, where the performance of the suggested code and protocols were examined, were set up. According to the results of the experiment 35 users can be supported from 1023 chips/bit. Figure B.3.5 illustrates the experimental links that were set up.

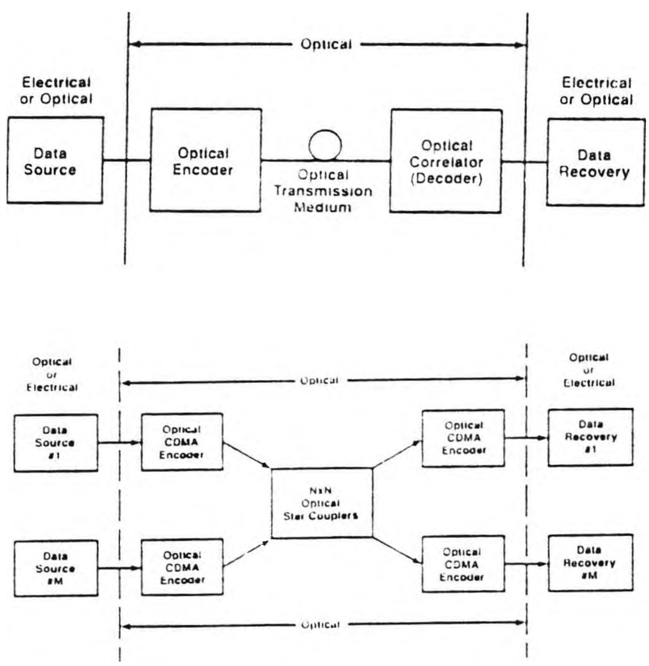
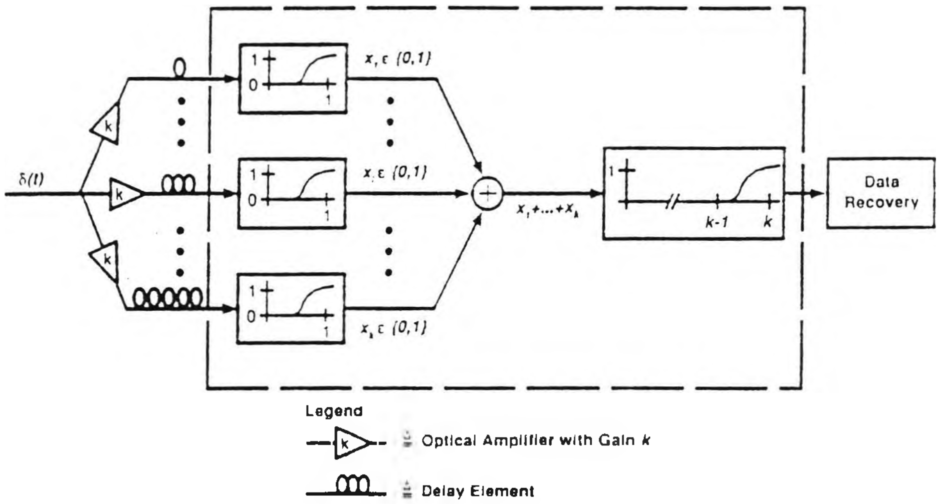
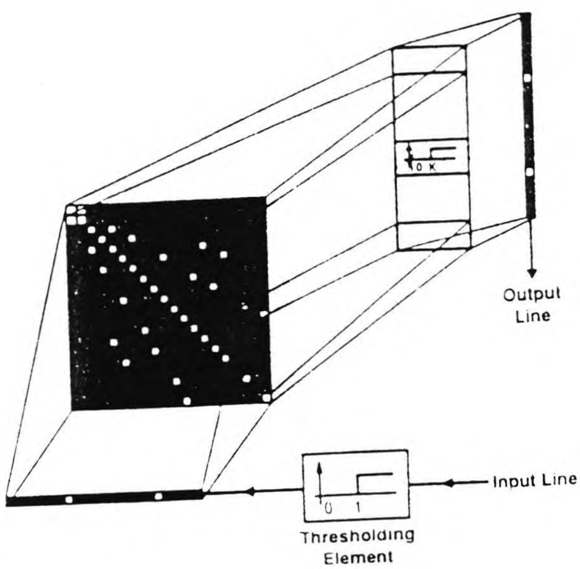
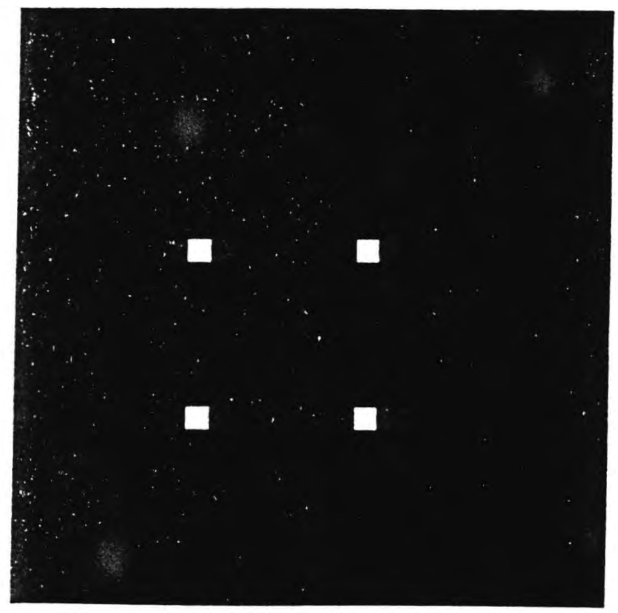


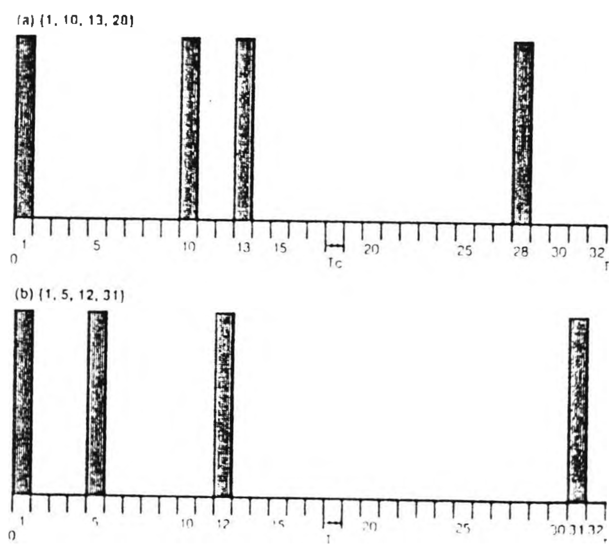
FIG. B.3.5 The proposed star connection from 'Bell communication research'.

FIG. B.3.6 The development principles of the suggested optical orthogonal code from 'Bell communication research'.









'Bell communication research' also suggested an SPSC CDMA optical system (D2,D17,D18,D19). Their proposal is for a star connection (fig. B.3.3). A new type of optical orthogonal codes, with processing methods for them, were developed. Simulation and mathematical analysis results are presented. According to them 50 users are supported from a PG of 1000. Figure B.3.6 shows the principle used for the development of the code and its optical processing method.

'Bell laboratories' are also involved in research in the area (D10, D20). Their suggestion is for a star 10 THz fiber optic CDMA system where the users choose randomly the carrier in the spectrum of up to 10 THz. An ideal theoretical model is described and the hardware requirements are given. According to the proposal the system can support thousands of concurrent transmissions.

So up to now a lot of suggestions exist for the design of SPSC LANs especially using fiber optics. These LANs, independently of the individually used protocols and topologies, have many advantages, such as a better performance than other conventional LANs, easy expansion of the network, concurrent communications. The main disadvantage of the up to now proposed architectures are the lack of survivability and security, which in many cases are of high importance. Survivability depends upon the continuation of the cable in bus topologies and upon the operation of the central servers in the other types of suggested architectures. Security is a combination of the whole network architecture and used technology.

C. DESCRIPTION OF THE PROPOSED PRINCIPLES FOR THE DESIGN OF MESH TOPOLOGY SPSC LANs

Some of the main requirements and characteristics of a large class of LANs are survivability, security and high performance. Survivability means uninterrupted operation under various conditions. This can be achieved through hardware redundancy, decentralisation, alternative routing, and dynamic reconfiguration through communication, signalling and synchronisation protocols. Security is the protection of the data against unauthorised reception. It is achieved mainly at the level of the physical layer through appropriate topology, technology and coding. At higher layers it is ensured through the use of secure protocols and passwords. High performance is achieved with low delays, low BER, high throughput and low blocking and collision probabilities, etc.

All these requirements can be fulfilled by using interconnected mesh topology SPSC sub-LANs in combination with continuous retransmission of the received signal in all directions (flooding routing) (D25). These sub-LANs are groups of nodes that are connected into smaller networks. The users are connected on the nodes through SPSC interface units (SPSCIU).

Survivability of this LAN is achieved through the use of the fully distributed architecture in combination with mesh topologies and flexible routing and communication protocols. Security is a result of the used topology in combination with the SPSC techniques and the signalling protocols. Good performance characteristics are offered through the use of the DS SPSC techniques in combination with packet switching methods and a fully distributed and flexible architecture.

This part of the thesis will give a high level description of the architecture and of the design principles of the proposed SPSC LANs. It will be restricted to the three first layers of the OSI model, without extension to the higher ones and to the user environment and services. The topics that will be analysed are the topology, the communication protocols, the signalling protocols and finally brief details about the implementation of the suggested LAN and its problems. The protocols will be described, from an operational point of view. These protocols are general, they are not limited to any of the suggested topologies, providing that these topologies are supported by the appropriate hardware. The selection of the topology influences the performance of the LAN, but not the philosophy and principles of the design and the operation.

C.1. THE TOPOLOGY

C.1.1. SECURITY AND LAN's TOPOLOGY

It is well known that security is achieved mainly :

- at the level of the physical layer through the use of the appropriate :
  - topology (physical separation of the users to groups),
  - technology (e.g. wire transmission, use of fiber optics techniques etc.) and
  - coding and
- at the level of the higher layers mainly through the use of :
  - secure protocols
  - cryptographic methods and
  - passwords.

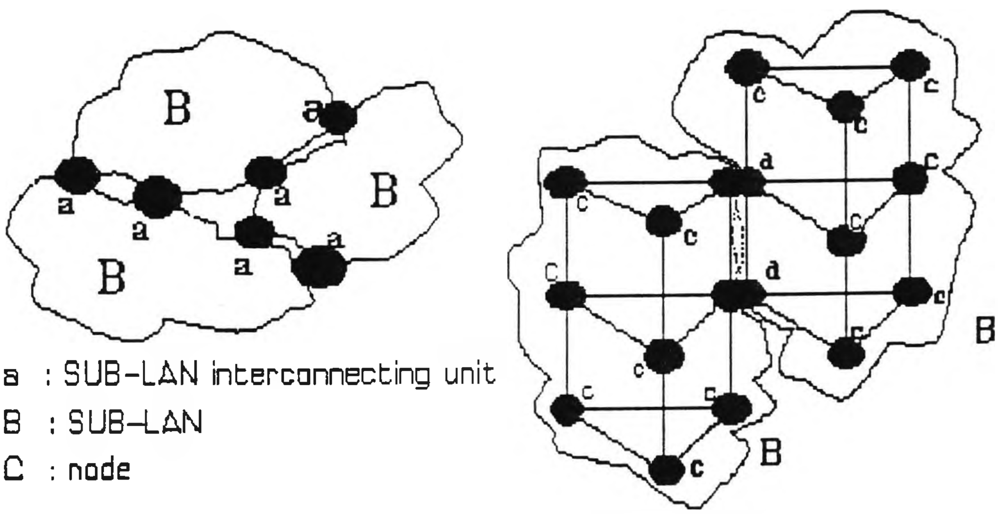


FIG. C.1.1.1 Interconnection of sub-LANs.

Every one of these methods offers a different type and degree of security, therefore their combination is used for the design of the security policy of communication systems. Among these current trends give high importance to the isolation of the highly secure data within groups of intercommunicating work-stations and to the use of secure crypto-codes.

In this family of LANs the security is inherent since (D24, D26):

- its topology design has been based mainly at the use of physically separated users into groups (sub-LANs) that are interconnected with secure bridges,
- its media multiple access method has been based on the use of secure coding (CDMA).

In addition to this, the use of passwords and of secure protocols, at the higher layers, is not prohibited and depends upon the design of each particular LAN.

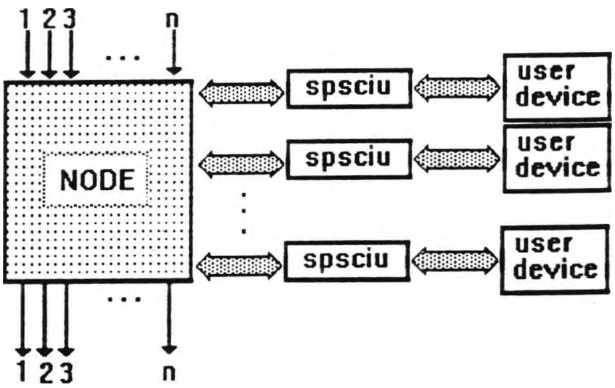


FIG. C.1.1.2 Configuration of a work station.

The interconnecting the above mentioned Sub-LANs bridges are known as Sub-LAN Interconnecting units (SIU) (fig C.1.1.1). The SIUs control the data flow according to the confidentiality of the data and to the security clearance of the far end destination. Every one of the Sub-LANs serves a particular part of the total traffic. In this way users that have similar characteristics, or that work under the same security requirements or restrictions, are allocated to the same sub-LAN. The number of users that are connected to a node depends upon the design (fig. C.1.1.2), creating so sets of work stations (the users that belong to the same node). The SPSCIU controls the output of the data from the user to the node. It contains all the required security information for giving the allowance for the implementation of any user to user connection.

So this LAN's architecture provides security based on trusted bridges of two hierarchical levels. The first (lower) level is at the node the SPSCIU and the second one is at the SIUs. The system controls the information flow both at the SPSCIU (before the output of the node to the sub-LAN) and before the transfer from one sub-LAN to another one at the SIUs. So the degree of security achieved at the lower layers depends upon two factors :

- the crypto security provided by the spreading PR code and
- the control of data at the exit from the SPSCIU to the node, and from one sub-LAN to another.

In addition to this, in the case of the use of fiber optic techniques a further security enhancement is succeeded.

C.1.2. TOPOLOGY's DESIGN PRINCIPLES

The described philosophy for the topology design creates a three levels structure. At the highest level is the Sub-LANs interconnection pattern, at the next one is the topology used inside the Sub-LAN and at the lowest is the node with the connected on it users. The selection of any particular topology at any one of these levels, influences the final survivability, the distribution of the created traffic over the LAN (the local traffic into the sub-LAN and the inter-Sub-LAN data stream), and consequently the performance of the LAN.

The internal topology of the Sub-LAN is important for the success of the desired degree of survivability. Conventional topologies like the bus, ring, tree and star do not offer survivability. The mesh topology sub-LANs, built according to the suggested architecture, offer the required hardware redundancy, decentralisation, alternative routing between any two nodes, and possibilities of dynamic reconfiguration through the appropriate support of communication, signalling and synchronisation protocols. Since there is extensive bibliography (H1, H2, H3, H5, H6) analysing the mesh topologies in networks, this topic will not be examined.

The interior sub-LAN topology should be designed according to the case, considering the local traffic and any other existing requirements. It influences its operation as following :

- A graph that follows geometrical rules, or that has some symmetry, and is not built in an arbitrary way :

- is easier to study and its behaviour and performance is easier to predict and to estimate,

- the design of signalling protocols is more flexible,

- its expansion is easier,

- in cases of nodes and links failures, it has always under control its dynamic reconfiguration, modifying its behaviour and performance accordingly.

- The size of the graph and its connectivity policy influences the power both of the signal and of the echoes and the amount of traffic locally at the nodes and at the links, affecting the performance.

So the selection of any particular family of graphs for the creation of the internal mesh topology of the sub-LAN is very important.

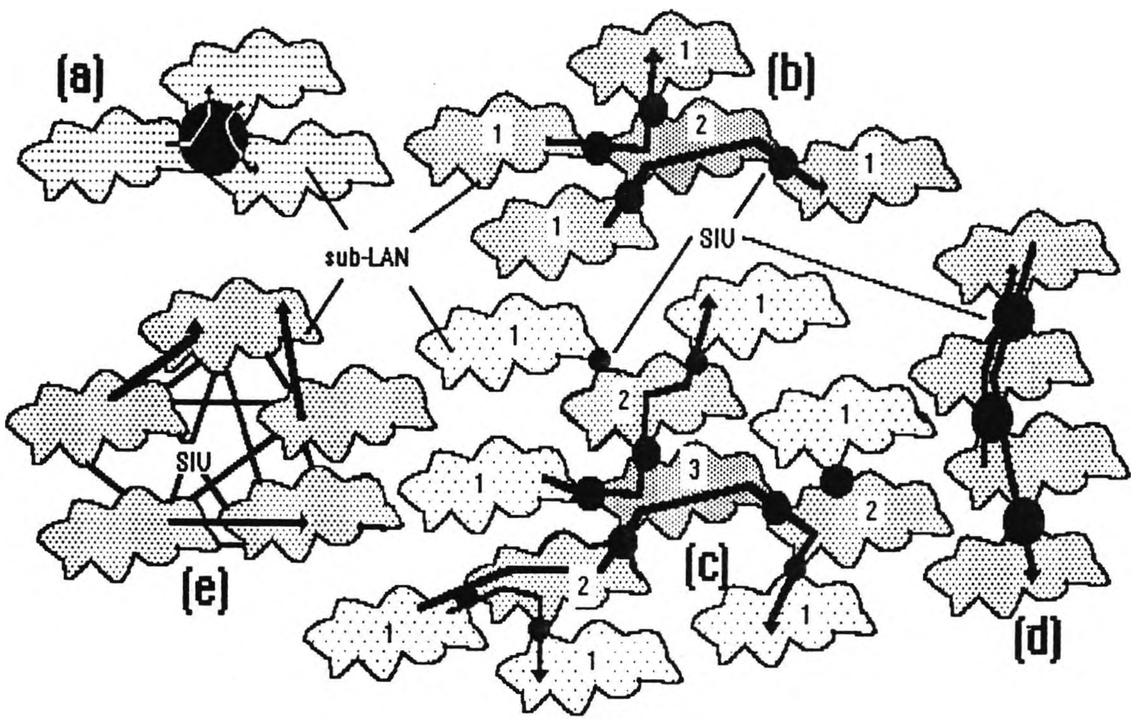


FIG. C.1.2.1 Configurations of various topologies that can be used in a mesh topology SPSC LAN.

The inter-sub-LAN connectivity scheme influences :

- the security,

- the survivability,

- the amount of inter-Sub-LAN traffic,

- the delays and

- the overall performance of the system.

Figures C.1.2.a to C.1.2.e illustrate various philosophies according to which the Sub-LANs can be interconnected. These are just a sample of the ways that the sub-LANs can be combined toward the design of the LANs' topologies.

In figure C.1.2.a a central bridge interconnects the sub-LANs. At this architecture

- shorter physical links between any two nodes of different sub-LANs are used than the physical links of some other topologies that are described,
- the topology is cheaper to install,
- the inter-sub-LAN traffic load that it can be supported depends upon the design of the central bridge (SIU),
- dispersion of the switching function between the sub-LANs is not offered, resulting so to low survivability,
- the inter-Sub-LAN traffic is routed through the central node (SIU) doing any switching functions between the sub-LANs and
- the central node (SIU) despreads, remodulates and then retransmits the SPSC information, giving so a degradation to the offered security.

All the above required functions have to be implemented by the SIU concurrently for any SPSC channel, otherwise system performance will be reduced. This makes the central SIU complicated.

The architecture of figure C.1.2.b, appears improved characteristics, compared with the above described one. In this case a sub-LAN interconnects several SIUs. Each one of them serves a number of sub-LANs. These sub-LANs can be defined as sub-LANs of rank 1, while the sub-LAN that connects the SIU can be named as sub-LAN of rank 2. The sub-LAN of rank 2 executes all the switching functions in the same way but at a more distributed mode.

If the SIUs are replaced by sub-LANs then a hierarchical modular structure is created (fig. C.1.2.c). In this case a fully distributed and hierarchical LAN is created. In this variation of the topology super-groups of subscribers, according to the probability of activating communication links between the members of the different groups (sub-LANs) are created. So subscribers with a very high probability of communication with each other, may belong to the same sub-LAN of rank 1. Subscribers that belong in different sub-LANs of rank 1, but have a high probability of intercommunication, would be served by the same sub-LAN of rank 2 and so on. So the sub-LANs of rank 1 serve subscribers, while the sub-LANs of higher ranks in the structure, serve the SIUs that interconnect the sub-LANs of lower ranks. This type of topology addresses the inter-sub-LAN traffic toward the higher rank sub-LANs, creating in this way long links and high delays for their set-up. This topology requires rather complicated routing and signalling protocols in order to be supported. The implementation of such a topology requires a lot of redundancy that increases the total cost, without this redundancy to offer a higher degree of distribution and to improve drastically the survivability. So from a survivability point of view this topology depends upon the operation of the higher rank sub-LANs. The main advantages of this hierarchical structure are that :

- it often fits the functional structure of institutes, serving better their requirements,
- it offers multilevel security control of the data flow and
- it offers a rather simple management system.

A different architecture is illustrated in figure C.1.2.d. In this case a serial chain of sub-LANs is used. Each one of these sub-LANs serves a number of subscribers. SIUs are used for the interconnection of the sub-LAN with the adjacent left and right ones. These SIUs process the incoming and outgoing signals of the sub-LAN (they demodulate the incoming signals, they read the destination, they remodulate it and they transmit it to the other sub-LAN). In the case that an incoming signal is destined to a subscriber of another sub-LAN, the SIU transmits it toward the SIU that interconnects this sub-LAN with the next one. The same procedure is repeated till the sub-LAN of the final destination has been reached. Because of the routing characteristic, the traffic distribution over the sub-LANs is not flat, but it depends upon the position of the sub-LAN in the chain. The sub-LANs that are at the middle, have higher traffic than the ones that are at the two ends of the chain. This topology appears to have :

- a high probability of congestion,
- a low degree of survivability (the failure of any sub-LAN will separate the system into two parts) and
- rather long channel set-up and transmission time delays.

Figure C.1.2.1.e illustrates another topology that overcomes many of the above mentioned problems. It is built under the principles of a modular distributed system. Each one of the Sub-LANs has the possibility of being connected via SIUs to any other Sub-LAN, so providing intercommunication with it. Such a structure resembles a fully connected graph, with each vertex corresponding to a Sub-LAN and each edge to a SIU. This structure contributes to making the system very robust. Because of

- the immediate access of any Sub-LAN to any other one,
- due to the inter-Sub-LAN traffic minimisation and consequently to the reduction of the noise power inside the sub-LANs,

the performance (BER, collision probability, throughput, transmission delays) and the survivability are improved.

C.2. COMMUNICATION PROTOCOLS

As has been mentioned, the operation of the network will be based at a flooding protocol. Flooding routing protocols have the characteristic of retransmitting all incoming signals, at any node, along every outgoing link. Thus the signal arrives first at the destination, following the shortest path. There are two ways of implementing the flooding :

- Passive flooding. The incoming power is retransmitted without being demodulated (fig. C.2.1). This phenomenon is similar to the way that water is flooded at a node of a grill of pipes. This means that the incoming signal at any node, is distributed equally to all the outgoing ports, for onward transmission in such a way that the total incoming power W_{in} is greater than the total outgoing power W_{out}. In principle this implies that the process is a passive one although in practice amplifiers may be needed, because of line impedance matching requirements. Clearly such a passive flooding procedure results in numerous signal echoes being transmitted around the network (comparable to multi-path distortion in radio communications). However, the SPSC technique provides immunity against delayed echoes of signals, enabling only the synchronised signal to be decoded at the destination node. The failure of any link carrying this synchronised signal will not cause a break in communications because then, another synchronised signal will arrive at the destination node, through another route. The echoes act as wideband background noise. They depend upon the topology and should be absorbed gradually, otherwise the continuous increase of their power would result in infinite noise and unit bit error rate (BER). In this way the network will be overloaded in power and damaged. It is obvious that if the flooding meets the referred criteria (e.g. $W_{out} < W_{in}$), the power cannot increase with time, but it stays at most constant. If there is a packet transmission scheme, where packets are generated and transmitted at random time intervals, power will decrease and increase with time, according to the packet generation model, without exceeding a maximum value.

- Active flooding. The incoming power at any node is demodulated, read, and if the destination is at another node, it is remodulated and retransmitted. Such a procedure should always be under the control of routing protocols that prohibit the continuous regeneration of the same signal (e.g. limitation to the signal retransmissions to a particular number 'n'). With this scheme, due to the sequential regenerations of the signal, the echoes are replaced with a controlled heavy traffic environment. The following drawbacks are involved with this scheme :

- Requires a large amount of hardware per node for the implementation of all the required receivers and transmitters. Such a node would be very expensive and complicated.
- Reduction of the security, since the data are demodulated at every node.
- The continuous increase of the traffic load may :
    - overload and damage the network,
    - result in congestion due to power increase and
    - result in collision, if the number of existing receivers and transmitters is lower from the required number by the traffic load.

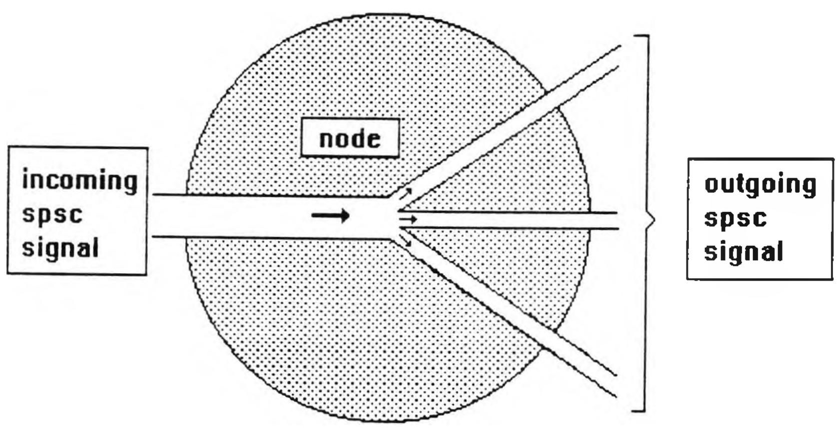


FIG. C.2.1 The flooding procedure at a node.

With the passive flooding scheme the echoes generation is a big problem for the LAN. There are solutions to it as the followings :

- A. The division of the LAN into intercommunicating sub-LANs for security reasons is also a tool used to reduce echo power. This feature allows for the creation of groups of nodes with size that fits the traffic requirements and the PG capabilities.

- B. The use of a statistical packet switching method, in a stochastic system, where every subscriber transmits packets at random time intervals without taking into account if at the same time, any other transmissions occur. This optimises the total amount of traffic flooded in the network.

- C. The use of a fully controlled media access method, where the subscribers, at predefined time intervals, using a distributed reservation scheme, gain permission for transmission.

- D. Appropriate selection of the spreading code (length, orthogonality and chip rate).

- E. Use of a fully controlled power environment, where part of the flooded power is absorbed, progressively with time, through the sequential floodings, by the system.

The code selection is another important factor that influences the operation and performance of the SPSC LAN. There is a large variety of families of codes that have properties appropriate for usage in a SPSC system (Section B.1.2). The selection among them clearly depends upon the architecture used (the design and the required performance, in relation with the developed signalling and synchronisation system).

The codes members of these families should be assigned to the transmissions. Many methods of code assignments are given in various published material (G8, D3). Some of them are :

- There is an one to one correspondence between the codes and the users. Every transmitter uses the code of the receiver of its destination.

- There is an one to one correspondence between the codes and the users. Every transmitter uses the code that corresponds to the transmitting user.

- There is a code control service that assigns the codes according to the security requirements or to the availability.

Every one of these methods has its own advantages and disadvantages. The main draw back is that the more complicated the code assignment protocol, the more complicated the signalling protocol becomes.

In the case of a passive flooding sub-LAN the existing interferences are classified as follows :

a. AWGN (AWGN).

b. Interference from the transmissions of other subscribers. These are considered as wide band interferences for any connection between a particular pair of subscribers.

c. Interference created by the transmission of signalling information, if the signalling information is transmitted on a separate channel.

d. Multi-path interferences created by the flooding of the signal. These are considered as wide band interference.

The AWGN cannot be avoided. The LAN has to operate within its limitations. SPSC signals and echoes that arrive at a node not synchronised with the locally generated code or with a different code than the locally generated one are considered as wide band noise. These signals, after the correlation procedure, are spread for a second time and their power spectrum density is reduced. Consequently this results in an improvement of the SNR. Signalling information according to its nature is treated as narrow band interference and is processed differently.

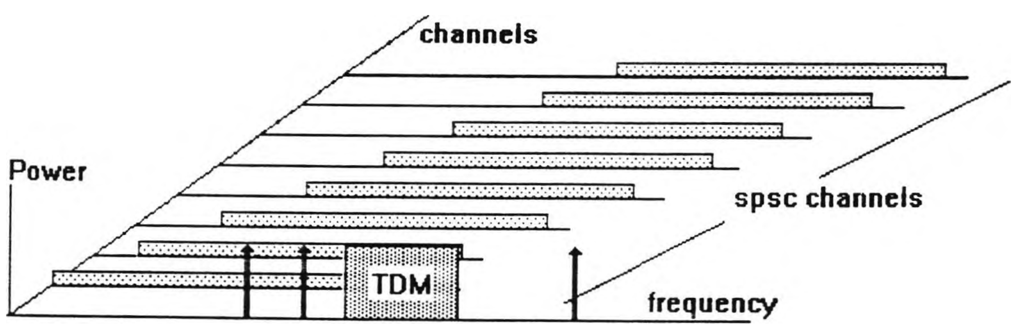


FIG. C.2.2 **The occupancy of the frequency spectrum by the TDM channel, the SPSC channels and the transmitted beacons by the SIUs.**

Another problem that also appears in a mesh topology passive flooding system is the "near far problem" (chapter B.1.2). This always has to be taken into account during the design phase. At section E.2 estimates of the probability of it will be taken. In addition to it in the case of LANs that use MS is possible for echoes, or for some of the SPSC signals created by various subscribers, to arrive at a node synchronised (in phase) with the locally generated PR reference sequence.

There are a lot of strategies that can be used for the solution of the above problem. Some of them are :

- An analogue modulation scheme can be used (A3). Consider a bank of carrier frequencies. Every one of them differs from the next one $k*f_{B_d}$. There is a correspondence between these frequencies and the users according to the design. So suppose that subscriber 'n' transmits the chips using analogue modulation with a particular carrier frequency $F_{tr(n)}$ (fig C.2.2). The frequency $F_{tr(n)}$ can be considered as a frequency shifted from a nominal one F_c, with a factor $f_{(n)}=n*k*f_{B_d}$, where :

$f_{B_d} = 1 / T_d$

$F_{tr(n)} = F_c+f_{(n)}$

T_d = bit rate

The exact benefits from this shifting are analysed in Appendix 2. As is shown there, this shifting does not influence the orthogonality of the signals transmitted by different subscribers. Figure C.2.3 shows the results of this modulation at the receiver, in the frequency domain, after the demodulation of the signal. The signal of the monitored subscriber occupies its own region of the frequency spectrum and it can be isolated by the use of a filter. According to the spacing between any pair of carrier modulation frequencies the ISI (Intersymbol Interference) is reduced.

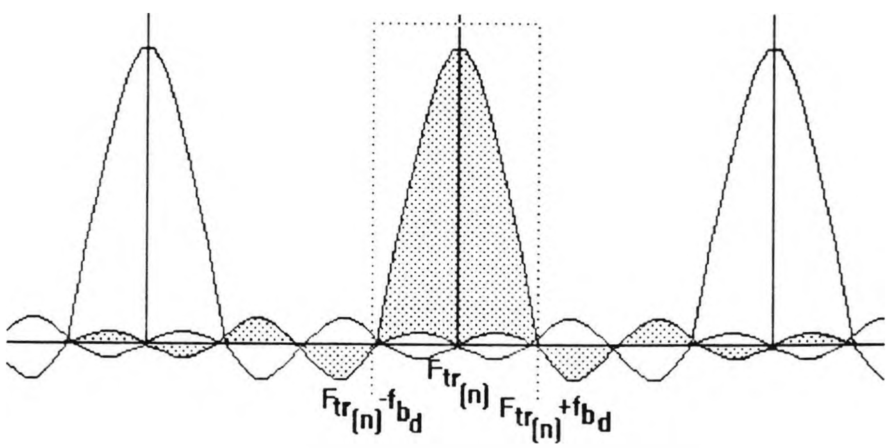


FIG. C.2.3 The results to the demodulation of the SPSC signal, when analogue modulation with different carriers has been used.

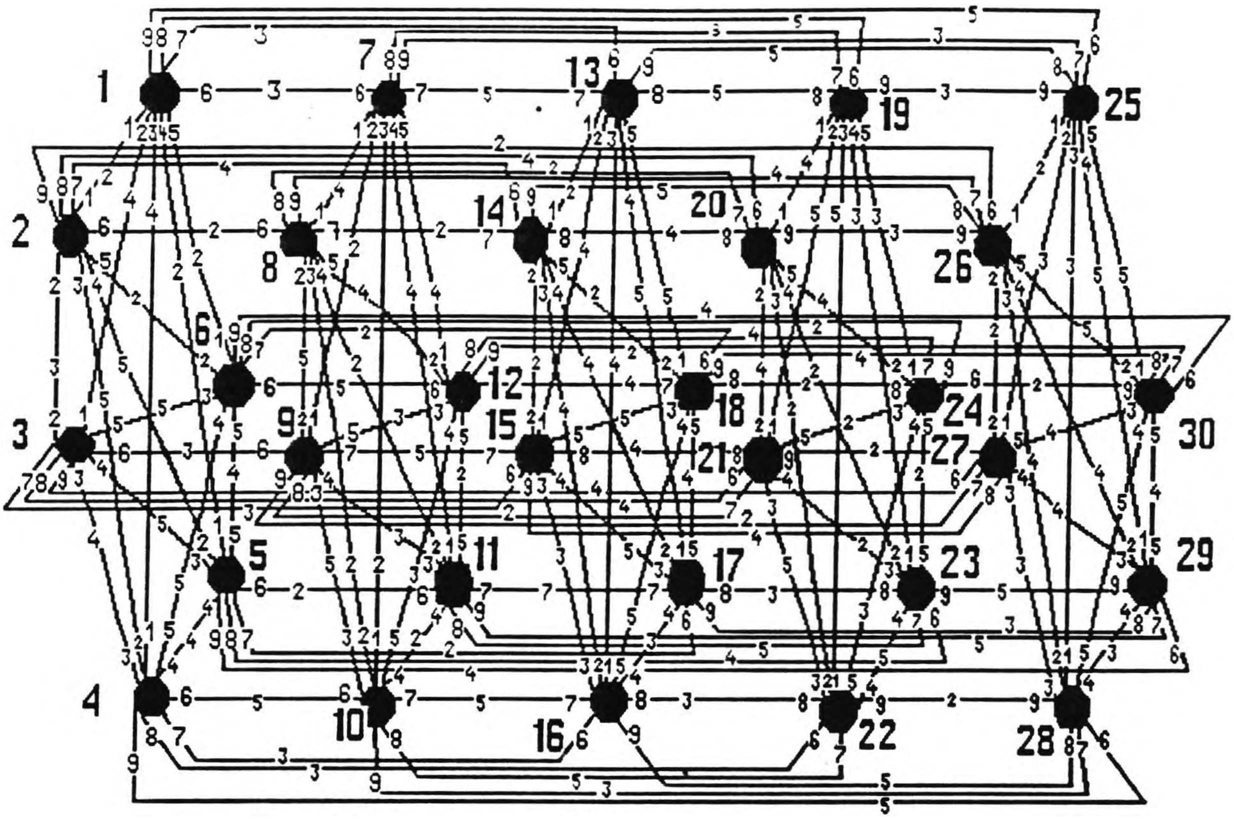


FIG. C.2.4 A 30 nodes topology of a sub-LAN.

- At the input of any port a constant delay unit can be used. This unit creates a delay to the incoming signals, equal to an integer number of chips. This changes the transmission delays between any two nodes. Any signal that arrives at the destination from any route other than the shortest one, has followed a path that includes a larger number of nodes. Consequently in this way the final transmission delay is higher and the received signal is out of phase from the locally generated code at the destination. However it may happen that after the signal has gone througn too many nodes, it will arrive again in phase at the destination. In this case, this signal power spectrum density will have been highly reduced, resulting in a negligible level of interference. This is because of the sequential splitting and of the matching attenuation at the input of the nodes, that the signal has gone through. For example suppose we have a mesh topology sub-LAN with 30 nodes each of degree 9 and matching attenuation at the input port of any node of 0.8. Figure C.2.4 illustrates such a topology. At this figure the serial number (SN) of the nodes and of the ports and the length of the links measured in time units are given. The addition of any node in the path that connects the transmitter with the receiver, adds an attenuation of 10 dB to the outgoing SPSC signal. So the signal that will arrive synchronised to the receiver having followed a longer path of n hops difference, will be n*10 dB weaker in power than the signal received through the shortest path (e.g. for n=3 this corresponds to 30 dB).

So, supposing that there is the appropriate signalling synchronisation and hardware support, a statistical packet switching LAN of this family, independently of the type of active or passive flooding it uses and of the particular topology that has been built, will operate as follows (D24):

- Because of the use of the SPSC technique, the users connected to a node can gain access to the network by CDMA, without having to determine in advance if the medium is idle, as it is required by ETHERNET systems. Simultaneous access by many users is possible because each one selects a spreading sequence uncorrelated with the others. In this way at any physical link that connects any two nodes we have at any time the temporarily creation of virtual channels that operate at a concurrent basis and that connect particular pairs of users. The sequence's choice is mainly determined according to the code assignment protocol used.

- Suppose that a subscriber wants to transmit to another one. The SPSCIU selects the code that will be used, and spreads with it the information. It assembles it into packets and transmits them in a random way. Assuming there is accurate information about the current topology, the transmission is performed only from the port that corresponds to the shortest route. When the signal arrives at the first node, it is flooded in all the possible directions. When the generated signals arrive at the next node, they are reflooded and so on.

- As the SPSC signal is getting into a node in order to be flooded, it is monitored continuously. When the signal passes through the node of the destination, its code should be fully synchronised with the locally generated replica of the spreading code. The destination receiver monitors all the ports of its node checking the codes and the synchronisation of the incoming signals. It reads any signal that happens to be synchronised with the locally generated code.

- For a transmission towards a subscriber of another sub-LAN, the data are modulated appropriately for the transmission toward the SIU that connects this Sub-LAN with the next one and that belongs to the shortest route. There the signal is reflooded into the next sub-LAN. This procedure is repeated until the packet arrives at the destination.

The performance of the LAN described so far is design dependent. Due to the use of flooding routing protocols

- the BER is a function
    - of the signal power,
    - of the echo power,
    - of the traffic and
    - of the chip rate.
- the traffic depends
    - upon the active user distribution over the network,
    - upon the packet generation distribution scheme per user and per sub-LAN and
    - upon the other end selection distribution over the spatial area of the Sub-LAN.
- echoes are a function of the topology (of the used connectivity scheme of the nodes in the sub-LAN and of the sub-LAN interconnection method) and of the traffic.

The appropriate value of chip rate can optimise the BER (theoretically BER=0) for any combination of these parameters. Since CDMA offers concurrent communications, delay (ignoring the transmission delay) is a function only of the collision and congestion probability. Collision and congestion probabilities are defined at section D.3 and depend mainly upon the chip rate, the topology and the signalling protocols used.

C.3. SIGNALLING AND SYNCHRONISATION PROTOCOLS

The third of the main aspects of the design of a communication system is the signalling protocol and the synchronisation method that will be used. Signalling protocols usually offer :

- routing information,
- timing and synchronisation information,
- acknowledgement information,
- charging information,
- addressing information,
- topology information,
- any other required administration and network management information,
- etc.

Regarding the signalling information, a SPSC LAN has the following characteristics :

- SPSC techniques have inherent addressing capabilities.
- Routing information is usually hardware implementation dependent. Usually flooding routing protocols on mesh topologies do not need routing information.
- In the case of survivable networks, a mechanism should exist that will recognise any change to the current topology or routing paths, so that the network to act as a self-learning machine (according to the used architecture the topology knowledge may not be required).
- Synchronisation and timing information in SPSC systems can be obtained through the processing of the received signal (A5).
- LANs usually are local networks installed within private premises, excluding therefore the need for charging.
- SPSC systems can offer theoretically an absolute BER of zero for any network, under the preconditions
    - of an ideal system,

- of correct selection of the chip rate and

- of accurate synchronisation.

Therefore the need of acknowledgement information depends upon the BER succeed and the collision and congestion probabilities.

It can be concluded that the existence of a signalling protocol, for the proposed mesh topology SPSC LANs, is not important and that it may be useless for any reason other than for obtaining network administration and management information. However the existence of a signalling mechanism could offer enhanced information and services (e.g. code assignment services, users security clearance information, etc.). Such services make the network more intelligent, but they are not required for the pilot operation (implementation of simple communication links). So according to the design :

- the signalling mechanism may get merged with the synchronisation mechanism into one, or even
- the signalling mechanism may be omitted or
- the synchronisation mechanism may be omitted or
- both of them may be omitted.

So for the implementation of the timing and synchronisation system of this family of SPSC LANs two policies can be followed :

- A timing and signalling protocol can be used. This defines a hand shaking procedure between the transmitters and the receivers and operates on hardware and software built for this purpose. The existence of a channel that will exchange the required information is necessary. This channel can be used for data transfer or of any other required signalling information. This design, although it looks more complex, is more convenient because it allows the creation of more flexible and intelligent systems, with a variation of services, at the lower levels of the OSI model, for network operation. In addition to this a quicker and more stable synchronisation is obtained. The separate synchronisation and signalling channel can be of many types (D4, D5, D6). Some of them are :

    - A normal SPSC channel from the standard ones that are used for traffic between any particular pair of users, according to the case.

- A separate SPSC channel from the standard ones that are used for traffic, operating on a common code, simultaneously with the other SPSC channels used for traffic. This channel will be shared among the users on a TDMA basis, or on a random basis, operating on the principle that when it is unused it can be seized by any one who needs it.

- A separate signalling channel common for all the users, over the SPSC channel operating on a TDM basis or on a random basis, under the principle that when it is unused it can be seized by any one who needs it.

- A separate channel operating on a burst mode, on a time sharing basis among the users on a common code.

- A timing only protocol is used. This defines a hand shaking procedure between the transmitters and the receivers and uses some of the well known and widely used SPSC system synchronisation methods (A1, A3, A5). It is implemented through the use of simpler and more hardware oriented protocols. At the receiver from the incoming signal, through the acquisition and tracking methods employed, synchronisation is obtained. The timing and synchronisation information are extracted from the incoming signal by correlation and other signal processing techniques. In this case there is not a real need for the existence of a separate channel. Signalling information can be omitted and a less intelligent system will be designed. This method has the following disadvantages :

- it is not certain that the timing information will be extracted from the signal,
- it requires complicated hardware and
- a time delay is introduced to achieve synchronisation.

C.4. TECHNOLOGY ASPECTS FOR THE IMPLEMENTATION OF THE PROPOSAL

Building a new product is not something easy. It involves a lot of work in many areas. The coordination of all the technical aspects for meeting the required specifications is difficult and needs the cooperation of a lot of experts in many fields. The first step is always the construction of the laboratory prototype. Then the second step is the design of the industrial prototype and the final one is the design of the production line. The main factors that have to be considered are :

- the specifications,
- the low cost,
- the easy maintenance,
- the appearance of the product and
- the cost of the production line.

In the case of the initial construction of a network, the main difficulty comes with the implementation of the ideas that are written on the paper, into a laboratory prototype, so that the evaluated performance through mathematical models and simulation tools to be achieved and measured. Since this LAN can be considered as a high technology product, built to offer communication services in specialised environments, the rest of the factors are of minor importance :

- Appearance is important for commercial products that are aimed at the consumer.
- The production line of this type of product (of a LAN) is rather simple, since it is based on the construction and assembly of PCBs.
- The maintenance of this type of product up to the PCB level is simple as far as the product has a modular structure and BITE (built in test equipment).
- The cost is a secondary factor for products that are destined for specialised environments.

For the implementation of a network member of this family of SPSC LANs the main question that arises is whether its construction is feasible, from a technical and economical point of view, due to the created highly noisy environment. The design of the SPSCIU, the node and SIU can be done through the use of known techniques, while the required services can be implemented using microprocessor and higher level programming. Technical difficulties are introduced at the following points :

- SPSC systems require very wide bandwidth and consequently high chip rates and complicated hardware. However due to the continuous development of VLSI and fiber optics techniques, and the simultaneous continuous reduction of their cost, these techniques can be considered as low cost ones.
- The construction of a stabilised and balanced passive flooding matrix unit, when a passive flooding protocol is used needs very accurate circuit analysis, and very careful implementation. If for avoiding this problem an active flooding method is used, then a more complicate and expensive in hardware node has to be built. As has been mentioned, this solution degrades systems security. The use of fiber optics techniques simplifies the problem's solution.
- The extraction of the timing information from the incoming signal needs complex hardware that creates delays in the decoding of the information. The use of a separate signalling channel that will also be used for any type of timing information exchange, gives the best solution.

D. ANALYSIS OF A LAN BUILT ACCORDING TO THE PROPOSED PRINCIPLES

D.1. INTRODUCTION

In this part of the thesis the description of the architecture and the operation of a LAN, a member of the suggested family of SPSC LANs, is given. It is just a novel example, indicating the way that the implementation can be realised. This LAN has been built according to the previously mentioned design principles. The used architecture has been based on :

- the topology of figure C.1.2.1.e,
- a passive flooding protocol according to the description of section C.2 and
- a separate signalling channel, operating on a TDMA basis.

It is characterised by :

- high survivability,
- homogenous and uniform traffic and echo distribution, due to the symmetry
    - of the sub-LAN connectivity scheme and
    - of the topology the interior the sub-LAN (nodes connectivity scheme),
- low required quantities of inter-Sub-LAN traffic, due to the direct access of any sub-LAN with all the others,
- relatively cheap hardware for node implementation, due to the :
    - passive flooding protocol used, that does not require the demodulation of all the signals on the incoming ports of the nodes and
    - the signalling protocol that allows the design of simple receivers for each user, since the SPSC signal does not carry the timing and synchronisation information,
- fulfilment of the security specifications,
- modularity,
- distribution and
- possibility of independent performance, characteristics and even design per sub-LAN. Every sub-LAN can behave as an independent module, as far as the SIU operates as an

interface that on the one hand isolates the sub-LANs that inter-connects, and on the other hand connects these sub-LANs knowing the characteristics of each one of them.

D.2. TOPOLOGY AND HARDWARE OF THE PROPOSED LAN

D.2.1. OVERVIEW OF THE TOPOLOGY OF THE PROPOSED LAN

The topology used, (figure C.1.2.1.e), is fully distributed and modular. It offers a high degree of survivability, good performance and relatively low required transmission rates.

Figure D.2.1.1 illustrates the philosophy used for the design of a Sub-LAN's topology graph. It consists of a number of similar, fully connected, subgraphs (denoted category A). A SN is allocated to every node of a subgraph. All the nodes of the various subgraphs of category A of the Sub-LAN, that have the same SN, are connected in such a way as to create another fully connected subgraph (denoted category B). In this way the topology achieves a symmetry and offers survivability. Figure D.2.1.2 illustrates the correspondence between these subgraphs and the nodes in a sub-LAN of 20 nodes.

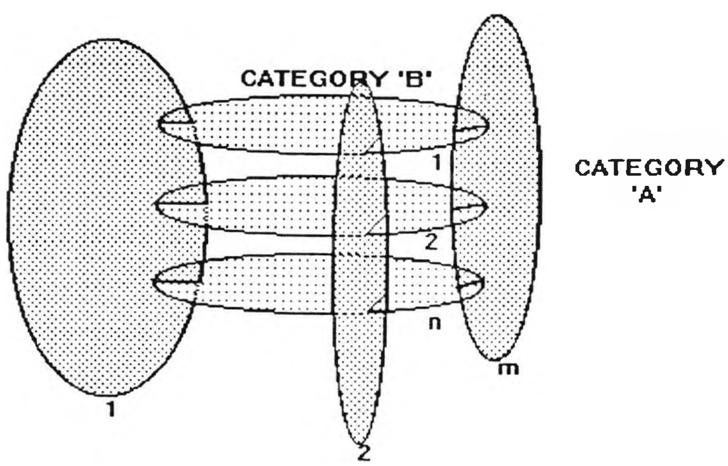


FIG. D.2.1.1 The philosophy used for the design of a graph of a sub-LAN of the proposed topology.

This topology offers at least two different paths of minimum length, measured in hops, that interconnect any nodes. Each one of them consists of a maximum of two hops. In this way the shortest path (considering the number of links and not their physical length) between any two nodes of the same sub-LAN, before any failure in the network occur, includes the maximum three nodes. These are the node where the source of the signal belongs, the node of the far end destination and one more node between them. In addition to this shortest route there are also many other alternatives longer paths, that interconnect these two nodes. Although the shortest path regarding the number of hops is the described one, physically the shortest path measured in time length may follow a different route, that contains a higher number of hops.

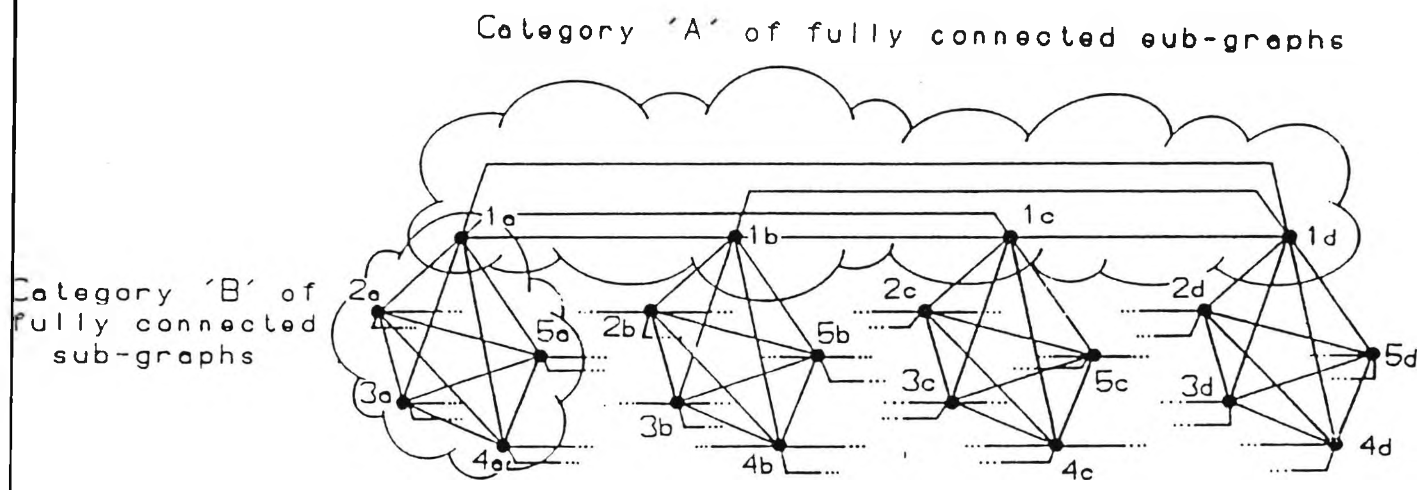


FIG. D.2.1.2 **An example of a sub-LAN of 20 nodes.**

The size of the Sub-LAN influences the echoes created and consequently affects the SNR and hence the maximum transmission rate for obtaining the required PG. The philosophy that has been used for the connection of the Sub-LANs influences the traffic load that can be supported, the inter-Sub-LAN data stream and the overall performance characteristics.

For maximisation of survivability and performance of the inter-sub-LAN traffic, procedures for its uninterrupted flow exist. These are based on the existence of two SIUs between any two sub-LANs (figure C.1.1.1). One of them is in operation, while the other one is spare undertaking the traffic when the first one gets out of order. In the case of failure of both the SIU no interruption of the inter-sub-LAN traffic could be caused, due to its restoration through alternative longer inter-sub-LAN paths, through other sub-LANs. In this way extra traffic load is created to the added sub-LANs at the path. A number of receivers exists to every incoming port of the SIU. This enables the SIU to receive several signals through the same port so improving the performance. The disadvantage of this redundancy is that increases the cost of the LAN and influences the complexity of the hardware, but on the other hand it ensures its smooth operation.

The SPSCIU are connected on the nodes through ports. The number of these ports defines the number of users per node. Each one of these ports has a SN. These numbers :

- are consecutive
- are given always by the system, independently of the existence of a user connected on it.

The use of more than one user and SPSCIU per node reduces the size of the sub-LANs and consequently the created interference. This also makes the configuration of the LAN cheaper but it reduces the survivability, since in this case the failure of any node will disconnect more than one user.

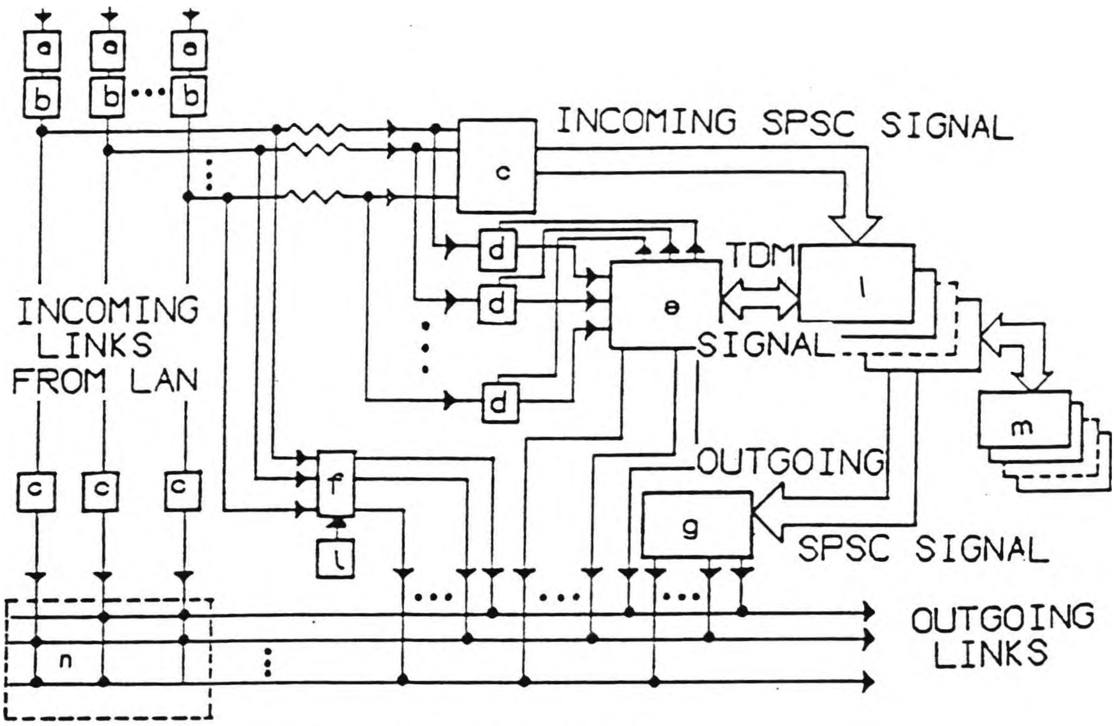
So any user at this topology is characterised upon the sub-LAN, the node and the SPSCIU, therefore its identification consists of :

- the SN of the sub-LAN that the user belongs,
- the SNs of the node at both the subgraphs and
- the SN of the port that the SPSCIU is connected on.

D.2.2. OVERVIEW OF THE OFFERED SERVICES BY THE APPARATUS OF THE PROPOSED LAN

The proposed LAN according to the description consists of three types of apparatus :

- the nodes,
- the SIU and
- the SPSCIU.



a : Impentance matching unit
b : Chip delay unit
c : Limiters
d : TDM buffers
e : TDM processing unit
f : Initial synchronization unit
g : Spsc signal transmission unit
l : First node definition unit
I : Spsciu
m : Users
n : Flooding matrix unit

FIG. D.2.2.1 The block diagram of a node.

In this section a high level description of the features of these devices structure is discussed. This description is functionally oriented and it aims to give a clearer understanding of the suggested operation of the sub-LAN.

Figure C.1.1.2 illustrates the configuration of a node. Figure D.2.2.1 shows the block diagram (the modules required) (D24, D26) for the implementation of the node at a coaxial LAN. For fiber optics LANs this node's configuration needs to be modified. Its operations are :

- The nodes execute the passive flooding function (fig C.2.1) through directional physical links. Limiters remove the TDM information, which is used for signalling reasons, from the SPSC signal that carries the data. The TDM information follows an active flooding scheme.
- Each node serves a number 'I' of subscribers, through the SPSCIUs.
- The nodes monitor the incoming links and pass the received data to the SPSCIUs.
- The nodes have their own degree of intelligence.
    - The nodes execute any required switching function when two of the subscribers who are served by the same node want to intercommunicate.
    - The nodes execute the initial synchronisation function.

The TDM information is processed separately from the SPSC one. It is received and transmitted through the TDM Processing Unit of the node. The SPSC information is exchanged with the connected users on the node via the SPSCIUs. The outgoing SPSC data are transmitted through a SPSC Signal Transmission Unit. The flooding of the incoming information is realised through the Flooding Matrix Unit.

A number of SPSCIUs is connected at each node. Each SPSCIU serves a different subscriber. There is an one to one correspondence between the SPSCIUs and the subscribers :

- The SPSCIU processes the received information from the subscriber. This incoming information may be at any bit rate higher or lower than its nominal output, while the outgoing chip rate is a constant one.
- It checks, from a security point of view, the validity of the demanded connection for signal's transmission.
- It creates and modulates (analogue modulation) the SPSC signal.
- It creates any required signalling, timing, control or synchronisation signal.

- It reads the channels through the nodes to examine if anybody transmits toward the subscriber that it serves.

- It demodulates any receiving signal separately for every incoming port. Any resulting signal is transformed to the required format to be understood by the subscriber's terminal.

- It handles the TDM channel.

For the intercommunication between any two sub-LANs a common node, the SIU, is needed. This node is the bridge between these two sub-LANs. The SIU :

- interconnects two sub-LANs transferring data from the one sub-LAN to the other one, executing any required function :

    - receives all the packets that are addressed to the other sub-LAN that is interconnected on it.

    - demodulates the received packets and checks the security classification of the data and the validity of the transfer from a security point of view.

    - modulates the packets and retransmits them to the other sub-LAN.

- handles the TDM channels of both the sub-LANs,

- performs the part of the initial synchronisation functions that correspond to it (according to chapter D.5.1).

- executes the flooding of the local traffic in both the sub-LANs,

D.3. OVERVIEW OF THE PROTOCOLS AND THE OPERATION OF THE PROPOSED LAN

The proposed LAN can operate under two different signalling schemes. One of them will be called a synchronous architecture and the other, asynchronous. Both of them use :

- the same topology,
- the same principles of sub-LANs interconnection, and
- the same flooding method and protocols for communication.

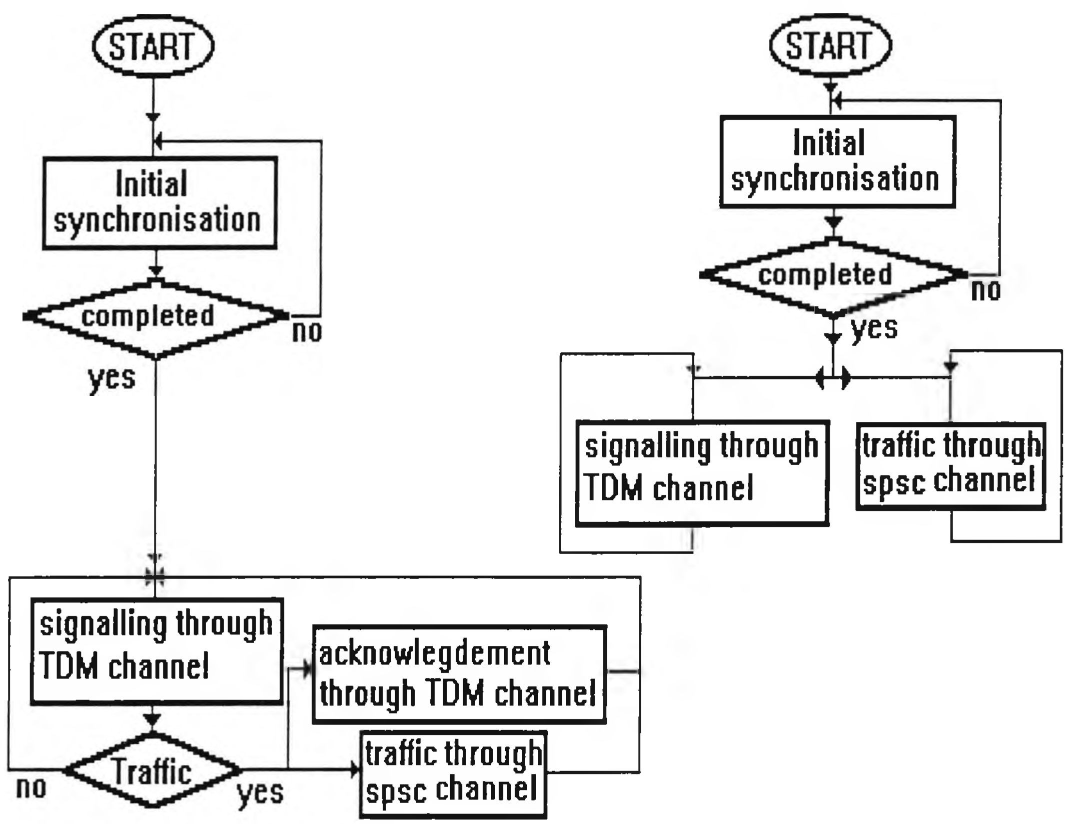


FIG. D.3.1 Overview of the operation of the LAN.

The exchange of data between the subscribers is implemented through a packet switching method, using the SPSC channels. The packets are transmitted using synchronisation and routing information that is obtained through the TDM channel operation. Figure D.3.1 illustrates high level flow charts of the overall operation of the LAN under the two different signalling schemes. The individuality of the asynchronous architecture in relation with the synchronous one, comes in the content of the time slots (TS) of the TDM channel and consequently in the procedure that the subscribers follow in order to communicate with each other. As far as the compatibility with the OSI model is concerned, nothing changes. The nodes, the SPSCIU, the SIUs, the TDM channel, the SPSC channel and the cancellation of the synchronised echoes are modules, operations and services that exist and operate under the same principles and in the same way.

The asynchronous architecture follows a random asynchronous statistical packet generation model. SPSC channels are created, that are occupied only for the packet duration. The packets are transmitted at random time intervals, as soon as they are generated. With this protocol virtual circuit routes are used. These routes are the same as far as no changes to the topology occur. This results to an improved performance.

The synchronous protocol sets up a link between the transmitter and receiver, something like a virtual circuit switching system, for the whole duration of the communication and packets transmission. The access to the media is fully controlled, while the transmission of the packets, after the channel has been seized, is asynchronous. In this way a synchronous procedure is followed that is free of collision or congestion, but with a penalty of :

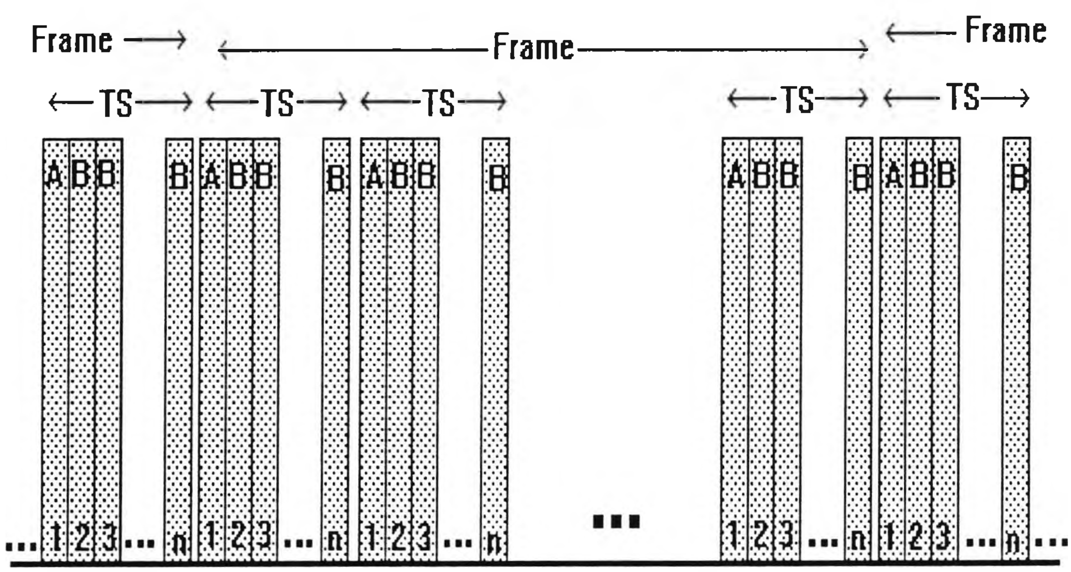
- a low utilisation of the receivers,
- a low throughput,
- a rather limited number of simultaneously communicating subscribers (in comparison with the other protocol),
- high set up delays for the set up of a connection link,

Because of the packet switching method used, the load of the asynchronous LAN is a stochastic phenomenon (section E.2) and is different from the load of the synchronous protocol, which can be examined deterministically. So the asynchronous LAN, running concurrent communications, can support a higher number of subscribers, due to the probabilistic nature of its load.

The SPSC technique employed in combination with the passive flooding protocol used ensures that communication takes place over the shortest path, at any time, between any pair of source and destination nodes of the same Sub-LAN. The signal that arrives at the destination through this path, is synchronised with the locally generated replica of the spreading code. In the event of shortest's path failure of links or of intermediate nodes, a new shortest path, among all the many other alternative paths exists. This path is always selected by the protocol for the transmission. This mechanism provides survivability over interruptions and failures in links and nodes.

During the operation of any sub-LAN three types of signals exist (fig. C.2.2):

- A series of beacons is transmitted by each one of the SIU that are in operation.
- The timing and control signal for signalling purposes.
- The SPSC channels for data transfer.



A: Identification routing and timing information
B: SIU or node or spsciu

FIG. D.3.2 The correspondence of the TSs to the subscribers and to the nodes in a sub-LAN.

The required timing and signalling information for the realisation of the above schemes is obtain through the continuous distribution of a timing-control channel over the LAN. This timing-control channel works on a time sharing base (TDMA) within the same frequency band as the SPSC signals (D24). The SPSC signals and this TDM channel are concurrently and continuously flooded into the network.

The use of separate signalling channels for a SPSC LAN is not essential for its operation (section C3). Their use depends mainly upon the required services of the LAN and the information needed for it. In this design the existence of a separate signalling channel has been considered of great importance, due to :

- the plurality of information that it can carry,
- the rather simple required hardware for its implementation, compared with the required receiver complexity in the case where synchronisation is extracted from the received signal,
- the avoidance of the uncertainty and delay that is introduced in the case where synchronisation is extracted from the received signal.

This signalling channel operates on an active flooding scheme (section C.2). Using this scheme every node receives, processes and retransmits the signalling information along all outgoing links. Every sub-LAN has its own independent in operation TDM channel. All nodes and users of the sub-LAN share this channel on a slotted (TDMA) basis (fig. D.3.2). The allocation scheme of the slots to the nodes and users is predefined, permanent and continuous. Each TS is divided into time portions that are occupied by data produced from the TDM Processing Unit of the node and by the SPSCIU of the users of this node. So this TDM channel is shared between all the nodes, the SPSCIU and the SIUs of the sub-LAN, that are in operation. There is a fixed, one to one relation between the TSs and the nodes and the time portions and the subscribers.

The TDM channel operation guarantees the continuous availability all over the network of :

- timing and synchronisation information,
- routing information,

- information about the transmission delays,

- information about status of the subscribers (not at the asynchronous scheme),

- exchange of the acknowledgement information for the received data,

- etc. (any other type of signalling information that is required for offering the LAN other services, e.g. data security classification and users security clearance information).

The protocols operation have been based on the available signalling information (section D.5 describes in detail the operation of these two architectures). Regarding the synchronisation, the operation of the signalling protocol of both these architectures is separated in two phases. The first one is the initial synchronisation procedure. This procedure is common for both these LANs. The other one is the normal exchange of information through the TDM channel operation.

The LAN's operation requires a universal timing system. Any sub-LAN, any node, and consequently any user, has its own independent clock, and is synchronised with the rest of the system. This universal timing is obtained in the starting phase of the operation of the LAN, through an initial synchronisation protocol. According to it, nodes exchange timing information, sequentially and in a circular mode, until synchronisation is achieved. This procedure is repeated for all the sub-LANs. The obtained synchronisation is maintained through the continuous distribution of timing information that is flooded into the sub-LAN by the TDM channel.

The information that each subscriber transmits during his own TS is flooded into the network. It arrives at all the other nodes always firstly through the shortest route, measured in time. From the obtained timing information the transmission delay between any two users is estimated. This time delay is used by the SPSC transmitters in order to find the appropriate phase shift of the PR sequence that will be used for the modulation of the data.

Because of the use of the SPSC technique, the users connected to a node can gain access to the network by CDMA, without having to determine in advance if the medium is idle, as is required by ETHERNET systems. Simultaneous access by many users is possible because each one selects a spreading sequence uncorrelated with the others. These sequences should form a set with low mutual cross-correlation. MS have these characteristics, as described in part B.1.2. The use of this family of sequences is adequate for this example, although other sequences might be used in practice. Each sequence is a phase shifted replica of the basic MS. There is an one to one correspondence between the users and the phase shifts of the used MS. However the used phase shift for the spreading is different from the nominal one that corresponds to the user and it is the summation :

- of the standard phase shift which corresponds to the destination user and
- of the required transmission delay, for travelling the signal the distance transmitter destination, for the interconnection of this particular pair of users.

In this way the signal arrives always synchronised with the locally generated replica of the code.

The choice of the used connection phase shift of the sequence is determined mainly by the identity of the receiver (the transmitting node modulates its signal with the receiver's phase shift), but it can be also determined by the identity of the transmitter. In this way addressing becomes inherent to the system as it simply involves choosing the particular sequence allocated to the intended destination. The number of subscribers cannot exceed the number of different phase-shifts, that the used MS can provide (less or equal to the period of the code). Longer codes have to be used as the number of subscribers is increased. Since the length of the period of the code is always near to a power of 2 (e.g. 2^n-1), an increase of the number of subscribers up to a number equal to the code period does not influence the hardware. However this increase influences the overall traffic load of the sub-LAN, so deteriorating the performance. The number 'n' is defined during the design of the network and is the appropriate number to create long enough sequences to serve the traffic requirements.

According to the above, we define congestion and collision as follows :

- Collision occurs if the total power at the receiving port of the destination node is higher than a threshold so preventing demodulation of the signal. This threshold designates whether the signal is recoverable or not. Cases of collision are created when more than one packets overlap each other, on the same link and at the same time (these packets are considered as noise the one for the other).

- Congestion occurs when more than one user tries to transmit data to the same destination at the same time through the same port, so that more than one synchronised signals to arrive concurrently at the node of the destination through the same port.

The combination of the SPSC techniques with the packet switching method used, allows multiple access to the network with low probability of collision or congestion (section E.2). This results in good message delivery times.

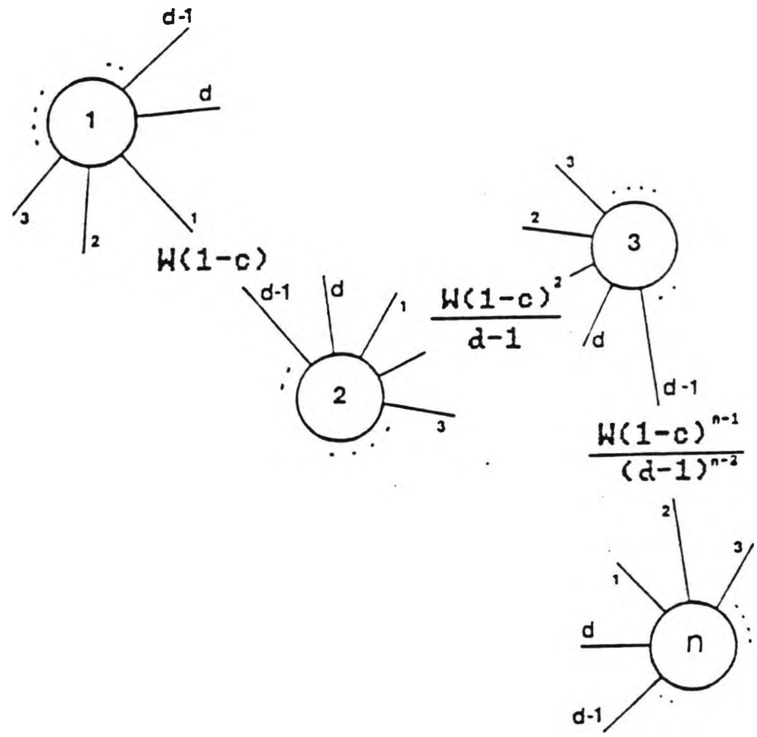


FIG. D.3.3 **The introduced attenuation of a path that connects n nodes.**

As explained in Part C, the routing scheme based on passive flooding involves every node, retransmitting all incoming signals along every outgoing link. Therefore together with the signal many echoes are also created. These echoes act as wide-band background noise. They depend upon the topology and are attenuated gradually. This means that the degree d of each node is of great importance. The degree of the node is defined as the number of one direction links (outgoing or incoming) connected to the node. The attenuation that is introduced, due to the flooding protocol, by the equal splitting of the incoming signal power to the node between the outputs, depends upon the degree of the node.

If the incoming power to node i from port j is $W_{in(i,j)}$, then the power at the output port k, due to $W_{in(i,j)}$ is $W_{out(i,k)}$, given by the following formula :

$$W_{out(i,k)} = W_{in(i,j)} *((1-c)/(d-1))$$

where

c : All the types of losses that are introduced during the implementation of a physical link (e.g. impedance miss-matching during the flooding, propagation attenuation etc.) plus an intended loss are included in 'c'. This intended loss is used for absorbing the transmitted power in the system. This is a controlled way, for prohibiting a dynamic increase of the power and so avoiding an uncontrolled power condition. According to the value of the input node attenuation the rhythm of the absorption of both the signal power and the echoes power changes affecting so the SNR.

d : degree of the node.

As the signal is flooded sequentially through the nodes the attenuation is accumulated in an exponential way (fig. D.3.3). So the higher the number of successive nodes in a path, the higher the total attenuation. Therefore there is a limitation to the number of nodes that the longest path between two subscribers could afford, without the signal disappearing. This number is highly dependent upon the degree of the nodes and is also influenced by the chip rate (section E.1).

If the node of the transmitting subscriber knows the shortest route towards the destination, then instead of flooding the signal towards all the output ports, this node transmits it only towards the direction of the shortest route. In this way the sequential floodings are reduced by one. This reduction means that the power of the spread signal at the destination is (1-c)/(d-1) times higher. This results in an improvement of the final SNR and consequently the system can support a higher number of subscribers or longer paths with higher number of nodes between the source and the destination.

Summary of the operation described up to now has as follows :

- After the data signal has been modulated using the MS and the SPSC techniques in the above described way, it is transmitted toward the outgoing link of the shortest route. At the next node it is distributed to all outgoing links in accordance with the passive flooding method. The nodes are acting as passive physical repeaters that after they attenuate and split the signal, they retransmit it. In this way through sequential flooding the signal arrives to any node through all possible routes (echoes). The required routing information for the initial transmission is available through the TDM channel. The route defined as the shortest one is not always the one that has the smallest number of hops, but it is the one that has the shortest transmission delay.

- Every receiving SPSCIU through its node monitors the network and picks up any information that has the shift of the code that corresponds to the subscriber that it serves. A locally generated PR sequence is correlated with the incoming data. This sequence is the particular one which defines the address of the user, and so if the received signal includes data that have been modulated with the same sequence and are synchronised with it, then this means that there are data addressed to this particular receiver. In this case the correlation process reduces the bandwidth of the appropriate part of the incoming signal, so achieving demodulation and recovering the data intended for this destination. Other components of the received signal (echoes and transmissions intended for other destinations) will be uncorrelated with the local sequence, and so will not have their bandwidth reduced, but on the contrary will be spread again over the full transmission bandwidth. The signals of the TDM channel and the transmitted beacons are treated as narrow band interferences and therefore are handled easily by the receivers, through well-known techniques (A14). The resultant signal power after the demodulation should always be higher than a threshold, otherwise the demodulated signal is considered as background noise. According to the level of this threshold the required SNR of the incoming signal is determined. The value of the threshold depends upon the design and is a function

  - of the length of the accepted longest path (measured in sequential hops),
  - of the topology,
  - of the current traffic and

- of the chip rate.

Increasing the value of the threshold means that the number of hops is reduced (section E.1).

The inter-sub-LAN traffic is implemented through the SIUs. The SIUs, of any pair of SIUs, operate alternatively. One of them is used as a spare unit that starts operating, replacing the other one, in cases of malfunctions. The two SIUs are absolutely similar. The working one transmits a beacon indicating that is in working condition. As soon as this transmission stops, the second SIU starts its operation. The beacons are transmitted continuously by all the SIUs in operation. These are analogue modulated signals at different carrier frequencies that carry the identification of the transmitting SIU and the identification of the other sub-LAN that is interconnected by it.

For reducing congestion probabilities, any SIU may handle simultaneously a number of SPSC signals, proportional to the number of the subscribers of the sub-LAN. So for having a congestion probability of 0 and no delays, a SIU at every one of its input ports should have as many receivers and transmitters as is the maximum number of subscribers of the sub-LAN. If a smaller number of receivers and transmitters is used, then the performance of the inter-sub-LAN communication deteriorates. The optimum number of receivers and transmitters depends upon the amount of the inter-sub-LAN traffic and the values of the other end destination preferability coefficient, that is a stochastic parameter.

Half of the transmitters and receivers of a SIU are towards the one sub-LAN and the other half towards the other sub-LAN. A particular phase-shift of the reference MS corresponds to every one of the receivers of a port. The selection of the receiving code of the SIU depends highly upon the load of the input port through which the SPSC signal arrives at the SIU.

According to the description of the previous sections survivability and security are inherent in the system :

- Good overall survivability properties are achieved by :
  - the mesh topology,

- the properties of the passive flooding protocol and

- the synchronisation information that is provided through the operation of the TDM channel.

Through these protocols the LAN acts as a kind of a self-learning machine. So at any modification of the topology, it always finds the shortest routes, following the disconnection, the interruptions and the failures in links or at nodes. The operation of the TDM channel updates the information about the topology and according to it the routing information and the transmission delays of the SPSC information are estimated.

- The structure provides security at two hierarchical levels (section C.1.1). The first (lowest) level is at the node the SPSCIU and the second one is at the SIUs. The system may control the information flow both through the intelligence of the SPSCIU, before the output of the node to the Sub-LAN, and before the transfer from one Sub-LAN to another, at the SIUs. The SIUs act as trusted bridges between the sub-LANs, so the degree of security achieved depends upon two factors :

- the crypto-security provided by the spreading code and
- the control at the exit of data
    - from the node to the sub-LAN and
    - from one Sub-LAN to another one.

Another major requirement of any network is the possibility of easy expansion. In this case the modular structure of the LAN under design allows :

- At the level of the sub-LAN the operation of one sub-LAN and the later expansion of the LAN in an evolving pattern.

- At the level of the user the operation of the LAN even without users. Users can be connected at any time to the nodes and at any node.

The expansion capacity of the LAN to sub-LANs is not unlimited, but it is programmable and it depends upon the initial design of the size of the sub-LAN. However in the case that no similar sub-LANs will be connected, then an endless structure can be organised, under the limitation that the inter-sub-LAN topology will not any longer be a fully connected graph, with all the consequences to traffic load distribution and to survivability. The signalling protocol described in this work does not cover this case of the creation of an endless structure from different sub-LANs. So the expansion can take place in two successive steps. Firstly the empty nodes of a sub-LAN are filled with users, till the total capacity of the sub-LAN is saturated. In the second step a new sub-LAN is added. Then this sub-LAN also starts to be occupied with subscribers, until it also has been filled up and so on. For the addition of any one subscriber, simply the SPSCIU and the user device have to be connected to the node.

The expansion's protocol cornerstone is the signalling channel's existence. The TDM channel used for any sub-LAN is independent and it is always working with a particular number of TSs, even if some of them are empty. This number is the maximum capacity of the sub-LAN. So the addition of a new subscriber to a node or of a new sub-LAN to a SIU does not require the interruption of any part of the LAN, but it is implemented through a simple 'plug in' function.

D.4. COMPATIBILITY WITH THE OSI MODEL

The present design is not extended further than the three first layers of the OSI model. Because of the peculiarities of the used SPSC techniques :

- the boundaries among these successive layers are not clear and
- some of the performed functions and operations can be allocated to other layers (G9).

The physical layer offers the majority of the functions that are performed in the three first layers.

Figure D.4.1 illustrates the compatibility of the present design with the OSI model.

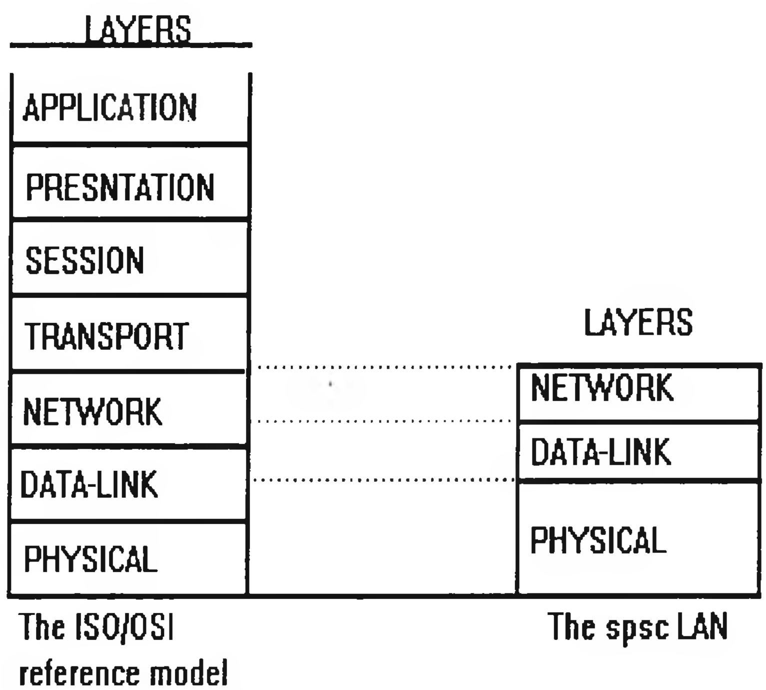


FIG. D.4.1 **The compatibility of present design the with the OSI model.**

The main functions that are implemented in the proposed LAN are :

- 1. Line coding of the data and of the signalling and synchronisation information,
- 2. Error control coding of the data and of the signalling and synchronisation information,
- 3. Packet assembling/disassembling of the data,
- 4. Spreading, monitoring, correlation, despreading of the data,

- 5. Security checking of the data,

- 6. Flooding of the data and the signalling and synchronisation information,

- 7. Synchronisation,

- 8. Signalling (routing information, acknowledgement information, topology information, user's status information, etc.).

- 9. Transmission and reception of the signalling and synchronisation information.

The physical layer, in the present design, is the physical interface that connects the processing mechanisms, of any kind of data, of the higher levels, with their transportation system (nodes and channels). The following functions are executed in it :

- The SPSC data and the TDM information that are to be transmitted through the transportation system (the flooding operation), are processed appropriately, in order to obtain the required physical characteristics (function No 4,9).

- The addressing and routing of the packets (function No 4).

- The SPSC chip stream and the information of the TDM channel that are exchanged through the transportation system, using the flooding method (function No 6).

- The information of the SPSC channel and the TDM information that is flooded in the network is monitored and demodulated at the inputs of the nodes by the nodes and the SPSCIUs (function No 4,9).

- The creation, processing exchange of the routing and topology information, that is required for the routing and synchronisation functions of the LAN (function No.8).

- The synchronisation, the coding and the routing of the received information from the user and of the signalling information (functions No 1,7).

The function No. 8 offers many different services, therefore some of them may belong to this layer while others to higher ones. The spreading/despreading function (No. 4) although

- it contains a mean of error free communication (the SPSC techniques are noise resistant) and

- it has inherent addressing capabilities

since is implemented through the lowest level of the operations is considered as part of this layer.

The operation of the data link layer aims to ensure the communication channel to an error free one. It executes the following operations :

- The packet assembling/disassembling (function No 3).
- The error correction detection and the collision and congestion detection through the acknowledgement procedures (functions No 2,8).

In the network layer an end to end flow control is taking place. Functions of this layer have been transferred to the previous ones, since the addressing and routing are imbedded in the SPSC principles (physical layer). Function No. 5 (security checking) is implemented in this layers. The exchange also of any required information (function No.8) for the implementation of other intelligent services, that are offered by the LAN, is part of this layer.

D.5. DESCRIPTION OF THE SYNCHRONOUS AND ASYNCHRONOUS ARCHITECTURES

D.5.1. INITIAL SYNCHRONISATION

The initial synchronisation phase is the same for both the types of architectures. During this phase a universal timing environment and a common clock, are established all over the LAN. Initial synchronisation is implemented in two steps.

- During the first one initial synchronisation is achieved in one sub-LAN.
- During the second one initial synchronisation is repeated sequentially to all the other sub-LANs till all of them share the same timing and clock.

The initial synchronisation procedure is a function that concerns the nodes and is executed by them. Every time and for any reason, that the network starts or at any cold start, this procedure is repeated.

D.5.1.1. INITIAL SYNCHRONISATION. STEP 1

Suppose

- that every sub-LAN consists of 'k' nodes,
- that each node i has 'd' input-output ports (degree of the node) and
- that a serial number corresponds to every one of the nodes.

Since the suggested topology is the mesh one and since the network of the sub-LAN is a connected graph, there will be always a circular route, from node to node, that will include all the k nodes and each one of them only once.

The first and the d_{th} input-output port of every two successive nodes are connected the one with the other. In this way a ring is created (figure D.5.1.1.1). Node No 1 is defined manually at the initial starting up of the network. This is the master node for the synchronisation of the LAN. This must always be the starting point, for numbering the rest of the nodes of the whole LAN. Node No. 1 can be any node of the LAN.

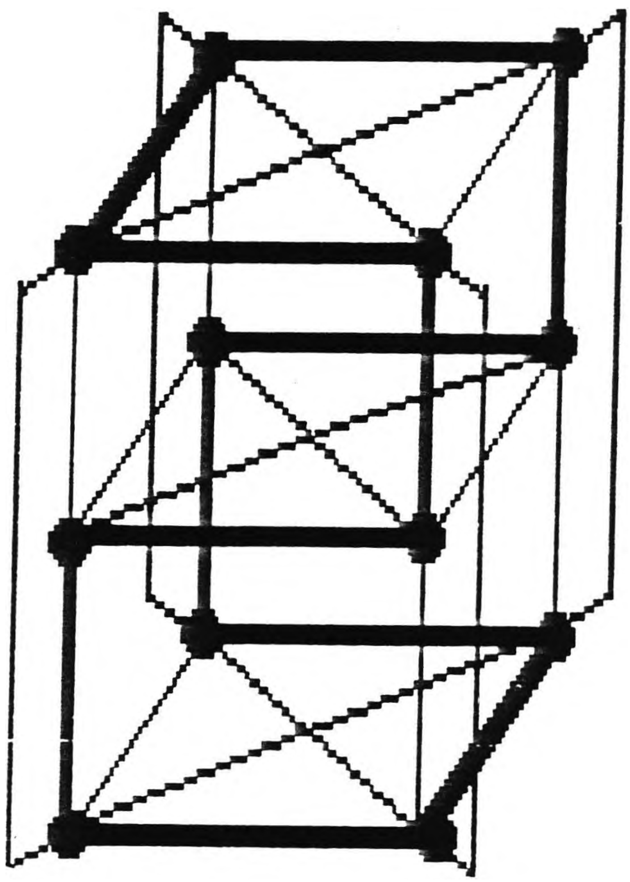


FIG. D.5.1.1.1 **Initial synchronisation. The creation of the ring.**

When node No 1 is destroyed or fails, then the initial synchronisation procedure is repeated. In this case another node is defined as node No 1 manually.

Node No 2 takes its serial number from the system, and is the one that is connected to the first port of node No 1. Node No 3 is connected to the first port of No 2 and so on.

The initial synchronisation procedure between any two nodes within a sub-LAN is completed in two phases :

- Phase 1 : For achieving the initial synchronisation, node No 1 transmits timing bursts to node No 2. Every time burst consists of a number of bits that express the exact time that the transmission of the burst from Node No 1 started. As soon as node No 2 receives them, it reflects them back. In this way the transmission delay of this physical link, $T_{rd_{(1,2)}}$, is estimated. These bursts are transmitted with a time period of T_S (figure D.5.1.1.2), where :

$$T_S > 2 * T_{rd_{(i,j)}} + T_1 + T_{pr}$$

T_{pr} is the time that a bit spends in the node before being reflected back.

T_1 is the total duration of each burst.

After $T_{rd_{(1,2)}}$ has been estimated, phase 1 is terminated and this transmission stops.

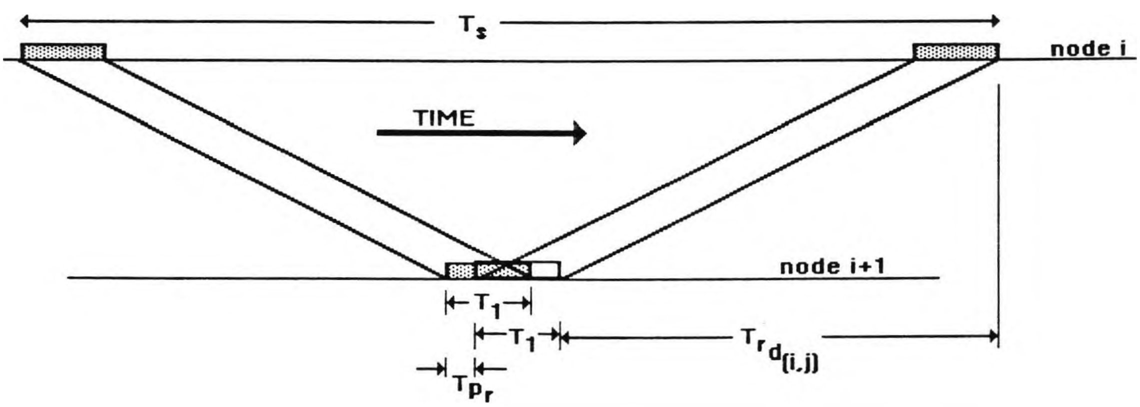


FIG. D.5.1.1.2 **The burst transmission of the timing information during the initial synchronisation procedure.**

- Phase 2 : Node No 1 starts transmitting timing information in bursts to node No 2. The bit rate of these bursts is the same as the internal timing clock of Node No 1. Every one of these bursts consists of a number of bits that express the transmission delay between these two particular nodes and the current time of Node No 1. Through this transmission :

- the clock of the receiving node (Node No 2) is synchronised with the incoming bit stream,
- Node No 2 learns the transmission delay of the physical link 1-2 and
- Node No 2 obtains the same time as the transmitting node.

When synchronisation is achieved, the last received burst is reflected back as acknowledgement.

After this synchronisation has been achieved the link between the Nodes No 1 and No 2 is kept active. Node No 1 stops the transmission of timing bursts and starts transmitting timing information. This information consists of a bit stream that gives the current time of node No 1. Through this transmission :

- the clock synchronisation between the two nodes is retained and
- the timer of node No 2 is kept synchronised with the one of node No 1.

As soon as Node No 2 is fully synchronised with Node No 1, Node No 2 activates its link with the next node, Node No 3. Then the above described procedure is repeated.

Through the sequential repetition of this procedure the last node, Node No k, is synchronised with the previous one. Then the Node No k activates the link with the first node, Node No 1. In this way the ring is closed. If the first and the k_{th} nodes are found to be synchronised, all the timing links are interrupted and the TDM channel of the sub-LAN starts operating. If synchronisation between the first and the k_{th} node is found to be different, then synchronisation has not been achieved. In this case the whole procedure is repeated.

If any node is faulty the ring never closes. The detection of the faulty equipment is done by the system, while its isolation is a manual procedure. If after time T_a the ring has not closed, Node No 1 asks for timing information from Node No 2. In the same way Node No 2 asks for the same timing information from the next one and so on, until the faulty unit is found. Node No 1 indicates this information. After recovery from the malfunction the initial synchronisation procedure is repeated.

D.5.1.2. INITIAL SYNCHRONISATION. STEP 2

The initial synchronisation of all the other sub-LANs that compose the LAN takes place sequentially and in a circular mode.

Let's name the already synchronised sub-LAN 'A'. After sub-LAN 'A' has been synchronised the same procedure is repeated at one of the adjacent sub-LANs, supposed 'B'. This sub-LAN is the one that is connected to the SIU of the synchronised sub-LAN, that corresponds to the node of the lower serial number. In sub-LAN 'B' this SIU is considered automatically as node No 1. This SIU already carries the timing information of sub-LAN 'A'. From this SIU the initial synchronisation procedure in sub-LAN 'B' starts.

When sub-LAN 'B' has been synchronised, then the procedure is repeated for the sub-LAN 'C'. The SIU that connects 'A' with 'C' has at 'A', during the synchronisation procedure, a serial number higher than the SIU that connects 'A' with 'B' and lower than all the other serial numbers of all the other SIUs of 'A'.

The same procedure is repeated until the last sub-LAN is synchronised. Then synchronisation should be the same within all the sub-LANs. If it is not, the same procedure is repeated again, from the beginning, starting again from the initial sub-LAN 'A'.

D.5.2. ASYNCHRONOUS PROTOCOL

D.5.2.1. THE TDM CHANNEL

After the initial synchronisation phase the TDM channel starts operating normally, and independently at every one of the sub-LANs. It is shared between all the nodes, the SPSCIU and SIUs of any sub-LAN. Through this channel the synchronisation information is always available in the network and consequently the whole system is kept synchronised. Some other information that this channel carries is the tracking of the routing that has been followed. This operation, in combination with the common timing, gives at the end of every frame a complete picture of the shortest paths that connect any two nodes and of all the transmission delays for the intercommunication of any two SPSCIUs. Because of the importance of the information that is carried by the TDM channel, any distortion of it should be avoided. For this reason the use of error detecting and correcting codes is imposed. This will add some redundancy to the channel. In the following chapters it will be assumed that this channel is an error free one.

D.5.2.1.1. DESCRIPTION OF THE TDM CHANNEL OF A SUB-LAN

The TDM channel of every sub-LAN consists of frames. Every frame contains a sequence of TSs and every TS corresponds to a node. The TS is divided into 4 main blocks :

- Node's identification (ID).
- Timing information.
- Routing information.
- Acknowledgement information. This block is divided into a number of successive time portions, in such a way, so that a one to one correspondence exists between the time portions and the SPSCIUs connected to the node (fig D.3.2).

According to the design, additional blocks may be appended to the TS. These will carry the required information for various services offered by the LAN (e.g. security checking of the transmitted information, users security clearance, etc.). After the end of the time portion of the last SPSCIU of a node, the TS of the next node comes. Figure D.5.2.1.1.1 shows the minimum information that is carried through the TS of the TDM channel and the structure of the frame, for the operation of the LAN.

The TSs are of two distinct kinds :

- The TSs that correspond to the user nodes.
- The TSs that correspond to the SIU.

Both of them have the same structure but they differ in size. In the case of the TS of a SIU the block of the acknowledgement information is divided into as many parts as the number of users of the other sub-LAN. There is an one to one correspondence between these parts and the users.

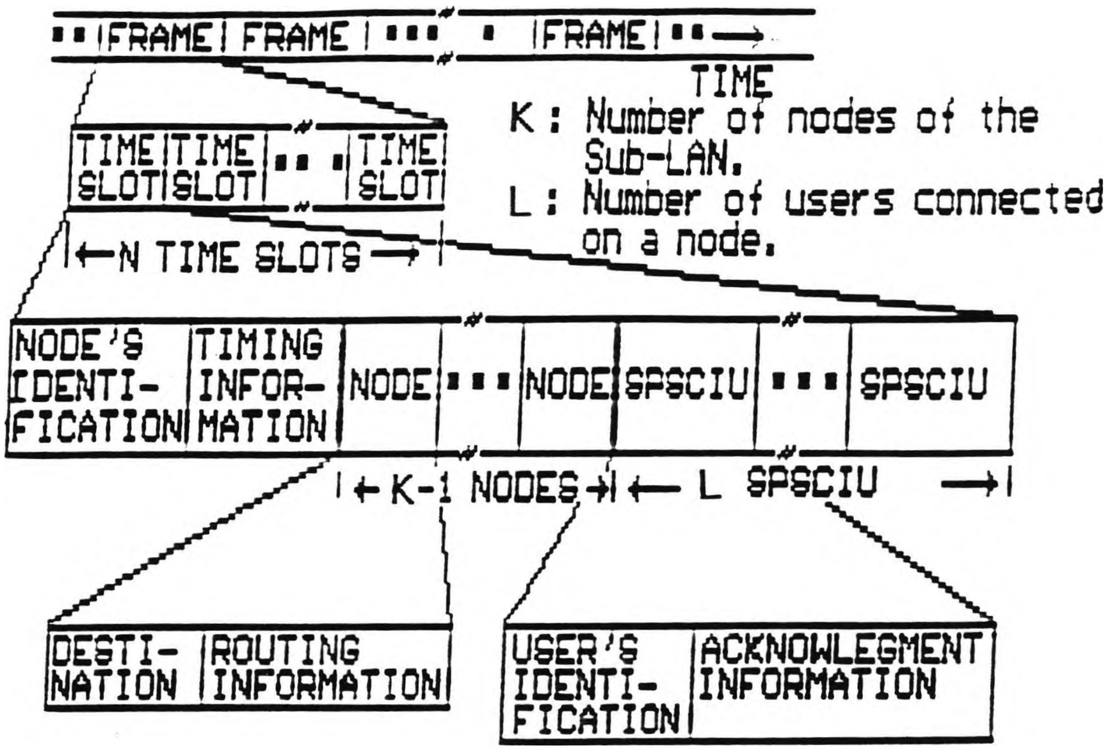


FIG. D.5.2.1.1.1 The structure of the TDM channel.

The first block of the TS is the identification of the node that is currently transmitting into the channel.

The second block is referrenced to the TDM signal's transmission time from the source node (the node to which the TS is dedicated). The difference between this time and the time that the signal is received by the destination node gives the transmission delay between these two nodes.

The third block shows the route that the TDM channel has followed from the source up to the node where it is read. It is divided into K-1 parts (as many as the nodes of the sub-LAN, minus one). Every one of them contains the identification of the node through which the signal has been flooded and the receiving port of this node. The information of this block is required during the initial transmission towards the shortest path.

The forth block is divided into as many parts as is the maximum number of users that can be connected on the node. Every part contains two portions. The first one of them includes the SPSCIU identification and the other one acknowledgement information for the data received from this SPSCIU. The acknowledgement consists of the serial numbers of the correctly received packets, with the identification of their source. The information of this block is required for data corruption and loss avoidance. Since :

- The length of the PR sequence and the chip rate can improve theoretically the BER to zero (section E.1).
- The system design can reduce or even null the collision and blocking probabilities (section E.2).

depending on the design this block may be omitted.

The existence of more types of blocks in the TS depends upon the required services by the LAN, e.g. security checking, etc.

In the following an example of the structure of the TDM TS of a user node is given. We accept that :

- the maximum 300 users are connected on a LAN,

- for security reasons these users are connected to physical groups of 30, since this is the usual size of a small LAN (in this way the 300 users LAN is divided into 10 sub-LANs), and that

- two or three users are connected at every node,

According to the above numbers and the selected topology we can design a topology consisting from sub-LANs of 30 nodes (16 user nodes and 14 SIU) with two users connected per node. For this example we describe the composition of the TDM channel, without taking into account the required blocks of the TSs for various extra services.

In the case of the above example the identification of a node can be fully expressed with 8 bits and of a user with 13 bits :

- the first 3 of them specify the sub-LAN,
- the next 5 describe the position of the node in the sub-LAN,
- the next 1 gives the identification of the SPSCIU and
- the last 4 are the identification of the incoming port.

So the first block contains 8 bits.

Suppose that the maximum measured time window by any node is one hour. Then on every hour the nodes update their time and start counting again from zero. If we assume that

- the clock used, for the accurate timing, is a submultiple of the chip rate,
- the chip rate is 511 times the users bit rate, and
- the bit rate is the standard 64000 bits/sec,

then it can be accepted that 37 bits are required for the accurate expression of the time :

$2^{37} > 60*60*511*64000$.

Through this clock the transmission delay can be estimated very accurately. Using a clock at submultiples of the chip rate the transmission delay can be estimated at submultiples of the chip period resulting in accurate synchronisation and maximisation of the succeeding PG. With 41 bits the time delay is estimated at time intervals of 1/10 of the chip. Block two contains 41 chips.

The third block consists of 30-1 parts. In every one of them the IDs of the succeeding nodes that determine the path from the source node to the destination and the IDs of the corresponding input ports are stored. Each one of them has 12 bits (omitting the 9th one that gives the user of the node). So 29*12 = 348 bits.

If arbitrarily we assume that the serial number of the packets is null every 128 packets, then 7 bits can express it. Suppose that between any two frames 'm' packets from various users (suppose 'x') have been received from a SPSCIU. Then the acknowledgement information for this SPSCIU is the serial numbers of all the received packets together with the ID numbers of the transmitting them SPSCIUs. The acknowledgement can be described by (7+13)*y bits, where

- the number m is expressed by y bits
- the number 13 expresses the identifications of the transmitting users and
- the number 7 is the SN of the packet.

The values of parameters 'x' and 'm' are a function of the traffic that any sub-LAN carries. Since in the current example it has been accepted that the node has up to 2 SPSCIUs on it, the total number of bits of the forth block of a user node will be : 2*(y*(7+13)+13)=26+40*y bits. For a SIU this part will have : 2*16*(y*(7+13)+13)=416+640*y bits.

The total number of bits of a TS will be :

- Users node : 423 + 40 * y bits
- SIU : 813 + 640 * y bits

For the 16 user nodes the length of the 16 TSs will be : 6768 + 640 * y bits

For the 14 SIU the length of the 14 TSs will be : 11382 + 8960 * y bits

The total number of bits of a frame will be : 18150 + 9600 * y bits.

D.5.2.1.2. OPERATION OF THE TDM CHANNEL

The operation of the TDM channel starts from the node with the lower SN, which is '1', and continues with the node of the next higher one. The TSs are shared between the node and the

SPSCIUs connected on it. If however there is not a SPSCIU connected on a port of a node or in the case a SPSCIU failure, then during this particular time portion of the TS, the node transmits timing information. Since the duration of the

- TDM frame,
- TS and
- time portion

is preassigned, as soon as the corresponding time to the missing element or to the out of order element expires, the next transmitting element starts its operation.

After a SPSCIU has created the TDM signal, the node floods it into the network from all the outgoing ports. The transmitted signal arrives at the incoming ports of the first nodes around the transmitting node. There it is read. The receiving nodes read one input at a time. Meanwhile any incoming information from the other ports of the node, is temporarily stored at the input of this node. The received data are compared with the data that are already stored in the memory of the node, which are the contents of the previous TS. If they are the same, the incoming data are ignored, otherwise the memory content is updated. The new data are stored in the memory of the node and transmitted through the rest of the outgoing ports, towards all the other nodes. Before this transmission, the identifications of the node and of the corresponding incoming port are stored in the appropriate part of the third portion of the TS.

In this way the TDM signal arrives, at any other node, except the transmitting one, through the shortest route and gives to this node timing information and information about the route that has been followed. Through this mechanism the flooding of the signal of the TDM channel is not continuous and it stops as soon as the information has arrived at all the nodes. In cases of extensive nodes failures or link interruptions then the virtual path that connects two nodes may be too long in hops. In this case the power spectral density of the SPSC signal will be very low for the signal's recovery. Then operation of the TDM channel may be interrupted earlier.

D.5.2.2. COMMUNICATION BETWEEN ANY TWO SUBSCRIBERS

D.5.2.2.1. COMMUNICATION WITHIN THE SAME SUB-LAN

A major assumption for the correct operation of the network is that the synchronisation is not lost.

Suppose that a subscriber wants to transmit to another one and that both of them belong to the same sub-LAN. When the transmitting SPSCIU, receives the first data that are to be transmitted :

- checks the destination clearance classification, according the data security classification,
- assembles them in packets,
- chooses the appropriate phase-shift that corresponds to the destination,
- finds the transmission delay that corresponds to this particular link,
- modulates the packets to SPSC signal using the above information,
- transmits the packets at random time intervals, without taking into account :
    - if the destination at this particular moment is occupied,
    - if somebody else in the sub-LAN has already started transmitting to this particular destination,
    - the load of the network.

The SPSCIUs, through their nodes, are monitoring continuously the incoming ports. The incoming signal and consequently the received data are under a continuous correlation process. Through this process any information that is addressed towards this particular SPSCIU is demodulated.

If two packets from different sources are sent to the same destination and happen to arrive there from the same port at the same time, then congestion takes place (section D.3). If at the receiver the traffic load is higher than a threshold, then the quality of the communication deteriorates and the BER increases as a function of the load. The continuous increase of the BER, results in collision (section D.3). In both the above cases, through the acknowledgement procedure of the TDM channel, an order for packet retransmission is given.

In more detailed, the description of the operation of the protocol is as follows :

Transmitting part :

- The SPSCIU of the transmitting user receives the information from the subscriber (voice or data) and stores it in a buffer. This information may be at any bit rate up to a predefined maximum.

- The transmitter denotes the security classification of the data and the security clearance of the receiver. The SPSCIU examines (from existing tables) the validity of the given information and issues, according to the case, transmission allowance.

- The existing information in the buffer is read and is processed sequentially (A3, B1, B2, B3) :

  - waveform or source or mixed coding for the voice,
  - for both the voice and data line coding,
  - packetizing,
  - error control coding,
  - adding of the appropriate overheads, etc. The added overheads contain information like security classification, transmitting and receiving SPSCIU identifications, etc.

- Simultaneously the SPSCIU finds from its stored tables the phase-shift of the spreading code that corresponds to the far end destination and the propagation delay of the shortest path that corresponds to this link.

- With these data the SPSCIU of the transmitting node shifts the locally generated spreading code appropriately, and adds ('exclusive or' addition or multiplication) the code to the packetized data.

- When this procedure has been completed the signal is ready to be transmitted. The created packets are transmitted from the outgoing port that corresponds to the shortest path, for further flooding at the next node. In this way the transmitted signal, is received by the destination, fully synchronised with the PR sequence that is generated locally at the receiver.

- Every packet after it is transmitted is stored in a buffer for a period of time equal to the duration of two frames of the TDM channel. If during this period the acknowledgement has been received then the buffer is discharged of the packets that have been acknowledged. Otherwise they are retransmitted.

Receiving part :

- The SPSCIU of the receiving subscriber, through the node, monitors continuously the power of the incoming channels.
- It samples this signal according to the chip rate clock and stores the samples in separate buffers, one for every one of the ports.
- For every one of the buffers an individual correlation process takes place. If the processed signal is found containing information modulated with the same phase shift as the locally generated code, then this information is revealed from the incoming signal. So the SPSCIU decodes the voice or data that were transmitted by the source, and feeds them to the user.
- The acknowledgement of the received information is sent back through the TDM channel. It is consisted from the serial numbers of the correctly received packets and from the identification of the SPSCIU that transmitted them.

D.5.2.2.2. INTER-COMMUNICATION BETWEEN DIFFERENT SUB-LANs

A major assumption for the correct operation of the network is that the synchronisation is not lost.

A subscriber that requires a connection with a destination, that belongs to another sub-LAN, transmits towards the active SIU, that inter-connects the two sub-LANs in the following way.

- He detects which is the operating SIU.
- He selects in a random way one of the receivers of the SIU's port that corresponds to the shortest route.

- He transmits using the code (phase shift) of this receiver, following the procedure described at section D.5.2.2.1.

- If it happens this receiver is occupied by another transmitter, and so a congestion takes place, this is recognised through the acknowledgement procedure. In this case after a random time interval, he chooses again randomly another receiver and repeats his trial.

The SIU receives this signal demodulates it and correlates it with the locally generated replica of the spreading code (according to the procedure of section D.5.2.2.1). After the initially transmitted information has been obtained, the overheads are checked. According to the security specifications of the system, a retransmission allowance is issued. Assuming retransmission permission, then the SIU reads the other end destination code and transmission delay and modulates again the data according to this information. After the modulation retransmissions into the other sub-LAN follows.

Any required signalling is exchanged through the TDM channel of every one of the sub-LANs separately, in the way that has been described. Regarding the acknowledgement services, these are offered :

- once locally at any one of the sub-LANs, between the SIU and the user, and

- once after the packet reception from the destination, between the source of the data and the destination.

The routing and timing procedures of the TDM channel, concern the internal communication in every one of the sub-LANs, therefore their retransmission is not required.

D.5.2.2.3. FAULTY NODES BY-PASS

When a node of the shortest route that connects two communicating subscribers fails or when some links of this route are interrupted, then the SPSC signal arrives at its destination through another route (since it is flooded into the network). This new path will be the shortest one at this time. The new route will be of a different propagation delay. Therefore the SPSC information will arrive at the destination not synchronised with the locally generated replica of the spreading code.

Till the exchange of the next TDM frame no data will be demodulated at the destination. Both the TDM and the SPSC information always follow the same path, that is the shortest existing one. With the next TDM frame, the TDM channel, having followed the same route with the SPSC channel, will carry the appropriate information for the new propagation delay estimation. In this way the next transmission will be implemented with the new propagation delay and the link will be restored.

The transmitting SPSCIU stores always a reasonable amount of information (packets), till the reception of the acknowledgement (e.g. the packets that correspond to two TDM frames time period). Acknowledgement is given through the TDM frames. The transmitting SPSCIU will retransmit the required information (not received packets) along the followed alternative route with the new adjusted transmission delay and using the corresponding phase shift of the receiver.

If a SIU is faulty then another one undertakes the operation. The faulty SIU stops transmitting the flag that shows its operational condition, and the other SIU starts transmitting its own one.

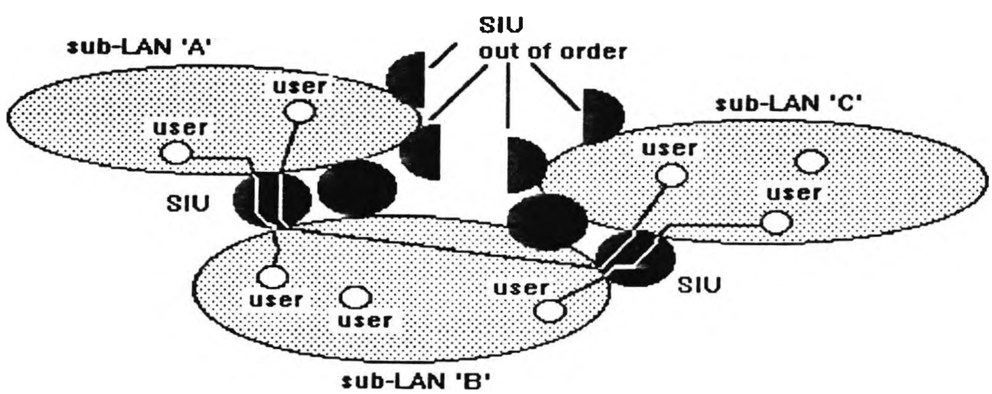


FIG. D.5.2.2.3.1 The creation of alternative routing in the case of an inter-sub-LAN connection interruption.

If both the SIU that interconnect two particular sub-LANs get out of order, then the communication between these two areas is not interrupted, but it is kept through longer inter-sub-LAN paths. The information is transmitted to another sub-LAN and is then retransmitted to the sub-LAN of the destination (figure D.5.2.2.3.1). The distribution of the inter-sub-LAN traffic within the others sub-LANs is implemented in a random way. This results to traffic load increase at the sub-LANs that serve the faulty connection's inter-sub-LAN traffic.

The used chip rate determines the maximum traffic supported by the sub-LAN. Increasing it a tolerance is offered for serving extra inter-sub-LAN traffic load, so that the performance to be kept constant, without any significant deterioration of the quality. For being the SIUs able to serve this increased incoming load, some redundancy at the number of the concurrently served subscribers by them, should exist.

D.5.2.3. PACKET LENGTH ESTIMATION

This part will examine the effects of the TDM channel use, to the packet length and to the SPSCIUs memory requirements. These two magnitudes will be examined

- for the topology of section D.5.2.1.1 example (figure C.2.4),
- for node's degree = 10 and
- for the interior sub-LAN traffic.

The size of the memory is influenced by the number of already transmitted packets that have to be stored (acknowledgement's procedure realisation). Since the LAN is integrated for any type of traffic, a major restriction that has to be taken into account is the tolerance of voice to delays up to 250 msec (B3). This time is analysed as the required time for:

- the packets transmission,
- the acknowledgement transmission through the next TDM channel's frame,
- the required retransmission in case of packet's reception failure and

- the new acknowledgement of the retransmitted packets through the next TDM channel's frame.

TABLE D.5.2.3.1. : THE RELATION SHIP BETWEEN THE PACKET LENGTH AND THE PERIOD OF THE FRAME OF THE TDM CHANNEL FOR THE INTERIOR THE SUB-LAN TRAFFIC.

Column A: The value of 'y'.

Column B: Period of the frame of the TDM channel in msec.

Column C: The length of the frame in bits.

Column D: Number of transmitted frames during 250 msec.

Column E: Maximum number of packets received from the SPSCIU during a frame period.

Column F: Maximum number of packets per incoming port received from the SPSCIU during a frame period.

Column G: Corresponding number of bits per packet.

Column H: SPSCIU required memory

A	B	C	D	E	F	G	H
1	16.65	33300	15.00	1	1	1066	2132
2	22.41	44820	11.15	3	1	1434	8164
3	28.17	56340	8.87	7	1	1803	25242
4	33.96	67860	7.36	15	1	2172	65160
5	39.69	79380	6.30	31	2	1268	78616

It will be assumea

- 64000 bits/sec data bit rate,
- negligible transmission delay and processing time of the TDM signal at any node,
- 2 Mbits/sec TDM channel bit rate,
- that any packet is transmitted the maximum 3 times,
- that any packet is stored for two frame period waiting for the acknowledgement and,

- that the length of a frame of a sub-LAN will be FL1=18150+9600*y (y is the number of bits that expresses the maximum number of packets that are received during a frame period from a user (section D.5.2.1.1)),

If A% redundancy is added at the number of bits of each frame, for error control coding is included, then FL1 becomes :

FL1 = (18150+9600*y)*A /100

If we accept arbitrarily that A=20% then FL1 becomes :

FL1 = 21780 + 11520 * y.

Then the frame period becomes :

FL1/2,000,000 sec

Table D.5.2.3.1 illustrates the relationship of y with the packet length for the interior the sub-LAN traffic. For three retransmissions of the same packet in the case of errors, the minimum six frames should be transmitted every 250 msec.

D.5.3. SYNCHRONOUS PROTOCOL DESCRIPTION

D.5.3.1. THE TDM CHANNEL

After the phase of the initial synchronisation, the TDM channel starts operating, independently for every one of the sub-LANs. It is shared between all the SPSCIUs and SIUs of any node and of any sub-LAN. Its operation offers two main kinds of service :

- It maintains the correct timing and synchronisation status of the LAN in all the phases of network's operation.
- It implements the required channel for the exchange of the signalling and acknowledgement information.

A more detailed view of TDM's channel operation, has as follows :

- During the initial synchronisation phase, the timing information is spread all over the sub-LAN, creating a universal timing platform.
- After the initial synchronisation, through this channel :
  - Any required timing and synchronisation information, is always available in the network.
  - Information about the tracking of the routing that has been followed, is always available in the network. This is required for obtaining :
    - a complete picture of the shortest paths that connect any two nodes,
    - a complete knowledge of the used incoming ports of the nodes,
    - all the required information for the estimation of the transmission delays during the intercommunication of any two nodes.
  - The acknowledgement service is exchanged among the intercommunicating users.
  - Information about the status of the subscribers, (if they are receiving, transmitting or if they are in an idle situation), for congestion's avoidance, is always available in the network.
  - Information used for other LAN's services, is always available by the LAN.

The TDM channel operates under exactly the same principles and in the same way as the TDM channel of the asynchronous protocol (chapter D.5.2.1). The only difference arises in the additional information about the status of the subscribers, that is carried by the TSs.

Every frame of the TDM channel of a sub-LAN consists of two types of TS :

- The TSs that correspond to the SIU.
- The TSs that correspond to the rest of the nodes.

Both these types of TSs have the same structure but they differ in interior size (number of SPSCIU). The TS is divided in 4 main blocks :

- Node's identification.
- Timing information.

- Routing information.

- SPSCIUs portions. Each one of them contains three parts :

  - SPSCIU identification

  - status information of the transmitters and the receivers (this block of information is used for the congestion's avoidance)

  - acknowledgement information.

In the case of the TS of a SIU this part contains information about :

  - the receivers allocation in the SIU's incoming ports to the sub-LAN's transmitting SPSCIU,

  - the status information of the transmitters and the receivers of the other sub-LAN.

  - acknowledgement information.

According to the design additional blocks may be appended to the TS. These will carry the required information for extra LAN's services (e.g. security checking of the transmitted information).

The first, the second and the third blocks of the TS are identical with already those described in chapter D.5.2.1.2. The fourth block is divided into as many parts as the maximum number of users that can be connected on the node. The contents of the SPSCIU identification and of the acknowledgement information have also been described at chapter D.5.2.1.2. The status information contains :

- the destination of the transmitted information,

- the source of the received information.

Since LAN's topology of this type is not concrete but flexible, according to every case's requirements, TDM channel's frame length varies according to the design (section D.5.2.3).

D.5.3.2. COMMUNICATION BETWEEN ANY TWO SUBSCRIBERS

D.5.3.2.1. COMMUNICATION WITHIN THE SAME SUB-LAN

Suppose that subscriber 'I' wants to transmit to the 'L' one and that both of them belong to the same sub-LAN. As soon as subscriber 'I' indicates this decision, his SPSCIU waits for one frame period of the TDM channel (the whole next frame) to find out:

- if anybody else is transmitting to subscriber 'L', and
- if the port that he is intending to use, is busy.

This is found through the continuous reading of the TDM channel. The following information is obtained through this procedure :

- Whether or not subscriber 'L' is receiving SPSC signals. If he is, from which user and through what node's input port.
- Whether or not any subscriber has expressed the desire to communicate with the 'L' one. If any one has, through what node's input port is this transmission going to be realised.

If subscriber 'L' is already receiving through the particular input port that interests 'I', or if anyone else has expressed the intention to transmit towards 'L' through this input port, then the indication 'busy' is given to 'I'. If neither of these is happening, then subscriber 'I' puts an indication that he wants to transmit to 'L' in the next frame. If in the same frame any other subscribers have also expressed an initial intention to transmit to 'L' through the same node's input port, then a queue is created. There are many ways for precedence to be allocated amongst the users. If for example it is accepted that the SN of each one of them is the main criteria, then :

- Suppose that no precedence difference exists. A higher priority is given to the subscriber with the lower SN. The rest of them are put in a waiting list in a sequence according to their SN.
- Otherwise, 'I', according to his precedence and to the precedence of the other connection's candidates with 'L', is appended at the appropriate position of the waiting list. Also, according always to 'I's' precedence, it is possible, if 'L' is busy, for 'L' to be interrupted, and the line to be occupied by 'I'.

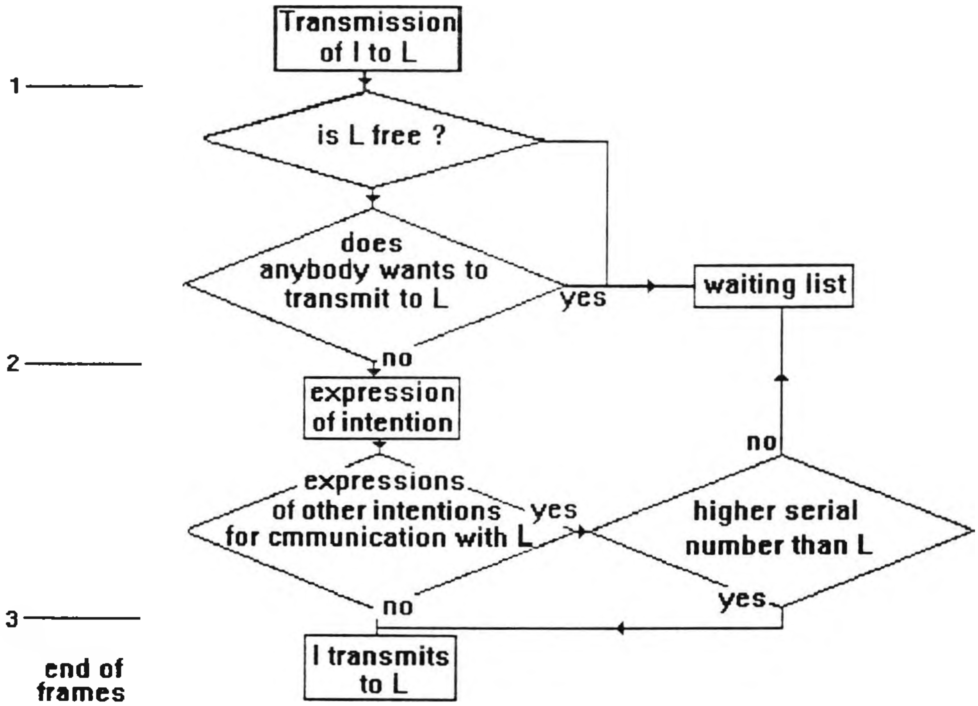


FIG. D.5.3.2.1.1 The actions that take place per frame for the set up of a link.

When 'I' takes the priority to communicate with 'L', he starts transmitting to 'L', using the SPSC channel. He selects the code sequence's phase shift that corresponds to 'L', and with the beginning of the next frame he starts the transmission. So the set up delay time is 3 periods of a TDM channel's frame (fig. D.5.3.2.1.1). After the set up of the channel the connection is implemented according to section's D.5.2.2.1 description.

D.5.3.2.2. INTER-COMMUNICATION BETWEEN DIFFERENT SUB-LANs

Suppose that a SIU inter-connects sub-LANs 'A' with 'B'. The SIU receives any signal originated from 'A' and destined towards 'B' and decodes it. It examines the connection's validity from a security point of view. If it is O.K. it modulates the data again with the appropriate code and retransmits it into the other sub-LAN 'B'. Since sub-LAN's 'A' SPSCIUs should know which SIU receivers are free (not occupied), the SIU during its own TS of the TDM channel declares the busy receivers.

For the set up of the path the following procedure takes place. Suppose that subscriber 'A_m' from sub-LAN 'A' wants to transmit toward another one 'B_n' of sub-LAN 'B'. 'A_m' starts the usual procedure towards the SIU that interconnects the two sub-LANs. 'A_m' during his TDM channel's TS puts the indication that he wants to communicate with 'B_n'. The appropriate SIU reads it. The SIU with every TDM channel's frame dedicates a free receiver to every one of the SPSCIU that want to communicate with it. If there is not a receiver available then a busy indication is given. In this case the SPSCIU is put in a waiting list. This procedure forbids the same input port's receiver to be selected by more than one user transmitters. With the start of the next TDM channel's frame of sub-LAN 'B', the SIU, following the above mentioned procedure and acting as a sub-LAN's 'B' subscriber, captures destination 'B_n' and dedicates a free transmitter to it. As soon as destination 'B_n' is dedicated to 'A_m' the SIU informs 'A' about it. With the next frame 'A_m' starts transmitting. In this way the virtual channel 'A_m'-->'B_n' is set up. The total required set-up time for an inter-sub-LAN connection is 5 frames' period.

After the communication link's set up the data transmission starts. The SIU receives the SPSC signal demodulates and correlates it with the locally generated replica of the spreading code. After the initially transmitted information has been obtained, checks the transmission's security validity, modulates it again with the new code and retransmits it in the other sub-LAN. So the signal arrives at the destination subscriber. Any required signalling or acknowledgement information is exchanged through the TDM channel.

If 'B_n' is occupied then this information is given to the SIU by the appropriate TS of sub-LAN's 'B' TDM channel. This information is retransmitted by the SIU to 'A_m' through the next TDM channel's frame of 'A'.

D.6. PROPOSED LAN'S PERFORMANCE DESCRIPTION AND PARAMETERS

The performance of these LANs depends upon the particular values that will be given to various variables in the implementation and installation phase. These variables are :

- The maximum number of sub-LANs.
- The used topology inside the sub-LAN (number of subgraphs, number of nodes per subgraph, maximum number of users per node).
- The used attenuation at the input port of any node.
- The accepted maximum length of a link measured in hops (not in time).
- The used chip rate.
- The used flooding scheme.

These variables influence the total amount of created traffic and the power of the echoes.

Accepting that the passive flooding protocol is used, the echoes power is a function of :

- the topology
- the traffic and
- the input node attenuation.

So finally the performance is influenced by the above referred factors and the amount of created traffic. Traffic depends upon :

- the user distribution over the network,
- the packet generation distribution,
- the other end selection distribution and
- the topology.

According to the described architecture we define the BER of a physical link that connects two particular nodes, as the summation of all the corrupted bits of all the transmitted packets through the virtual links of this physical link over the total summation of the bits of these packets. The BER is a function of the echoes power, the topology, the input node attenuation, the traffic and the chip rate. BER is reduced in the same way for all the virtual channels of any particular link.

Since the traffic load and the echoes vary throughout the topology, the BER is not constant and is different in the various paths that connect any two nodes. The average BER is defined as the summation of all the corrupted bits of all the transmitted packets through every virtual link over the total summation of the bits.

When a passive flooding protocol is used, as the number of nodes in a sub-LAN is increased, while the final number of users and the created traffic are kept constant, the distributed power of the noise over the links and the nodes is reduced. At the same time the links are becoming longer in hops and the degree of the nodes is increased. Therefore the power of the received signal is reduced and so the total PG of the sub-LAN is changed and the final BER deteriorates. Increasing the chip rate produces a better PG and BER and consequently longer paths and higher amounts of traffic can be served.

The traffic distribution, under a passive flooding protocol scheme, affects the power distribution over the LAN and consequently the BER. The worst case of traffic occurs when all the users try to communicate with destinations located in a particular area of the network. During any transmission the transmitted power of the signal of interest is reduced progressively following the hops. Any transmission is initially directioned towards the shortest route and the signal arrives always at the destination through this shortest route. Due to all these factors at the worst case of traffic a great amount of the initially transmitted power accumulates at the area of the receivers of the destination. This power is kept flooded to the rest of the network. In this way, in the area of the receivers a highly noisy environment exists. The required chip rate for serving this type of traffic will also serve, with improved performance, any other traffic situation.

Regarding the concurrent communications, under a passive flooding protocol scheme, the number of concurrent transmitting users that any particular topology may support is not constant and depends upon the chip rate used, and the distance of the destination, measured in hops. The higher the chip rate, the higher the PG and consequently the higher the afforded power of noise due to echoes can be, or alternatively lower the incoming SNR. The performance of all the virtual channels created during the communication of the users is the same and depends upon the instantaneous traffic load and the echoes in any particular link or node. The BER is a direct function of the SNR. The higher the SNR the lower the BER is.

The input node attenuation controls the value of absorbed power from the sub-LAN. This influences the SNR and consequently the final BER. Assuming that the input node attenuation is 1 then no power loss exists in the system. In this case a continuous linear increase of the power in the sub-LAN occurs. As it gets higher both the power of the echoes and of the signal of interest are reduced, but at a different rate, due to the different number of sequential floodings that they have gone through. After time t the amount of power that has been absorbed by the system becomes equal to the initially transmitted power. A static power equilibrium is obtained. The selection of the correct input node attenuation in combination with the appropriate chip rate value can give the required PG for nullifying the BER

Since CDMA offers concurrent communications, delay is a function only of the collision and congestion probability (ignoring the required transmission time). Due to the CDMA qualities, to the very low congestion probability (fig. E.2.1.1 and E.2.1.2) and to the mesh topology, both of them can be considered as zero. Collision and congestion probability depend mainly upon the

- chip rate,
- used topology and
- signalling protocol.

As the chip rate is reduced collisions start to appear, and consequently delays due to retransmissions. So collision is a design problem and delays due to the required retransmissions can be nulled. For these reasons delay is not considered as a performance parameter. Theoretically in a sub-LAN without any type of thermal noise and the appropriate selection of the value of the chip rate, the BER can be nulled. For a null BER this LAN can be considered as collision free.

E. SHORT MATHEMATICAL ANALYSIS OF THE PROPOSED LAN.

The performance of any network depends mainly upon the used architecture and communication protocols. Any one of them is influenced by a lot of factors. For the suggested network the interactive factors that have a dominating role are the used chip rate, the spatial distribution of the active (transmitting and receiving) users, the LAN's topology and the traffic load.

In SPSC systems when the noise overcomes a threshold then the BER is increased as a function of the incoming SNR. For a particular user as noise is considered the summation of the white gaussian one with the transmissions of the other subscribers, that are out of his interest. In the present design, in any one of the sub-LANs, due to the used packet switching method, when more than one packet overlap each other, on the same link and at the same time, then these packets are considered as noise the one for the other. This creates cases of collision. Collision and congestion have been defined earlier in this work (section D.3).

In this part of the work a mathematical model of the passive flooding scheme is developed. Through this model the following estimations are taken for the environment of a sub-LAN :

- the influence of the topology to the traffic served and to the required chip rate,
- the congestion probability and
- the probabilities of having various power figures in it.

Through these estimations is proved

- theoretically that a null BER can be achieved
- that the collision and congestion probabilities are negligible,

when the optimum value of the chip rate is used, independently of the use of signalling information. Another task of this analysis is to show that this optimum value of the chip rate is feasible according to today is technology for the implementation of such a LAN.

E.1. POWER ANALYSIS AND TRAFFIC SUPPORTED AS A FUNCTION OF THE TOPOLOGY

E.1.1. POWER ANALYSIS

In this section the traffic power that can be supported is examined in relation to the topology and the number of subscribers that can be served, taking into consideration the requirements for survivability. Although the model has been based on the suggested topology in section D, this does not introduce a major restriction that limits the application of these estimations to this topology and influences the generalisation of the results.

The estimations are based on the environment of a Sub-LAN, with the following simplifying assumptions :

- Every one of the users of a Sub-LAN is transmitting data packets to a station of another Sub-LAN, while at the same time is receiving data from a subscriber of another Sub-LAN.
- The flooded data are packets of constant size transmitted at random time intervals.
- The traffic created by any user will be examined as a parameter that describes the normalised average time that the user occupies the channel.
- The link attenuation is zero (the attenuation of connecting cables or optical fibers is assumed to be compensated for by appropriate signal amplification at the input of each node).
- All the nodes of a Sub-LAN have the same degree.
- The channel noise is low enough that it can be ignored.
- The flooded power accumulates at the nodes in accordance with a homogeneous distribution model, as if the physical links that interconnect the nodes of the Sub-LANs do not exist and every node is straight connected to the other ones.
- The transmitted signals are continuously flooded.
- All the physical links are unidirectional.
- Each pair of Sub-LANs is connected together by two SIUs for survivability reasons.

- The SIUs are symmetrically distributed all over the Sub-LAN, so that the inter-Sub-LAN traffic is homogeneously distributed all over the sub-LAN.

- One period of the spreading sequence corresponds to the period of one data bit.

- The spreading sequences used are the maximal length linear binary sequences. This assumption is adequate for performance estimation, although other sequences might be used in practice.

- The signal initially flooded into the network by a user is transmitted along the route of the shortest virtual path. The required routing information is available through the continuous operation of the TDM channel.

- The voice and/or data transmission bit rate is 64000 bits/sec.

The following parameters are taken into account in the performance estimates :

- The power, W, transmitted by a user.
- The number, l, of subscribers per node.
- The number, m, of fully connected subgraphs that comprise any Sub-LAN, and the number, s, of nodes that the subgraph contains.
- The total number, N, of subscribers per LAN.
- The attenuation, c, of any link of the Sub-LAN ($0<c<1$ as described at section D.3).
- The number, h, of nodes that form the shortest virtual path between any two nodes.
- The required chip rate, B_c, in Kchips/sec.
- The required chip sequence-length, e, for the Sub-LAN.
- The number, j, of Sub-LANs of the LAN.
- The total number, g, of subscribers per Sub-LAN.
- The degree, d, of the nodes.
- The PG 'PG'.
- The average normalised time, T_{tr}, that the traffic created by any user occupies a virtual communication channel.
- The number of stages, n, of the LSR that produces the PR sequence.

The average total power 'W_t' that exist throughout any one of the Sub-LANs will be the power of the initial transmissions '$2*g*T_{tr}*W$' plus the power arising from the echoes of the previously transmitted, flooded and attenuated packets. The upper limit of W_t may be calculated as follows :

$$W_t = 2\, T_{tr}\, g\, W\, (1 + p + p^2 + \ldots + p^n + \ldots) =$$

$$= 2\, T_{tr}\, g\, W \sum_{n=0}^{\infty} p^n =$$

$$= 2\, T_{tr}\, g\, W \frac{1}{1-p} \left| \begin{array}{l} p=1-c \\ 0<p<1 \end{array} \right| =>$$

$$W_t = 2\, T_{tr}\, g\, W \frac{1}{c} \qquad .1.$$

where $g = l*(k-2*(j-1))$ and the number of nodes of a sub-LAN is $k = s * m$

If we consider a particular transmission and we examine the power W_d of the received signal at the destination, then, as a function of the transmitted power, W, this will be given by :

$$W_d = \frac{p^h\, W}{(d-1)^{h-1}} \qquad .2.$$

where $d = m + s - 2$

because the signal has been received by the node but not flooded by it yet (figure D.3.3). The total attenuation that is imposed on the signal depends upon the number of nodes that compose the virtual path that connects the source of the signal with the destination. Therefore there is a limit to the maximum number of nodes that the shortest path between two subscribers could be allowed to have. This limit is highly dependent upon the particular topology used, the attenuation at the input port of a node and the chip rate. Table E.1.1.1 presents such results for a LAN of 240 subscribers.

If we assume that the total power is not distributed all over the network (links and nodes) but that is gathered at the nodes, then the existing power 'W_n', at a particular input port of a node will be the total power divided with the number of nodes 'k' and the number of input ports 'd', less the locally transmitted power:

$$Wn = \frac{W_t}{k\, d} - W\, l\, T_{tr} =$$

$$= \frac{[2[k - 2(j - 1)] - (1 - p)\, k\, d]\, W\, l\, T_{tr}}{(1 - p)\, k\, d} \qquad .3.$$

Thus the SNR at any input port of this node is given by :

$$SNR = \frac{W_d}{W_n - W_d}$$

$$SNR = \frac{p^h (1 - p)\, k\, d}{(d-1)^{h-1} [2[k - 2(j - 1)] - (1 - p)\, k\, d]\, I\, T_{tr} - p^h (1 - p)\, k\, d} \qquad .4.$$

$$SNR_{out} = PG\ SNR = \frac{B_c}{B_d}\, SNR = \frac{B_d\, e}{B_d}\, SNR$$

For a SPSC receiver the output signal to noise ratio, SNR_{out} after the correlation procedure used to recover (de-spread) the wanted signal is given by :

$$SNR_{out} = e\ SNR \qquad .5.$$

B_d denotes the information-data bit rate in kbits/sec.

For a matched filter demodulator the required e is estimated to be given by (Section B.1.2, A2):

$$e = 2\, SNR_{out}\, Q$$

where

$$Q = \frac{(d-1)^{h-1} [2[k - 2(j - 1)] - (1 - p)\, k\, d]\, I\, T_{tr} - p^h (1 - p)\, k\, d}{p^h (1 - p)\, k\, d} \qquad .6.$$

The actual transmission chip rate of the SPSC LAN is the information transmission bit rate multiplied by the length of the PR spreading sequence. With the assumption that a MS is used, the period length is an integer of the form 2^n-1 which must be chosen so that it is greater than or equal to the period, e, required to meet the SNR requirements. Hence the transmission chip rate, B_c, will always be greater than or equal to e times the data rate :

$$B_c = 64\ 10^3\ (2^n - 1) \geq 64\ 10^3\ e \qquad .7.$$

Let 'a' be a bandwidth efficiency coefficient, where $0<a\leq 1$, defined by $e=a(2^n-1)$. The higher 'a' is, the better is the utilisation of the bandwidth by the users of the sub-LAN and the less is the redundancy. This redundancy may be used for the support of inter-Sub-LAN traffic (in this case users of different sub-LANs could still intercommunicate, through a third sub-LAN, when failures occur). The smaller 'a' is the more inter-sub-LAN traffic may be supported by the system.

TABLE E.1.1.1. : THE INFLUENCE OF THE CHIP-RATE FROM THE TSC, THE ATTENUATION AND THE NUMBER OF HOPS

TSC : TOPOLOGY SPREADING COEFFICIENT

B : REQUIRED CHIP RATE (kilochips / sec)

N : TOTAL NUMBER OF SUBSCRIBERS SERVED BY A LAN

TRAFFIC : PERCENTAGE OF CHANNEL OCCUPANCY PER USER IN EVERY TIME UNIT

ATTENUATION : ATTENUATION OF ANY LINK PLUS THE MATCHING ATTENUATION

HOPS : NUMBER OF SEQUENTIAL FLOODINGS THROUGH THE SHORTEST VIRTUAL PATH BETWEEN THE SOURCE OF THE DATA AND THE DESTINATION

B	TRAFFIC	TSC	N	NODES	ATT/TION	HOPS
2788.6	0.80	88.20	240.00	54	20%	2
9002.9	0.30	88.20	240.00	54	20%	3
80629.8	0.40	88.20	240.00	54	10%	3
71681.4	0.30	88.20	240.00	54	20%	4
2422.5	0.30	144.00	240.00	66	20%	3
73924.2	0.40	144.00	240.00	66	10%	3
35089.2	0.40	144.00	240.00	66	20%	4
88682.9	1.00	144.00	240.00	66	20%	4
75940.2	0.40	182.25	240.00	66	10%	3
39919.7	0.30	256.00	240.00	72	10%	3
80479.3	0.60	256.00	240.00	72	10%	3

E.1.2. TRAFFIC SUPPORTED

The number of users that any particular topology may support is not constant and depends upon the chip rate used. The higher the chip rate is the higher is the PG and consequently a higher power due to echoes can be tolerated.

The performance of all the virtual channels created during the communication of any two users is the same and depends upon the instantaneous traffic load and the echoes at any particular link or node. As the traffic is increased the performance is reduced in the same way for all the channels of this particular link or node. Any change of the topology influences the noise environment because of the echoes. So for any particular chip rate the amount of traffic that may be served successfully by the LAN is a function of the topology.

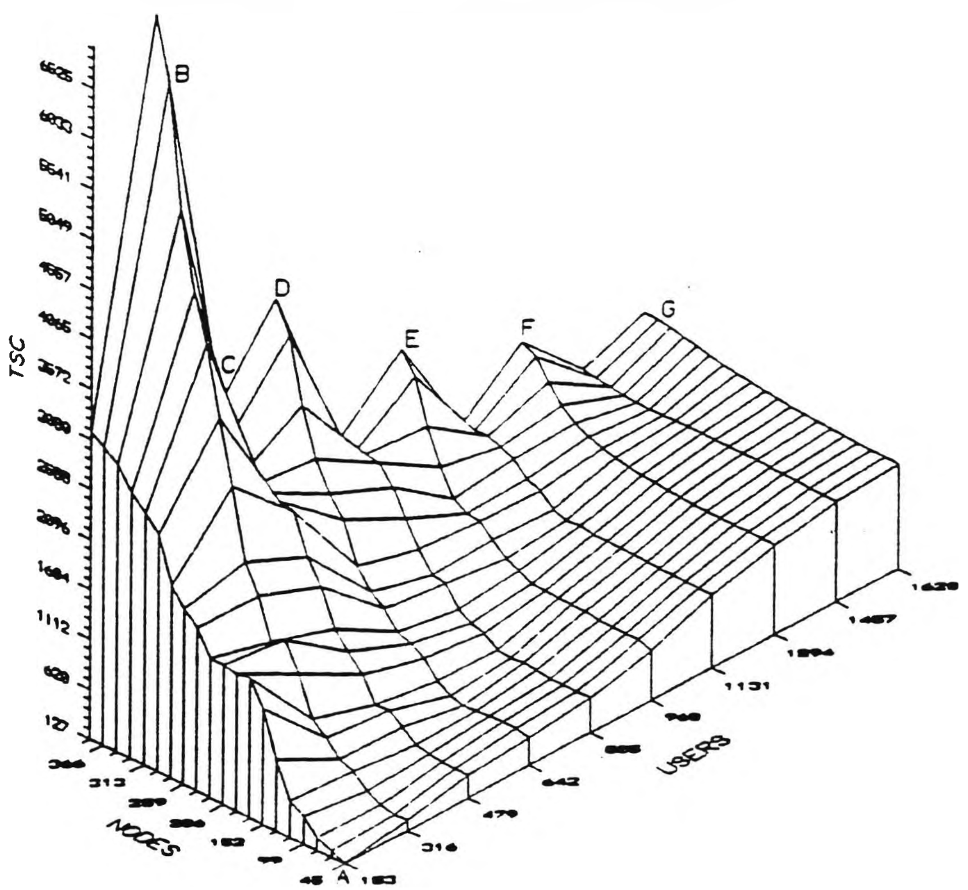


FIG. E.1.2.1 The TSC as a function of the users and the nodes.

We define the Topology Spreading Coefficient (TSC) as a measurement of the density of users of the LAN in relation to the complexity of the topology and to the size of the LAN (D24) :

$$TSC = \frac{j^2 d^2}{i}$$

The smaller TSC is, the smaller is the number of nodes of the LAN and the greater is the number of users per node. The higher TSC is the more the users are spread over the geographical area of the LAN. The surface of figure E.1.2.1 gives a picture of the TSC. Point 'A' corresponds to a small and dense LAN. Point 'B' corresponds to a LAN with a topology that has many nodes and a few users (TSC=7056, 324 users, 1 user per node, 354 nodes and 6 sub-LANs). Point 'C' corresponds to TSC=2592, 456 users distributed to 6 Sub-LANs 258 nodes, having connected 2 users per node. The peaks 'D', 'E', 'F', 'G' of this surface correspond to the same topology with the one of point 'B' increasing the number of users connected on a node, at each one of them, by 1. At point 'G' there are 6 users per node. The TSC of any particular topology is reduced as the number of users per node is increased.

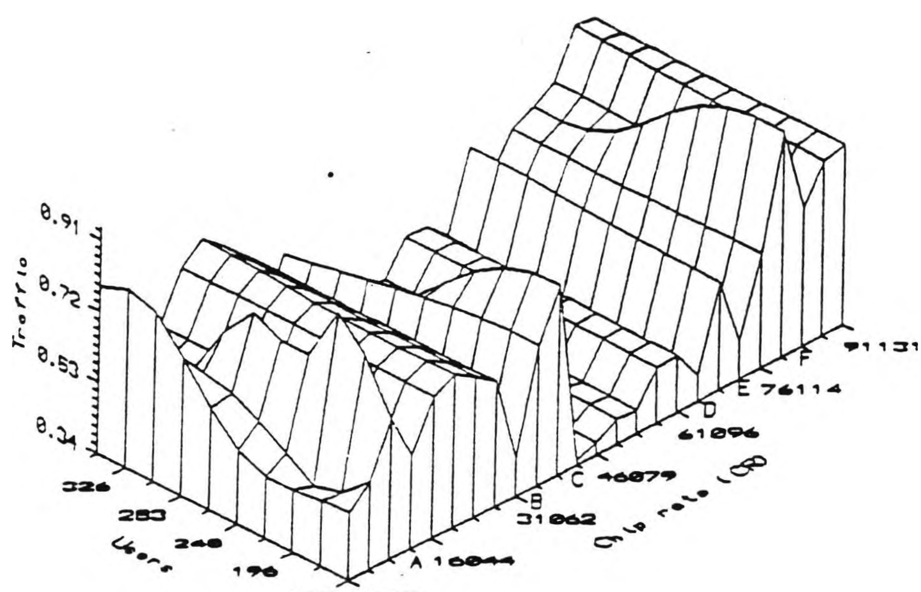


FIG. E.1.2.2 The traffic as a function of the users and the chip rate.

The surface of figure E.1.2.1 gives a first understanding of the characteristics of the topology (nodes, users) that corresponds to every value of the TSC. Further information about the topologies that correspond to any particular value of TSC can be obtained from existing tables. Appendix C has an example of such a table. Every one of these topologies has its own requirements in chip rate for serving the same amount of traffic, as it is shown in figures E.1.2.3 and E.1.2.4.

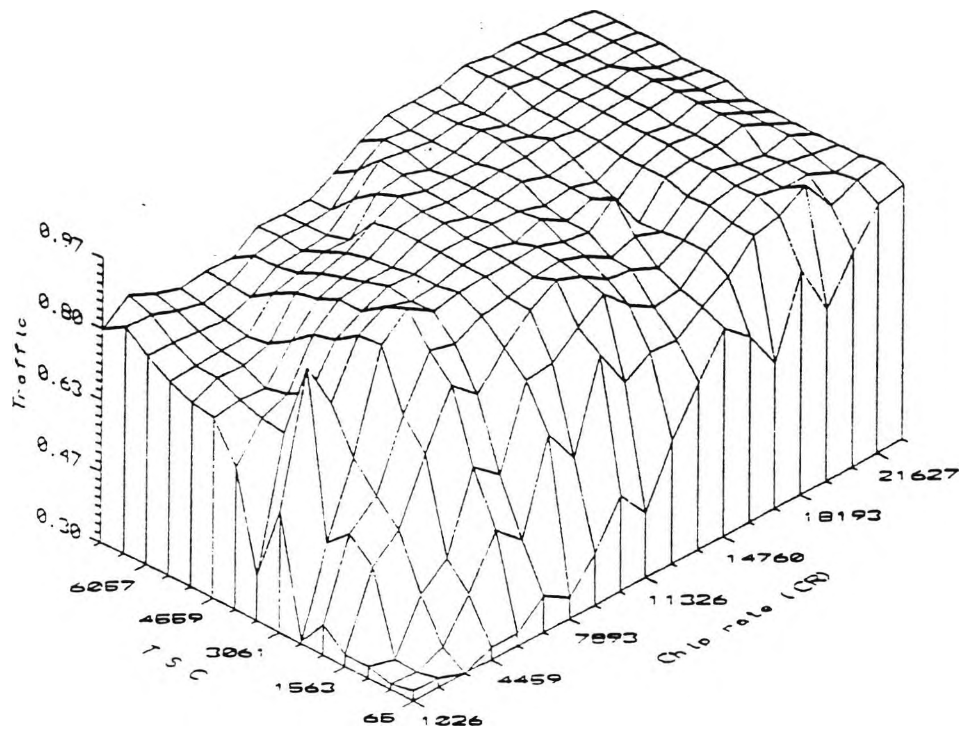


FIG. E.1.2.3 **The traffic as a function of the chip rate and the TSC for 2 hops.**

Figure E.1.2.2 describes the traffic that can be supported as a function of the number of users and of the chip rate. The variation of the values around the minima of points 'A', 'B', 'C', 'D', 'E', 'F' for 153 users are the results of the influence of the number of the sequential floodings (2, 3 or 4 hops) and of the total attenuation per link (20% or 10%). The variation of the traffic supported along the axes of users is due to the change of the value of the size (spreading) of the topology that is given by TSC. These parameters do not appear in the figure but have been taken into account in the estimations. The influence of the chip rate and of the traffic due to the attenuation and the number of the sequential floodings can also be seen in TABLE E.1.1.1.

Surfaces of figures E.1.2.3 and E.1.2.4 show the traffic that can be supported by the system as a function of the TSC and of the chip rate for a virtual path of 2 or 3 sequential floodings between the transmitter and the receiver.

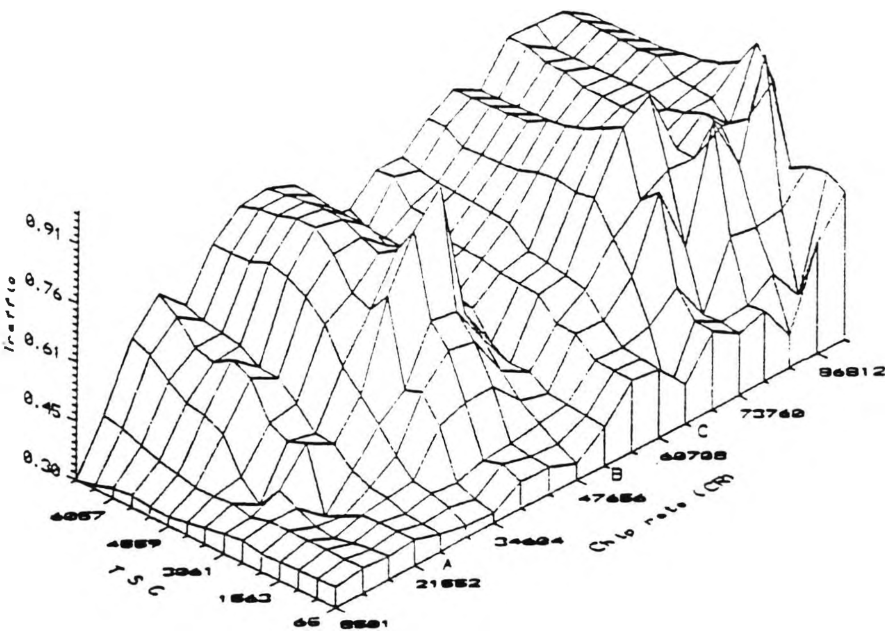


FIG. E.1.2.4 **The traffic as a function of the chip rate and the TSC for 3 hops.**

In both figures E.1.2.3 and E.1.2.4 the chip rate depends upon the TSC and the traffic. The more distributed the topology is the higher is the traffic that may be supported with a relatively low chip rate. The existing local peaks are due to particular topologies that are widely spread in the geographical sense, like for example the local peak of figure E.1.2.4 between the points 'A' and 'B'. This peak corresponds to the marked topology of appendix C.

Both the surfaces of figures E.1.2.3, and E.1.2.4 have been drawn for a total attenuation, at the input of any node of 10% and a 30% redundancy at the required chip rate for serving inter-sub-LAN traffic.

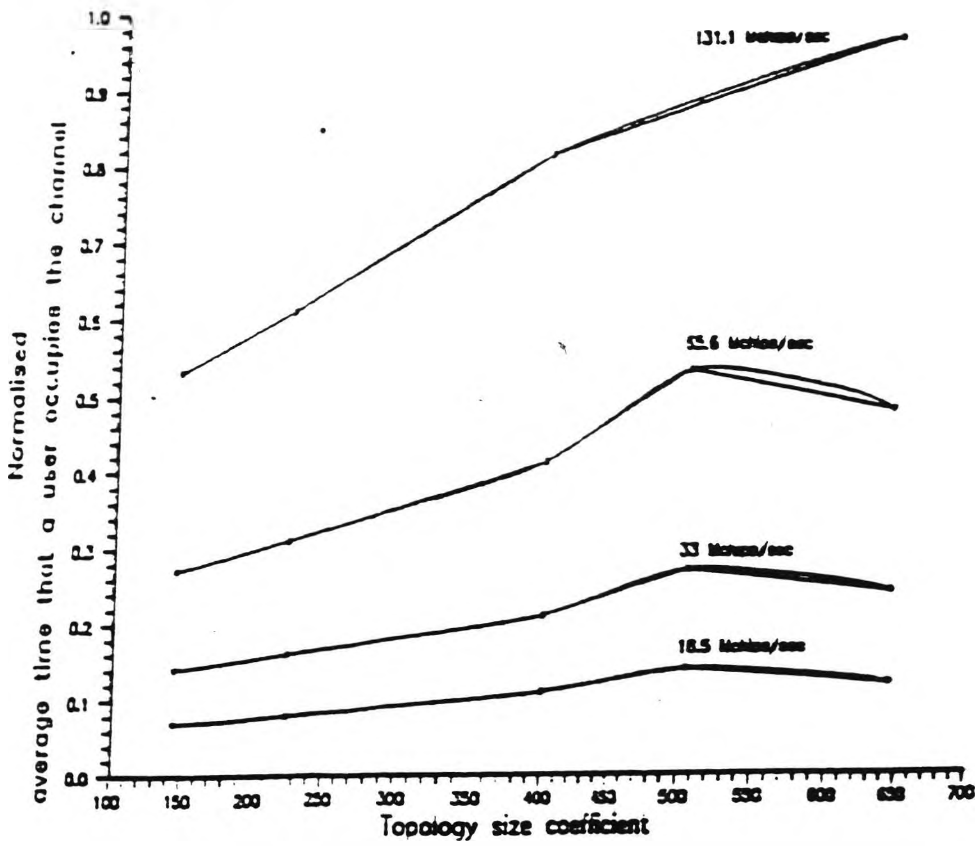


FIG. E.1.2.5 **The influence of the average time that a user occupies the channel, as a function of the topology for a LAN of 480 subscribers.**

Figure E.1.2.5 illustrates the relationship between the TSC for topologies that support 480 users and the traffic for different values of the required chip rate (D24). These curves have been drawn for 3 hops virtual links under attenuation of 10%. The performance of all these virtual channels is the same and depends upon the instantaneous traffic load and the echoes of any particular link or node. As the traffic is increased the performance is reduced, in the same way, for all the channels of this particular link or node. The increase of the traffic influences the noise environment because of the echoes.

E.2. ESTIMATION OF THE CONGESTION AND OF THE WORST CASE POWER STATUS PROBABILITY

According to the description of the flooding architecture is obvious that at any sub-LAN will exist areas (links and incoming ports) where locally and for limited period of time peaks in power value will occur. These peaks depend highly upon the topology (the existing shortest routes) and the values of prefer ability of a user to communicate with another one and the total traffic generated by any user. So the power status of the sub-LAN varies in space and time.

In this section the estimation of the congestion probability will be analysed and the probabilities of the worst case power status of the sub-LAN will be calculated. These estimations are examined in relation to the traffic and the number of subscribers that can be served, taking into consideration the use of the passive flooding protocol and of the mesh topology. Although measurements have been taken only for the suggested topology of figure C.2.4, this does not introduce a restriction that limits the application of these estimations to any topology and that influences the results.

The estimations are based on the environment of a Sub-LAN, with the following simplifying assumptions :

- The flooded data are packets of constant size transmitted at random time intervals.
- The traffic created by any user will be examined as a parameter that describes the normalised average time that the user occupies the channel.
- All the nodes of a Sub-LAN have the same degree.
- The channel noise is low enough that it can be ignored.
- The flooded power accumulates at the nodes in accordance with a homogeneous distribution model, like if the physical links that interconnect the nodes of the Sub-LANs do not exist and every node is straight connected to the other ones.
- The transmitted signals are continuously flooded.
- All the physical links are one direction.

- Every two Sub-LAN are connected together by two SIUs for survivability reasons, that operate simultaneously.

- The SIUs are symmetrically distributed all over the Sub-LAN, so that the Inter-Sub-LAN traffic can be homogeneously distributed all over the sub-LAN.

- The created traffic by the SIUs is considered as equal with the traffic created by the rest of the users nodes .

- There is a homogenous distribution of the traffic generated all over the network. This means that there is the same probability for any user to transmit a packet.

- Both the local generation of any packet by any individual subscriber and the generation of packets by all the subscribers all over the system, are independent events that follow a Poisson distribution (X1).

For the estimation the following parameters will be considered :

- Due to the sequential floodings the power of a packet reduces continuously its power. This means that in practice after time 'Te' this power will be faded at such a degree that can be ignored.

- The mean time between two succeeding transmissions of a packet into the network independently of its source is 'T_n' (from any user). So the total number of the transmitted packets over time T_e are T_e/T_n.

- The duration of a packet is 'T_p',

- The mean transmission delay from the output of a node to the input of the next one is 'T_r',

- The mean transmission delay of the SPSC signal from the moment that is coming into a node till the output from it is 'T_{rn}',

- The preferability of calling a subscriber 'i' of node 'n' any other one 'j' of node 'm' is defined by a coefficient of preference '$K_{n_i m_j}$', where both i and j belong to the under consideration sub-LAN. For the inter-sub-LAN traffic the far end destinations are considered as users connected on the corresponding SIU.

- The probability of implementing a physical connection from to 'n' through the port 'a' of node 'n' is defined by a coefficient of port usage 'D_a'.

- The total traffic generated by subscriber 'i' of node 'n' is 'O_{ni}',

- The average normalised time, 'T_{tr}', that the traffic created by any user occupies a virtual communication channel.

- The parameters k,l,g,d,w,c,p,h,B_c,e,j,PG have been defined in chapter E.1.

Due to the modularity, homogeneity and symmetry of the system, and also to the similarities in the structure of the sub-LANs, we will accept that the figures that express the congestion probability and the probability of the worst case power status for one sub-LAN describe the theoretical performance of the rest of the sub-LANs. Therefore these probabilities will be estimated only for one of them.

The overall congestion probability is the summations of the individual congestion probability of the sub-LANs of the system. The total probability of missing a packet will be the summation of the probability of collision and of congestion of the node. The collision probability depends upon the probability of the worst case power status.

E.2.1. ESTIMATION OF THE CONGESTION PROBABILITY

The probability of a free source to transmit a packet during a time interval 'T_p' (T_p = packet duration) is Poisson. It can happen to exist more than one transmissions concurrently at any time. The probability of x sources being occupied (x users being transmitting) during a packet period for a particular 'T_n' (T_n = mean time between packets transmission) is given by (X2) :

$$e^{-x_1} \frac{x_1^x}{x!} \quad .1.$$

where :

- $x_1 = T_p/T_n$ (the integer part of the division) is the mean number of the packets that are transmitted all over the network during the period of a packet.

- 'x' is of lattice type,

The probability of the implementation of any one of the 'x' transmissions is still the same, since this is a conditional probability that is always 1 if 'x' users are transmitting concurrently.

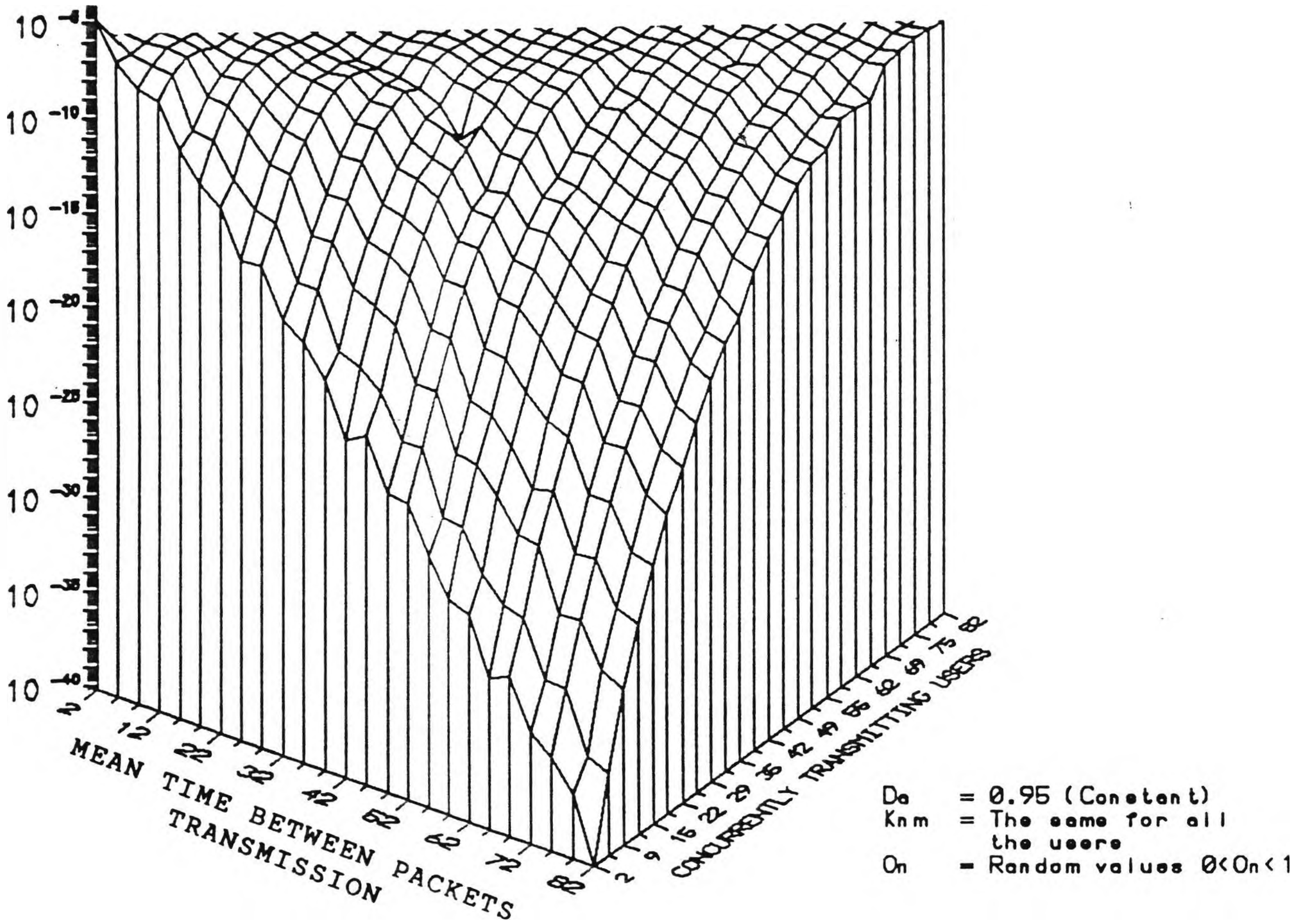


FIG. E.2.1.1.a **The congestion probability for the sub-LAN of fig. C.2.4 as a function of the number of concurrently transmitted packets and the mean time between packets transmission.**

The probability '$Pr_{(j/i)}$' that user 'j' of node 'q' receives traffic from user 'i' of node 's' is given by

$$\frac{O_{s_i} K_{s_i q_j}}{\sum_{n=1}^{k} \sum_{i=1}^{l} \left[O_{n_i} K_{n_i q_j} \right]} \qquad .2.$$

where

- '$O_{s_i} K_{s_i q_j}$' is the traffic that is generated by subscriber 's_i' towards the 'q_j' one,

- the denominator expresses the total traffic that is generated by all the users of the sub-LAN toward user 'q_j',

- $K_{s_iq_j} \in R$, and

- $0<K_{s_iq_j}<1$.

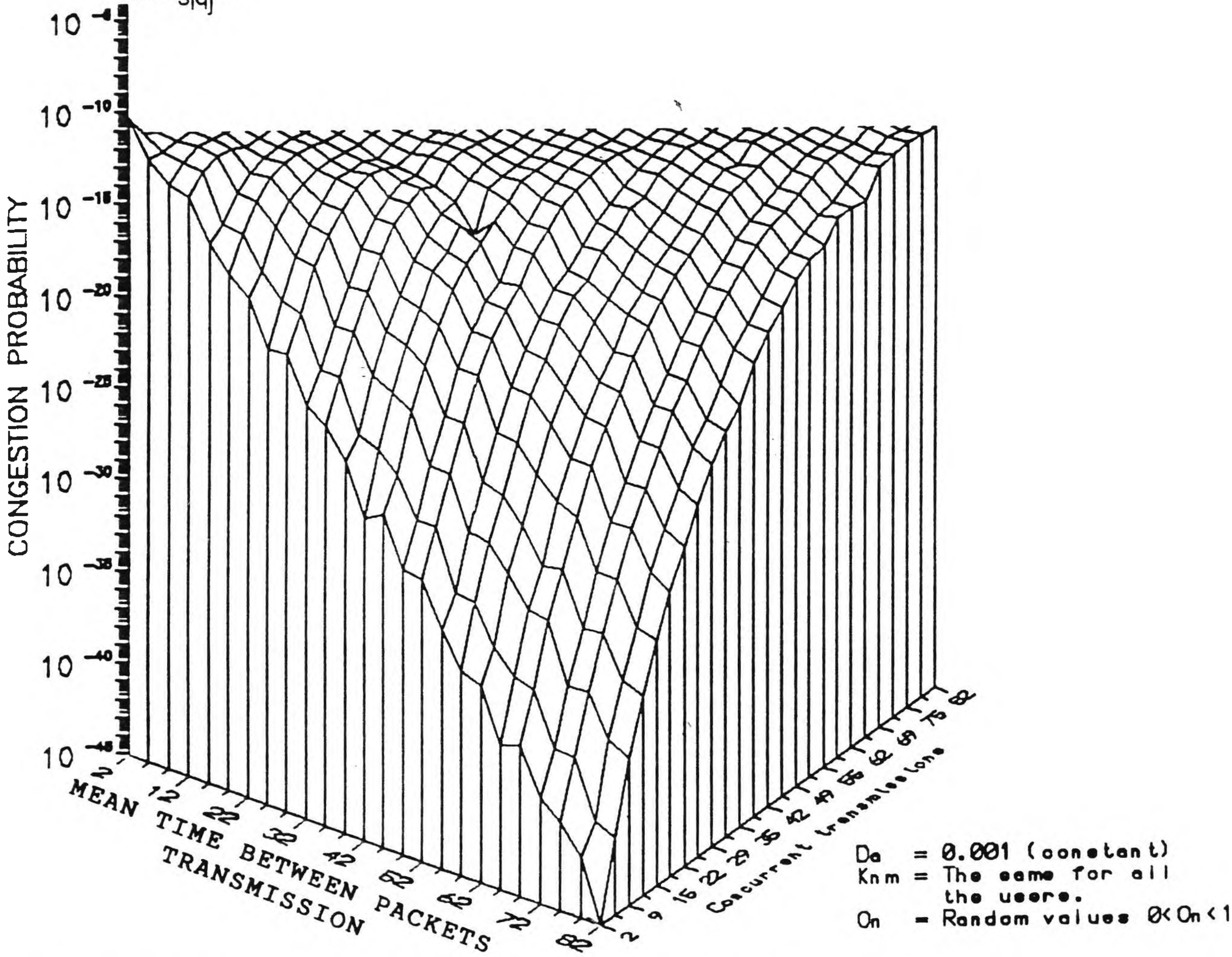


FIG. E.2.1.1.b **The congestion probability for the sub-LAN of fig. C.2.4 as a function of the number of concurrently transmitted packets and the mean time between packets transmission.**

The probability that the connection of node 's' with node 'q' is implemented through port 'a' of node 'q' is given by :

$$D_a \frac{O_{s_i} K_{s_i q_j}}{\sum_{n=1}^{k} \sum_{i=1}^{l} \left[O_{n_i} K_{n_i q_j} \right]}$$

where

$$\sum_{n=1}^{d} D_n = 1$$

In the same way is estimated that the probability that user 'j' of node 'q' receives traffic from user 'i' of node 'm' from port 'a' is given by :

$$D_a \frac{O_{m_i} K_{m_i q_j}}{\sum_{n=1}^{k} \sum_{i=1}^{l} \left[O_{n_i} K_{n_i q_j} \right]}$$

The probability that 'q_j' receives a packet from one of the 'x' transmitting sources suppose 's' is :

$$D_a e^{-x_1} \frac{x_1^x}{x!} \frac{O_{s_i} K_{s_i q_j}}{\sum_{n=1}^{k} \sum_{i=1}^{l} \left[O_{n_i} K_{n_i q_j} \right]} \qquad .3.$$

Assuming that x>2 then the probability of having at least 2 concurrent transmissions is given by '1'. Then the probability of receiving 'q' from 'm'and 's' simultaneously becomes :

$$P = D_a^2 e^{-x_1} \frac{x_1^x}{x!} \frac{O_{s_i} K_{s_i q_j}}{\sum_{n=1}^{k} \sum_{i=1}^{l} \left[O_{n_i} K_{n_i q_j} \right]} \frac{O_{m_i} K_{m_i q_j}}{\sum_{n=1}^{k} \sum_{i=1}^{l} \left[O_{n_i} K_{n_i q_j} \right]}$$

From this equation at figures E.2.1.1.a, E.2.1.1.b and E.2.1.2 the congestion probability has been estimated, assuming :

- a sub-LAN of 90 users (topology of fig. C.2.4),
- that all the traffic from all the users toward any destination has the same coefficient of preference '$K_{n_i m_j}$' and
- that the amount of traffic generated by any user 'O_{n_i}', follows a Gaussian distribution with mean 0.5 and standard deviation 0.3.

From the created graphs it can be seen that the resultant congestion probability is negligible. This yields from the assumption that the packet transmission probability is an independent event. If the packets transmissions are related to each other then these results do not hold any longer.

Figures E.2.1.1.a and E.2.1.1.b illustrate the congestion probability as a function of the number of concurrent transmissions, and of the mean number of transmitted packets at the sub-LAN, assuming that

- the coefficient of port usage of the receiving node for the incoming port of interest 'a' is D_a=0.95 (fig. E.2.1.1.a) and D_a=0.001 (fig. E.2.1.1.b),
- the maximum possible number of connected users on the sub-LAN is 90 (g=90) while the mean number of concurrently transmitted packets x_1 is progressively increased from 2 to 82.

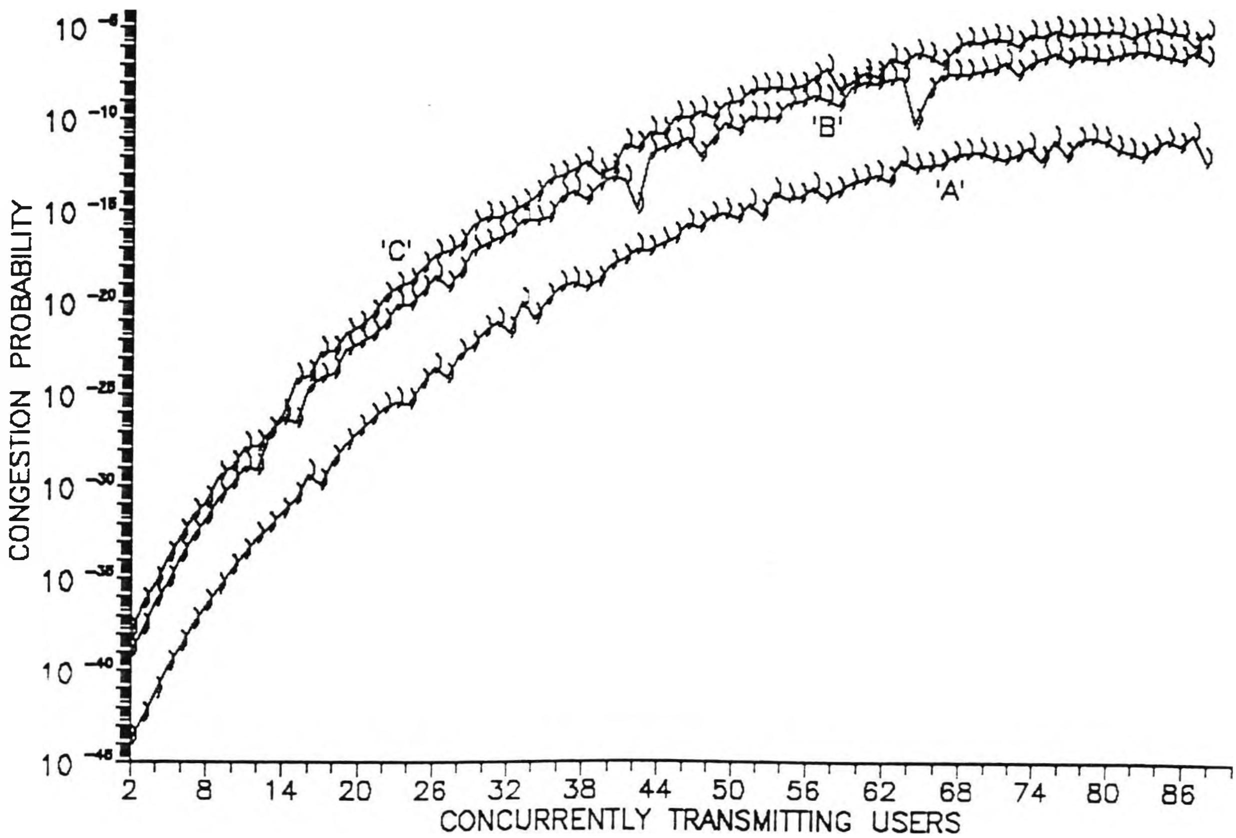


FIG. E.2.1.2 The congestion probability for the sub-LAN of fig. C.2.4 for 87 users as a function of the number of concurrently transmitted packets for various values of D_a (curve 'A' : D_a=0.001, 'B' : D_a=0.25, 'C' : D_a=0.95).

As the number of transmitted packets 'x' is increased up to the number of users, the traffic is increased and consequently there are more cases of receiving the same user data, from one port and from more than one transmitters concurrently, resulting so to the congestion probability increase. For the worst case of traffic and for a high value of D_a (D_a=0.95) this probability becomes 10^{-5}. As the number of concurrently existing in the network packets gets smaller, this probability is highly reduced. For a low value of D_a (D_a=0.001) and for the worst case of traffic this probability is reduced to 10^{-12}.

Figure E.2.1.2 gives some curves from the above surfaces. It illustrates the congestion probability as a function of the number of concurrent packet transmissions, for mean number of packets transmissions x_1=87, during time period T_p, and for various values of D_a (D_a=0.95, D_a=0.25, D_a=0.001).

E.2.2. ESTIMATION OF THE WORST CASE POWER STATUS PROBABILITY

We assume for simplification reasons that all the physical links from node to node are of the same length in time. After time t from its transmission a packet will have been flooded through a number of nodes 'n'. Therefore 'n' arises as follows :

$$\frac{t}{T_r + T_{rn}} = n + t \bmod (T_r + T_{rn})$$

$$n = \frac{t}{T_r + T_{rn}} - t \bmod (T_r + T_{rn}) \quad .1.$$

Where T_r+T_{rn} expresses the transmission delay of the signal from the input of a node till the input of the next one.

Then at the input of any node the transmitted power has been attenuated 'p' (p=1-c) times. At the output of the node, after the flooding, the power has been attenuated 'p(d-1)' times. So the power of a packet 'W_{packet}' at the input of a node after time t from transmission, ignoring the created echoes and including the attenuation 'p' (section E.1.1 equation 1) is :

$$W_{packet} = \frac{p^n W}{(d-1)^{n-1}} \quad .2.$$

Because of the flooding and of the attenuation, practically the power of a packet is faded to a negligible value after time 'T_e'. We can accept that for any faded packet, a new one is created (the packet generation follows the Poisson model). During this time interval 'T_e'

$$x_1 = T_e/T_n - T_e \bmod(T_n)$$

packets are initially generated and transmitted in the system, by all the subscribers together. The upper bound to this number of packets is

$$(T_e/T_p - T_e \bmod(T_p))^* g$$

The probability distribution of 'x' packets being generated during time 'T_e' is Poisson :

$$P_{r_x} = e^{-x_1} \frac{x_1^x}{x!} \quad .3.$$

Assuming a cold start at time $-T_{rn}$ and the initial transmission of a packet, then every time interval 'T_r+T_{rn}' a new flooding is implemented. Each packet through the flooding procedure creates at any time '$(d-1)^n$' more packets, but attenuated correspondingly in power ('n' is defined at equation 1). So due to the created echoes in multiples of time 'T_r+T_{rn}' and for a time period 'T_e' the following numbers of packets are distributed at the input ports of the nodes:

TIME	NUMBER OF PACKETS
$-T_{rn}+ T_r+T_{rn}$	1
$-T_{rn}+2(T_r+T_{rn})$	$(d-1)^{2-1}$
$-T_{rn}+3(T_r+T_{rn})$	$(d-1)^{3-1}$
....	
$-T_{rn}+m(T_r+T_{rn})$	$(d-1)^{m-1}$

The total number of echoes 'n_1' that a packet creates in the system at the input of the nodes, is the summation of the number of packets of the above table. 'n_1 ' is given by :

$$n_1 = \sum_{n=1}^{\dfrac{\frac{T_e}{T_r + T_{rn}} - T_e \bmod (T_r + T_{rn})}{}} (d-1)^{n-1} \qquad .4.$$

Thus for each packet sent into the network, the number of packets produced as echoes is continuously increased with time. Because of the attenuation of the echoes their total power conveys to a finite limit (section E.1.1).

For simplification reasons suppose that when $T_r+T_{rn}>T_n$, then :

$$T_r+T_{rn}= n_2*T_n, \text{ where } n2\in N$$

then during the required time period for the transmission of a packet from the input of a node to the input of the next one, $n_2=(T_r+T_{rn})/T_n$ packets are generated. So the total number of packets and echoes that are generated from n_2 transmissions during time 'T_e' in the system is n_1*n_2. The total number of packets and echoes that exists at any time in a sub-LAN is :

$$n_3 = n_2\, n_1 \left[\frac{T_e}{T_r + T_{rn}} - T_e \bmod (T_r + T_{rn}) \right]$$

For simplification reasons we assume that

- T_p, T_r, T_{rn} are constants with the same value for all the packets, links and nodes
- a homogenous distribution of the packet generation between the k nodes of the sub-LAN exists,
- the probability of receiving any one of the 'n_3' packets of the echoes through any one of the 'd' input ports of a node is the same,
- $T_n<T_p$.

Since $T_n<T_p$, the echoes overlap each other at the inputs of the nodes (fig. E.2.2.1). Equation 3 gives the probability distribution function for the initial transmission of 'x' packets. Any one packet of them creates n1 echoes. So the probability of creating n1 echoes from packet 'i' is '1' under the condition that the packet has been transmitted. So the probability of creating n_1 echoes from packet 'i' is the same with the probability of the initial transmission of this packet : $P_{r_x}=P_{r_{echoes}}$.

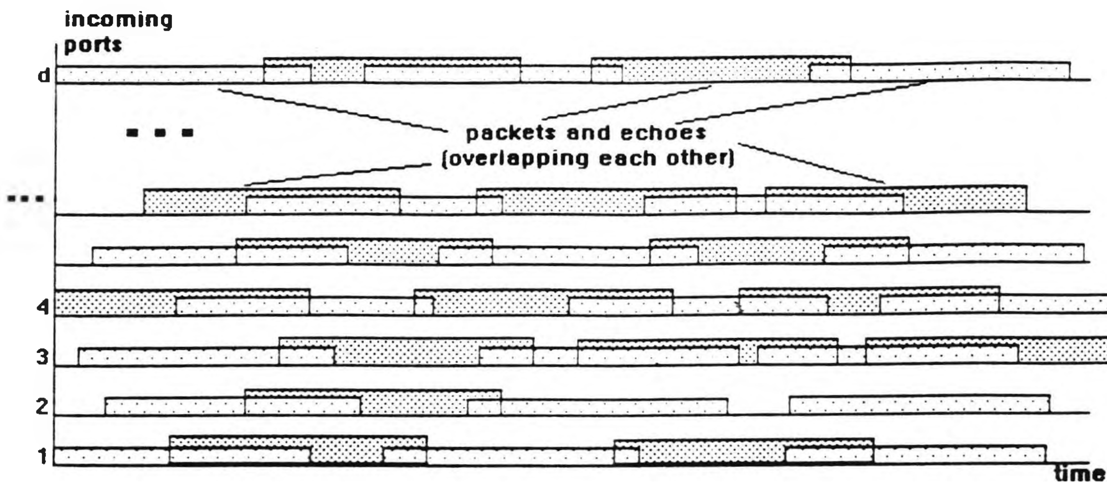


FIG. E.2.2.1 **The packets arrival at the input ports of a node as a function of time.**

We can assume, without affecting significantly the accuracy of the model, that the power of all the echoes, of all the 'x' initially transmitted packets, after the second hop, are homogeneously distributed all over the nodes and their input ports. Therefore we have the same probability '$P_{r_{echoes}}$', estimated from equation 3, of receiving any one of these echoes (after the second hop) through any one of the incoming ports of any node. Then according to equations 1, 2, 4 the power of these echoes met at an input port, for n_2 packet initial transmissions, becomes :

$$\frac{n_2}{k\,d}\sum_{n=3}^{\frac{T_e}{T_r+T_{rn}} - T_e \bmod (T_r+T_{rn})}\left[(d-1)^{n-1}\frac{p^n W}{(d-1)^{n-1}}\right]$$

So, at any incoming port and at any time, for the n_3/n_1 initial packets transmissions, the following value of power due to echoes will exist:

$$W_{echoes} = W\frac{1}{k\,d}\,\frac{n_3}{n_1}\sum_{n=3}^{\frac{T_e}{T_r+T_{rn}} - T_e \bmod (T_r+T_{rn})}\left[p^n\right] \quad .5.$$

For any one of the x packets initial transmissions, the power W*p of the first hop, will be at only one incoming port and the power $W^*p^2/(d-1)$ of the second hop, will be at only 'd-1' incoming ports. So assuming that x (x=n3/n1) transmissions are generated during time interval 'T_e', equation .3. gives the probability of having at :

- x incoming ports of the sub-LAN during time interval 'T_e' power W^*p+W_{echoes},
- x*(d-1) incoming ports of the sub-LAN power $W^*p^2/(d-1)+W_{echoes}$ during time interval 'T_e',
- any incoming port at any moment power W^*p+W_{echoes} and
- any incoming port at any moment power $W^*p^2/(d-1)+W_{echoes}$.

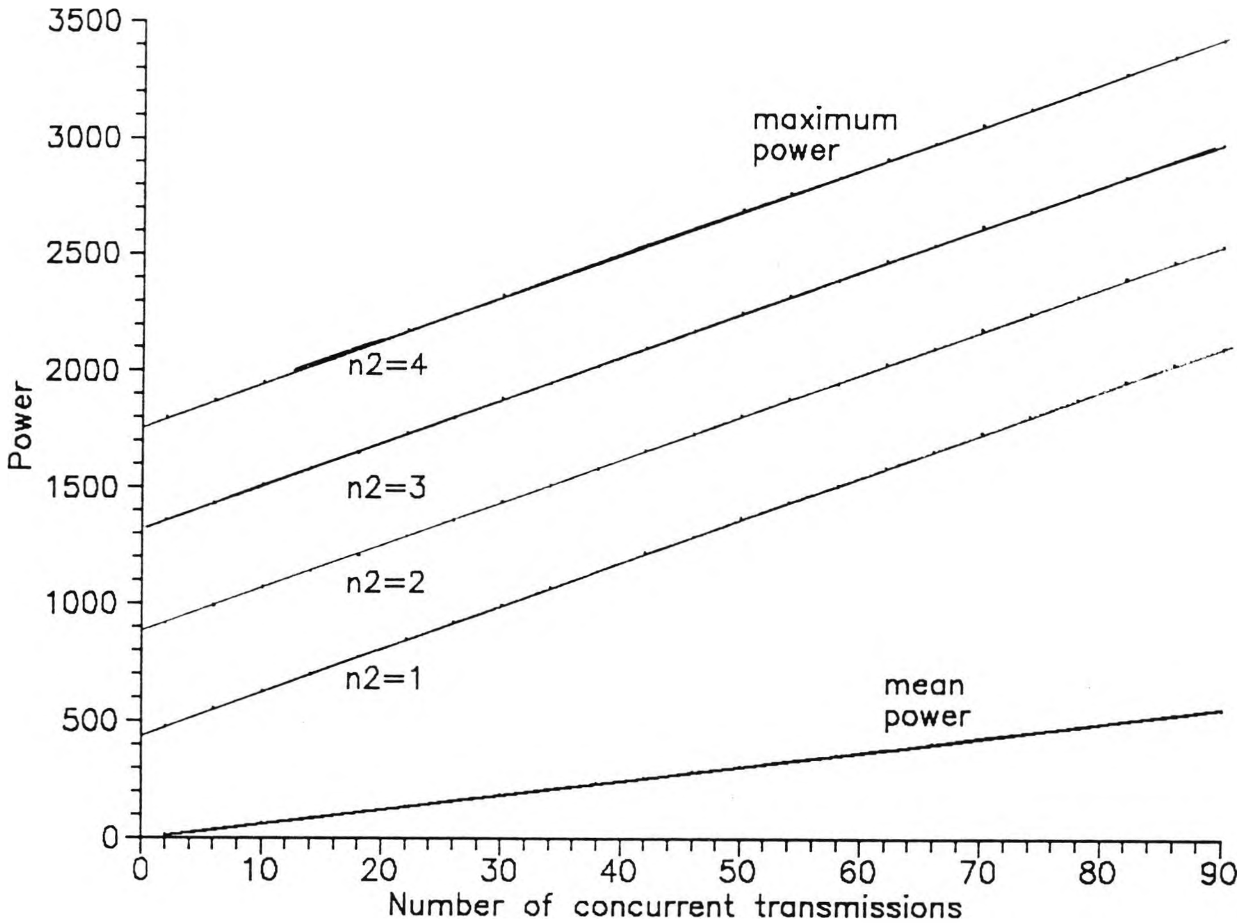


FIG. E.2.2.2 **The mean and maximum power in a sub-LAN of fig. C.2.4 as a function of the number of concurrent transmissions.**

Let's examine a particular incoming port, suppose the 'a' of node 's'. There during time interval 'T_p' we receive :

- the power W_{echoes} of the echoes with probability $P_{r_{echoes}}$,

- the power W*p of the first hop of the initial transmission of one packet from node 's-1' that is connected on port 'a' of 's' with probability (the equation 3 of E.2.1 modified) :

$$P = D_a \, e^{-n_2} \frac{n_2^{\,n_2}}{n_2!} \frac{\sum_{i=1}^{l}\sum_{j=1}^{l} O_{(s-1)_i} K_{(s-1)} q_j}{\sum_{n=1}^{k}\sum_{i=1}^{l}\sum_{j=1}^{l}\left[O_{n_i} K_{n_i} q_j\right]} \quad .6.$$

where

$$\frac{\sum_{i=1}^{l}\sum_{j=1}^{l} O_{(s-1)_i} K_{(s-1)} q_j}{\sum_{n=1}^{k}\sum_{i=1}^{l}\sum_{j=1}^{l}\left[O_{n_i} K_{n_i} q_j\right]}$$

expresses the probability of any one of the 'l' users of node 's-1' to transmit a packet to any one of the 'l' users of node 'q' and

$$e^{-n_2} \frac{n_2^{\,n_2}}{n_2!}$$

expresses the probability of having up to n2 transmissions during time interval 'T_r+T_{rn}'. The maximum number of packets that can be transmitted from 's-1' during this time 'T_r+T_{rn}' is 'n_2'. It is possible 'n_2' of the 'l' users of node 's-1' to transmit a packet toward node 's'. Due to the relatively large duration of the packet compared with 'T_r+T_{rn}' or 'T_n' these packets will overlap each other. In this case the received power from the first hop becomes $W_1=n_2*W*p$. So assuming that $n_2<x$ and $l>n_2$ then the probability of receiving at the input port 'a' of node 'q' power W_1 becomes (from equation 6) :

$$P_1 = e^{-n_2} \frac{n_2^{\,n_2}}{n_2!} \left[D_a \frac{\sum_{i=1}^{l}\sum_{j=1}^{l} O_{(s-1)_i} K_{(s-1)} q_j}{\sum_{n=1}^{k}\sum_{i=1}^{l}\sum_{j=1}^{l}\left[O_{n_i} K_{n_i} q_j\right]} \right]^{n_2} \quad .7.$$

Since a packet duration is T_p during this period are generated

$$n_4 = \frac{T_p}{T_n} - T_p \bmod (T_n)$$

packets. However only the n_2 are created during the duration of a flooding period. The rest of them are generated during the next floodings. These means that in our case they will arrive at node 'q' as second hop signal or as echoes.

- the power $n_2 * W * p^2/(d-1)$ of the second hop of the initial transmission of n_2 packets from the node 's_{jj}-2' connected on port 'b_j' of node 's-1' with probability (from the equation 7) :

$$P_2 = e^{-\bar{n}_2} \frac{\bar{n}_2^{\,n_2}}{n_2!} \left[D_8 \frac{\sum_{jj=1}^{d-1} \sum_{i=1}^{l} \sum_{j=1}^{l} O_{(s_{jj}-2)_i} K_{(s_{jj}-2)_i q_j}}{\sum_{n=1}^{k} \sum_{i=1}^{l} \sum_{j=1}^{l} \left[O_{n_i} K_{n_i q_j} \right]} \right]^{n_2} \quad .8.$$

So the maximum accumulated power at the input of a node is expressed by :

$$n_2 W p + n_2 W \frac{p^2}{d-1} + W_{echoes} \quad .9.$$

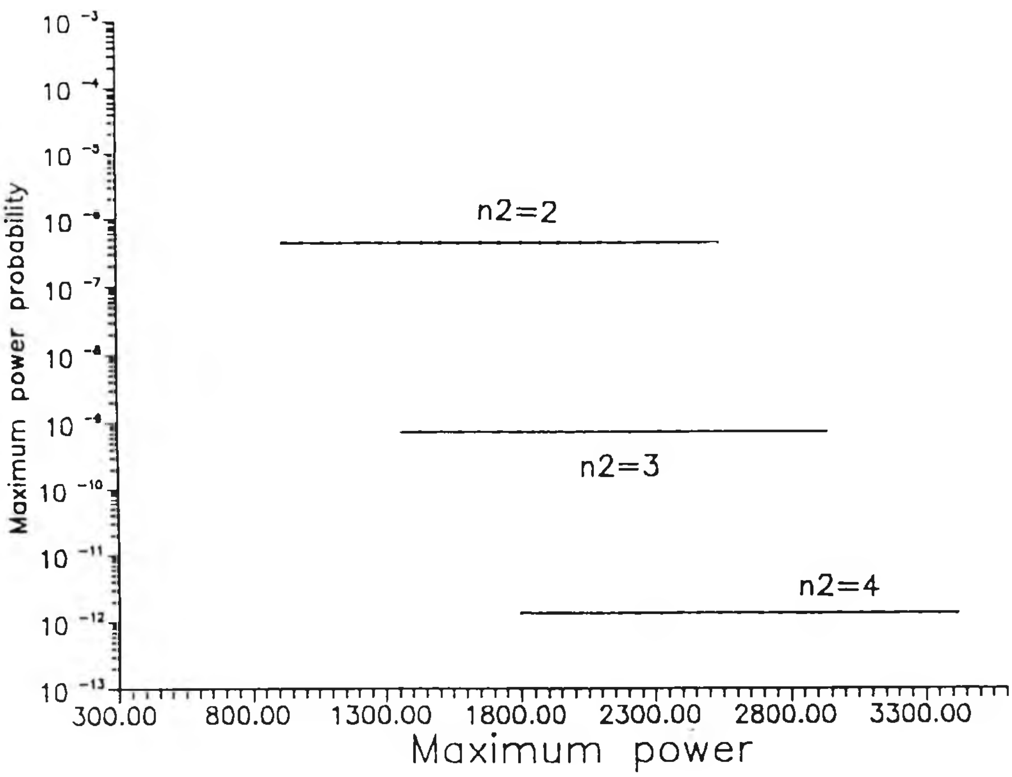


FIG. E.2.2.3 The maximum power probability for the sub-LAN of fig. C.2.4 at a particular input port of a particular node.

Since according to the model described a precondition of having packets transmissions is the creation of echoes, accepting that the probabiliy of having ehoes is one, then the probability of having this maximum power at a particular input of a particular node is a conditional probability given by :

$P_1 * P_2$.(10).

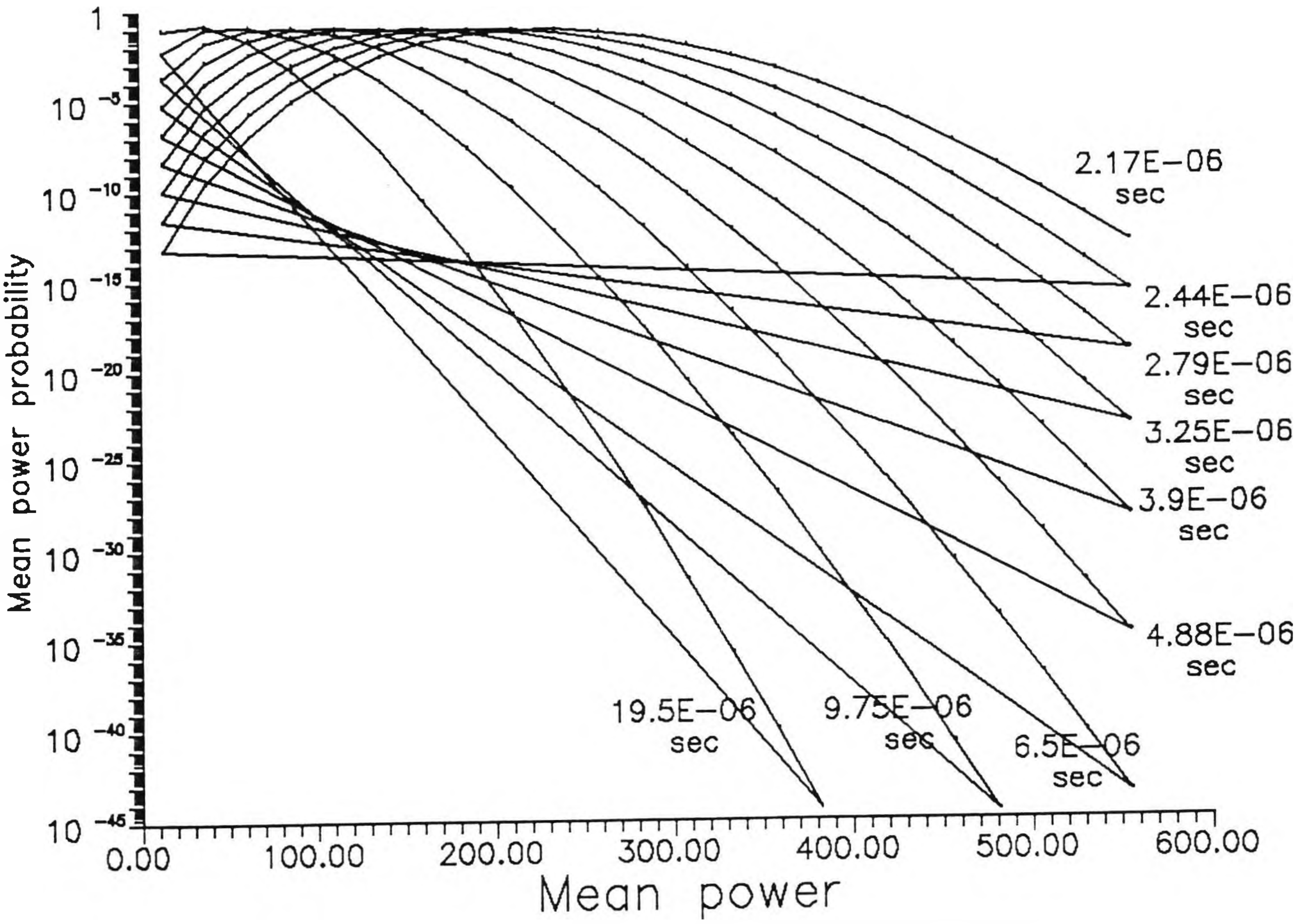


FIG. E.2.2.4 **The mean power probability for the sub-LAN of fig. C.2.4 as a function of the power and the mean time between packets transmission at any input port of any node.**

The described mathematical model is simplified by a lot of factors. This model, (equations 3, 7, 8 and 10) gives the probability of having the various power status at a sub-LAN. The maximum power (equation 9) defines the upper bound in power at any incoming port of any node and at a particular incoming port of a particular node. The collision probability, according to the given definition (section D.2), depends upon the ability of the receiver to demodulate the signal (section D.6). This ability is a function mainly of :

- the length of the spreading code
- the maximum number of hops of a route and
- the threshold of the receiver.

Considering these factors, an upper bound for the probability of collision has to be defined. This is a techno-economical problem, since the higher this upper bound is the more expensive the required hardware becomes.

The Tables 2, and 3 of Appendix 6 give solutions to equations 3, 7, 11 and 12. These solutions apply to the sub-LAN of fig. C.2.4 having connected three users per node. The following values have been given to the variables :

- The coefficient of preference K_{ij} is the same for all the pairs of users.
- The distribution of the total traffic that is generated by the users is Gaussian with mean 0.5 and deviation 0.3.
- The coefficient of port usage 'D_a', anywhere it is used, accepts the values 0.001, 0.5, and 0.95.
- The packet duration is $195*10^{-6}$sec.
- The packet is practically extinguished in $80*10^{-6}$sec.
- The total transmission delay is $8*10^{-6}$sec.
- The incoming total link attenuation (incoming port to incoming port) takes the values of 0.9 and 0.8.
- The maximum 90 packets from different users can be transmitted during one packet period, $2.17*10^{-6}\text{sec}<T_n<19.5*10^{-6}\text{sec}$.
- The transmitted power of a chip is 500 power units.
- The received power of the signal of interest, that is buried under the estimated mean power, for the various values of the total attenuation is given by table 6.1 of Appendix 6.

Table 6.2 results from equations 3 and 5. It gives the incoming power (columns D, E, F) for various mean times between packet transmissions (column 'B'), for various values of the attenuation (column 'C') while the actual number of transmitted packets varies from 2 to 90 (column 'A'). Column 'G' gives the probability of having concurrently, as many transmissions as is given by column 'A'. Column 'D' gives the average power of the echoes that will be met at any point of the sub-LAN with probability 1 if the number of transmissions of column 'A' is implemented. Column 'E' gives the power of the echoes plus the power of the first hop. The power of column 'E' is met at equal number of points of the sub-LAN with the number of transmissions. Column 'F' describes the resulting power from the echoes and the second hop of an initially transmitted signal. This power will be met at (d-1)*(the number of initial transmissions) points of the sub-LAN.

It can be seen that the probability of having the various values of power depends upon the number of the concurrent transmissions and the mean time between packet transmissions, while the value of power depends upon the number of the concurrent transmissions and the attenuation. As the number of concurrent transmissions is increased the traffic is also increase and so the amount of power becomes higher, simultaneously the probability of having this number of packets concurrently flooded in the sub-LAN gets lower. As the attenuation is increased the absorbed power gets higher resulting to lower load of the network. As the difference between the number of concurrent transmissions and the mean time between packet transmissions gets higher the probability of having this number of concurrent transmissions gets lower.

Table 6.3 results from equations 7, 8, 9 and 10. It gives the maximum incoming power of a particular incoming port of a particular node (column 'F') and the probability of its occurrence (column 'I') for various mean times between packet transmissions (column 'B') for various values of the attenuation (column 'C'), for the number of concurrent transmissions (column 'A') and for various values of D_a (column 'E'). As the number of concurrent transmissions is increased the traffic is also increased and so the amount of power becomes higher, simultaneously as the attenuation is increased the absorbed power gets higher resulting to lower load of the network. On the other hand as the number of concurrent transmissions is increased, while the mean time between packets transmissions do not changes the probability of having this number of packets concurrently flooded in the sub-LAN gets lower. This in combination with the probability of having a lot of packets transmitted from one node and also with the probability of having one node receiving the power of a number of packets that are flooded for a second time, makes the probability of having the maximum possible power negligible. The results of table 6.3 are also influenced from D_a, the lower the value of this parameter is, the lower the probabilities of the table are.

Figures E.2.2.2, E.2.2.3 and E.2.2.4 are resulting from tables 6.2 and 6.3. Figure E.2.2.2 illustrates the average echoes power and the maximum power as a function of the number of concurrently transmitted packets, for p=0.8, and n_2=1, n_2=2, n_2=3 and n_2=4. Figure E.2.2.3 illustrates the probability of the shown in fig. E.2.2.2 maximum power occurrence, as a function of n_2, for D_a=0.5. This probability is not influenced by the mean time between packets transmissions. Combining the results of this figure with fig. E.2.2.2, the number of concurrent transmissions can be found. Fig. E.2.2.4 shows the probability of occurrence of the mean power as a function of the power for various values of the mean time between packets transmissions. The axes of 'x' gives the mean power, but not the number of concurrent transmissions. Changing the value of 'p' the mean power will also be changed. Combining the results of this figure with fig. E.2.2.2, the number of concurrent transmissions can be found. From these two figures is concluded that the probability of having any particular value of mean power has an upper limit, while its value depends upon the mean time between packets transmissions.

F. SIMULATION OF THE PROPOSED LAN

This chapter will give a short description :

- of the architecture of the software that has been built for the simulation of the passive flooding idea of the proposed LAN,
- of the model that is simulated and
- of the obtained performance results.

The major task is to prove that the passive flooding implemented on a mesh topology using SPSC techniques, is a cost effective one and that an optimum theoretical BER (BER=0) can be achieved, with low required chip rates. This results from the relation ship between the incoming power of the spread signal and the existing power in the channel.

The rest of the performance estimates (the BER, the delays and the throughput) of the various types of LANs, that are members of this family, depend upon the protocols and hardware design of each one individually. These estimates are of minor importance, due to the negligible delays because of the concurrent communication offered, of the low congestion probability (section E.2), of the possibility to achieve a theoretical zero BER (section E.1) and of the use of short overheads.

For the implementation of desired system goal simulation tools were developed. These tools consist of a simulation environment where the topology is generated, the TDM channel operates and the users' data are generated, spread, flooded, received and evaluated. The analysis and design of these tools were done with the aid of MASCOT. The required software was written in SIMULA.

These simulation tools can be considered as a framework for the development of a general simulation environment, that can be used for the study of mesh topologies and multiple access broadcast networks. In this integrated environment the following services will be available :

- the possibility of developing random mesh topologies,
- the possibility of studying the routing of these topologies and their survivability,
- the possibility of studying the behaviour of broadcast networks at the physical layer,
- the possibility of studying the behaviour of the SPSC receiver,
- the possibility of installing any communication protocol on the network,
- the possibility of studying the behaviour and the performance of the protocol,
- the possibility of studying the overall performance of the three first layers of the OSI model.

F.1. AN INTRODUCTION TO MASCOT (R1).

MASCOT (Modular Approach to Software Construction, Operation and Test) provides the definitions of both :

- a design method for real time software and
- a support environment within which the software is designed, developed, used and maintained.

These definitions are language independent. MASCOT has been implemented in languages as diverse as FORTRAN, CORAL 66 and most recently Ada.

MASCOT provides the means to achieve many of the goals of software engineering in real time systems :

- structured design,	- multi-tasking,
- modularity,	- ordered construction,
- controlled operation,	- testing,
- decision postponement	- maintainability,
- quality assurance,	- language independence,
- multi-processor capabilities,	- static network size.

The features of MASCOT version 3.1 known as MASCOT 3 break down into three main areas :

- communication model
- structural forms
- progressive development

The structural elements of the communication model are

- the activities,
- the intercommunication data areas (IDA),
- the paths,
- the access interfaces,
- the ports and
- the windows.

MASCOT provides a number of constructional forms to express design structures :

- sub-systems

- servers

- composite components

During the development of a project there is the need to provide facilities that enable a support environment to record the progression of a design. MASCOT 3 provides basic facilities in this area to control the progressive capture of design details. The facilities are a natural extension to those of the hierarchical design representation and are tied to the concept of separately defined controlled interface specifications. Three status values are defined :

- registered module,

- introduced module,

- enrolled module.

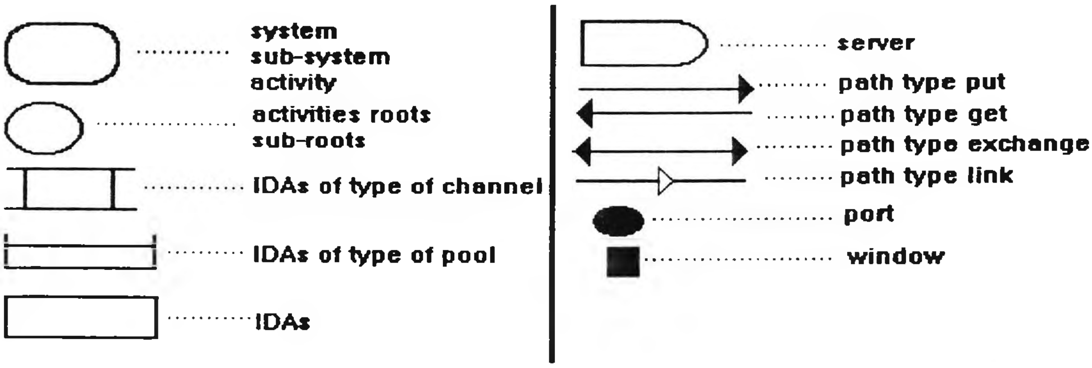


FIG. F.1.1 MASCOT's elements representation.

So following the above MASCOT principles, the parts of the system that is to be designed are represented in a data flow form. Each one of them is named an activity and consists an individual module of the software. The data that is used by the activities are stored in memory areas named pools. Channels interconnect activities and read the pools. Figure F.1.1 illustrates the symbols of MASCOT elements.

F.2. AN INTRODUCTION TO SIMULA (R2, R3)

SIMULA is a general purpose programming language. It inherits the algorithmic properties of ALGOL 60 and introduces methods for structuring data. The main characteristic of SIMULA is that it is easily modelled towards specialised problem areas, and hence can be used as a basis for Special Application Languages.

SIMULA is a language for programming both small problems and large and complex systems in administration science and technology. Among the main advantages of SIMULA are its object oriented approach to programming, which allows very cost effective program development, and the standardisation of the language which means that SIMULA programs can easily be transferred between different SIMULA systems.

Simulation involves complex entities, called processes, which consist of data structures and algorithms that operate on these structures. SIMULA is general enough to serve as the base for the definition of a simulation language.

SIMULA uses the Algol 60 notions of classes and objects, as well as facilities for the treatment of quasi parallel systems. Classes permit the definition of complex entities which later can be used as elementary entities. In other words these complex entities can be used globally without having to refer to their components. Because of this feature SIMULA can be used to define program oriented languages. For example, facilities for handling symmetrical lists have been defined in the class SIMSET. Similarly the class SIMULATION has been defined which offers facilities for handling quasi-parallelism.

So SIMULA is a dynamic discrete event simulation language. It describes the sequence of actions in space and time, as well as relationships. It creates a time environment and it generates a pseudo-parallel domain in it, where the various processes run simultaneously.

F.3. THE SIMULATION MODEL

F.3.1. DESCRIPTION OF THE SIMULATED MODEL

The model that has been built offers two different and independent functions for the communication links of a mesh topology sub-LAN :

- estimates the BER and
- estimates the existing power.

Therefore it focuses on the topology and routing analysis and the power and voltage status of the network. It operates as follows:

- A sub-LAN of 'M' nodes is created. This sub-LAN is built according the topology defined in section D.2. The use of this topology does not restrict the generality of the obtained results, that can be considered as a characteristic sample.
- In the initial phase of simulation the TDM channel starts to operate. From the first frame all the subscribers learn all the required routing and timing information.
- Next all the users start to generate data. After the data have been appropriately processed, through the SPSC techniques, every user's data are transmitted to a predefined destination concurrently with all the others.
- The SPSC signals are flooded into the network.
- All the destination users, read any incoming signal. After the required processing the transmitted information is recovered and compared with what was transmitted. From the comparison of the results, the performance of the system is estimated.

The built program for the simulation of this model is divided into two parts :

-The first one, the TDM operation (TDM.SIM), builds the topology with the possibility for future changes. In this program the TDM channel is created, and flooded. It operates in the time domain and for the total time period of the LAN's operation. The created signalling, synchronisation and routing data are stored in files for further use.

- The other one, the LAN operation (LOP.SIM), runs the activities,

  - of data generation,

- of SPSC signal creation,
- of transmission and flooding and
- of data receiving.

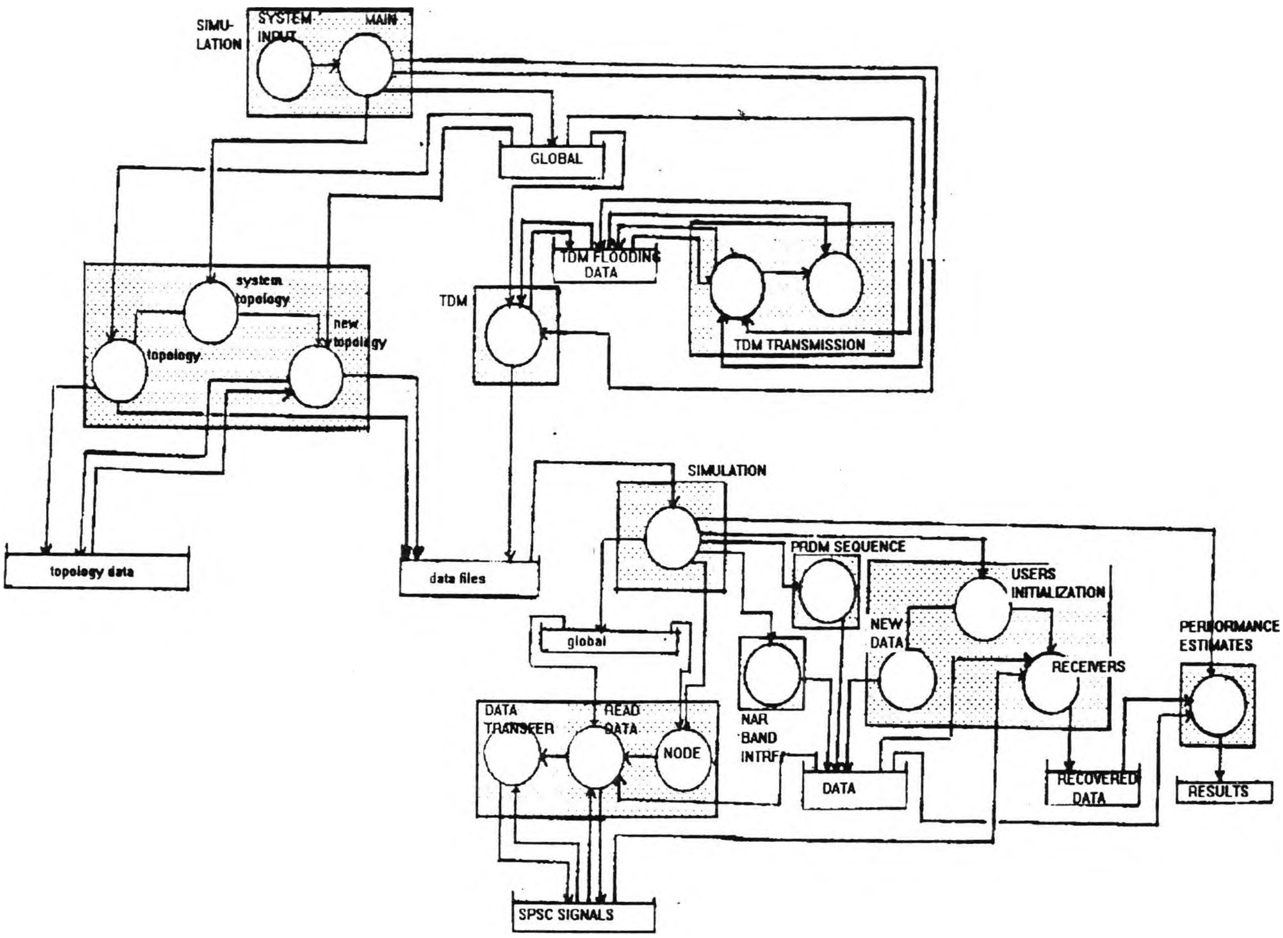


FIG. F.3.1.1 **The overall MASCOT model of the implemented program.**

Figure F.3.1.1 illustrates the main modules of the software and their interconnection in a MASCOT graphical form (D24, D26). Figure F.3.1.2 and F.3.1.3 presents more detailled MASCOT diagrams of the two programs. Figure F.3.1.4 gives the correspondence of the activities to classes. The channels in these programs are implemented through the exploitation of SIMULA characteristics. Figure F.3.1.5 presents the hierarchical activation relationship between the classes and procedures of the programs.

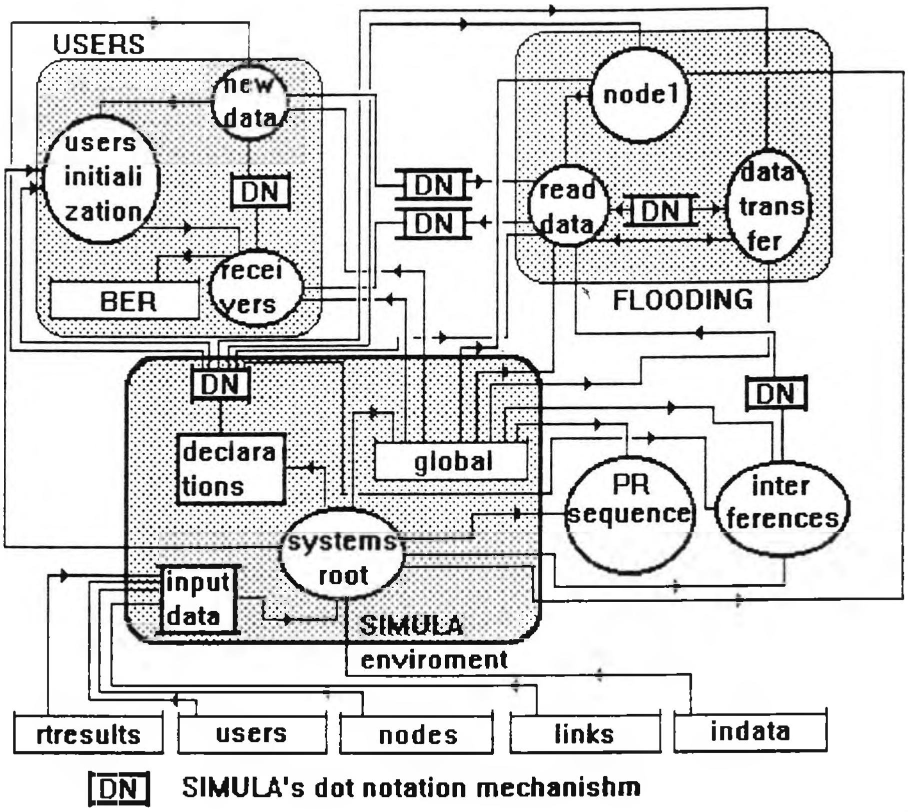


FIG. F.3.1.2 LAN operation. Detailed MASCOT description.

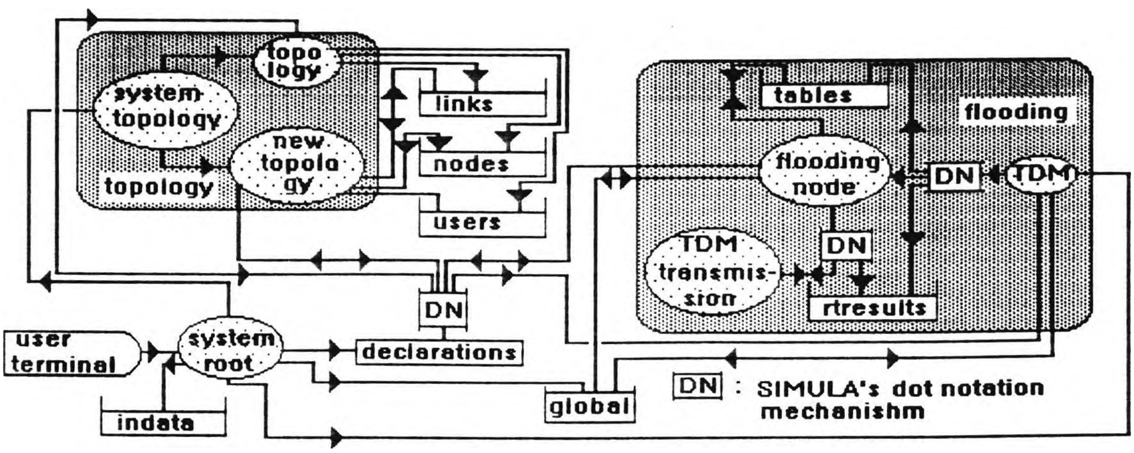


FIG. F.3.1.3 TDM operation. Detailed MASCOT description.

sn	ACTIVITIES (MASCOT)	SIMULA CLASSES
1	topology	system topology, new topology, topology
2	system input	inputdata
3	simulation system	declarations, main program
4	new data	users initialization, new data, pdrdm sequence
5	narrow band interference	TDM, narbandintrf
6	flooding	flooding node, tdm transmission, node1, read data, data transfer
7	DSP	receivers
8	performance estimation	performance

FIG. F.3.1.4 The correspondence between the MASCOT activities and the classes of the implemented program.

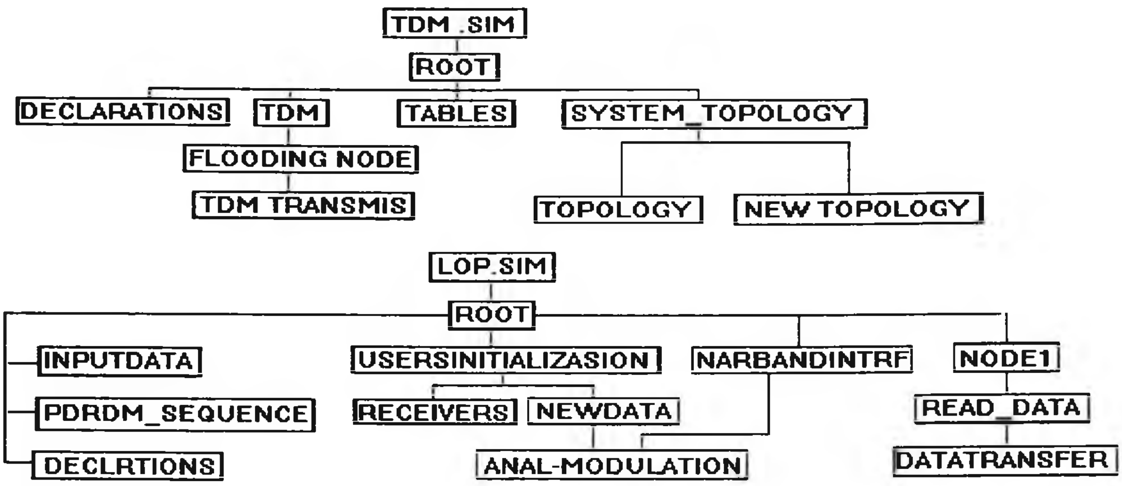


FIG. F.3.1.5 Software classes and procedures activation diagram.

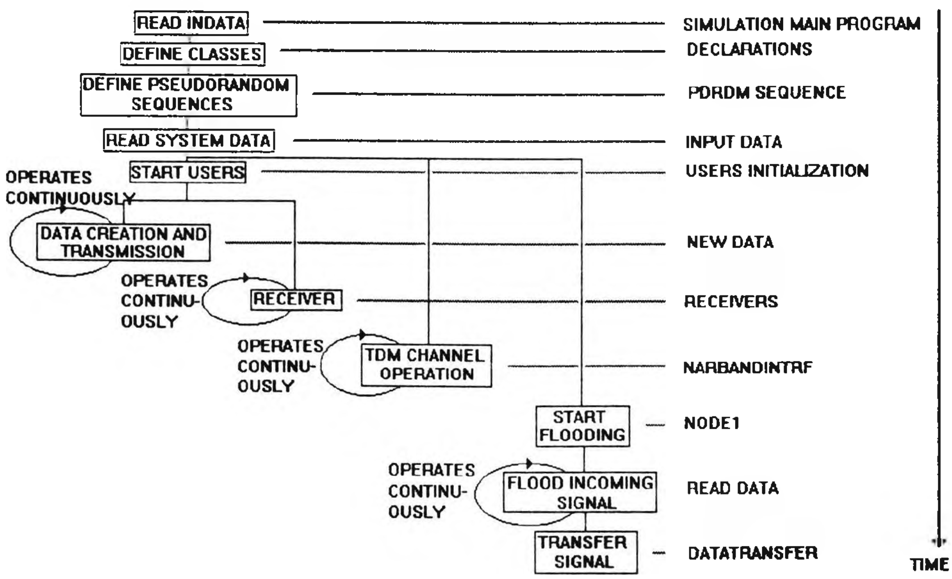
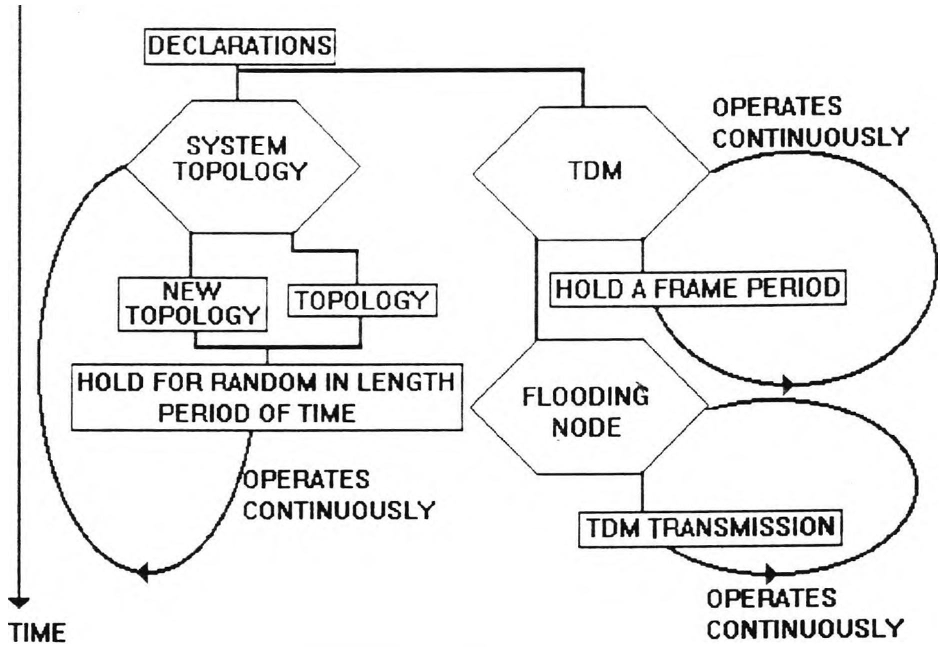
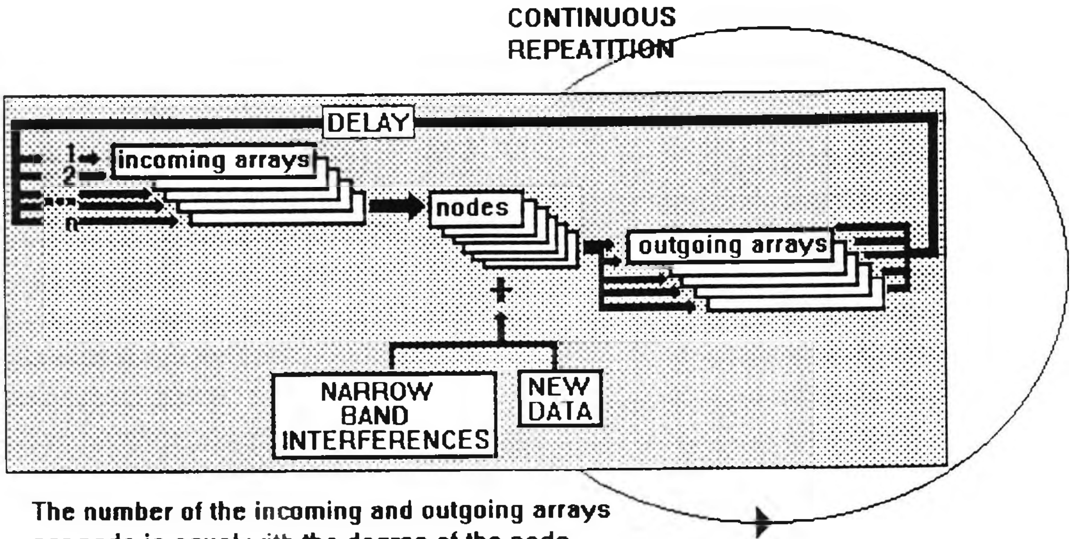


FIG. F.3.1.6 Program LOP.SIM. Flow chart at the class level.



class system topology : Checks if a change to the topology has to be done.
class new topology : Change the existing topology.
class topology : Creates the initial topology.
class TDM : Activates the time slots of the nodes.
class flooding node : Executes the flooding of the information of the TDM channel.
class TDM transmission : Transfers the information from the output of a link to the input of thenext one.

FIG. F.3.1.7 Program TDM.SIM. Flow chart at the class level.



The number of the incoming and outgoing arrays per node is equal with the degree of the node.

FIG. F.3.1.8 The used algorithm for the implementation of the flooding.

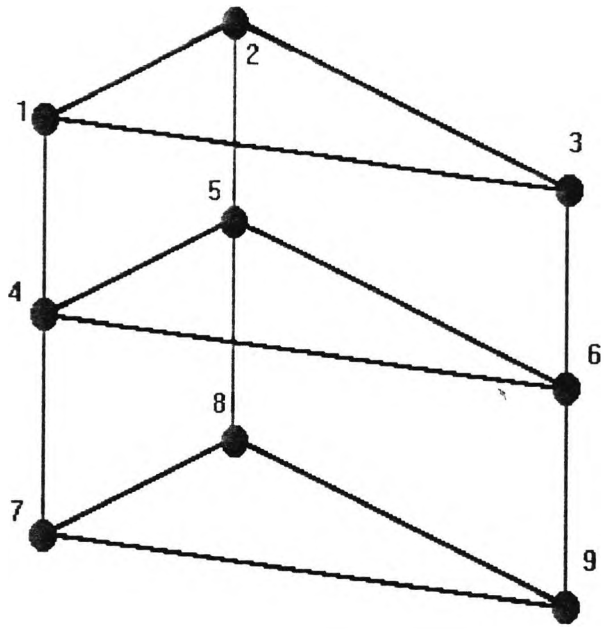


FIG. F.3.1.9 A 9 nodes topology of a sub-LAN.

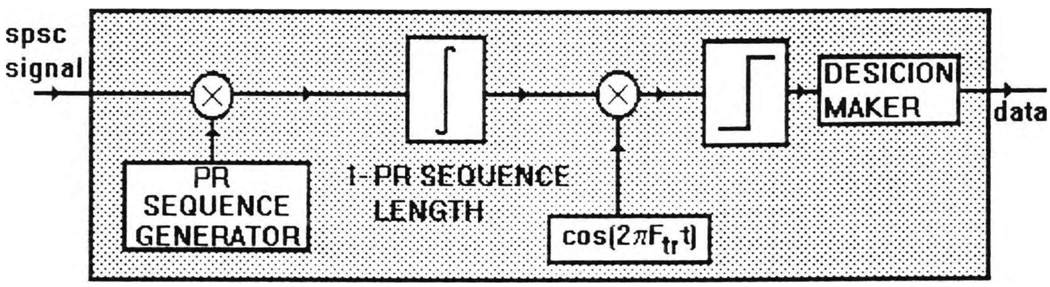


FIG. F.3.1.10 The simulated receiver.

Flow charts of the created programs 'LAN operation (LOP.SIM)' and 'TDM operation (TDM.SIM)' are illustrated in figures F.3.1.6 and F.3.1.7. Figure F.3.1.8 shows the flooding and the new data creation algorithms.

The outputs of the program are the accumulated power and the incoming voltage at the input of any node. These are different and independent each other. From the accumulated and distributed power over the spatial area of the LAN and in comparison with the power of the signal of interest, the optimum chip rate can be estimated. From the incoming voltage the corresponding voltage at the output of the receiver and the BER are estimated. Through them the average BER of the system and the corrupted bits per link will be discussed as a function of the input node attenuation. Further than this, examples will be given of how the incoming power to a node and the output voltage of the receivers are influenced from the topology, the matching attenuation and the other end selection distribution. The concurrent transmission of only one packet of 10 bits from all the users, does not influence the final results. This is because an ideal hardware system has been supposed where external noise sources, others than the signal echoes, do not exist. The TDM channel (not the created by it data) is not used at the LAN operation program, since its existence, from a power point of view, does not influence the system performance.

Using these tools two different topologies were built :

- A 9 nodes topology with 2, 4, 6 and 10 users connected per node (fig. F.3.1.9).
- A 30 nodes topology with 3 and 4 users connected per node (fig. C.2.4).

Measurements have been implemented on them under the following types of traffic :

- Type 1 : All the users transmit packets to a destination of the same sub-graph (e.g. user of node 1 to user of node 3 in fig. F.3.1.9 and user of node 13 to user of node 16 in fig. C.2.4).
- Type 2 : All the users transmit packets to a destination of another sub-graph (e.g. user of node 1 to user of node 6 in figure F.3.1.9 and user of node 13 to user of node 30 in figure C.2.4).
- Type 3 : All the users transmit packets to a destination randomly chosen (e.g. user of node 1 to user of node 9 in figure F.3.1.9 and user of node 13 to user of node 11 in figure C.2.4).
- Type 4 : All the users transmit packets to a destination of one particular sub-graph (e.g. user of node 2 to user of node 3 and user of node 4 to user of node 8 in figure F.3.1.9 and user of node 13 to user of node 30 and user of node 2 to user of node 25 in figure C.2.4).

- Type 5 : All the users transmit packets to a destination of one particular sub-graph. The selection of the destination is such that no congestion occurs. (e.g. user of node 2 to user of node 3 and user of node 4 to user of node 8 in figure F.3.1.9 and user of node 13 to user of node 30 and user of node 2 to user of node 25 in figure C.2.4). This can be considered as the worst case of traffic.

In order to restrict our estimations all simulation results were obtained under the following assumptions :

- One packet of 10 bits per user is transmitted. So the total number of transmitted concurrently packets is equal to the number of users.
-The chip rate is always examined in conjunction with the bit rate. This means that the chip rate is taken as the transmitted number of chips per bit. This number is always an integer and corresponds to the full length of the pseudorandom sequence.
- The packet generation is not random but simultaneous for all the users (worst case of traffic).
- No congestion exists in the network.
- The whole simulated model is considered as an ideal one where no losses due to internal noise is introduced.
- The acknowledgement procedures are not used.

Figure F.3.1.10 illustrates the block diagram of the simulated receiver. The transmitted signal is considered in terms of the power and the voltage of the chips. For simplification reasons the power that corresponds to a chip is processed separately to the voltage. At the nodes and at the receivers during the flooding procedure the accumulated power is estimated, while the voltage is processed (voltage and power are not related). The negative sign of the voltage at the output of the correlator indicates the reception of a negative bit.

All these measurements have been taken for the worst case of traffic (traffic 5) and for simultaneous transmission starting of all the packets (one packet per user). In this way the worst traffic conditions into the sub-LAN are simulated. The concurrent transmission of only one packet of 10 bits from all the users, does not influence the final results. This is because an ideal hardware system has been supposed where external noise sources, others than the signal echoes, do not exist. The influence of the type of channel that has been used is ignored, although usually fiber optics SPSC LANs use optical codes and optical processing.

In the following and in the tables and curves that are appended, the figure of attenuation will describe the amount of power that has gone through the attenuation unit. For example input node attenuation : 0.8 means that the 80% of the signal has gone through the attenuation unit and that the remaining 20% has been absorbed by it.

F.3.2. THE SIMULATION RESULTS

Tables of Appendix 4 examine one by one the corrupted communication links. The information that is found in these tables are the starting and ending node of the physical link, the length of the physical link measured in hops, the number of the corrupted virtual links on it and the total number of the corrupted bits of the virtual links as a function of the attenuation for various chip rates. Every one of these tables is referred to a particular topology and to particular chip rate. They illustrate the influence of the number of hops to the number of corrupted bits per virtual link. As the number of hops is increased, the performance deteriorates. When the chip rate is increased the performance is improved.

Figures F.3.2.1 and F.3.2.2 illustrate the overall BER of all the communication links of the sub-LAN. The curves of these figures have resulted by averaging the data of all the tables of Appendix 4. Every figure presents the average BER as a function of the attenuation for the various chip rates that have been used. It can been seen, that the more concentrated the sub-LAN is, the lower the required chip rate is to nullify the BER. More analytically fig. F.3.2.1 corresponds to the topology of fig. F.3.1.9. The measurements have been taken for 63, 127 and 255 chips and for 2, 6 and 10 users per node. Fig. F.3.2.4 corresponds to the topology of fig. C.2.4. The measurements have been taken for 127, 255 and 511 chips and for 3 and 4 users per node. For the topology of fig. C.2.4 (30 nodes and 90 users) 127 chips support communication links of 2 hops and 511 chips support communication links of 3 hops. For the topology of fig. F.3.1.9 communication links of 2 hops are supported from 127 chips. In this topology there are no physical links that require 3 hops connections.

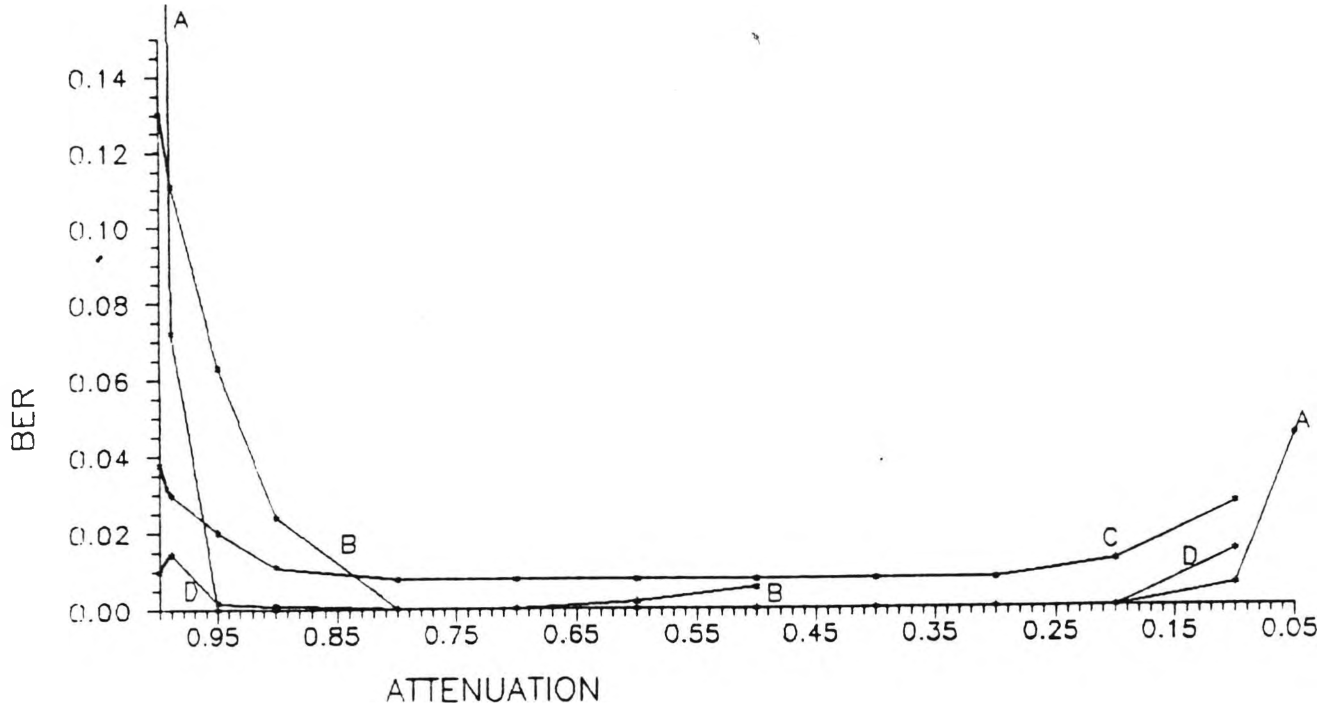


FIG. F.3.2.1 **The average BER as a function of attenuation for the topology of fig. F.3.1.9. Curve 'A' corresponds to 63 chips, 2 users/node, 'B' to 63 chips, 3 users/node, 'C' : 127 chips 10 users/node, 'D' : 255 chips 10 users/node.**

The number of concurrent transmitting users that any particular topology may support is not constant and depends upon the chip rate used, and the distance of the destination, measured in hops. The higher the chip rate is the higher the processing gain is and consequently higher the afforded power of noise due to echoes can be, or alternatively lower the incoming SNR. Echoes power is not only a function of the topology but also of the traffic, the used attenuation at the input port of any node, the accepted maximum length of a link measured in hops (not in time).

The performance of all the virtual channels created during the communication of the users is the same and depends upon the instantaneous traffic load and the echoes at any particular link or node. The BER is a direct function of the incoming into the node SNR. The higher the SNR the lower the BER is. As the number of nodes at a sub-LAN is increased (while the final number of users and the created traffic are kept constant) the distributed power of the noise over the links and the nodes is reduced. At the same time the links are becoming longer in hops and the degree of the nodes is increased. During the transmission, the transmitted power of the signal of interest, is reduced progressively following the hops. Therefore the power of the received signal of interest is reduced and so the total required processing gain of the sub-LAN is changed. By increasing the chip rate better processing gain is achieved and consequently longer paths and higher amount of traffic can be served. So for any particular chip rate the amount of traffic that may be served successfully by the LAN is a function of the topology.

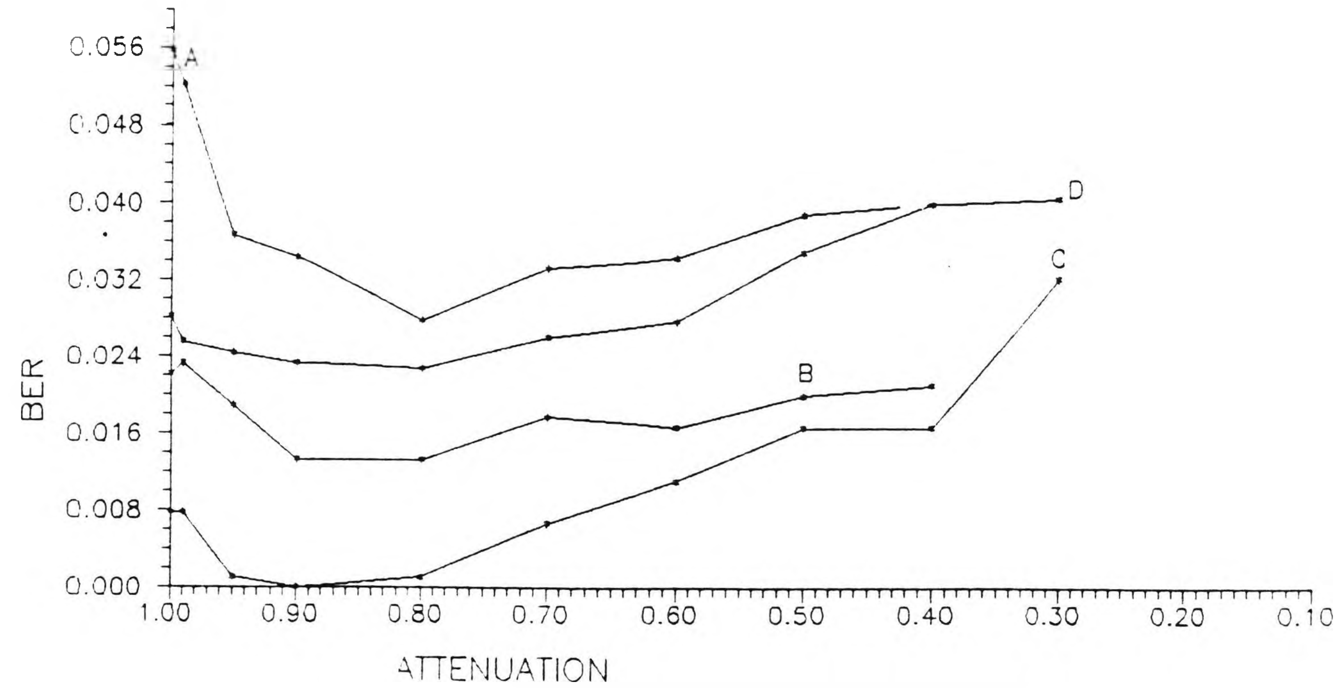


FIG. F.3.2.2 The average BER as a function of the attenuation for the topology of fig. C.2.4. Curve 'A' corresponds to 127 chips, 3 users/node, 'B' : 255 chips 3 users/node, 'C' : 511 chips 3 users/node, 'D' : 511 chips 6 users/node.

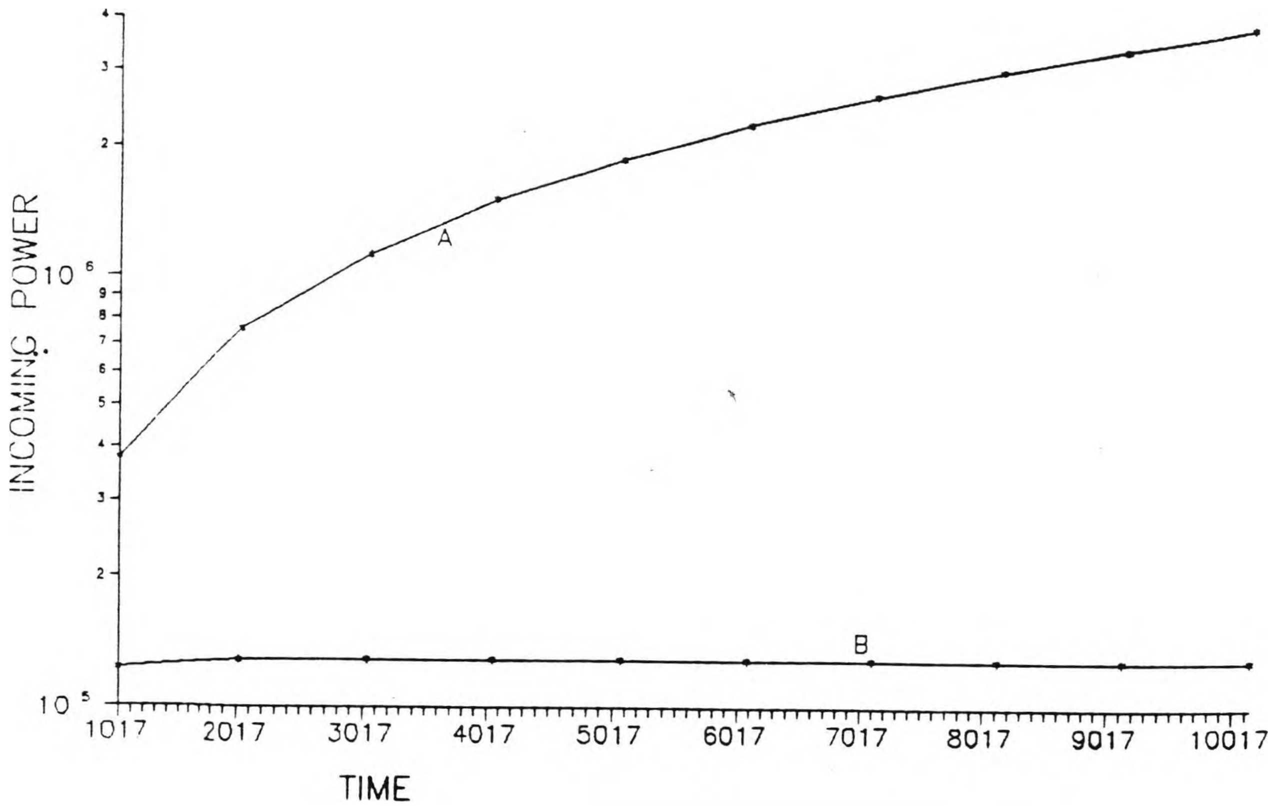


FIG. F.3.2.3 **The incoming power at the receiver and the power of the signal of interest after the first and second hop as a function of the attenuation for the topology of fig. F.3.1.9 and for traffic type 5.**

At figures F.3.2.3 and F.3.2.4 the accumulated power (incoming) at an input of a randomly chosen node as a function of the attenuation has been plotted. Together with this curve the change of the signal of interest at the same input of the same node also as a function of the attenuation is shown for various hops. As signal of interest are considered the spread data that are flooded in the sub-LAN. The incoming power is the signal of interest plus the echoes and the initial transmissions of any other users. The curves of figure F.3.2.3 correspond to the topology of fig. F.3.1.9 (at the topology of fig. F.3.1.9 the signal of interest arrives at the destination from only one or two hops routes) and of fig. F.3.2.4 to the topology of fig. C.2.4.

Every time that the signal of interest is flooded through a node (hop) the signal's power is reduced in accordance with the relation of section D.3. This power reduction is subject to the attenuation value. The same holds for the incoming power also. Therefore the signals of all these curves of figures F.3.2.3 and F.3.2.4 results from a continuous and sequential use of this equation of section D.3 (fig. D.3.3). As the attenuation is increased the signals of the curves change at a different rate. This change is exponential and depends upon how many times the equation has been applied

- individually to the components that the incoming signal consists of and
- to the signal of interest.

From these curves the SNR can be estimated.

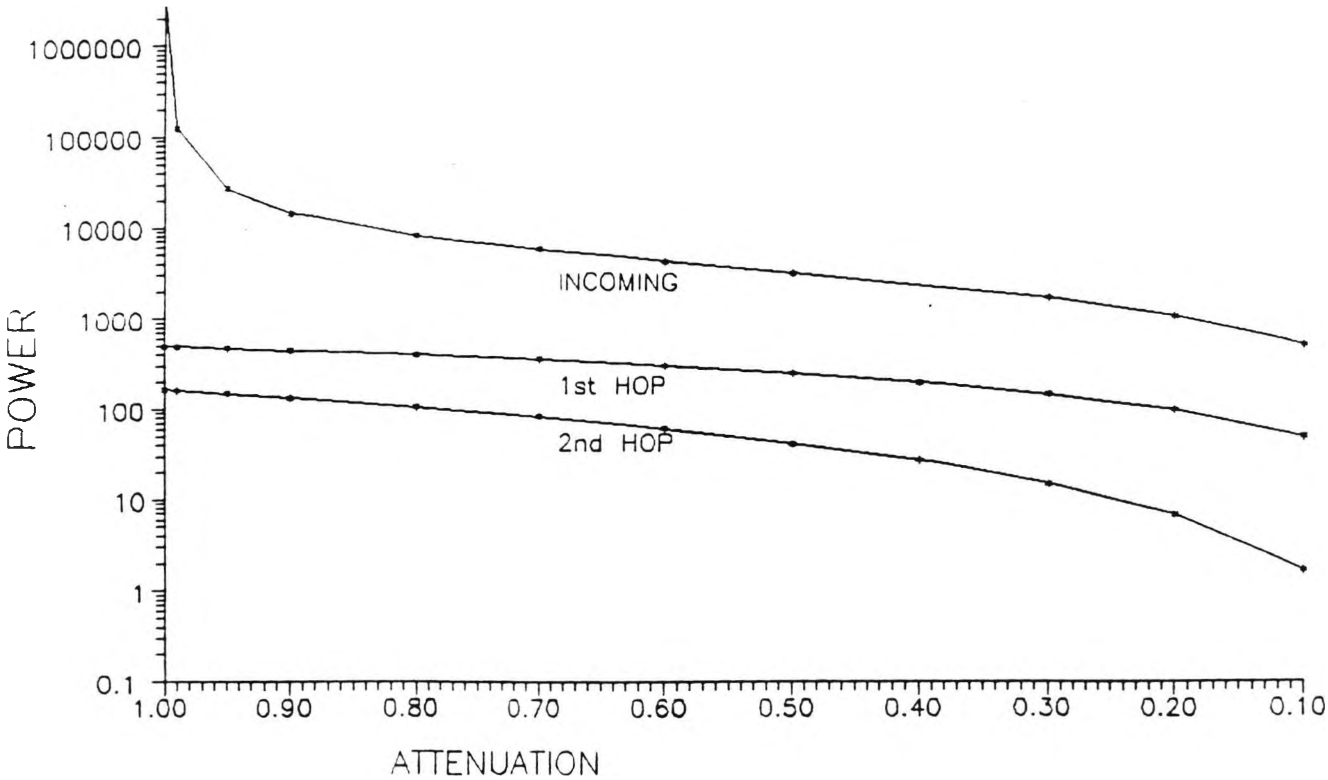


FIG. F.3.2.4 **The incoming power at the receiver and the power of the signal of interest after the first, second and third hop as a function of the attenuation for the topology of fig. C.2.4 and for traffic type 5.**

From figures F.3.2.1, F.3.2.2, F.3.2.3 and F.3.2.4 and from the tables of Appendix 4 an indication of the importance of the influence of the attenuation to the performance of the system is given. For the optimised value of this parameter BER=0 is obtained for the minimum required chip rate.

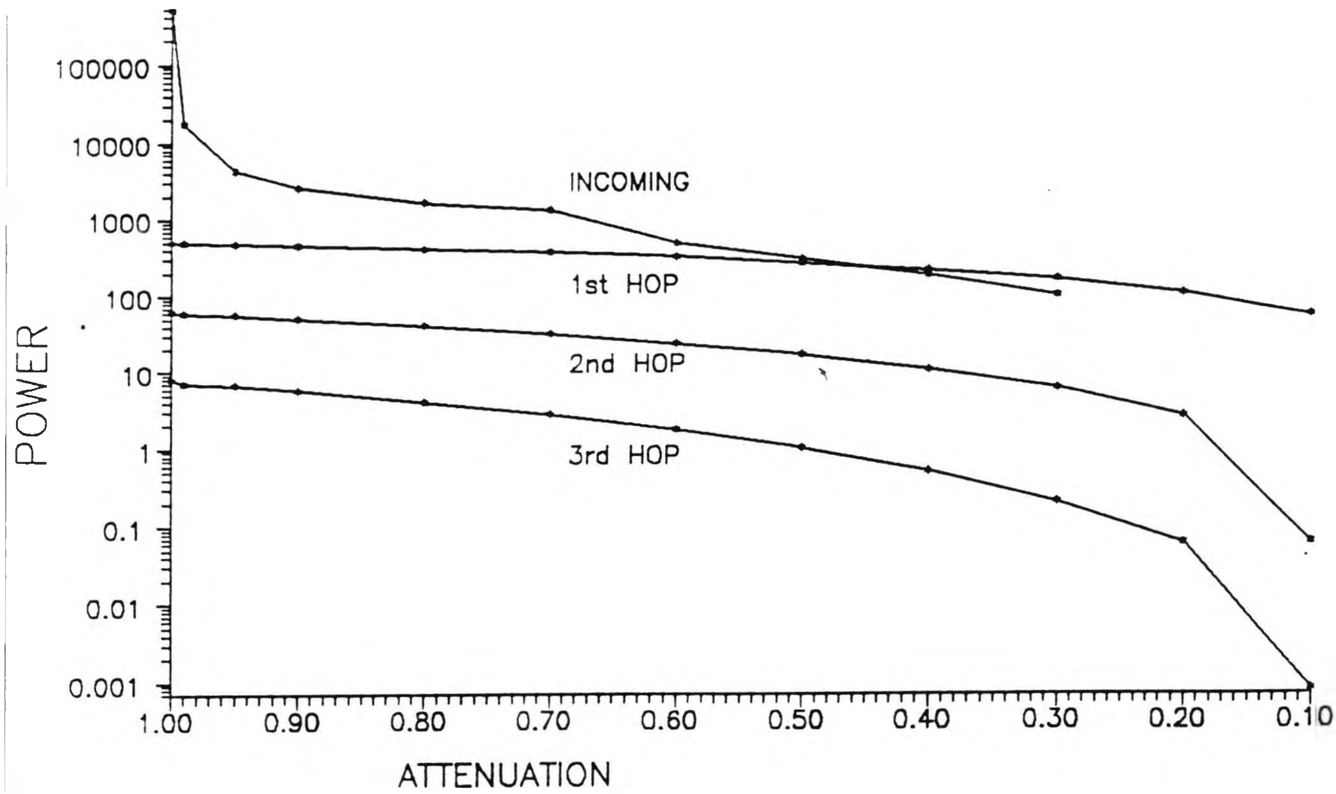


FIG. F.3.2.5 **The incoming power as a function of time for any receiver of the topology of fig. F.3.1.9. Curve 'A' corresponds to attenuation 1 and curve 'B' to attenuation 0.9.**

Assuming that the input node attenuation is 1 then no power is absorbed and consequently no power loss exists at the system. As the attenuation is increased a percentage of both the echoes and the signal power are absorbed resulting to a reduction of their value, but at a different rate. After time t the amount of power that has been absorbed by the system becomes equal to the initially transmitted power. The required time delay for reaching this saturation point is decreased as the attenuation increases (the saturation point comes closer to the transmission starting point). This time delay is relatively short. A static power equilibrium is obtained. This relation is described in fig. F.3.2.5. This figure is referred

- to the topology of fig. F.3.1.9,
- to an arbitrarily chosen receiver (from the second port of node 8),
- to traffic of type 5,

- to 10 users connected on every node and
- to chip rate 127 chips per bit.

It describes the relationship between the incoming power and the time. The time corresponds to the time instance that the data are received.

- Curve 'A' is referred to the case of an ideal system without loss (case of attenuation 1), then the flooded power into the system is accumulated, and a continuous increase of the incoming power takes place. This increase is illustrated for an arbitrarily chosen receiver. It can been seen that there is a linear increase of the power as a function of the time.
- Curve 'B' is referred to the case of attenuation different from 1 then the power does not increase continuously. After some time the power loss due to attenuation is balanced with the incoming one and then the incoming power is stabilised.

So the incoming power, at any incoming port, for any attenuation value different from 1 can be considered as a constant independent of the time.

The traffic distribution affects the power distribution over the LAN and consequently the BER. The tables of Appendix 5 illustrate the incoming power distribution over the network as a function of the attenuation, the used chip rate and the used type of traffic, for both the topologies of figures C.2.4 and F.3.1.9. For cases of traffic 1 and 2 we have a homogenous distribution of the traffic over the network for any value of the attenuation. For traffic 5 the traffic is examined only in the subgraph where the receivers are. This is the worst case of traffic since all the users try to communicate with destinations located at a particular area of the network. Any transmission is initially directed to the shortest route and the signal arrives always at the destination through this route. Due to all this factors of traffic type 5, a great amount of the initially transmitted power accumulates in the area of the receivers of the destination. This power is kept flooded to the rest of the network. In this way in the receivers area a highly noisy environment exists. The required chip rate for serving this type of traffic will also serve, with improved performance, any other traffic situation.

G. CONCLUSIONS

This work involves a lot of fields of research :

- An overall description of the architecture and the design principles of a family of SPSC LANs built on mesh topologies.
- An example of a LAN member of this family is described and analysed and
- Simulation tools are built for the study of the behaviour of the OSI lower layers of mesh topology LANs. These tools were used for the performance evaluation of the flooding idea implemented in a LAN member of this family of LANs.

The suggested family of LANs is built on a mesh, modular topology (D24, D25). According to the modules' configuration and size, the number of connected users varies. These architectures offer security survivability and good performance. The topology used is fully distributed and the suggested routing always offers alternative paths. The used protocols give the ability of learning the system the existing, at any time, topology. The users and the traffic that may be supported are a function of the topology. The following ideas are introduced throughout this thesis :

- The use of SPSC techniques on wired mesh topology LANs, using broadcasting flooding protocols is realistic. Examining it from a cost effectiveness point of view, it can be considered as implementable. Such an architecture offers security and survivability with good performance results.
- The combination of security and survivability can only be achieved if the architecture of the system is constructed from interconnected mesh topology sub-LANs (under the precondition that is supported by the appropriate hardware and protocols).
- The signalling is not vital for the operation of this family of LANs. However its existence makes the LAN more flexible and enhances the offered services. Signalling can be realised through a separate channel (e.g. a TDMA channel), without this to deteriorate the performance (under the precondition that is supported by the appropriate hardware protocols).
- The performance of this family of LANs, when a passive flooding scheme is used, as far the delays and the congestion and collision probabilities concern, appears good.

- The simulation of any system is usually based on a top to bottom design. MASCOT (D24, D26) is the correct tool for the implementation of this design, since it gives the required structures that are independent of the language. SIMULA is an object oriented programming language whose layouts fit to MASCOT design principles. Theirs combined use creates an object oriented environment.

- The developed tools can be considered as the basic framework for the development of a general simulation environment, where the operation of the Physical layer, for any kind of LAN, will be examined.

The main qualities of this LAN can be summarised as : Almost contention free multiple access, security, survivability, noise resistance communication, integrated traffic, inherent addressing capabilities, possibility of grouping the users in separate sub-LANs according to their features, requirements and security demands, simultaneous access to the network, low time delays, and the same performance for all the virtual communication channels within any link. The BER depends upon the design and is a function mainly of the used chip rate and of the attenuation.

An architecture of a LAN member of this family has been analysed. It has the following characteristics :

- Its symmetrical topology creates a homogenous noise environment that improves the performance.

- For the solution of the big problem of SPSC techniques, that of synchronisation, the use of a separate TDM communication channel, on the same physical link that is used by the SPSC channels, is suggested. This channel carries continuously the timing information and any other required control, routing or signalling information, offering uninterrupted availability of any necessary timing and synchronisation information.

- The problem of code orthogonality has been solved by the use of the same code for all the subscribers, shifted by a different number of bits, related to a reference version of the code in each case (e.g. using a different phase for each subscriber).

- As a routing protocol has been introduced the fully passive flooding in a mesh topology. Passive flooding allows the data to arrive at the destination through any possible route.

-The combination of the maximal length sequences used with the existence of a universal timing environment, simplifies the hardware, reduces the probability of errors, due to loss of synchronisation, and improves the performance, due to low transmission delays.

A simplified mathematical model has been built and analysed for the study of the performance evaluation of the flooding idea implemented at this family of LANs. Through this model :

- the influence of the topology to the traffic supported, for various chip rates
- the congestion probabilities, for various sub-LAN designs, and
- the various power status probabilities, for the passive flooding architecture

can be estimated. Some results have been presented. These results give a good performance image. The performance estimates were concentrated mainly on providing an answer to the crucial question :

"What is the relationship between the transmitted data bit rate, the chip rate, the topology and the attenuation for optimising the BER (assuming ideal channels and a system with no noise or errors due to the hardware)?"

This answer defines the required bandwidth for the implementation of the LAN and consequently the cost effectiveness of it.

Simultaneously with this mathematical model simulation tools were developed with the aid of MASCOT, using SIMULA. The developed package can be used as the basic framework for the creation of a simulation environment for testing any type of mesh topology LANs and protocols in the lower layers of the OSI model.

Regarding the current work, the aim of this simulation was also to prove the cost effectiveness of the flooding idea on mesh topologies and the influence of the attenuation to it, as far as the relationship of the chip rate with the bit rate was concerned. The simulation of the operation of the protocols that can be developed, using these ideas, for further performance estimations, is beyond of the scope of this work, since it depends upon the particular designs. The simulation results were estimated for a particular sub-LAN, and for the concurrent transmission from all the users of one packet, with a limited number of bits, due to computing power hardware limitations, assuming ideal channels and a system with no noise or errors due to the hardware. The results obtained from the simulation program match with the results from the mathematical analysis.

According to the definitions of the performance characteristics and by examining the results of the mathematical analysis and the simulation, it can be concluded that the traffic at a passive flooding architecture, is mainly depended upon the topology configuration, the user distribution over the network, the packet generation distribution and the other end selection distribution. The most condense the LAN is the shortest paths exist at a penalty of lack of survivability. The input node attenuation is of main importance since it controls the power of the echoes in the LAN. The traffic supported depends always upon the used chip rate. Supposing an ideal hardware and using the correct value of the chip rate a theoretical zero BER can be achieved. The selection of the chip rate depends upon the input node attenuation. The BER depends upon the design and is a function mainly of the used chip rate and of the attenuation. In addition to the above factors, the length of the links in hops is a function of the receiver's threshold. The lower this threshold is the longer the link. From the above we conclude that the selection of the correct values of these parameters is a design optimisation problem. Congestion is a traffic load function, while the major factor that influences the collision is the chip rate used.

Evaluating the received measurements according to the characteristics of the architecture, it can be concluded that :

- The more spread a sub-LAN is the longer the routes (in hops) that are created.
- The longer a route is the higher the required chip rate is.
- The optimum value of the attenuation parameter is between 0.9 and 0.8 (fig. F.3.2.1 and F.3.2.2).
- The more spread a sub-LAN is the lower the incoming power at any port and consequently the higher the tolerance of the sub-LAN to inter-sub-LAN traffic is.
- The flooded power is homogeneously distributed all over the network.

- Considering the sub-LAN of 30 nodes as a basic unit for the composition of a LAN, then BER=0 can be achieved for any type of traffic, using a chip rate of 511 chips/bit with attenuation 0.9 (fig. F.3.2.2). For the same sub-LAN it was also estimated :

  - that the worst case of congestion probability was 10^{-5} and

  - that for having theoretically BER=0 and covering any possible case of traffic (probability of occurrence 10^{-43}) 2047 chips per bit were required while for covering the usual maximum load of traffic (probability of occurrence $4*10^{-2}$) 511 chips per bit were required.

This type of LAN is appropriate for serving the main types of traffic, that is voice and data, because :

- of the use of dedicated channels to any one of the transmissions
- of the introduced low delays,
- of its good performance and
- of the statistical properties of the SPSC channels to exist only for the period of time that the transmission lasts,

The suitability of this type of LAN for real time image transmission or for slow scanning image transmission, depends upon the characteristics and the design of every particular sub-LAN. This is because for this type of traffic a high transmission bit rate is required. This family of SPSC LANs, according to the design of every one of its members individually, can support various bit rates and types of traffic. Previous hardware limitation to for the increase of channel capacities, transmission rates and for building complicated hardware circuits have been overcome, through the progress in the area of fibre optics and VLSI technology. Due to these qualities such a LAN can be used to various environments such as a bank, a war ship, etc.

Comparison of the performance results of this work with already existing systems, as for example ETHERNET or the bus designed SPSC LANs, has not been done. This is difficult to be implemented, due to the main differences that exist between these systems and the current work.

In this thesis a basic knowledge of the properties, the operation, the performance and the potentials of a new family of LANs has been provided. The implementation of a LAN with these qualities and characteristics needs rather complicated and expensive software and hardware compared with the conventional ones. However this cost is traded against the offered services and since its use is oriented toward special applications, it can be consider as cost effective.

Since the analysis of a communication system is endless, a lot of further research is required in this area. This research can stimulate :

- the study of the qualities and survivability of particular topologies that can be used at SPSC LANs,
- the study of the influence of particular topologies to the performance of the LAN,
- the design of communication and signalling protocols that can be implemented at mesh topology SPSC LANs, either on coaxial or fiber optics channels,
- the comparison of the performance of this work with the performance of other LANs that exist in the market or that are under development,
- the performance estimates through mathematical models or using simulation tools and
- the hardware design and implementation for building such a LAN,

APPENDIX

1. SHANNON's THEOREM

Shannon's theorem is the basis of the SPSC techniques. According to the theorem there is a relationship between the signal to noise ratio and the ability of the channel to transfer error free information (A5) :

$$C = F \log 2 \left(1 + \frac{W}{N}\right)$$

where C = the capacity in bits per second,

F = bandwidth in hertz,

N = noise power,

W = signal power

If S/N << 0.1, then we can accept :

$$C = 1.44\, F \frac{W}{N}$$

$$F = \frac{1}{1.44} \frac{N}{W} C$$

2. ESTIMATION OF THE INFLUENCE OF THE CARRIER FREQUENCY SHIFTING TO THE ORTHOGONALITY OF THE USED CODES

In this appendix is shown that for analogue modulated SPSC signals, the frequency shifting of the carrier does not influence the orthogonality of the used çodes. For simplicity reasons it will be assumed that ASK is used and that all the subscribers transmit information at the same bit rate. The same methodology can be used for any kind of modulation and for different transmission bit rates of the users.

Suppose the existence of 'g' users transmitting analogue SPSC signal. The used carriers are selected according to the described methodology at section C.2. Figure C.2.3 illustrates such a system. For simplicity reasons it can be assumed that only two subscribers the 'i' and 'j' transmit at any time, without this to be a limitation for the general case of 'g' simultaneous transmissions. Suppose that the user No i transmits on the carrier $F_{tr(i)}$ and that the No j one on a frequency $F_{tr(j)}$:

$$F_{tr(i)} = F_C + f_{(i)}$$

$$F_{tr(j)} = F_C + f_{(j)}$$

Suppose that the spreading code is transmitted at a chip rate B_C of e chips/sec and period T_C.

Suppose that the transmitted data by i and j are correspondingly:

$$\left.\begin{matrix} m_i(n) \\ m_j(n) \end{matrix}\right| n \in Z$$

of a bit rate of B_d bits/sec. Then the period of one bit will be:

$T_d = 1 / B_d$

Suppose that the spreading code used from subscriber i is $C_{(i)}$ and that the spreading code used from subscriber j is $C_{(j)}$. Any sequence of data can be considered as a sequence of numbers. So the $C_{(i)}$, $C_{(i+j)}$, $m_{(i)}$, $m_{(j)}$ can be written in the time domain as:

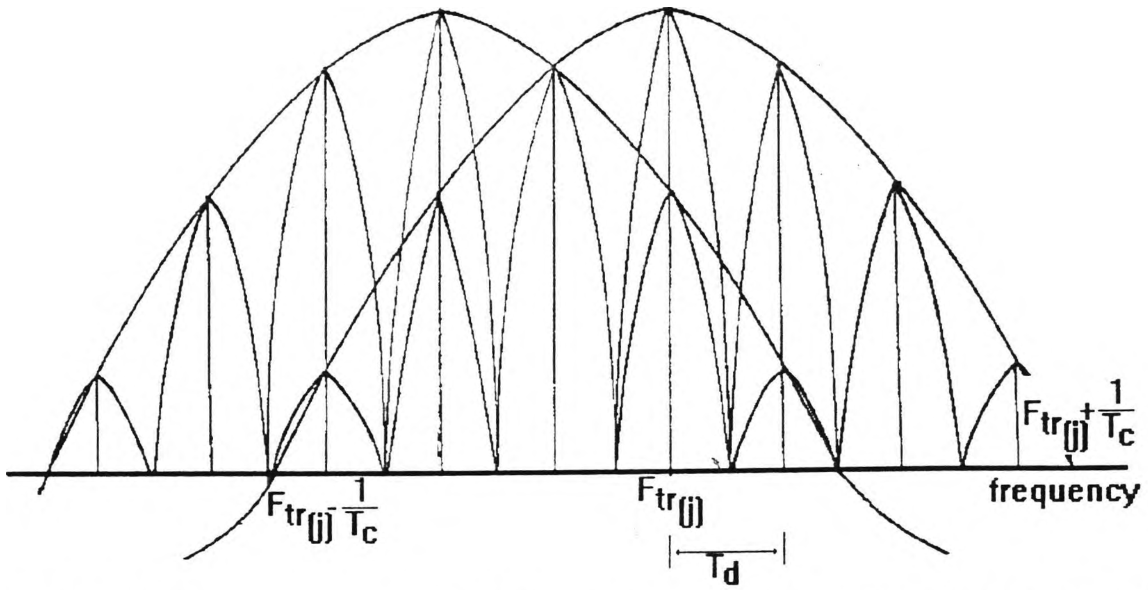


FIG. 2.1 The SPSC signal with ASK modulation in the frequency domain.

$$C_{i(t)} = \sum_{n=-\infty}^{\infty}\left[C_{(i)}\,\delta(t-iT_c) * \mathrm{rect}\left(\frac{t}{T_c}\right)\right] \qquad m_{i(t)} = \sum_{n=-\infty}^{\infty}\left[m_{i(n)}\,\delta(t-nT_d) * \mathrm{rect}\left(\frac{t}{T_d}\right)\right]$$

$$C_{j(t)} = \sum_{n=-\infty}^{\infty}\left[C_{(j)}\,\delta(t-(j)T_c) * \mathrm{rect}\left(\frac{t}{T_c}\right)\right] \qquad m_{j(t)} = \sum_{n=-\infty}^{\infty}\left[m_{j(n)}\,\delta(t-nT_d) * \mathrm{rect}\left(\frac{t}{T_d}\right)\right]$$

where $C_{(i)}=0$ if $i<0$ or $i>e-1$.

After the spreading process the following signals will be created:

$$S_{i(t)} = m_{i(t)}\, C_{i(t)}$$

$$S_{j(t)} = m_{j(t)}\, C_{j(t)}$$

These signals after the analogue modulation will be:

a. time domain

$$g_{i(t)} = S_{i(t)}\ \cos(2\pi F_{tr(i)} t)$$

$$g_{j(t)} = S_{j(t)}\ \cos(2\pi F_{tr(j)} t)$$

b. frequency domain

$$G_{i(f)} = \left[\left[\sum_{n=-\infty}^{\infty}\left[m_{i(n)}\, e^{-j2\pi nT_d}\right]\right] T_d\ \mathrm{sinc}\,(fT_d)\right] * \left[\frac{1}{2}\delta(f+F_{tr(i)}) + \frac{1}{2}\delta(f-F_{tr(i)})\right] * $$
$$* \left[\left[\sum_{n=-\infty}^{\infty}\left[C_{(i)}\, e^{-j2\pi i T_c}\right]\right] T_c\,\mathrm{sinc}\,(fT_c)\right]$$

$$G_{j(f)} = \left[\left[\sum_{n=-\infty}^{\infty}\left[m_{j(n)}\, e^{-j2\pi nT_d}\right]\right] T_d\ \mathrm{sinc}\,(fT_d)\right] * \left[\frac{1}{2}\delta(f+F_{tr(j)}) + \frac{1}{2}\delta(f-F_{tr(j)})\right] * $$
$$* \left[\left[\sum_{n=-\infty}^{\infty}\left[C_{(j)}\, e^{-j2\pi(i+j)T_c}\right]\right] T_c\,\mathrm{sinc}\,(fT_c)\right]$$

Figure 2.1 gives these two signals in the frequency domain.

At the receiver of the destination of subscriber 'j' the following signal will be received :

$$R_{(t)} = b_i g_{i(t)} + b_j g_{j(t)} + n_{(t)}$$

where :

- b_i, b_j are the attenuation factors of the signals of interest due to their flooding into the sub-LAN and to the attenuation 'c' (section D.3) and
- $n_{(t)}$ is the channel noise.

The receiver demodulates the signal and then applies the crosscorrelation procedure. The demodulation procedure will be:

$$B_{(t)} = R_{(t)}\cos(2\pi F_{tr(j)}t) = b_i g_{i(t)}\cos(2\pi F_{tr(j)}t) + b_j g_{j(t)}\cos(2\pi F_{tr(j)}t) +$$
$$+ n_{(t)}\cos(2\pi F_{tr(j)}t) =$$
$$= b_i S_{i(t)}\cos(2\pi F_{tr(i)}t)\cos(2\pi F_{tr(j)}t) + b_j S_{j(t)}\cos(2\pi F_{tr(j)}t)\cos(2\pi F_{tr(j)}t) + n_{(t)}\cos(2\pi F_{tr(j)}t)$$

Suppose that $F_{tr(i)} - F_{tr(j)} = f_{(i-j)}$ then :

$$B_{(t)} = (b_j/2)S_{j(t)} + (b_j/2)S_{j(t)}\cos(4\pi F_{tr(j)}t) + (b_i/2)S_{i(t)}\cos(2\pi f_{(i-j)}t) +$$
$$+ (b_i/2)S_{i(t)}\cos(2\pi(F_{tr(i)}+F_{tr(j)})t) + n_{(t)}\cos(2\pi F_{tr(j)}t)$$

All the high frequency products (harmonic frequencies of F_C, etc.) can be removed by the use of the appropriate low pass filter. At the output of the filter the signal will be:

$$B_{(t)} = (b_j/2)S_{j(t)} + (b_i/2)S_{i(t)}\cos(2\pi f_{(i-j)}t) + n_{(t)}$$

Because of the nature of the SPSC system and of the properties of the crosscorrelation procedure, the signal at the output of the correlator will be :

$$B_{(t)}C_{j(t)} = (b_j/2)S_{j(t)}C_{j(t)} + (b_i/2)S_{i(t)}C_{j(t)}\cos(2\pi f_{(i-j)}t) + n_{(t)}C_{j(t)}$$
$$B_{(t)}C_{j(t)} = (b_j/2)m_{j(t)}C_{j(t)}C_{j(t)} + (b_i/2)m_{i(t)}C_{j(t)}C_{i(t)}\cos(2\pi f_{(i-j)}t) + n_{(t)}C_{j(t)}$$

If $S_{j(t)}$ arrive at the destination of j with $C_{(j)}$ highly uncorrelated with $C_{(i)}$ then :

$$B_{(t)}C_{j(t)} = (b_j/2)m_{j(t)}$$

If $S_{j(t)}$ arrive at the destination of j with $C_{(j)}$ highly correlated with $C_{(i)}$, then if we accept that $C_{(j)}=C_{(i)}$:

$$B_{(t)}C_{j(t)} = (b_j/2)m_{j(t)}C_{j(t)}C_{j(t)} + (b_i/2)m_{i(t)}C_{i(t)}C_{i(t)}\cos(2\pi f_{(i-j)}t) + n_{(t)}C_{j(t)}$$

$$B_{(t)}C_{j(t)} = (b_i/2)m_{j(t)} + (b_i/2)m_{i(t)}\cos(2\pi f_{(i-j)}t)$$

By the use of a filter (fig. C.2.3) the signal of interest can be isolated.

3. TSC DATA

TABLE 3.1. : DATA THAT DEFINE THE VARIOUS VALUES OF TSC.

TSC : Topology Spreading Coefficient

N : Total number of user of the LAN

g : Number of users of a sub-LAN

L : Maximum number of users per node

j : Number of sub-LANs of a LAN

D : Degree of a node

E : Total Number of Nodes of the LAN

TSC	N	g	L	J	D	Total Number of Nodes of the LAN
64.80	165	55	5	3	6	39
64.80	180	60	5	3	6	42
110.25	168	56	4	3	7	48
88.20	210	70	5	3	7	48
110.25	192	64	4	3	7	54
88.20	240	80	5	3	7	54
192.00	153	51	3	3	8	57
144.00	204	68	4	3	8	57
115.20	255	85	5	3	8	57
156.80	240	60	5	4	7	60
192.00	180	60	3	3	8	66
144.00	240	80	4	3	8	66
115.20	300	100	5	3	8	66
243.00	180	60	3	3	9	66
182.25	240	80	4	3	9	66
145.80	300	100	5	3	9	66
196.00	224	56	4	4	7	68
156.80	280	70	5	4	7	68
192.00	189	63	3	3	8	69
144.00	252	84	4	3	8	69
115.20	315	105	5	3	8	69
256.00	240	60	4	4	8	72
204.80	300	75	5	4	8	72
243.00	216	72	3	3	9	78
182.25	288	96	4	3	9	78
145.80	360	120	5	3	9	78
245.00	300	60	5	5	7	80
341.33	216	54	3	4	8	84
256.00	288	72	4	4	8	84
204.80	360	90	5	4	8	84
364.50	156	52	2	3	9	84
243.00	234	78	3	3	9	84
182.25	312	104	4	3	9	84
145.80	390	130	5	3	9	84
432.00	216	54	3	4	9	84
324.00	288	72	4	4	9	84
259.20	360	90	5	4	9	84
400.00	260	52	4	5	8	85
320.00	325	65	5	5	8	85
341.33	228	57	3	4	8	88
256.00	304	76	4	4	8	88
204.80	380	95	5	4	8	88
450.00	168	56	2	3	10	90
300.00	252	84	3	3	10	90
225.00	336	112	4	3	10	90
180.00	420	140	5	3	10	90
460.80	330	55	5	6	8	96
450.00	186	62	2	3	10	99
300.00	279	93	3	3	10	99
225.00	372	124	4	3	10	99
180.00	465	155	5	3	10	99
432.00	264	66	3	4	9	100
324.00	352	88	4	4	9	100
259.20	440	110	5	4	9	100
506.25	320	64	4	5	9	100
405.00	400	80	5	5	9	100
400.00	320	64	4	5	8	100
320.00	400	80	5	5	8	100
450.00	192	64	2	3	10	102
300.00	288	96	3	3	10	102
225.00	384	128	4	3	10	102
180.00	480	160	5	3	10	102
533.33	255	51	3	5	8	105
400.00	340	68	4	5	8	105
320.00	425	85	5	5	8	105
432.00	288	72	3	4	9	108
324.00	384	96	4	4	9	108
259.20	480	120	5	4	9	108
576.00	336	56	4	6	8	114
460.80	420	70	5	6	8	114
729.00	336	56	4	6	9	114
583.20	420	70	5	6	9	114
544.50	216	72	2	3	11	114
363.00	324	108	3	3	11	114

2592.00	468	78	2	6	12	264
1728.00	702	117	3	6	12	264
1296.00	936	156	4	6	12	264
1036.80	1170	195	5	6	12	264
4900.00	280	56	1	5	14	300
2450.00	560	112	2	5	14	300
1633.33	840	168	3	5	14	300
1225.00	1120	224	4	5	14	300
980.00	1400	280	5	5	14	300
3042.00	552	92	2	6	13	306
2028.00	828	138	3	6	13	306
1521.00	1104	184	4	6	13	306
1216.80	1380	230	5	6	13	306
7056.00	324	54	1	6	14	354
3528.00	648	108	2	6	14	354
2352.00	972	162	3	6	14	354
1764.00	1296	216	4	6	14	354
1411.20	1620	270	5	6	14	354
756.25	640	128	4	5	11	180
605.00	800	160	5	5	11	180
1200.00	450	75	3	6	10	180
900.00	600	100	4	6	10	180
720.00	750	125	5	6	10	180
1152.00	344	86	2	4	12	184
768.00	516	129	3	4	12	184
576.00	688	172	4	4	12	184
460.80	860	215	5	4	12	184
1800.00	312	52	2	6	10	186
1200.00	468	78	3	6	10	186
900.00	624	104	4	6	10	186
720.00	780	130	5	6	10	186
1764.00	180	60	1	3	14	186
882.00	360	120	2	3	14	186
588.00	540	180	3	3	14	186
441.00	720	240	4	3	14	186
352.80	900	300	5	3	14	186
1512.50	340	68	2	5	11	190
1008.33	510	102	3	5	11	190
756.25	680	136	4	5	11	190
605.00	850	170	5	5	11	190
2178.00	360	60	2	6	11	210
1452.00	540	90	3	6	11	210
1089.00	720	120	4	6	11	210
871.20	900	150	5	6	11	210
1352.00	400	100	2	4	13	212
901.33	600	150	3	4	13	212
676.00	800	200	4	4	13	212
540.80	1000	250	5	4	13	212
1800.00	400	80	2	5	12	220
1200.00	600	120	3	5	12	220
900.00	800	160	4	5	12	220
720.00	1000	200	5	5	12	220
2178.00	384	64	2	6	11	222
1452.00	576	96	3	6	11	222
1089.00	768	128	4	6	11	222
871.20	960	160	5	6	11	222
1800.00	410	82	2	5	12	225
1200.00	615	123	3	5	12	225
900.00	820	164	4	5	12	225
720.00	1025	205	5	5	12	225
3136.00	232	58	1	4	14	244
1568.00	464	116	2	4	14	244
1045.33	696	174	3	4	14	244
784.00	928	232	4	4	14	244
627.20	1160	290	5	4	14	244
2592.00	456	76	2	6	12	258
1728.00	684	114	3	6	12	258
1296.00	912	152	4	6	12	258
1036.80	1140	190	5	6	12	258
2112.50	480	96	2	5	13	260
1408.33	720	144	3	5	13	260
1056.25	960	192	4	5	13	260
845.00	1200	240	5	5	13	260

800.00	240	60	2	4	10	132
533.33	360	90	3	4	10	132
400.00	480	120	4	4	10	132
320.00	600	150	5	4	10	132
972.00	324	54	3	6	9	138
729.00	432	72	4	6	9	138
583.20	540	90	5	6	9	138
648.00	264	88	2	3	12	138
432.00	396	132	3	3	12	138
324.00	528	176	4	3	12	138
259.20	660	220	5	3	12	138
833.33	360	72	3	5	10	140
625.00	480	96	4	5	10	140
500.00	600	120	5	5	10	140
648.00	270	90	2	3	12	141
432.00	405	135	3	3	12	141
324.00	540	180	4	3	12	141
259.20	675	225	5	3	12	141
968.00	272	68	2	4	11	148
645.33	408	102	3	4	11	148
484.00	544	136	4	4	11	148
387.20	680	170	5	4	11	148
972.00	360	60	3	6	9	150
729.00	480	80	4	6	9	150
583.20	600	100	5	6	9	150
1250.00	270	54	2	5	10	155
833.33	405	81	3	5	10	155
625.00	540	108	4	5	10	155
500.00	675	135	5	5	10	155
968.00	288	72	2	4	11	156
645.33	432	108	3	4	11	156
484.00	576	144	4	4	11	156
387.20	720	180	5	4	11	156
1250.00	280	56	2	5	10	160
833.33	420	84	3	5	10	160
625.00	560	112	4	5	10	160
500.00	700	140	5	5	10	160
1200.00	396	66	3	6	10	162
900.00	528	88	4	6	10	162
720.00	660	110	5	6	10	162
1521.00	156	52	1	3	13	162
760.50	312	104	2	3	13	162
507.00	468	156	3	3	13	162
380.25	624	208	4	3	13	162
304.20	780	260	5	3	13	162
1512.50	320	64	2	5	11	180
1008.33	480	96	3	5	11	180
756.25	640	128	4	5	11	180
605.00	800	160	5	5	11	180
1152.00	336	84	2	4	12	180
768.00	504	126	3	4	12	180
576.00	672	168	4	4	12	180
460.80	840	210	5	4	12	180
1512.50	320	64	2	5	11	180
1008.33	480	96	3	5	11	180

4. SIMULATION RESULTS. CORRUPTED LINKS AND BITS AS A FUNCTION OF THE ATTENUATION.

TABLE 4.1. : CORRUPTED LINKS AND BITS AS A FUNCTION OF THE ATTENUATION FOR THE SUB-LAN OF FIG. F.3.1.9 FOR THE TRANSMISSION OF 10 BITS PER USER.

NODES	:	9
USERS	:	2
CHIPS PER BIT	:	63
CHIP PERIOD	:	16
SIMULATION DURATION	:	11250
TYPE OF TRAFFIC	:	5
RECEIVERS THRESHOLD	:	0
LACK OF SYNCHRONIZATION	:	0

COLUMN A	:ID OF NODE
COLUMN C	: ID OF INCOMING PORT
COLUMN D	: NUMBER OF CORRUPTED VIRTUAL LINKS ON THE PHYSICAL CONNECTION
COLUMN E	: TOTAL NUMBER OF CORRUPTED BITS
TR	: TRANSMITTER
RC	: RECEIVER

ID OF TR	ID OF RC		HOPS	ATTENUATION 0.1		0.99		0.95		0.9		0.8		0.7		0.6		0.5		0.4	
A	A	C		D	E	D	E	D	E	D	E	D	E	D	E	D	E	D	E	D	E
1	8	1	2	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	7	3	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	8	3	2	2	4	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	9	4	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	7	1	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	8	4	2	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0

TABLE 4.2. : CORRUPTED LINKS AND BITS AS A FUNCTION OF THE ATTENUATION FOR THE SUB-LAN OF FIG. F.3.1.9 FOR THE TRANSMISSION OF 10 BITS PER USER.

NODES	:	9
USERS	:	6
CHIPS PER BIT	:	63
CHIP PERIOD	:	16
SIMULATION DURATION	:	11250
TYPE OF TRAFFIC	:	5
RECEIVERS THRESHOLD	:	0
LACK OF SYNCHRONIZATION	:	0

COLUMN A	:ID OF NODE
COLUMN C	: ID OF INCOMING PORT
COLUMN D	: NUMBER OF CORRUPTED VIRTUAL LINKS ON THE PHYSICAL CONNECTION
COLUMN E	: TOTAL NUMBER OF CORRUPTED BITS
COLUMN F	: NUMBER OF HOPS
TR	: TRANSMITTER
RC	: RECEIVER

ID OF			HOPS	ATTENUATION															
TR	RC			0.1		0.99		0.95		0.9		0.8		0.7		0.6		0.5	
A	A	C		D	E	D	E	D	E	D	E	D	E	D	E	D	E	D	E
1	8	1	2	6	18	6	16	6	11	5	7	0	0	0	0	0	0	0	0
2	7	3	2	6	9	6	10	4	5	0	0	0	0	0	0	0	0	0	0
3	8	3	2	6	12	6	12	5	8	3	3	0	0	0	0	0	0	0	0
4	9	4	2	6	12	5	7	2	2	1	1	0	0	0	0	0	0	0	0
5	7	1	2	5	6	4	4	0	0	0	0	0	0	0	0	0	0	0	0
6	8	4	2	5	11	5	10	5	8	2	2	0	0	0	0	1	1	1	3
7	9	1	1	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	9	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0

TABLE 4.3. : CORRUPTED LINKS AND BITS AS A FUNCTION OF THE ATTENUATION FOR THE SUB-LAN OF FIG. F.3.1.9 FOR THE TRANSMISSION OF 10 BITS PER USER.

NODES	:	9
USERS	:	10
CHIPS PER BIT	:	127
CHIP PERIOD	:	8
SIMULATION DURATION	:	11250
TYPE OF TRAFFIC	:	5
RECEIVERS THRESHOLD	:	0
LACK OF SYNCHRONIZATION	:	0

COLUMN A	:ID OF NODE
COLUMN C	: ID OF INCOMING PORT
COLUMN D	: NUMBER OF CORRUPTED VIRTUAL LINKS ON THE PHYSICAL CONNECTION
COLUMN E	: TOTAL NUMBER OF CORRUPTED BITS
COLUMN F	: NUMBER OF HOPS
TR	: TRANSMITTER
RC	: RECEIVER

ID OF			HOPS	ATTENUATION																			
TR	RC			0.1		0.99		0.95		0.9		0.8		0.7		0.6		0.5		0.4		0.3	
A	A	C		D	E	D	E	D	E	D	E	D	E	D	E	D	E	D	E	D	E	D	E
1	8	1	2	6	6	10	12	10	10	3	3	0	0	0	0	0	0	0	0	0	0	0	0
2	7	3	2	3	3	4	4	3	3	2	2	0	0	0	0	0	0	0	0	0	0	0	0
3	8	3	2	4	4	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	9	4	2	8	8	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	7	1	2	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	8	4	2	1	5	1	5	1	5	1	5	1	7	1	7	1	7	1	7	1	7	1	7
7	9	1	1	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	9	1	1	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

TABLE 4.4. : CORRUPTED LINKS AND BITS AS A FUNCTION OF THE ATTENUATION FOR THE SUB-LAN OF FIG. F.3.1.9 FOR THE TRANSMISSION OF 10 BITS PER USER.

NODES	:	9
USERS	:	10
CHIPS PER BIT	:	255
CHIP PERIOD	:	4
SIMULATION DURATION	:	11250
TYPE OF TRAFFIC	:	5
RECEIVERS THRESHOLD	:	0
LACK OF SYNCHRONIZATION	:	0

COLUMN A :ID OF NODE

COLUMN C : ID OF INCOMING PORT

COLUMN D : NUMBER OF CORRUPTED VIRTUAL LINKS ON THE PHYSICAL CONNECTION

COLUMN E : TOTAL NUMBER OF CORRUPTED BITS

COLUMN F : NUMBER OF HOPS

TR : TRANSMITTER

RC : RECEIVER

ID OF TR/R			HOPS	ATTENUATION																			
	RC/R			0.1		0.99		0.95		0.9		0.8		0.7		0.6		0.5		0.4		0.3	
A	A	C		D	E	D	E	D	E	D	E	D	E	D	E	D	E	D	E	D	E	D	E
1	8	1	2	0	0	10	10	4	4	1	1	0	0	0	0	0	0	0	0	0	0	0	0
2	7	3	2	3	3	3	3	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	9	4	2	6	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

TABLE 4.5. : CORRUPTED LINKS AND BITS AS A FUNCTION OF THE ATTENUATION FOR THE SUB-LAN OF FIG. C.2.4 FOR THE TRANSMISSION OF 10 BITS PER USER.

NODES	:	30
USERS	:	3
CHIPS PER BIT	:	127
CHIP PERIOD	:	8
SIMULATION DURATION	:	11250
TYPE OF TRAFFIC	:	5
RECEIVERS THRESHOLD	:	0
LACK OF SYNCHRONIZATION	:	0

COLUMN A	:ID OF NODE
COLUMN C	: ID OF INCOMING PORT
COLUMN D	: NUMBER OF CORRUPTED VIRTUAL LINKS ON THE PHYSICAL CONNECTION
COLUMN E	: TOTAL NUMBER OF CORRUPTED BITS
COLUMN F	: NUMBER OF HOPS
TR	: TRANSMITTER
RC	: RECEIVER

ID OF			HOPS	ATTENUATION																	
TR	RC			0.1		0.99		0.95		0.9		0.8		0.7		0.6		0.5		0.4	
A	A	C		D	E	D	E	D	E	D	E	D	E	D	E	D	E	D	E	D	E
1	26	6	2	2	2	3	3	3	3	1	1	0	0	0	0	0	0	0	0	0	0
2	27	2	2	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	30	7	3	8	2	6	2	4	2	4	2	3	2	3	2	3	2	3	2	3	2
6	25	1	3	10	3	12	3	9	3	10	3	9	3	9	3	9	3	10	3	10	3
12	26	2	3	9	3	9	3	8	2	7	2	7	2	9	3	9	3	10	3	11	3
14	29	8	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	30	3	2	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	27	9	3	8	3	8	3	6	2	6	3	6	3	9	3	10	3	12	3	12	3
20	30	9	2	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	1	1	3	6	3	8	3	3	3	3	3	0	0	0	0	0	0	0	0	0	0

TABLE 4.6. : CORRUPTED LINKS AND BITS AS A FUNCTION OF THE ATTENUATION FOR THE SUB-LAN OF FIG. C.2.4 FOR THE TRANSMISSION OF 10 BITS PER USER.

NODES	:	30
USERS	:	3
CHIPS PER BIT	:	255
CHIP PERIOD	:	4
SIMULATION DURATION	:	11250
TYPE OF TRAFFIC	:	5
RECEIVERS THRESHOLD	:	0
LACK OF SYNCHRONIZATION	:	0

COLUMN A :ID OF NODE

COLUMN C : ID OF INCOMING PORT

COLUMN D : NUMBER OF CORRUPTED VIRTUAL LINKS ON THE PHYSICAL CONNECTION

COLUMN E : TOTAL NUMBER OF CORRUPTED BITS

COLUMN F : NUMBER OF HOPS

TR : TRANSMITTER

RC : RECEIVER

ID OF TR	ID OF RC		HOPS	ATTENUATION 0.1		0.99		0.95		0.9		0.8		0.7		0.6		0.5		0.4		0.3	
A	A	C		D	E	D	E	D	E	D	E	D	E	D	E	D	E	D	E	D	E	D	E
5	30	7	3	2	2	2	2	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
6	25	1	3	4	2	5	2	6	2	6	2	6	2	6	2	4	2	4	2	3	2	2	2
12	26	2	3	7	3	5	2	5	3	3	2	4	3	7	3	7	3	9	3	9	3	11	3
18	27	9	3	4	3	5	3	4	2	2	2	2	2	3	2	4	2	5	2	7	3	9	3
27	1	1	3	3	3	4	3	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0

TABLE 4.7. : CORRUPTED LINKS AND BITS AS A FUNCTION OF THE ATTENUATION FOR THE SUB-LAN OF FIG. C.2.4 FOR THE TRANSMISSION OF 10 BITS PER USER.

NODES	:	30
USERS	:	3
CHIPS PER BIT	:	511
CHIP PERIOD	:	2
SIMULATION DURATION	:	11250
TYPE OF TRAFFIC	:	5
RECEIVERS THRESHOLD	:	0
LACK OF SYNCHRONIZATION	:	0

COLUMN A	:ID OF NODE
COLUMN C	: ID OF INCOMING PORT
COLUMN D	: NUMBER OF CORRUPTED VIRTUAL LINKS ON THE PHYSICAL CONNECTION
COLUMN E	: TOTAL NUMBER OF CORRUPTED BITS
COLUMN F	: NUMBER OF HOPS
TR	: TRANSMITTER
RC	: RECEIVER

ID OF TR/R	RC/R		HOPS	ATTENUATION																			
				0.1		0.99		0.95		0.9		0.8		0.7		0.6		0.5		0.4		0.3	
A	A	C		D	E	D	E	D	E	D	E	D	E	D	E	D	E	D	E	D	E	D	E
5	30	7	3	2	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	25	2	3	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	26	2	3	1	1	0	0	0	0	0	0	1	1	1	1	3	1	7	3	7	3	14	3
18	27	9	3	1	1	3	2	0	0	0	0	5	3	7	3	8	3	8	3	15	3	0	0
27	1	1	3	3	3	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

TABLE 4.8. : CORRUPTED LINKS AND BITS AS A FUNCTION OF THE ATTENUATION FOR THE SUB-LAN OF FIG C.2.4 FOR THE TRANSMISSION OF 10 BITS PER USER.

NODES	:	30
USERS	:	6
CHIPS PER BIT	:	511
CHIP PERIOD	:	2
SIMULATION DURATION	:	11250
TYPE OF TRAFFIC	:	5
RECEIVERS THRESHOLD	:	0
LACK OF SYNCHRONIZATION	:	0

COLUMN A	:ID OF NODE
COLUMN C	: ID OF INCOMING PORT
COLUMN D	: NUMBER OF CORRUPTED VIRTUAL LINKS ON THE PHYSICAL CONNECTION
COLUMN E	: TOTAL NUMBER OF CORRUPTED BITS
COLUMN F	: NUMBER OF HOPS
TR	: TRANSMITTER
RC	: RECEIVER

ID OF			HOPS	ATTENUATION																			
TR	RC			0.1		0.99		0.95		0.9		0.8		0.7		0.6		0.5		0.4		0.3	
A	A	C		D	E	D	E	D	E	D	E	D	E	D	E	D	E	D	E	D	E	D	E
5	30	7	3	24	5	19	5	19	5	18	5	18	5	18	5	19	5	19	5	17	5	16	5
6	25	1	3	9	4	9	5	9	5	8	5	7	5	8	6	7	6	7	6	8	6	8	6
11	26	7	2	4	1	4	1	4	1	4	1	4	1	4	1	4	1	4	1	4	1	4	1
12	26	2	3	7	4	7	4	7	4	7	5	6	4	7	4	8	4	14	5	19	6	20	6
18	27	9	3	7	6	7	6	5	5	5	5	6	5	10	5	12	5	17	6	24	6	25	6

5. SIMULATION RESULTS. THE DISTRIBUTION OF THE INCOMING POWER OVER THE TOPOLOGY

TABLE 5.1. : POWER DISTRIBUTION OVER THE NETWORK FOR VARIOUS TYPES OF TRAFFIC IN THE SUB-LAN OF FIG. F.3.1.9.

NODES : 9

USERS : 10

CHIPS PER BIT : 255

CHIP DURATION : 4

SIMULATION DURATION : 11250

RC : RECEIVER

COLUMN A :ID OF NODE

COLUMN C : ID OF INCOMING PORT

		TRAFFIC : 1			TRAFFIC : 2		
ATT/TION:		0.99	0.8	0.2	0.99	0.8	0.2
RC A	C	INCOMING POWER	INCOMING POWER	INCOMING POWER	INCOMING POWER	INCOMING POWER	INCOMING POWER
3	1	1.27&+05	8.28&+03	1.07&+03	1.28&+05	8.51&+03	1.08&+03
1	1	1.28&+05	8.56&+03	1.08&+03	1.28&+05	8.51&+03	1.08&+03
2	2	1.28&+05	8.70&+03	1.08&+03	1.28&+05	8.51&+03	1.08&+03
6	1	1.26&+05	7.44&+03	1.01&+03	1.28&+05	8.51&+03	1.08&+03
4	2	1.22&+05	4.12&+03	7.78&+01	1.28&+05	8.51&+03	1.08&+03
5	2	1.27&+05	8.21&+03	1.07&+03	1.28&+05	8.51&+03	1.08&+03
9	1	1.27&+05	8.28&+03	1.07&+03	1.28&+05	8.51&+03	1.08&+03
7	1	1.28&+05	8.56&+03	1.08&+03	1.28&+05	8.51&+03	1.08&+03
8	2	1.28&+05	8.70&+03	1.08&+03	1.28&+05	8.51&+03	1.08&+03

TABLE 5.2. : POWER DISTRIBUTION OVER THE NETWORK FOR VARIOUS TYPES OF TRAFFIC IN THE SUB-LAN OF FIG. C.2.4.

NODES	:	30
USERS	:	3
CHIPS PER BIT	:	511
CHIP DURATION	:	2
SIMULATION PERIOD	:	11250

RC : RECEIVER

COLUMN A :ID OF NODE

COLUMN C : ID OF INCOMING PORT

	TRAFFIC : 1			TRAFFIC : 2		
AT/TION:	0.99	0.8	0.2	0.99	0.8	0.2
RC A C	INCOMING POWER	INCOMING POWER	INCOMING POWER	INCOMING POWER	INCOMING POWER	NCOMING POWER
3 1	1.78&+4	1.74&+3	3.09&+2	1.78&+4	1.74&+3	3.09&+2
4 2	1.78&+4	1.73&+3	3.08&+2	1.77&+4	1.64&+3	3.02&+2
5 3	1.78&+4	1.75&+3	3.09&+2	1.78&+4	1.74&+3	3.09&+2
6 4	1.78&+4	1.76&+3	3.09&+2	1.78&+4	1.74&+3	3.09&+2
1 4	1.79&+4	1.78&+3	3.09&+2	1.78&+4	1.74&+3	3.09&+2
2 5	1.78&+4	1.76&+3	3.09&+2	1.78&+4	1.74&+3	3.09&+2
9 1	1.77&+4	1.65&+3	3.02&+2	1.79&+4	1.78&+3	3.09&+2
10 2	1.76&+4	1.62&+3	3.01&+2	1.80&+4	1.85&+3	3.16&+2
11 3	1.78&+4	1.74&+3	3.09&+2	1.79&+4	1.78&+3	3.09&+2
12 4	1.80&+4	1.86&+3	3.16&+2	1.79&+4	1.78&+3	3.09&+2
7 3	1.65&+4	6.62&+2	1.66&+1	1.79&+4	1.78&+3	3.09&+2
8 4	1.65&+4	6.76&+2	1.68&+1	1.79&+4	1.78&+3	3.09&+2
15 1	1.78&+4	1.74&+3	3.09&+2	1.78&+4	1.75&+3	3.09&+2
16 2	1.78&+4	1.73&+3	3.08&+2	1.65&+4	6.52&+2	1.64&+1
17 3	1.78&+4	1.75&+3	3.09&+2	1.78&+4	1.75&+3	3.09&+2
18 4	1.78&+4	1.76&+3	3.09&+2	1.78&+4	1.75&+3	3.09&+2
13 4	1.79&+4	1.78&+3	3.09&+2	1.78&+4	1.75&+3	3.09&+2
14 5	1.78&+4	1.76&+3	3.09&+2	1.78&+4	1.75&+3	3.09&+2
21 1	1.78&+4	1.74&+3	3.09&+2	1.78&+4	1.75&+3	3.09&+2
22 2	1.76&+4	1.63&+3	3.01&+2	1.67&+4	7.73&+2	2.39&+1
23 3	1.78&+4	1.74&+3	3.09&+2	1.78&+4	1.75&+3	3.09&+2
24 4	1.78&+4	1.76&+3	3.09&+2	1.78&+4	1.75&+3	3.09&+2
19 4	1.80&+4	1.87&+3	3.16&+2	1.78&+4	1.75&+3	3.09&+2
20 4	1.65&+4	6.76&+2	1.68&+1	1.78&+4	1.75&+3	3.09&+2
27 1	1.78&+4	1.74&+3	3.09&+2	1.78&+4	1.74&+3	3.09&+2
28 2	1.78&+4	1.73&+3	3.08&+2	1.76&+4	1.62&+3	3.01&+2
29 3	1.78&+4	1.75&+3	3.09&+2	1.78&+4	1.74&+3	3.09&+2
30 4	1.78&+4	1.76&+3	3.09&+2	1.78&+4	1.74&+3	3.09&+2
25 4	1.79&+4	1.78&+3	3.09&+2	1.78&+4	1.74&+3	3.09&+2
26 5	1.78&+4	1.76&+3	3.09&+2	1.78&+4	1.74&+3	3.09&+2

TRAFFIC : 5

RC A C	INCOMING POWER	INCOMING POWER	INCOMING POWER
AT\TION:	0.99	0.8	0.3
26 6	1.78&+4	1.78&+3	4.86&+2
27 2	1.66&+4	7.35&+2	4.35&+1
28 3	1.71&+4	1.06&+3	9.27&+1
29 4	1.68&+4	8.64&+2	6.09&+1
30 7	1.61&+4	4.13&+2	6.15&+0
25 1	1.69&+4	8.79&+2	6.16&+1
27 7	1.79&+4	1.82&+3	4.88&+2
28 7	1.62&+4	5.11&+2	2.17&+1
29 3	1.71&+4	1.07&+3	9.33&+1
25 7	1.62&+4	5.00&+2	2.11&+1
26 7	1.63&+4	5.33&+2	2.30&+1
26 2	1.86&+4	2.27&+3	5.43&+2
28 1	1.68&+4	8.41&+2	5.97&+1
29 8	1.76&+4	1.65&+3	4.69&+2
30 3	1.72&+4	1.08&+3	9.39&+1
25 3	1.68&+4	8.54&+2	6.03&+1
26 4	1.66&+4	7.44&+2	4.41&+1
27 9	1.76&+4	1.60&+3	4.55&+2
29 1	1.66&+4	7.31&+2	4.34&+1
30 9	1.63&+4	5.75&+2	3.59&+1
25 2	1.69&+4	9.47&+2	7.58&+1
26 9	1.62&+4	5.05&+2	2.16&+1
29 9	1.76&+4	1.59&+3	4.55&+2
28 9	1.62&+4	4.83&+2	2.04&+1
27 1	1.82&+4	2.03&+3	5.09&+2
28 2	1.84&+4	2.09&+3	5.12&+2
1 1	1.62&+4	5.03&+2	2.11&+1
30 4	1.84&+4	2.08&+3	5.12&+2
25 4	1.82&+4	1.96&+3	4.94&+2
26 5	1.80&+4	1.84&+3	4.78&+2

6. MATHEMATICAL ANALYSIS RESULTS.

TABLE 6.1. : THE POWER OF THE SIGNAL OF INTEREST AT THE INCOMING PORTS OF THE NODES AT POWER UNITS FOR THE SUB-LAN OF FIGURE C.2.4.

NUMBER OF HOPS	INCOMING POWER OF SIGNAL OF INTEREST AFTER THE FLOODING WITH ATTENUATION OF			
	0.05%	0.1%	0.2%	0.3%
1	475.00	450.00	400.00	350.00
2	56.40	50.60	40.00	30.60
3	6.70	5.70	4.00	2.68
4	0.80	0.64	0.40	0.23

TABLE 6.2. : THE USUAL VALUES OF POWER THAT CAN BE MET IN A SUB-LAN AND THEIR PROBABILITY OF OCCURENCE AS A FUNCTION OF THE USED ATTENUATION, THE NUMBER OF CONCURRENT TRANSMISSIONS AND THE MEAN TIME BETWEEN PACKET TRANSMISSION (FOR THE SUB-LAN OF FIGURE C.2.4 WITH 3 USERS CONNECTED ON EACH NODE).

COLUMN A : NUMBER OF CONCURRENTLY TRANSMITTED PACKETS.
COLUMN B : MEAN TIME BETWEEN PACKET TRANSMISSIONS, MEASURED IN MICRO-SECONDS.
COLUMN C : THE TOTAL ATTENUATION.
COLUMN D : MEAN POWER DUE TO ECHOES .
COLUMN E : MEAN POWER DUE TO ECHOES AND THE FIRST HOP OF AN INITIALLY TRANSMITTED SIGNALS AT ANY INPUT PORT.
COLUMN F : MEAN POWER DUE TO ECHOES, THE SECOND HOP OF AN INITIALLY TRANSMITTED SIGNAL AT ANY INPUT PORT.
COLUMN G : THE PROBABILITY OF HAVING THE INDICATING POWER AT COLUMN 'D' OR 'E' OR 'F'.

A	B	C	D	E	F	G
2	1.95E+01	8.00E-01	1.23E+001	4.12E+002	6.23E+001	8.42E-002
6	1.95E+01	8.00E-01	3.70E+001	4.37E+002	8.70E+001	1.46E-001
10	1.95E+01	8.00E-01	6.17E+001	4.62E+002	1.12E+002	1.81E-002
14	1.95E+01	8.00E-01	8.63E+001	4.86E+002	1.36E+002	4.72E-004
18	1.95E+01	8.00E-01	1.11E+002	5.11E+002	1.61E+002	4.02E-006
22	1.95E+01	8.00E-01	1.36E+002	5.36E+002	1.86E+002	1.43E-008
26	1.95E+01	8.00E-01	1.60E+002	5.60E+002	2.10E+002	2.49E-011
30	1.95E+01	8.00E-01	1.85E+002	5.85E+002	2.35E+002	2.37E-014
34	1.95E+01	8.00E-01	2.10E+002	6.10E+002	2.60E+002	1.33E-017
38	1.95E+01	8.00E-01	2.34E+002	6.34E+002	2.84E+002	4.69E-021
42	1.95E+01	8.00E-01	2.59E+002	6.59E+002	3.09E+002	1.09E-024
46	1.95E+01	8.00E-01	2.84E+002	6.84E+002	3.34E+002	1.74E-028
50	1.95E+01	8.00E-01	3.08E+002	7.08E+002	3.58E+002	1.97E-032
54	1.95E+01	8.00E-01	3.33E+002	7.33E+002	3.83E+002	1.62E-036
58	1.95E+01	8.00E-01	3.58E+002	7.58E+002	4.08E+002	9.95E-041
62	1.95E+01	8.00E-01	3.82E+002	7.82E+002	4.32E+002	4.64E-045
66	1.95E+01	8.00E-01	4.07E+002	8.07E+002	4.57E+002	1.68E-049
70	1.95E+01	8.00E-01	4.32E+002	8.32E+002	4.82E+002	4.77E-054
74	1.95E+01	8.00E-01	4.56E+002	8.56E+002	5.06E+002	1.08E-058
78	1.95E+01	8.00E-01	4.81E+002	8.81E+002	5.31E+002	1.97E-063
82	1.95E+01	8.00E-01	5.06E+002	9.06E+002	5.56E+002	2.93E-068
86	1.95E+01	8.00E-01	5.30E+002	9.30E+002	5.80E+002	3.60E-073
90	1.95E+01	8.00E-01	5.55E+002	9.55E+002	6.05E+002	3.66E-078
2	9.75E+00	8.00E-01	1.23E+001	4.12E+002	6.23E+001	5.00E-003
6	9.75E+00	8.00E-01	3.70E+001	4.37E+002	8.70E+001	9.11E-002
10	9.75E+00	8.00E-01	6.17E+001	4.62E+002	1.12E+002	1.19E-001
14	9.75E+00	8.00E-01	8.63E+001	4.86E+002	1.36E+002	3.24E-002
18	9.75E+00	8.00E-01	1.11E+002	5.11E+002	1.61E+002	2.89E-003
22	9.75E+00	8.00E-01	1.36E+002	5.36E+002	1.86E+002	1.08E-004
26	9.75E+00	8.00E-01	1.60E+002	5.60E+002	2.10E+002	1.98E-006
30	9.75E+00	8.00E-01	1.85E+002	5.85E+002	2.35E+002	1.97E-008
34	9.75E+00	8.00E-01	2.10E+002	6.10E+002	2.60E+002	1.16E-010
38	9.75E+00	8.00E-01	2.34E+002	6.34E+002	2.84E+002	4.31E-013
42	9.75E+00	8.00E-01	2.59E+002	6.59E+002	3.09E+002	1.05E-015
46	9.75E+00	8.00E-01	2.84E+002	6.84E+002	3.34E+002	1.76E-018
50	9.75E+00	8.00E-01	3.08E+002	7.08E+002	3.58E+002	2.09E-021
54	9.75E+00	8.00E-01	3.33E+002	7.33E+002	3.83E+002	1.81E-024
58	9.75E+00	8.00E-01	3.58E+002	7.58E+002	4.08E+002	1.17E-027
62	9.75E+00	8.00E-01	3.82E+002	7.82E+002	4.32E+002	5.71E-031
66	9.75E+00	8.00E-01	4.07E+002	8.07E+002	4.57E+002	2.17E-034
70	9.75E+00	8.00E-01	4.32E+002	8.32E+002	4.82E+002	6.46E-038
74	9.75E+00	8.00E-01	4.56E+002	8.56E+002	5.06E+002	1.53E-041
78	9.75E+00	8.00E-01	4.81E+002	8.81E+002	5.31E+002	2.94E-045
82	9.75E+00	8.00E-01	5.06E+002	9.06E+002	5.56E+002	4.59E-049
86	9.75E+00	8.00E-01	5.30E+002	9.30E+002	5.80E+002	5.91E-053
90	9.75E+00	8.00E-01	5.55E+002	9.55E+002	6.05E+002	6.33E-057
2	6.50E+00	8.00E-01	1.23E+001	4.12E+002	6.23E+001	1.91E-004
6	6.50E+00	8.00E-01	3.70E+001	4.37E+002	8.70E+001	1.52E-002
10	6.50E+00	8.00E-01	6.17E+001	4.62E+002	1.12E+002	8.59E-002
14	6.50E+00	8.00E-01	8.63E+001	4.86E+002	1.36E+002	1.02E-001
18	6.50E+00	8.00E-01	1.11E+002	5.11E+002	1.61E+002	3.97E-002
22	6.50E+00	8.00E-01	1.36E+002	5.36E+002	1.86E+002	6.46E-003
26	6.50E+00	8.00E-01	1.60E+002	5.60E+002	2.10E+002	5.14E-004
30	6.50E+00	8.00E-01	1.85E+002	5.85E+002	2.35E+002	2.23E-005
34	6.50E+00	8.00E-01	2.10E+002	6.10E+002	2.60E+002	5.73E-007
38	6.50E+00	8.00E-01	2.34E+002	6.34E+002	2.84E+002	9.24E-009
42	6.50E+00	8.00E-01	2.59E+002	6.59E+002	3.09E+002	9.82E-011
46	6.50E+00	8.00E-01	2.84E+002	6.84E+002	3.34E+002	7.16E-013
50	6.50E+00	8.00E-01	3.08E+002	7.08E+002	3.58E+002	3.70E-015
54	6.50E+00	8.00E-01	3.33E+002	7.33E+002	3.83E+002	1.39E-017
58	6.50E+00	8.00E-01	3.58E+002	7.58E+002	4.08E+002	3.91E-020
62	6.50E+00	8.00E-01	3.82E+002	7.82E+002	4.32E+002	8.33E-023
66	6.50E+00	8.00E-01	4.07E+002	8.07E+002	4.57E+002	1.38E-025
70	6.50E+00	8.00E-01	4.32E+002	8.32E+002	4.82E+002	1.79E-028
74	6.50E+00	8.00E-01	4.56E+002	8.56E+002	5.06E+002	1.85E-031
78	6.50E+00	8.00E-01	4.81E+002	8.81E+002	5.31E+002	1.54E-034
82	6.50E+00	8.00E-01	5.06E+002	9.06E+002	5.56E+002	1.05E-037
86	6.50E+00	8.00E-01	5.30E+002	9.30E+002	5.80E+002	5.88E-041
90	6.50E+00	8.00E-01	5.55E+002	9.55E+002	6.05E+002	2.74E-044
2	4.88E+00	8.00E-01	1.23E+001	4.12E+002	6.23E+001	5.98E-006
6	4.88E+00	8.00E-01	3.70E+001	4.37E+002	8.70E+001	1.39E-003
10	4.88E+00	8.00E-01	6.17E+001	4.62E+002	1.12E+002	2.30E-002

2	1.95E+01	8.00E-01	1.23E+001	4.12E+002	6.23E+001	8.42E-002
6	1.95E+01	8.00E-01	3.70E+001	4.37E+002	8.70E+001	1.46E-001
10	1.95E+01	8.00E-01	6.17E+001	4.62E+002	1.12E+002	1.81E-002
14	1.95E+01	8.00E-01	8.63E+001	4.86E+002	1.36E+002	4.72E-004
18	1.95E+01	8.00E-01	1.11E+002	5.11E+002	1.61E+002	4.02E-006
22	1.95E+01	8.00E-01	1.36E+002	5.36E+002	1.86E+002	1.43E-008
26	1.95E+01	8.00E-01	1.60E+002	5.60E+002	2.10E+002	2.49E-011
30	1.95E+01	8.00E-01	1.85E+002	5.85E+002	2.35E+002	2.37E-014
34	1.95E+01	8.00E-01	2.10E+002	6.10E+002	2.60E+002	1.33E-017
38	1.95E+01	8.00E-01	2.34E+002	6.34E+002	2.84E+002	4.69E-021
42	1.95E+01	8.00E-01	2.59E+002	6.59E+002	3.09E+002	1.09E-024
46	1.95E+01	8.00E-01	2.84E+002	6.84E+002	3.34E+002	1.74E-028
50	1.95E+01	8.00E-01	3.08E+002	7.08E+002	3.58E+002	1.97E-032
54	1.95E+01	8.00E-01	3.33E+002	7.33E+002	3.83E+002	1.62E-036
58	1.95E+01	8.00E-01	3.58E+002	7.58E+002	4.08E+002	9.95E-041
62	1.95E+01	8.00E-01	3.82E+002	7.82E+002	4.32E+002	4.64E-045
66	1.95E+01	8.00E-01	4.07E+002	8.07E+002	4.57E+002	1.68E-049
70	1.95E+01	8.00E-01	4.32E+002	8.32E+002	4.82E+002	4.77E-054
74	1.95E+01	8.00E-01	4.56E+002	8.56E+002	5.06E+002	1.08E-058
78	1.95E+01	8.00E-01	4.81E+002	8.81E+002	5.31E+002	1.97E-063
82	1.95E+01	8.00E-01	5.06E+002	9.06E+002	5.56E+002	2.93E-068
86	1.95E+01	8.00E-01	5.30E+002	9.30E+002	5.80E+002	3.60E-073
90	1.95E+01	8.00E-01	5.55E+002	9.55E+002	6.05E+002	3.66E-078
14	3.90E+00	8.00E-01	8.63E+001	4.86E+002	1.36E+002	2.82E-002
18	3.90E+00	8.00E-01	1.11E+002	5.11E+002	1.61E+002	7.47E-002
22	3.90E+00	8.00E-01	1.36E+002	5.36E+002	1.86E+002	8.28E-002
26	3.90E+00	8.00E-01	1.60E+002	5.60E+002	2.10E+002	4.49E-002
30	3.90E+00	8.00E-01	1.85E+002	5.85E+002	2.35E+002	1.33E-002
34	3.90E+00	8.00E-01	2.10E+002	6.10E+002	2.60E+002	2.32E-003
38	3.90E+00	8.00E-01	2.34E+002	6.34E+002	2.84E+002	2.55E-004
42	3.90E+00	8.00E-01	2.59E+002	6.59E+002	3.09E+002	1.84E-005
46	3.90E+00	8.00E-01	2.84E+002	6.84E+002	3.34E+002	9.15E-007
50	3.90E+00	8.00E-01	3.08E+002	7.08E+002	3.58E+002	3.22E-008
54	3.90E+00	8.00E-01	3.33E+002	7.33E+002	3.83E+002	8.25E-010
58	3.90E+00	8.00E-01	3.58E+002	7.58E+002	4.08E+002	1.58E-011
62	3.90E+00	8.00E-01	3.82E+002	7.82E+002	4.32E+002	2.29E-013
66	3.90E+00	8.00E-01	4.07E+002	8.07E+002	4.57E+002	2.57E-015
70	3.90E+00	8.00E-01	4.32E+002	8.32E+002	4.82E+002	2.27E-017
74	3.90E+00	8.00E-01	4.56E+002	8.56E+002	5.06E+002	1.60E-019
78	3.90E+00	8.00E-01	4.81E+002	8.81E+002	5.31E+002	9.10E-022
82	3.90E+00	8.00E-01	5.06E+002	9.06E+002	5.56E+002	4.22E-024
86	3.90E+00	8.00E-01	5.30E+002	9.30E+002	5.80E+002	1.61E-026
90	3.90E+00	8.00E-01	5.55E+002	9.55E+002	6.05E+002	5.10E-029
2	3.25E+00	8.00E-01	1.23E+001	4.12E+002	6.23E+001	4.34E-009
6	3.25E+00	8.00E-01	3.70E+001	4.37E+002	8.70E+001	4.71E-006
10	3.25E+00	8.00E-01	6.17E+001	4.62E+002	1.12E+002	3.65E-004
14	3.25E+00	8.00E-01	8.63E+001	4.86E+002	1.36E+002	5.94E-003
18	3.25E+00	8.00E-01	1.11E+002	5.11E+002	1.61E+002	3.16E-002
22	3.25E+00	8.00E-01	1.36E+002	5.36E+002	1.86E+002	7.02E-002
26	3.25E+00	8.00E-01	1.60E+002	5.60E+002	2.10E+002	7.65E-002
30	3.25E+00	8.00E-01	1.85E+002	5.85E+002	2.35E+002	4.54E-002
34	3.25E+00	8.00E-01	2.10E+002	6.10E+002	2.60E+002	1.59E-002
38	3.25E+00	8.00E-01	2.34E+002	6.34E+002	2.84E+002	3.51E-003
42	3.25E+00	8.00E-01	2.59E+002	6.59E+002	3.09E+002	5.11E-004
46	3.25E+00	8.00E-01	2.84E+002	6.84E+002	3.34E+002	5.10E-005
50	3.25E+00	8.00E-01	3.08E+002	7.08E+002	3.58E+002	3.60E-006
54	3.25E+00	8.00E-01	3.33E+002	7.33E+002	3.83E+002	1.85E-007
58	3.25E+00	8.00E-01	3.58E+002	7.58E+002	4.08E+002	7.11E-009
62	3.25E+00	8.00E-01	3.82E+002	7.82E+002	4.32E+002	2.08E-010
66	3.25E+00	8.00E-01	4.07E+002	8.07E+002	4.57E+002	4.69E-012
70	3.25E+00	8.00E-01	4.32E+002	8.32E+002	4.82E+002	8.32E-014
74	3.25E+00	8.00E-01	4.56E+002	8.56E+002	5.06E+002	1.18E-015
78	3.25E+00	8.00E-01	4.81E+002	8.81E+002	5.31E+002	1.34E-017
82	3.25E+00	8.00E-01	5.06E+002	9.06E+002	5.56E+002	1.25E-019
86	3.25E+00	8.00E-01	5.30E+002	9.30E+002	5.80E+002	9.58E-022
90	3.25E+00	8.00E-01	5.55E+002	9.55E+002	6.05E+002	6.10E-024
2	2.79E+00	8.00E-01	1.23E+001	4.12E+002	6.23E+001	1.07E-010
6	2.79E+00	8.00E-01	3.70E+001	4.37E+002	8.70E+001	2.10E-007
10	2.79E+00	8.00E-01	6.17E+001	4.62E+002	1.12E+002	2.95E-005
14	2.79E+00	8.00E-01	8.63E+001	4.86E+002	1.36E+002	8.68E-004
18	2.79E+00	8.00E-01	1.11E+002	5.11E+002	1.61E+002	8.36E-003
22	2.79E+00	8.00E-01	1.36E+002	5.36E+002	1.86E+002	3.37E-002
26	2.79E+00	8.00E-01	1.60E+002	5.60E+002	2.10E+002	6.64E-002
30	2.79E+00	8.00E-01	1.85E+002	5.85E+002	2.35E+002	7.14E-002
34	2.79E+00	8.00E-01	2.10E+002	6.10E+002	2.60E+002	4.54E-002
38	2.79E+00	8.00E-01	2.34E+002	6.34E+002	2.84E+002	1.81E-002
42	2.79E+00	8.00E-01	2.59E+002	6.59E+002	3.09E+002	4.77E-003
46	2.79E+00	8.00E-01	2.84E+002	6.84E+002	3.34E+002	8.61E-004
50	2.79E+00	8.00E-01	3.08E+002	7.08E+002	3.58E+002	1.10E-004
54	2.79E+00	8.00E-01	3.33E+002	7.33E+002	3.83E+002	1.03E-005
58	2.79E+00	8.00E-01	3.58E+002	7.58E+002	4.08E+002	7.14E-007
62	2.79E+00	8.00E-01	3.82E+002	7.82E+002	4.32E+002	3.77E-008
66	2.79E+00	8.00E-01	4.07E+002	8.07E+002	4.57E+002	1.54E-009
70	2.79E+00	8.00E-01	4.32E+002	8.32E+002	4.82E+002	4.95E-011
74	2.79E+00	8.00E-01	4.56E+002	8.56E+002	5.06E+002	1.27E-012
78	2.79E+00	8.00E-01	4.81E+002	8.81E+002	5.31E+002	2.62E-014
82	2.79E+00	8.00E-01	5.06E+002	9.06E+002	5.56E+002	4.42E-016
86	2.79E+00	8.00E-01	5.30E+002	9.30E+002	5.80E+002	6.13E-018
90	2.79E+00	8.00E-01	5.55E+002	9.55E+002	6.05E+002	7.07E-020
2	2.44E+00	8.00E-01	1.23E+001	4.12E+002	6.23E+001	2.54E-012
6	2.44E+00	8.00E-01	3.70E+001	4.37E+002	8.70E+001	8.36E-009
10	2.44E+00	8.00E-01	6.17E+001	4.62E+002	1.12E+002	1.97E-006
14	2.44E+00	8.00E-01	8.63E+001	4.86E+002	1.36E+002	9.71E-005
18	2.44E+00	8.00E-01	1.11E+002	5.11E+002	1.61E+002	1.57E-003
22	2.44E+00	8.00E-01	1.36E+002	5.36E+002	1.86E+002	1.06E-002
26	2.44E+00	8.00E-01	1.60E+002	5.60E+002	2.10E+002	3.50E-002
30	2.44E+00	8.00E-01	1.85E+002	5.85E+002	2.35E+002	6.31E-002
34	2.44E+00	8.00E-01	2.10E+002	6.10E+002	2.60E+002	6.72E-002
38	2.44E+00	8.00E-01	2.34E+002	6.34E+002	2.84E+002	4.50E-002
42	2.44E+00	8.00E-01	2.59E+002	6.59E+002	3.09E+002	1.99E-002
46	2.44E+00	8.00E-01	2.84E+002	6.84E+002	3.34E+002	6.02E-003
50	2.44E+00	8.00E-01	3.08E+002	7.08E+002	3.58E+002	1.29E-003
54	2.44E+00	8.00E-01	3.33E+002	7.33E+002	3.83E+002	2.02E-004
58	2.44E+00	8.00E-01	3.58E+002	7.58E+002	4.08E+002	2.35E-005
62	2.44E+00	8.00E-01	3.82E+002	7.82E+002	4.32E+002	2.08E-006
66	2.44E+00	8.00E-01	4.07E+002	8.07E+002	4.57E+002	1.43E-007
70	2.44E+00	8.00E-01	4.32E+002	8.32E+002	4.82E+002	7.69E-009
74	2.44E+00	8.00E-01	4.56E+002	8.56E+002	5.06E+002	3.30E-010
78	2.44E+00	8.00E-01	4.81E+002	8.81E+002	5.31E+002	1.14E-011
82	2.44E+00	8.00E-01	5.06E+002	9.06E+002	5.56E+002	3.23E-013
86	2.44E+00	8.00E-01	5.30E+002	9.30E+002	5.80E+002	7.52E-015
90	2.44E+00	8.00E-01	5.55E+002	9.55E+002	6.05E+002	1.45E-016
2	2.17E+00	8.00E-01	1.23E+001	4.12E+002	6.23E+001	5.84E-014
6	2.17E+00	8.00E-01	3.70E+001	4.37E+002	8.70E+001	3.04E-010
10	2.17E+00	8.00E-01	6.17E+001	4.62E+002	1.12E+002	1.13E-007
14	2.17E+00	8.00E-01	8.63E+001	4.86E+002	1.36E+002	8.82E-006
18	2.17E+00	8.00E-01	1.11E+002	5.11E+002	1.61E+002	2.25E-004
22	2.17E+00	8.00E-01	1.36E+002	5.36E+002	1.86E+002	2.40E-003
26	2.17E+00	8.00E-01	1.60E+002	5.60E+002	2.10E+002	1.26E-002
30	2.17E+00	8.00E-01	1.85E+002	5.85E+002	2.35E+002	3.58E-002
34	2.17E+00	8.00E-01	2.10E+002	6.10E+002	2.60E+002	6.02E-002
38	2.17E+00	8.00E-01	2.34E+002	6.34E+002	2.84E+002	6.37E-002
42	2.17E+00	8.00E-01	2.59E+002	6.59E+002	3.09E+002	4.45E-002
46	2.17E+00	8.00E-01	2.84E+002	6.84E+002	3.34E+002	2.13E-002
50	2.17E+00	8.00E-01	3.08E+002	7.08E+002	3.58E+002	7.21E-003
54	2.17E+00	8.00E-01	3.33E+002	7.33E+002	3.83E+002	1.78E-003
58	2.17E+00	8.00E-01	3.58E+002	7.58E+002	4.08E+002	3.28E-004
62	2.17E+00	8.00E-01	3.82E+002	7.82E+002	4.32E+002	4.59E-005
66	2.17E+00	8.00E-01	4.07E+002	8.07E+002	4.57E+002	4.97E-006
70	2.17E+00	8.00E-01	4.32E+002	8.32E+002	4.82E+002	4.24E-007
74	2.17E+00	8.00E-01	4.56E+002	8.56E+002	5.06E+002	2.87E-008
78	2.17E+00	8.00E-01	4.81E+002	8.81E+002	5.31E+002	1.57E-009
82	2.17E+00	8.00E-01	5.06E+002	9.06E+002	5.56E+002	7.03E-011
10	9.75E+00	8.00E-01	6.17E+001	4.62E+002	1.12E+002	1.19E-001
14	9.75E+00	8.00E-01	8.63E+001	4.86E+002	1.36E+002	3.24E-002
18	9.75E+00	8.00E-01	1.11E+002	5.11E+002	1.61E+002	2.89E-003
22	9.75E+00	8.00E-01	1.36E+002	5.36E+002	1.86E+002	1.08E-004
26	9.75E+00	8.00E-01	1.60E+002	5.60E+002	2.10E+002	1.98E-006
30	9.75E+00	8.00E-01	1.85E+002	5.85E+002	2.35E+002	1.97E-008
34	9.75E+00	8.00E-01	2.10E+002	6.10E+002	2.60E+002	1.16E-010
38	9.75E+00	8.00E-01	2.34E+002	6.34E+002	2.84E+002	4.31E-013
42	9.75E+00	8.00E-01	2.59E+002	6.59E+002	3.09E+002	1.05E-015
46	9.75E+00	8.00E-01	2.84E+002	6.84E+002	3.34E+002	1.76E-018
50	9.75E+00	8.00E-01	3.08E+002	7.08E+002	3.58E+002	2.09E-021
54	9.75E+00	8.00E-01	3.33E+002	7.33E+002	3.83E+002	1.81E-024
58	9.75E+00	8.00E-01	3.58E+002	7.58E+002	4.08E+002	1.17E-027
62	9.75E+00	8.00E-01	3.82E+002	7.82E+002	4.32E+002	5.71E-031

66	9.75E+00	8.00E-01	4.07E+002	8.07E+002	4.57E+002	2.17E-034
70	9.75E+00	8.00E-01	4.32E+002	8.32E+002	4.82E+002	6.46E-038
74	9.75E+00	8.00E-01	4.56E+002	8.56E+002	5.06E+002	1.53E-041
78	9.75E+00	8.00E-01	4.81E+002	8.81E+002	5.31E+002	2.94E-045
82	9.75E+00	8.00E-01	5.06E+002	9.06E+002	5.56E+002	4.59E-049
86	9.75E+00	8.00E-01	5.30E+002	9.30E+002	5.80E+002	5.91E-053
90	9.75E+00	8.00E-01	5.55E+002	9.55E+002	6.05E+002	6.33E-057
2	6.50E+00	8.00E-01	1.23E+001	4.12E+002	6.23E+001	1.91E-004
6	6.50E+00	8.00E-01	3.70E+001	4.37E+002	8.70E+001	1.52E-002
10	6.50E+00	8.00E-01	6.17E+001	4.62E+002	1.12E+002	8.59E-002
14	6.50E+00	8.00E-01	8.63E+001	4.86E+002	1.36E+002	1.02E-001
18	6.50E+00	8.00E-01	1.11E+002	5.11E+002	1.61E+002	3.97E-002
22	6.50E+00	8.00E-01	1.36E+002	5.36E+002	1.86E+002	6.46E-003
26	6.50E+00	8.00E-01	1.60E+002	5.60E+002	2.10E+002	5.14E-004
30	6.50E+00	8.00E-01	1.85E+002	5.85E+002	2.35E+002	2.23E-005
34	6.50E+00	8.00E-01	2.10E+002	6.10E+002	2.60E+002	5.73E-007
38	6.50E+00	8.00E-01	2.34E+002	6.34E+002	2.84E+002	9.24E-009
42	6.50E+00	8.00E-01	2.59E+002	6.59E+002	3.09E+002	9.82E-011
46	6.50E+00	8.00E-01	2.84E+002	6.84E+002	3.34E+002	7.16E-013
50	6.50E+00	8.00E-01	3.08E+002	7.08E+002	3.58E+002	3.70E-015
54	6.50E+00	8.00E-01	3.33E+002	7.33E+002	3.83E+002	1.39E-017
58	6.50E+00	8.00E-01	3.58E+002	7.58E+002	4.08E+002	3.91E-020
62	6.50E+00	8.00E-01	3.82E+002	7.82E+002	4.32E+002	8.33E-023
66	6.50E+00	8.00E-01	4.07E+002	8.07E+002	4.57E+002	1.38E-025
70	6.50E+00	8.00E-01	4.32E+002	8.32E+002	4.82E+002	1.79E-028
74	6.50E+00	8.00E-01	4.56E+002	8.56E+002	5.06E+002	1.85E-031
78	6.50E+00	8.00E-01	4.81E+002	8.81E+002	5.31E+002	1.54E-034
82	6.50E+00	8.00E-01	5.06E+002	9.06E+002	5.56E+002	1.05E-037
86	6.50E+00	8.00E-01	5.30E+002	9.30E+002	5.80E+002	5.88E-041
90	6.50E+00	8.00E-01	5.55E+002	9.55E+002	6.05E+002	2.74E-044
2	4.88E+00	8.00E-01	1.23E+001	4.12E+002	6.23E+001	5.98E-006
6	4.88E+00	8.00E-01	3.70E+001	4.37E+002	8.70E+001	1.39E-003
10	4.88E+00	8.00E-01	6.17E+001	4.62E+002	1.12E+002	2.30E-002
14	4.88E+00	8.00E-01	8.63E+001	4.86E+002	1.36E+002	8.00E-002
18	4.88E+00	8.00E-01	1.11E+002	5.11E+002	1.61E+002	9.09E-002
22	4.88E+00	8.00E-01	1.36E+002	5.36E+002	1.86E+002	4.33E-002
26	4.88E+00	8.00E-01	1.60E+002	5.60E+002	2.10E+002	1.01E-002
30	4.88E+00	8.00E-01	1.85E+002	5.85E+002	2.35E+002	1.28E-003
34	4.88E+00	8.00E-01	2.10E+002	6.10E+002	2.60E+002	9.60E-005
38	4.88E+00	8.00E-01	2.34E+002	6.34E+002	2.84E+002	4.52E-006
42	4.88E+00	8.00E-01	2.59E+002	6.59E+002	3.09E+002	1.41E-007
46	4.88E+00	8.00E-01	2.84E+002	6.84E+002	3.34E+002	3.00E-009
50	4.88E+00	8.00E-01	3.08E+002	7.08E+002	3.58E+002	4.53E-011
54	4.88E+00	8.00E-01	3.33E+002	7.33E+002	3.83E+002	4.99E-013
58	4.88E+00	8.00E-01	3.58E+002	7.58E+002	4.08E+002	4.09E-015
62	4.88E+00	8.00E-01	3.82E+002	7.82E+002	4.32E+002	2.55E-017
66	4.88E+00	8.00E-01	4.07E+002	8.07E+002	4.57E+002	1.23E-019
70	4.88E+00	8.00E-01	4.32E+002	8.32E+002	4.82E+002	4.68E-022
74	4.88E+00	8.00E-01	4.56E+002	8.56E+002	5.06E+002	1.42E-024
78	4.88E+00	8.00E-01	4.81E+002	8.81E+002	5.31E+002	3.45E-027
82	4.88E+00	8.00E-01	5.06E+002	9.06E+002	5.56E+002	6.87E-030
86	4.88E+00	8.00E-01	5.30E+002	9.30E+002	5.80E+002	1.13E-032
90	4.88E+00	8.00E-01	5.55E+002	9.55E+002	6.05E+002	1.53E-035
2	3.90E+00	8.00E-01	1.23E+001	4.12E+002	6.23E+001	1.67E-007
6	3.90E+00	8.00E-01	3.70E+001	4.37E+002	8.70E+001	9.03E-005
10	3.90E+00	8.00E-01	6.17E+001	4.62E+002	1.12E+002	3.49E-003
14	3.90E+00	8.00E-01	8.63E+001	4.86E+002	1.36E+002	2.82E-002
18	3.90E+00	8.00E-01	1.11E+002	5.11E+002	1.61E+002	7.47E-002
22	3.90E+00	8.00E-01	1.36E+002	5.36E+002	1.86E+002	8.28E-002
26	3.90E+00	8.00E-01	1.60E+002	5.60E+002	2.10E+002	4.49E-002
30	3.90E+00	8.00E-01	1.85E+002	5.85E+002	2.35E+002	1.33E-002
34	3.90E+00	8.00E-01	2.10E+002	6.10E+002	2.60E+002	2.32E-003
38	3.90E+00	8.00E-01	2.34E+002	6.34E+002	2.84E+002	2.55E-004
42	3.90E+00	8.00E-01	2.59E+002	6.59E+002	3.09E+002	1.84E-005
46	3.90E+00	8.00E-01	2.84E+002	6.84E+002	3.34E+002	9.15E-007
50	3.90E+00	8.00E-01	3.08E+002	7.08E+002	3.58E+002	3.22E-008
54	3.90E+00	8.00E-01	3.33E+002	7.33E+002	3.83E+002	8.25E-010
58	3.90E+00	8.00E-01	3.58E+002	7.58E+002	4.08E+002	1.58E-011
62	3.90E+00	8.00E-01	3.82E+002	7.82E+002	4.32E+002	2.29E-013
66	3.90E+00	8.00E-01	4.07E+002	8.07E+002	4.57E+002	2.57E-015
70	3.90E+00	8.00E-01	4.32E+002	8.32E+002	4.82E+002	2.27E-017
74	3.90E+00	8.00E-01	4.56E+002	8.56E+002	5.06E+002	1.60E-019
78	3.90E+00	8.00E-01	4.81E+002	8.81E+002	5.31E+002	9.10E-022
82	3.90E+00	8.00E-01	5.06E+002	9.06E+002	5.56E+002	4.22E-024
86	3.90E+00	8.00E-01	5.30E+002	9.30E+002	5.80E+002	1.61E-026
90	3.90E+00	8.00E-01	5.55E+002	9.55E+002	6.05E+002	5.10E-029
2	3.25E+00	8.00E-01	1.23E+001	4.12E+002	6.23E+001	4.34E-009
6	3.25E+00	8.00E-01	3.70E+001	4.37E+002	8.70E+001	4.71E-006
10	3.25E+00	8.00E-01	6.17E+001	4.62E+002	1.12E+002	3.65E-004
14	3.25E+00	8.00E-01	8.63E+001	4.86E+002	1.36E+002	5.94E-003
18	3.25E+00	8.00E-01	1.11E+002	5.11E+002	1.61E+002	3.16E-002
22	3.25E+00	8.00E-01	1.36E+002	5.36E+002	1.86E+002	7.02E-002
26	3.25E+00	8.00E-01	1.60E+002	5.60E+002	2.10E+002	7.65E-002
30	3.25E+00	8.00E-01	1.85E+002	5.85E+002	2.35E+002	4.54E-002
34	3.25E+00	8.00E-01	2.10E+002	6.10E+002	2.60E+002	1.59E-002
38	3.25E+00	8.00E-01	2.34E+002	6.34E+002	2.84E+002	3.51E-003
42	3.25E+00	8.00E-01	2.59E+002	6.59E+002	3.09E+002	5.11E-004
46	3.25E+00	8.00E-01	2.84E+002	6.84E+002	3.34E+002	5.10E-005
50	3.25E+00	8.00E-01	3.08E+002	7.08E+002	3.58E+002	3.60E-006
54	3.25E+00	8.00E-01	3.33E+002	7.33E+002	3.83E+002	1.85E-007
58	3.25E+00	8.00E-01	3.58E+002	7.58E+002	4.08E+002	7.11E-009
62	3.25E+00	8.00E-01	3.82E+002	7.82E+002	4.32E+002	2.08E-010
66	3.25E+00	8.00E-01	4.07E+002	8.07E+002	4.57E+002	4.69E-012
70	3.25E+00	8.00E-01	4.32E+002	8.32E+002	4.82E+002	8.32E-014
74	3.25E+00	8.00E-01	4.56E+002	8.56E+002	5.06E+002	1.18E-015
78	3.25E+00	8.00E-01	4.81E+002	8.81E+002	5.31E+002	1.34E-017
82	3.25E+00	8.00E-01	5.06E+002	9.06E+002	5.56E+002	1.25E-019
86	3.25E+00	8.00E-01	5.30E+002	9.30E+002	5.80E+002	9.58E-022
90	3.25E+00	8.00E-01	5.55E+002	9.55E+002	6.05E+002	6.10E-024
2	2.79E+00	8.00E-01	1.23E+001	4.12E+002	6.23E+001	1.07E-010
6	2.79E+00	8.00E-01	3.70E+001	4.37E+002	8.70E+001	2.10E-007
10	2.79E+00	8.00E-01	6.17E+001	4.62E+002	1.12E+002	2.95E-005
14	2.79E+00	8.00E-01	8.63E+001	4.86E+002	1.36E+002	8.68E-004
18	2.79E+00	8.00E-01	1.11E+002	5.11E+002	1.61E+002	8.36E-003
22	2.79E+00	8.00E-01	1.36E+002	5.36E+002	1.86E+002	3.37E-002
26	2.79E+00	8.00E-01	1.60E+002	5.60E+002	2.10E+002	6.64E-002
30	2.79E+00	8.00E-01	1.85E+002	5.85E+002	2.35E+002	7.14E-002
34	2.79E+00	8.00E-01	2.10E+002	6.10E+002	2.60E+002	4.54E-002
38	2.79E+00	8.00E-01	2.34E+002	6.34E+002	2.84E+002	1.81E-002
42	2.79E+00	8.00E-01	2.59E+002	6.59E+002	3.09E+002	4.77E-003
46	2.79E+00	8.00E-01	2.84E+002	6.84E+002	3.34E+002	8.61E-004
50	2.79E+00	8.00E-01	3.08E+002	7.08E+002	3.58E+002	1.10E-004
54	2.79E+00	8.00E-01	3.33E+002	7.33E+002	3.83E+002	1.03E-005
58	2.79E+00	8.00E-01	3.58E+002	7.58E+002	4.08E+002	7.14E-007
62	2.79E+00	8.00E-01	3.82E+002	7.82E+002	4.32E+002	3.77E-008
66	2.79E+00	8.00E-01	4.07E+002	8.07E+002	4.57E+002	1.54E-009
70	2.79E+00	8.00E-01	4.32E+002	8.32E+002	4.82E+002	4.95E-011
74	2.79E+00	8.00E-01	4.56E+002	8.56E+002	5.06E+002	1.27E-012
78	2.79E+00	8.00E-01	4.81E+002	8.81E+002	5.31E+002	2.62E-014
82	2.79E+00	8.00E-01	5.06E+002	9.06E+002	5.56E+002	4.42E-016
86	2.79E+00	8.00E-01	5.30E+002	9.30E+002	5.80E+002	6.13E-018
90	2.79E+00	8.00E-01	5.55E+002	9.55E+002	6.05E+002	7.07E-020
2	2.44E+00	8.00E-01	1.23E+001	4.12E+002	6.23E+001	2.54E-012
6	2.44E+00	8.00E-01	3.70E+001	4.37E+002	8.70E+001	8.36E-009
50	4.88E+00	8.00E-01	3.08E+002	7.08E+002	3.58E+002	4.53E-011
54	4.88E+00	8.00E-01	3.33E+002	7.33E+002	3.83E+002	4.99E-013
58	4.88E+00	8.00E-01	3.58E+002	7.58E+002	4.08E+002	4.09E-015
62	4.88E+00	8.00E-01	3.82E+002	7.82E+002	4.32E+002	2.55E-017
66	4.88E+00	8.00E-01	4.07E+002	8.07E+002	4.57E+002	1.23E-019
70	4.88E+00	8.00E-01	4.32E+002	8.32E+002	4.82E+002	4.68E-022
74	4.88E+00	8.00E-01	4.56E+002	8.56E+002	5.06E+002	1.42E-024
78	4.88E+00	8.00E-01	4.81E+002	8.81E+002	5.31E+002	3.45E-027
82	4.88E+00	8.00E-01	5.06E+002	9.06E+002	5.56E+002	6.87E-030

TABLE 6.3. : THE MAXIMUM VALUES OF POWER THAT CAN BE GATHERED IN A SUB-LAN TOGETHER WITH THE PROBABILITY TO MEET IT AT A PARTICULAR INPUT PORT OF A PARTICULAR NODE, AS A FUNCTION OF THE USED ATTENUATION, THE NUMBER OF CONCURRENT TRANSMISSIONS AND THE MEAN TIME BETWEEN PACKET TRANSMISSION (FOR THE SUB-LAN OF FIGURE C.2.4 WITH 3 USERS CONNECTED ON EACH NODE).

COLUMN A : NUMBER OF CONCURRENTLY TRANSMITTED PACKETS.
COLUMN B : MEAN TIME BETWEEN PACKET TRANSMISSIONS, MEASURED IN MICRO-SECONDS.
COLUMN C : THE TOTAL ATTENUATION.
COLUMN D : NUMBER OF CONCURRENTLY ARRIVED PACKETS AT AN INPUT PORT AFTER THEIR FIRST HOP (n_2).
COLUMN E : MEAN POWER DUE TO ECHOES .
COLUMN F : COEFFICIENT OF PORT USAGE.
COLUMN G : MEAN POWER DUE TO ECHOES AND THE FIRST HOP OF n_2 INITIALLY TRANSMITTED SIGNALS AT A PARTICULAR INPUT PORT.
COLUMN H : THE PROBABILITY OF HAVING THE INDICATING POWER AT COLUMN 'G'.
COLUMN F : MEAN POWER DUE TO ECHOES, THE FIRST HOP OF n_2 INITIALLY TRANSMITTED SIGNALS AND THE SECOND HOP OF n_2 INITIALLY TRANSMITTED SIGNALS AT A PARTICULAR INPUT PORT.
COLUMN I : THE PROBABILITY OF HAVING THE INDICATING POWER AT COLUMN 'I'.

A	B	C	D	E	F	G	H	I
34	6.50E+00	8.00E-01	2	1.00E-03	1.01E+003	3.13E-010	1.51E+003	6.95E-018
38	6.50E+00	8.00E-01	2	1.00E-03	1.03E+003	3.13E-010	1.58E+003	6.95E-018
42	6.50E+00	8.00E-01	2	1.00E-03	1.06E+003	3.13E-010	1.66E+003	6.95E-018
46	6.50E+00	8.00E-01	2	1.00E-03	1.08E+003	3.13E-010	1.73E+003	6.95E-018
50	6.50E+00	8.00E-01	2	1.00E-03	1.11E+003	3.13E-010	1.81E+003	6.95E-018
54	6.50E+00	8.00E-01	2	1.00E-03	1.13E+003	3.13E-010	1.88E+003	6.95E-018
58	6.50E+00	8.00E-01	2	1.00E-03	1.16E+003	3.13E-010	1.95E+003	6.95E-018
62	6.50E+00	8.00E-01	2	1.00E-03	1.18E+003	3.13E-010	2.03E+003	6.95E-018
66	6.50E+00	8.00E-01	2	1.00E-03	1.21E+003	3.13E-010	2.10E+003	6.95E-018
70	6.50E+00	8.00E-01	2	1.00E-03	1.23E+003	3.13E-010	2.18E+003	6.95E-018
74	6.50E+00	8.00E-01	2	1.00E-03	1.26E+003	3.13E-010	2.25E+003	6.95E-018
78	6.50E+00	8.00E-01	2	1.00E-03	1.28E+003	3.13E-010	2.32E+003	6.95E-018
82	6.50E+00	8.00E-01	2	1.00E-03	1.31E+003	3.13E-010	2.40E+003	6.95E-018
86	6.50E+00	8.00E-01	2	1.00E-03	1.33E+003	3.13E-010	2.47E+003	6.95E-018
90	6.50E+00	8.00E-01	2	1.00E-03	1.36E+003	3.13E-010	2.54E+003	6.95E-018
2	4.88E+00	8.00E-01	2	1.00E-03	8.12E+002	3.13E-010	9.17E+002	6.95E-018
6	4.88E+00	8.00E-01	2	1.00E-03	8.37E+002	3.13E-010	9.91E+002	6.95E-018
10	4.88E+00	8.00E-01	2	1.00E-03	8.62E+002	3.13E-010	1.07E+003	6.95E-018
14	4.88E+00	8.00E-01	2	1.00E-03	8.86E+002	3.13E-010	1.14E+003	6.95E-018
18	4.88E+00	8.00E-01	2	1.00E-03	9.11E+002	3.13E-010	1.21E+003	6.95E-018
22	4.88E+00	8.00E-01	2	1.00E-03	9.36E+002	3.13E-010	1.29E+003	6.95E-018
26	4.88E+00	8.00E-01	2	1.00E-03	9.60E+002	3.13E-010	1.36E+003	6.95E-018
30	4.88E+00	8.00E-01	2	1.00E-03	9.85E+002	3.13E-010	1.44E+003	6.95E-018
34	4.88E+00	8.00E-01	2	1.00E-03	1.01E+003	3.13E-010	1.51E+003	6.95E-018
38	4.88E+00	8.00E-01	2	1.00E-03	1.03E+003	3.13E-010	1.58E+003	6.95E-018
42	4.88E+00	8.00E-01	2	1.00E-03	1.06E+003	3.13E-010	1.66E+003	6.95E-018
46	4.88E+00	8.00E-01	2	1.00E-03	1.08E+003	3.13E-010	1.73E+003	6.95E-018

70	3.90å+00	8.00å-01	3	1.00å-03	1.63å+003	8.79å-015	2.62å+003	4.63å-026
74	3.90å+00	8.00å-01	3	1.00å-03	1.66å+003	8.79å-015	2.69å+003	4.63å-026
78	3.90å+00	8.00å-01	3	1.00å-03	1.68å+003	8.79å-015	2.76å+003	4.63å-026
82	3.90å+00	8.00å-01	3	1.00å-03	1.71å+003	8.79å-015	2.84å+003	4.63å-026
86	3.90å+00	8.00å-01	3	1.00å-03	1.73å+003	8.79å-015	2.91å+003	4.63å-026
90	3.90å+00	8.00å-01	3	1.00å-03	1.76å+003	8.79å-015	2.98å+003	4.63å-026
2	3.25å+00	8.00å-01	3	1.00å-03	1.21å+003	8.79å-015	1.36å+003	4.63å-026
6	3.25å+00	8.00å-01	3	1.00å-03	1.24å+003	8.79å-015	1.43å+003	4.63å-026
10	3.25å+00	8.00å-01	3	1.00å-03	1.26å+003	8.79å-015	1.51å+003	4.63å-026
14	3.25å+00	8.00å-01	3	1.00å-03	1.29å+003	8.79å-015	1.58å+003	4.63å-026
18	3.25å+00	8.00å-01	3	1.00å-03	1.31å+003	8.79å-015	1.65å+003	4.63å-026
22	3.25å+00	8.00å-01	3	1.00å-03	1.34å+003	8.79å-015	1.73å+003	4.63å-026
26	3.25å+00	8.00å-01	3	1.00å-03	1.36å+003	8.79å-015	1.80å+003	4.63å-026
30	3.25å+00	8.00å-01	3	1.00å-03	1.39å+003	8.79å-015	1.88å+003	4.63å-026
34	3.25å+00	8.00å-01	3	1.00å-03	1.41å+003	8.79å-015	1.95å+003	4.63å-026
38	3.25å+00	8.00å-01	3	1.00å-03	1.43å+003	8.79å-015	2.02å+003	4.63å-026
42	3.25å+00	8.00å-01	3	1.00å-03	1.46å+003	8.79å-015	2.10å+003	4.63å-026
46	3.25å+00	8.00å-01	3	1.00å-03	1.48å+003	8.79å-015	2.17å+003	4.63å-026
50	3.25å+00	8.00å-01	3	1.00å-03	1.51å+003	8.79å-015	2.25å+003	4.63å-026
54	3.25å+00	8.00å-01	3	1.00å-03	1.53å+003	8.79å-015	2.32å+003	4.63å-026
58	3.25å+00	8.00å-01	3	1.00å-03	1.56å+003	8.79å-015	2.39å+003	4.63å-026
62	3.25å+00	8.00å-01	3	1.00å-03	1.58å+003	8.79å-015	2.47å+003	4.63å-026
66	3.25å+00	8.00å-01	3	1.00å-03	1.61å+003	8.79å-015	2.54å+003	4.63å-026
70	3.25å+00	8.00å-01	3	1.00å-03	1.63å+003	8.79å-015	2.62å+003	4.63å-026
74	3.25å+00	8.00å-01	3	1.00å-03	1.66å+003	8.79å-015	2.69å+003	4.63å-026
78	3.25å+00	8.00å-01	3	1.00å-03	1.68å+003	8.79å-015	2.76å+003	4.63å-026
82	3.25å+00	8.00å-01	3	1.00å-03	1.71å+003	8.79å-015	2.84å+003	4.63å-026
86	3.25å+00	8.00å-01	3	1.00å-03	1.73å+003	8.79å-015	2.91å+003	4.63å-026
90	3.25å+00	8.00å-01	3	1.00å-03	1.76å+003	8.79å-015	2.98å+003	4.63å-026
2	2.79å+00	8.00å-01	3	1.00å-03	1.21å+003	8.79å-015	1.36å+003	4.63å-026
6	2.79å+00	8.00å-01	3	1.00å-03	1.24å+003	8.79å-015	1.43å+003	4.63å-026
10	2.79å+00	8.00å-01	3	1.00å-03	1.26å+003	8.79å-015	1.51å+003	4.63å-026
14	2.79å+00	8.00å-01	3	1.00å-03	1.29å+003	8.79å-015	1.58å+003	4.63å-026
18	2.79å+00	8.00å-01	3	1.00å-03	1.31å+003	8.79å-015	1.65å+003	4.63å-026
22	2.79å+00	8.00å-01	3	1.00å-03	1.34å+003	8.79å-015	1.73å+003	4.63å-026
26	2.79å+00	8.00å-01	3	1.00å-03	1.36å+003	8.79å-015	1.80å+003	4.63å-026
30	2.79å+00	8.00å-01	3	1.00å-03	1.39å+003	8.79å-015	1.88å+003	4.63å-026
34	2.79å+00	8.00å-01	3	1.00å-03	1.41å+003	8.79å-015	1.95å+003	4.63å-026
38	2.79å+00	8.00å-01	3	1.00å-03	1.43å+003	8.79å-015	2.02å+003	4.63å-026
42	2.79å+00	8.00å-01	3	1.00å-03	1.46å+003	8.79å-015	2.10å+003	4.63å-026
46	2.79å+00	8.00å-01	3	1.00å-03	1.48å+003	8.79å-015	2.17å+003	4.63å-026
50	2.79å+00	8.00å-01	3	1.00å-03	1.51å+003	8.79å-015	2.25å+003	4.63å-026
54	2.79å+00	8.00å-01	3	1.00å-03	1.53å+003	8.79å-015	2.32å+003	4.63å-026
58	2.79å+00	8.00å-01	3	1.00å-03	1.56å+003	8.79å-015	2.39å+003	4.63å-026
62	2.79å+00	8.00å-01	3	1.00å-03	1.58å+003	8.79å-015	2.47å+003	4.63å-026
66	2.79å+00	8.00å-01	3	1.00å-03	1.61å+003	8.79å-015	2.54å+003	4.63å-026
70	2.79å+00	8.00å-01	3	1.00å-03	1.63å+003	8.79å-015	2.62å+003	4.63å-026
74	2.79å+00	8.00å-01	3	1.00å-03	1.66å+003	8.79å-015	2.69å+003	4.63å-026
78	2.79å+00	8.00å-01	3	1.00å-03	1.68å+003	8.79å-015	2.76å+003	4.63å-026
82	2.79å+00	8.00å-01	3	1.00å-03	1.71å+003	8.79å-015	2.84å+003	4.63å-026
86	2.79å+00	8.00å-01	3	1.00å-03	1.73å+003	8.79å-015	2.91å+003	4.63å-026
90	2.79å+00	8.00å-01	3	1.00å-03	1.76å+003	8.79å-015	2.98å+003	4.63å-026
2	2.44å+00	8.00å-01	4	1.00å-03	1.61å+003	2.61å-019	1.80å+003	3.43å-034
6	2.44å+00	8.00å-01	4	1.00å-03	1.64å+003	2.61å-019	1.87å+003	3.43å-034
10	2.44å+00	8.00å-01	4	1.00å-03	1.66å+003	2.61å-019	1.95å+003	3.43å-034
50	1.95å+01	8.00å-01	1	5.00å-01	7.08å+002	6.25å-003	1.37å+003	3.30å-004
54	1.95å+01	8.00å-01	1	5.00å-01	7.33å+002	6.25å-003	1.44å+003	3.30å-004
58	1.95å+01	8.00å-01	1	5.00å-01	7.58å+002	6.25å-003	1.51å+003	3.30å-004
62	1.95å+01	8.00å-01	1	5.00å-01	7.82å+002	6.25å-003	1.59å+003	3.30å-004
66	1.95å+01	8.00å-01	1	5.00å-01	8.07å+002	6.25å-003	1.66å+003	3.30å-004
70	1.95å+01	8.00å-01	1	5.00å-01	8.32å+002	6.25å-003	1.74å+003	3.30å-004
74	1.95å+01	8.00å-01	1	5.00å-01	8.56å+002	6.25å-003	1.81å+003	3.30å-004
78	1.95å+01	8.00å-01	1	5.00å-01	8.81å+002	6.25å-003	1.88å+003	3.30å-004
82	1.95å+01	8.00å-01	1	5.00å-01	9.06å+002	6.25å-003	1.96å+003	3.30å-004
86	1.95å+01	8.00å-01	1	5.00å-01	9.30å+002	6.25å-003	2.03å+003	3.30å-004
90	1.95å+01	8.00å-01	1	5.00å-01	9.55å+002	6.25å-003	2.10å+003	3.30å-004
2	9.75å+00	8.00å-01	1	5.00å-01	4.12å+002	6.25å-003	4.77å+002	3.30å-004
6	9.75å+00	8.00å-01	1	5.00å-01	4.37å+002	6.25å-003	5.51å+002	3.30å-004
10	9.75å+00	8.00å-01	1	5.00å-01	4.62å+002	6.25å-003	6.25å+002	3.30å-004
14	9.75å+00	8.00å-01	1	5.00å-01	4.86å+002	6.25å-003	6.99å+002	3.30å-004
18	9.75å+00	8.00å-01	1	5.00å-01	5.11å+002	6.25å-003	7.73å+002	3.30å-004
22	9.75å+00	8.00å-01	1	5.00å-01	5.36å+002	6.25å-003	8.47å+002	3.30å-004
26	9.75å+00	8.00å-01	1	5.00å-01	5.60å+002	6.25å-003	9.21å+002	3.30å-004
30	9.75å+00	8.00å-01	1	5.00å-01	5.85å+002	6.25å-003	9.95å+002	3.30å-004
34	9.75å+00	8.00å-01	1	5.00å-01	6.10å+002	6.25å-003	1.07å+003	3.30å-004
38	9.75å+00	8.00å-01	1	5.00å-01	6.34å+002	6.25å-003	1.14å+003	3.30å-004
42	9.75å+00	8.00å-01	1	5.00å-01	6.59å+002	6.25å-003	1.22å+003	3.30å-004
14	2.44å+00	8.00å-01	4	1.00å-03	1.69å+003	2.61å-019	2.02å+003	3.43å-034
18	2.44å+00	8.00å-01	4	1.00å-03	1.71å+003	2.61å-019	2.09å+003	3.43å-034
22	2.44å+00	8.00å-01	4	1.00å-03	1.74å+003	2.61å-019	2.17å+003	3.43å-034
26	2.44å+00	8.00å-01	4	1.00å-03	1.76å+003	2.61å-019	2.24å+003	3.43å-034
30	2.44å+00	8.00å-01	4	1.00å-03	1.79å+003	2.61å-019	2.32å+003	3.43å-034
34	2.44å+00	8.00å-01	4	1.00å-03	1.81å+003	2.61å-019	2.39å+003	3.43å-034
38	2.44å+00	8.00å-01	4	1.00å-03	1.83å+003	2.61å-019	2.46å+003	3.43å-034
42	2.44å+00	8.00å-01	4	1.00å-03	1.86å+003	2.61å-019	2.54å+003	3.43å-034
46	2.44å+00	8.00å-01	4	1.00å-03	1.88å+003	2.61å-019	2.61å+003	3.43å-034
50	2.44å+00	8.00å-01	4	1.00å-03	1.91å+003	2.61å-019	2.69å+003	3.43å-034
54	2.44å+00	8.00å-01	4	1.00å-03	1.93å+003	2.61å-019	2.76å+003	3.43å-034
58	2.44å+00	8.00å-01	4	1.00å-03	1.96å+003	2.61å-019	2.83å+003	3.43å-034
62	2.44å+00	8.00å-01	4	1.00å-03	1.98å+003	2.61å-019	2.91å+003	3.43å-034
66	2.44å+00	8.00å-01	4	1.00å-03	2.01å+003	2.61å-019	2.98å+003	3.43å-034
70	2.44å+00	8.00å-01	4	1.00å-03	2.03å+003	2.61å-019	3.06å+003	3.43å-034
74	2.44å+00	8.00å-01	4	1.00å-03	2.06å+003	2.61å-019	3.13å+003	3.43å-034
78	2.44å+00	8.00å-01	4	1.00å-03	2.08å+003	2.61å-019	3.20å+003	3.43å-034
82	2.44å+00	8.00å-01	4	1.00å-03	2.11å+003	2.61å-019	3.28å+003	3.43å-034
86	2.44å+00	8.00å-01	4	1.00å-03	2.13å+003	2.61å-019	3.35å+003	3.43å-034
90	2.44å+00	8.00å-01	4	1.00å-03	2.16å+003	2.61å-019	3.42å+003	3.43å-034
2	2.17å+00	8.00å-01	4	1.00å-03	1.61å+003	2.61å-019	1.80å+003	3.43å-034
6	2.17å+00	8.00å-01	4	1.00å-03	1.64å+003	2.61å-019	1.87å+003	3.43å-034
10	2.17å+00	8.00å-01	4	1.00å-03	1.66å+003	2.61å-019	1.95å+003	3.43å-034
14	2.17å+00	8.00å-01	4	1.00å-03	1.69å+003	2.61å-019	2.02å+003	3.43å-034
18	2.17å+00	8.00å-01	4	1.00å-03	1.71å+003	2.61å-019	2.09å+003	3.43å-034
22	2.17å+00	8.00å-01	4	1.00å-03	1.74å+003	2.61å-019	2.17å+003	3.43å-034
26	2.17å+00	8.00å-01	4	1.00å-03	1.76å+003	2.61å-019	2.24å+003	3.43å-034
30	2.17å+00	8.00å-01	4	1.00å-03	1.79å+003	2.61å-019	2.32å+003	3.43å-034
34	2.17å+00	8.00å-01	4	1.00å-03	1.81å+003	2.61å-019	2.39å+003	3.43å-034
38	2.17å+00	8.00å-01	4	1.00å-03	1.83å+003	2.61å-019	2.46å+003	3.43å-034
42	2.17å+00	8.00å-01	4	1.00å-03	1.86å+003	2.61å-019	2.54å+003	3.43å-034
46	2.17å+00	8.00å-01	4	1.00å-03	1.88å+003	2.61å-019	2.61å+003	3.43å-034
50	2.17å+00	8.00å-01	4	1.00å-03	1.91å+003	2.61å-019	2.69å+003	3.43å-034
54	2.17å+00	8.00å-01	4	1.00å-03	1.93å+003	2.61å-019	2.76å+003	3.43å-034
58	2.17å+00	8.00å-01	4	1.00å-03	1.96å+003	2.61å-019	2.83å+003	3.43å-034
62	2.17å+00	8.00å-01	4	1.00å-03	1.98å+003	2.61å-019	2.91å+003	3.43å-034
66	2.17å+00	8.00å-01	4	1.00å-03	2.01å+003	2.61å-019	2.98å+003	3.43å-034
70	2.17å+00	8.00å-01	4	1.00å-03	2.03å+003	2.61å-019	3.06å+003	3.43å-034
74	2.17å+00	8.00å-01	4	1.00å-03	2.06å+003	2.61å-019	3.13å+003	3.43å-034
78	2.17å+00	8.00å-01	4	1.00å-03	2.08å+003	2.61å-019	3.20å+003	3.43å-034
82	2.17å+00	8.00å-01	4	1.00å-03	2.11å+003	2.61å-019	3.28å+003	3.43å-034
86	2.17å+00	8.00å-01	4	1.00å-03	2.13å+003	2.61å-019	3.35å+003	3.43å-034
90	2.17å+00	8.00å-01	4	1.00å-03	2.16å+003	2.61å-019	3.42å+003	3.43å-034
2	1.95å+01	8.00å-01	1	5.00å-01	4.12å+002	6.25å-003	4.77å+002	3.30å-004
6	1.95å+01	8.00å-01	1	5.00å-01	4.37å+002	6.25å-003	5.51å+002	3.30å-004
10	1.95å+01	8.00å-01	1	5.00å-01	4.62å+002	6.25å-003	6.25å+002	3.30å-004
14	1.95å+01	8.00å-01	1	5.00å-01	4.86å+002	6.25å-003	6.99å+002	3.30å-004
18	1.95å+01	8.00å-01	1	5.00å-01	5.11å+002	6.25å-003	7.73å+002	3.30å-004
22	1.95å+01	8.00å-01	1	5.00å-01	5.36å+002	6.25å-003	8.47å+002	3.30å-004
26	1.95å+01	8.00å-01	1	5.00å-01	5.60å+002	6.25å-003	9.21å+002	3.30å-004
30	1.95å+01	8.00å-01	1	5.00å-01	5.85å+002	6.25å-003	9.95å+002	3.30å-004
34	1.95å+01	8.00å-01	1	5.00å-01	6.10å+002	6.25å-003	1.07å+003	3.30å-004
38	1.95å+01	8.00å-01	1	5.00å-01	6.34å+002	6.25å-003	1.14å+003	3.30å-004
42	1.95å+01	8.00å-01	1	5.00å-01	6.59å+002	6.25å-003	1.22å+003	3.30å-004
46	1.95å+01	8.00å-01	1	5.00å-01	6.84å+002	6.25å-003	1.29å+003	3.30å-004
46	9.75å+00	8.00å-01	1	5.00å-01	6.84å+002	6.25å-003	1.29å+003	3.30å-004
50	9.75å+00	8.00å-01	1	5.00å-01	7.08å+002	6.25å-003	1.37å+003	3.30å-004
54	9.75å+00	8.00å-01	1	5.00å-01	7.33å+002	6.25å-003	1.44å+003	3.30å-004
58	9.75å+00	8.00å-01	1	5.00å-01	7.58å+002	6.25å-003	1.51å+003	3.30å-004
62	9.75å+00	8.00å-01	1	5.00å-01	7.82å+002	6.25å-003	1.59å+003	3.30å-004
66	9.75å+00	8.00å-01	1	5.00å-01	8.07å+002	6.25å-003	1.66å+003	3.30å-004
70	9.75å+00	8.00å-01	1	5.00å-01	8.32å+002	6.25å-003	1.74å+003	3.30å-004
74	9.75å+00	8.00å-01	1	5.00å-01	8.56å+002	6.25å-003	1.81å+003	3.30å-004
78	9.75å+00	8.00å-01	1	5.00å-01	8.81å+002	6.25å-003	1.88å+003	3.30å-004
82	9.75å+00	8.00å-01	1	5.00å-01	9.06å+002	6.25å-003	1.96å+003	3.30å-004
86	9.75å+00	8.00å-01	1	5.00å-01	9.30å+002	6.25å-003	2.03å+003	3.30å-004
90	9.75å+00	8.00å-01	1	5.00å-01	9.55å+002	6.25å-003	2.10å+003	3.30å-004
2	6.50å+00	8.00å-01	2	5.00å-01	8.12å+002	7.82å-005	9.17å+002	4.34å-007
6	6.50å+00	8.00å-01	2	5.00å-01	8.37å+002	7.82å-005	9.91å+002	4.34å-007
10	6.50å+00	8.00å-01	2	5.00å-01	8.62å+002	7.82å-005	1.07å+003	4.34å-007
14	6.50å+00	8.00å-01	2	5.00å-01	8.86å+002	7.82å-005	1.14å+003	4.34å-007
18	6.50å+00	8.00å-01	2	5.00å-01	9.11å+002	7.82å-005	1.21å+003	4.34å-007
22	6.50å+00	8.00å-01	2	5.00å-01	9.36å+002	7.82å-005	1.29å+003	4.34å-007

26	6.50E+00	8.00E-01	2	5.00E-01	9.60E+002	7.82E-005	1.36E+003	4.34E-007
30	6.50E+00	8.00E-01	2	5.00E-01	9.85E+002	7.82E-005	1.44E+003	4.34E-007
34	6.50E+00	8.00E-01	2	5.00E-01	1.01E+003	7.82E-005	1.51E+003	4.34E-007
38	6.50E+00	8.00E-01	2	5.00E-01	1.03E+003	7.82E-005	1.58E+003	4.34E-007
42	6.50E+00	8.00E-01	2	5.00E-01	1.06E+003	7.82E-005	1.66E+003	4.34E-007
46	6.50E+00	8.00E-01	2	5.00E-01	1.08E+003	7.82E-005	1.73E+003	4.34E-007
50	6.50E+00	8.00E-01	2	5.00E-01	1.11E+003	7.82E-005	1.81E+003	4.34E-007
54	6.50E+00	8.00E-01	2	5.00E-01	1.13E+003	7.82E-005	1.88E+003	4.34E-007
58	6.50E+00	8.00E-01	2	5.00E-01	1.16E+003	7.82E-005	1.95E+003	4.34E-007
62	6.50E+00	8.00E-01	2	5.00E-01	1.18E+003	7.82E-005	2.03E+003	4.34E-007
66	6.50E+00	8.00E-01	2	5.00E-01	1.21E+003	7.82E-005	2.10E+003	4.34E-007
70	6.50E+00	8.00E-01	2	5.00E-01	1.23E+003	7.82E-005	2.18E+003	4.34E-007
74	6.50E+00	8.00E-01	2	5.00E-01	1.26E+003	7.82E-005	2.25E+003	4.34E-007
78	6.50E+00	8.00E-01	2	5.00E-01	1.28E+003	7.82E-005	2.32E+003	4.34E-007
82	6.50E+00	8.00E-01	2	5.00E-01	1.31E+003	7.82E-005	2.40E+003	4.34E-007
86	6.50E+00	8.00E-01	2	5.00E-01	1.33E+003	7.82E-005	2.47E+003	4.34E-007
90	6.50E+00	8.00E-01	2	5.00E-01	1.36E+003	7.82E-005	2.54E+003	4.34E-007
2	4.88E+00	8.00E-01	2	5.00E-01	8.12E+002	7.82E-005	9.17E+002	4.34E-007
6	4.88E+00	8.00E-01	2	5.00E-01	8.37E+002	7.82E-005	9.91E+002	4.34E-007
10	4.88E+00	8.00E-01	2	5.00E-01	8.62E+002	7.82E-005	1.07E+003	4.34E-007
14	4.88E+00	8.00E-01	2	5.00E-01	8.86E+002	7.82E-005	1.14E+003	4.34E-007
18	4.88E+00	8.00E-01	2	5.00E-01	9.11E+002	7.82E-005	1.21E+003	4.34E-007
22	4.88E+00	8.00E-01	2	5.00E-01	9.36E+002	7.82E-005	1.29E+003	4.34E-007
26	4.88E+00	8.00E-01	2	5.00E-01	9.60E+002	7.82E-005	1.36E+003	4.34E-007
30	4.88E+00	8.00E-01	2	5.00E-01	9.85E+002	7.82E-005	1.44E+003	4.34E-007
34	4.88E+00	8.00E-01	2	5.00E-01	1.01E+003	7.82E-005	1.51E+003	4.34E-007
38	4.88E+00	8.00E-01	2	5.00E-01	1.03E+003	7.82E-005	1.58E+003	4.34E-007
42	4.88E+00	8.00E-01	2	5.00E-01	1.06E+003	7.82E-005	1.66E+003	4.34E-007
46	4.88E+00	8.00E-01	2	5.00E-01	1.08E+003	7.82E-005	1.73E+003	4.34E-007
50	4.88E+00	8.00E-01	2	5.00E-01	1.11E+003	7.82E-005	1.81E+003	4.34E-007
54	4.88E+00	8.00E-01	2	5.00E-01	1.13E+003	7.82E-005	1.88E+003	4.34E-007
58	4.88E+00	8.00E-01	2	5.00E-01	1.16E+003	7.82E-005	1.95E+003	4.34E-007
62	4.88E+00	8.00E-01	2	5.00E-01	1.18E+003	7.82E-005	2.03E+003	4.34E-007
66	4.88E+00	8.00E-01	2	5.00E-01	1.21E+003	7.82E-005	2.10E+003	4.34E-007
70	4.88E+00	8.00E-01	2	5.00E-01	1.23E+003	7.82E-005	2.18E+003	4.34E-007
74	4.88E+00	8.00E-01	2	5.00E-01	1.26E+003	7.82E-005	2.25E+003	4.34E-007
78	4.88E+00	8.00E-01	2	5.00E-01	1.28E+003	7.82E-005	2.32E+003	4.34E-007
82	4.88E+00	8.00E-01	2	5.00E-01	1.31E+003	7.82E-005	2.40E+003	4.34E-007
86	4.88E+00	8.00E-01	2	5.00E-01	1.33E+003	7.82E-005	2.47E+003	4.34E-007
90	4.88E+00	8.00E-01	2	5.00E-01	1.36E+003	7.82E-005	2.54E+003	4.34E-007
2	3.90E+00	8.00E-01	3	5.00E-01	1.21E+003	1.10E-006	1.36E+003	7.24E-010
6	3.90E+00	8.00E-01	3	5.00E-01	1.24E+003	1.10E-006	1.43E+003	7.24E-010
10	3.90E+00	8.00E-01	3	5.00E-01	1.26E+003	1.10E-006	1.51E+003	7.24E-010
14	3.90E+00	8.00E-01	3	5.00E-01	1.29E+003	1.10E-006	1.58E+003	7.24E-010
18	3.90E+00	8.00E-01	3	5.00E-01	1.31E+003	1.10E-006	1.65E+003	7.24E-010
22	3.90E+00	8.00E-01	3	5.00E-01	1.34E+003	1.10E-006	1.73E+003	7.24E-010
26	3.90E+00	8.00E-01	3	5.00E-01	1.36E+003	1.10E-006	1.80E+003	7.24E-010
30	3.90E+00	8.00E-01	3	5.00E-01	1.39E+003	1.10E-006	1.88E+003	7.24E-010
34	3.90E+00	8.00E-01	3	5.00E-01	1.41E+003	1.10E-006	1.95E+003	7.24E-010
38	3.90E+00	8.00E-01	3	5.00E-01	1.43E+003	1.10E-006	2.02E+003	7.24E-010
42	3.90E+00	8.00E-01	3	5.00E-01	1.46E+003	1.10E-006	2.10E+003	7.24E-010
46	3.90E+00	8.00E-01	3	5.00E-01	1.48E+003	1.10E-006	2.17E+003	7.24E-010
50	3.90E+00	8.00E-01	3	5.00E-01	1.51E+003	1.10E-006	2.25E+003	7.24E-010
54	3.90E+00	8.00E-01	3	5.00E-01	1.53E+003	1.10E-006	2.32E+003	7.24E-010
58	3.90E+00	8.00E-01	3	5.00E-01	1.56E+003	1.10E-006	2.39E+003	7.24E-010
62	3.90E+00	8.00E-01	3	5.00E-01	1.58E+003	1.10E-006	2.47E+003	7.24E-010
66	3.90E+00	8.00E-01	3	5.00E-01	1.61E+003	1.10E-006	2.54E+003	7.24E-010
70	3.90E+00	8.00E-01	3	5.00E-01	1.63E+003	1.10E-006	2.62E+003	7.24E-010
74	3.90E+00	8.00E-01	3	5.00E-01	1.66E+003	1.10E-006	2.69E+003	7.24E-010
78	3.90E+00	8.00E-01	3	5.00E-01	1.68E+003	1.10E-006	2.76E+003	7.24E-010
82	3.90E+00	8.00E-01	3	5.00E-01	1.71E+003	1.10E-006	2.84E+003	7.24E-010
86	3.90E+00	8.00E-01	3	5.00E-01	1.73E+003	1.10E-006	2.91E+003	7.24E-010
90	3.90E+00	8.00E-01	3	5.00E-01	1.76E+003	1.10E-006	2.98E+003	7.24E-010
2	3.25E+00	8.00E-01	3	5.00E-01	1.21E+003	1.10E-006	1.36E+003	7.24E-010
6	3.25E+00	8.00E-01	3	5.00E-01	1.24E+003	1.10E-006	1.43E+003	7.24E-010
10	3.25E+00	8.00E-01	3	5.00E-01	1.26E+003	1.10E-006	1.51E+003	7.24E-010
14	3.25E+00	8.00E-01	3	5.00E-01	1.29E+003	1.10E-006	1.58E+003	7.24E-010
18	3.25E+00	8.00E-01	3	5.00E-01	1.31E+003	1.10E-006	1.65E+003	7.24E-010
22	3.25E+00	8.00E-01	3	5.00E-01	1.34E+003	1.10E-006	1.73E+003	7.24E-010
26	3.25E+00	8.00E-01	3	5.00E-01	1.36E+003	1.10E-006	1.80E+003	7.24E-010
30	3.25E+00	8.00E-01	3	5.00E-01	1.39E+003	1.10E-006	1.88E+003	7.24E-010
34	3.25E+00	8.00E-01	3	5.00E-01	1.41E+003	1.10E-006	1.95E+003	7.24E-010
38	3.25E+00	8.00E-01	3	5.00E-01	1.43E+003	1.10E-006	2.02E+003	7.24E-010
42	3.25E+00	8.00E-01	3	5.00E-01	1.46E+003	1.10E-006	2.10E+003	7.24E-010
46	3.25E+00	8.00E-01	3	5.00E-01	1.48E+003	1.10E-006	2.17E+003	7.24E-010
50	3.25E+00	8.00E-01	3	5.00E-01	1.51E+003	1.10E-006	2.25E+003	7.24E-010
54	3.25E+00	8.00E-01	3	5.00E-01	1.53E+003	1.10E-006	2.32E+003	7.24E-010
58	3.25E+00	8.00E-01	3	5.00E-01	1.56E+003	1.10E-006	2.39E+003	7.24E-010
62	3.25E+00	8.00E-01	3	5.00E-01	1.58E+003	1.10E-006	2.47E+003	7.24E-010
66	3.25E+00	8.00E-01	3	5.00E-01	1.61E+003	1.10E-006	2.54E+003	7.24E-010
70	3.25E+00	8.00E-01	3	5.00E-01	1.63E+003	1.10E-006	2.62E+003	7.24E-010
74	3.25E+00	8.00E-01	3	5.00E-01	1.66E+003	1.10E-006	2.69E+003	7.24E-010
78	3.25E+00	8.00E-01	3	5.00E-01	1.68E+003	1.10E-006	2.76E+003	7.24E-010
82	3.25E+00	8.00E-01	3	5.00E-01	1.71E+003	1.10E-006	2.84E+003	7.24E-010
86	3.25E+00	8.00E-01	3	5.00E-01	1.73E+003	1.10E-006	2.91E+003	7.24E-010
90	3.25E+00	8.00E-01	3	5.00E-01	1.76E+003	1.10E-006	2.98E+003	7.24E-010
2	2.79E+00	8.00E-01	3	5.00E-01	1.21E+003	1.10E-006	1.36E+003	7.24E-010
6	2.79E+00	8.00E-01	3	5.00E-01	1.24E+003	1.10E-006	1.43E+003	7.24E-010
10	2.79E+00	8.00E-01	3	5.00E-01	1.26E+003	1.10E-006	1.51E+003	7.24E-010
14	2.79E+00	8.00E-01	3	5.00E-01	1.29E+003	1.10E-006	1.58E+003	7.24E-010
18	2.79E+00	8.00E-01	3	5.00E-01	1.31E+003	1.10E-006	1.65E+003	7.24E-010
22	2.79E+00	8.00E-01	3	5.00E-01	1.34E+003	1.10E-006	1.73E+003	7.24E-010
26	2.79E+00	8.00E-01	3	5.00E-01	1.36E+003	1.10E-006	1.80E+003	7.24E-010
30	2.79E+00	8.00E-01	3	5.00E-01	1.39E+003	1.10E-006	1.88E+003	7.24E-010
34	2.79E+00	8.00E-01	3	5.00E-01	1.41E+003	1.10E-006	1.95E+003	7.24E-010
38	2.79E+00	8.00E-01	3	5.00E-01	1.43E+003	1.10E-006	2.02E+003	7.24E-010
42	2.79E+00	8.00E-01	3	5.00E-01	1.46E+003	1.10E-006	2.10E+003	7.24E-010
46	2.79E+00	8.00E-01	3	5.00E-01	1.48E+003	1.10E-006	2.17E+003	7.24E-010
50	2.79E+00	8.00E-01	3	5.00E-01	1.51E+003	1.10E-006	2.25E+003	7.24E-010
54	2.79E+00	8.00E-01	3	5.00E-01	1.53E+003	1.10E-006	2.32E+003	7.24E-010
58	2.79E+00	8.00E-01	3	5.00E-01	1.56E+003	1.10E-006	2.39E+003	7.24E-010
62	2.79E+00	8.00E-01	3	5.00E-01	1.58E+003	1.10E-006	2.47E+003	7.24E-010
66	2.79E+00	8.00E-01	3	5.00E-01	1.61E+003	1.10E-006	2.54E+003	7.24E-010
70	2.79E+00	8.00E-01	3	5.00E-01	1.63E+003	1.10E-006	2.62E+003	7.24E-010
74	2.79E+00	8.00E-01	3	5.00E-01	1.66E+003	1.10E-006	2.69E+003	7.24E-010
78	2.79E+00	8.00E-01	3	5.00E-01	1.68E+003	1.10E-006	2.76E+003	7.24E-010
82	2.79E+00	8.00E-01	3	5.00E-01	1.71E+003	1.10E-006	2.84E+003	7.24E-010
86	2.79E+00	8.00E-01	3	5.00E-01	1.73E+003	1.10E-006	2.91E+003	7.24E-010
90	2.79E+00	8.00E-01	3	5.00E-01	1.76E+003	1.10E-006	2.98E+003	7.24E-010
2	2.44E+00	8.00E-01	4	5.00E-01	1.61E+003	1.63E-008	1.80E+003	1.34E-012
6	2.44E+00	8.00E-01	4	5.00E-01	1.54E+003	1.63E-008	1.87E+003	1.34E-012
10	2.44E+00	8.00E-01	4	5.00E-01	1.66E+003	1.63E-008	1.95E+003	1.34E-012
14	2.44E+00	8.00E-01	4	5.00E-01	1.69E+003	1.63E-008	2.02E+003	1.34E-012
18	2.44E+00	8.00E-01	4	5.00E-01	1.71E+003	1.63E-008	2.09E+003	1.34E-012
22	2.44E+00	8.00E-01	4	5.00E-01	1.74E+003	1.63E-008	2.17E+003	1.34E-012
26	2.44E+00	8.00E-01	4	5.00E-01	1.76E+003	1.63E-008	2.24E+003	1.34E-012
30	2.44E+00	8.00E-01	4	5.00E-01	1.79E+003	1.63E-008	2.32E+003	1.34E-012
34	2.44E+00	8.00E-01	4	5.00E-01	1.81E+003	1.63E-008	2.39E+003	1.34E-012
38	2.44E+00	8.00E-01	4	5.00E-01	1.83E+003	1.63E-008	2.46E+003	1.34E-012
42	2.44E+00	8.00E-01	4	5.00E-01	1.86E+003	1.63E-008	2.54E+003	1.34E-012
46	2.44E+00	8.00E-01	4	5.00E-01	1.88E+003	1.63E-008	2.61E+003	1.34E-012
50	2.44E+00	8.00E-01	4	5.00E-01	1.91E+003	1.63E-008	2.69E+003	1.34E-012
54	2.44E+00	8.00E-01	4	5.00E-01	1.93E+003	1.63E-008	2.76E+003	1.34E-012
58	2.44E+00	8.00E-01	4	5.00E-01	1.96E+003	1.63E-008	2.83E+003	1.34E-012
62	2.44E+00	8.00E-01	4	5.00E-01	1.98E+003	1.63E-008	2.91E+003	1.34E-012
66	2.44E+00	8.00E-01	4	5.00E-01	2.01E+003	1.63E-008	2.98E+003	1.34E-012
70	2.44E+00	8.00E-01	4	5.00E-01	2.03E+003	1.63E-008	3.06E+003	1.34E-012
74	2.44E+00	8.00E-01	4	5.00E-01	2.06E+003	1.63E-008	3.13E+003	1.34E-012
78	2.44E+00	8.00E-01	4	5.00E-01	2.08E+003	1.63E-008	3.20E+003	1.34E-012
82	2.44E+00	8.00E-01	4	5.00E-01	2.11E+003	1.63E-008	3.28E+003	1.34E-012
86	2.44E+00	8.00E-01	4	5.00E-01	2.13E+003	1.63E-008	3.35E+003	1.34E-012
90	2.44E+00	8.00E-01	4	5.00E-01	2.16E+003	1.63E-008	3.42E+003	1.34E-012
2	2.17E+00	8.00E-01	4	5.00E-01	1.61E+003	1.63E-008	1.80E+003	1.34E-012
6	2.17E+00	8.00E-01	4	5.00E-01	1.64E+003	1.63E-008	1.87E+003	1.34E-012
10	2.17E+00	8.00E-01	4	5.00E-01	1.66E+003	1.63E-008	1.95E+003	1.34E-012
14	2.17E+00	8.00E-01	4	5.00E-01	1.69E+003	1.63E-008	2.02E+003	1.34E-012
18	2.17E+00	8.00E-01	4	5.00E-01	1.71E+003	1.63E-008	2.09E+003	1.34E-012
22	2.17E+00	8.00E-01	4	5.00E-01	1.74E+003	1.63E-008	2.17E+003	1.34E-012
26	2.17E+00	8.00E-01	4	5.00E-01	1.76E+003	1.63E-008	2.24E+003	1.34E-012
30	2.17E+00	8.00E-01	4	5.00E-01	1.79E+003	1.63E-008	2.32E+003	1.34E-012

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2. A. Davies, T Mastichiadis. "SPSC techniques at Local Area Networks". Greek Computer Society. 2nd Hellenic Conference on Information Technology. November 1988. Athens. (Greek Language).

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SIMULATION OF A LOCAL AREA NETWORK PROTOCOL USING SPREAD SPECTRUM TECHNIQUES BUILT ON A MESH TOPOLOGY

Theodoros Mastichiadis

The City University, London, England

Eleftherious Economou

Hellenic Telecommunications Organization (OTE), Athens, Greece

1.0 Abstract

This paper describes a new type of Local Area Network (LAN) as well as software built for its simulation.

The proposed LAN uses spread spectrum (spsc) techniques as a multiple access method. The modular, cellular, mesh topology in combination with a passive continuous retransmission of any received signal in all directions (flooding routing) guarantees survivability and offers security. The synchronization problem has been solved by the use of a separate TDM channel in a universal timing system.

For the performance estimation of the LAN simulation, tools have been developed. The required software has been designed using MASCOT III concepts and written in SIMULA 67.

2.0 Introduction

Current trends for LANs include the use of spsc techniques [1,2] for their design. Some LANs of this type already exist [3] while others are under development [4,5,6].

An overview of the protocol and the operation of the proposed spsc LAN is given in section 2. Section 3 discusses computer simulation of this LAN, and presents results about the traffic that it supports and some topics for future research. Finally some concluding remarks are given in section 4.

3.0 Description of the Spsc LAN

The design of the proposed LAN utilizes the following features : mesh topology, flooding routing, spread spectrum direct sequence (DS) techniques and an independent signalling channel.

The LAN is based on a modular cellular mesh topology as shown in figure 1. The same number of subscribers can be supported by a variety of topologies of different sizes. Any such topology offers many alternative paths between any two nodes. A passive flooding routing scheme is used. Every node simply retransmits all incoming signals along every outgoing link. Thus the signal arrives first through the shortest path at the destination, while at the same time a lot of echos are also created. These echos act as wideband background noise, they depend upon the topology and are absorbed gradually.

The structure of the node is illustrated in figure 2. At every node a number of stations may be connected, through spsc interface units (spsciu). Because of the spsc techniques used, each one can gain access to the network by code division multiple access (CDMA) without having to determine in advance if the medium is idle, as would required by Ethernet systems. Also the combination of the spsc techniques with the packet switching method used allows multiple access to the network with low probability of collision or congestion. This results in good message delivery time.

The transmitter of the node modulates the data using a high bit rate pseudo-random binary sequence which is a member of a large family of sequences. There is an one to one correspondance between these sequences and the receivers. In this way addressing becomes inherent in the system. Addressing is achieved by choosing the pseudo-random sequence of the destination for data modulation. After the signal has been modulated, it is flooded into the network.

Every receiving node senses the medium and a locally generated pseudo-random sequence is correlated with the incoming data. If the signal that has been read from the medium includes data that has been modulated with the same pseudo-random sequence and is synchronized with it, then there is data addressed to this particular receiver. In this case, through the correlation process the bandwidth of the incoming data will collapse to that of the original data signal, so acheiving demodulation.

Simultaneously with the spsc channels and within the same frequency band a signalling channel operates based on an active flooding scheme. Every node, as soon as it receives the information, reads it, processes it and then retransmits it in all outgoing directions. All nodes share this channel on a slotted (TDMA) basis. The reservation scheme of the slots by the nodes is permanent and continuous. This TDM channel guarantees the continuous availability of timing and synchronization information, routing information, information about the status of the subscribers, acknowledgment information etc.

Survivability is inherent to the system. It is acheived by the mesh topology used and by the properties of the passive flooding protocol. Through this protocol the LAN acts as a self-learning machine that always finds the new topology.

Finally this LAN has a certain degree of security. This depends upon two factors: the crypto-security provided by the spreading code, and the physical separation of the users into groups that intercommunicate through local bridges.

4.0 System simulation and results

The simulation of the LAN is under development using the software design method MASCOT III (Modular Approach to Software Construction Operation and Test) and the simulation programming language SIMULA 67.

Following the MASCOT [7] principles the parts of the system that is to be designed are represented in a data flow form. Each one of them is named an activity and consists of an individual module of the software. The data that is used by the activities is stored in memory areas named pools. Channels interconnect activities and read the pools.

SIMULA [8] is an Algol like dynamic discrete event simulation language. It describes the sequence of actions in space and time as well as relationships. It creates a time environment and it generates in it a pseudo-parallel domain where the various processes run simultaneously.

Figure 3 illustrates an overlay of the MASCOT machine where the structure of the program and a functional relationship among its various parts is presented. Since this machine is implemented in the SIMULA environment, in a lot of cases, the implementation of pools is unnecessary. Figure 4 shows the interconnection of the software sections in the time domain and their parallel processing environment.

Through this simulation program the performance of the LAN will be estimated. Especially the following will be examined: survivability of the LAN as function of the topology, the required chip rate, the bit error rate, the throughput, the created delays, the congestion and collision probabilities.

We define the Topology Size Coefficient (TSC) as a function of the degree of the nodes in the Sub-LANs, the number of the Sub-LANs and the maximum number of stations that may be connected to the node. Figure 5 illustrates the TSC for topologies that support 480 users as a function of the traffic (normalised average percentage of time that every station uses the created channel) for different values of the required chip rate. The performance of all these communication channels is the same and depends upon the instantaneous traffic load and the echos of any particular link or node. As the traffic increases the performance reduces, in the same way for all virtual channels of this particular link or node. The increase of the traffic influences the noise enviroment because of the echos.

5.0 Conclusions.

An overall description of a new type of LAN that uses CDMA methods has been presented. The main qualities of this LAN can be summarised as: almost contention-free multiple access, high throughput, privacy or security, survivability, noise resistant communication, integrated traffic, inherent addressing capabilities, possibility of grouping of the users in separate sub-LANs according to their features and qualities or to their requirements and security demands, simultaneous access to the network, low time delays, low congestion probabilities, the same performance for all the virtual communication channels within any link.

The performance of this LAN will be estimated through simulation tools.

6.0 Acknowledgment

We would like to thank Professor A.C. Davies of King's College, University of London and Professors G. Philokiprou and K.Caroubalos of the University of Athens for their help with the realization of this work.

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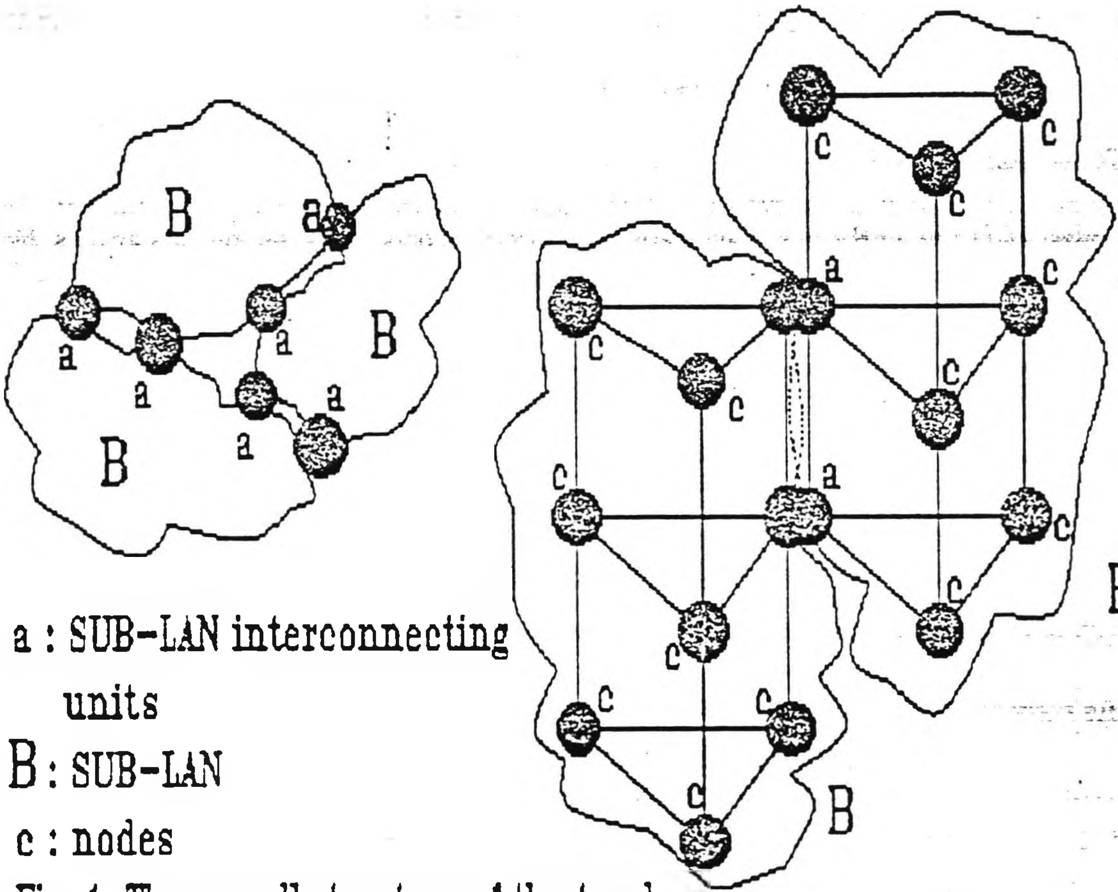

Fig. 1: The overall structure of the topology

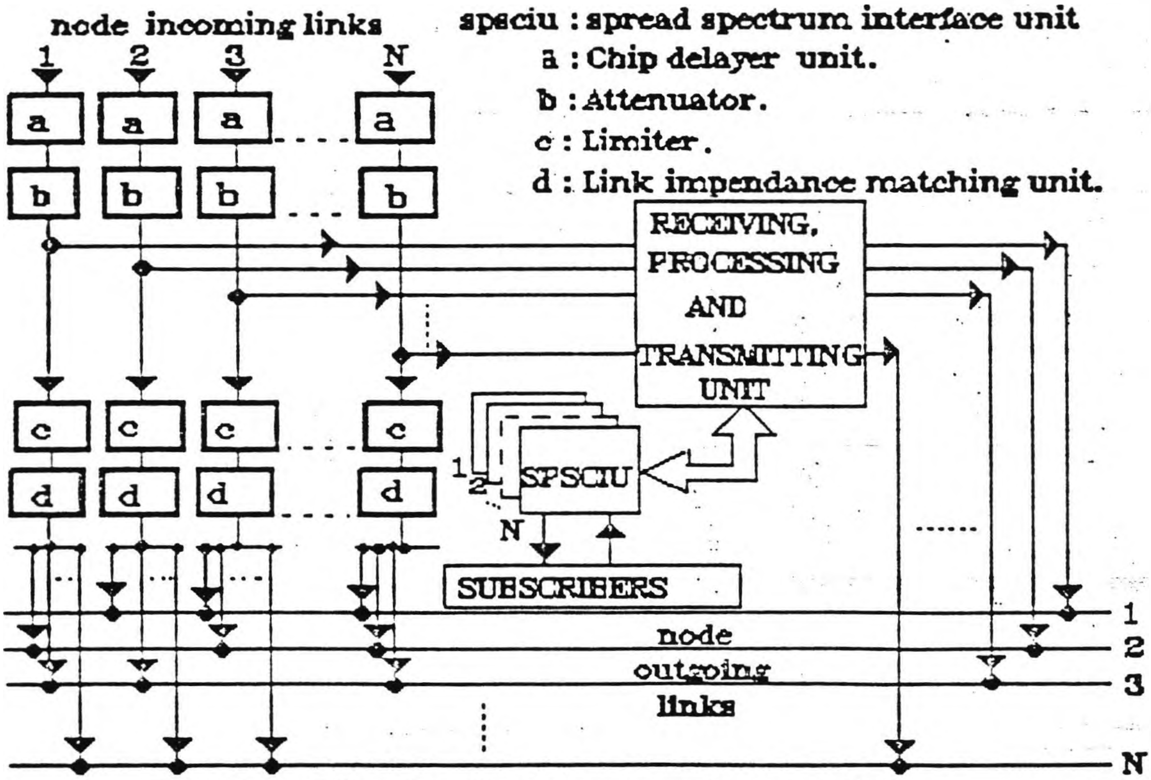

Fig.2 : Block diagram of a node.

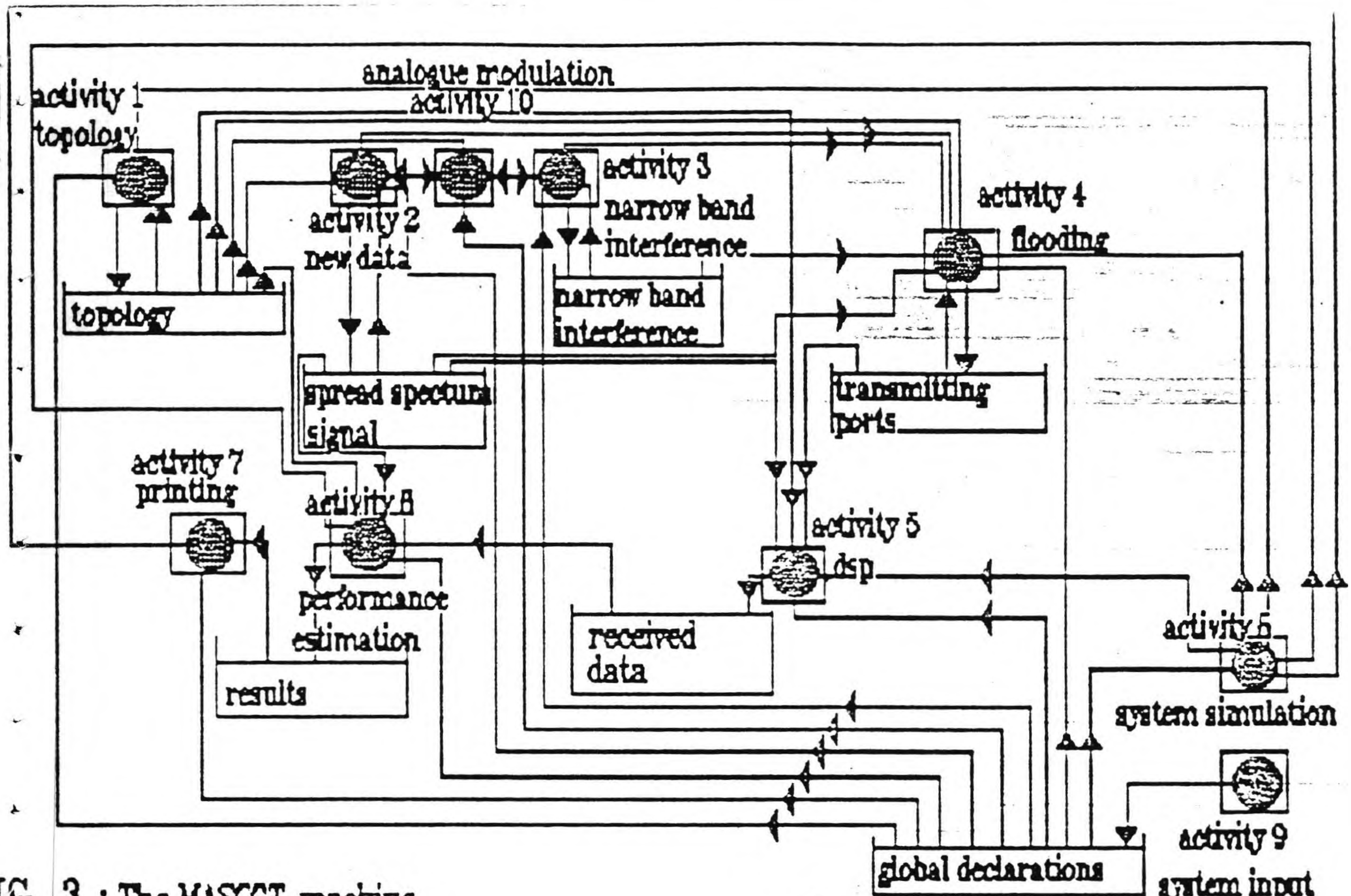

FIG. 3 : The MASCOT machine

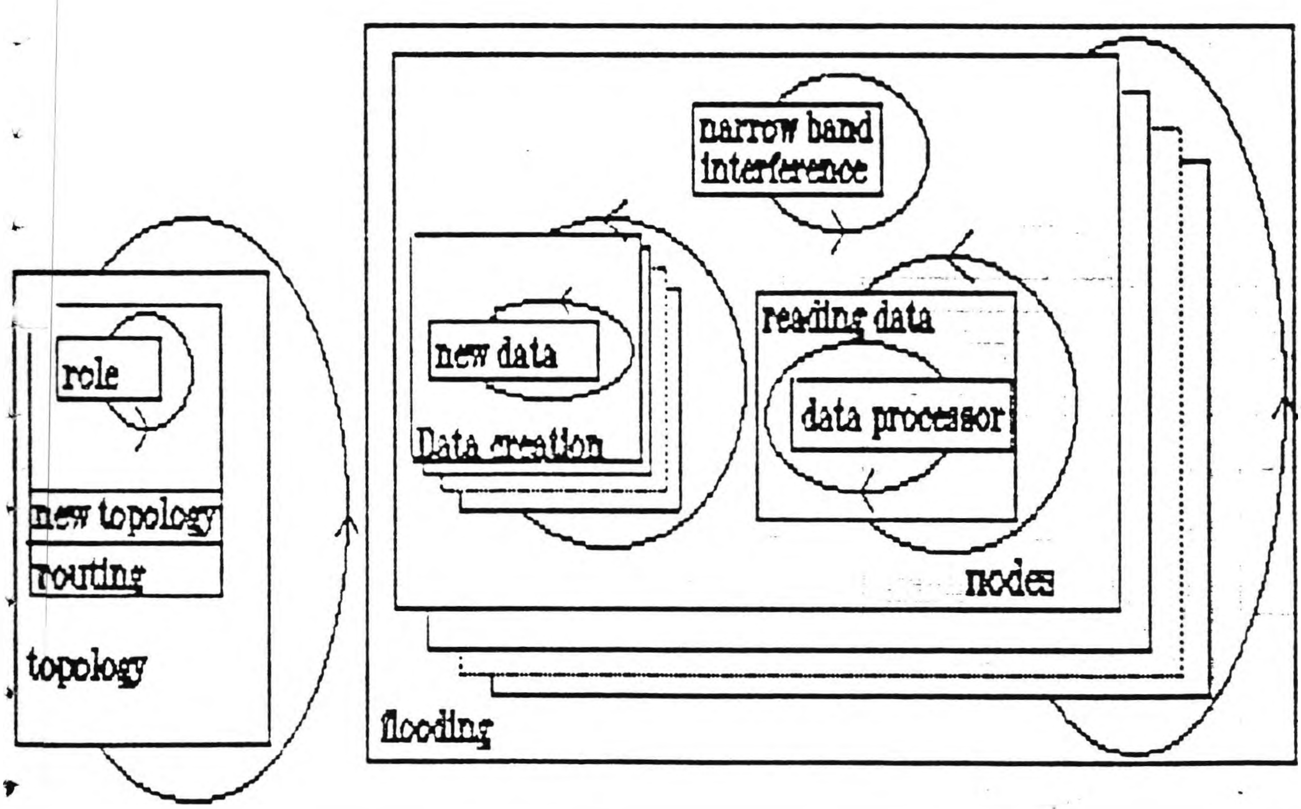

FIG. 4 : Parallel processing enviroment of the simulation system.

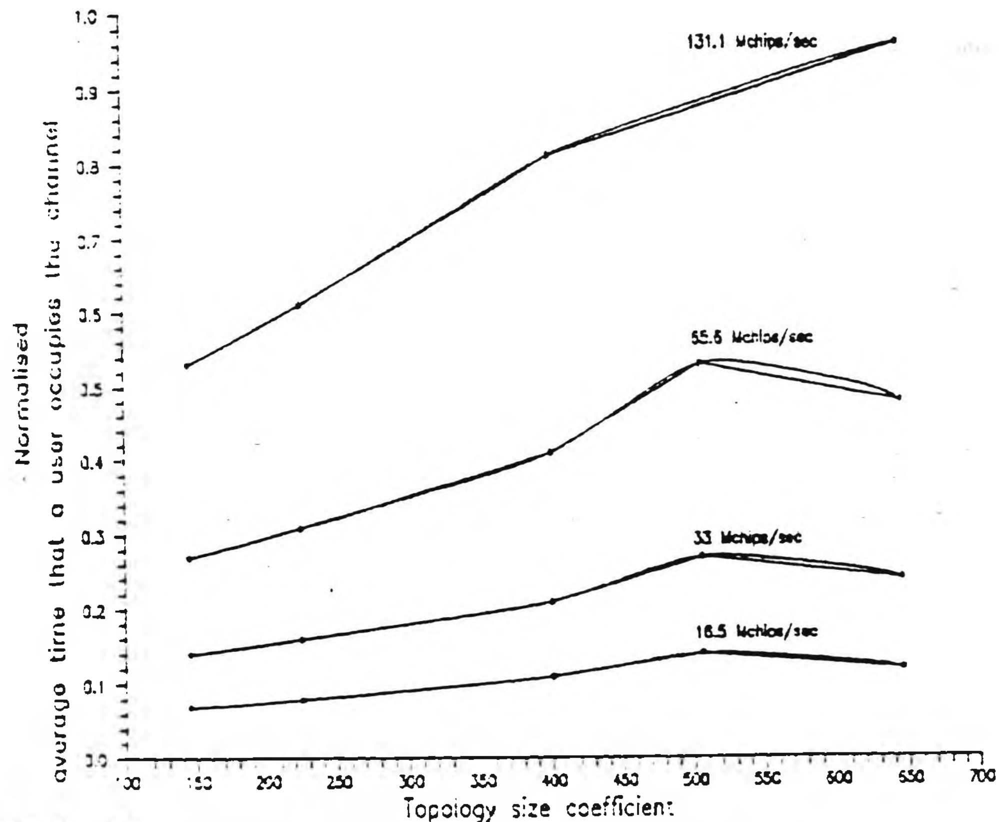

Fig. 5 : The influence of the average time that a user occupies the channel, as a function of the topology, for a LAN of 480 subscribers

2ο Πανελλήνιο Συνέδριο Πληροφορικής, Θεσσαλονίκη, 1988

ΤΕΧΝΙΚΕΣ ΔΙΕΥΡΥΜΕΝΟΥ ΦΑΣΜΑΤΟΣ ΣΤΑ ΤΟΠΙΚΑ ΔΙΚΤΥΑ

ANTONY DAVIES - ΜΑΣΤΙΧΙΑΔΗΣ ΘΕΟΔΩΡΟΣ.

THE CITY UNIVERSITY
CENTRE FOR INFORMATION ENGINEARING
NORTHAMPTON SQUARE
LONDON ECIV , OHB

ΠΕΡΙΛΗΨΗ

Αυτή είναι η περιγραφή μιάς νέας οικογένειας Τοπικών Δικτύων-ΤΔ.Η χρήση των προτεινομένων τεχνικών διευρυμένου φάσματος-ΔΦ (SPREAD SPECTRUM) δίνει σε όλα τα κανάλια επικοινωνίας απλότητα, δυνατότητα ταυτόχρονης επικοινωνίας,αποκλειστικότητα (PRIVACY) ή ακόμα και κρυπτασφάλεια και την ίδια απόδοση.Οι στατιστικές ιδιότητες της χρησιμοποιούμενης μεταγωγής πακέτων βελτιώνουν πολύ την ρυθμαπόδοση (THROUGHPUT) στο σύστημα.Η απόδοση(PERFORMANCE) του συστήματος,ο αριθμός των συνδρομητών του και ο βαθμός της προσφερόμενης ασφάλειας εξαρτάται από την επιλογή της οικογένειας των κωδικών που θα χρησιμοποιηθούν.Η χρήση οπτικών ινών βελτιώνει την ποιότητα αυτής της οικογένειας των ΤΔ.Η υλοποίηση ενός τέτοιου ΤΔ,σε μιά τυχαία τοπολογία πλέγματος δίνει υψηλό βαθμό επιβιωσιμότητας.Αυτό το ΤΔ είναι κατάλληλο να χρησιμοποιηθεί όπου απαιτούνται μικρά ολοκληρωμένα δίκτυα (INTEGRATES NETWORKS).

ABSTRACT

This is a description of a new family of LANs. The use of the suggested spread spectrum (spsc) techniques as a multiple access method gives simplicity, privacy or even sequracy, possibility of simultaneous communication and similar performance to all the communication channels. The statistical properties of the used packet switching method improves highly the throughput of the system. The performance of the system, the number of the subscribers, and the succeded degree of sequracy depends upon the selection of the spreading codes. The use of fiber-optics highly improves the quality of this family of LANs. The implementation of such a LAN on a mesh topology gives a high degree of survivability. This LAN appears appropriate for small integrated (voice, data, etc.) networks.

1. Εισαγωγή

Το CITY UNIVERSITY έχει μεγάλη ιστορία στην τεχνολογία ης πληροφορικής.Προσπαθώντας να συνεισφέρει στην ανάπτυξη των πικοινωνιών υπεισήλθε στην σχεδίαση νέων τύπων ΤΔ για ειδικές φαρμογές.Ανάμεσά τους είναι και η παρούσα εργασία.Η εργασία αυτή σήμερα συνεχίζεται στο Πανεπιστήμιο Αθηνών σε συνεργασία με το CITY UNIVERSITY.

Η εργασία αυτή αφορά ένα νέο τύπο ΤΔ που ξεπερνά τους περιορισμούς διαφόρων ήδη υπαρχόντων ΤΔ και προσφέρει υψηλό βαθμό επιβιωσιμότητας.Η λειτουργία του βασίζεται στην εκμετάλλευση των τεχνικών ΔΦ.Στα επόμενα,το κεφάλαιο δύο κάνει μία σύντομη αναδρομή στην θεωρία των ΤΔ.Το κεφάλαιο τρία περιγράφει τις αρχές που ακολουθούν οι τεχνικές ΔΦ.Το κεφάλαιο τέσσερα περιέχει τα χαρακτηριστικά (QUALITIES) τα πρωτόκολλα και την λειτουργία του νέου αυτού τύπου ΤΔ.Τελικά στο κεφάλαιο πέντε εξάγωνται σχετικά συμπεράσματα.

2. Τοπικά Δικτυώματα

Μετά το 1960 οι Η/Υ άρχισαν να χρησιμοποιούνται στην καθημερινή ζωή.Το γεγονός αυτό δημιούργησε την ανάγκη για επικοινωνίες δεδομένων (DATA).Οι επικοινωνίες δεδομένων έχουν διαφορετικά χαρακτηριστικά από τις επικοινωνίες φωνής.Απαιτούν υψηλότερους ρυθμούς εκπομπής,έχουν εκ φύσεως εκπομπές κατά ριπάς,δεν απαιτούν εκπομπή σε πραγματικό χρόνο και δεν ανέχονται σφάλματα. Επειδή ένα μεγάλο μέρος των επικοινωνιών δεδομένων όπως η αυτοματοποίηση γραφείου είναι τοπικές,ανεπτύχθηκαν τα ΤΔ για να καλύψουν τις ανάγκες αυτές.

Τα ΤΔ είναι δίκτυα επικοινωνιών δεδομένων που έχουν από κοινού χρησιμοποίηση των μέσων,χρησιμοποιούν υψηλούς ρυθμούς μετάδοσης (πάνω από 1 MBIT/SEC),εκτείνονται σε περιορισμένες αποστάσεις από 0,1 έως 10 KM και συνήθως είναι ιδιοκτησία των φορέων που τα χρησιμοποιούν (1).Συναντώνται σε Πανεπιστήμια,επιχειρήσεις,εργοστάσια κλπ.Αν και αρχικά σχεδιάστηκαν για να εξυπηρετήσουν τις ανάγκες των επικοινωνιών σε δεδόμενα,σήμερα γίνονται προσπάθειες να επιτευχθεί η ολοκλήρωση των διαφόρων μορφών μετάδοσης (TRAFFIC) φωνής,δεδομένων κλπ.

Τα ΤΔ αποτελούνται από επικοινωνιακούς κόμβους συνδεδεμένους μεταξύ τους.Ο όρος τοπολογία σημαίνει το χρησιμοποιούμενο μοντέλο σύνδεσης των διαφόρων κόμβων του δικτύου.Οι πλέον διαδεδομένες τοπολογίες είναι:η τύπου αγωγού,η τύπου αστέρος,η τυχαίας εσχάρας (σχήμα 1) (1,2,3).

Η τύπου αστέρας τοπολογία (4,3) έχει ένα κεντρικό μεταγωγέα από όπου ξεκινούν οι συνδέσεις με τις περιφεριακές μονάδες. Το μεγαλύτερο πρόβλημα αυτής της τοπολογίας είναι η συγκεντρωτική της μορφή.Χρησιμοποιείται συνήθως για να υποστηρίξει ένα αριθμό τερματικών συσκευών που επικοινωνούν με κεντρικό σύστημα καταμερισμού χρόνου.Στην περίπτωση αυτή ο κεντρικός μεταγωγέας μπορεί να είναι και η μηχανή καταμερισμού του χρόνου.

Η τοπολογία τύπου δακτυλίου (4,3),είναι μία αποκεντρωτική δομή όπου κάθε κόμβος έχει τη δική του νοημοσύνη.Συνήθως τα ηλεκτρονικά κυκλώματα (HARDWARE) που απαιτούνται για να υποστηρίζουν ένα τέτοιο κόμβο δεν είναι πολύπλοκα.Σε ένα τέτοιο ΤΔ η πληροφορία αναμεταδίδεται από κόμβο σε κόμβο μέχρι τον τελικό αποδέκτη.Τα πλεονεκτήματα της τοπολογίας αυτής έναντι των άλλων είναι ότι οι κόμβοι μπορούν να ενωθούν με διπλούς αγωγούς, ότι ο απαιτούμενος χρόνος για την μετάδοση της πληροφορίας είναι προκαθορισμένος,και ότι δίνει στον χρήση ένα δυναμικό σύστημα χειρισμού του δικτύου.Το μεγαλύτερο μειονέκτημά της είναι ότι η βλάβη έστω και ενός κόμβου συνεπάγεται διακοπή του δικτύου.

Μία άλλη αποκεντρωμένη τοπολογία είναι η τύπου αγωγού (3,4). Πρόκειται για ένα παθητικό δίκτυο όπου η πληροφορία δεν αναγεννάται σε κάθε κόμβο αλλά εκπέμπεται κατά μήκος όλου του δικτύου. Ο τελικός αποδέκτης διαβάζει την πληροφορία καθώς περνάει.Αυτού του τύπου το δίκτυο χρησιμοποιεί παθητικούς κόμβους,των οποίων οιαδήποτε βλάβη δεν επηρεάζει το δίκτυο.Σ΄ αυτή τη μορφή ΤΔ είναι εύκολη η επέκταση σε επιπλέον συνδρομητή αλλά δύσκολη η χρήση και δεύτερου ταυτόχρονα αγωγού.

Τέλος μία άλλη μορφή τοπολογίας που δεν υπακούει σε συγκεκριμένους κανόνες είναι η τύπου τυχαίου πλέγματος.Αυτή σχεδιάζεται συνήθως για να καλύψει συγκεκριμένες ανάγκες επικοινωνιών,σύμφωνα με τις προδιαγραφές που δίνονται.Στην περίπτωση αυτή και τα χρησιμοποιούμενα πρωτόκολλα σχεδιάζονται για να καλύψουν τις ανάγκες που προκύπτουν.Το μεγαλύτερο πλεονέκτημα που έχει είναι ότι λόγω του υφισταμένου υψηλού βαθμού πλεονασμού το δίκτυο αυτό είναι συνήθως πλέον επιβιώσιμο.Το μειονέκτημα που υπάρχει συνήθως σε αυτή την τοπολογία είναι η απαιτουμένη πολυπλοκότητα των κόμβων.Μία τέτοια τοπολογία χρησιμοποιείται και στην παρούσα εργασία.

Ο συνδιασμός της τοπολογίας μαζί με τα χρησιμοποιούμενα πρωτόκολλα και την μέθοδο πολλαπλής προσπέλασης στο φυσικό μέσο αποτελούν την αρχιτεκτονική του ΤΔ.Μία ποικιλία από τέτοιες στρατηγικές έχουν χρησιμοποιηθεί μέχρι σήμερα.Αυτές προσφέρουν στον χρήστη ένα πρωτόκολλο για απόκτηση προσπέλασης (ACCESS) στο φυσικό μέσο και του δίνουν την δυνατότητα να επιλύσει το πρόβλημα της σύγκρουσης (COLLISION) της πληροφορίας όταν περισσότερος από ένας συνδρομητής ζητούν πρόσβαση στο φυσικό μέσο ταυτόχρονα. Οι πιο γνωστές μέθοδοι είναι: η πολλαπλή προσπέλαση με ανιχνευτή φέροντος και αναγνώριση συγκρούσεων (CARRIER SENCE MULTIPLE ACCESS COLLISION DETECTION) και το δικαίωμα πρόσβασης (TOKEN PASSING). Και οι δύο χρησιμοποιούνται με αποκεντρωμένες δομές.

Η CSMA/CD (1,3) συνήθως συναντάται με την τοπολογία τύπου αγωγού.Βασίζεται στην μέθοδο εκπομπής ALOHA. Πριν ο χρήστης προσπαθήσει να εκπέμψει ακούει το κανάλι,να διαπιστώσει εάν είναι κατειλημμένο.Αν δεν είναι κατειλημμένο η πληροφορία εκπέμπεται. Αν είναι κατειλημμένο τότε περιμένει ένα αυθαίρετο χρονικό διάστημα και προσπαθεί ξανά.Είναι όμως δυνατό σε ένα εκτεταμένο αγωγό αφ΄ ένος μεν λόγω της καθυστέρησης στην διάδοση του σήματος,αφ΄ ετέρου δε λόγω του μη μηδενικού απαιτουμένου χρόνου για την ανάγνωση του φυσικού μέσου να δημιουργηθεί σύγκρουση της πληροφορίας που εκπέμπει ένας χρήστης και του πακέτου που έχει ήδη εκπέμψει ένας άλλος χρήστης και δεν έφθασε ακόμα στον πρώτο. Όταν συμβαίνει η σύγκρουση αυτή όλα τα εμπλεκόμενα μέρη αμέσως εγκαταλείπουν την εκπομπή,περιμένουν ένα τυχαίο χρονικό διάστημα και επαναλαμβάνεται η διαδικασία εκπομπής.

Η μέθοδος με δικαίωμα πρόσβασης (1,3) δίνει ελεγχόμενη προσπέλαση στο φυσικό μέσον.Αυτό έχει σαν αποτέλεσμα να μη παρουσιάζεται το πρόβλημα της σύγκρουσης των πληροφοριών όταν περισσότεροι από ένας χρήστης ζητούν ταυτόχρονη προσπέλαση στο φυσικό μέσον. Όταν ο χρήστης επιθυμεί να εκπέμψει ένα πακέτο πληροφοριών,καταλαμβάνει ένα ελεύθερο TOKEN.Σ΄ αυτό το TOKEN αλλάζει την κατάστασή του από ελεύθερη σε κατειλημένη και προσαρτά το πακέτο του. Έτσι δικαίωμα χρήσης του καναλιού αποκτά ο χρήστης οπότε υπάρχει ελεύθερο TOKEN.Η μέθοδος αυτή χρησιμοποιείται στις τοπολογίες τύπου αγωγού και δακτυλίου.

Η επιτροπή IEEE 802 έχει προβεί στη τυποποίηση των παραπάνω μεθόδων προσπέλασης με σχετικές συστάσεις.

Επί του παρόντος γίνονται πολλές προσπάθειες για την βελτίωση και τον ακριβή υπολογισμό της απόδοσης των διαφόρων ΤΔ, τον σχεδιασμό νέων πρωτοκόλλων συγχρονισμού,εξεύρεση αλγορίθμων δρομολόγησης (ROUTING),τον καθορισμό νέων τοπολογιών κλπ.Επίσης ένα άλλο πεδίο έρευνας στην ίδια περιοχή των ΤΔ είναι η ολοκλήρωση των διαφόρων μορφών κίνησης πάνω σε ένα ΤΔ.

3. Αρχές Τεχνικών Διευρυμένου Φάσματος

Με την χρήση των τεχνικών ΔΦ γίνεται μία εντελώς διαφορετική προσέγγιση στην επίλυση του προβλήματος της πολλαπλής προσπέλασης σε ένα ΤΔ.Σύμφωνα με τις τεχνικές αυτές το εκπεμπόμενο φάσμα διευρύνεται,η πυκνότητα ενέργειας σ΄ αυτό μειώνεται και όλοι οι συνδρομητές χρησιμοποιούν ταυτόχρονα την ίδια περιοχή του φάσματος αλλά ο κάθε ένας από αυτούς μέσω ενός διαφορετικού κώδικα (σχήματος).Η μέθοδος αυτή επιτρέπει την ταυτόχρονη προσπέλαση στο φυσικό μέσο πολλών συνδρομητών (Πολλαπλή Προσπέλαση Διανομής Κωδικών - ΠΠΔΚ (CODE DIVISION MULTIPLE ACCESS-CDMA),προσφέρει ένα βαθμό ασφάλειας στην διεξαγωμένη επικοινωνία που εξαρτάται από τον χρησιμοποιούμενο κώδικα,έχει την ίδια απόδοση και ικανότητες εύρεσης του αποδέκτου για όλους τους διαύλους επικοινωνίας.

Η μείωση της πυκνότητας της ισχύος (POWER SPECTRUM DENSITY) γίνεται με ταυτόχρονη αύξηση του καταλαμβανομένου φάσματος ενώ,η εκπεμπόμενη ισχύς διατηρήται σταθερά (σχήμα 3).Συνήθως αυτό επιτυγχάνεται με πολλαπλασιασμό των δεδομένων με έναν υψηλοτέρου ρυθμού μετάδοσης ψηφιακό κώδικα (CHIP RATE).Η περαιτέρω εκπομπή του σήματος στο φυσικό μέσον συνήθως είναι αναλογική με χρήση διαμόρφωσης φάσης.

Το σχήμα 4 δείχνει μία απλοποιημένη μορφή ενός πομποδέκτη για ένα σύστημα επικοινωνίας ΔΦ,καθώς επίσης και το χρησιμοποιούμενο φάσμα.Το σχήμα 5 παρουσιάζει την διαδικασία ανίχνευσης του επιθυμητού σήματος και απόρριψης του ανεπιθύμητου.Η κυματομορφή διεύρυνσης του φάσματος είναι,όπως προαναφέρθηκε,ένας ψηφιακός κώδικας υψηλού σχετικά ρυθμού μετάδοσης.Συνήθως ο κώδικας αυτός είναι μία ψευδοτυχαία διαδική ακολουθία που μπορεί να αναπαραχθεί. Επειδή σε κάθε ανταποκριτή αντιστοιχεί διαφορετικός κώδικας,η χρήση αυτών των κωδικών αποτελεί ένα στοιχείο αναγνωρίσεων των αποδεκτών και συνεπώς επιλεκτικές δυνατότητες.Επειδή ο αριθμός των συνδρομητών και η ποιότητα και ο διαχωρισμός των επικοινωνιακών διαύλων εξαρτάται από το ποσοστό ορθογωνιότητας των χρησιμοποιουμένων κωδικών (ιδιότητα του αυτοσυσχετισμού (AUTOCORRELATION) και ετεροσυσχετισμού (CROSSCORRELATION),η επιλογή της οικογένειας των κωδικών που θα χρησιμοποιηθεί είναι πολύ κρίσιμη.Για να επιτευχθεί η υλοποίηση ενός τέτοιου επικοινωνιακού συστήματος,ένα άλλο πολύ λεπτό και δύσκολο σημείο είναι η επίτευξη του συγχρονισμού. Ο συγχρονισμός πρέπει να επιτευχθεί αφ'ενός μεν στο επίπεδο του κώδικα, δηλαδή ο αναδημιουργούμενος στον δέκτη και ο λαμβανόμενος κώδικας να είναι σε φάση, όσο και σε επίπεδο CHIP. Για την επίτευξη του συγχρονισμού έχουν σχεδιαστεί πολλοί αλγόριθμοι και πρωτόκολλα. Η μέθοδος αυτή που περιγράφτηκε ονομάζεται Τεχνική Διεύρυνσης Φάσματος Συνεχούς Ακολουθίας - ΔΦΣΑ (DIVERT SEQUENCE-DS). Εκτός από αυτή υπάρχουν και διάφοροι άλλοι μέθοδοι ΔΦ όπως είναι η FREQUENCY HOPPER μέθοδος κλπ. Το σχήμα 6 παρουσιάζει το σχηματικό διάγραμμα ενός τυπικού πομπού και δέκτη ενός συστήματος ΔΦΣΑ. Το σχήμα 7 δείχνει ένα τυπικό σύστημα επικοινωνιών CDMA. Τα (5),(6) δίνουν μία πιο εμπεριστατομένη περιγραφή των παραπάνω.

Λόγω των ιδιοτήτων των τεχνικών ΔΦ η έρευνα στην περιοχή των ασυρμάτων δικτύων πακέτων έχει κατευθυνθεί εξ ολοκλήρου στην εκμετάλλευση των τεχνικών ΔΦΣΑ (7), ενώ ταυτόχρονα τελευταία άρχισε να παρουσιάζεται μία προσπάθεια να επεκταθούν οι τεχνικές αυτές στην αυτοματοποίηση του γραφείου, μέσω της σχεδίασης ΤΔ. Στα πλαίσια αυτής της κίνησης αναπτύχθηκε και η παρούσα εργασία.

4. Περιγραφή του Προτεινομένου Τοπικού Δικτύου Διεύρυνσης Φάσματος

Η παρούσα εργασία περιγράφει ένα ΤΔ που σε σύγκριση με τα συμβατικά μπορεί να θεωρηθεί σαν πρωτότυπο αφ'ενός μεν λόγω των ιδιοτήτων των χρησιμοποιουμένων τεχνικών ΔΦ, αφ'ετέρου δε λόγω της τοπολογίας του και των χρησιμοποιουμένων πρωτοκόλλων. Οι κύριες ιδιότητες του είναι επιβιωσιμότητα, ασφάλεια, πολλαπλή προσπέλαση χωρίς σύγκρουση της πληροφορίας (CONTENTION FREE MULTIPLE ACCESS), υψηλή διέλευση (THROUGH PUT), επικοινωνίες ανθεκτικές στον θόρυβο, ολοκληρωμένη κίνηση (INTEGRATED TRAFFIC), και ενδογενείς δυνατότητες επιλογής του ανταποκριτή.

Αυτό το ΤΔ έχει κατασκευαστεί σε μία τοπολογία τύπου τυχαίου πλέγματος (σχήμα 16) και χρησιμοποιεί ένα πρωτόκολλο τύπου διάχυσης (FLOODING). Μ'αυτή τη σχεδίαση είναι σίγουρο ότι το σήμα θα φθάνει πάντοτε στον προορισμό του αφού ξαναδιαχέεται σε κάθε κόμβο. Αν και το ιδανικό φυσικό μέσο για την υλοποίηση του δικτύου αυτού είναι οι οπτικές ίνες επειδή προσφέρουν μεγάλο φάσμα εκπομπής και χαμηλή εξασθένιση, ωστόσο μπορεί να χρησιμοποιηθεί και ομοαξωνικό καλώδιο.

Σε κάθε κόμβο αντιστοιχεί ένας συνδρομητής.Για την επικοινωνία μεταξύ τους χρησιμοποιούνται δύο ειδών πρωτόκολλα,αυτά που βασίζονται στον δέκτη και αυτά που βασίζονται στον πομπό.Η υλοποίηση και των δύο αυτών πρωτοκόλλων βασίζεται στις τεχνικές ΔΦΣΑ. Όπως προαναφέρθηκε κάθε πομπός διαμορφώνει την πληροφορία χρησιμοποιώντας μία ψευδοτυχαία δυαδική ακολουθία ενός υψηλότερου ρυθμού διάδοσης (CHIP RATE).Η ακολουθία αυτή είναι μέλος μιάς οικογένειας κωδικών που παρουσιάζει υψηλό αυτοσυσχετισμό και χαμηλό ετεροσυσχετισμό.Τέτοιοι κώδικες είναι οι λεγόμενοι χρυσοί κώδικες (GOLD CODES),οι ακολουθίες μέγιστου μήκους (MAXIMUM LENGTH SEQUENCES) κλπ.Κατ' αρχήν κάθε δέκτης λαμβάνει χρησιμοποιώντας ένα συγκεκριμένο κώδικα από αυτήν την οικογένεια που αποτελεί την ταυτότητα του εν λόγω δέκτη.Εάν ο πομπός εκπέμψει χρησιμοποιώντας τον κώδικα του αποδέκτη τότε έχουμε χρήση πρωτοκόλλου που βασίζεται στον αποδέκτη.Κάθε δέκτης ακούει διαρκώς το φυσικό μέσον.Μία τοπικά παραγόμενη ψευδοτυχαία ακολουθία συσχετίζεται με τα εισερχόμενα δεδόμενα.Αν στο λαμβανόμενο σήμα υπάρχουν δεδόμενα που κατευθύνονται σ'αυτόν τον αποδέκτη τότε θα ξαναδημιουργηθεί το αρχικό σήμα στη κανονική του μορφή.Εάν ο πομπός χρησιμοποιήσει για την εκπομπή τον κώδικα του δέκτη του τότε έχουμε πρωτόκολλο που βασίζεται στον πομπό.Εάν ένας αποδέκτης θέλει να παρακολουθήσει αυτή την εκπομπή,τότε αντικαθιστά προσωρινά τον κώδικα του εκπέμποντος.Κατά τον τρόπο αυτό για την σύνδεση οιουδήποτε ζεύγους συνδρομητών δημιουργούνται ειδικοί επικοινωνιακοί δίαυλοι που θα υπάρχουν μόνο κατά την διάρκεια της εκπομπής. Αυτή η ιδιότητα κάνει αυτό το δίκτυο κατάλληλο για ολοκληρωμένες μορφές κίνησης (INTEGRATED TRAFFIC).

Πέραν τούτου τα συμβατικά ΤΔ είναι πολύ ευαίσθητα στον θόρυβο.Έτσι αν σε ένα σύστημα πολλαπλής προσπέλασης καταμερισμού χρόνου (TDMA) υπάρξει μία ριπή θορύβου ή λευκός θόρυβος,αυτό θα έχει σαν αποτέλεσμα την απώλεια της πληροφορίας.Για να αντιμετωπιστεί αυτό το πρόβλημα ή θα πρέπει να γίνει χρήση μεθόδου ανίχνευσης και διόρθωσης σφαλμάτων (ERROR CORRECTION AND DETECTION METHODS) ή θα πρέπει να γίνει επανάληψη της εκπομπής (ACKNOWLEDGMENT PROCEDURE). Επακόλουθο αυτού είναι η μείωση της διέλευσης του δικτύου.Στο προτεινόμενο ΤΔ η χρήση ψευδοτυχαίων ακολουθιών για την διαμόρφωση των δεδομένων δημιουργεί μία φυσική προστασία της πληροφορίας από τέτοια φαινόμενα.Η ποιότητα αυτής της προστασίας εξαρτάται από τα χαρακτηριστικά της χρησιμοποιούμενης ομάδας κωδικών.

Επειδή ο συσχετισμός του θορύβου με την τοπικά παραγόμενη ακολουθία είναι μικρός,η πράξη του συσχετισμού στον δέκτη των δύο αυτών σημάτων οδηγεί σε μιά διεύρυνση του πλάτους του θορύβου και υποβιβασμό της πυκνότητας της ισχύος του θορύβου.

Ένα άλλο πολύ ουσιώδες χαρακτηριστικό του προτεινομένου ΤΔ είναι η επιβιωσιμότητα.Αυτή επιτυγχάνεται με δύο τρόπους.

α. Η χρησιμοποιούμενη τοπολογία είναι τύπου πλέγματος με αποτέλεσμα να δημιουργεί μία φυσική ασφάλεια έναντι οποιασδήποτε βλάβης του φυσικού μέσου λόγω της πολλαπλότητας των διαδρόμων μεταξύ πομπού-δέκτη.Αντίθετα στα συνήθη ΤΔ που είναι τύπου αγωγού δακτυλίου ή αστέρα ένα τέτοιο πρόβλημα θα δημιουργούσε διακοπή της επικοινωνίας.

β. Το ΤΔ εργάζεται με ένα πρωτόκολλο τύπου διάχυσης.Αυτό έχει σαν συνέπεια το σήμα να φθάνει στον προορισμό του από διαφορετικές διαδρομές και σχεδόν ταυτόχρονα.Άρα υπάρχει ασφάλεια έναντι βλάβης οποιουδήποτε κόμβου.

Εκτός όμως από την επιβιωσιμότητα που εγγυάται το ότι θα φθάσει η πληροφορία στον προορισμό της και το γεγονός ότι δεν θα είναι η πληροφορία παραμορφωμένη,η χρήση των τεχνικών ΔΦ δίνει την δυνατότητα να ασφαλιστεί η πληροφορία και από την υποκλοπή εξασφαλίζοντας έτσι το απόρρητο της επικοινωνίας.Ο βαθμός της επιτυγχανόμενης ασφάλειας εξαρτάται από την κρυπτασφάλεια που παρέχει η χρησιμοποιούμενη οικογένεια κωδικών.Η ασφάλεια αυτή είναι ενδογενής στο σύστημα και παρέχεται στον ίδιο βαθμό σε όλους τους συνδρομητές χωρίς να απαιτείται η χρήση επιπλέον συσκευής ή άλλου υλικού.Αυτό ελαττώνει το κόστος και την πολυπλοκότητα του εν λόγω ΤΔ σε σύγκριση με άλλα ΤΔ.

Επί πλέον των προηγουμένων ιδιοτήτων το προτεινόμενο δίκτυο έχει την δυνατότητα της ταυτόχρονης προσπέλασης των συνδρομητών στο μέσο,χωρίς πρώτα να πρέπει να αποφασίσουν εάν αυτό είναι κατειλημμένο ή όχι,και χωρίς να υπάρχει ο φόβος της σύγκρουσης της πληροφορίας.Αυτό επιτυγχάνεται βάσει:

α. Της περιγραφείσας μεθόδου απόρριψης του θορύβου και επιλογής του επιθυμητού σήματος.

β. Της ιδιότητας του χαμηλού ετεροσυσχετισμού και υψηλού αυτοσυσχετισμού,λόγω της οποίας ο δέκτης θεωρεί οποιοδήποτε σήμα που δεν φέρει τον κώδικα που διαβάζει εκείνη τη στιγμή σαν θόρυβο.

γ. Τον υποβιβασμό της ισχύος του σήματος στον ελάχιστο δυνατό,λόγω σήματος προς θόρυβο χωρίς να χαθεί η πληροφορία.

Αυτό έχει σαν αποτέλεσμα αφ'ενός πολλοί χρήστες να μπορούν να χρησιμοποιούν το δίκτυο ταυτόχρονα με παρόμοια απόδοση όλων των διαύλων,αφ'ετέρου δε μηδενικό χρόνο αποστολής του σήματος.Η απόδοση αυτών των διαύλων εξαρτάται από τον συνολικό αριθμό των χρηστών που εκπέμπουν ταυτόχρονα και μειώνεται καθώς αυτός αυξάνεται.

Κάτι άλλο που είναι άξιο προσοχής είναι ο υπολογισμός των χρησιμοποιούμενων ρυθμών μετάδοσης σε ένα ΤΔ που χρησιμοποιεί τεχνικές ΔΦ ΣΑ.Στην περίπτωση αυτή,ο συνολικός ρυθμός μετάδοσης εξαρτάται από τους περιορισμούς του φυσικού μέσου μετάδοσης και όχι από τα χαρακτηριστικά και τις δυνατότητες εκπομπής των κόμβων,όπως συμβαίνει με τα συμβατικά δίκτυα προσπέλασης καταμερισμού χρόνου. Σαν παράδειγμα στο ETHERNET που λειτουργεί με ένα ρυθμό μετάδοσης 10 MBIT/SEC είναι αναγκαίο κάθε κόμβος να εκπέμψει στον ρυθμό αυτό,έστω και αν οι ανάγκες του κόμβου περιορίζονται σε λίγα BITS/SEC.Αντιθέτως στα ΔΦ ΣΑ τοπικά δίκτυα,ο ρυθμός μετάδοσης είναι το άθροισμα του επιμέρους ρυθμού μετάδοσης ενός εκάστου κόμβου.Έτσι σε ένα σύστημα ΠΠΔΚ εάν υποθέσουμε ότι το συνολικό φορτίο είναι 16 CHIP/SEC και ότι έχουμε 100 συνδρομητές,τότε ο κάθε ένας από αυτούς δεν εκπέμπει στο 16 CHIP/SEC αλλά μόνο στα 10 MBIT/SEC.Αυτό σημαίνει ότι οι κόμβοι ενός τέτοιου δικτυώματος είναι ευκολότερο να κατασκευαστούν και ότι η ιδιότητα αυτή σε συνδυασμό με την μέθοδο μεταγωγής των πακέτων (PACKET SWITCHING) βελτιώνει στο μέγιστο την αποτελεσματική απόδοση του μέσου.

5. Συμπεράσματα

Η παρούσα εργασία περιέγραψε ένα νέο τύπο ΤΔ που χρησιμοποιεί τεχνικές ΔΦ ΣΑ,έχει πολλές και πρωτότυπες ιδιότητες και έναν υψηλό βαθμό επιβιωσιμότητας που το κάνει πολύ πιο κατάλληλο για ειδικές εφαρμογές από τα υπάρχοντα ΤΔ.Στη συνέχεια αυτής της εργασίας θα γίνει υπολογισμός της απόδοσης αυτού του ΤΔ μέσω μοντέλων εξομοίωσης σε Η/Υ που θα υλοποιηθούν με την γλώσσα SIMULA.

6. Ευχαριστίες

Κατά κύριο λόγο θα ήθελα να ευχαριστήσω τον Δρ. Οικονόμου του Πανεπιστημίου Αθηνών για την ουσιαστική του βοήθεια,τις ενθαρρύνσεις του,τα σχόλια του και τις διορθώσεις του.Επίσης θα ήθελα να ευχαριστήσω τον καθηγητή Γ.Φιλοκύπρου του Πανεπιστημίου Αθηνών, που βοήθησε την υλοποίηση της συνεργασίας των δύο πανεπιστημίων και έκανε δυνατή τη συνέχιση της εργασίας αυτής.

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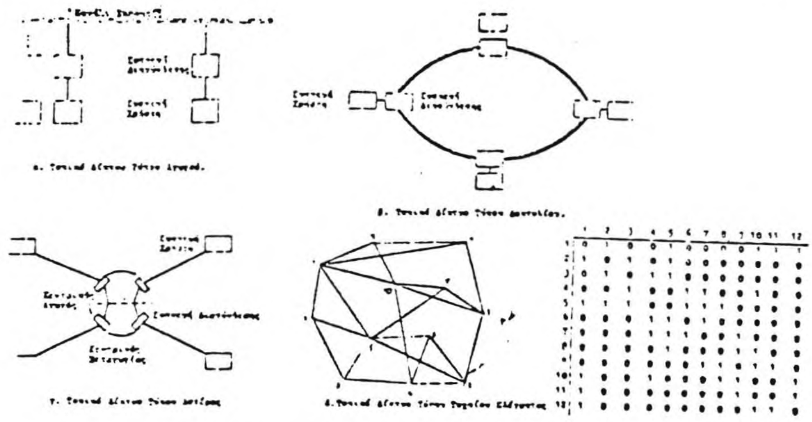
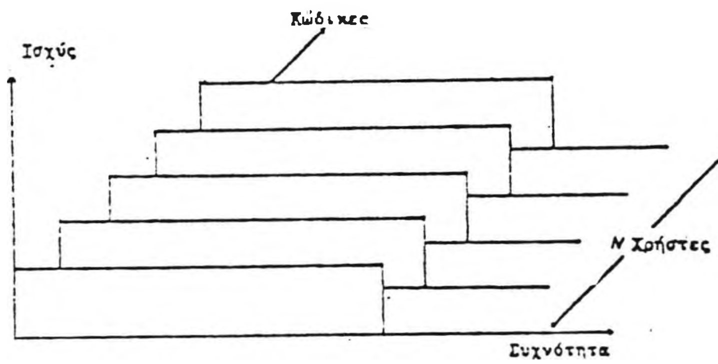
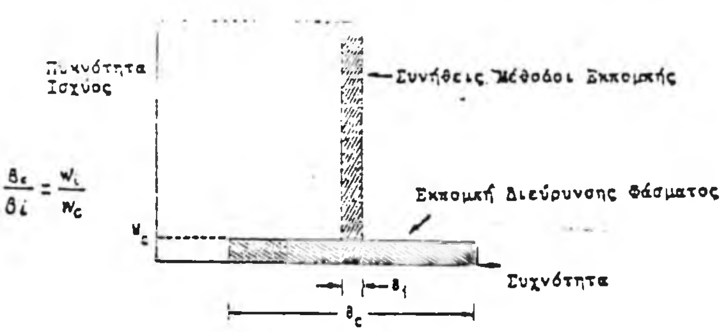


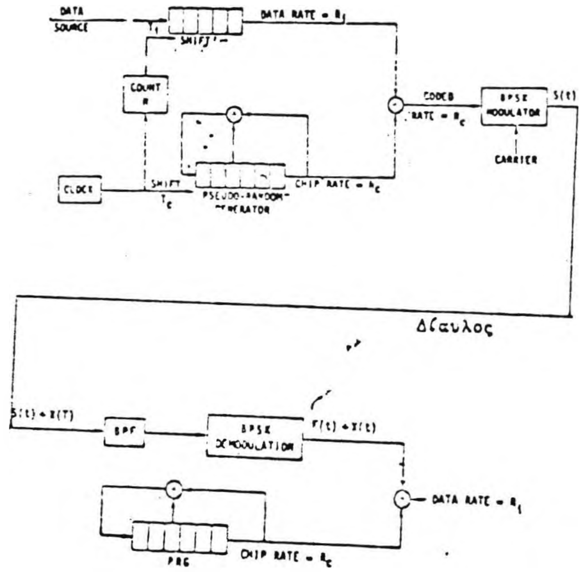
ΣΧΗΜΑ 1: Βασικοί Τύποι Τοπικών Δικτύων.



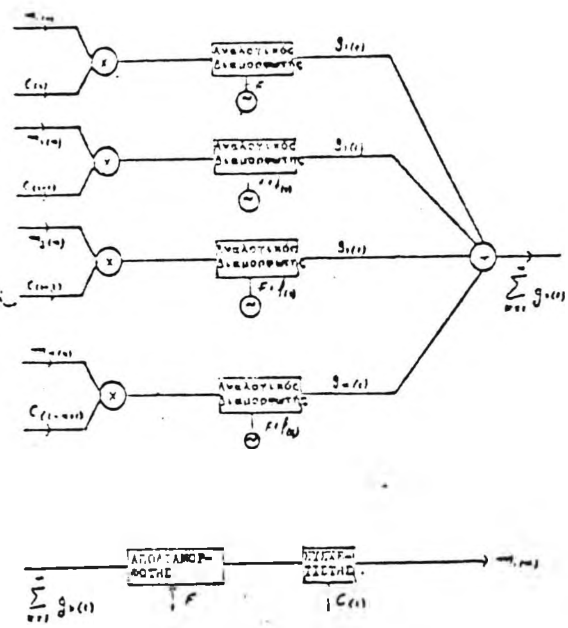
ΣΧΗΜΑ 2 Αρχή Λειτουργίας της Μεθόδου ΠΠΔΚ



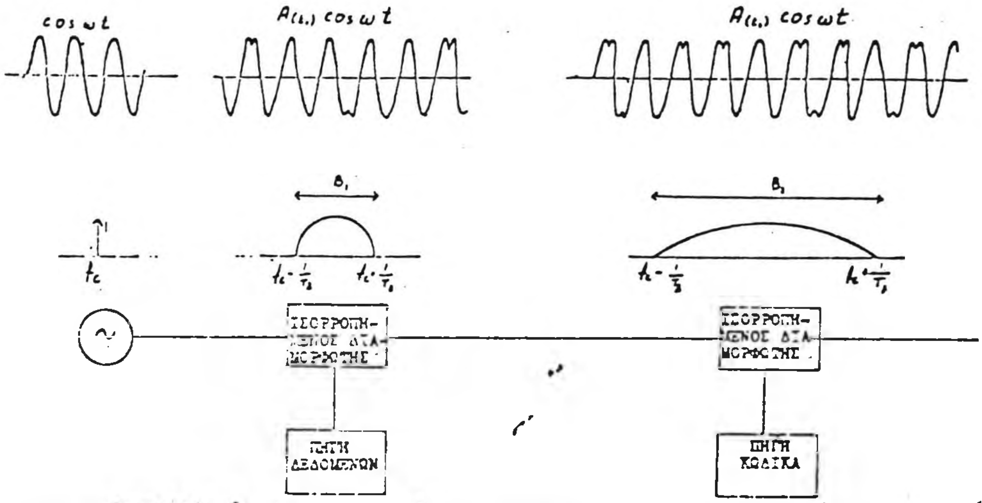
ΣΧΗΜΑ 3: Βασική Αρχή της Διεύρυνσης Φάσματος.



ΣΧΗΜΑ 6 : Αναλυτικό Σχηματικό Διάγραμμα Πομποδέκτη Τύπου ΔΦΣΑ.

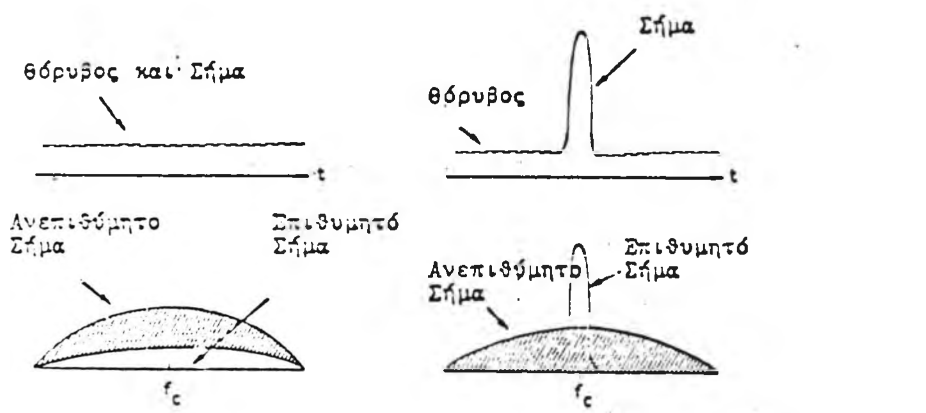


ΣΧΗΜΑ 7 : Σχηματικό Διάγραμμα Ενός Συστήματος ΣΠΔΚ.



ΣΧΗΜΑ 4: Σχηματικό Διάγραμμα Πομπού ΔΦ με τις Αντίστοιχες Παραγόμενες Κυματομορφές και τα Απαιτούμενα Φάσματα Συχνοτήτων.

ΣΧΗΜΑ 5: Διαδικασία Ανίχνευσης Επιθυμητού και Ανεπιθύμητου Σήματος.



Λαμβανόμενο σήμα

Σήμα μετά την επεξεργασία από κωδικο-

Μοντελοποίηση ενός Νέου Τύπου Τοπικού Δικτύου Υπολογιστών σε γλώσσα SIMULA με χρήση των αρχών της MASCOT

Θ.Μαστιχιάδης, City University
Ε. Οικονόμου, Τμήμα Πληροφορικής Πανεπιστημίου Αθηνών

ΠΕΡΙΛΗΨΗ: Στην παρούσα εργασία περιγράφεται ένας νέος τύπος τοπικού δικτύου υπολογιστών (ΤΔ) που χρησιμοποιεί την τεχνική διευρύνσεως φάσματος για την πρόσβαση στο μέσο. Η δομημένη, κυψελλοειδής τοπολογία τυχαίου πλέγματος σε συνδυασμό με την παθητική επανεκπομπή κάθε λαμβανομένου σήματος προς όλες τις κατευθύνσεις εξασφαλίζει βιωσιμότητα και ασφάλεια. Ο συγχρονισμός επιτυγχάνεται με την χρήση ενός χωριστού καναλιού διαίρεσης χρόνου (TDM), μέσα σε ένα ενιαίο περιβάλλον χρονισμού. Ιδιαίτερη έμφαση δίδεται στην απεικόνιση του συστήματος μέσω των αρχών της MASCOT III προκειμένου να γίνει προσομοίωση του με την γλώσσα SIMULA.

Abstract: This paper describes a new type of Local Area Network (LAN) that uses spread spectrum (Spsc) techniques for medium access. The modular, cellular, mesh topology in combination with a passive retransmission of any received signal in all directions guarantees survivability and security. The synchronization is achieved by a separate time division channel (TDM) in a universal timing system. Special attention is given to the presentation of this LAN using MASCOT III principles for its simulation via SIMULA programming language.

1. ΕΙΣΑΓΩΓΗ

Οι σύγχρονες τάσεις στην γραφή του λογισμικού επιβάλλουν την χρήση μεθόδων που βασίζονται στην σχεδίαση ανεξαρτήτων προγραμμάτων που συνεργάζονται (object oriented programming). Η φιλοσοφία αυτή είναι ιδιαίτερα αποτελεσματική στην περίπτωση που απαιτείται να παρασταθούν πολύπλοκα συστήματα που εργάζονται σε πραγματικό χρόνο (Real time Programming).

Για την ικανοποίηση αυτού του στόχου αναπτύχθηκαν στην Αγγλία η MASCOT [1] και στην Νορβηγία η SIMULA [2]. Στην παρούσα εργασία δίδονται :

- μία σύντομη περιγραφή της MASCOT και της SIMULA.
- η περιγραφή ενός νέου τύπου ΤΔ που λειτουργεί σε τοπολογία τύπου πλέγματος (Mesh Topology) και χρησιμοποιεί τεχνικές Διευρύνσεως φάσματος (Spread spectrum techniques) [3,4].
- ένα μοντέλο προσομοιώσης αυτού του ΤΔ, όπου φαίνεται πως προγράμματα σε SIMULA μπορούν να σχεδιαστούν μέσω της MASCOT. Βάσει αυτού του μοντέλου θα γραφεί το λογισμικό για να υπολογισθεί η απόδοση του ΤΔ.

Γενικά για τον υπολογισμό της απόδοσης ενός ΤΔ ακολουθούνται οι εξής μέθοδοι:

- Κατασκευή μαθηματικού μοντέλου και επίλυση του, μέσου υπολογιστή.
- Προσομοίωση των λειτουργιών του συστήματος με την βοήθεια ειδικών γλωσσών προγραμματισμού.

Στη μέθοδο προσομοίωσης πού περιγράφεται δημιουργείται ένα χρονικό περιβάλλον μέσα στο οποίο προσομοιώνεται η λειτουργία, σε πραγματικό χρόνο, του προς εξέταση ΤΔ.

2. ΠΕΡΙΓΡΑΦΗ ΤΟΥ ΤΟΠΙΚΟΥ ΔΙΚΤΥΟΥ

Το προς προσομοίωση ΤΔ έχει τα ακόλουθα χαρακτηριστικά: Τοπολογία τύπου πλέγματος, δρομολόγηση τύπου διάχυσης (Flooding routing), τεχνικές διευρύνσεως φάσματος συνεχούς ακολουθίας (spread spectrum direct sequence techniques) και ανεξάρτητο κανάλι σηματοδοσίας.

Το ΤΔ βασίζεται σε μια τοπολογία τύπου πλέγματος κυψελλοειδούς μορφής όπως φαίνεται στό σχήμα 1. Σε κάθε κόμβο της τοπολογίας συνδέεται ένας αριθμός χρηστών. Ο μέγιστος αριθμός χρηστών που το ΤΔ μπορεί να υποστηρίξει δεν είναι σταθερός και εξαρτάται από το μέγεθος και τα χαρακτηριστικά του γραφήματος (graph) που σχηματίζεται. Ετσι ο αυτός αριθμός συνδρομητών μπορεί να υποστηριχθεί από μία ποκιλία τοπολογιών με διαφορετικά μεγέθη, χαρακτηριστικά και τιμές των παραμέτρων τους. Ανάμεσα σε δύο οποιουσδήποτε κόμβους υπάρχει ένας αριθμός από διαφορετικές διαδρομές.

Η δρομολόγηση γίνεται μέσω ενός πρωτοκόλλου παθητικής διάχυσης και αναμετάδοσης του σήματος με υποδιαίρεση της ισχύος του (passive flooding). Ετσι κάθε κόμβος απλά διαχέει την εισερχόμενη ενέργεια ομοιόμορφα προς όλες τις εξόδους και την εκπέμπει. Κατά αυτό τον τρόπο το σήμα φθάνει στον προορισμό του, πρώτα από τον συντομώτερο δρόμο ενώ ταυτόχρονα δημιουργούνται πολλές αντηχήσεις (echos). Αυτές οι αντηχήσεις συμπεριφέρονται σαν θόρυβος ευρείας ζώνης του καναλιού (Wideband background noise). Ο αριθμός τους και η ισχύς τους εξαρτάται από την τοπολογία και αποσβένονται σταδιακά.

Στην εικόνα 2 φαίνεται η βασική δομή ενός κόμβου. Η σύνδεση των χρηστών σε αυτόν γίνεται μέσω Μονάδων Διασύνδεσης Διευρύνσεως Φάσματος (spread spectrum Inferface units). Λόγω της χρήσης των Τεχνικών Διευρύνσεως Φάσματος κάθε σταθμός, χρησιμοποιώντας την Μεθοδο πολλαπλής προσπέλασης με διαίρεση κώδικα, μπορεί να αποκτήσει προσπέλαση στο δίκτυο χωρίς να χρειάζεται να γνωρίζει αν το μέσο είναι κατηλειμμένο ή όχι, όπως συμβαίνει στο πρωτόκολλο CSMA/CD.

Ο πομπός του συνδρομητή διαμορφώνει τα δεδομένα χρησιμοποιώντας ψευδοτυχαίες δυαδικές ακολουθίες υψηλού ρυθμού μετάδοσης, που είναι μέλη μιάς μεγαλύτερης οικογένειας ακολουθιών. Σε κάθε χρήστη αντιστοιχεί και μία από αυτές τις ακολουθίες. Με αυτό τον τρόπο δεν χρειάζεται διαδικασία σηματοδότησης για τον προσδιορισμό του αποδέκτη, διότι ο αποδέκτης έχει καθοριστεί από τον κώδικα που χρησιμοποιήθηκε για την διαμόρφωση. Τα διαμορφωμένα δεδομένα εκπέμπονται στο δίκτυο. Σε κάθε μονάδα διασύνδεσης διευρύνσεως φάσματος ο δέκτης ακούει συνέχεια μέσω του κόμβου το δίκτυο. Μία τοπικά δημιουργούμενη ακολουθία συγκρίνεται με την εισερχόμενη στον κόμβο ενέργεια. Αν αυτή η ενέργεια περιέχει σήμα το οποίο έχει διαμορφωθεί με ένα συγχρονισμένο αντίτυπο της τοπικά δημιουργουμένης ακολουθίας τότε το σήμα απευθύνεται στον συγκεκριμένο δέκτη και αυτόματα επιτυγχάνεται η αποκωδικοποίηση και η εμφάνιση του αρχικού μηνύματος.

Ταυτόχρονα με τα κανάλια που λειτουργούν με χρήση τεχνικών διευρύνσεως φάσματος και στο ίδιο φάσμα συχνοτήτων, λειτουργεί ένα κανάλι πολλαπλής προσπέλασης με διαίρεση χρόνου (TDM) που εξυπηρετεί ανάγκες σηματοδότησης. Όλοι οι κόμβοι και οι χρήστες μοιράζονται τις χρονικές σχισμές (time slots) αυτού του καναλιού, βάσει μιάς μονίμου προκαθορισμένης μεθόδου. Μέσω αυτού υπάρχει συνέχεια διαθέσιμη στο δίκτυο κάθε απαιτούμενη πληροφορία χρονισμού, δρομολόγησης ή σχετική με την λήψη ενός σήματος. Η δρομολόγηση στο κανάλι αυτό βασίζεται στην μέθοδο της ενεργού διάχυσης (active flooding method). Δηλαδή κάθε κόμβος μόλις λάβει την πληροφορία την διαβάζει, την επεξεργάζεται και την επανεκπέμπει προς όλες τις εξόδους.

Τα κύρια λοιπόν χαρακτηριστικά του δικτύου είναι η επιβιωσιμότητα, οι μικρές καθυστερήσεις και η μικρή πιθανότητα συγκρούσης της πληροφορίας. Οι ιδιότητες αυτές είναι εσωτερικές στο σύστημα. Αυτό οφείλεται στον συνδυασμό της τοπολογίας τύπου πλέγματος με τις ιδιότητες του χρησιμοποιούμενου πρωτοκόλλου παθητικής διάχυσης σε συνδιασμό με τις τεχνικές διευρύνσεως φάσματος.

3. ΧΑΡΑΚΤΗΡΙΣΤΙΚΑ ΤΗΣ MASCOT

Η MASCOT (Modular Approach to Software Construction Operation and Test) απλοποιεί την ανάλυση, σχεδίαση, γραφή και έλεγχο του λογισμικού συστημάτων που λειτουργούν σε περιβάλλον πραγματικού χρόνου. Ειδικότερα η MASCOT αποτελεί:

- Μια μέθοδο τμηματικής προσέγγισης στο κτίσιμο, λειτουργία και έλεγχο του λογισμικού.
- Ενα μέσο παρουσίασης της σχεδίασης του προγράμματος.
- Μία μέθοδο σχεδίασης του λογισμικού.
- Ενα τρόπο κτισίματος του λογισμικού ώστε να είναι σύμφωνο με την σχεδίαση.
- Ενα μέσο εκτέλεσης του κτισθέντος λογισμικού ώστε η δομή που σχεδιάστηκε να μπορεί να παρακολουθηθεί κατά την εκτέλεση.
- Ενα εργαλείο για τον έλεγχο του λογισμικού σε σχέση με την δομή που σχεδιάστηκε.

Είναι ιδιαιτέρας σημασίας στην παρουσίαση της σχεδίασης η ικανότητα της MASCOT να δείχνει τις ταυτόχρονες πράξεις και την ροή των δεδομένων ανάμεσά τους. Μία άλλη ιδιότητα της ιδίας σημασίας στην μεθόδο αυτή είναι η ικανότητα να καθορίζει τα διάφορα μέρη της προς σχεδίαση δομής και να αποσύνδέει το ένα από το άλλο. Αυτό επηρεάζει τόσο την δομή όσο και την στατηγική ελέγχου και οδηγεί σε μά μορφή "τεχνολογίας με εξαρτήματα" παρόμοιας με τους άλλους τύπους μηχανικής. Ετσι κάθε τμήμα έχει τα δικά του χαρακτηριστικά και τους δικούς του περιορισμούς στο που και πως μπορεί να συνδεθεί με άλλα τμήματα.

Το κύριο στοιχείο στην MASCOT είναι ότι η ροή των δεδομένων μέσα στο σύστημα, από την δημιουργία τους από κάποιο χρήστη ή αισθητήρα μέχρι την τελική χρήση τους από κάποιο σταθμό εξόδου, ελέγχεται από ομάδες κομματιών λογισμικού που ονομάζονται δραστηριότητες (activities) και λειτουργούν ταυτόχρονα. Αυτές τοποθετούνται στο χρονικό πεδίο από ένα λειτουργικό σύστημα που συνήθως ονομάζεται πυρήνας της MASCOT (MASCOT KERNEL) και το οποίο υλοποιείται άπο την γλώσσα προγραμματισμού που έχει επιλεγεί.

Για την διακίνηση των δεδομένων ανάμεσα στις δραστηριότητες χρησιμοποιούνται οι περιοχές Δεδομένων Ενδοεπικοινωνίας IDA (Interconnection data areas). Αυτές διακρίνονται σε δύο κατηγορίες στα κανάλια (channels) και στις δεξεμενές (Pools) Τα κανάλια χαρακτηρίζονται από την ικανότητα τους να διαβάζουν τις δεξαμενές, ενώ οι δεξαμενές από την ικανότητα τους να αποθηκεύουν τα δεδομένα.

Η MASCOT παρέχει δύο τρόπους παρουσίασης της σχεδίασης. Ο ένας είναι με ειδικά σύμβολα και ο άλλος με ψευδοκώδικα.

' Στο σχεδιάγραμμα 3 φαίνονται οι τρόποι παρουσίασης των δραστηριοτήτων, δεξαμενών και καναλιών στην μορφή των ειδικών συμβόλων.

4. ΧΑΡΑΚΤΗΡΙΣΤΙΚΑ ΤΗΣ SIMULA

Η γλώσσα προγραμματισμού SIMULA βασίζεται στην γλώσσα Algol 60 και σχεδιάστηκε για να διευκολύνει την επίλυση συνθέτων προβλημάτων προσομοίωσης. Για την μελέτη τέτοιων προβλημάτων είναι αναγκαία η διαίρεση του προβλήματος σε αυτόνομα τμήματα. Αυτό γίνεται με την βοήθεια των κλάσεων (classes) που είναι αυτοτελείς ενότητες προγράμματος που περιγράφουν την λειτουργία ξεχωριστών τμημάτων του προβλήματος.

Κάθε κλάση μπορεί να δημιουργήσει αντίτυπα του εαυτού της με διαφορετικές τιμές στις μεταβλητές. Τα αντίτυπα αυτά ονομάζονται ομοιότυπα (objects).

Η παραγωγή και συνύπαρξη ομοιοτύπων μιας κλάσης είναι ένα ακόμη χαρακτηριστικό της SIMULA. Σε επίπεδο προγράμματος προσομοίωσης του συστήματος σε γλώσσα SIMULA είναι απαραίτητη η συσχέτιση μεταξύ των ομοιοτύπων κάθε κλάσης. Η συσχέτιση αυτή γίνεται στον χώρο (Linked lists) και στον χρόνο (Time sequence). Ο καθορισμός χρονικής προτεραιότητας χαρακτηρίζει τα ομοιότυπα των κλάσεων σαν διεργασίες (processes). Η εκτέλεση των διεργασιών γίνεται σε ένα ημι-παραλληλο (quasiparalled) περιβάλλον.

Ειδικότερα, όσον αφόρα την προσομοίωση, η γλώσσα SIMULA διαθέτει δύο ειδικές κλάσεις: Την κλάση SIMSET που είναι υπεύθυνη για την διαμόρφωση μίας ακολουθίας από διεργασίες και την κλάση SIMULA που είναι υπεύθυνη για τον χρονικό προγραμματισμό των διεργασιών.

Η επιλογή της γλώσσας SIMULA για να υλοποιείση λογισμικού που σχεδιάστηκε με την MASCOT έγινε για τους παρακάτω λόγους:
- Είναι σχεδιασμένη ώστε να εξυπηρετεί ανάγκες δομημένου προγραμματισμού.
- Εχει σχετικά απλές και γενικής μορφής δομές.
- Είναι αρκετά διαδεδομένη και εφαρμόζεται με αποτελεσματικό και ασφαλή τρόπο σε πολλούς υπολογιστές.
- Είναι προσανατολισμένη προς τις διεργασίες έτσι ώστε να απεικονίζεται καλύτερα το πρόβλημα.
- Εχει αυστηρή και σαφή τεκμηρίωση (Documentation).

5. ΠΕΡΙΓΡΑΦΗ ΜΟΝΤΕΛΟΥ ΠΡΟΣΟΜΟΙΩΣΗΣ

Το σύστημα προσομοίωσης που δημιουργήθηκε σχεδιάστηκε ακολουθώντας τις αρχές της MASCOT. Ο πυρήνας MASCOT βασίστηκε πάνω SIMULA, στην οποία γράφτηκε και ο απαιτούμενος κωδικας.

Οπως φαίνεται στο σχήμα 4 το σύστημα προσομοίωσης αποτελείται από τις εξής δραστηριότητες:
- Δημιουργία της τοπολογίας (δραστηριότητα 1)
- Δημιουργία των δεδομένων και του σήματος διευρυμένου φάσματος (δραστηριότητα 2)
- Δημιουργία του καναλιού σηματοδοσίας (δραστηριότητα 3)
- Μηχανισμός διάχυσης (δραστηριότητα 4)
- Δέκτης (δραστηριότητα 5)
- Μηχανισμός υπολογισμού απόδοσης και εκτύπωση (δραστηριότητα 7 και 8)

Κάθε μία από αυτές τις δραστηριότητες αποτελείται από έναν αριθμό κλάσεων.

Στο σχήμα 5 βλέπουμε τα ομοιότυπα των κλάσεων που αποτελούν τις δραστηριότητες του τμήματος εκπομπής να λειτουργούν ταυτόχρονα. Το τμήμα αυτό υλοποιείται από τον συνδυασμό των δραστηριοτήτων 1,2,3,4. Η χρονική συσχέτιση των δραστηριοτήτων αυτών, γίνεται από τους μηχανισμούς της SIMULA και παριστάνεται απο την δραστηριότητα 6. Η δραστηριότητα αυτή είναι ο πυρήνας της MASCOT.

Το μοντέλο αυτό προσομοίωσης θα χρησιμοποιηθεί για τον υπολογισμό της απόδοσης του συστήματος. Ειδικότερα θα υπολογιστούν:
- Η προσφερόμενη επιβιωσιμότητα.
- Οι βέλτιστες διαστάσεις του δικτύου.
- Οι καθυστερήσεις.
- Η πιθανότητα σύγκρουσης.
- Η πιθανότητα κορεσμού.
- Η απόδοση του φυσικού μέσου.

- Το απαιτούμενο chip rate.
- Ο ρυθμός σφαλμάτων (BER).
- Η κίνηση που μπορεί να υποστηρίξει κ.λ.π.

6. ΣΥΜΠΕΡΑΣΜΑΤΑ

Στην εργασία αυτή παρουσιάστηκε ένας νέος τύπος Τ.Δ. και η φιλοσοφία που ακολουθήθηκε για την μελέτη της απόδοσης του μέσω εργαλείων προσομοίωσης.

Το Τοπικό αυτό Δίκτυο παρουσιάζει υψηλό βαθμό επιβιωσιμότητας και πολύ μικρές καθυστερήσεις στην άφιξη του σήματος στον προορισμό του. Η πιθανότητα σύγκρουσης της πληροφορίας είναι μικρή και εξαρτάται και από την γεωμετρική κατανομή των χρηστών.

Η μελέτη της απόδοσης γίνεται με την κατασκευή ειδικών εργαλείων λογισμικού. Τα εργαλεία αυτά σχεδιάσθηκαν με χρήση των αρχών της MASCOT στην SIMULA. Μέσω αυτών τόσο η επιβιωσιμότητα όσο και τα λοιπά χαρακτηριστικά του δικτύου θα υπολογιστούν.

Ευχαριστίες

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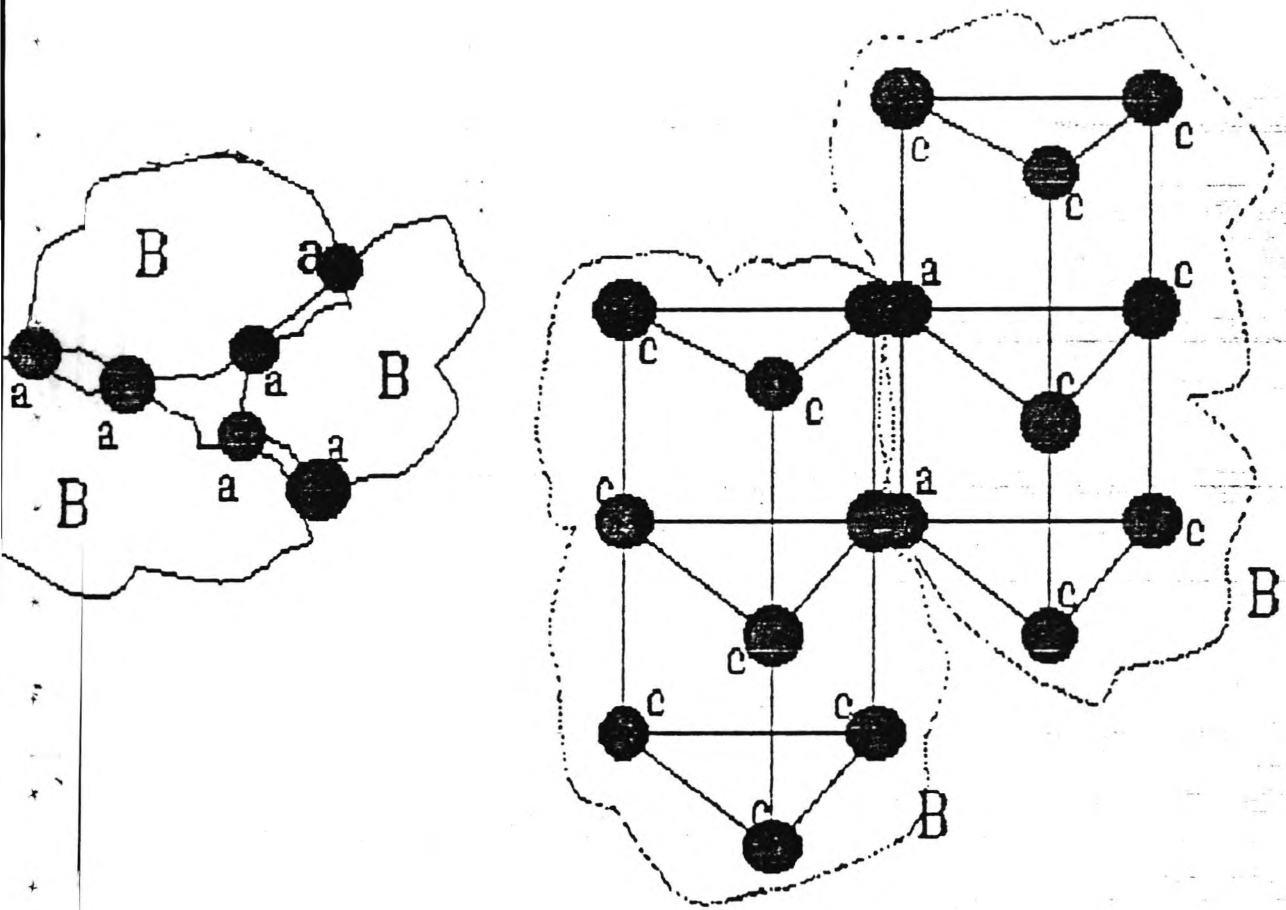
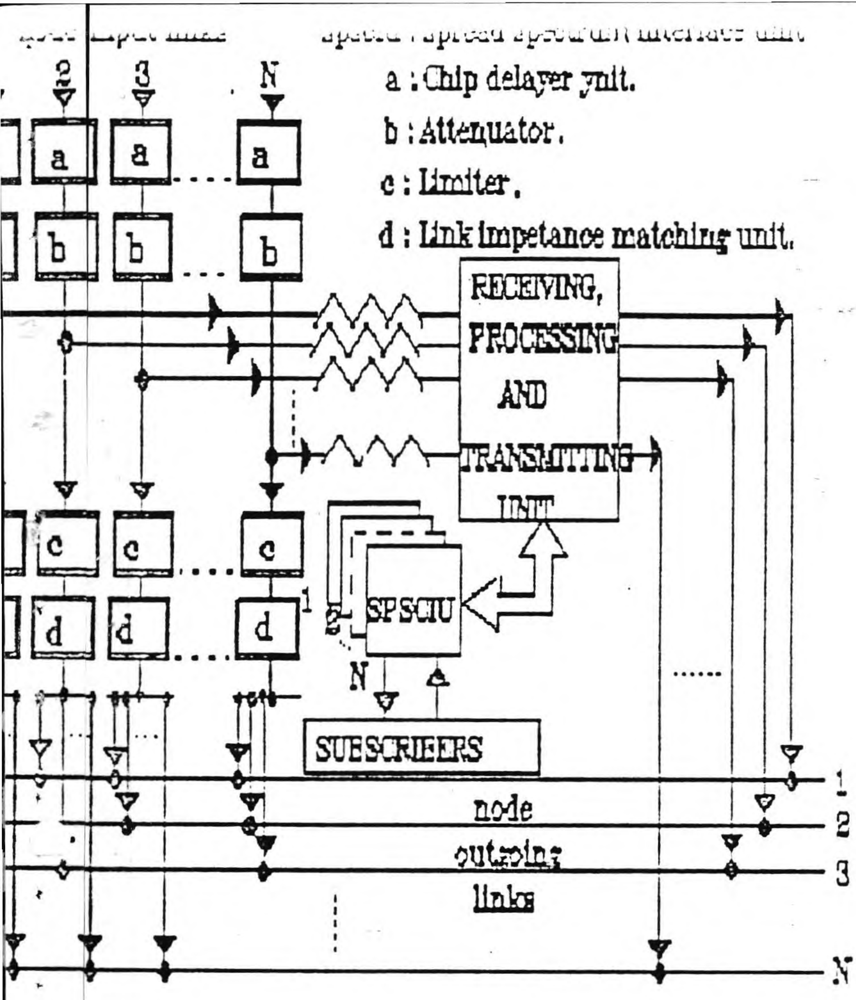


a : Μονάδες Διασύνδεσης Υποδικτύων

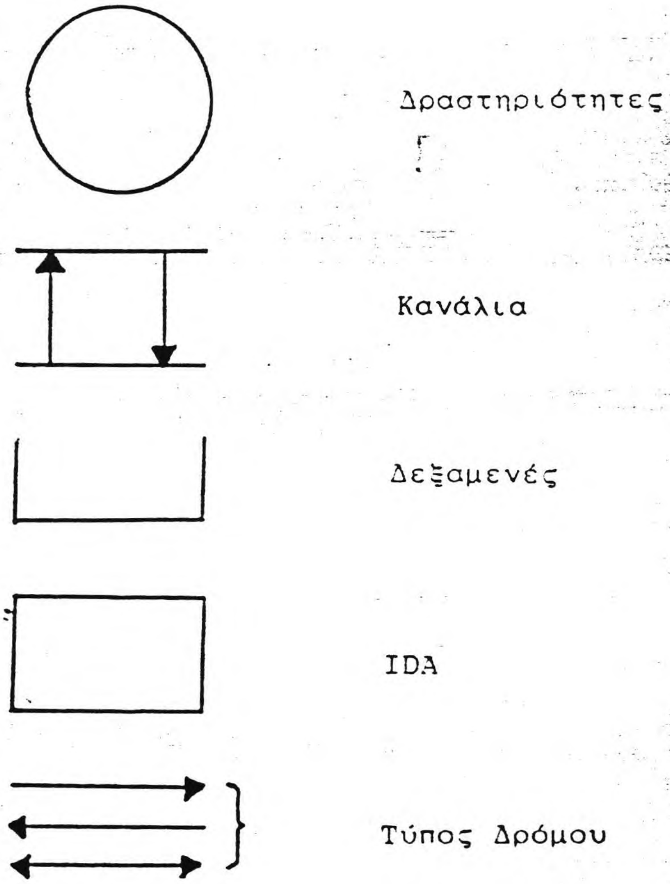
B : Υποδίκτυο

c : Κόμβοι

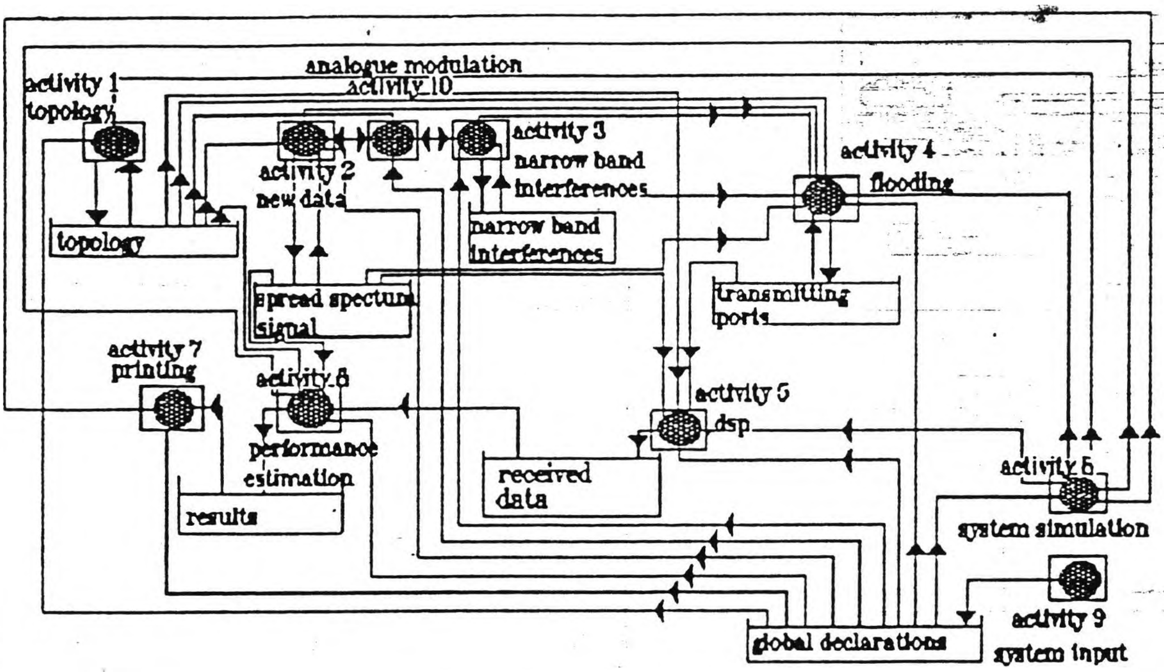
Σχήμα 1 : Τοπολογία Δικτύου



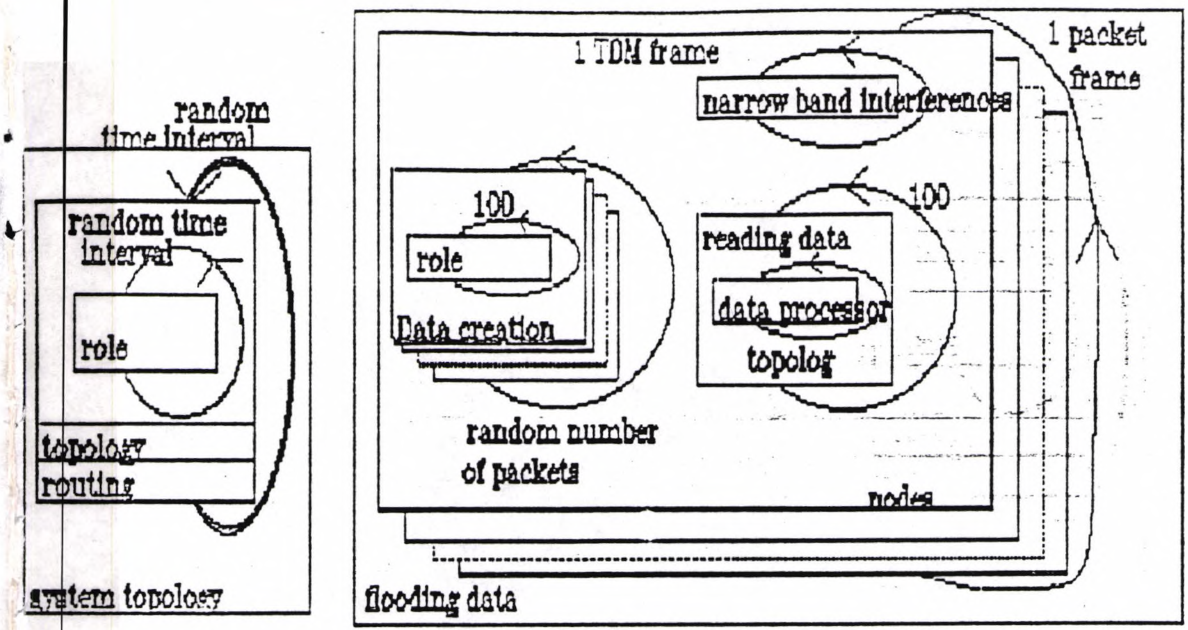
Σχήμα 2 : Δομή Κόμβου



Σχήμα 3 : Σύμβολα MASCOT



Σχήμα 4 : Η Μηχανή MASCOT του Δικτύου



Σχήμα 5 : Παράλληλη Επεξεργασία των Δραστηριοτήτων του Τμήματος Εκπομπής

Dr Victor B Lawrence
Editor-in-Chief
AT & T Bell Labs
Room 1P-246
200 Laurel Avenue
MIDDLETOWN, NJ 07748
USA

6 November 1991

Dear Dr Lawrence

I enclose five copies of a paper entitled 'Traffic Estimation of a spread spectrum LAN" by T Mastichiadis, E.Economou and myself. We would like this considered for publication in IEEE "Selected areas in Communications" Journal.

We selected this Journal because of the 'Call" in the January 1991 issue for more papers in the Networks, Systems and Services areas. However, if the subject does not fit forthcoming issues, we would be pleased if you could forward the manuscript to an appropriate editor of the Transactions on Communications.

I would like to add a comment about the diagrams submitted with the paper. I regret they are not of very good appearance, which arose from the paper being partly prepared in London and partly in Athens, and some incompatibilities in the Software we used to prepare the paper. If the paper is accepted, we shall be able to provide better quality diagrams. The equations are poorly laid out for the same reason.

I hope these problems will not cause difficulties for your reviewers.

I look forward to hearing from you about the acceptability of the paper.

Yours sincerely

PROFESSOR A C DAVIES

Encs.

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TITLE OF PAPER (hereinafter, "The Work"): TRAFFIC ESTIMATION OF A SPREAD-SPECTRUM LAN BUILT ON A MESH TOPOLOGY

AUTHOR(S) T. MASTICHIADIS, E. ECONOMOU, A DAVIES

PUBLICATION TITLE/DATE: SELECTED AREAS IN COMMUNICATIONS

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TRAFFIC ESTIMATION OF A SPREAD SPECTRUM LAN BUILT ON A MESH TOPOLOGY

THEODOROS MASTICHIADIS

(Centre for Information Engineering, City University, Northampton Square, London, EC1V 0HB, England)

ELEFTHERIS ECONOMOU

(Department of Informatics, University of Athens, Typa Building, 15771, Athens, Greece).

ANTHONY DAVIES

(Department of Electronic and Electrical Engineering, King's College, University of London, Strand, London, WC2R 2LS, England)

ABSTRACT

The topology and the protocols of a novel type of local area network (LAN) are presented. The suggested mesh topology is designed as a set of intercommunicating graphs. This LAN uses spread spectrum techniques as multiple access method, in order to achieve simultaneous access to the network with a low probability of collision. The LAN is characterised by modularity, survivability, security and a relatively low bandwidth of the physical channel. Parameters that influence the topology and the traffic load of such a LAN are examined, and estimates presented of the traffic capacity as a function of the number of subscribers.

1. Introduction

Current technological trends in design of Local Area Networks (LANs) include the use of spread spectrum (spsc) techniques (1,2). Some LANs of this type already exist (3), while others are under development (4,5,6). All these are based on a bus structure. Although they have the advantages of the Code Division Multiple Access (CDMA) method, which includes simultaneous access to the network by many subscribers, privacy or security, similar performance of all the created "virtual" communication channels etc., they suffer from lack of survivability. Survivability is important in cases where uninterrupted operation is required.

The LAN proposed in this paper aims to improve the survivability by means of a fully distributed structure using a mesh topology with separate sub-LANs and by distributing the signals at each node for onward transmission by means of a passive flooding protocol.

The paper is organised as follows: In section 2 an overview of the proposed topology and the flooding protocol is given. Section 3 presents a power analysis of the nodes and gives estimated results of the number of users as a function of the traffic load that this LAN can support. Further estimates of the performance of the LAN (not presented here) have been based on simulation using the Simula 67 language (7). Conclusions are presented in section 4.

2. Description of the Spread-Spectrum LAN

2.1 The Topology

For survivability reasons a fully distributed architecture is suggested for the LAN. A mesh topology has been chosen, involving multiple routes between any node. The routing of signals around the network is based on the concept of passive flooding. This means that the incoming signal at any node is distributed equally to all the

outgoing ports for onward transmission in such a way that the total incoming power is greater than the total outgoing power. In principle this implies that the process is a passive one although in practice amplifiers may be needed, because of line impedance matching requirements. Clearly such a passive flooding procedure results in numerous signal echoes being transmitted around the network (comparable to multi-path distortion radio communications). However, the choice of the spread spectrum technique provides immunity against delayed echoes of signals, enabling the synchronised signal to be decoded at the destination node. The failure of any link carrying this synchronised signal will generally not cause a break in communications because then, another synchronised signal will be available at the destination node which has arrived via another route.

Another requirement to be achieved is the creation of a secure system. The current trend in successfully providing data security in computer networks is through the isolation of the highly-secure data within groups of intercommunicating workstations. These groups are interconnected with secure bridges. Therefore, for fulfilment of this requirement, the LAN topology is characterised by the separation of the nodes into groups, named Sub-LANs. In this way users that have similar characteristics or work under the same security requirements or restrictions, are allocated to the same Sub-LAN.

Each one of the Sub-LANs serves a particular part of the total traffic. The size of the Sub-LAN influences the echoes created and consequently affects the Signal to Noise Ratio (SNR) and hence determines the minimum transmission rate needed to obtain the required processing gain (PG) for the spread-spectrum communication. This processing gain is needed to recover the wanted signal from its multipath echoes (e.g. versions arriving via other routes) and from the other traffic on the LAN. The Sub-LANs intercommunicate through Sub-LAN Interconnecting Units (SIUs).

The philosophy that is used for the connection of the Sub-LANs influences the traffic load that can be supported, the inter-Sub-LAN data stream and the overall performance characteristics. According to this philosophy various topologies can be created with differing degrees of survivability and performance.

The topology used is illustrated by Figure 1, and is fully distributed and modular. It offers a high degree of survivability, good performance and relatively low required transmission rates. Each of these Sub-LANs has the possibility of being connected via SIUs to any other Sub-LAN, so providing intercommunication with it. Such a structure resembles a fully connected graph, with each vertex corresponding to a Sub-LAN and each edge to a SIU. This structure contributes to making the system very robust. Because of the immediate access of any Sub-LAN to any other one, the performance characteristics - (bit error rate, collision probability, throughput, transmission delays) - and survivability are improved, due to the inter-Sub-LAN traffic minimisation and consequently to the reduction of the noise power inside the sub-LANs.

Figure 2 illustrates the philosophy used for the design of the graph of a Sub-LAN. It consists of a number of similar, fully connected, subgraphs (denoted category B). A serial number (SN) is allocated to every node of a subgraph. All the nodes of the various subgraphs of category A of the Sub-LAN that have the same SN are connected in such a way as to create another fully connected subgraph (denoted category A). In this way the topology achieves a symmetry and offers survivability.

In addition to the spread-spectrum signals, a narrow-band time division multiplex (TDM) signal (as described below) is provided throughout the LAN for the distribution of timing and synchronisation information, and assists with the network reconfiguration in the event of a link failure.

The spread spectrum technique employed in combination with the passive flooding protocol ensures that communication takes place over the shortest path between any pair of source and destination nodes of the same Sub-LAN. This path results in a signal synchronised with the locally-generated pseudorandom sequence at the receiving destination, whereas signals (echoes) arriving at the receiver via other longer paths are not synchronised and so are not decoded by the correlation procedure used to recover the wanted signal. In the event of a failure in one of the links of the path or at an intermediate node, the shortest path along the many other alternative paths which exist is always selected by the same protocol. This mechanism provides survivability over interruptions and failures in links and nodes.

Figure 3 shows the block diagram of the main modules required for the implementation of a node. The nodes monitor the incoming links. Amplitude limiters separate the TDM information, which is used for signalling reasons, from the spsc signal that carries the data. The TDM information is processed separately. It is received and transmitted through the TDM Processing Unit. The spsc information is exchanged with the users connected on the node via Spread Spectrum Interface Units (spsciu). The outgoing spread spectrum data is transmitted through a Spread Spectrum Signal Transmission Unit. The flooding of the incoming information is achieved through the Flooding Matrix Unit.

2.2 Protocol description

The protocol of the proposed LAN entails the following features:

- 1. a passive flooding routing method as described above
- 2. the spread spectrum direct sequence (DS) technique
- 3. an independent signalling channel.

As explained in Section 2.1, the routing scheme, based on passive flooding, involves every node retransmitting all incoming signals along every outgoing link. Therefore together with the signal many echoes are also created. These echoes act as wideband background noise. They depend upon the topology and are absorbed gradually by the transmission losses of the paths.

The degree of a node is defined as the number of links connected to it. If the incoming power to some node from one of its input ports is W_{in}, then the power W_{out} at each output port of this node is given by the following formula :

$$W_{out} = (W_i(1 - c)) / (d - 1)$$

where

c : attenuation due to propagation between the output of the node and the input of the next node plus the attenuation of the matching network at the input of this next node.

d : degree of the node.

An example of the attenuation process of a signal is shown in figure 4.

Because of the use of the spread spectrum technique, the users connected to a node can gain access to the network by code division multiple access (CDMA), without having to determine in advance if the medium is idle, as is required by Ethernet systems. Simultaneous access by many users is possible because each one selects a spreading sequence uncorrelated with the others: The choice of sequence is determined by the identity of the receiver and not by the identity of the transmitter. Therefore congestion occurs only when more than one user wishes to transmit data to the same destination at the same time, and more than one synchronised signal arrives at the node of the destination through the same port.

In addition the combination of the spread spectrum technique with packet switching allows multiple access to the network with low probability of collision or congestion. This results in good message delivery time.

Modulation of the data at the transmitter of the node is by the standard direct-sequence method of spectrum-spreading using a high bit rate pseudo-random binary sequence. This transmission rate is known as the chip rate. The sequence is selected from a large family of sequences which form a set with low mutual cross- correlation. Methods of choosing such families of sequences are well-known. There is a one to one correspondence between these sequences and the receivers. In this way addressing becomes inherent in the system as it simply involves choosing the particular sequence allocated to the intended destination.

After the data signal has been modulated in this way it is distributed to all outgoing links in accordance with the passive flooding method.

Every receiving unit senses the transmission medium and a locally-generated pseudorandom sequence is correlated with the incoming data. This sequence is the particular one which defines the address of the receiving user, and so if the received signal includes data that has been modulated with the same sequence and is synchronised with it, then this means that there is data addressed to this particular receiver. In this case the correlation process reduces the bandwidth of the appropriate part of the incoming signal, so achieving demodulation and recovering the data intended for this destination. Other components of the received signal (echoes and transmissions intended for other destinations) will be uncorrelated with the local sequence, and so will not have their bandwidth reduced, but on the contrary will remain spread over the full transmission bandwidth.

In order to distribute timing and signalling information over the LAN a separate time-division multiple (TDMA) channel is proposed. Simultaneously with the spread spectrum data transmission channels and the same frequency band, a signalling channel is provided which operates on a scheme called active flo Using this scheme every node receives, processes and retransmits the signalling information along all ou links. All nodes and users share this channel on a slotted (TDMA) basis. The allocation scheme of the s the nodes is permanent and continuous. This TDM channel guarantees the continuous availability of and synchronisation information, routing information, information about the status of the subsc acknowledgment information etc.

The synchronisation and timing information is essential for the transmitter nodes to be able to transn pseudorandom spreading sequence for a particular receiving node with the appropriate phase.

The use of more than one user and spsciu per node reduces the size of the sub-LANs and locally modifi signal power of the accumulated echoes. This also reduces the survivability of the LAN, because in the c the failure of any such node more than one user will be disconnected. On the other hand this t configuration creates local groups of work-stations or users comprising all the stations connected on the node and so local survivability is inherent in the system.

The good overall survivability properties are achieved by the mesh topology, by the properties of the p flooding protocol and by the synchronisation information that is provided through the operation of the channel. Through these protocols the LAN acts as a kind of a self-learning machine that always finds th topology, following disconnections, interruptions and failures in links or at nodes.

The structure provides security based upon two hierarchical levels. The first (lowest) level is the node a the second one is at the SIUs. The system controls the information flow both before the output of the nc the Sub-LAN and before transfer from one Sub-LAN to an other one at the SIUs. The SIUs act as t bridges between the sub-LANs. The degree of security achieved depends upon two factors cryptographic-security provided by the spreading code and the control at the exit of data from one Sub-L an other.

3. Power analysis and traffic supported

3.1. Power analysis

The performance of the proposed network is influenced by many interacting factors. Among those hav dominant role are the achievable chip rate, the spatial distribution of the active users, the topology of the and the traffic load.

In this section the traffic that can be supported is examined in relation to the topology and the numb subscribers that can be served taking into consideration the requirements for survivability.

The estimations are based on the environment of a Sub-LAN, with the following simplifying assumptions :

- Every one of the users of a Sub-LAN is transmitting data packets to a station of another Sub-LAN and at the same time is receiving data from a subscriber of another Sub-LAN.
- The flooded data are packets of constant size transmitted at random time intervals.
- The traffic created by any user will be examined as a parameter that describes the normalised average time that the user occupies the channel.
- The link attenuation is zero (the attenuation of connecting cables or optical fibers is assumed to be compensated for by appropriate signal-amplification at the input of each node).
- All the nodes of a Sub-LAN have the same degree.
- The channel noise is low enough that it can be ignored.
- The flooded power accumulates at the nodes in accordance with a homogeneous distribution model, as if the physical links that interconnect the nodes of the Sub-LANs do not exist and every node is directly connected to the other ones.
- The transmitted signals are continuously flooded.
- All the physical links are unidirectional.
- Each pair of Sub-LANs is connected together by two SIUs for survivability reasons.

- The SIU are uniformly and symmetrically distributed all over the Sub-LAN, so that the inter Sub-LAN traffic is homogeneously distributed all over the sub-LAN.
- One period of the spreading sequence corresponds to one data bit.
- The spreading sequences used are maximal length linear binary sequences. This assumption is adequate for performance estimation, although other sequences might be used in practice.
- The signal initially flooded into the network by a user is transmitted along the route of the shortest virtual path. The required routing information is available through the continuous operation of the TDM channel.
- The voice and/or data transmission bit rate is 64000 bits/sec.

The following parameters are taken into account in the performance estimates :

- The power, W, transmitted by a user.
- The number, q, of subscribers per node.
- The number, m, of fully connected subgraphs that comprise any Sub-LAN, and the number, s, of nodes that the subgraph contains.
- The total number, N, of subscribers per LAN.
- The attenuation, c, of any link of the Sub-LAN. ($0 < c < 1$ as described above.)
- The number, h, of nodes that form the shortest virtual path between any two nodes.
- The required chip rate, B, in kilochips/sec.
- The required chip sequence-length, e, for the Sub-LAN.
- The number, j, of Sub-LANs of the LAN.
- The total number, g, of subscribers per Sub-LAN.
- The degree, d, of the nodes.
- The processing gain PG.
- The average normalised time, f, that the traffic created by any user occupies a virtual communication channel.
- The number of stages, n, of the shift register that produces the pseudorandom sequence.

The average total power, W_t, that exists throughout any one of the Sub-LANs will be the power of the initial transmissions, $2\,g\,f\,W$, plus the power arising from the echoes of the previously transmitted, flooded and attenuated packets. The upper limit of W_t may be calculated as follows:

$$W_t = 2fgW(1 + p + p^2 + p^3 + \ldots + p^n + \ldots)$$

$$W_t = 2fgW \sum_{n=0}^{\infty} p^n$$

$$W_t = 2fgW[1/(1 - p)]$$

Since $p = 1 - c$ and $0 < p < 1$,

$$W_t = 2fgW / c$$

where $g = q(k-2(j-1))$ and the number of nodes of a sub-LAN is $k = s\,m$

If we consider a particular transmission and we examine the power W_d of the received signal at the destination, then, as a function of the transmitted power, W, this will be given by:

$$W_d = p^h W / (d - 1)^{h-1}$$

where $d = m + s - 2$

because the signal has been received by the node but not flooded by it yet (Figure 4). The total attenuation that is imposed on the signal depends upon the number of nodes that compose the virtual path that connects

the source of the signal with the destination. Therefore there is a limit to the maximum number of nodes that the shortest path between two subscribers could be allowed to have. This limit is highly dependent upon the particular topology used, the attenuation at the input port of a node and the chip rate. Table 1 presents such results for a LAN of 240 subscribers.

If we assume that the total power is not distributed all over the network (links and nodes) but that is gathered at the nodes, then the existing power W_n, at a particular input port of a node will be the total power divided by the number of nodes, k, and the number of input ports, d, less the locally transmitted power:

$$W_n = (W_t / kd) - Wqf$$

$$= \{ 2[k - 2(j - 1)] - (1 - p)kdWqf \} / [(1 - p)kd]$$

Thus the signal to noise ratio, SNR, at any input port of this node is given by:

$$SNR = W_d / (W_n - W_d)$$

$$SNR = p^h(1 - p)kd / \{ (d - 1)^{h-1}[2(k - 2(j - 1)) - (1 - c)kd]qf - p^h(1 - p)kd \}$$

For a spread spectrum receiver the output signal to noise ratio, SNR_{out}, after the correlation procedure used to recover (de-spread) the wanted signal is given by:

$$SNR_{out} = PG.SNR = (B/B_{inf})SNR = (B_{inf}.e/B_{inf})SNR$$

$$\therefore\ SNR_{out} = e.SNR$$

B_{inf} denotes the information-data bit rate in kbits/sec.

For a matched filter demodulator the required e is estimated to be given by (8):

$$e = 2.SNR_{out}.Q$$

where

$$Q = (d - 1)^{h-1}[2(k - 2(j - 1)) - (1 - p)kd]qf - p^h(1 - p)kd / [p^h(1 - p)kd]$$

The actual transmission chip rate of the spread spectrum LAN is the information transmission bit rate multiplied by the length of the pseudorandom spreading sequence. With the assumption that a maximal length linear sequence is used, the period length is an integer of the form $2^n - 1$, which must be chosen so that it is greater than or equal to the period, e, required to meet the SNR requiremnents. Hence the actual transmission chip rate, B, will always be greater than or equal to e times the data rate:

$$B = 64.10^3(2^n - 1) \geq 64.10^3 e$$

Let a be a bandwidth efficiency coefficient, where $0 < a \leq 1$, defined by $e = a(2^n - 1)$. The larger a is, the better is the utilisation of the bandwidth by the users of the sub-LAN and the less is the redundancy. This redundancy may be used for the support of inter-Sub-LAN traffic (in this case users of different sub-LANs could still intercommunicate through a third sub-LAN when failures occur). The smaller a is the more inter-sub-LAN traffic may be supported by the system.

3.2. Traffic supported

The number of users that any particular topology may support is not constant and depends upon the chip rate used. The higher the chip rate is, the higher is the processing gain, and consequently a higher power due to echoes can be tolerated.

The performance of all the virtual channels created during the communication of any two users is the same and depends upon the instantaneous traffic load and the echoes at any particular link or node. As the traffic is increased the performance is reduced in the same way for all the channels of this particular link or node. Any change of the topology influences the noise environment because of the echoes. So for any particular chip rate the amount of traffic that may be served successfully by the LAN is a function of the topology.

We define the Topology Spreading Coefficient (TSC) as a measurement of the density of users of the LAN in relation to the complexity of the topology and to the size of the LAN :

$$TSC = j^2 d^2 / q$$

The smaller TSC is, the smaller is the number of nodes of the LAN and the greater is the number of users per node. The higher TSC is the more the users are spread over the geographical area of the LAN.

The surface of figure 5 gives a picture of the Topology Spreading Coefficient. Point 'A' corresponds to a small and dense LAN. Point 'B' corresponds to a LAN with a topology that has many nodes and a few users (TSC=7056, 324 users, one user per node, 354 nodes and 6 sub-LANs). Point 'C' corresponds to TSC=2592, 456 users distributed to 6 Sub-LANs 258 nodes, having connected two users per node. The peaks 'D', 'E', 'F', 'G' of this surface correspond to the same topology with the one of point 'B' increasing the number of users connected on a node, at each one of them, by one. At point 'G' there are 6 users per node. The Topology Spreading Coefficient of any particular topology is reduced as the number of users per node is increased.

The surface of figure 5 gives a first understanding of the characteristics of the topology (nodes, users) that corresponds to each value of the Topology Spreading Coefficient. Further information about the topologies that correspond to any particular value of Topology Spreading Coefficient can be obtained from data we have obtained and tabulated. Every one of these topologies has its own requirements in chip rate for serving the same amount of traffic, as is shown by Figures 7 and 8.

Figure 6 describes the traffic that can be supported as a function of the number of users and of the chip rate. The variation of the values around the minima of points 'A', 'B', 'C', 'D', 'E', 'F' for 153 users are the results of the influence of the number of the sequential floodings (2, 3 or 4 hops) and of the total attenuation per link (20% or 10%). The variation of the traffic supported along the axes of users is due to the change of the value of the size (spreading) of the topology that is given by TSC. These parameters do not appear in the Figure but have been taken into account in the estimations. The influence of the chip rate and of the traffic due to the attenuation and the number of the sequential floodings is also shown in TABLE 1.

The surfaces of Figures 7 and 8 show the traffic that can be supported by the system as a function of the TSC and of the chip rate for a virtual path of two or three sequential floodings between the transmitter and the receiver.

In both Figures 7 and 8 the chip rate depends upon the Topology Spreading Coefficient and the traffic. The more distributed the topology is the higher is the traffic that may be supported with a relatively low chip rate. The existing local peaks are due to particular topologies that are widely spread in the geographical sense (for example the local peak of figure 8 between the points 'A' and 'B').

Both the surfaces of Figures 7 and 8 have been drawn for a total attenuation at the input of any node of 10%, and a 30% redundancy in the required chip rate for serving inter-sub-LAN traffic.

4. Conclusions

This paper has given an overall description of a suggested spread spectrum LAN built on a modular, cellular mesh topology. Depending upon the configuration and size of the modules, the number of connected users varies. This architecture offers security, survivability and a good performance. The topology used is fully distributed and offers many alternative paths between nodes. The protocols proposed give an ability to learn the topology of the system existing at any time. The users and the traffic that may supported are always a function of the topology.

The results of further simulation studies of this LAN support the analysis presented in this paper.

The main qualities that could be expected from an implementation of this LAN can be summarised as: almost contention free multiple access, high throughput, privacy or security, survivability, noise resistant communication, integrated traffic, inherent addressing capabilities, possibility of grouping of the users in separate sub-LANs according to their features, requirements and security demands, simultaneous access to the network, low time delays, low congestion probabilities, and the same performance for all the virtual communication channels within any link.

6. Acknowledgments

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TABLE I

THE INFLUENCE OF THE CHIP-RATE ON THE TSC, THE ATTENUATION AND THE HOPS

TSC: TOPOLOGY SPREADING COEFFICIENT (see SECTION 3.2)

B: REQUIRED CHIP RATE (kilochips / sec)

N: TOTAL NUMBER OF SUBSCRIBERS SERVED BY A LAN

TRAFFIC: PERCENTAGE OF CHANNEL OCCUPANCY PER USER IN TIME UNIT

ATTENUATION: ATTENUATION OF ANY LINK PLUS THE MATCHING ATTENUATION

HOPS: NUMBER OF SEQUENTIAL FLOODINGS THROUGH THE SHORTEST VIRTUAL PATH BETWEEN THE SOURCE OF THE DATA AND THE DESTINATION

B	TRAFFIC	TSC	N	NODES	ATTENUATION	HOPS
2788.6	0.80	88.20	240	54	20%	2
9002.9	0.30	88.20	240	54	20%	3
80629.8	0.40	88.20	240	54	10%	3
71681.4	0.30	88.20	240	54	20%	4
2422.5	0.30	144.00	240	66	20%	3
73924.2	0.40	144.00	240	66	10%	3
35089.2	0.40	144.00	240	66	20%	4
88682.9	1.00	144.00	240	66	20%	4
75940.2	0.40	182.25	240	66	10%	3
39919.7	0.30	256.00	240	72	10%	3
80479.3	0.60	256.00	240	72	10%	3

TRAFFIC ESTIMATION OF A SPREAD SPECTRUM LAN BUILT ON A MESH TOPOLOGY

Figure Captions

Fig. 1. The structure of the suggested topology

Fig. 2. An example op a sub-LAN of 20 nodes.

These nodes are distributed over four subgraphs of five nodes of category 'A' and five sub-graphs of four nodes of category 'B'.

Fig. 3. The block diagram of a node

a : impedance matching unit

b : chip delay unit

c : limiters

d : TDM buffers

e : TDM processing unit

f : Initial synchronisation unit

g : spread spectrum signal transmission unit

i : first node definition unit

l : spsciu

m : users

n : flooding matrix unit

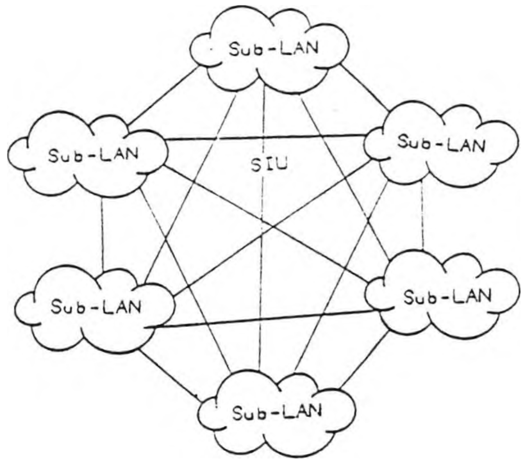
Fig. 4. The attenuation introduced in a path which consits of n nodes

Fig. 5. The TSC as a function of the users and the nodes

Fig. 6. The traffic as a function of the users and the chip rate (CR)

Fig. 7. The traffic as a function of the chip rate (CR) and the TSC for two hops

Fig. 8. The traffic as a function of the chip rate (CR) and the TSC for three hops



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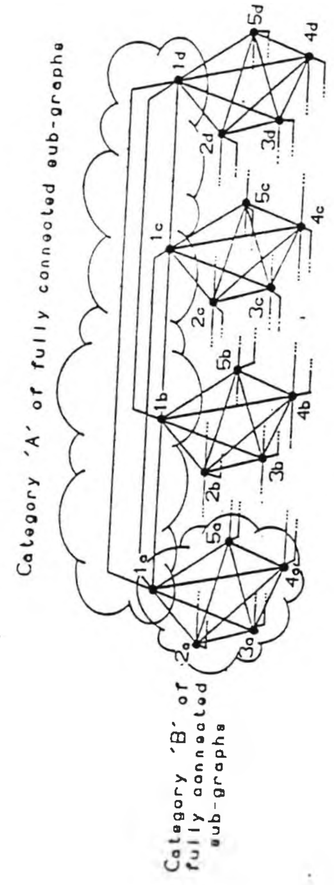

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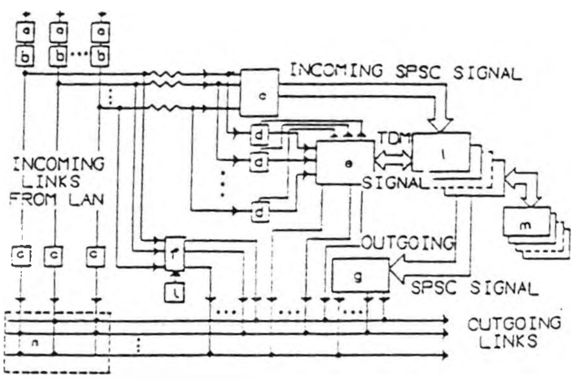

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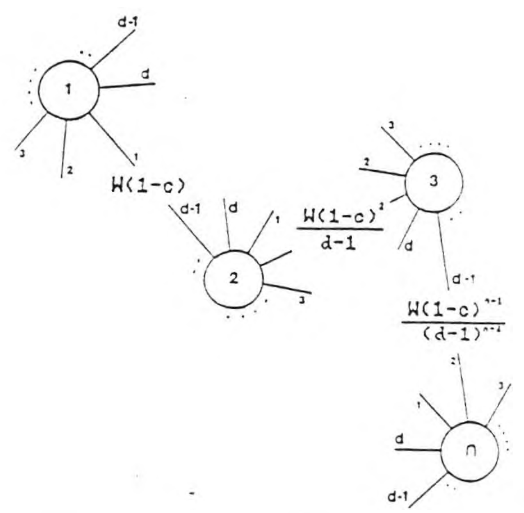
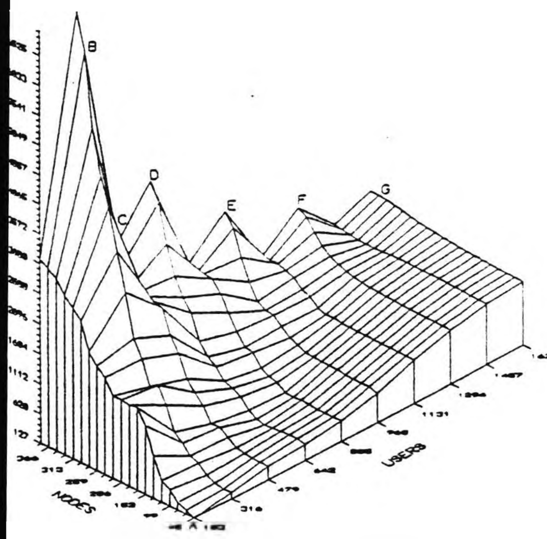


Fig. 4. The attenuation introduced in a path which consists of n nodes



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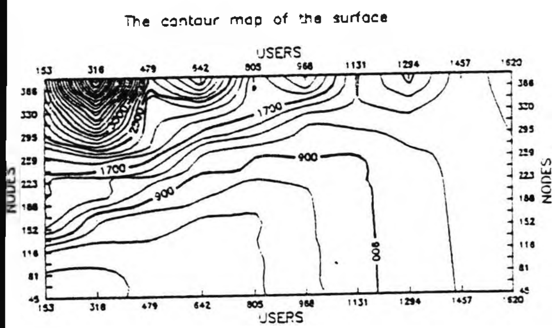


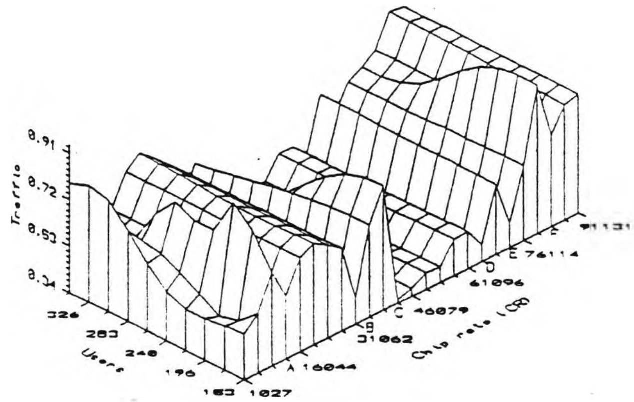


Fig. 6. The traffic as a function of the users and the chip rate (CR)

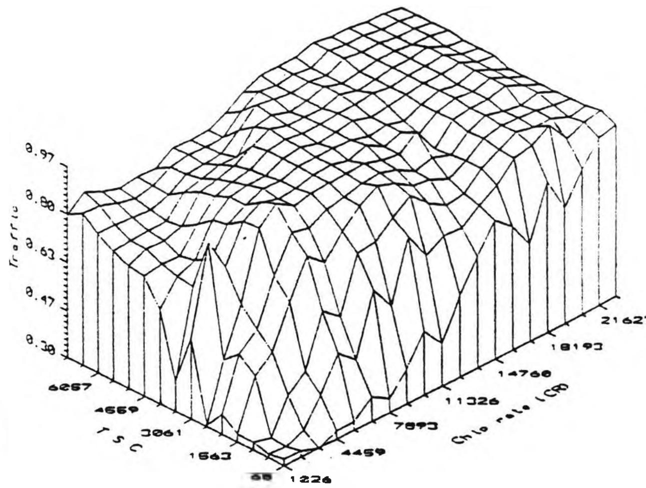


Fig. 7. The traffic as a function of the chip rate (CR) and the TSC for two hops

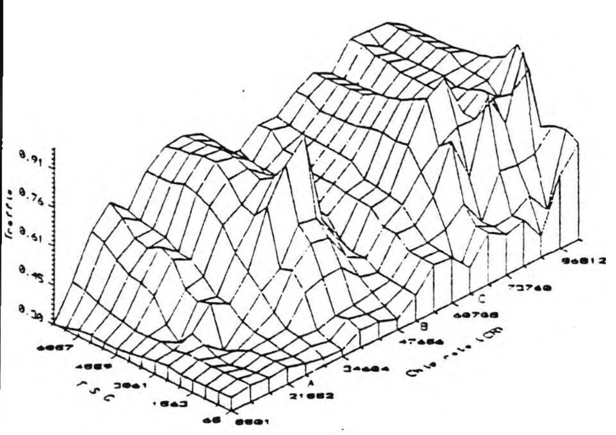
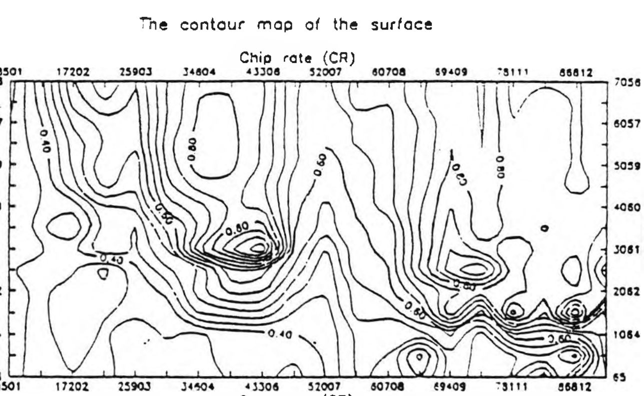


Fig. 8. The traffic as a function of the chip rate (CR) and the TSC for three hops



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computer communications

PO Box 140
Aldershot
Hants GU12 5QX, UK
Tel: 0252 519239

B H

9th October 1992

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Dr E G Economou
Dept of Informatics
University of Athens
Panepistimiopolis, TYPA Buildings
15771 Athens
GREECE

Dear Dr Economou,

Thank you for submitting your paper 'Design principles and performance results for flooding routing mesh topology spread spectrum LANs' for publication in *Computer Communications*.

I am arranging for the paper to be sent out to our referees, and as soon as I receive their comments I will let you know of its suitablity for publication in the journal.

Please note that all correspondence regarding the journal should be directed to me at the above address.

Yours sincerely,

Jeremy Thompson
Editor, *Computer Communications*

DESIGN PRINCIPLES AND PERFORMANCE RESULTS FOR FLOODING ROUTING MESH TOPOLOGY SPREAD SPECTRUM LANs

THEODOROS MASTICHIADIS: (Centre for Information Engineering, The City University, Northampton Square, London, EC1V OHB, England)

ELEFTHERIS ECONOMOU: (Department of Informatics, University of Athens, Typa Building, 15771, Athens, Greece).

ANTHONY DAVIES: (Department of Electronic and Electrical Engineering, King's College, University of London, Strand, London, WC2R 2LS, England).

ABSTRACT

This paper presents a family of mesh topology LANs. This family of LANs uses spread spectrum techniques as a method for media access control, in order to enhance the simplicity, to offer the possibility of simultaneous access to the network as well as to provide similar performance to all communication channels while reducing the probability of collision. For routing flooding algorithms are proposed.

The recommended architecture is characterised by survivability, security and relatively low bandwidth requirements.

A LAN member of this family is analysed. It is built on a topology that consists of a set of inter-communicating sub-LANs and inter-connected subgraphs. The topology, the communication and the signalling protocols that support this architecture are presented. Parameters that influence the traffic load of such a LAN are examined, and estimates of the BER as a function of them are presented.

1. INTRODUCTION

The use of spread spectrum (SPSC) techniques (1,2) for Local Area Network (LAN) design has attracted a lot of interest recently. There is a number of LANs under design that use spsc technique on bus or star topology (3-9). Although these topologies offer simplicity they suffer from lack of survivability. Our proposal is based on the exploitation of the spsc techniques by using the Code Division Multiple Access (CDMA) methods (1,2) on a mesh topology. The result of this combination is the design of a LAN that has the benefits offered by the spsc with a high degree of survivability and security. Survivability is important in cases where uninterrupted operation is required. Security is required at a large number of applications, where there are classified information that must be accessible only from a restricted number of users.

The rest of this paper is organised as follows :

- Section 2 describes the principles according to which the architecture of this family of mesh spsc LANs, should be built. This is followed by an analysis of the topology of a particular LAN of this family and the protocols according to which this particular LAN operates.
- Section 3 addresses the issue of the performance evaluations of the described LAN. The evaluations have been based on simulation tools. The architecture of the simulation model and the obtained performance results as a function of the topology, of the traffic and of the protocol characteristics are discussed.
- Section 4 presents some concluding remarks.

2. DESIGN PRINCIPLES OF THE ARCHITECTURES OF THE FAMILY OF SPSC LANs BUILT ON MESH TOPOLOGY

Some of the main requirements and characteristics of a large class of LANs are survivability, security and high performance. In simple words survivability means uninterrupted operation under various conditions. This can be achieved through hardware redundancy, decentralisation, alternative routing, and dynamic reconfiguration through communication, signalling and synchronisation protocols. Security is the protection of the data against unauthorised reception. It is achieved mainly at the level of the physical layer through appropriate topology, technology and coding. At higher layers it is ensured through the use of secure protocols and passwords. High performance is achieved with low delays, low BER, high throughput and low blocking and collision probabilities, etc.

All these requirements can be fulfilled by using interconnected mesh topology spsc sub-LANs in combination with continuous retransmission of the received signal in all directions (flooding routing). These sub-LANs are groups of nodes that are connected into smaller networks. The users are connected on the nodes through spsc interface units (SPSCIU).

The mesh topology, in combination with the flooding routing, offers survivability. Multiple routes between any two nodes are provided. Any node is connected to many others in a random way or under some rules, so creating an arbitrary graph or one that has a shape produced following geometrical rules. An infinite variety of families of graphs exist that comply with these requirements. The selection of any one of them is an important factor for the design of a LAN, that influences its operation.

Figure 1 gives an example of a topology that can be used for a LAN. It is fully distributed and modular. It offers a high degree of survivability, good performance and relatively low required transmission rates. Any Sub-LANs inter-communicate through Sub-LAN Interconnecting Units (SIUs) with any other Sub-LAN. Such a structure resembles a fully connected graph, with each vertex corresponding to a Sub-LAN and each edge to a SIU. This topology makes the LAN robust. Due to the immediate access of any Sub-LAN to any other one the survivability is improved, the inter-Sub-LAN traffic is minimised and consequently the noise power within the sub-LAN is reduced, so providing improved performance (BER, collision probability, throughput, transmission delays).

Flooding routing protocols have the characteristic of retransmitting all incoming signals at any node along every outgoing link. There are two ways of implementing the flooding the passive and the active. At passive flooding the incoming signal is retransmitted without being demodulated, while at the active the signal is demodulated at any node and then remodulated for further transmission. Each one of them is supported by its own protocols and hardware.

With passive flooding the incoming signal at any node, is distributed equally to all the outgoing ports, for onward transmission in such a way that the total incoming power W_{in} is greater than the total outgoing power W_{out}. In principles this implies that the process is a passive one although in practice amplifiers may be needed, because of line impedance matching requirements. Clearly such a passive flooding procedure results in numerous signal echoes being transmitted around the network (comparable to multi-path distortion radio communications). However, the spread spectrum technique provides immunity against delayed echoes of signals, enabling the synchronised signal to be decoded at the destination node. The failure of any link carrying this synchronised signal will generally not cause a break in communications because another synchronised signal will arrive at the destination node through another route. The echoes act as wideband background noise. They depend upon the topology and should be absorbed gradually, otherwise the continuous increase of their power would result to infinite noise and unit BER overloading in power the network and damaging it. It is obvious that if the flooding meets the referred criteria (e.g. $W_{out}<W_{in}$), the total power cannot increase with time, it can at most stay constant.

Each Sub-LAN serves a particular part of the total traffic. The size of the Sub-LAN influences the echoes created, affects the Signal to Noise Ratio (SNR) and defines the maximum transmission rate for obtaining the required processing gain (PG). When the noise overcomes a threshold then the BER is increased as a function of the incoming SNR. The routing scheme, based on passive flooding involves every node, retransmitting all incoming signals along every outgoing link. If the incoming power to some node i from one of its input ports is W_{in}, then the power W_{out} at each output port of this node is given from the following formula :

$$W_{out} = (W_{in} \cdot c) / (d - 1)$$

where

c : Attenuation. This term describes the percentage of power that results after the appliance on the signal of any type of absorption from the output of the node up to the input of the next one, plus the matching attenuation at the input of the node. So all types of losses that are introduced during the implementation of a transmission on a physical link (e.g. impedance miss-matching, during the flooding, etc.) plus an intended loss are included in 'c'. The intended loss is used to absorb the transmitted power in the system. For example an attenuation of 0.8 means that the 80% of the signal have survived and that the rest 20% of it have been absorbed.

d : Degree of the node.

The spsc technique employed at mesh topologies in combination with the flooding protocol ensures that communication takes place over the shortest path between any pair of source and destination nodes of the same sub-LAN. In case of a failure in one of the links of this path or at an intermediate node, the next shortest path is always selected automatically by the protocol. This mechanism provides survivability over interruptions and failures in links and nodes.

The spsc technique employed in combination with the sub-LAN structure offers security. Current trends, in successfully providing data security in computer networks, are through the isolation of the highly-secure data within groups of intercommunicating work-stations. These groups are interconnected with secure bridges. Therefore, to fulfil this requirement, the LAN topology should be deployed through the separation of the nodes into groups, (Sub-LANs). In this way users that have similar characteristics or work under the same security requirements or restrictions, are allocated to the same Sub-LAN. Further the security is inherent in the spsc system through the use of the pseudorandom code and the security offered by it.

This LAN's architecture provides security based on two hierarchical levels. The first (lower) level is at the node and the second one is at the SIUs. The system controls the information flow both at the SPSCIU (before the output of the node to the sub-LAN) and before the transfer from one sub-LAN to an other one at the SIUs. The SIUs act as trusted bridges between the sub-LANs. The degree of security achieved depend upon two factors :

- the crypto security provided by the spreading code and
- the control of data at the exit from one sub-LAN to an other one, and from the SPSCIU to the node.

The use of more than one user and SPSCIU per node reduces the size of the sub-LANs and influences the signal power of the accumulated echoes. This reduces also the survivability of the LAN, because in case of the failure of any node, more than one user will be disconnected. On the other hand this type of configuration creates local groups of work-stations or users, comprising all the stations connected on the same node, so enhancing the security.

The use of the spsc techniques offers good performance characteristics, while their combination with packet switching methods reduces the probability of collision or congestion. This results to a good message delivery time.

Because of the use of the spsc technique, the users connected to a node can gain access to the network by code division multiple access (CDMA), without having to determine in advance if the medium is idle, as it is required by ETHERNET systems. Simultaneous access by many users is possible because each one selects a spreading sequence uncorrelated with the others. In this way at any physical link that connects any two nodes we have at any time the temporarily creation of virtual channels that operate at a concurrent basis and that connect particular pairs of users. The sequence's choice is mainly determined from the identity of the receiver or even from the identity of the transmitter (3). So we define congestion and collision as following :

- Congestion occurs when more than one users try to transmit data to the same destination at the same time through the same port, so that more than one synchronised signals to arrive concurrently at the node of the destination through the same port.
- Collision occurs if the total power at the receiving port of the destination node is higher than a threshold preventing demodulation of the signal. Cases of collision are created when more than one packets overlap each other, on the same link and at the same time (these packets are considered as noise the one for the other).

The modulation of data at the transmitter of the node is done with the standard direct-sequence method (1,2) of spectrum-spreading using a high bit rate pseudo-random binary sequence. This transmission rate is named chip rate. The pseudo-random sequence is selected from a large family of sequences which forms a set with low mutual cross-correlation. Methods of choosing such families of sequences are well-known (1,2). There is an one to one correspondence between these sequences and the receivers. In this way addressing becomes inherent in the system as it simply involves selection of the particular sequence allocated to the intended destination.

After the data signal has been modulated, it is transmitted toward the outgoing link through the shortest route. At the next node the signal is distributed to all outgoing links in accordance with the passive flooding method.

Every receiving unit senses the transmission medium. A locally generated pseudorandom sequence is correlated with the incoming data. This sequence is the particular one which defines the address of the user. So if the received signal includes data that have been modulated with this sequence and are synchronised with it, then this means that there are data addressed to this particular receiver. In this case the correlation process reduces the bandwidth of the appropriate part of the incoming signal, so achieving demodulation and recovering of the data that intended for this destination. Other components of the received signal (echoes and transmissions intended for other destinations) will be uncorrelated with the local sequence, and so will not have their bandwidth reduced, but on the contrary will be spread again over the full transmission bandwidth. The succeeded BER is a function of the relation between the transmission bandwidth and the reduced one. Theoretically it can be nullified.

The operation of this LAN requires a universal timing system. Any node, and consequently any user, is synchronised with the rest of the system. This synchronisation is maintained through the continuous distribution of timing information over the network.

In order to distribute timing and signalling information over the LAN a separate time-division multiple access (TDMA) channel is proposed. This signalling channel operates on an active flooding scheme, simultaneously with the spread spectrum data transmission channels and within the same frequency band. Using this scheme every node receives, processes and retransmits the signalling information along all outgoing links. All nodes and users share this channel on a slotted TDMA basis. The allocation scheme of the slots to the nodes is permanent and continuous. This TDM channel guarantees the continuous availability of timing and synchronisation information, routing information, information about the status of the users, acknowledgement information etc. Each time slot is divided into time portions that are allocated to the node and to the SPSCIU of its users, for the transmission of the above information.

The synchronisation and timing information is essential for the transmitting SPSCIU. It is used in estimating the phase shift of the pseudorandom spreading sequence modulating the data to be transmitted, so that the signal arrives at the destination synchronised with the locally generated replica of the code.

Due to the properties of the passive flooding protocol and to the synchronisation information that is provided through the operation of the TDM channel, the LAN through the mesh topology acts as a kind of a self-learning machine. So at any modification of the topology, it always finds the shortest routes, follows the disconnection, the interruptions and the failures in links or at nodes. So the operation of the TDM channel updates the information about the topology and according to it the routing information and the transmission delays of the spsc information are estimated.

3. PERFORMANCE EVALUATION AND SIMULATION RESULTS

The simulated model

For the performance evaluation simulation tools were developed. These tools consist of a simulation environment where the topology is generated, the TDM channel operates and the users data are generated, spread, flooded, received and processed. The analysis and design of these tools were done with the aid of MASCOT III (Modular Approach to Software Construction Operation and Test) method (10). The required software was written in SIMULA (11).

Using these tools two different topologies were built :

- A 9 nodes topology with 2, 4, 6 and 10 users connected per node (fig. 2).
- A 30 nodes topology with 3 and 4 users connected per node (fig. 3).

Measurements have been implemented on them under the following types of traffic :

- Type 1 : All users transmit packets to a destination of the same sub-graph (e.g. user of node 1 to user of node 3 in fig. 2 and user of node 13 to user of node 16 in fig. 3).
- Type 2 : All users transmit packets to a destination of another sub-graph (e.g. user of node 1 to user of node 6 in fig. 2 and user of node 13 to user of node 30 in fig. 3).
- Type 3 : All users transmit packets to a destination randomly chosen (e.g. user of node 1 to user of node 9 in fig. 2 and user of node 13 to user of node 11 in fig. 3).
- Type 4 : All users transmit packets to a destination of one particular sub-graph. (e.g. user of node 2 to user of node 3 and user of node 4 to user of node 8 in fig. 2 and user of node 13 to user of node 30 and user of node 2 to user of node 25 in fig. 3).
- Type 5 : All users transmit packets to a destination of one particular sub-graph. The selection of the destination is such that no congestion occurs. (e.g. user of node 2 to user of node 3 and user of node 4 to user of node 8 in fig. 2 and user of node 13 to user of node 30 and user of node 2 to user of node 25 in fig. 3). This can be considered as the worst case of traffic.

In order to restrict our estimations all simulation results were obtained under the following assumptions :

- One packet of 10 bits per user is transmitted. So the total number of transmitted concurrently packets is equal to the number of users.
-The chip rate is always examined in congestion with the bit rate. This means that as chip rate is taken the transmitted number of chips per bit. This number is always an integer and corresponds to the full length of the pseudorandom sequence.
- The packet generation is not random but simultaneous for all the users (worst case of traffic).
- No congestion exists at the network.
- The whole simulated model is considered as an ideal one where no losses due to internal noise is introduced.
- The acknowledgement procedures are not used.

The major task is to prove that the passive flooding implemented on a mesh topology using spsc techniques, is a cost effective one so that an optimum theoretically BER (BER=O) to be achieved, with low required chip rates. To prove it we use the relationship between the incoming power of the spread signal and the existing power at the channel. The outputs of the program are the accumulated power and the incoming voltage at the input of any node. These are different and independent each other. From the incoming voltage the corresponding voltage at the output of the receiver and the BER are estimated. Through them the average BER of the system and the corrupted bits per link will be discussed as a function of the input node attenuation. Further than this, examples will be given of how the incoming to a node power and the output voltage of the receivers are influenced from the topology, the matching attenuation and the other end selection distribution. The concurrent transmission of only one packet of 10 bits from all the users, does not influence the final results. This is because an ideal hardware system has been supposed where external noise sources, others than the signal echoes, do not exist.

All these measurements have been taken for the worst case of traffic (traffic 5) and for simultaneous transmission starting of all the packets (one packet per user). In this way the worst traffic conditions into the sub-LAN are simulated.

The rest of the performance estimates (the BER, the delays and the throughput) of the various types of LANs, that are members of this family, depend upon the protocols and hardware design of each one individually. These estimates are of minor importance, due to the negligible delays because of the concurrent communication offered, of the low congestion probability, of the possibility to succeed a theoretically zero BER and of the use of short overheads.

The simulation results

According to the described architecture we define BER of a physical link that connects two particular nodes, the summation of all the corrupted bits of all the transmitted packets through the virtual links of this physical link over the total summation of the bits of these packets. The BER is a function of the echoes power, the topology, the input node attenuation, the traffic and the chip rate. BER is reduced in the same way for all the virtual channels of any particular link. Since the traffic load and the echoes vary through out the topology, the BER is not constant and is different in the various paths that connects any two nodes. As average BER is defined the summation of all the corrupted bits of all the transmitted packets through every virtual link over the total summation of the bits.

Tables 1 and 2 are a sample from a set of tables that examine one by one the corrupted communication links. The information that are found at these tables are the starting and ending node of the physical link, the length of the physical link measured in hops, the number of the corrupted virtual links on it and the total number of the corrupted bits of the virtual links as a function of the attenuation for various chip rates. Every one of these tables is referred to a particular topology and to particular chip rate. They illustrate the influence of the number of hops to the number of corrupted bits per virtual link. As the number of hops is increased, the performance deteriorates. When the chip rate is increased the performance is improved.

Figures 4 and 5 illustrate the overall BER of all the communication links of the sub-LAN. The curves of these figures have resulted by averaging the data of all the tables a sample of which is presented through tables 1 and 2. Every figure presents the average BER as a function of the attenuation for the various chip rates that have been used. It can been seen, that the most concentrated the sub-LAN is, the lower the required chip rate is to nullify the BER. More analytically fig. 4 corresponds to the topology of fig. 2. The measurements have been taken for 63, 127 and 255 chips and for 2, 6 and 10 users per node. Fig. 5 corresponds to the topology of fig. 3. The measurements have been taken for

127, 255 and 511 chips and for 3 and 4 users per node. For the topology of fig. 3 (30 nodes and 90 users) 127 chips support communication links of 2 hops and 511 chips support communication links of 3 hops. For the topology of fig. 2 the communication links of 2 hops are supported from 127 chips. At this topology there are no physical links that require 3 hops connections.

The number of concurrent transmitting users that any particular topology may support is not constant and depends upon the chip rate used, and the distance of the destination, measured in hops. The higher the chip rate is the higher the processing gain is and consequently higher the afforded power of noise due to echoes can be, or alternatively lower the incoming SNR. Echoes power is not only a function of the topology but also of the traffic, the used attenuation at the input port of any node, the accepted maximum length of a link measured in hops (not in time). The performance of all the virtual channels created during the communication of the users is the same and depends upon the instantaneous traffic load and the echoes at any particular link or node. The BER is a direct function of the incoming into the node SNR. The higher the SNR the lower the BER is. As the number of nodes at a sub-LAN is increased (while the final number of users and the created traffic are kept constant) the distributed power of the noise over the links and the nodes is reduced. At the same time the links are becoming longer in hops and the degree of the nodes is increased. During the transmission, the transmitted power of the signal of interest, is reduced progressively following the hops. Therefore the power of the received signal is reduced and so the total processing gain of the sub-LAN is changed. By increasing the chip rate better processing gain is achieved and consequently longer paths and higher amount of traffic can be served. So for any particular chip rate the amount of traffic that may be served successfully by the LAN is a function of the topology.

At figures 6 and 7 the accumulated power (incoming) at an input of a randomly chosen node as a function of the attenuation has been plotted. Together with this curve the change of the signal of interest at the same input of the same node also as a function of the attenuation is shown for various hops. As signal of interest are considered the spread data that are flooded in the sub-LAN. The incoming power is the signal of interest plus the echoes and the initial transmissions of any other users. The curves of figure 6 correspond to the topology of fig. 2 (at the topology of fig. 2 the signal of interest arrives at the destination from only one or two hops routes) and of fig. 7 to the topology of fig. 3.

Every time that the signal of interest is flooded through a node (hop) the signal's power is reduced in accordance with the relation of section 2. This power reduction is subject to the attenuation value. The same holds for the incoming power also. Therefore the signals of all these curves of figures 6 and 7 results from a continuous and sequential use of this type of section 2. As the attenuation is increased the signals of the curves change at a different scale. This change is exponential and depends upon how many times the type has been applied

- individually to the components that the incoming signal consists of
- to the signal of interest.

From these curves the SNR can be estimated.

From figures 4, 5, 6 and 7 and from the tables 1 and 2 an indication of the importance of the influence of the attenuation to the performance of the system is given. For the optimised value of this parameter the BER=O is obtained for the minimum required chip rate.

Assuming that the input node attenuation is 1 then no power is absorbed and consequently no power loss exists at the system. As the attenuation is increased a percentage of both the echoes and the signal power are absorbed resulting to a reduction of their value, but at a different scale. After time t the amount of the power that is absorbed by the system gets equal with the initially transmitted power in it. The required time delay for reaching this saturation point is decreased as the attenuation increases (the saturation point comes closer to the transmission starting point). This time delay is relatively short. A static power equilibrium is obtained. This relation is described in fig. 8. This figure is referred to the topology of fig. 2, to an arbitrarily chosen receiver (from the second port of node 8), to traffic of type 5, to 10 users connected on every node and to chip rate 127 chips per bit. It describes the relation ship between the incoming power and the time. The time corresponds to the time instance that the data are received.

- Curve 'A' is referred to the case of an ideal system without loss (case of attenuation 1), then the flooded power into the system is accumulated, and a continuous increase of the incoming power takes place. This increase is illustrated for an arbitrarily chosen receiver. It can been seen that there is a linear increase of the power as a function of the time.
- Curve 'B' is referred to the case of attenuation different than 1 then the power does not increase continuously. After some time the lose power due the

attenuation is balanced with the incoming one and then the incoming power is stabilised.

So the incoming power, at any incoming port, for any attenuation value different than 1 can be considered as a constant independent of the time.

The traffic distribution affects the power distribution over the LAN and consequently the BER. The tables 3 and 4 illustrate the incoming power distribution over the network as a function of the attenuation, the used chip rate and the used type of traffic, for both the topologies of figures 2 and 3. For cases of traffic 1 and 2 we have a homogenous distribution of the traffic over the network for any value of the attenuation. For traffic 5 the traffic is examined only at the subgraph where the receivers are. This is the worst case of traffic since all the users try to communicate with destinations located at a particular area of the network. Any transmission is initially directed to the shortest route and the signal arrives always at the destination through this route. Due to all this factors of traffic type 5, a great amount of the initially transmitted power accumulates in the area of the receivers of the destination. This power is kept flooded to the rest of the network. In this way in the receivers area a highly noise environment exists. The required chip rate for serving this type of traffic will also serve, with improved performance, any other traffic situation.

4. CONCLUSION

This work involves a lot of fields of research :

- an overall description of the architecture and the design principles of a family of spread spectrum LANs built on mesh topologies is given.
- an example of a LAN member of this family is described and analysed and
- simulation tools are built for the study of the behaviour of the OSI lower layers of mesh topology LANs. These tools were used for the performance evaluation of the flooding idea implemented at a LAN member of this family of LANs.

According to the definitions of the performance characteristics and by examining the results of the simulation, under a passive flooding scheme, it can be concluded that the traffic is mainly depended upon the topology configuration. The most condense the LAN is the shortest paths exist at a penalty of lack of survivability. The input node attenuation is of main importance since it controls the power of the echoes in the LAN. The traffic supported depends always upon the used chip rate. Supposing an ideal hardware and using the correct value of the chip rate a theoretical zero BER can be achieved. The selection of the chip rate depends upon the input node attenuation. The BER depends upon the design and is a function mainly of the used chip rate and of the attenuation. In addition to the above factors, the length of the links in hops is a function of the receiver's threshold. The lower this threshold is the longer the link. From the above we conclude that the selection of the correct values of these parameters is a design optimisation problem.

So finally the performance is influenced by the above referred factors and the amount of the created traffic. Traffic depends upon the user distribution over the network, the packet generation distribution, the other end selection distribution and the topology. Evaluating the received measurements according to the characteristics of the architecture, it can be concluded that :

- The most spread a sub-LAN is the longest routes (in hops) are created.
- The longest a route is the higher the required chip rate is.
- The optimum value of the attenuation parameter is between 0.9 and 0.8 (fig. 4 and 5).
- The most spread a sub-LAN is the lower the incoming power at any port is and consequently the higher the tolerance of the sub-LAN to inter-sub-LAN traffic is.
- The flooded power is homogeneously distributed all over the network.
- Considering the sub-LAN of 30 nodes as a basic unit for the composition of a LAN, then BER=0 can be achieved for any type of traffic at it, using a chip rate of 511 chips/bit with attenuation 0.9 (fig. 5).

This type of LAN is appropriate for serving the main types of traffic, that is voice and data, because :

- of the use of dedicated channels to any one of the transmissions
- of the introduced low delays,
- of its good performance and
- of the statistics properties of the spsc channels to exist only for the period of time that the transmission lasts,

The suitability of this type of LAN for real time image transmission or for slow scanning image transmission, depends upon the characteristics and the design of every one particular sub-LAN. This is because for this type of traffic a high transmission bit rate is required. This family of spsc LANs can support various bit rates and types of traffic.

Existing hardware limitation of the past for the increase of channel capacities, transmission rates and for building complicated hardware circuits have been over come, through the progress in the area of fibre optics and VLSI technology.

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TABLE 1

CORRUPTED LINKS AND BITS AS A FUNCTION OF THE ATTENUATION FOR THE SUB-LAN OF FIG. 2 FOR THE TRANSMISSION OF 10 BITS PER USER

NODES	9
USERS :	10
CHIPS PER BIT	255
CHIP DURATION	1
TYPE OF TRAFFIC	5
RECEIVERS THRESHOLD	0
LACK OF SYNCHRONIZATION	0

COLUMN A	ID OF NODE
COLUMN C	ID OF INCOMING PORT
COLUMN D	NUMBER OF CORRUPTED VIRTUAL LINKS ON THE PHYSICAL CONNECTION
COLUMN E	TOTAL NUMBER OF CORRUPTED BITS

TR	TRANSMITTER
RC	RECEIVER
ID	IDENTIFICATION

ID OF			HOPS	ATTENUATION																			
TR	RC			1		0.99		0.95		0.9		0.8		0.7		0.6		0.5		0.4		0.3	
A	A	C		D	E	D	E	D	E	D	E	D	E	D	E	D	E	D	E	D	E	D	E
1	8	1	2	0	0	10	10	4	4	1	1	0	0	0	0	0	0	0	0	0	0	0	0
2	7	3	2	3	3	3	3	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	9	4	2	6	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

TABLE 2

CORRUPTED LINKS AND BITS AS A FUNCTION OF THE ATTENUATION FOR THE SUB-LAN OF FIG 3 FOR THE TRANSMISSION OF 10 BITS PER USER

NODES	:	30
USERS	:	3
CHIPS PER BIT	:	511
CHIP DURATION	:	2
TYPE OF TRAFFIC	:	5
RECEIVERS THRESHOLD	:	0
LACK OF SYNCHRONIZATION	:	0

COLUMN A	:	ID OF NODE
COLUMN C	:	ID OF INCOMING PORT
COLUMN D	:	NUMBER OF CORRUPTED VIRTUAL LINKS ON THE PHYSICAL CONNECTION
COLUMN E	:	TOTAL NUMBER OF CORRUPTED BITS

TR	:	TRANSMITTER
RC	:	RECEIVER
ID	:	IDENTIFICATION

ID OF			HOPS	ATTENUATION																			
TR	RC			1		0.99		0.95		0.9		0.8		0.7		0.6		0.5		0.4		0.3	
A	A	C		D	E	D	E	D	E	D	E	D	E	D	E	D	E	D	E	D	E	D	E
5	30	7	3	2	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	25	2	3	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	26	2	3	1	1	0	0	0	0	0	0	1	1	1	1	3	1	7	3	7	3	14	3
18	27	9	3	1	1	3	2	0	0	0	0	5	3	7	3	8	3	8	3	15	3	0	0
27	1	1	3	3	3	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

TABLE 3

THE DISTRIBUTION OF THE INCOMING POWER OVER THE TOPOLOGY FOR A SUB-LAN OF FIG. 2 FOR THREE TYPES OF TRAFFIC AND FOR VARIOUS VALUES OF ATTENUATION

NODES : 9

USERS : 10

CHIPS PER BIT : 255

CHIP DURATION : 4

TYPE OF TRAFFIC : 5

RECEIVERS THRESHOLD : 0

LACK OF SYNCHRONIZATION : 0

RC : RECEIVER

AT : ATTENUATION

ID : IDENTIFICATION

COLUMN A : ID OF NODE

COLUMN C : ID OF INCOMING PORT

		TRAFFIC : 1			TRAFFIC : 2		
ATT/TION:		0.99	0.8	0.2	0.99	0.8	0.2
RC A	C	INCOMING POWER	INCOMING POWER	INCOMING POWER	INCOMING POWER	INCOMING POWER	INCOMING POWER
3	1	1.27&+05	8.28&+03	1.07&+03	1.28&+05	8.51&+03	1.08&+03
1	1	1.28&+05	8.56&+03	1.08&+03	1.28&+05	8.51&+03	1.08&+03
2	2	1.28&+05	8.70&+03	1.08&+03	1.28&+05	8.51&+03	1.08&+03
6	1	1.26&+05	7.44&+03	1.01&+03	1.28&+05	8.51&+03	1.08&+03
4	2	1.22&+05	4.12&+03	7.78&+01	1.28&+05	8.51&+03	1.08&+03
5	2	1.27&+05	8.21&+03	1.07&+03	1.28&+05	8.51&+03	1.08&+03
9	1	1.27&+05	8.28&+03	1.07&+03	1.28&+05	8.51&+03	1.08&+03
7	1	1.28&+05	8.56&+03	1.08&+03	1.28&+05	8.51&+03	1.08&+03
8	2	1.28&+05	8.70&+03	1.08&+03	1.28&+05	8.51&+03	1.08&+03

TABLE 4

THE DISTRIBUTION OF THE INCOMING POWER OVER THE TOPOLOGY FOR A SUB-LAN OF FIG. 3 FOR THREE TYPES OF TRAFFIC AND FOR VARIOUS VALUES OF ATTENUATION.

NODES	30
USERS	3
CHIPS PER BIT	511
CHIP DURATION	2
TYPE OF TRAFFIC	5
RECEIVERS THRESHOLD	0
LACK OF SYNCHRONIZATION	0

RC	RECEIVER
AT	ATTENUATION
ID	IDENTIFICATION
COLUMN A :	ID OF NODE
COLUMN C :	ID OF INCOMING PORT

	TRAFFIC : 1			TRAFFIC : 2		
AT/TION:	0.99	0.8	0.2	0.99	0.8	0.2
RC A C	INCOMING POWER	INCOMING POWER	INCOMING POWER	INCOMING POWER	INCOMING POWER	NCOMING POWER
3 1	1.78&+4	1.74&+3	3.09&+2	1.78&+4	1.74&+3	3.09&+2
4 2	1.78&+4	1.73&+3	3.08&+2	1.77&+4	1.64&+3	3.02&+2
5 3	1.78&+4	1.75&+3	3.09&+2	1.78&+4	1.74&+3	3.09&+2
6 4	1.78&+4	1.76&+3	3.09&+2	1.78&+4	1.74&+3	3.09&+2
1 4	1.79&+4	1.78&+3	3.09&+2	1.78&+4	1.74&+3	3.09&+2
2 5	1.78&+4	1.76&+3	3.09&+2	1.78&+4	1.74&+3	3.09&+2
9 1	1.77&+4	1.65&+3	3.02&+2	1.79&+4	1.78&+3	3.09&+2
10 2	1.76&+4	1.62&+3	3.01&+2	1.80&+4	1.85&+3	3.16&+2
11 3	1.78&+4	1.74&+3	3.09&+2	1.79&+4	1.78&+3	3.09&+2
12 4	1.80&+4	1.86&+3	3.16&+2	1.79&+4	1.78&+3	3.09&+2
7 3	1.65&+4	6.62&+2	1.66&+1	1.79&+4	1.78&+3	3.09&+2
8 4	1.65&+4	6.76&+2	1.68&+1	1.79&+4	1.78&+3	3.09&+2
15 1	1.78&+4	1.74&+3	3.09&+2	1.78&+4	1.75&+3	3.09&+2
16 2	1.78&+4	1.73&+3	3.08&+2	1.65&+4	6.52&+2	1.64&+1
17 3	1.78&+4	1.75&+3	3.09&+2	1.78&+4	1.75&+3	3.09&+2
18 4	1.78&+4	1.76&+3	3.09&+2	1.78&+4	1.75&+3	3.09&+2
13 4	1.79&+4	1.78&+3	3.09&+2	1.78&+4	1.75&+3	3.09&+2
14 5	1.78&+4	1.76&+3	3.09&+2	1.78&+4	1.75&+3	3.09&+2
21 1	1.78&+4	1.74&+3	3.09&+2	1.78&+4	1.75&+3	3.09&+2
22 2	1.76&+4	1.63&+3	3.01&+2	1.67&+4	7.73&+2	2.39&+1
23 3	1.78&+4	1.74&+3	3.09&+2	1.78&+4	1.75&+3	3.09&+2
24 4	1.78&+4	1.76&+3	3.09&+2	1.78&+4	1.75&+3	3.09&+2
19 4	1.80&+4	1.87&+3	3.16&+2	1.78&+4	1.75&+3	3.09&+2
20 4	1.65&+4	6.76&+2	1.68&+1	1.78&+4	1.75&+3	3.09&+2
27 1	1.78&+4	1.74&+3	3.09&+2	1.78&+4	1.74&+3	3.09&+2
28 2	1.78&+4	1.73&+3	3.08&+2	1.76&+4	1.62&+3	3.01&+2
29 3	1.78&+4	1.75&+3	3.09&+2	1.78&+4	1.74&+3	3.09&+2
30 4	1.78&+4	1.76&+3	3.09&+2	1.78&+4	1.74&+3	3.09&+2
25 4	1.79&+4	1.78&+3	3.09&+2	1.78&+4	1.74&+3	3.09&+2
26 5	1.78&+4	1.76&+3	3.09&+2	1.78&+4	1.74&+3	3.09&+2

TRAFFIC : 5

AT\TION:	0.99	0.8	0.3
RC A C	INCOMING POWER	INCOMING POWER	INCOMING POWER
26 6	1.78&+4	1.78&+3	4.86&+2
27 2	1.66&+4	7.35&+2	4.35&+1
28 3	1.71&+4	1.06&+3	9.27&+1
29 4	1.68&+4	8.64&+2	6.09&+1
30 7	1.61&+4	4.13&+2	6.15&+0
25 1	1.69&+4	8.79&+2	6.16&+1
27 7	1.79&+4	1.82&+3	4.88&+2
28 7	1.62&+4	5.11&+2	2.17&+1
29 3	1.71&+4	1.07&+3	9.33&+1
25 7	1.62&+4	5.00&+2	2.11&+1
26 7	1.63&+4	5.33&+2	2.30&+1
26 2	1.86&+4	2.27&+3	5.43&+2
28 1	1.68&+4	8.41&+2	5.97&+1
29 8	1.76&+4	1.65&+3	4.69&+2
30 3	1.72&+4	1.08&+3	9.39&+1
25 3	1.68&+4	8.54&+2	6.03&+1
26 4	1.66&+4	7.44&+2	4.41&+1
27 9	1.76&+4	1.60&+3	4.55&+2
29 1	1.66&+4	7.31&+2	4.34&+1
30 9	1.63&+4	5.75&+2	3.59&+1
25 2	1.69&+4	9.47&+2	7.58&+1
26 9	1.62&+4	5.05&+2	2.16&+1
29 9	1.76&+4	1.59&+3	4.55&+2
28 9	1.62&+4	4.83&+2	2.04&+1
27 1	1.82&+4	2.03&+3	5.09&+2
28 2	1.84&+4	2.09&+3	5.12&+2
1 1	1.62&+4	5.03&+2	2.11&+1
30 4	1.84&+4	2.08&+3	5.12&+2
25 4	1.82&+4	1.96&+3	4.94&+2
26 5	1.80&+4	1.84&+3	4.78&+2

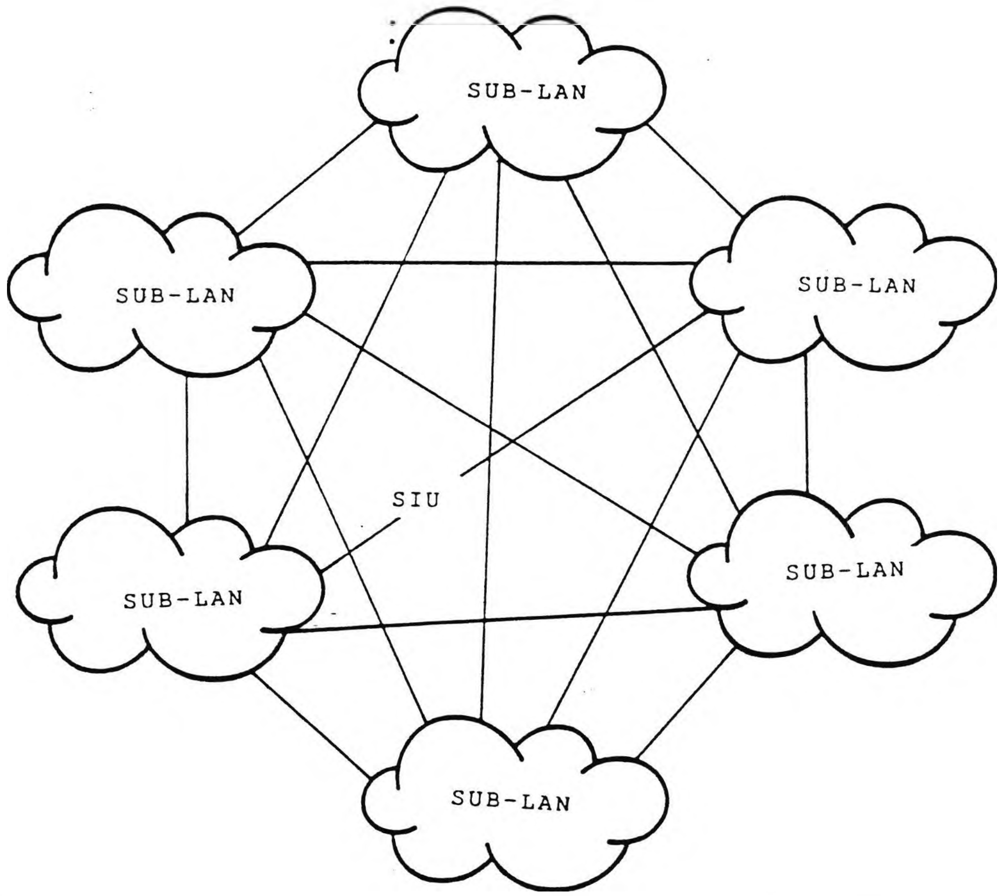

FIG.1 : The philosophy used for the design of a LAN of the proposed topology.

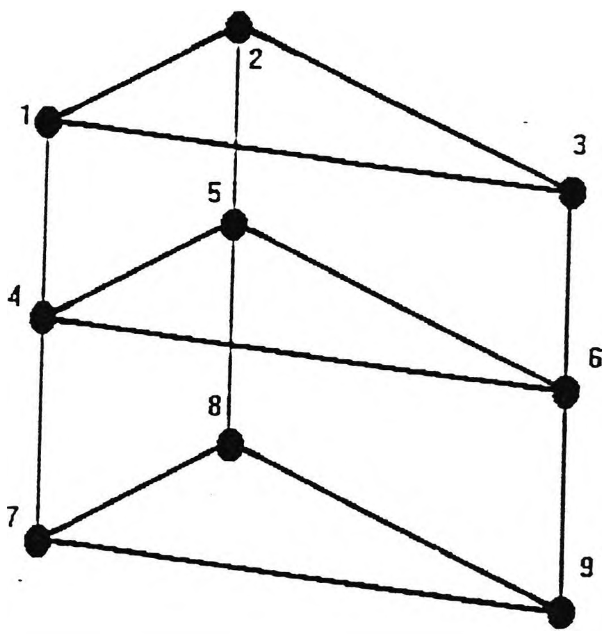

FIG. 2 : A 9 node topology of a sub-LAN.

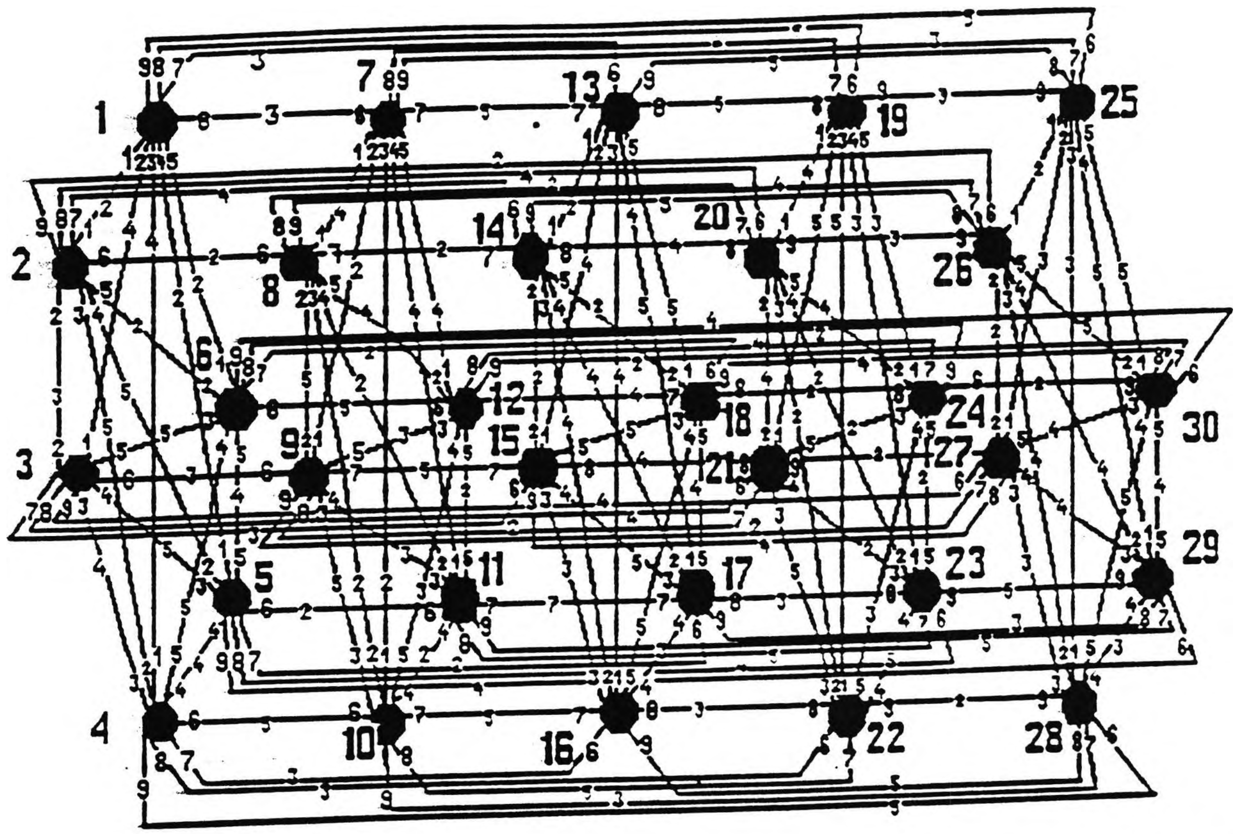

FIG. 3 : A 30 nodes topology of a sub-LAN. The numbers at the middle of the links indicate their length. The numbers around the nodes are the nodes and the ports identifications.

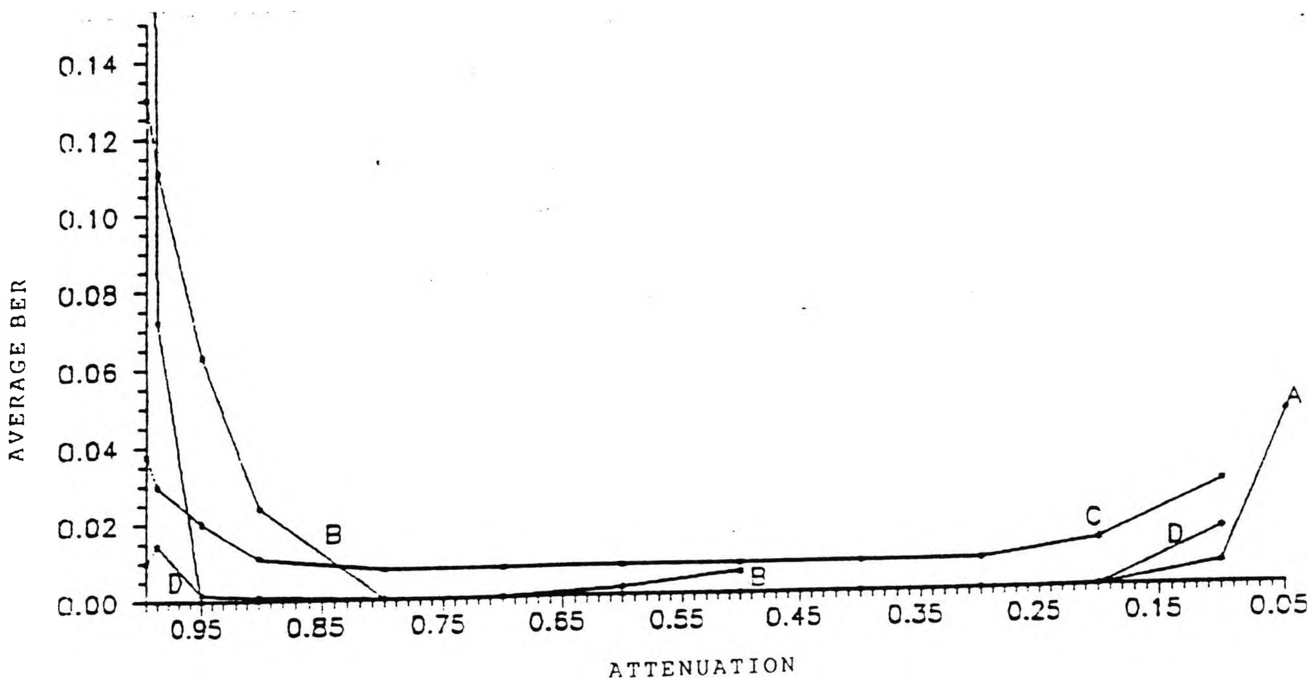

FIG. 4 : The average BER as a function of attenuation for the topology of fig. 2. Curve 'A' corresponds to 63 chips, 2 users/node, 'B' : 63 chips, 6 users/node, 'C' : 127 chips, 10 users/node, 'D' : 255 chips, 10 users/node.

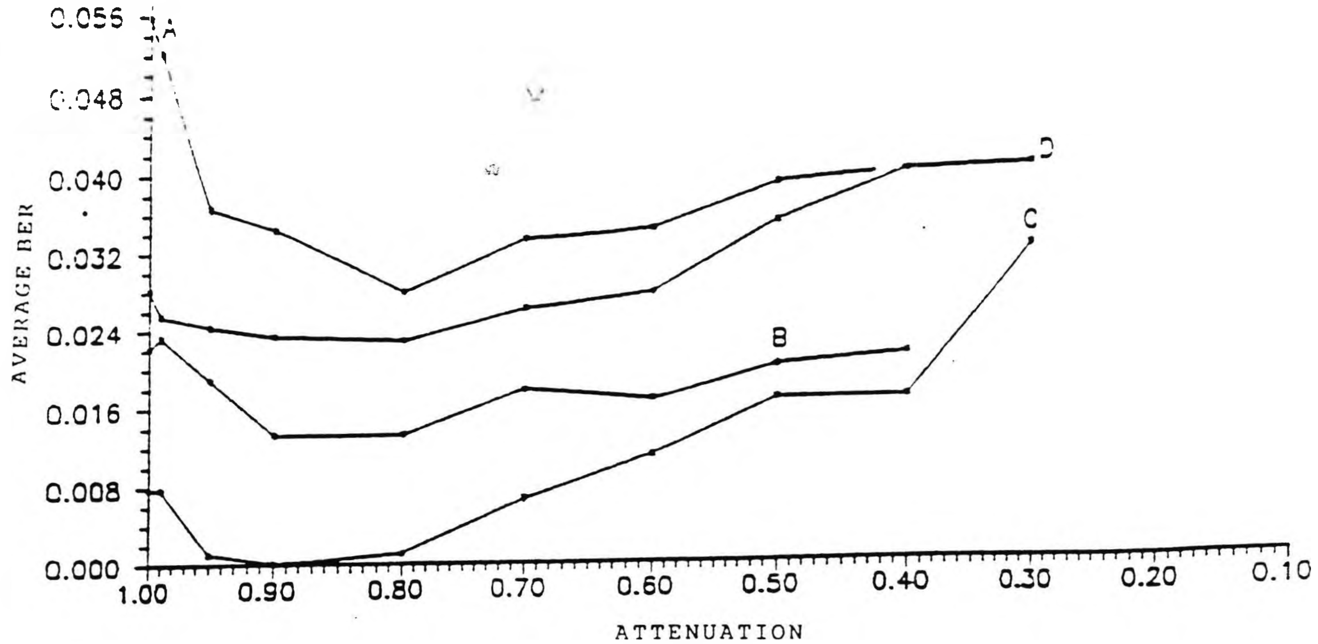

FIG. 5 : The average BER as a function of attenuation for the topology of fig. 3. Curve 'A' corresponds to 127 chips, 3 users/node, 'B' : 255 chips, 3 users/node, 'C' : 511 chips, 3 users/node, 'D' : 511 chips, 6 users/node.

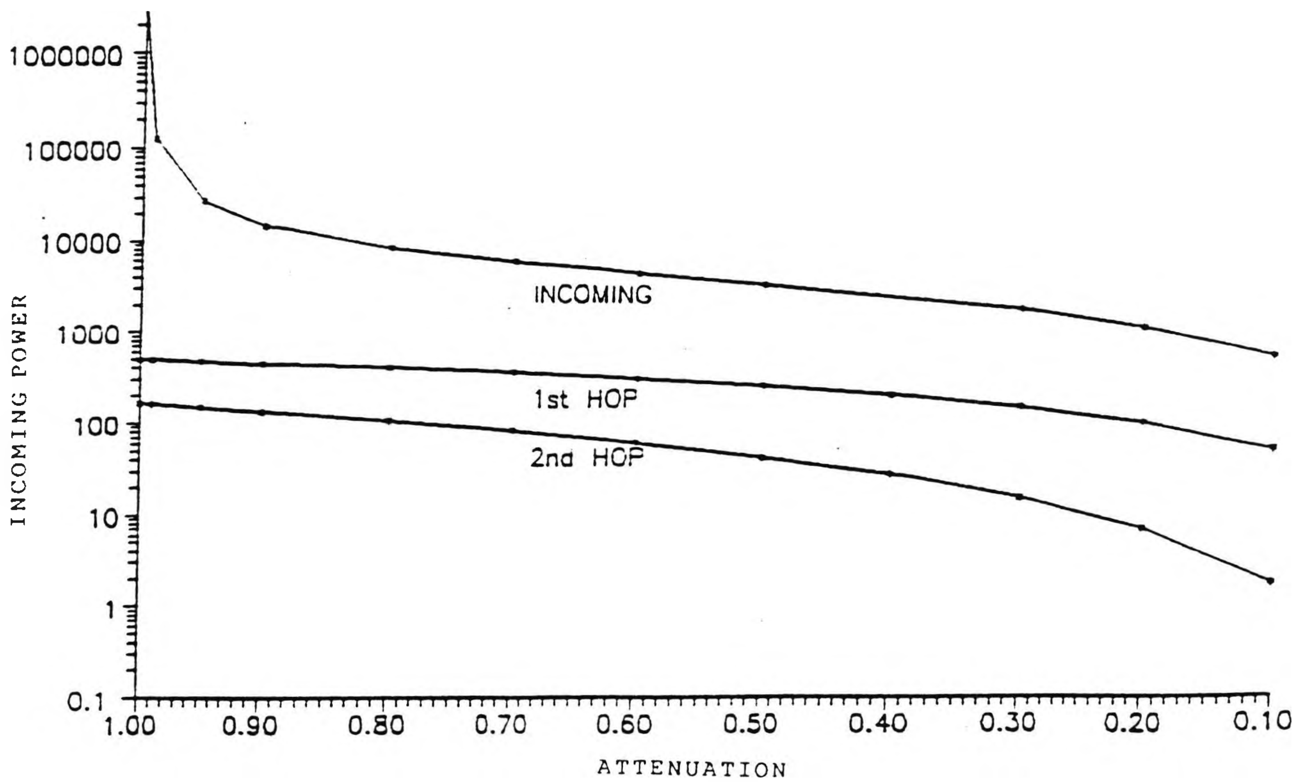

FIG. 6 : The incoming power at the receiver and the power of signal of interest after the first and the second hop as a function of attenuation for the topology of fig. 2 and for traffic type 5.

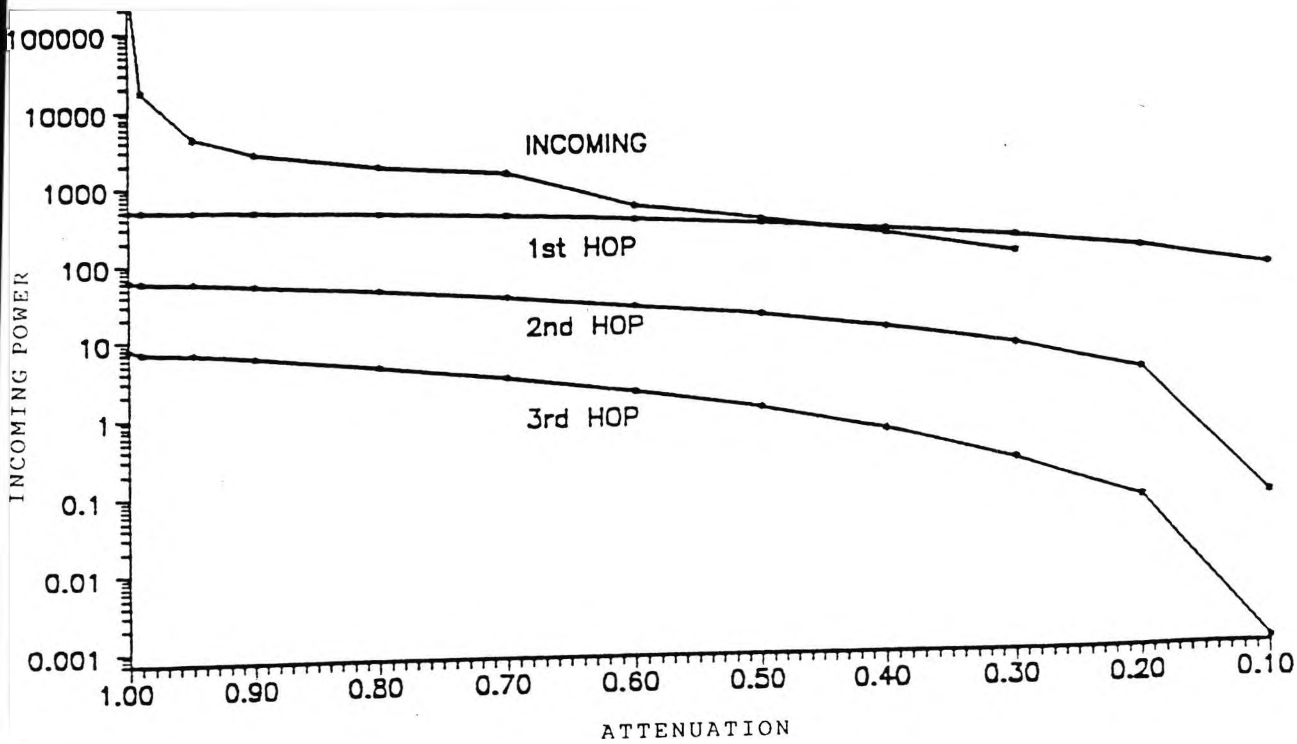

FIG. 7 : The incoming power at the receiver and the power of signal of interest after the first, the second and the third hop as a function of attenuation for the topology of fig. 3 and for traffic type 5.

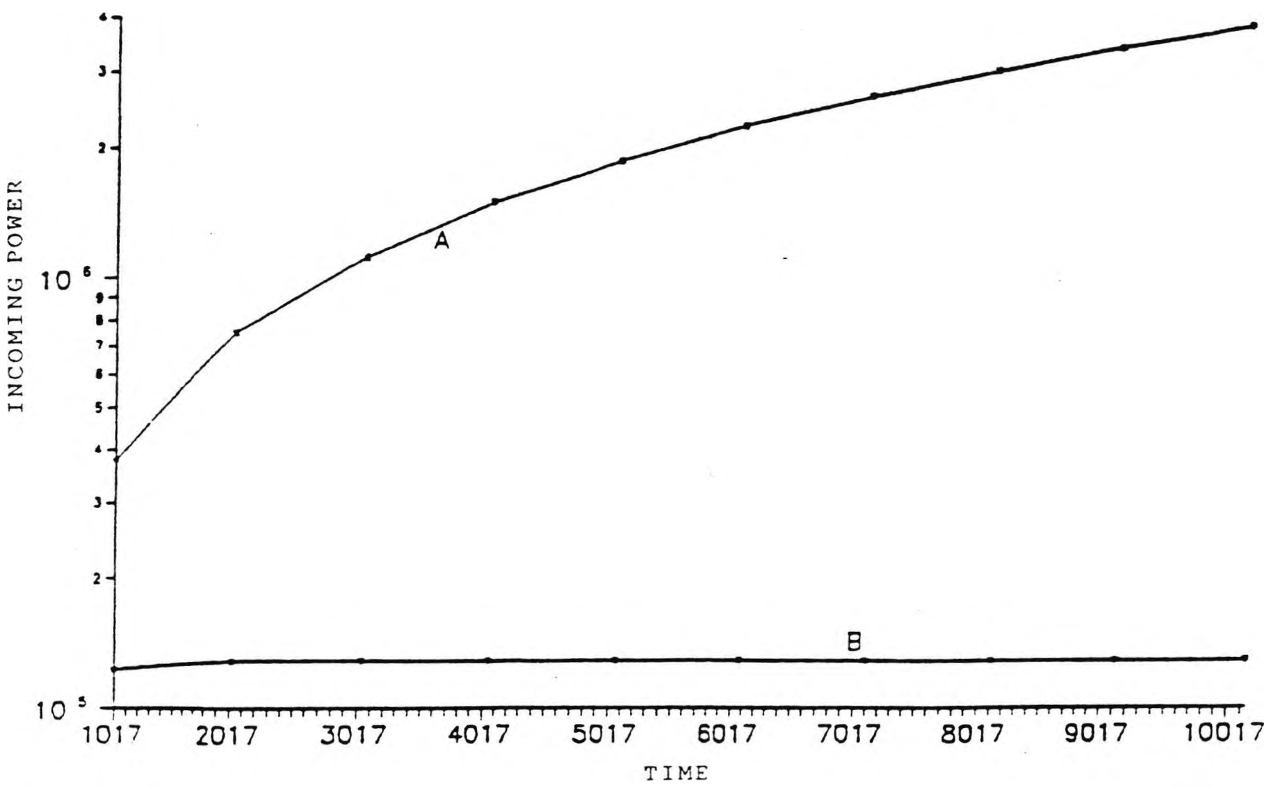

FIG. 8 : The incoming power as a function of time for any receiver of the topology of fig. 2. Curve 'A' corresponds to attenuation 1 and curve 'B' to attenuation 0.9.