An initialisation protocol for a CDMA based communications scheme for HFC CATV networks

An Initialisation Protocol for a CDMA based Communications Scheme for HFC CATV Networks

R.P.C.Wolters, *member IEEE*, G.D. Khoe, *fellow IEEE*, and Juergen Otterbach[1].

Abstract - **An initialization protocol for a CDMA based communications system for Hybrid Fiber Coax (HFC) Central Antenna Television (CATV) networks is described. HFC CATV networks are shared medium access networks, employing the coaxial bus principle between an optical network terminator and the subscriber. To realize access in the upstream direction, a multiple access scheme based on CDMA can be used [1,2,3]. However, before access is granted in the upstream direction, each cable modem connected to the coaxial bus needs to undergo a startup procedure at activation of the modem to determine timing and physical layer related settings. The initialization mechanism described here performs time synchronization of a modem and the determination of the power the modem should use. Next to these physical layer settings, also the identity of a modem is determined during the initialization process.**

I. Introduction

CURRENTLY, many communications systems are being developed that can deliver a high bitrate information stream to the customers' premises using HFC CATV networks. Many of these systems are based on the proven TDMA multiple access scheme [5]. Next to TDMA, however, many attention is directed to spread spectrum techniques such as Code Division Multiple Access (CDMA). This attention is due to the advantages offered by CDMA with respect to the ingress noise in the upstream channel [1,4] and the flexibility of bandwidth assignment. In a CDMA based system certain factors related to upstream transmission have to be taken into account before a modem can actually start its transmission. This article describes which parameters have to be determined before a modem can start upstream transmission. The initialization procedures required for the determination of the parameters and the basics of the communication system are described.

The work described in this paper is conducted within related projects that are aimed on the development of a bi-directional communications system for HFC CATV networks. For the realization of upstream communication, direct sequence spread spectrum techniques (DS-CDMA) have been chosen. The project conducted at the Eindhoven University of Technology is supported by the Dutch National Foundation for Research, STW ('Stichting Technische Wetenschappen'.

II. Description of the transport scheme.

Figure 1 on the next page shows an overview of the full CDMA system architecture. At the head-end, the Head Network Adaptation (HNA) provides the termination of the core (e.g. ATM) network and provides the modulation of the downstream channels in compliance with DVB (64-QAM). These downstream channels are shared by all Optical Network Terminators (ONTs) in the network, or are dedicated to a specific ONT, depending on the bandwidth demand of the users connected to an ONT. For the upstream direction, one separate receiver is available at the head-end for each group of modems or CDMA Network Terminators (CNTs) which are sharing the same time and frequency resources. Such a group of modems is also referred to as a MAC domain. One receiver can handle a multiple of modems that, in normal operation are transmitting with synchronized spreading code generators, but without synchronized carriers. After down conversion, additional digital circuitry is provided in the receiver for the removal of the residual modulation component, and the decorrelation of each distinct upstream information channel. At the subscribers' premises a modem or CDMA Network Terminator (CNT) is available, that is equipped with a 64-QAM DVB demodulator and a CDMA modulator. The CATV network has been maintained

[1]R.P.C. Wolters is with Alcatel Telecom in Antwerp, Francis Wellesplein 1, B-2018, Belgium. E-mail: woltersr@btmaa.bel.alcatel.be
G.D. Khoe is with the Eindhoven University of Technology, Den Dolech 2, 5612 AZ, The Netherlands. E-Mail: g.d.khoe@ele.tue.nl
Juergen Otterbach is with Alcatel Telecom in Stuttgart, Holderaeckerstrasse 35, D-70499 Germany. E-mail: jotterba@rcs.sel.de

Publisher Item Identifier S 0018-9316(97)07912-2

transparent, it only provides optical to electrical and vice versa conversion in the ONT.

At the head-end, a Local Information Server (LIS) may be provided that can contain operator specific information, or that can form a buffer for other servers which are localized elsewhere, preventing the core network from being overloaded with redundant traffic. Also shown in the picture is a local switch that can be placed at the head-end. This switch provides the handling of e.g. local calls, the access to the LIS, and the access to the backbone networks.

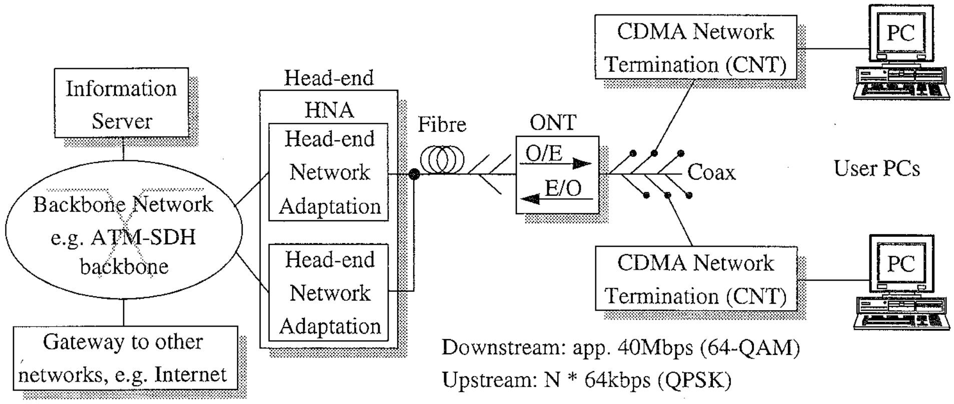


Figure 1: *System overview of the CDMA HFC communications system.*

III. CDMA properties of the system.

A Upstream transmission format

The CDMA modulator at the CNT operates at a channel speed of multiples of 64kbps, using Preferentially Phased Gold (PPG) spreading sequences [2]. These spreading sequences have almost perfect cross-correlation properties if they are correctly aligned, but have the cross-correlation properties of normal Gold codes if they are not perfectly aligned or used asynchronously. The PPG sequences have a length of 127, resulting in 128 usable codes. With the use of QPSK as modulation format, the chip rate in both the I and Q channel amounts app. 4Mchips/s. If separate spreading codes are chosen for the I and Q channel, the transmission capacity that can be realized with a filter coefficient equal to ¼ amounts four megabit/s in a bandwidth of five megahertz. This implies that in an upstream bandwidth of app. sixty megahertz a maximum transmission capacity of forty-eight megabit/s can be realized, divided over at least twelve separate frequency bands.

B Advantages of the use of CDMA.

Compared to a system based on TDMA, the use of CDMA offers two main advantages:

- Resistance to narrowband noise sources such as short-wave broadcasting stations.
- Flexible bandwidth management

Resistance to narrowband noise sources is inherent to the use of spread spectrum techniques, and offers advantages with regards to the use of the available upstream frequency region. This region is contaminated with various types of noise, i.e. narrowband noise and impulse noise [2]. Flexible bandwidth means that the capacity of a certain frequency region can be exploited to the full extend. Typical for a CATV network is that it is power limited. If TDMA is used in such a system, insufficient signal to noise ratio may lead to a situation in which a complete TDMA carrier is lost. In the case of CDMA, however, the useable power budget can be divided over as much CDMA signals as can be allowed by the system (figure 2). This is due to the fact that in CDMA all upstream transmitters in a single MAC domain are allowed to use the full time and frequency resources simultaneously, while the power resources are distributed over the transmitters.

Multiplexing is done by means of the orthogonal CDMA spreading sequences. The more CDMA signals are present, the higher the resulting signal power will be. The number of allowed CDMA carriers in a single frequency channel thus depends on the maximum signal to noise ratio that can be achieved without causing a disturbance of the system resulting from a too high transmit power.

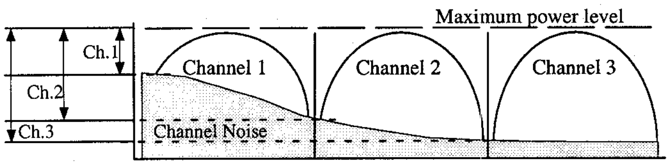


Figure 2: *Useable power budget in upstream CATV channels with CDMA.*

C Operation modes of the system.

In normal operation mode the upstream spreading sequence generators at the modems are aligned in such a way that an almost perfect cross-correlation is realized at the head-end, meaning that a near maximum system capacity can be achieved. The exact frequency of the upstream spreading sequence generators is dictated by a master clock at the head-end. Because perfect cross-correlation values have to be realized at the head-end, the head-end has been chosen as the timing reference point. At activation of a modem, however, the phase of the upstream spreading sequence generator of the modem will be in a random but non-fluctuating state with respect to the master clock in the head-end and the phase of other aligned spreading sequence generators. As a result, the modem must be seen as an asynchronously operating modem, which will lead to a capacity decrease of the system. It should be prevented that the capacity of the system will drop that far that an interruption of other transmissions occurs due to insufficient signal to noise ratio resulting from a too high increase in Multiple Access Interference (MAI).

In a practical system, there will be a mixture of synchronously and asynchronously operating modems. The amount of and the ratio between asynchronously and synchronously operating modems determines the measure of MAI, and thus also how many additional asynchronous connections can be established, with the prior knowledge of power limitations of the network and the properties of the noise environment. To prevent a too large decrease in capacity, modems operating in asynchronous mode are operating with a lower power level and a "longer" spreading sequence. This spreading sequences are created out of a concatenation of multiple sequences with normal length. The concatenation in itself is realized by transmitting the same bit multiple times, and by correlating at the receiver over all sequences associated with the same bit. This way, an equal ratio of energy per bit is maintained while the transmit power can be reduced. The resulting lower bitrate does not form a problem since during the asynchronous operation the modem is in an initialization state, meaning that very low amounts of data have to be transmitted.

IV. Description of the initialization procedures.

The main task of the initialization procedures is to determine physical layer and MAC related settings of the modem, such that a flawless operation of the multiple access scheme is guaranteed and that a nearly optimized capacity is achieved. The following parameters have to be determined:

- Phase of the local spreading sequence generator => requires phase monitoring.
- Upstream path attenuation => requires power ranging.
- Determination of the MAC address => requires modem identification.

The unique MAC address is determined by using a modem identification procedure that does not require prior knowledge of MAC addresses of the modems present in a single MAC domain, as will be explained in the next sections.

A Phase determination of local spreading sequence generator

In a CDMA based communications system the importance of timing is emphasized by the fact that modems sharing the upstream bandwidth all encounter a different physical delay from the modem to the head-end. This is due to the fact that modems mostly are located at different physical locations. The result is that the timing relationship between the head-end and a modem is different for each modem. Consequently, in order to align all CDMA signals at the head-end, the phase of the spreading sequence generator at the modem needs to be adjusted such that the most optimum alignment is achieved. This process is also referred to as distance ranging [6]. To enable easy alignment, a master and slave principle has been applied in which all modems are provided a common reference clock by the head-end via the downstream DVB channels. Thus after powering on a modem, only a fixed phase error between the various overlaying CDMA signals remains to be nullified. Because CDMA is used in the upstream, it is not required that the absolute difference in physical delay between the modems is known and compensated for by the ranging process. A closed-loop mechanism has been used that allows the head-end receiver to control the phase of the spreading sequence generators at the modem by sending dedicated ATM cells through the DVB channels. The phase is tuned such that the best achievable (i.e. as low as possible) cross-correlation value is realized and maintained. The accuracy of the phase control mechanism plays a relatively large role. Here, the alignment has an accuracy of one eight of a chip time. This choice results in an average penalty loss of about 0.3dB [3] due to misalignments between the various spreading sequence generators.

The delay between a modem and the head-end consists of several contributions, such as the transmission delay over the network, the processing delay of the equipment, and the delay resulting from DVB compliant modulation, such as interleaving and de-interleaving, Reed Solomon encoding, etc. Some of these delays mentioned are non-changing entities and thus they do not play an important role in the distance ranging process. The transmission delay, however, is a changing entity, although the modem may reside at a fixed position in the network. Due to temperature effects, the transmission properties of network components such as amplifiers, in-house networks, but also cabling may be subject to changes. As a result, a continuous monitoring of the phase of the spreading sequence generators is required, after the distance ranging process has been completed.

B Modem identification: anonymous ranging.

Each modem has been supplied with its own unique MAC address that is used by the modem to identify itself at the head-end. However, this unique address is not used by the head-end to address a modem after completion of the initialization procedure. Instead, a 2-byte short MAC address is assigned in the final stage of the initialization procedure, to prevent unnecessary and excessive bandwidth usage in the downstream direction. A short MAC address of 2 bytes offers sufficient addressing space for all modems in a single MAC domain.

Modem identification by anonymous ranging means the determination of the MAC addresses of all modems that are operating within a single MAC domain. The algorithm applied to perform this task is contention oriented. This means that multiple modems are allowed access to the same asynchronous CDMA channel, which can lead to collisions between modems that simultaneously try to initialize. These collisions can be detected by the head-end receiver, and they are resolved by a contention resolution mechanism. This mechanism uses the ability of the head-end receiver to address a sub-range of the full MAC address range. Based on certain network properties and the number of active, synchronous connections in the network, the head-end receiver first determines the number of allowable asynchronous connections. Next, an equal number of PPG sequences is selected that may be used by all modems that are waiting for an asynchronous connection. The information related to the MAC address ranges and the spreading sequences to be used is stored in special ranging permits that are broadcast to all modems.

Modems waiting for a ranging permit and whose MAC address falls within the range specified in the ranging permit, respond by transmitting a first identification message to the head-end. If within the MAC address range only one modem has responded, no collisions will occur and the modem can start initializing immediately. If multiple modems have responded, a collision will occur. The head-end reacts by reducing the MAC address range, and by issuing a new permit. This process is repeated until only one modem has responded, after which the ranging procedure of that modem can start.

C Power ranging

Power ranging is required because the attenuation of the physical path from a modem to the head-end receiver may differ from modem to modem. The variations in attenuation can mainly be found in the coaxial network between the client modem (the CNT) and the ONT. In a practical CATV network these differences in attenuation of the coaxial network are limited to within a 30dB. In figure 3, the assumed attenuation levels in the coaxial access network as well as in the optical network between the ONT and the head-end have been depicted. The attenuation of the optical link cannot be compensated for by the modem since the optical link is shared by multiple modems. Thus the reference point for the power ranging lies at the ONT for all modems sharing the same optical link. However, to achieve a sufficient signal to noise ratio at the head-end, the modulation index of the laser needs to be as optimum as possible, putting a certain requirement on the upstream input levels measured at the ONT. The attenuation of the optical link itself is commonly compensated for by an AGC mechanism in the optical receiver at the head-end. A second stringent requirement is imposed on the received upstream power levels since the difference between these levels directly influences the capacity of the system. This requirement is more stringent the moment modems are operating in asynchronous mode, thus during the execution of the initialization procedures. Since the attenuation from modem to head-end is unknown, a modem has to start initializing with the lowest power level possible to prevent a sudden increase in MAI.

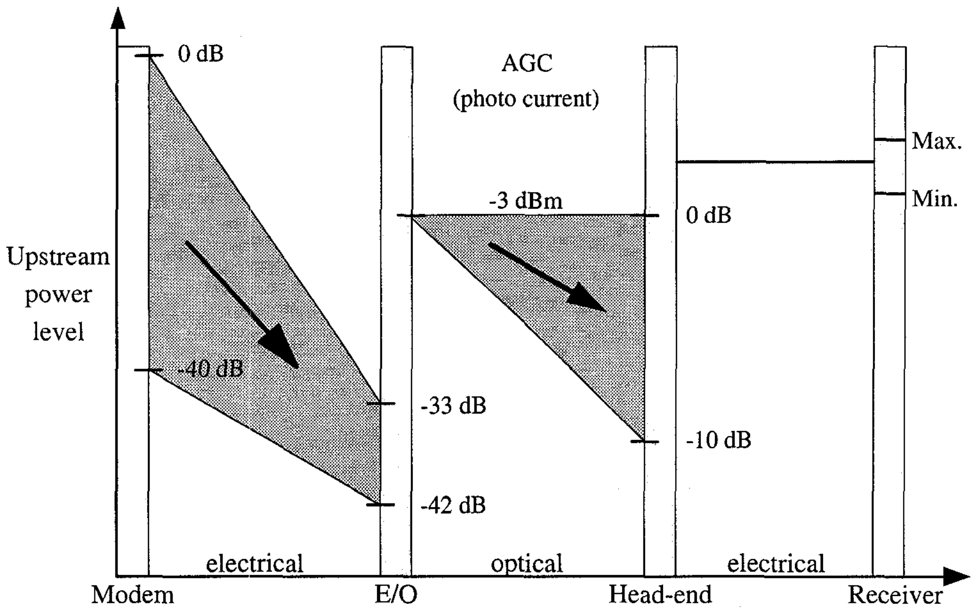


Figure 3: *Attenuation in the upstream path of a CATV network.*

The power level is optimized by means of a closed loop control mechanism, that allows the head-end to adjust the power level of the modems until the most optimum power level has been reached. Because multiple modems can simultaneously try to initialize, it can occur that one modem encounters a high attenuation and a second modem a low attenuation. This can lead to a situation in which a collision has occurred, but that the difference in received power is too high to be notified by the head-end receiver. These collisions are automatically resolved because all messages exchanged between head-end and the initializing modem are specifically addressed the moment the head-end has been able to determine the MAC address of one of the modems, typically the one with the highest received power. This inherently indicates to all other modems that they have to stop sending identification messages, and that they'll have to wait for the next ranging permit.

V. The full initialization protocol.

The above described procedures of power ranging, delay ranging, and anonymous ranging cannot be seen as independent processes, but they are strongly related to each other and they influence each others performance. For example, delay ranging can be performed better when the power level has already been optimized to a certain level. On the other hand, if the delay has already been optimized, the requirements concerning the control of the power level will somehow become less stringent. The mechanism describing the order in which the distinct processes are executed is shown in figure 4. The algorithm first determines the MAC address range that is allowed to start the initialization procedure. The next step is that the modems that have responded to the first permit are asked to increase their power level, such that the head-end receiver is able to detect whether only modem, or a multiple modems have responded to the ranging permit. If the receiver has detected that multiple modems have responded, then the MAC address range is adjusted and a new ranging permit is send. If only one modem has responded, delay ranging is immediately applied. Each time a modem has been initialized, the ranging process increases the address range again to the full MAC address range, such that all other modems who still require ranging can again take part in the next ranging cyclus.

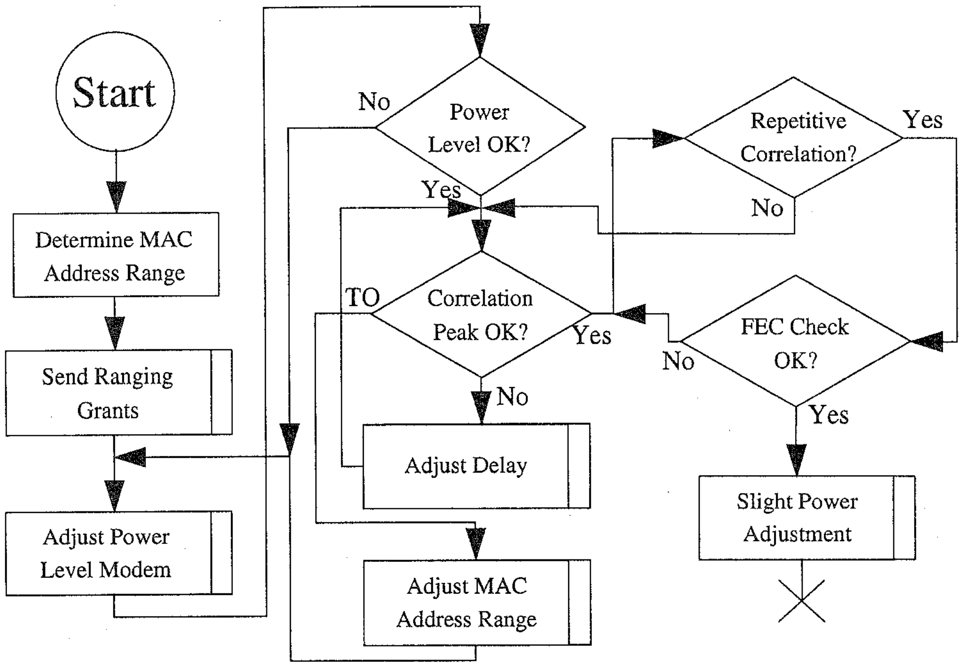


Figure 4: *Full (simplified) ranging protocol for anonymous ranging using CDMA*

VI. Conclusions

In this paper we have described an initialization protocol for a communications system in a shared medium network such as a CATV network. The shared medium aspects imply uncertainty concerning factors such as path attenuation, delay, and identity or MAC address of a modem. These factors must be determined before access can be granted in the upstream. We have described a protocol that performs modem identification based on a collision oriented and adaptive ranging mechanism that initially allows all modems within a certain MAC address range to respond to a ranging permit. We've also described mechanisms that perform delay ranging and power ranging. The delay ranging mechanism is based on a relative delay ranging measurement, which means that not the absolute difference in physical delay is compensated for. The three processes of power ranging, delay ranging, and anonymous ranging are strongly related to each other, and they need to be executed in the correct order of MAC range determination, coarse power level adjustment, delay ranging, anonymous ranging, and fine power adjustment.

References.

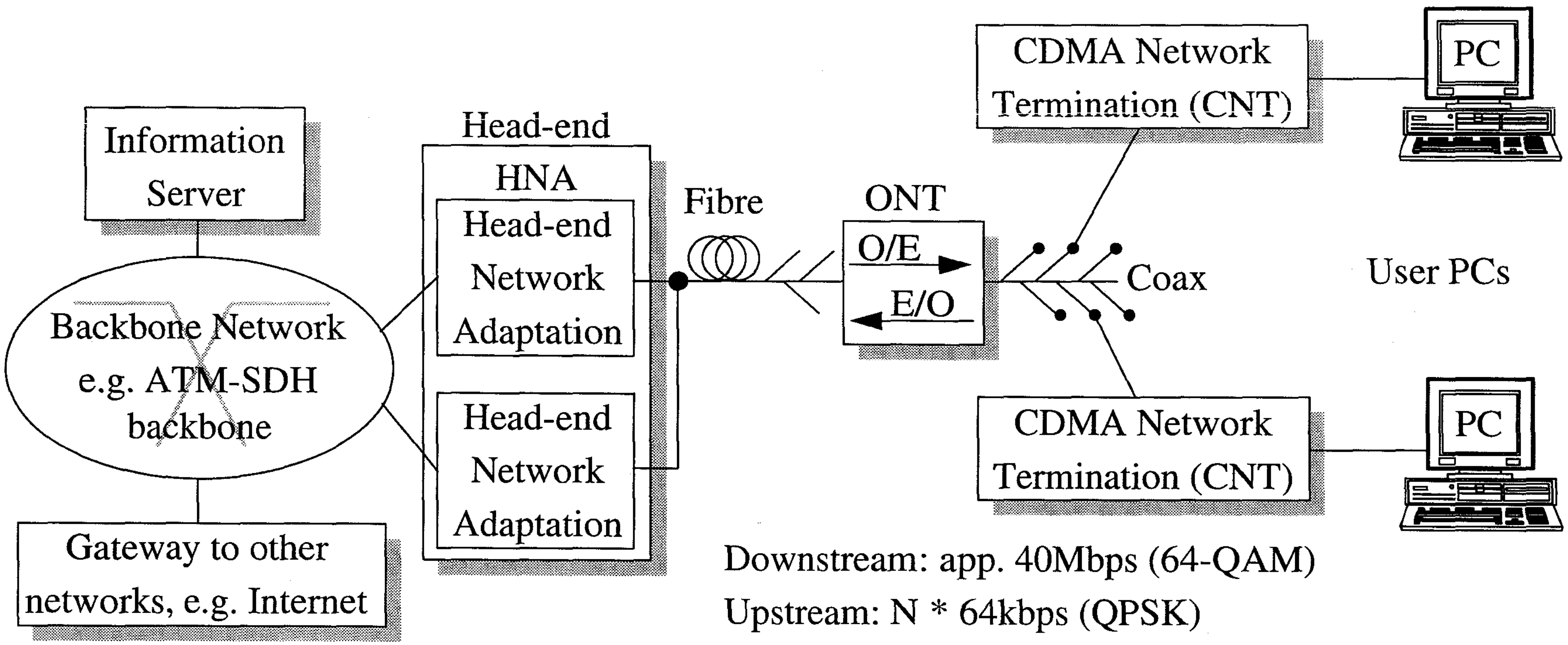
1] R.P.C. Wolters, Bi-directional Transmission in Hybrid Fiber-Coax CATV networks; A Framework, *Eindhoven University of Technology*, 1995.

2] R.P.C.Wolters and Y.L.C. de Jong, A Novel Hybrid-Access CDMA Communication System for CATV networks, *paper presented at NOC '96*.

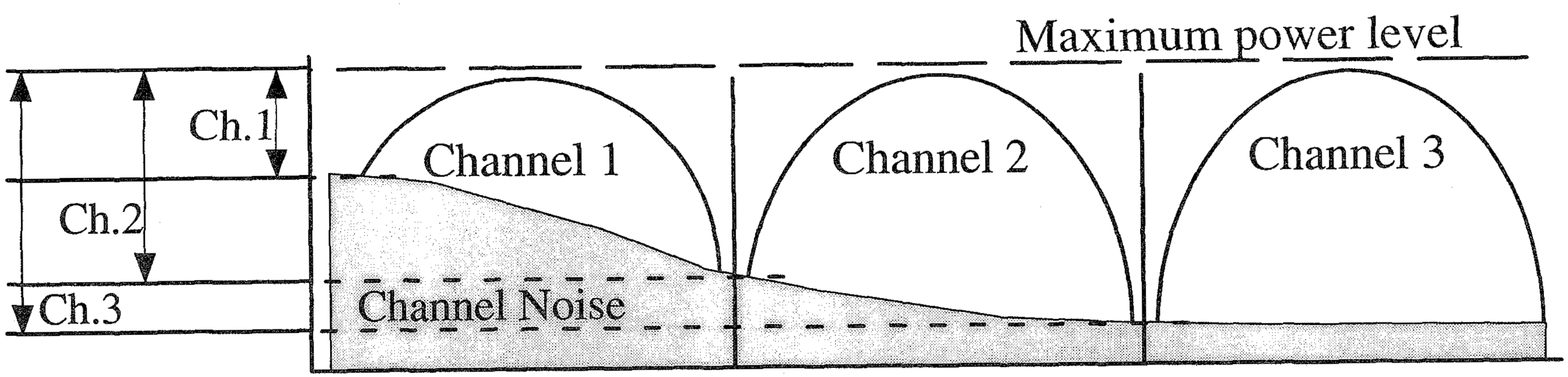
3] Y.L.C. de Jong et al., A CDMA Based Bi-directional Communication System for Hybrid Fiber-Coax CATV Networks; *IEEE Transactions on Broadcasting*, vol. 43, June 1997, pp. 127 - 135.

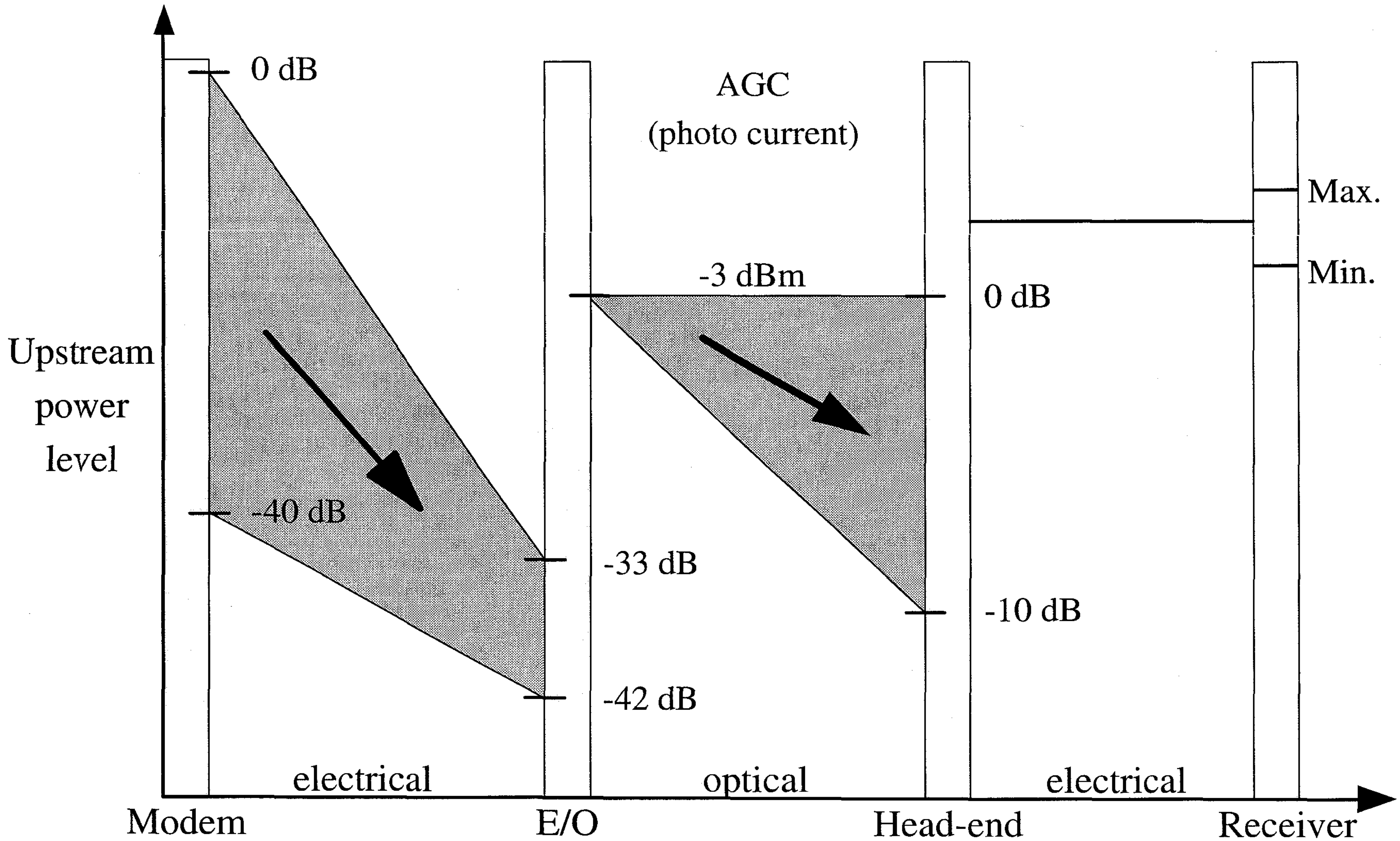
4] R.P.C. Wolters, Characteristics of Upstream Channel Noise in CATV networks; *IEEE Transactions on Broadcasting*, vol.42, December 1996, pp. 328 - 332.

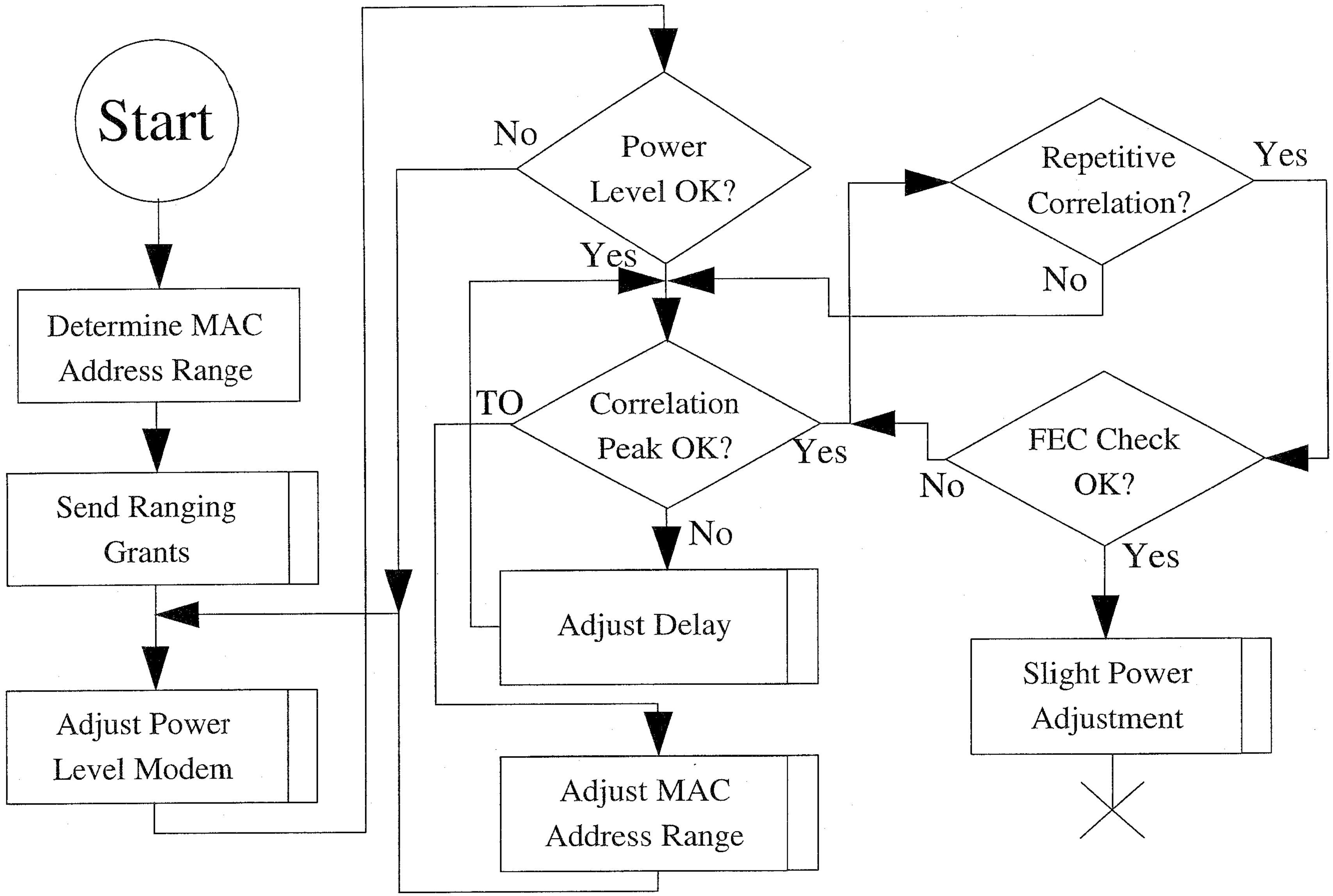
5] R.P.C.Wolters et al., A Novel ATM based Data Transport System for Hybrid Fiber Coax CATV Networks; paper presented at the *IEEE ATM '97 workshop* at Lisboa, Portugal.



Information
Server
Backbone Network
e.g. ATM-SDH
backbone
Gateway to other
networks, e.g. Internet
Head-end
HNA
Head-end
Network
Adaptation
Head-end
Network
Adaptation
Fibre
ONT
O/E
E/O
Coax
CDMA Network
Termination (CNT)
CDMA Network
Termination (CNT)
PC
PC
User PCs
Downstream: app. 40Mbps (64-QAM)
Upstream: N * 64kbps (QPSK)


Maximum power level
Ch.1
Ch.2
Ch.3
Channel 1
Channel 2
Channel 3
Channel Noise


0 dB
AGC
(photo current)
Max.
-3 dBm
Min.
0 dB
Upstream
power
level
-40 dB
-33 dB
-10 dB
-42 dB
electrical
optical
electrical
Modem
E/O
Head-end
Receiver


Start
Determine MAC Address Range
Send Ranging Grants
Adjust Power Level Modem
No
Power Level OK?
Yes
TO
Correlation Peak OK?
Yes
No
Adjust Delay
Adjust MAC Address Range
Repetitive Correlation?
Yes
No
FEC Check OK?
No
Yes
Slight Power Adjustment