The Space Congress® Proceedings 1970 (7th) Technology Today and Tomorrow

Apr 1st, 8:00 AM

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A NEW MULTIPLE ACCESS TECHNIQUE FOR USE WITH SATELLITE NETWORKS

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ABSTRACT

The Multiple Access Discrete Address System described is particularly applicable to future digital modulation systems. A high degree of efficiency is achieved using methods which provide the advantages of time division without the critical dependence on precise timing characteristic of more conventional techniques. A performance comparison with current fm/fdm is provided.

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In communicating through a satellite repeater, a modulation technique must be selected to serve two separate functions. The first is the address function which must permit the receiver to separate the desired signal from other transmissions simultaneously using a given repeater. The second function is to transfer a message between two users. This presentation relates to the first function and describes a Multiple Access Discrete Address System that has unique features, particularly applicable to future digital communications networks.

In a sense, a satellite communications link is nothing more than a microwave circuit with an unattended repeater. One of the prime differences, however, is that due to the high cost of the satellite a number of circuits must use the same repeating amplifier. It is also a characteristic that the satellite is severely power limited. This power limitation at the present time is not a technological limit, but results from the sharing of frequency band with ground-based systems and international agreements covering satellite radiated power. The multiple users combined with the power limit places constraints on the system and is the fundamental reason for the presence of a multiple access problem. It may also be observed that in any communications network it is necessary for the receiver to be able to select a particular transmission of interest from the multiple signals that it has access to; hence, the requirement for discrete addressing.

In a recent paper by John Wittman[1], twenty six multiple access techniques were identified and categorized according to their distribution of energy per access in a bounded time-frequency plane. There are three basic techniques. These are frequency division, time division, and code division. All other multiple access techniques are necessarily combinations of these three. Space division was excluded, since it is really a special case which requires separate amplifiers. In fact, multiple satellites are a form of space division multiple access.

Frequency division multiple access (FDMA) systems are characterized by signals which have constant envelopes and spectra which are confined to non-over-lapping frequency bands. Multiple Access Demodulation is accomplished by a filter tuned to the selected frequency band. Its advantages are that it makes use of existing technology and hardware to a greater extent than the other techniques and does not require system timing. In an FDMA system, however, multiple signals tend to produce intermodulation noise, which reduces the useable repeater output power. Uplink power coordination or power management to within .5 dB is required and operation with separate receiving systems is difficult.

Time division systems have carriers which are gated on and off in such a way that only one signal at a time is present in the repeater at any given instant. Demodulation is accomplished by time-gating the desired signal. Its advantage is that it avoids the power management problem and provides considerable system flexibility. In theory, it has the highest capacity of all known systems. The disadvantage is that it requires good system timing. A second possible disadvantage of TDMA is that it requires time compression of the message. In analog systems, this is sometimes difficult to instrument and as a result TDMA is usually instrumented in conjunction with digital modulation.

Code division systems are generally fairly complex to instrument and, depending on the particular code used, may have some of the disadvantages associated with both TD and FD systems. It's main advantage is that it tends to degrade gradually in the event of overload or malfunction and because of this is frequently employed in sys-

tems having a large number of users with relatively small capacity requirements with low duty factors. It is generally conceded to be the least efficient of the three systems.

The advantages and disadvantages of the various techniques must be traded off against the requirements of any system. Several basic sets of requirements exist which impose completely different conditions on the system designer. One set relates to a system which would be used in a broadcast network where one station would transmit to a large number of receivers. In this case, the multiple access problem is relatively minor. A second system is characterized by a large number of small users. In other words, a system where there may be several thousand accesses where each requirement may be for a voice channel or a single channel teletype. This is typical of tactical communications systems such as the one being developed under the TACSAT program. A third system is typically one where the number of accesses is relatively small, but the requirement for each link in the system may be for a hundred or more voice channels. It is this last type which is considered in this paper.

A commercial requirement for a system of this type may be found in the South American environment. In a traffic study completed for the Inter-American Development Bank, it was determined that in the 1970 time period, South America would have requirements for seven earth stations with a total of 264 telephone channels. In Figure 1, each slot is a part of an access and was set equal to a group of 12 channels. The 12 channel group was selected to be consistant with current telephone standards. As noted, Argentina is likely to be the largest user with a requirement for two groups to Chile, one to Peru, one to Venezuela and two to Brazil. Conversely, Uruguay is expected to require only one group of 12 channels to Brazil.

A similar requirement exists for the U. S. Armed Forces for a satellite communications network over the Pacific. This network would consist of comparatively short links, such as from Bangkok to Saigon as well as long circuits such as Saigon to California. The network might consist of eight stations and seventeen lines. Each link would be 614 kilobits per second with several links carrying 1.2 megabits. Total system capacity would be of the order of 10 to 12 megabits per second. This is roughly equivalent to several hundred PCM voice channels.

To answer the requirements of this type of network, a system should have the following features:

1. Avoid multiple carriers at the repeater and the resulting intermodulation and power management problems.

2. In the event that system timing were required, loss of synchronism would result in "graceful degradation" and not the catastrophic failure typical of most time division systems.

3. System operation is simple and does not require the use of a "master" or controlling station. This is of importance in certain military applications where it is undesirable to have an entire network dependent on a single station, as well as in the South America situation where politics make a controlling station a matter of national prestige.

4. Each user requires only a single receiver instead of one for each link appearing at that node.

5. The system is readily switched over to a Random Access Mode where a complete breakdown in discipline occurs, or into an anti-jam system where interfering signals are intentionally or unintentionally radiated.

6. The system provides flexibility as to modulation and data rates such that a user can adapt his requirements without affecting other participants sharing the repeater.

The resulting system consists of a combination of time division and frequency division, but is not of the usual time frequency keying matrix which requires sophisticated demodulation techniques. This system simply assigns each user a transmit time period or periods and a receive frequency. A typical example is shown in Figure 2. In this example, for user A to transmit to user B, he transmits in time block A and on frequency B.

Time division systems imply a time reference. Time reference can be provided in a number of ways. In Figure 2, a very simple system is suggested which would require minimum site coordination. The first "user" assumes control and transmits a short reference pulse. Subsequent users would then use this reference to determine their appropriate transmit times. Each station would be equipped to provide control.

The following is presented as an example of system operation:

1. "A" wishes to transmit to "E" and all other systems are idle.

2. "A" first checks the "time reference" frequency and finds no reference being transmitted.

3. "A" assumes control and transmits a reference pulse. He then counts down seven time slots and transmits on "E's" assigned frequency and communication is immediately established.

4. "E" then establishes a return link by first monitoring the reference time. "E" counts down 20 time slots from the reference time and transmits to "A" on "A's" receive frequency.

5. Subsequently, "B" wishes to establish a link

with "A".

6. "B" monitors the "Time Reference" frequency and determines system time.

7. "B" counts down r-time slots and transmits to "A's" receiver frequency.

8. Identical procedures are followed in the establishment of additional links.

The system shown in Figure 2 has been derived to allow one time slot between separate link transmissions for transmitter retuning. For example, if "A" is transmitting to "C" in time slot 1 on frequency 3, and then to "E" in time slot 3 on frequency 5, time slot 2 is available for transmitter frequency adjustment.

The system arrangement illustrated provides that if a user is out of time sync by one time slot, the system still operates. Degradation would be experienced in a fully loaded system due to power division in the repeater. Catastrophic failure of two links would result if two stations transmitted to the same receiver at the same time. Further effort in assigning transmit time slots could provide additional tolerance to timing error.

Some experiments have been conducted with pure time division systems. In these systems a computer is used to determine from satellite position, orbit data and from a received signal the precise time that a transmission burst should occur. Due to the catastrophic results of over-lapping another transmission, a probing pulse is placed in the center of the calculated burst period. Its time is then advanced until the pulse appears at the beginning of the desired time. Transmission of data may then commence.

In the illustrated system, the requirement for the computer is eliminated. Each station transmits a time reference signal at a relatively low level. Data transmission is locked out until the station's time reference overlaps that of the controlling station's reference. Station reference signals are kept separate by code division.

Basic similarities exist between multiple access, frequency hopping random access, and an antijam (A/J) systems. In the multiple access system, a receiver is addressed by a single frequency. In the Random Access Discrete Address (RADA) configuration the address is a repeating time frequency code of short duration. In the A/J configuration, a pseudo-random or long code is used.

Typical system bandwidth requirements can be estimated. Assuming a bit rate of 614 Kbits/sec and four phase PSK keying, then a network made up of 15 links with 6 transmit and receive stations would require a minimum bandwidth of 27 megahertz. Similarly, 8 stations and 19 links would require 47 megahertz bandwidth, and allow-

ing 50% for frequency guard bands still provides a total system requirement of less than 70 megahertz. These bandwidths are well within the state-of-the-art. Limitations on radiated energy in certain frequency bands in fact make the band spreading desirable.

In a system of this type, which is basically a time division system, storage is required to permit compression and burst transmission. Time must be allotted in each frame for transmission of information which permits data and system synchronization. The time required for this information results in a decrease in channel capacity. Since the synchronizing time tends to be fixed, and is independent of frame length, increasing the frame results in a decrease in "lost capacity". Conversely, however, storage requirements are increased directly as the frame length is extended.

Figure 3 shows the results of an economic trade-off analysis made under the following assumptions:

1. A one way channel is worth $15,000 per year.

2. Storage costs are $1.00 per bit, amounting over a five year period to $0.20 per bit per year.

3. A 24 bit word is sufficient to provide the required synchronizing information.

The results of this analysis show that a frame length of about 6 milli-seconds is about optimum for the assumed conditions. It should be noted that this does introduce additional delays in the system; however, considering the 250 milli-second delay inherent in a synchronous satellite relay, it does not appear to be significant. With frame lengths of this order, a system efficiency of better than 99% can be achieved.

Figure 4 shows the results of a comparison of a digital system with the current fdm/fm. In a digital system, one must first decide the number of bits per second that are equivalent to a voice channel. Bell uses a PCM system that requires 64 kilobits per second to digitize a voice signal. The Bell System provides excellent quality but does not permit a large number of channels in, say, a 600 Kbit capability. Even at this rate, however, it may be noted that the PCM compares favorably with the fm system.

If the interest is in data only, then 2400 bits per second might be a reasonable equivalency. In this case, the digital system shows a significant power advantage. A reasonable compromise between the two extremes appears to be about 9600 bits per second. Voice digitizing systems are being developed which provide good quality at this rate. Here again, the advantage of digital modulation is significant.

Another factor in favor of digital modulation results from the fact that most long-haul circuits

are relayed through a number of systems. In other words, a message may go through cable, microwave, satellite and maybe even a tropo-scatter link. In analog modulation noise is cumulative; whereas, the digital signal can be regenerated at each relay point. The net effect is that digital techniques ease the link performance requirements.

Figure 5 shows the digital rates that can be achieved with various antenna sizes. For example, with an INTELSAT III Satellite and a transportable 42 foot antenna over 10 megabits per second is realizable. With a fixed station in the 100 foot class, up to seventy megabits is possible.

CONCLUSION

The multiple access technique discussed above offers advantages not available with other MADA techniques. It is especially compatible with digital communications requirements, compares favorably with current fm/fdm approaches, and provides an efficient and economical means of communications handling over satellite links. Network coordination and operation can be the least complex of systems currently available.

REFERENCES

1. Whittman, J. H., "Categorization of Multiple-Access Modulation Techniques," IEEE Transactions on Communications Techniques, 15-5, October 1967, p. 724-726.
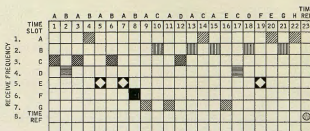
Figure 2. A Possible Time Slot A Receive Frequency Assignment
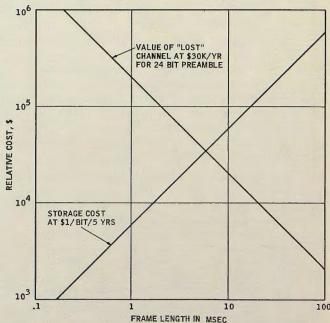
Figure 3. Frame Length Optimization
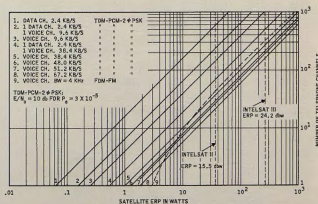
Figure 4. Satellite EIRP vs. Number of Telephone Channels

EACH SLOT IS EQUAL TO A GROUP OF 12 CHANNELS.

Figure 1. Traffic Model for South American Satellite Network

	ARGENTINA	CHILE	PERU	COLOMBIA	VENEZUELA	BRAZIL	URAGUAY	NO. OF 12 CH. GROUPS	NO. OF VOICE CHANNELS
1. ARGENTINA		2	1		1	2		6	72
2. CHILE	2			1		1		4	48
3. PERU	1				1			2	24
4. COLOMBIA		1				1		2	24
5. VENEZUELA	1		1					2	24
6. BRAZIL	2	1		1			1	5	60
7. URAGUAY						1		1	12
							TOTAL	22	264

PCM-2ΦPSK SYSTEM
$E/N_0 = 10$ db $P_e = 3 \times 10^{-5}$
RECEIVE $F_0 = 7.5$ GHz
RECEIVING SYSTEM NOISE TEMPERATURE: 90° K.
ELEVATION ∠: 5°
OPERATING MARGIN: 6 db
TRANSMITTER POWER SUFFICIENT
TO SATURATE REPEATER.

INTELSAT III

INTELSAT II

IDCSP

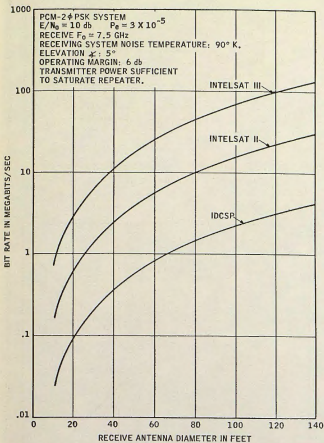BIT RATE IN MEGABITS/SEC

RECEIVE ANTENNA DIAMETER IN FEET

Figure 5. Satellite Capacities as a Function of the
Earth Station Antennas