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Multiple Access Protocols for Data Communications via VSAT Networks

C. J. Wolejsza
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One of the most significant advantages of VSAT Networks is the ability to link together many terminals at remote sites under a single manageable network and to adapt the performance characteristics of the network to the requirements of the type of data traffic presented to the network.

Over the past 20 years, the technology of satellite communications has achieved a tremendous growth in capacity and geographic span for voice and video applications, resulting in a worldwide communications network and the current emergence of regional networks [1-4]. Until recently, however, the primary mode of data transmission via satellite networks has been via low speed voice band signaling, and has not taken full advantage of the capabilities of a satellite-based communications system. The use of satellites for data communications has a number of significant advantages compared to terrestrial networks. Because any earthstation within the field of view of the satellite antenna could access the satellite network directly, the potential for maximum connectivity is available. In addition, satellites offer substantial flexibility in bandwidth and power utilization, thus providing the capability for much higher data rates than are generally available through terrestrial networks. Satellite systems also facilitate the utilization of centrally controlled networks, since each node in the network could have a direct link to the central site. This offers the possibility of providing private networks which are under total control of the network user.

The potential for satellite data communications networks has been given significant impetus by recent advances in technology, especially in the area of microwave integrated circuits. This includes solid-state power amplifiers (SSPA's) with up to 5 watts output power at C-band and 2 watts at Ku band, as well as integrated low cost up converters and low noise down converters [5]. Current digital technology also permits significant processing power in a small size and cost. This capability has led to the introduction of Very Small Aperture Terminal (VSAT) Satellite Networks for data communications applications using satellite technology [6,7]. The benefits of such networks include wide area coverage, lower operating costs than terrestrial networks, ease of installation and maintenance in remote areas and, high performance which is independent of distance. One of the most significant advantages of VSAT Networks is the ability to link together many terminals at remote sites under a single manageable network and to adapt the performance characteristics of the network to the requirements of the type of data traffic presented to the network.

VSAT Data Network Characteristics

The fundamental characteristics of such VSAT Networks require the use of low power transmitters (1-2 watts for Ku band) with small (1.2-2.5 meter) antennas, but relatively high EIRP from the satellite. This results in a situation in which the satellite itself is used in a power limited mode, rather than a bandwidth limited mode. The network is generally operated in a Frequency Division Multiple Access (FDMA) mode with several narrow bandwidth carriers, because the maximum available bit rate from any VSAT is relatively small compared to the available bandwidth. If the entire capacity of one such carrier is allocated to a single user, the mode of operation is termed Single Channel Per Carrier (SCPC). Forward error correction (FEC) coding is often

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used to optimize the trade-off between bit error rate and SSPA power to maintain high throughput. The total satellite capacity itself is determined by the multi-carrier intermodulation distortion in the satellite. Ku band systems, which have the capability to achieve higher data rates for a given antenna size, require greater margins in the design to allow for the higher frequency and depth of fading due to rain.

The use of VSAT systems for data communications brings with it a number of special concerns which are unique to the satellite environment. The chief of these is the propagation delay associated with a round trip to the satellite of about 270 msec. When designing a transmission protocol to provide data integrity and to function efficiently with this delay, compromises between efficiency of channel utilization and processing complexity are required. VSAT networks also have some other unique characteristics which make the design of transmission protocols more complex. Early experiments with data communications protocols were conducted by the Defense Advanced Research Project Agency (DARPA) in the Atlantic ocean basin using an INTELSAT IV satellite and Standard A earthstations [8-13]. In this environment, each earthstation was the same size and used the same transmission channel. Therefore each station was able to hear its own transmissions. Collision detection (necessary for contention-based packet protocols) is therefore relatively easy. A VSAT network, however, is generally unbalanced with a large central hub and many small remote stations. In this situation, a single outbound carrier provides data transfer to the remote terminals operating in a straight forward TDM channel mode. The inbound channel consists of perhaps several lower bit rate carriers operating in some form of Time Division Multiple Access (TDMA). Because the inbound and outbound carriers are at different bit rates, the remote stations cannot hear their own transmissions. Thus, the use of contention protocols requires a positive acknowledgement scheme to prevent loss of data. This is also a desirable feature for any satellite system since packets could be lost due to bit errors as well as collisions. Unfortunately, this also results in a two round trip delay before the acknowledgement is received by the sender, and the acknowledgement packets add to the offered load on the transmission channel. In addition, the actual data traffic offered to the VSAT network would normally be unbalanced.

Satellite Transmission Protocols

Historically, as noted by Lam [14], multiple access protocols were designed for voice communications with the objective of maximizing the achievable channel capacity or throughput in terms of the number of available voice channels. The primary access techniques for this were frequency division multiple access (FDMA) and time division multiple access (TDMA). Channels could be either fixed assigned or demand assigned using a suitable control algorithm [15]. FDMA and TDMA are highly efficient access schemes for voice traffic and for some data traffic, notably long batch file transfers.

One of the key issues which impact the efficiency and consequent economics of a data only satellite network are the creation of multiple access transmission protocols which are more efficient for this type of traffic. These techniques are all oriented toward a packet switching approach and this aspect of the network is strongly tied to the actual nature of the data traffic to be offered to the network. This has resulted in a multiplicity of protocols which have been studied for satellite networks. Generally, these protocols have been oriented toward balanced networks in which each user can see his own transmissions [12,13,16,17]. Of major concern with any network is that each of these transmission protocols must interact with a higher level packet oriented communications protocol such as SDLC or X.25. This results in a considerable variation in the methods used to achieve the performance needs of the user, especially for unbalanced VSAT networks.

For the sake of consistency within this paper, it is useful to define a consistent nomenclature for describing the transmission protocols. In the current context, the designation *ALOHA* [18] will refer to a contention based protocol in which the actual data packets are not synchronized among the users and collisions at the satellite may occur when two users attempt to transmit a packet at the same time, with a consequent loss of data. Collisions are detected by local observation of the received signal. This class includes unslotted and slotted ALOHA. Since this class of protocols depends upon each earth station being able to receive its own transmission, they are generally not suitable for VSAT STAR networks with small remote sites or unbalanced capacity configurations. In addition, they are not suitable for higher level protocols which depend upon packet integrity since packets may be lost due to channel errors and other causes besides collisions. Because they utilize contention they also suffer from unstabilities caused by high traffic loads. They are included for completeness and because they are the most basic and thoroughly analyzed type of protocol [16-20].

A variation of slotted ALOHA in which all packets are acknowledged by the recipient is herein designated *Random Access TDMA*. This approach has capacity performance similar to slotted ALOHA and maintains packet integrity, although it suffers twice the propagation delay before an acknowledgment is received by the sender, and acknowledgment packets add to the offered load on the channel thus aggravating the stability problem. The actual data is still carried in contention mode on the channel. It is the only approach to implementing a contention channel in a STAR Network.

The other principal dynamic transmission protocols of interest for VSAT STAR applications are all variations of *Reservation TDMA*. These protocols are characterized by a frame structure on the channel consisting of reservable time slots which are assigned to users by a central network manager on a real time message-by-message basis. This class of protocols also requires a separate reservation "channel" by which each site communicates its capacity needs to the network manager. This channel may be on a separate frequency, or simply separate time slots (usually smaller than data slots) and may be used in contention ALOHA or non-contention TDMA mode. This mode of channel management also requires a tradeoff between the fraction of channel capacity allocated to the reservation traffic and that allocated to actual data traffic. Unbalanced networks also require a separate acknowledgment scheme to guarantee data integrity.

There are some data communication environments in which each remote site has a relatively fixed and well-defined, though small, traffic requirement. In this situation, the use of pre-assigned time slots in a TDMA format, allocated to each user provides efficient utilization of the satellite resources. This approach, *Fixed Frame TDMA,* essentially provide a "bit pipe" of specified average bit rate between each user and the central Hub. Reallocation of capacity is generally performed only occasionally and is done "offline."

It should be noted that none of the above simple protocols provide a perfect fit for all or even a majority of applications. In fact, for many applications, the traffic environment may change with time or circumstances in a periodic or stochastic sense and therefore more complex and adaptive modes have been proposed such as C-PODA [21,22] and SRUC [23] which attempt to exploit the benefits of each class of protocol as a function of traffic dynamics and reduce the detrimental effects of contention channel instability.

Performance Criteria

The VSAT user in general wishes to replace his present leased line network with a more efficient, flexible and less expensive system without loss of performance and, if at all possible, without loss of network availability.

The major factor effecting satellite network availability is the effect of propagation phenomena, particularly rain, on Ku-band transmissions. In normal VSAT systems [24] this at least one order of magnitude worse than the combined equipment availabilities and is on the order of 99.5-99.9 percent dependent on the choice of antenna size, transmit power and transmit data rates within the limits permitted by the FCC [25].

The network availability must be balanced relative to the other major performance criteria, namely Bit Error Rate (BER). Typical data users require BERs on the order of 10^{-6} or 10^{-7} and tend to think in these terms. Unfortunately, BER is not the best or easiest measure of performance in packet networks. As most packet networks are "bursty" in nature, and one either accepts or rejects transmissions on a packet basis, and retransmits faulty packets to prevent loss of data, Packet Error Rate (PER) becomes the measure of "goodness" of the network. However, satellite links are still calculated on a BER basis and a relationship between BER and PER must be established. This relationship for an uncoded system [26] is given by

$$Pe = L\,Pb \qquad (1)$$

where

Pe = *Packet Error Rate*
Pb = *Bit Error Rate*
L = *Packet Length in Bits*

for a system with a low PER. Due to the small size of the VSAT antenna most systems use some form of Forward Error Correction coding and for a convolutional coding with soft decision Viterbi decoding the relationship given in (1) becomes

$$10\,Log\,Pe = 10\,log\,(Pb) + Gp \qquad (2)$$

where Gp = the packet coding gain. Details and derivations are given in [26]. A similar expression for a sequential coding system has yet to be worked out. As the PER is easily monitored by counting the number of occurrences of a non-zero CRC it provides a simple online means to monitor BER performance and becomes a good maintenance tool. As a reference point, in a system utilizing a soft decision Viterbi decoder, a PER = 2×10^{-3} corresponds to a BER = 10^{-6} as shown in Fig. 1.

As in all system designs, trade-offs are required between the antenna size, transmit power and data rate as a function of the desired BER at given propagation availabilities.

The greater the availability required for any given BER/PER, the greater the required power from the satellite to the VSAT, hence the lower the transponder utilization per carrier in the power limited environment typical of VSAT operation. Other non-technical factors also enter the equation such as the aesthetics of a satellite antenna of a given size on the proposed structure, local building codes and, as always, the cost versus performance gain.

Two additional performance issues must be factored into the design equation; these are throughput (average percent of channel capacity carrying actual user data) and delay (average time between receipt of data by the VSAT network and error-free delivery to end user). Both of the above are directly related to the nature of the traffic being transmitted.

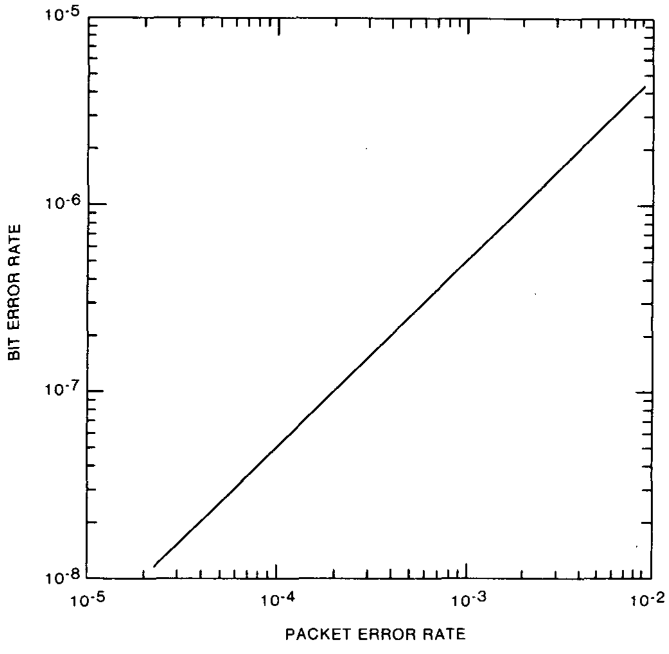


Fig. 1. Relationship between packet-error-rate and bit-error-rate for 128-byte packets when $r = 1/2$, $K = 7$ convolutional encoding and soft decision maximum likelihood decoding is employed.

Traffic Characteristics

The nature of the traffic will also profoundly effect the type of satellite protocol that is most efficient for a particular network. One can separate traffic into several basic types:

a) Interactive Data
b) Inquiry/Response
c) Batch (File Transfer)
d) SCADA (Supervisory Control and Data Acquisition)

The interactive data (for example, Bank Transactions, Automatic Teller Machine (ATM)) typically consists of a single packet inbound, VSAT to Hub, with 50 to 250 bytes, and an outbound reply of the same size in a single packet per message (SPPM). This is a low usage mode (low arrival rate) and lends itself to contention mode (Aloha, slotted Aloha) networks. It permits a relatively large number of VSATs on a single inbound channel. This type of network is typical of approximately 10 percent of the VSAT applications.

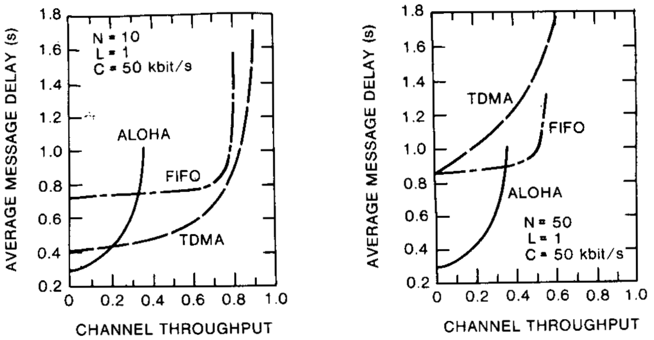
A more typical network is the inquiry/response type (for example, airline reservations) which features a short inbound packet, 30-100 bytes, and a multiple packet outbound response on the order of 500-2000 bytes. This is referred to as multiple packet per message (MPPM) since packets are limited to a maximum of 256 bytes in a typical SDLC environment.

Batch traffic (such as, ATM downloads) normally consists of down loads or printer traffic and are best suited to an SCPC type system for the duration of the down load.

SCADA networks (for example, pipeline monitoring) require a relatively small amount of data transmitted at fixed times from multiple sites in a *must have* mode and lend themselves to Fixed Frame TDMA networks. This type of traffic has the advantage of operating efficiently with pre-assigned slots and does not require positive acknowledgments.

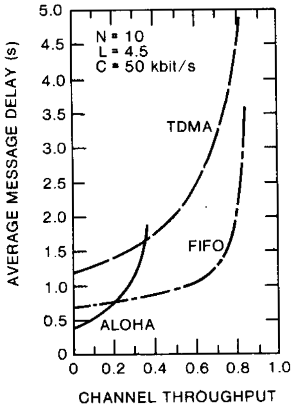
The reality of the marketplace is such that a typical network will contain elements of most or all of the above traffic types.

The effect of the type of traffic on the choice of network protocol must be balanced against the required throughput and delay. In general the contention modes provide a maximum throughput of 18 percent for Aloha and 36 percent for slotted Aloha and Random Access TDMA [27,28], though typical operation is 10 percent for the former and no higher than 30 percent for the latter two. Fixed Frame TDMA systems have 70-80 percent throughputs while Reservation TDMA approaches average about 60 percent. These throughputs must be balanced against the desired delay which is normally on the order of 2-8 seconds. Comparisons of delays, given in references 14 and 29, show that the least delay corresponds to the lowest throughput that is, slotted Aloha, while Fixed Frame TDMA yields the highest delay and throughput, with Reservation TDMA schemes holding the middle ground. It should also be noted that processing complexity is also the least for ALOHA based systems and increases for both Reservation TDMA (the most complex) and Fixed Frame TDMA, somewhat less complex. Figure 2 illustrates such a comparison and shows the throughput/delay trade-off for a balanced network. Details are given in [14].



(a) For 10 Users and Short Messages (One Packet per Message)

(b) For 50 Users and Short Messages (One Packet per Message)



(c) For 10 Users and Multipacket Messages

Fig. 2. Delay-throughput tradeoffs for three types of protocol illustrating the variation with the number of users and the number of packets per message. Reproduced from [14].

In addition, delay must be approached from two points of view; first that of the user and secondly that of the system designer. The user is only interested in how long it takes for a packet to transit the network. However, the requirement that the network ensure data integrity implies a positive acknowledgment (ACK). The VSAT/Hub must therefore retain the data until the acknowledgment is received. This implies at least an additional satellite delay which must be factored into the design.

The nature of the traffic has an even greater impact on the throughput. Once again the need for positive acknowledgments raises its head. In the Interactive data environment (one-for-one), an acknowledgment is required for each packet sent. On an outbound TDM link, depending on overhead, ACK packets of 20-40 bytes must be accommodated. On the inbound channels one either allows them to occupy the same size packet as the data and contend with the data for the available slots or adopts alternative approaches such as separate ACK channels or mixed slot sizes. In a N-for-one, inquiry/response system the problem is compounded. The inbound ACK traffic can be on the order of two to eight times the inbound data traffic in number of events and effectively swamps the actual data being transmitted. This requires the implementation of Group Acknowledgment schemes with a Go-Back-N or Selective Reject retransmission protocol [30].

Contention Channel Stability

Finally, one must consider the stability of the channel. Given that the delay is a prime requirement one might opt for a contention channel with acknowledgment (Random Access TDMA). Here again the positive ACK impacts the network. As the traffic increases or the number of terminals on the channel increases, the channel can become unstable [27,28]. When the channel becomes unstable, more packets are actually offered to the channel due to increasing the number of retransmissions and the throughput is reduced. This situation can only be alleviated by off loading traffic from the unstable channel until stability is restored. This requires spare space segment capacity to be held available for this purpose. An alternative solution is to increase the number of slots over which the retransmission is randomized which increases the average delay. This is only partially effective since continued increases in traffic will bring the system to unstability again.

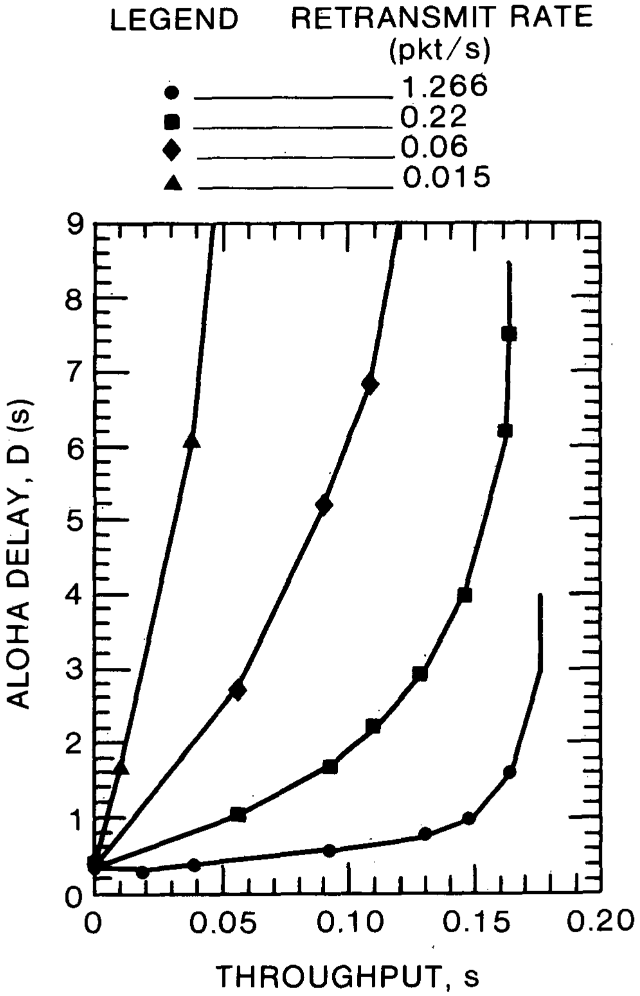
A very useful approach to the analysis of contention channel stability has been developed by Kleinrock [31]. This methodology is based upon a Markov model in which each user is permitted to be in one of two states; backlogged and available. In the available state, a user generates *and* transmits a new packet with some small probability, δ. In the backlogged state, the user is attempting to retransmit a collided packet with a random retransmission delay, with a probability $p >> \delta$. The Kleinrock model defines a locus of points in the plane defined by the channel input (S) (in expected packets per slots) and the number of backlogged packets (n), as shown in Figure 3a by the plotted points. This locus is a function of the average waiting delay for packet retransmission and divides the (S, n) plane into two regions. To the left of the locus, the expected channel throughput exceeds the offered load while to the right, the expected channel throughput is less than the offered load. The locus is in fact the equilibrium contour for which expected throughput equals offered load and hence represents a locus of possible operating points. Note that this equilibrium contour is a strong function of the number of slots over which the retransmissions are randomized (L).

For a finite population of users, the actual operating point must be on a straight line joining the total number of users M, on the Y-axis and the total possible load, $M\delta$ on the X-axis as shown by the "Load Line" in Fig. 3a. Kleinrock also showed that the system will be stable if and only if the load line intercepts the equilibrium contour in only one point, below the point of maximum throughput.

Typical load lines for interactive networks are shown in figure 3a. The figure shows that for a sample interactive system of 120 VSAT users per channel and a throughput of 30 percent, one would require a retransmission factor, L (the number of slots over which the retransmission is randomized exclusive of satellite delay) of approximately of 30 slots. This would yield (Fig. 3b) an average packet delay (exclusive of queueing or processing delays) of 1.5 seconds. If one can tolerate a longer delay one can increase the number of VSAT users per channel. On the other hand, if the delay is excessive, one can either reduce the number of VSAT users per channel or reduce the throughput per channel, both of which increase the number of satellite channels required and decrease satellite utilization. Once again one trades the number of channels required (satellite utilization) against the network delay requirements.

Multiple Access Protocols

In this section, we consider in more detail multiple access protocols for use in VSAT packet data communication networks. In a VSAT system, the suitability of a



(b) ALOHA Delay vs Throughput for Various Retransmission Rates

Fig. 3. Throughput versus backlog and throughput versus delay for purely interactive RA/TDMA. The straightline shows the loadline for a user population of 120 terminals. Note that L is the retransmission factor.

protocol is determined by the user traffic statistics, the connectivity of the network and the unavoidable long propagation delay.

As noted earlier, due to the bursty and diverse nature of VSAT data traffic, multiple access schemes such as FDMA and TDMA do not, in general, utilize the available satellite channel efficiently. In this bursty environment, more efficient use of the available capacity can be made by dynamically allocating it [12] among the users. The problem in designing a multiple access scheme is then the resolution of conflicts among those users wishing to transmit.

In general, multiple access schemes suitable for use in VSAT networks are packet-oriented. Loosely speaking, they may be classified into two broad categories; namely, contention or random access schemes and reservation schemes. The main contention schemes, suitable for use in VSAT systems, are based on the ALOHA [33] concept, of which there are three variations; namely, pure ALOHA [33], slotted ALOHA [34] and reservation ALOHA [35]. Classically, as noted earlier, these three protocols were considered only for the case of a balanced system in a broadcast channel, where the ability of each user to see his own transmissions and to detect any collisions provided any required acknowledgment with the channel being assumed to be otherwise error-free.

Most VSAT systems are, however, unbalanced and consist of a large central station or Hub and a large number of VSAT's. Almost all of these systems have star connectivity with all communications occurring between the Hub and the VSAT's with no terminal being able to see its own transmissions. In order then to apply ALOHA-type protocols, it is necessary to create an effective broadcast channel. This is done by using positive acknowledgments. As noted earlier in the paper, we refer to these as RA/TDMA protocols. They have essentially the same throughput properties as the corresponding ALOHA schemes, however, they tend to have longer delays due to the two-hop propagation delay required to detect collisions between packets. In the following paragraphs, we shall consider their properties in somewhat more detail.

Pure ALOHA Based RA/TDMA

In a RA/TDMA system based on the pure ALOHA protocol, users are completely unsynchronized. Each user having a packet to transmit immediately transmits it. In the classical version of this protocol, the user takes advantage of the broadcast nature of the satellite channel to monitor his own transmission and if he receives it correctly, assumes that it has been correctly received by the end user, assuming, of course, a very low channel error-rate. If two or more packets collide with each other at the satellite, each of the users involved will detect it after one round-trip delay time. Each will then retransmit its collided packet after a randomized delay. This randomization is critical to the delay, throughput and stability properties of the system [31]. In the RA/TDMA case, each packet contains a checksum (CRC) and positive acknowledgments by the Hub are used to detect collisons and to ensure the successful transmission of data.

Throughput or utilization of a pure ALOHA-based RA/TDMA channel may, for a large user population, be simply related to the offered traffic load [33] as:

$$S = Ge^{-2G}$$

where:

S = Aggregate channel throughput in packets/packet time

G = aggregate channel traffic in packets/packet time

From this it is clear that S achieves its maximum value of 0.184 at G = 0.5 packets/packet time; so that at best the ALOHA system achieves a channel utilization of about 18 percent.

The average per-packet delay in packet times of this protocol is readily approximated, assuming constant-duration packets, as [36]:

$$D = R + e^{2G}\,(2R + 1/2(L+1))$$

where:

R is the number of packet durations in a single-hop propagation delay,

and;

L is the maximum number of packet durations over which retransmissions are randomized.

An example of such a system is described by McBride [20] who shows that for predominantly interactive traffic with variable length packets, such a system provides an efficient protocol for a large number of low duty-factor users accessing the channel. Figure 4 illustrates the delay-throughput tradeoff for this system.

Slotted ALOHA Based RA/TDMA

The RA/TDMA protocol based on slotted ALOHA is almost identical to the pure ALOHA scheme described above with the additional requirement that the channel is slotted in time. Users must synchronize their packet transmissions into fixed length channel time slots each having the duration of a packet. This synchronization avoids partial overlaps of colliding packets. Under the same assumptions as above the channel throughput is then given in terms of the offered traffic as [31]:

$$S = Ge^{-G}$$

where S and G are as defined above. In this case, we find that S achieves its maximum value of 0.368 packets/slot at an average traffic load of 1 packet per slot. This is double the maximum throughput that is achievable in the unslotted case for fixed length packets.

The delay-throughput and stability tradeoffs of this protocol are analyzed in detail by Kleinrock, et al. [31] under the assumption of a broadcast channel. Its delay characteristics are very similar in form to those of the pure ALOHA system and as in the previous case the average packet delay may be approximated as:

$$D = R + 1.5 + e^{G}\,(2R + 0.5 + (L + 1)/2)$$

As in the previous case, we note the appearance of a two-hop propagation delay (2R) in the retransmission

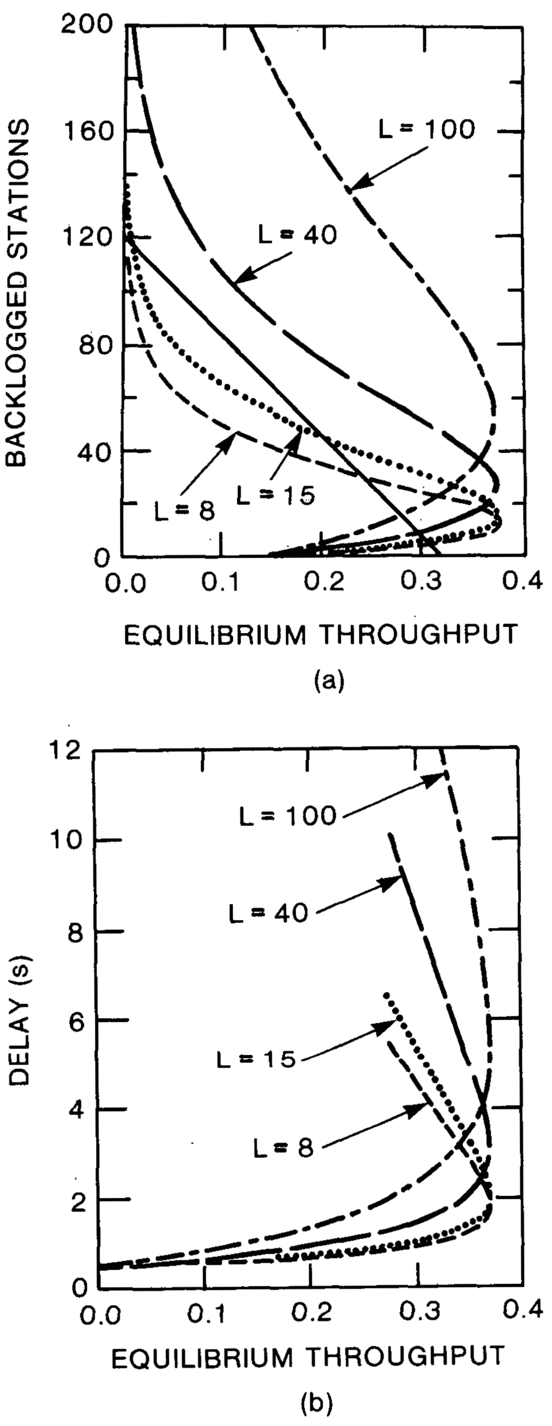


Fig. 4. Delay-throughput tradeoff for a pure ALOHA VSAT system as a function of the packet retransmission rate. This figure is reproduced from [20].

component of the delay. The resulting performance for a typical VSAT system is shown in Fig. 3.

Under light traffic conditions, the S-ALOHA based RA/TDMA protocol again provides an efficient multiple access protocol for a large number of low duty factor users, and indeed is the underlying basic protocol being used by most current VSAT systems. Moreover, because frame timing is inherently present, a slotted system has the advantage of being much easier to modify, under heavy traffic conditions, to a reservation TDMA system than is an unslotted system.

Reservation ALOHA Based RA/TDMA

Reservation ALOHA was originally proposed by Crowther, et al. [37] to cater, again in a broadcast channel, to a user population whose traffic tends to consist of multi-packet messages which is not well-suited to either pure ALOHA or S-ALOHA. In addition to the time slotting of S-ALOHA, the slots are organized into frames, each having a duration greater than the round trip propagation delay. This allows each user to be aware of the state of the channel in the preceding frame. A slot is considered to be unused if it is empty or if it contains a collision. All slots in the preceding frame that were unused are available in the current frame for random access as in S-ALOHA. A slot which contained a successful transmission by a given user may be used in the present frame only by that user and becomes available in the next frame only if the user fails to use it. The system can potentially achieve very high throughput for users having either long messages or continuously arriving short messages. However, it is not in its original form very useful for use in a STAR configured VSAT system.

Historically, R-ALOHA was the first approach to a packet reservation scheme for satellite data communications. It has been shown to provide significant improvement in channel utilization or throughput as the fraction of multi-packet messages increases [31]. Indeed, as noted by Lam [38], it is generally true that when the traffic consists primarily of multi-packet or batch messages, then reservation protocols make more efficient use of the available channel in terms of the achievable throughput. The R-ALOHA scheme may be regarded as both a contention and a reservation protocol in that under light traffic loads it behaves like S-ALOHA and under heavy traffic conditions, it behaves like a reservation system. However, it is normally considered to be a contention protocol since it does not use an independent reservation subchannel.

Under the assumptions of equilibrium conditions and that a user does not announce when he is finished using a slot, the throughput of the R-ALOHA system can be shown to be [39]:

$$S_{RA} = \frac{S_{SA}}{S_{SA} + 1/K}$$

where S_{SA} is the S-ALOHA throughput defined above and K is the average number of packets in a user message. This is somewhat lower than the S-ALOHA for small values of K, but approaches one packet per slot in the case of long messages. It may be improved slightly if each user includes an end-of-use flag in the last packet of each message [40]. The delay properties of the R-ALOHA protocol are very similar of that of S-ALOHA when messages are short and the traffic is light. They approach those of TDMA for large values of K and/or under heavy traffic conditions [40].

In the VSAT environment having star connectivity, the R-ALOHA protocol is not practicable. However, it does suggest that some mix of reservation and contention techniques may be the best design tradeoff for VSAT communications. In the following subsection, we shall consider packet reservation protocols.

Reservation TDMA Protocols

The objective of reservation protocols is to avoid contention entirely and to achieve high channel utilization or throughput, particularly when the traffic consists mainly of multi-packet messages. As we shall see later, this can be achieved only at the expense of increased system response time or delay. Lam [38] has summarized the characteristics of a number of packet reservation protocols and more recently several detailed analyses have appeared [10,40,41]. Characteristic of all of them are the requirements for an independent reservation subchannel and the implementation of a global queue. The reservation subchannel may be either time or frequency multiplexed with the data channel and may be operated as either a contention channel or a fixed-assignment TDMA channel.

The delay performance of any reservation technique is not as good as that achievable using contention techniques, because an extra round trip delay is required before actual data transmission can begin. However, the channel utilization or throughput can be made much higher—approaching one packet per channel time slot when the traffic intensity per user is high. The delay or system response time of a reservation system has two components, the delay in making a reservation and the delay in transmitting a message after a reservation has been secured.

If the reservation channel is operated in contention mode, as in [10], then the delay in making a reservation is essentially the same as for an S-ALOHA based RA/TDMA channel with additional components that depend on how the reservation subchannel is multiplexed with the data channel. If the reservation channel is operated as a fixed assigned TDMA subchannel on a separate rf carrier from the data subchannel, then its delay will be that of a TDMA channel [42]. On the other hand, if it is multiplexed onto the same rf carrier as the data, then the reservation delay becomes a complicated function of the overall channel performance [42].

The second component of the overall delay, the data channel delay is typically that of a TDMA system. However, most analyses of such systems to date make no attempt to separate the two components of delay. Instead, they compute the overall system response time from the initiation of a reservation until the successful transmission of the message. Typical examples of this are provided in the references [10,42] and an example of the delay performance to be expected when using a reservation protocol were previously shown in Fig. 2.

Adaptive Protocols

Some more recent work such as [43,44] has attempted to have the best of both types of protocol. That is they have investigated the use of adaptive protocols which under light traffic loading operate in a contention mode, and as the offered traffic increases, automatically become reservation protocols. These have the advantage of allowing for very flexible system designs; however they tend to be rather complex in their implementation. All of the analysis has again considered the case of a broadcast channel; so that while adaptive protocols look very promising in the VSAT environment, considerable work is required prior to any implementation.

These adaptive protocols typically achieve average channel utilizations or throughput lying between those of the pure contention schemes and the fixed frame TDMA schemes. However, their delay performance is most interesting. At light traffic loads they achieve response times that are comparable with that of S-ALOHA and under heavy traffic conditions they achieve average delays that are slightly smaller than those achievable using Fixed Frame TDMA. This depends to some extent on the frame structure in that for a given average number of packets per message and traffic intensity, there is an optimum frame duration. The performance analysis of these adaptive protocols is extremely complex and the reader is referred to the references for the details.

Summary

At this point in the evolution of VSAT-based data communications, there are still a large number of alternatives available to the system designer and a significant number of factors which must be considered. It is clear that the nature of the user's traffic should be the central focus of the designer's effort. Given the class of traffic and the required peak loading and availability, the task of evaluating the most effective protocols becomes a trade-off between throughput and delay.

Finally, the impact of the multiple access protocol on the overall costs of the network with the non-recurring costs (hardware and processing complexity) tradeoff against the recurring costs (satellite utilization) must be considered.

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