SOME SIMULATION RESULTS ON THE ERROR RATE PERFORMANCE OF SPREAD ALOHA

M. K. Goel

Department of Electrical Engineering
Indian Institute of Technology
New Delhi, India 110016

ABSTRACT

ALOHA is a random multiple access technique useful for interactive computer working. It, however, suffers from the limitation that it requires a high power output from the earth station that is accessing the channel. Spread ALOHA, a variation of ALOHA proposed by Abramson eliminates this problem by using the technique of bit spreading. In this paper the results of a simulation study on the error rate performance of spread ALOHA in the context of simultaneous transmissions of packets from earth stations are presented. The effect of the following parameters on chip error rate (CER) and bit error rate (BER) have been evaluated.

It is shown that the use of longer spreading sequences bring down the BER to facilitate the use of smaller earth stations. Simultaneous access is possible with the use of spread ALOHA, however, while the CER increases slowly as the number of interfering carriers is increased, the BER shoots up after a certain number of interfering carriers are reached. This suggests a limit on the number of simultaneous transmissions on a spread ALOHA channel and this limit is independent of the limitation imposed by the acquisition circuit.

INTRODUCTION

ALOHA is a random multiple access scheme useful for interactive computer working. It does not provide the continuous channels like the time division multiple access (TDMA) but transmits the brief sporadic random bursts of data that is characteristic of interactive computing. It uses the satellite in broadcast mode. The scheme is suited to transmission users with high peak-to-average data ratio. If many independent interactive computer users are to share a single common channel, the ALOHA system would be one way to organize the transmission. In an ALOHA system of transmission, each earth station is equipped with a transmission control unit. This unit collects the data as it arrives, forms them into a packet, and transmits it at a high speed burst as soon as the packet is complete.

The ALOHA system was first implemented at the University of Hawaii [13]. On the original Hawaii system the packets were of 704 bits length. Each packet contained a transmission header of 32 bits containing the addresses of the receiving and originating stations and some control bits. Thirty two redundant bits were employed by a powerful error detection scheme and had 640 bits of data.

The packet transmissions take place at random. All stations receiving on the frequency receive the packet. They all ignore it with the exception of the station (or stations) to which the packet is addressed. A station which receives a packet addressed to it transmits an acknowledgment if the packet appears to be free from error. The sending station waits for the acknowledgment confirming correct receipt. It waits for a given period and then if it has not received an acknowledgment, it retransmits the packet. In classical or pure ALOHA, packets are transmitted at continuously variable random times. In the case of damaged overlapping packets as detected by the error detecting codes, the packets are retransmitted. For this purpose, each station waits for a different time period before attempting retransmission. If the delay period of the two colliding stations is the same, the retransmitted packets will also collide. Therefore, each station is provided with a randomized delay circuit so that at each retransmission it can transmit the packet again after a random wait period. In general, the retransmitted packets are unlikely to collide a second time, but there is a very low and finite probability that this will happen and that a third retransmission will be required. A second or even third transmission does little harm if the delays before re-attempting transmission are low compared to the desired interactive terminal response. Figure 1 shows the classical ALOHA protocol.

The probability of a packet from one user interfering with a packet from another user is small as long as the total number of users on the common channel is not too large. As the number of users increases, however, the number of packet overlaps increases and the probability that a packet will be destroyed due to collision also increases. Norman Abramson [2] derived the capacity of a pure ALOHA channel, i.e., how many packets can be transmitted without overlap in a pure ALOHA channel. He showed that the channel throughput and channel traffic are related by the following equation:

$$S = Ge$$  

where $S$ indicates the channel throughput, i.e., it gives the number of successfully transmitted packets and $G$ gives the channel traffic, i.e., the total number of packets handled by the channel including the traffic due to retransmission. The curve given by Eq. (1) is plotted in Figure 2. It shows that as the channel traffic increases, the throughput also increases until it reaches its maximum at $S = 1/2e = 0.184$. This value of throughput is known as the capacity of an ALOHA channel, and it occurs for a value of channel traffic equal to 0.5. If the channel traffic is increased beyond 0.5 the throughput of the channel decreases.

SPREAD ALOHA TECHNIQUE

Abramson [2] has shown that when the maximum data rate of an ALOHA channel is compared to that of a conventional point-to-point channel of the same average power, the ratio of the data rates can easily exceed the 1/2e (or 1/e for slotted ALOHA) value. For a network composed of many small earth stations, under conditions of low signal-to-noise ratio and low value of channel traffic $G$, it has been shown that no signalling method can operate at a higher data rate than an ALOHA channel for a given average transmitter power and a given bandwidth.
In the case of an ALOHA channel operating at a low duty cycle, the average information rate of the channel (in bps) will ordinarily be much less than the bandwidth of the channel (in Hz). Also, the ratio of peak power to average power in this channel will be quite large. This characteristic of the low duty cycle ALOHA channel places a limitation on the application of this mode to a network composed of very small aperture terminals (VSATs). A VSAT is defined [10] as one with antenna less than six feet or 1.8 meters in diameter. These terminals are peak power limited. Abramson [9] has suggested that since the signal detectability depends upon the energy per bit and not the average signal power, spreading the transmitted packets in time will reduce the peak power requirements on the earth station transmitters while keeping the transmitted energy per bit constant.

In his scheme, which he called Spread ALOHA, each data bit of a packet to be transmitted is delayed by V units of time. This delayed packet is then passed through a spreader unit that imparts a unique V bit code to it. He has suggested the use of Barker Sequences for this purpose.

Mathematically, let the packet to be transmitted be given by

$$D(t) = \sum_{j} d_j p(t-j)$$

where $d_j = \pm 1$ are the data bits and $p$ represents the impulse response of the transmitter filter.

This packet after it passes through the delay network can be written as

$$\tilde{D}(t) = \sum_{j} d_j \tilde{p}(t-j)$$

The above equation can also be written as

$$\tilde{D}(t) = \sum_{j=0}^{n} d_j \tilde{p}(t-j)$$

The spread packet is produced by passing the delayed bits of the packet to be transmitted through a spreader, a time invariant linear filter with impulse response $p(t)$ when the input

$$\tilde{D}(t) = \sum_{j=0}^{n} d_j \tilde{p}(t-j)$$

As mentioned earlier, for time spreading of the delayed packet bits, one uses binary sequences with low autocorrelation properties. One such category of sequences is the Barker Sequences.

The impulse response function of these sequences is given by

$$S(t) = \sum_{j=0}^{r-1} S_j s(t-j)$$

where $S_j = \pm 1$. Their correlation properties are given by

$$\rho_{j} = r \quad \text{for } j = 0 \text{ and } 1 \leq j \leq r-1$$

The spread packet is produced by passing the delayed bits of the packet to be transmitted through a spreader, a time invariant linear filter with impulse response equal to $r^{-1/2}s(t)$. Figures 3 and 4 shows the delay and spreading operations.

The form of the spread packet is given by

$$D_r(t) = r^{-1/2} \sum_{j} d_j a_j p(t-j)$$

where

$$a_j = \sqrt{r}, \quad \text{and } S = \text{mod } r$$

The binary random variables, $a_j$ constitute the "chips" of the spread ALOHA signal. Since each bit of the original packet is encoded by a unique Barker sequence, the spread packet is multiplied by $r^{-1/2}$ in order to maintain the same energy transmitted per bit before and after spreading. The peak power requirement of the transmitter is decreased by a factor of $r$. Thus, it can be said that time spreading provides a mechanism for reducing the average power of the transmitter to a level consistent with a network of VSATs while maintaining a constant value for the energy per bit.

It should be noted that in contrast to the conventional spread spectrum for continuous signals, each packet in the spread ALOHA channel is spread by the same binary sequence, $S_j$. Separation of packets originating from different users is accomplished by means of the ALOHA contention protocol rather than by the cross-correlation of different spreading sequences.

And in contrast to the operation of a classical ALOHA channel, the separation is not limited by the overlap of the transmitted packets in the channel but by the overlap of the output pulses at the output of the matched filter.

SIMULATION OF SIMULTANEOUS TRANSMISSIONS

The work done has been in the context of simultaneous transmission of packets from the Remote Communication Terminals (RCTs). It has been mentioned earlier that the problem of packet overlap in the channel in the normal ALOHA transmission has been changed to the problem of overlap at the output of the matched filter. It suggests that in spread ALOHA, several users can simultaneously exist on the channel without destructive interference. Figure 5 shows the flowchart of the simulation. In this simulation, up to 10 RCTs have been considered. Each RCT is assumed to transmit one data packet consisting of 100 data bits. The packet to be transmitted is stretched and encoded by Barker sequences of various lengths. The data packet for every RCT has been generated by Monte Carlo simulation with 0.5 probability of occurrence of 1’s and 0’s. The packet length has been kept as 100 bits. In the actual network the data packets shall consist of bits corresponding to digitized voice, telex, facsimile or telegraph messages. This data packet is then passed through a delay routine. This routine delays the transmission of each data bit by ‘NBARK’ bit intervals ‘NBARK’ is the length of the Barker sequence to be used for spreading. The delayed data packet is then convolved with the Barker sequence to get the spread packet. The chips of the transmitted packet (or the bits of the spread packet) are then used to BPSK modulate a carrier. The two phase shifts pertaining to 1 and 0 data bits have been taken to be $\pi$ and 0 radians respectively. The carrier has been approximated by 10 discrete points in one cycle.
Each sample of the BPSK modulated signal is then transmitted over the white Gaussian noise (AWGN) channel. For this purpose the channel has been simulated and added to each sample of the transmitted signal. Interference from other users is also added here. Data for interfering RCTs is generated independently and spread packets are produced by using the same Barker sequence. From the detected chips, a Chip Error Rate (CER) is calculated. In the next stage, the chipped packet is correlated by the Barker sequence that had spread it, and matched filter detection is done over ‘NBARK’ bits. This gives the received data bits and the Bit Error Rate (BER).

In this simulation, the effect of the following parameters on CER and BER have been studied.

1. Various Lengths of Barker Sequences: The results indicate that under the condition of other factors remaining constant, CER in independent of the length of the Barker sequence used. However, BER is lower for the higher length sequence (Figure 6).

2. Delay of Interfering Carrier: The results show that the CER is independent of the delay between the main and the interfering carrier. However, BER is lower and shoots up considerably every time the arrival delay of the interfering carrier happens to be in the integral multiples of ‘NBARK’. The relative strengths of the interfering carriers have been assumed to be equal (Figure 7).

3. Simultaneous Transmissions: A number of equal strength carriers have been simulated to interfere with the main signal. The interfering carriers are assumed to originate with random arrival times. The results indicate that while the CER increases slowly as the number of interfering carriers is increased, the BER shoots up only at the addition of the nth carrier. This suggests some kind of a limit on the number of simultaneous transmissions on a spread ALOHA channel and that limit is independent of the limit imposed by the acquisition circuit (Figure 8).

4. Strength of the Interfering Carrier: The results show that CER and BER both increase with increasing strength of interfering carriers (Figure 9).

The curve given by Figure 6 suggests that one can possibly use longer spreading sequences and bring down the BER to facilitate the use of smaller earth stations. The rest of the curves in Figures 7 through 9 suggest that simultaneous access is possible with the use of spread ALOHA. This is important from throughput vs delay point of view because larger simultaneous accesses shall mean improvement in throughput-delay product.

A baseband level simulation has also been done to study the effect of simultaneous transmissions. It has been established that spreading by Barker sequence facilitates the recovery of the data packets colliding in the channel.

REFERENCES


the waiting time before transmission is a random variable.

Fig. 2 Channel throughput vs. channel traffic for an ALOHA channel.

Fig. 3 Simulation Flowchart.
Fig 6 Length of BARKER sequence vs. CER/BER

Fig 8 CER/BER VS No. of interfering corners

Fig 7 Delay of interfering carrier vs. CER/BER

Fig 9 CER/BER vs strength of interfering carrier