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Research paper

Introduction to random division multiple access (RDMA) applicable for mobile satellite communications

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Abstract

This paper describes in particular Random Division Multiple Access (RDMA) applicable in Mobile Satellite Communications (MSC). In satellite communication systems, as a rule, especially in Mobile Satellite Communications (MSC) many users are active at the same time. The problem of simultaneous communications between many single or multipoint mobile satellite users, however, can be solved by using Multiple Access (MA) technique. Since the resources of the systems such as the transmitting power and the bandwidth are limited, it is advisable to use the channels with complete charge and to create a different MA to the channel. This generates a problem of summation and separation of signals in the transmission and reception parts, respectively. Deciding this problem consists in the development of orthogonal channels of transmission in order to divide signals from various users unambiguously on the reception part.

Keywords: *FDMA; TDMA; CDMA; RDMA; MSC; MA; Aloha; Slotted Aloha; Slot Reservation Aloha.*

1. Introduction

In satellite fixed and mobile communication systems, as a rule, many users are active at the same time. The problem of simultaneous communications between many single or multipoint satellite users, can be solved by using Multiple Access (MA) technique. Thus, since the resources of the systems such as the transmitting power and the bandwidth are limited, it is advisable to use the channels with complete charge and to create a different MA to the channel. This generates a problem of summation and separation of signals in the transmission and reception parts, respectively. Therefore, deciding this problem consists in the development of orthogonal channels of transmission in order to divide signals from various mobile users unambiguously on the reception part. Here are listed the following principal forms of MA techniques:

1) Frequency Division Multiple Access (FDMA) – This concept is a first employed MA scheme where for each concerned Ground Earth Station (GES) or Mobile Earth Station (MES) terminal is assigned own working frequency carrier inside the spacecraft transponder bandwidth, illustrated in Figure 1 (FDMA). Actually, in this MA scheme transmitting signals occupy non-overlapping frequency bands with guard bands between radio signals to avoid interchannel interference. The bandwidth of a repeater channel is therefore divided into many sub-bands each assigned to the carrier transmitted by an Earth station.

The MES transmit continuously and the channel transmits several carriers simultaneously at a series of different frequency bands. Because of interchannel interference, it is necessary to provide guard intervals between each band occupied by a carrier to allow imperfections of oscillators and filters. The downlink Rx selects the required carrier in accordance with the appropriate frequency.

2) Time Division Multiple Access (TDMA) – The TDMA mode is a scheme where all concerned mobile Earth stations use the same carrier frequency and bandwidth with time sharing system, non-overlapping intervals. In Figure 1 (TDMA) is illustrated a concept of TDMA, where each mobile terminal transmits a data burst with a guard time to avoid overlaps. Since only one TDMA burst occupies the full bandwidth of the satellite transponder at a time, input back off, which is needed to reduce IM interference in FDMA, is not necessary in TDMA.

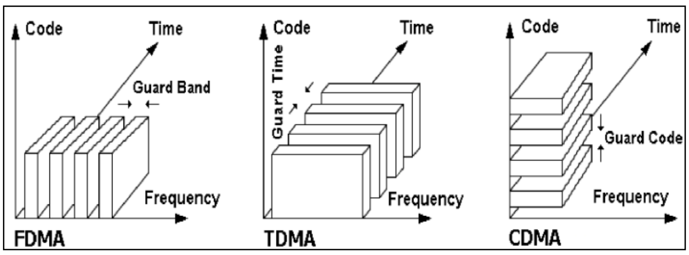

Fig. 1: Samples of Multiple Access Techniques.

3) Code Division Multiple Access (CDMA) – This mode is based on the modulation known as Spread Spectrum Multiple Access (SSMA), which spreads the information contained in a particular signal of interest over a much greater bandwidth than the original signal. In this scheme the resources of both frequency bandwidth and time are shared by all users employing orthogonal codes, shown in Figure 1 (CDMA). In CDMA all MES simultaneously share the same bandwidth and recognize the signals by various processes, such as code identification. In fact, they share the resources of both frequency and time using a set of mutually orthogonal codes, such as a Pseudorandom Noise (PN) sequence.
4) Space Division Multiple Access (SDMA) – Using this scheme all MES terminals can use the same frequency at the same time within a separate space available for each link. Previous systems have used frequency, time and code domains to achieve multiple access schemes, while SDMA scheme uses spatial separation. The ability to reject any jammer of adaptive arrays the system can be ensured for performing SDMA mode where several mobile terminals are allowed to share the same classical access in a cell (satellite transponder channel), leading to a capacity increase. In Figure 2 is shown SDMA sharing technique with possibility through the use of adaptive beam that forms and interferences rejection on the satellite uplink and downlink communication MES terminals, such as Personal Earth Station (PES), Aircraft Earth Station (AES), Vehicle Earth Station (VES) and Ship Earth Station (SES), which are located at different angular sectors in the space.
5) Random (Packet) Division Multiple Access (RDMA) – This MA scheme is used where a large number of satellite mobile users share asynchronously the same satellite transponder by randomly transmitting short burst or packet divisions in the separate satellite link, which scenario is illustrated in Figure 2. Currently, these special methods of MA techniques are widely in use with many advantages and disadvantages, together with their combination of hybrid schemes or with other types of modulations. Hence, multiple access technique assignment strategy can be classified into three methods as follows: (1) Preassignment or fixed assignment; (2) Demand Assignment (DA) and (3) Random Access (RA); the bits that make up the code words in some predetermined fashion, such that the effect of an error burst is minimized. Thus, in RA modulation scheme a large number of mobile users use the satellite resources in bursts, with long inactive intervals. In effect, to increase the satellite throughout, several mobile Aloha methods have been proposed. In the preassignment method satellite channel plans are previously determined for chairing the system resources, regardless of traffic fluctuations. This scheme is suitable for communication links with a large amount of steady traffic.

However, since most mobile users in MSC do not communicate continuously, the preassignment method is wasteful of the satellite resources. In Demand Assignment Multiple Access (DAMA) satellite channels are dynamically assigned to users according to the traffic requirements. Due to high efficiency and system flexibility, DAMA schemes are suited to MSC systems. In RA a large number of mobile users use the satellite resources in bursts, with long inactive intervals. In effect, to increase the system throughout, several mobile Aloha methods have been proposed.

Therefore, the MA techniques permit more than two Earth stations to use the same satellite network for interchanging information. Several transponders in the satellite payload share the frequency bands in use and each transponder will act independently of the others to filter out its own allocated frequency and further process that signal for transmission. Thus, this feature allows any GES located in the corresponding coverage area to receive carriers originating from several MES terminals and vice versa and carriers transmitted by one MES terminal can be received by any GES terminal. This enables a transmitting Earth station to group several signals into a single, multi-destination carrier. Access to a transponder may be limited to single carrier or many carriers may exist simultaneously. The baseband information to be transmitted is impressed on the carrier by the single process of multi-channel modulation.

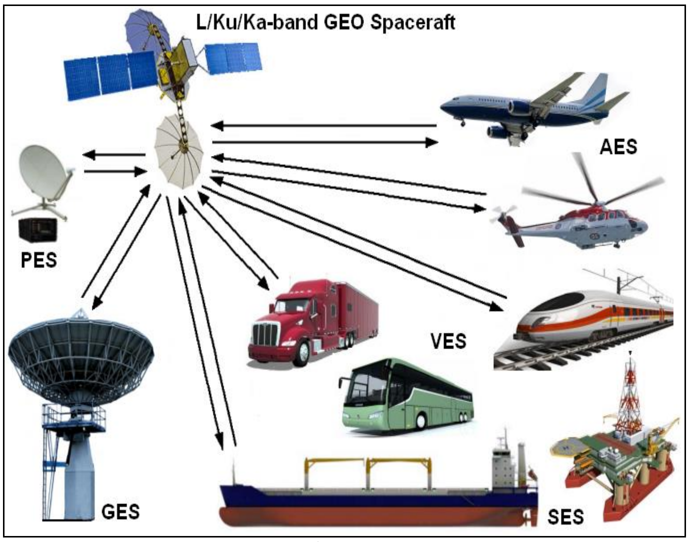

Fig. 2: SDMA for MSC Applications.

2. Random division multiple access (RDMA)

For data transmission, a bit stream may be sent continuously over an established channel without the need to provide addresses or unique words if the channel is not charred. In fact, where charring is implemented, data are sent in bursts, which thus, requires unique words or synchronization signals to enable time-sharing with other users, to be affected in the division of satellite channels. Each burst may consist in one or more packets comprising data from one or more sources that have been assembled over time, processed and made ready for transmission. However, this type of multiplex scheme is also known as Packet MA. In this sense, the Packet access can be used in special RDMA solutions, such as Aloha, where retransmission of blocked packets may be required.

Random access can be achieved to the satellite link by contention and for that reason is called a contention access scheme. This type of access is well-suited to satellite networks containing a large number of stations, such as MES terminals, where each station is required to transmit short randomly-generated messages with long dead times between messages. The principle of RDMA scheme is to permit the

transmission of messages almost without restriction, in the form of limited duration bursts, which occupy all the satellite bandwidth of the transmission channel.
Therefore, in other words, this is MA with time division and random transmission and an attribute for the synonym Random Division Multiple Access is quite assessable. A user transmits a message irrespective of the fact that there may be other users equally in connection. The probability of collisions between bursts at the satellite is accepted, causing the data to be blocked from receipt by GES terminal. In this case, the destination GES receiver will be confronted with interference noise, which can compromise message identification and retransmission after a random delay period. The retransmissions can occur as many times as probably are carried out, using random time delays. Therefore, such a scheme implies that the transmitter vies for satellite resources on a per-demand basis. In this case, it will provide that no other transmitter is attempting to access the same resources during the transmission burst period, when an error-free transmission can occur. The types of random protocols are distinguished by the means provided to overcome this disadvantage.
The performance of these protocols is measured in terms of the throughput and the mean transmission delay. Throughput is the ratio of the volume of traffic delivered at the destination to the maximum capacity of the transmission channels. The transmission time, i.e., delay is a random variable. Its mean value indicates the mean time between the generation of a message and its correct reception by the destination station.

2.1. Pure aloha

The most widely used contention multiple access scheme is Aloha or Pure Aloha and its associated derivatives. This modulation solution was developed in the late 1960s by the University of Hawaii and allows usage of small and inexpensive GES (including MES) terminals to communicate with a minimum of protocols and no any network supervision. This is the simplest mode of operation, which time-shares a single Radio Frequency (RF), divided among multiple users and consists in stations randomly accessing a particular resource that is used to transmit packets.
When an Aloha station has something to transmit, it immediately sends a burst of data pulses and can detect whether its transmission has been correctly received at the satellite by either monitoring the retransmission from the satellite or by receiving an acknowledgement message from the receiving party. Should a collision with another transmitting station occur, resulting in the incorrect reception of a packet at the satellite, the transmitting station waits for a random period of time, prior to retransmitting the packet. Otherwise, a remote station (MES) uses Aloha to get a hub station (LES) terminal's attention.
Namely, the MES terminal sends a brief burst requesting a frequency or time slot assignment for the main transmission. Thus, once the assignment for MES is made, there is no further need for the Aloha channel, which becomes available for other stations to use. After that, the main transmissions are then made on the assigned channels. At the end, the Aloha channel might be used again to drop the main channel assignments after the transmission is completed.
The advantages of Aloha are the lack of any centralized control, giving simple, low-cost stations and the ability to transmit at any time, without having to consider other users. In the case where the user population is homogenous, so that the packet duration and message generation rate are constant, it can be shown that the traffic carried S (packet correctly interpreted by the receiver), as a function of total traffic G (original and retransmitted message) is given by the relation:

$$S = G \exp(-2G) \text{ [packet/time slot]} \quad (1)$$

Where (S = transmission throughput) and (G) are expressed as a number of packets per time slot equal to the common packet duration. The Aloha protocol cannot exceed a throughput of 18% and the mean transmission time increases very rapidly as the traffic increases due to an increasing number of collisions and packet retransmissions. The Aloha mode is relatively inefficient with a maximum throughput of only 18.4% (1/2). However, this has to be counter-weight against the gains in simple network complexity, since no-coordination or complex timing properties are required at the transmitting MES terminal.

2.2. Slotted aloha

This form of Aloha or S-Aloha, where the time domain is divided into slots equivalent to a single packet burst time; there will be no overlap, as is the case with ordinary Aloha. The transmissions from different stations are now synchronized in such a way that packets are located at the satellite in time slots defined by the network clocks and equal to the common packet duration. Hence, there cannot be partial collisions; every collision arises from complete superposition of packets. In effect, the timescale of collision is thus, reduced to the duration of a packet, whereas with the Aloha protocol, this timescale is equal to the duration of both packets. This situation divides the probability of collision by two and the throughput becomes:

$$S = G \exp(-2G) \text{ [packet/time slot]} \quad (2)$$

Where (S = transmission throughput) and (G) is as a number of packets per time slot equal to the common packet duration.

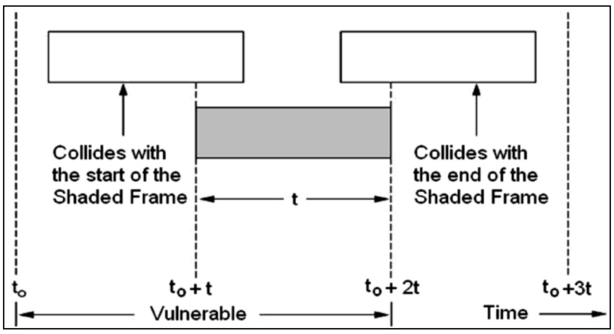

Fig. 3: Efficiency of Pure Aloha.

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$$S = G \exp(-G) \text{ [packet/time slot]} \quad (3)$$

This protocol enables collisions between new messages and retransmission to be avoided and increases the throughput of S-Aloha in the order of 50–60% by introducing a frame structure, which permits the numbering of time slots. Each packet incorporates additional information indicating the slot number reserved for retransmission in case of collision. For the same value of utilization as basic Aloha, the time delay and probability of packet loss are both improved. The major disadvantages of S-Aloha are that more complex equipment in the GES is necessary, because of the timing requirement and because there are fixed time slots, customers with a small transmission requirement are wasting capacity by not using the time slot to its full availability. In Figure 3 is shown efficiency of Pure Aloha, namely let T be the time needed to transmit one frame on the channel, and frame-time as a unit of time equal to T. Let G refer to the mean used in the Poisson distribution over transmission attempt amounts that is, on average, there are G transmission-attempts per frame-time. Let t be the time at which the sender wants to send a frame. Here is desirable to use the channel for one frame-time beginning at t, and so is needed all other stations to refrain from transmitting during this time. Moreover, it is necessary the other stations to refrain from transmitting between t-T and t as well, because a frame sent during this interval would overlap with our frame.

2.4. Slot reservation aloha

This solution of an extension for the slotted-Aloha scheme allows time slots to be reserved for transmission by an GES. In general terms this mode of operation is termed a Packed Reserved Multiple Access (PRMA). Slot reservation basically takes two forms:

1) Implicit – When a station acquires a slot and successfully transmits, the slot is reserved for that station for as long as it takes the station to complete its transmission. The network controller then informs all stations on the network that the slot is available for contention once more. There is only the problem that a station with much data to transmit could block the system to other users.
2) Explicit – Every user station may send a request for the reservation of a time slot prior to transmission of data. A record of all time slot occupation and reservation requests are kept. Actually, a free time slot could be allocated on a priority basis. Some kind of control for the reservation of slots is necessary and this could be accomplished by a single or all stations being informed of slot occupancy and reservation requests.

3. Comparison of pure and slotted aloha

Pure Aloha system does not require global time synchronization, which allows its users to transmit whenever they have data. A sender just like other users can listen to what it is transmitting, and due to this feedback broadcasting system is able to detect collision, if any. If the collision is detected the sender will wait a random period of time and attempt transmission again. The waiting time must not be the same or the same frames will collide and destroyed over and over. Systems in which multiple users share a common channel in a way that can lead to conflicts are widely known as contention systems.

1) Efficiency of Pure Aloha - Let T be the time needed to transmit one frame on the channel, and frame-time as a unit of time equal to T, shown in Figure 1. Thus, let G refer to the mean used in the Poisson distribution over transmission-attempt amounts that is, on average, there are G transmission-attempts per frame-time. Let t be the time at which the sender wants to send a frame. The intention is to use the channel for one frame-time beginning at t, and so all other mobile stations have to refrain from transmitting during this time. Moreover, will be needed the other stations to refrain from transmitting between t-T and t as well, because a frame sent during this interval would overlap with initial frame.

Vulnerable period for the shaded frame is 2t, if t is the frame time. A frame will not collide if no other frames are sent within one frame time of its start, before and after. For any frame-time, the probability of there being k transmission-attempts during that frame-time is: {G^k e^{-G}} / {k!}. If throughput (number of packets per unit time) is represented by S, under all load, S = GPo, where Po is the probability that the frame does not suffer collision. A frame does not have collision if no frames are sending during the frame time. Thus, in t time Po = (e)^(-G). In 2t time Po = e^(-2G), as mean number of frames generated in 2t is 2G. From the above, throughput in 2t time S = G*(Po) = G*e^(-2G).

2) Efficiency of Slotted Aloha – The Slotted Aloha does require global time synchronization during transmission. In such a way, however, assume that the sending stations have to wait until the beginning of a frame time (one frame time is one time slot) and arrivals still follow Poisson distribution, where they are assumed probabilistically independent. In this case the vulnerable period is just t time units. Then the Probability that k frames are generated in a frame time is effective: - Pk = (G^k)*(e^-G)/k! In t time, the probability of zero frames, Po = e^(-G). From the above throughput becomes: S = GPo = G*(e^-G).

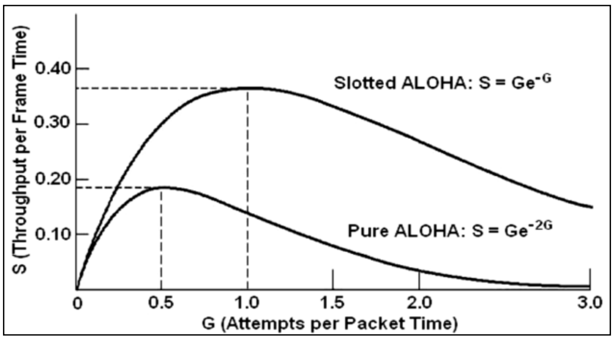

Fig. 4: Comparison of Pure and Slotted Aloha.

In Figure 4 is shown comparison diagram of Pure and Slotted Aloha or throughput versus load of offered traffic for Pure and Slotted Aloha systems, namely, plot of S against G, from S = Ge^(-2G) and S = Ge^(-G) formulas.

4. Conclusion

Recently was developed SDMA as an advanced solution for mobile applications, where all concerned MES terminals can share the same frequency at the same time within a separate space available for each link. On the other hand, the RDMA scheme is suitable for large number of users in MSC, where all MES terminals share asynchronously the same transponder by randomly transmitting short burst or packet divisions. In addition is developed several mobile Aloha methods, which successfully increase the system throughout.

Thanks to the adoption of state-of-the-art physical layer forward error correction and iterative signal processing at the GES, very large throughput can be achieved with very low packet loss ratio. The proposed RA schemes are providing very high robustness vis-a-vis received packet power unbalance, which in fact helps to boost RA performance.

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