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PERFORMANCE OF DA/FDMA ARCHITECTURE PROPOSED FOR MSS

DR. CHARLES WANG, DR. TSUN-YEE YAN AND DR. KHALED DESSOUKY*
Jet Propulsion Laboratory, United States

JET PROPULSION LABORATORY (JPL)
California Institute of Technology
Mail Stop 238-420
4800 Oak Grove Drive
Pasadena, CA 91109

ABSTRACT

This paper presents the system architecture proposed for the Mobile Satellite Service (MSS) by the National Aeronautics and Space Administration (NASA)/JPL. The demand assigned Frequency Division Multiple Access (FDMA) scheme is described, and results for the associated network access protocol developed by JPL are presented. Both the total number of users that the system can support and the system spectral efficiency are given for a variety of traffic conditions, including those postulated for the Mobile Satellite System Architectures and Multiple Access Techniques Workshop. The results are given for both first- and second-generation one- and two-satellite systems.

1. INTRODUCTION

The mobile satellite industry has reached a critical juncture. Different potential service providers are vying for market shares and are planning their systems to meet market requirements with the most efficient designs. The procurement of satellites for the U.S. and Canadian MSSs is also imminent. With these developments, the debate over system architecture and multiple-access techniques has come into focus.

The architecture proposed by JPL is based on FDMA. This choice of multiple-access scheme evolved out of system studies performed as early as 1983. In addition, the long propagation delay between the Earth and the geosynchronous satellite precludes the use of carrier sense type multiple access. To efficiently and effectively utilize the scarce resources of bandwidth and power, the approach of Demand Assigned Multiple Access (DAMA) is adopted for network implementation. Hence,

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the system architecture proposed by NASA/JPL utilizes a Demand Assigned/FDMA (DA/FDMA) scheme. In this paper, we describe this system, its capacity, and its spectral efficiency. Both first- and second-generation one- and two-satellite system concepts will be considered.

2. FIRST-GENERATION MSS PROPOSED BY NASA/JPL

As designated by the 1987 International World Administrative Radio Conference (WARC) [1], the Land Mobile Satellite System (LMSS) is assigned 7 MHz of uplink and 7 MHz of downlink bandwidth on a primary and co-equal primary basis. The uplink (mobile-to-satellite) band(s) are located roughly around 1.65 GHz, while the downlink (satellite-to-mobile) band(s) are located in the vicinity of 1.55 GHz. The results presented herein reflect these regulatory constraints.

The first-generation spacecraft assumed is consistent with the filing of the American Mobile Satellite Consortium (AMSC) with the U.S. Federal Communications Commission (FCC). Of most concern are the spacecraft power, weight, and antenna characteristics. Prime power is around 3.2 kW, weight is in the vicinity of 5000 lb at geosynchronous transfer orbit (GTO), and the satellite has two 5-m L-band antennas, one for transmit and one for receive. The L-band antenna covers the continental U.S. (CONUS) with four spot beams as depicted in Figure 1. The outer beams will reuse the same frequencies, implying a frequency reuse factor of 1.33.

In the proposed FDMA scheme, each 7 MHz is divided into 1400 5-kHz channels. This is consistent with the trellis coded modulation/8 differential phased shift keying (TCM/8DPSK) modulation/coding proposed by JPL wherein 4800 bps occupy only 5 kHz of bandwidth [1]. Assuming that the mobile users (MUs) are uniformly distributed over CONUS, the 1400 channels are evenly distributed among three beams, resulting in 466 channels per beam or a total of 1864 channels for the entire system. Since at least one channel is required within each spot beam for new arriving MUs to log into the network, a maximum of 465 channels per beam is considered for making connection requests, data transmissions, and voice conversations.

The system spectral efficiency is defined as the number of information bits that the system can convey per second per hertz. Furthermore, the maximum theoretical spectral efficiency is that obtained strictly from the total number of channels dictated by the modulation and frequency reuse, the data rate per channel, and the total bandwidth, i.e., without taking into consideration the effects of the efficiency of the networking protocol used.

Hence,

$$\eta_{max} = \frac{\text{bit rate} \times \text{maximum number of channels}}{\text{total bandwidth}}$$

With 1860 channels, 4800 bps through 5 kHz, and 7 MHz total bandwidth, η_{max} = 1.28 bps/Hz.

In the Mobile Satellite Experiment (MSAT-X), a two-satellite configuration is envisioned to double the capacity of the first-generation system. Two-satellite operation is accomplished through using the discrimination available on the proposed steerable medium-gain vehicle antennas [1]. This discrimination is complemented by polarization isolation to provide a minimum of 20-dB inter-satellite isolation. Under this scenario, orbital reuse is accomplished and the entire 7-MHz bandwidth is used with each satellite. This doubles system capacity, and the theoretical spectral efficiency becomes 2.56 bps/Hz.

3. NETWORK ACCESS PROTOCOL

3.1. General Description

The protocol developed under MSAT-X is referred to as the Integrated Adaptive Multiple Access Protocol (I-AMAP) [2]. The 465 channels within each beam are adaptively divided into request channels, data channels, and voice channels, based on the aggregate data and voice traffic. In the request channels, the slotted ALOHA multiple-access scheme is used. Whenever a subscriber wishes to initiate a connection, either data or a voice-call, his terminal sends a request through one of the request channels to the Network Management Center (NMC). After sending out a request, the terminal waits for an assignment packet from the NMC. If the subscriber does not receive the assignment packet within a preset time-out period, he will retransmit the request. In the case of a data connection, the length of the message is also included in the request packet.

Upon receiving a successful data connection request, the NMC assigns a time window on a data channel to this particular request on a first-come-first-served basis. Then the NMC sends the requester and the destination party an assignment packet which includes the scheduled time window and the identity of the assigned channel. After receiving the assignment packet, the requester waits until the scheduled transmission time, then sends the data on the assigned channel. The requester's terminal then waits for an acknowledgment. If any portion of the procedure is not successfully accomplished, the procedure starts from the very beginning. In order to assure reliable transmission, a selective repeat automatic retransmission request (ARQ) scheme has been adopted in the link layer protocol for data transmissions.

Upon receiving a successful voice-call connection request, the NMC sends a busy status to the requester if either the destination party is busy or all voice channels are occupied. Otherwise, the NMC assigns the request to one of the available voice channels, and sends an assignment packet to both the requester and the destination party. After receiving the assignment packet, the requester tunes to the assigned voice channel and starts the conversation. Voice conversations do not require ARQ schemes.

Reference [3] presents an optimized error control structure for MSS. In this structure, the request packet, assignment packet and acknowledgment packet are each 128 bits long, and the data message is packetized into 256-bit frames. The assignment and acknowledgment packets are replicated for each transmission.

3.2. Results

Under the scenario postulated for the workshop, if, on the average, each MU generates twelve 4096-bit messages and one 90-second phone call per hour at 4800 bps, the traffic becomes 0.00284 erlangs for data and 0.025 erlangs for voice (which represents the desired 9-to-1 traffic mix). Based on the analysis in [3], our calculations have shown that the proposed MSS architecture can support up to 58,500 users for the entire four-beam coverage under the constraint of a 2% voice-call blocking probability and 4-second average message delay. The optimal channel allocation for this traffic mix is [Nr (request), Nd (data), Nv (voice)] = [28, 54, 383]. This shows as the upper point on the curve in Figure 2. The corresponding system spectral efficiency is 1.118 bps/Hz. This is a remarkable 87% of the theoretical maximum—a testimony to how well the protocol matches the proposed FDMA architecture.

More results have been computed for a wide range of traffic conditions. If we fix the total traffic at 0.02784 erlangs and vary the traffic mix, the total number of users that the system can support and the system spectral efficiency are shown in Figure 2. Notice that since each data message takes only about 1/105 of the time that a voice call takes, the same amount of data traffic (in erlangs) as voice traffic requires approximately 105 times the request capacity. This obviously means that as the data traffic increases, the number of required request channels (Nr) will increase considerably, i.e., substantially more system overhead will be required. It can also be seen in Figure 2 that the spectral efficiency decreases as data traffic increases. Hence, it can be concluded that the connection request procedure must be improved to handle the increase in request packets for the situation in which a higher percentage of data traffic exists. A free-access tree algorithm has been developed at JPL [4] that is particularly suited for data-dominated traffic. The tree algorithm provides up to 40% higher stable throughput per channel than slotted ALOHA.

We now allow the total traffic to vary due to the variation in either voice or data traffic while the other is held constant. If we fix the amount of voice traffic and increase the data traffic, it is obvious that the number of users that the system can support will decrease, since the total amount of traffic generated by each individual user increases. Figure 3 shows the variation of the total number of users as a function of the data generation rate when the voice traffic is fixed at 1 phone call per hour per user. Also as seen in Figure 3, increasing the data traffic decreases the system spectral efficiency since more request channels are required. In contrast, if we fix the amount of data traffic and increase the voice traffic, the system spectral efficiency increases as seen in Figure 4. This is because the system is more efficiently utilized by a more dominant voice traffic.

4. POWER AND BANDWIDTH LIMITATIONS FOR A FIRST-GENERATION SYSTEM

For the guidelines of the workshop, the breakdown of channel types is given above, namely [Nr = 28, Nd = 54, Nv = 383]. Using this information, together with the postulated voice activity factor (vox) of 40%, and the link budgets proposed in MSAT-X [1], after allowing for a 5-m spacecraft antenna, yields 525 W of radio frequency (RF) power at L-band. The corresponding Ku-band RF power is 94 W. The total RF power should be achievable with a spacecraft whose prime power is in the range 3.2 to 3.5 kW. Accordingly, the first-generation system proposed by JPL lies, as desired, roughly at the intersection of power-limited and bandwidth-limited operation.

5. SECOND-GENERATION SYSTEM

The spacecraft envisaged for a second-generation system would have a larger L-band antenna with a larger number of beams than in the first generation, to enable a higher degree of frequency reuse. A 15-m L-band antenna with 31 spot beams is proposed. This system will have 7 frequency subbands and a frequency reuse factor of 4.43. With a channel bandwidth of 5 kHz, the number of channels per beam is 200 and the total number of channels in the entire system is 6200 (for one satellite). The corresponding theoretical maximum spectral efficiency is 4.25 bps/Hz.

Reapplying the analysis in [3], the number of users in this system is found to be 186,000 at an actual spectral efficiency of 3.55 bps/Hz. The efficiency of the I-AMAP protocol in this case is 84%. For the 90%/10% voice/data traffic mix, the 200 channels per beam are divided as [Nr = 12, Nd = 23, Nv = 165]. This division, with the new higher gain of the spacecraft antenna, translates into only 284 W of L-band RF power. However, the Ku-band RF power required to support the 6200 channels would be about 315 W. Therefore the power requirements for this second-generation satellite are about the same or a little less than for the first-generation one. This system design would be roughly at the intersection of power-limited and bandwidth-limited operation with a tendency to be bandwidth-limited.

Finally, to double the capacity of the proposed second-generation system, two-satellite operation would be implemented. This would double system capacity and achieve a maximum spectral efficiency of 8.5 bps/Hz.

6. SUMMARY

The DA/FDMA system architecture proposed by NASA/JPL for MSS was presented. The performance of the network access protocol developed was also given for a variety of traffic conditions. The high efficiency of the I-AMAP protocol, and the entire system as a result, was also demonstrated. 87% and 84% of theoretical maximum spectral efficiencies are achieved by I-AMAP in a first- and second-generation systems, respectively.

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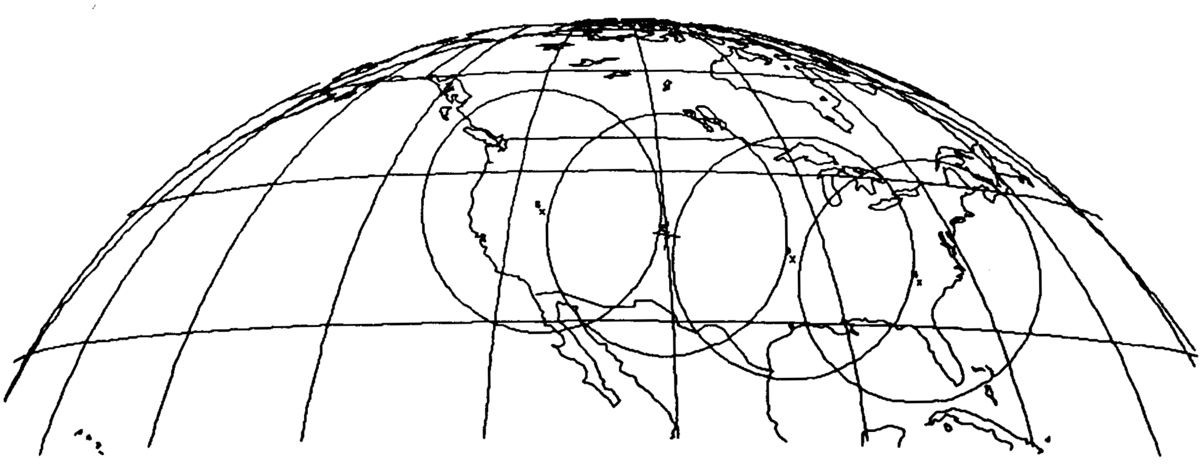

Figure 1. Four-Beam CONUS Coverage of a First-Generation Satellite

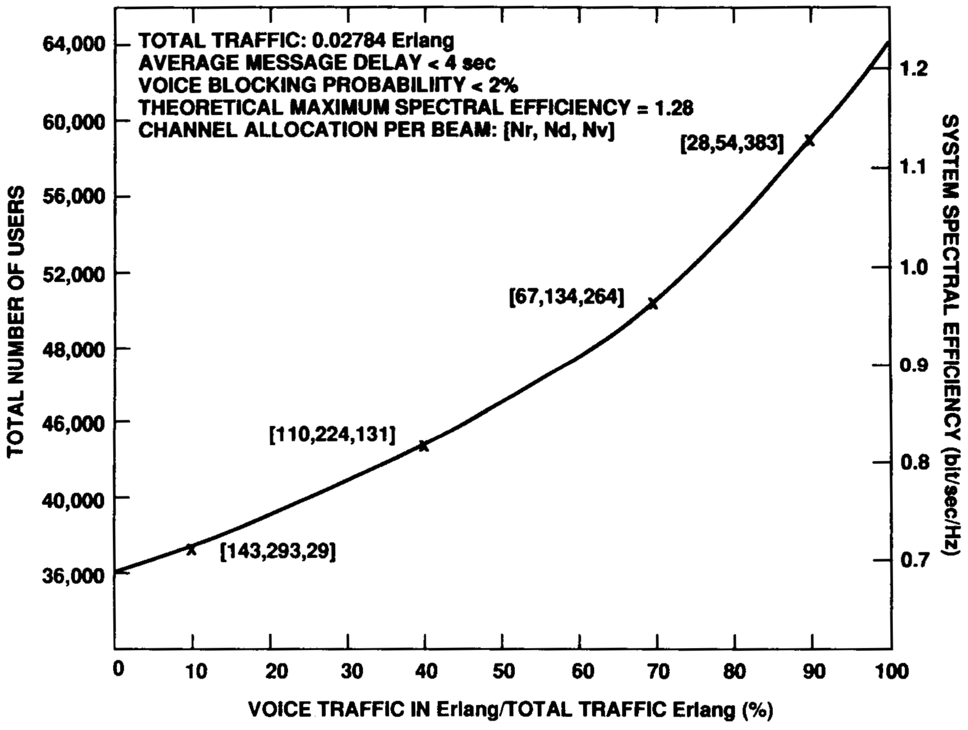

Figure 2. System Performance vs. Traffic Mix

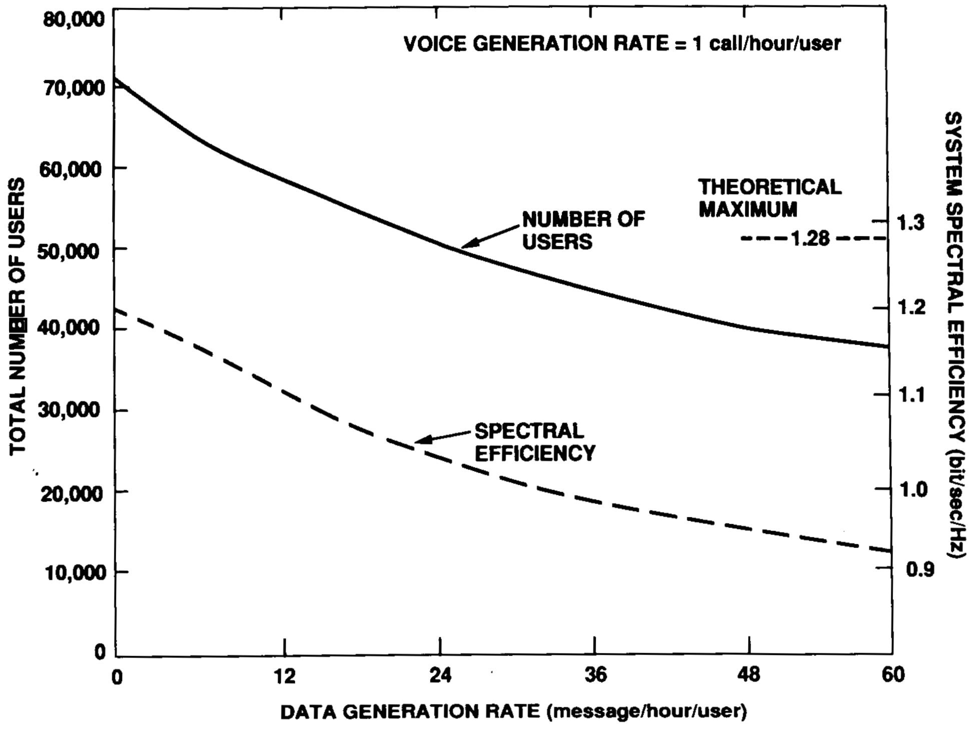

Figure 3. System Performance vs. Data Traffic

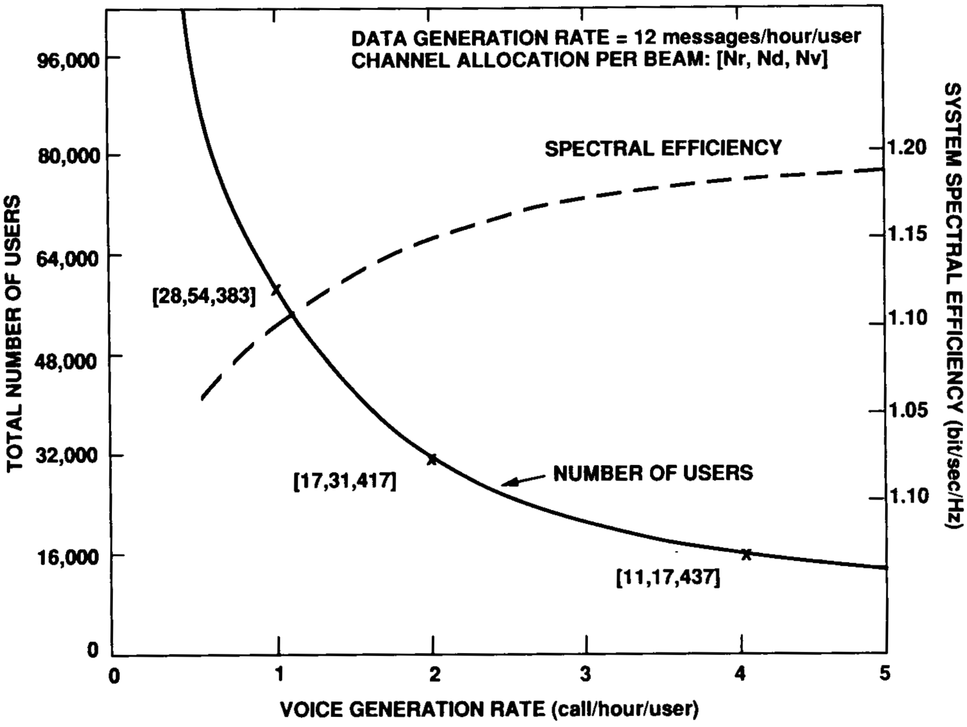

Figure 4. System Performance vs. Voice Traffic