VSAT Return Channel Optimizations for Broadband Internet Support in 2-Way Satellite Networks

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Abstract

In this paper we describe our work on a Very Small Aperture Terminal (VSAT) satellite Internet gateway with capacity and latency optimizations in the return channel so as to allow significantly higher number of users, and a better user experience. The gateway is based on the Cerona SkySPAN technology which uses the Digital Video Broadcast via Satellite 2nd standard (DVB-S2) in the forward channel, and single-channel slotted Aloha protocol in the return channel. In this paper we describe the Spread Aloha Multiple Access (SAMA) protocol which we implement in the return channel. The SAMA protocol promises to deliver high speeds at a third of the latency compared to competing technologies like DVB-RCS (multi-frequency TDMA), while allowing the same number of users in 3MHz bandwidth as is possible in TDMA using 36MHz. We also describe the implementation of the Fast Multi-channel Slotted Aloha (FMCSA) protocol that will co-exist with SAMA in the return channel. FMCSA combines slotted Aloha random access with packet level forward error correction (FEC) for new messages and scheduled retransmissions for partially received messages. Due to the parity packets sent in FMCSA, more load is offered to the channel than in SAMA to achieve the same throughput. The delay performance of FMCSA is also much more robust to load fluctuations than SAMA. The combination of SAMA and FMCSA improves the robustness and throughput of the SkySPAN return channel and reduces the channel latency, while supporting significantly higher number of users, in comparison to the competition.

1. Introduction

The Internet today is the Global Information Highway: it carries video, voice, audio and broadband data worldwide. In order to provide Internet access to a large customer base, and thus reduce the per-customer cost for broadband services, satellite-based broadband Internet services have been developed. Lack of wired network connectivity in developing countries in Asia, South America and Africa, and in rural and remote regions of North America, provides a unique window of opportunity for satellite-based broadband services delivery to very large customer bases with potentially high commercial payoffs. With the latest technological advancements, broadband Internet speeds comparable to wired networks are possible on the outbound/forward channel from the satellite to the users. However, on the inbound/return channel the bandwidth is not as large due to limitations of the technology used to share the medium. The primary challenge facing satellite network providers is how to efficiently use this expensive shared resource. The goal is to allow more users and lower per-user cost, so that the satellite backbone is more attractive to Internet service providers for broadband content delivery. The current media access algorithms are based on either packet connections, or session connections. In the former case, the control overhead for connection setup/teardown adds 1-2 seconds of latency, while in the latter case most of the channel capacity are wasted due to the bursty nature of the return channel Internet traffic – only

1%-3% of the capacity are utilized. Inefficient use restricts number of users, with the result being higher cost per user.

Therefore the current status of Internet over Satellite is not in a position to provide high performance with the scalability required for serving millions of customers. The problems are further exacerbated if one utilizes conventional Internet schemes over satellites. These weaknesses and problems are precisely those that have been addressed by a project undertaken at the University of Maryland in collaboration with Cerona Networks, USA. The primary goal of the project is to improve on current technologies and developments at the University of Maryland and at Cerona Networks, to design and build a prototype Very Small Aperture Terminal (VSAT) satellite Internet gateway and prototype satellite hub, with capacity and latency optimizations in the forward and return channels.

In this paper, we describe the media access protocols that are being implemented in the VSAT and hub to optimize the return channel. Section 2 provides a background to the research effort with a brief description of Cerona technology in this sphere. The media access algorithms, Spread Aloha Multiple Access (SAMA) and Fast Multi-Channel Slotted Aloha (FMCSA), are described in sections 3 and 4 respectively, and their advantages over competing technologies are highlighted. We conclude in section 5 with a mention of additional technologies that we are considering for further optimizations of the return channel.

2. Background and Motivation

The gateway and hub are based on Cerona's SkySPAN technology (1). SkySPAN currently uses the Digital Video Broadcast via Satellite 2nd standard (DVB-S2) (2) in the forward channel, and single-channel slotted Aloha protocol (3) in the return channel. The SkySPAN network (figure 1) consists of the receiver (hub) (figure 2), the space segment and the SkySPAN Router (VSAT) (figure 3).

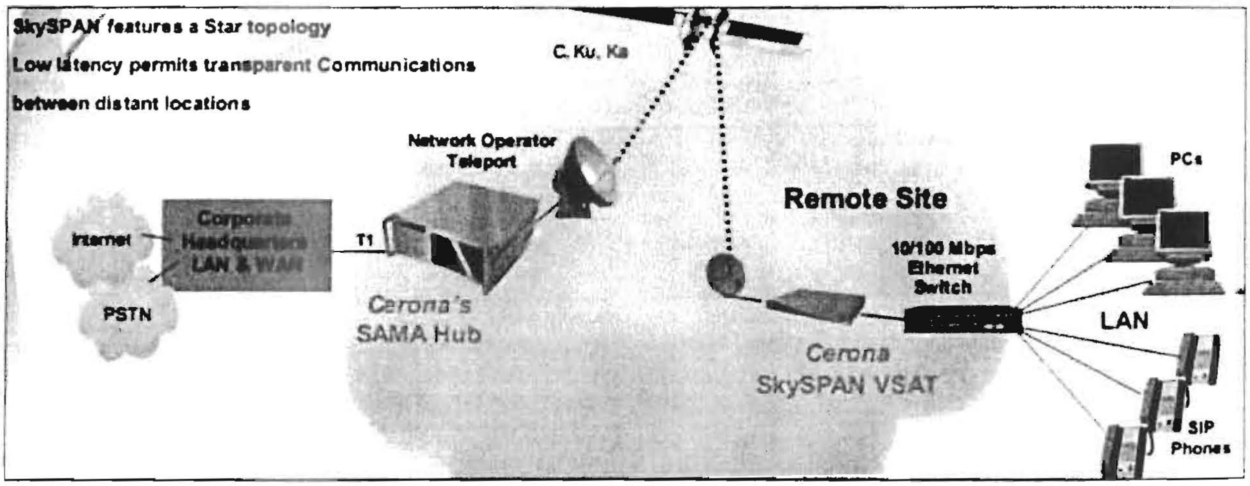


Figure 1: Cerona SkySPAN star satellite network

The overall objective of the project is to develop technologies to optimize the forward and return channels of the SkySPAN SAMA VSAT and hub, so that broadband Internet-over-Satellite services can be provided to a large number of users, with performance approaching that of terrestrial Internet connections. In order to achieve this goal, the project design calls for using Cerona's patented Spread Aloha Multiple Access (SAMA) (4) in the return channel. It is expected that with the SAMA protocol, the SkySPAN hub will be able to support up to 2665 remote terminals over a 3MHz channel, or 32,000 in full 36MHz transponder. One SkySPAN receiver card can support 4 hubs; therefore, the SAMA receiver will scale from 1 to 128,000 users in the same footprint. The SAMA protocol promises to deliver high speeds at a third of the latency compared to competing technologies like DVB-RCS (multi-frequency TDMA) (5), while allowing the same number of users in 3MHz bandwidth as is possible in TDMA using 36MHz. By using SAMA, SkySPAN will provide a more robust, spectrally efficient access for diverse uses, including: point of sales (retailers), Internet-over-Satellite, MNC, Government, Military, SME/SOHO/Enterprise, VPN, VoIP and Communications-On-The-Move (COTM).

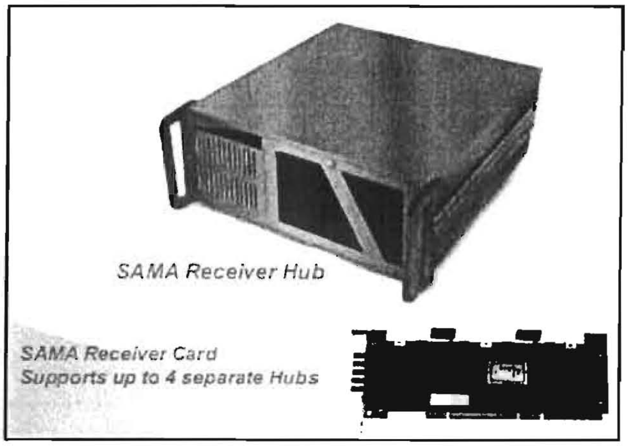


Figure 2: Cerona SkySPAN Receiver Hub

In addition to SAMA, the Fast Multi-channel Slotted Aloha (FMCSA) protocol is being implemented for the return channel. FMCSA will further reduce the latency and support higher number of users, compared to SAMA. SAMA and FMCSA will co-exist together. We also plan to incorporate technologies that will enable reconfiguration of the SAMA/FMCSA code length dynamically for changing channel conditions and also allow to dynamically assign the channel bandwidth on the return channel based on load.

3. Spread Aloha Multiple Access (SAMA)

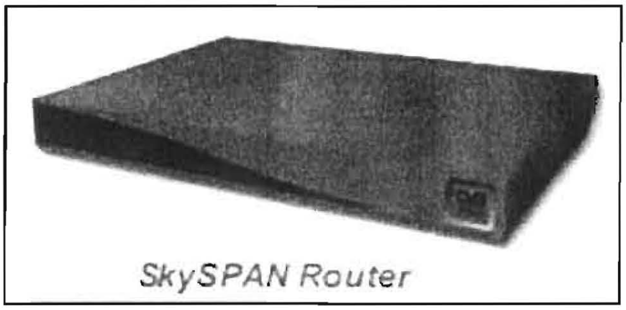


Figure 3: Cerona SkySPAN VSAT Router

Spread Aloha Multiple Access (SAMA) is based on the original Aloha protocol which was invented by N. Abramson in 1970 (6). The ARPANET ALOHA satellite system was implemented in 1972. The original Aloha (figure 4) was a narrowband system using only one communications channel. Each VSAT transmitted asynchronously, without regard to other terminals. The absence of an "ACK" from the hub indicated a collision. The VSAT would then wait with a binary exponential back-off time before retransmitting the message. The maximum throughput that can be obtained by Aloha is approximately 18%.

An improved Aloha system – the Slotted Aloha (figure 5) – was proposed by Roberts et al. in 1973 (3). In the Single Channel Slotted Aloha system, each VSAT transmits synchronously at the beginning of a "slot" time if data is available, without regard to other terminals. The absence of an "ACK" from the hub indicates collision.

A multi-channel version – the Multi-channel Slotted Aloha (MCSA) was invented by Birk and Keren in 1999 (7). MCSA is a set of "stacked" Aloha channels. The stacking can occur as multiple narrowband channels separated by frequency, or multiple spread spectrum channels separated by chips. The use of multiple channels reduces the chance of collisions, and also allows for immediate retransmission if there is one. MCSA doubles the throughput compared to Aloha (figure 6).

SAMA uses a combination of spread spectrum techniques in conjunction with MCSA where the spreading factor determines the channel throughput and capacity. SAMA uses Direct Sequence Spread Spectrum (DSSS) (8) to spread out the data transmission over a wide portion of the radio spectrum. The spreading results in low power density which reduces the risk of interference from adjacent satellites or adjacent channels. It also permits the use of phased array antennas or very small parabolic systems. In non-SAMA systems, these antennas suffer from substantial issues with side lobes causing interference to adjacent satellites. SAMA eliminates this problem and further enhances the system reliability by working in conjunction with phased array antennas or gimball mounted parabolic antennas that can be steered electronically in a fraction of a second, thus maintaining broadband communications in rapidly moving vehicles that are encountering bumps, air turbulence or other harsh terrains. This is particularly important for military "Comm.-On-The-Move" (COTM) applications and also applies to many commercial environments such as marine, rail and first responder requirements.

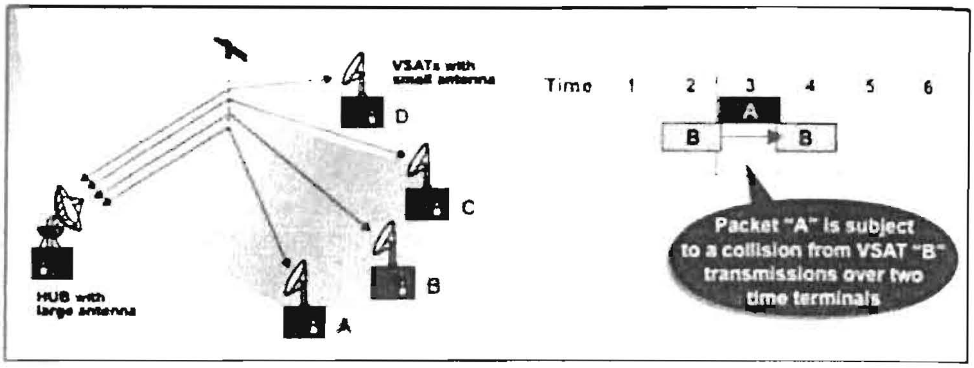


Figure 4: The Aloha protocol

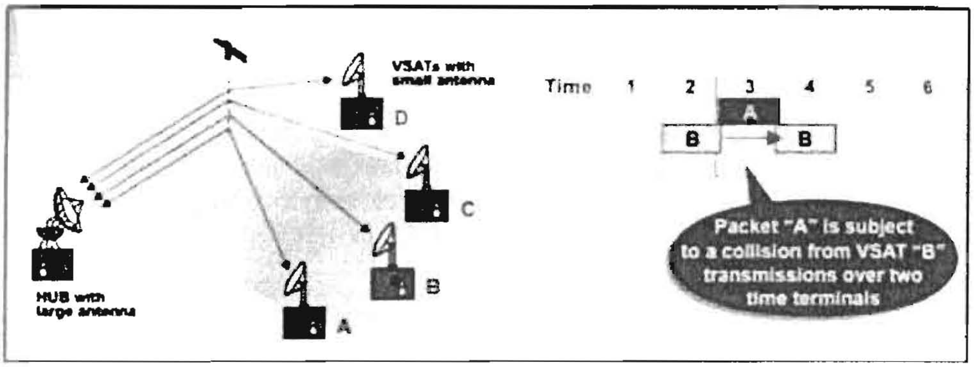


Figure 5: Slotted Aloha

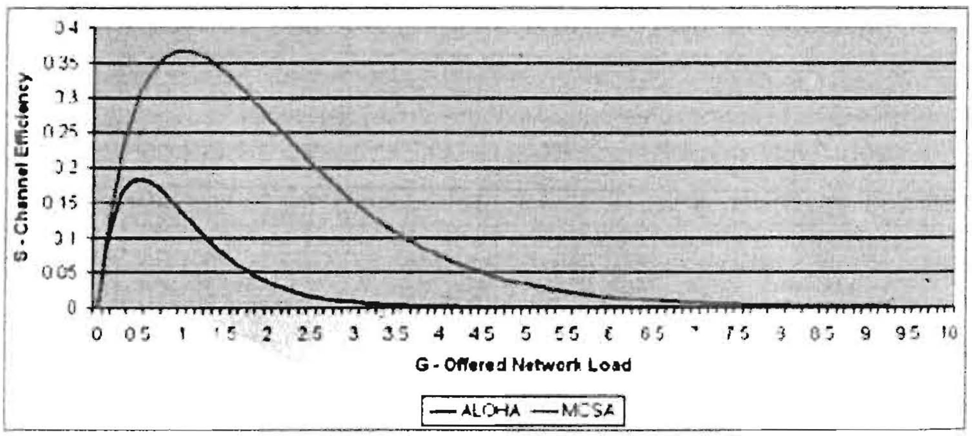


Figure 6: Aloha and Multi-channel Slotted Aloha throughput

In SAMA, power efficiency is governed by QPSK modulation and FEC. The bandwidth dedicated to the SAMA return channel is flexible between 3MHz and 15MHz. SAMA divides each 3MHz spectrum into 31 or 15 sub-channels, and each sub-channel is divided into frames (time slots). The return data rates can vary between 266kbps to 1064kbps. SAMA allows some sub-channels to be dynamically assigned on demand (DAMA) (figure 7) – therefore the system can provide bandwidth guarantees for latency-critical traffic like VoIP applications. Moreover, SAMA supports fast channel acquisition due to its connectionless format. The latency for a properly loaded SAMA network is 530 milliseconds, as compared to typical ranges of 510-2100 milliseconds for competing technologies. This is particularly important for bursty Internet traffic like users typing on keyboards, or VoIP.

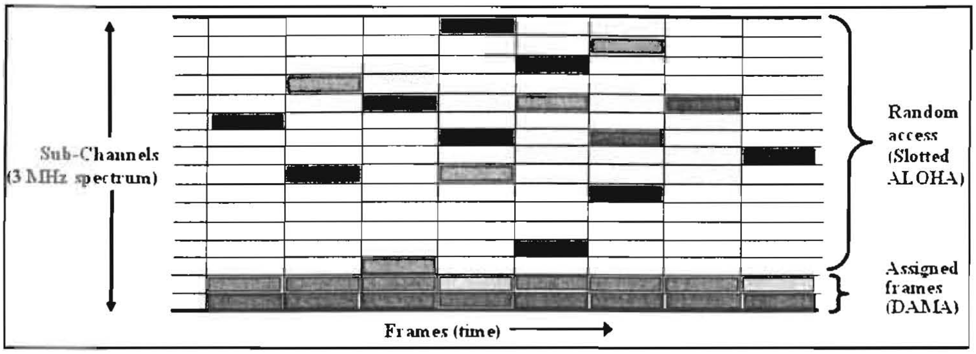


Figure 7: SAMA with DAMA sub-channels

4. Fast Multichannel Slotted Aloha (FMCSA)

In order to improve the delay performance of short message transfers in a multiple access channel with long propagation delay (for example, the VSAT return channel in a star satellite network), Fast Multi-channel Slotted Aloha (FMCSA) random access protocol was proposed by Zhou and Baras in 2004 (9). FMCSA combines random access with packet level forward error correction (FEC) for new messages and scheduled retransmissions for partially received messages. When the system is operating at the low load region, the short messages can be delivered in their first attempts with very high probability. With the load increasing, more messages will be received partially in their first attempts and the scheduled retransmission scheme will guarantee the partially received messages to be recovered in their second attempts. Therefore the delay performance of FMCSA is much more robust to the load fluctuation than slot ted Aloha. A brief description of FMCSA is given below, adapted from the detailed analytical model that is described in (9).

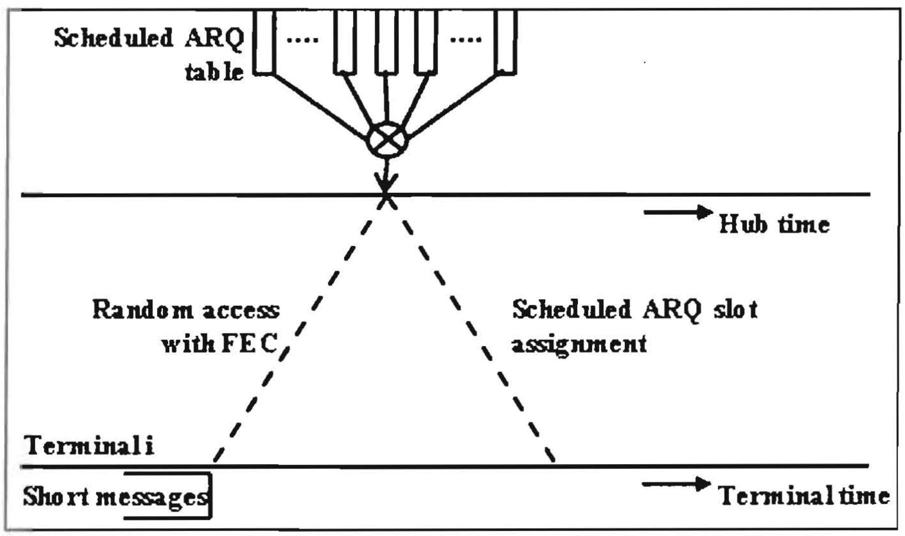


Figure 8: FMCSA system model

Figure 8 shows the system model of FMCSA. When a new message arrives from the upper network layer in the VSAT, it is first segmented into *k* MAC packets. Then the *k* packets are encoded into *n* code. The first *k* code packets contain the original message. The remaining *n-k* are parity packets. The *n* code packets are sent in *n* consecutive time slots and each slot is randomly chosen from the remaining FDMA Aloha channels which have not been reserved for the retransmissions. When the hub schedules the retransmissions, it ensures that for each slot there is at least one channel left for random access. For every *n* code packets, if any *k* or more out of them are received, the original message can be recovered correctly from the erasure. Each of the *n* code packets carries a unique message id number and a sequence number. In order to decrease the bandwidth overhead caused by sending the acknowledgements, FMCSA sends an acknowledgement for each message. There are three possible outcomes of a message after its first attempt. (i) In the first case, the message is fully received. In this case, the number *m* of packets received correctly is no less than *k* so that the message can be reassembled and forwarded to the upper layer. A positive acknowledgement for this message will be sent to the terminal as soon as *m* becomes equal to *k*. (ii) In the second case where the message is partially received i.e., $0 < m < k$, packet retransmission becomes necessary. A selective reject strategy is employed in FMCSA for packet recovery. From the sequence numbers and the message id number carried in the MAC packets, the hub figures out which packets collided in the message and it reserves $k-m$ slots for the message recovery, rather than let the terminal retransmit the collided packets in random access mode. Due to scheduled ARQ, FMCSA can guarantee the successful delivery of a message in the 2nd attempt as long as there is at least one packet getting through in its 1st attempt. (iii) In the third (worst) case where none of the *n* code packets get through i.e. the whole message is erased, the terminal will timeout and the collided *n* code packets will be sent again in the same way a new message is transmitted.

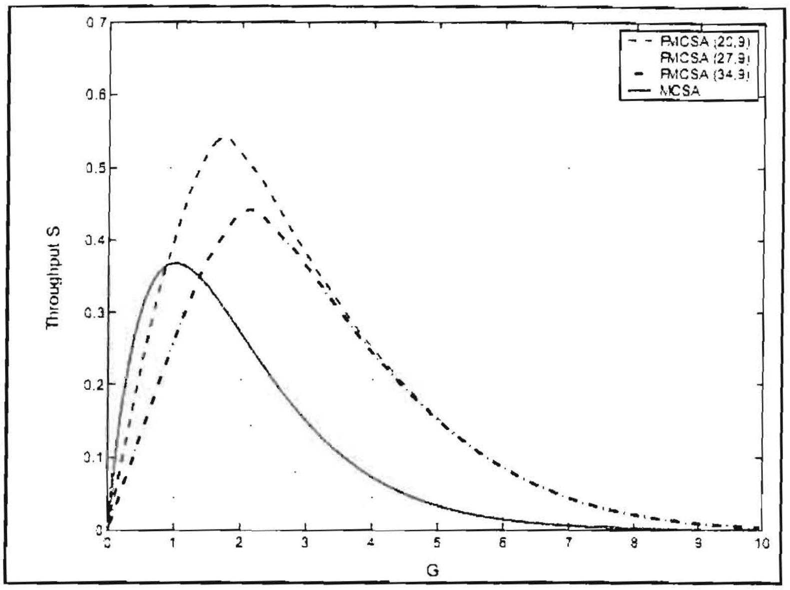
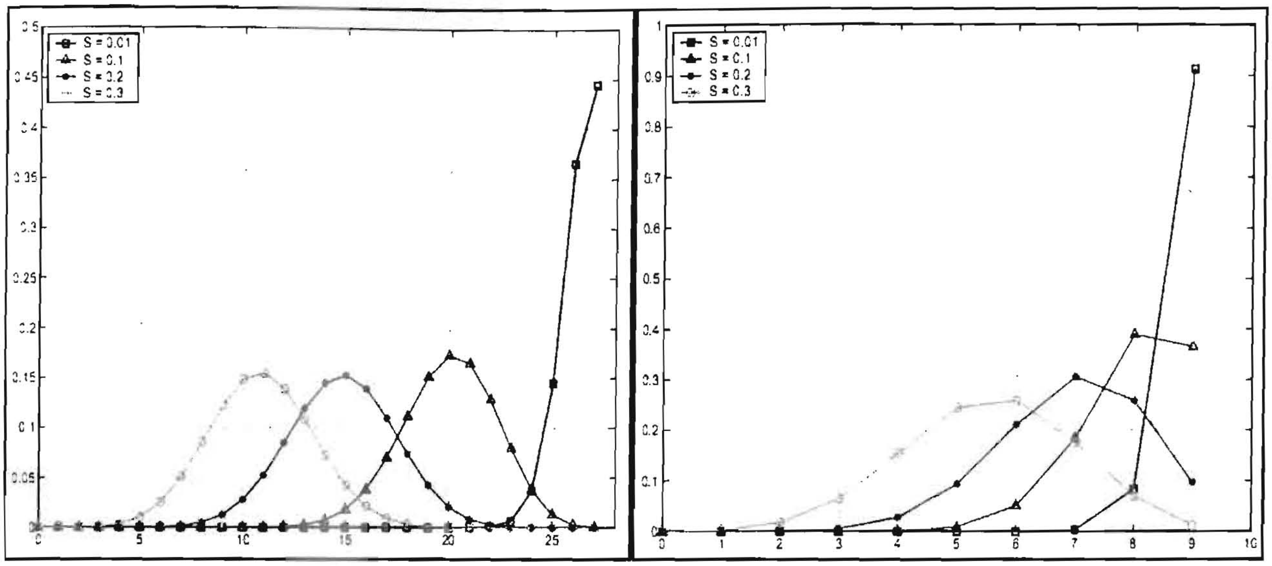


Figure 9: System throughput of FMCSA and MCSA

As described in (9), the throughput improvement of FMCSA over MCSA with respect to the total offered load *G* is illustrated by the simulation results in figure 9. The maximum throughput of MCSA is 0.368, while FMCSA with a FEC code (20, 9) has a maximum throughput of 0.542. Due to the parity packets sent in FMCSA, more load is offered to the channel than in MCSA to achieve the same throughput. Figure 10 shows the distribution of the number of packets that get through in the first attempt for different system throughput in MCSA and FMCSA respectively. In MCSA the probability of all the nine FEC packets received successfully decreases significantly with the increase of the load. While in FMCSA the probability that more than *k* FEC packets are received successfully decreases much more gracefully with the increase in throughput. At the same time, the probability of zero *n* code packets (n=27, k=9 in FMCSA and n=9, k=9 in MCSA) getting through is pretty low for both protocols even when the throughput is high. This means almost all the messages are either fully or partially received in the first attempt. Because the packets of a partially received message can reserve enough slots to retransmit the additional code packets in FMCSA, the message can be recovered in the second attempt. While MCSA does not take advantage of this fact, the retransmissions may again incur collisions. Therefore FMCSA can improve the delay performance significantly when compared with MCSA.

Slotted Aloha achieves approximately 60% first time message receipt; with FMCSA the number is 99%. Thus retransmissions for incorrectly received messages are dramatically reduced, leaving the VSAT return channel free to send user data. SAMA achieves channel efficiencies of 36% with 10% of channel load as shown on the S-ALOHA line. FMCSA extends this performance to over 50% channel efficiency and nearly doubles the load capacity on the return channel (figure 9). Therefore, using FMCSA can



MCSA with degenerated FEC code (9, 9) **FMCSA with FEC code (27, 9)**

Figure 10: Distribution of number of received packets in MCSA and FMCSA

double the SAMA subscribers per transponder or increase the channel efficiency by 30%. The improved performance of FMCSA compared to MCSA is robust to the FEC code rate, channel bandwidth, terminal population, arrival patterns, slot size as well as message length.

5. Conclusion

In this paper we have highlighted the work at the University of Maryland to design a two-way satellite system that can handle very high number of users at much lower latency than is currently possible. We have briefly described the SAMA and FMCSA algorithms that make the technologies possible.

We are currently creating a model of the two-way system in Opnet Modeler software (10) with comprehensive simulations of SAMA and FMCSA, in order to evaluate their performance. In addition to this, we are designing an algorithm for Adaptive Coding and Modulation (ACM) (11) to work with SAMA and FMCSA. The algorithm will automatically shift the SAMA/FMCSA coding length by mixing spreading factors based on the channel conditions. This will ensure robust data upload from the remotes to the hub, irrespective of the channel degradation due to interference, rain fade and other conditions.

We will also investigate and develop Dynamic Channel Allocation (DCA) algorithms (12) that will work seamlessly with SAMA/FMCSA to allocate return channel bandwidth based on the load – VSATs with high data rate traffic will be automatically assigned higher return bandwidth. DCA will allow SkySPAN to handle different Internet traffic types including bursty traffic, and utilize the satellite radio resources more efficiently.

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