RETURN CHANNEL PERFORMANCE EVALUATION OF ENHANCED SAMA VSAT WITH FMCSA AND ACM CAPABILITY

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Abstract

In this paper, we describe our work on developing and evaluating detailed OPNET simulation models of an enhanced Very Small Aperture Terminal (VSAT) satellite Internet gateway and an enhanced satellite hub based on Cerona SkySPAN technology with capacity and latency optimizations in the return channel so as to allow significantly higher number of users and a better user experience. The Cerona SkySPAN technology uses Digital Video Broadcast via Satellite 2nd standard (DVB-S2) in the forward channel and Spread Aloha Multiple Access (SAMA) protocol in the return channel. We augment the SAMA return channel protocol with Fast Multi-Channel Slotted Aloha (FMCSA) protocol and Adaptive Coding and Modulation (ACM). FMCSA combines Multi-Channel Slotted Aloha (MCSA) with packet level forward error correction (FEC) for new messages and scheduled retransmissions for partially received messages. This protocol increases the maximum possible throughput of SAMA, thus supporting higher number of users. FMCSA also reduces the delay of multi-slot short messages (e.g., HTTP requests) while providing more robust delay performance with respect to load fluctuations, thus resulting in a better user experience. We incorporate Adaptive Coding and Modulation in the return channel in order to automatically adapt the coding and modulation to changing channel conditions so as to ensure remote data service irrespective of the channel degradation due to interference, rain fade or other conditions. We show via OPNET simulations that the enhanced SAMA VSAT with FMCSA and ACM improves the throughput, latency and robustness of the SkySPAN SAMA system. We also compare, via OPNET simulations, the enhanced SAMA system (with FMCSA and ACM) with a DVB-RCS system to show improvements in user experience.

1. Introduction

Broadband Internet over Satellite serving large customer bases has the potential for high commercial payoffs in places where there is lack of wired connectivity such as in developing countries, in rural and mountainous areas, and for ships and aircrafts, as well as in disaster relief situations. 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 so as to allow more users and lower per-user cost. The current solutions to this problem are media access algorithms that 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 is wasted due to the bursty nature of the return channel Internet traffic – only 1%-3% of the capacity is 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. These weaknesses and problems are precisely those that are being 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 in order 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 develop and evaluate OPNET simulation models of an enhanced Very Small Aperture Terminal satellite Internet gateway and an enhanced satellite hub based on Cerona SkySPAN technology [1] with capacity and latency optimizations in the return channel so as to allow higher number of users and a better user experience. Section 2 provides a background to the research effort with a brief description of Cerona technology in this sphere. Section 3 briefly describes the media access algorithms, Spread Aloha Multiple Access (SAMA) [3] and Fast Multi-Channel Slotted Aloha (FMCSA) [4], highlighting their advantages over competing technologies. We then describe in section 4 our OPNET simulation models [9] of an enhanced VSAT satellite Internet gateway and an enhanced satellite hub that use DVB-S2 [2] in the forward channel and SAMA augmented with FMCSA protocol and Adaptive Coding and Modulation (ACM) in the return channel. Section 5 presents some results of running the OPNET simulation models developed to show improvements in system throughput and latency. Finally we conclude in section 6.

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 Spread Aloha Multiple Access [3] in the return channel. The SkySPAN network (figure 1) consists of the SAMA hub, the space segment and the SkySPAN VSAT.
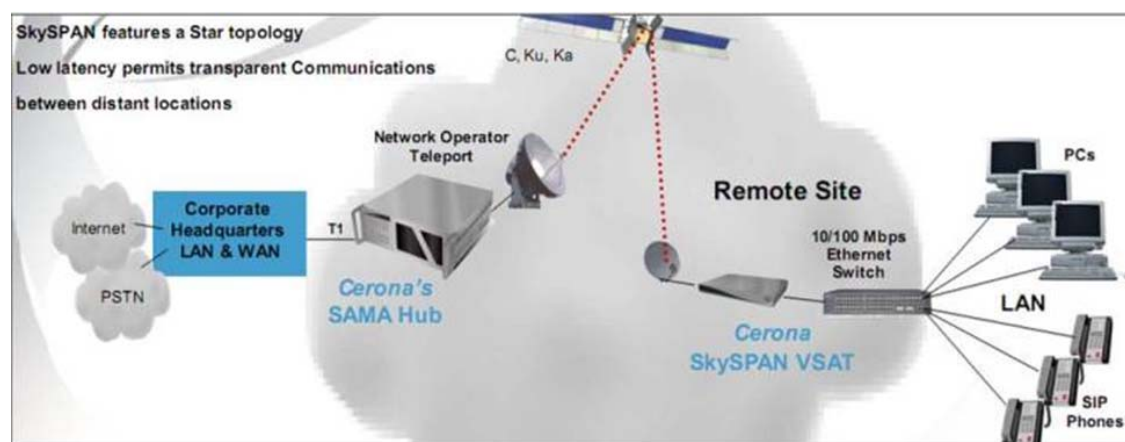
Figure 1: Cerona SkySPAN star satellite network

The overall objective of the project is to develop technologies to optimize the forward and return channels of the SkySPAN hub and VSAT, so that broadband Internet-over-Satellite services can be provided to a large number of users, with performance approaching that of terrestrial Internet connections. 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 hub can support 4 receiver cards; therefore, the SAMA hub 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) [6], 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).

The SAMA return channel is augmented with Fast Multi-Channel Slotted Aloha and Adaptive Coding and Modulation. FMCSA further reduces the latency and supports higher number of users, compared to SAMA alone. ACM on the return channel enables automatic adaptation of the coding and modulation to changing channel conditions so as to ensure remote data service irrespective of the channel degradation due to interference, rain fade or other conditions

3. SAMA and FMCSA

3.1. Spread Aloha Multiple Access (SAMA)

The original Aloha protocol was invented by N. Abramson in 1970 [7] and 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 1/(2e), i.e., approximately 18%. An improved Aloha system – the Slotted Aloha system - was proposed in 1973 by Roberts et al. [8]. 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 again indicates collision. Slotted Aloha doubles the maximum throughput compared to Aloha. A multi-channel version of Slotted Aloha – the Multi-Channel Slotted Aloha (MCSA) was invented by Birk and Keren in 1999 [5]. MCSA is a set of "stacked" Slotted Aloha channels. The stacking can occur as multiple narrowband channels separated by frequency, or multiple spread spectrum channels separated by chips. MCSA allows the use of a wideband channel among multiple VSATs where each VSAT has a peak power constraint. MCSA also doubles the maximum throughput compared to Aloha.

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) 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 small 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 "Comms.-On-The-Move" (COTM) applications and also applies to many commercial environments such as marine, rail and first responder requirements.

3.2. Fast Multi-Channel 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 [4]. 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 Slotted Aloha. A brief description of FMCSA is given below.

Figure 2 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 packets. 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
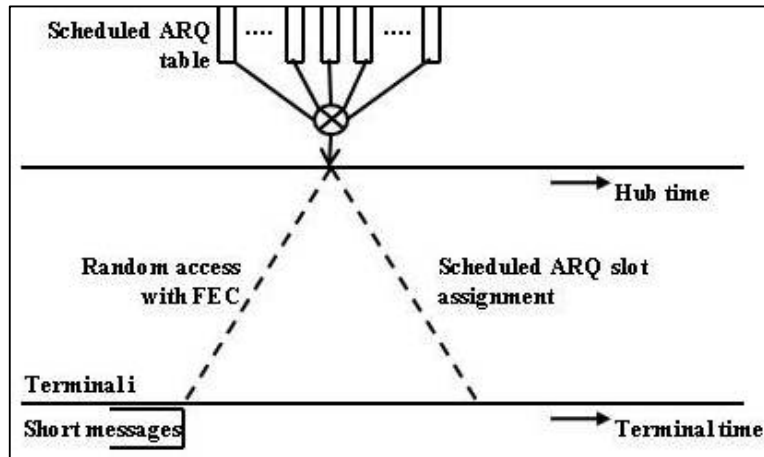
Figure 2: FMCSA system model

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.

As described in [4], the throughput improvement of FMCSA over MCSA with respect to the total offered load *G* is illustrated by the simulation results in Figure 3. 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 4 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

Figure 3: System throughput of FMCSA and MCSA

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
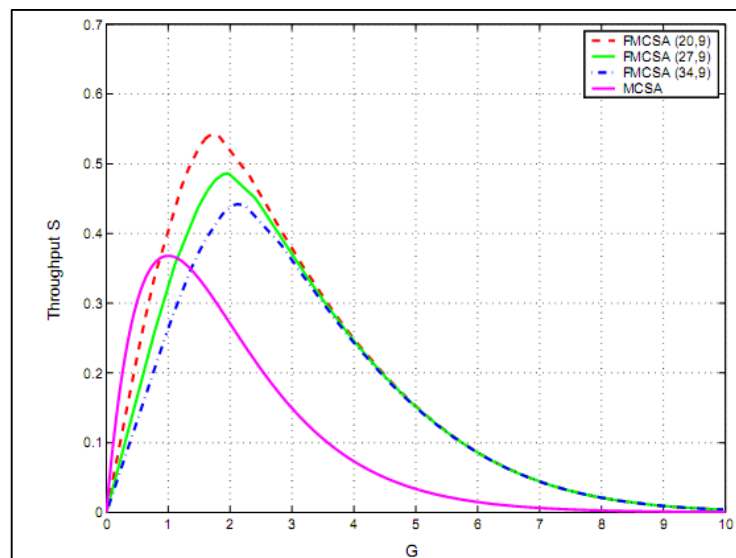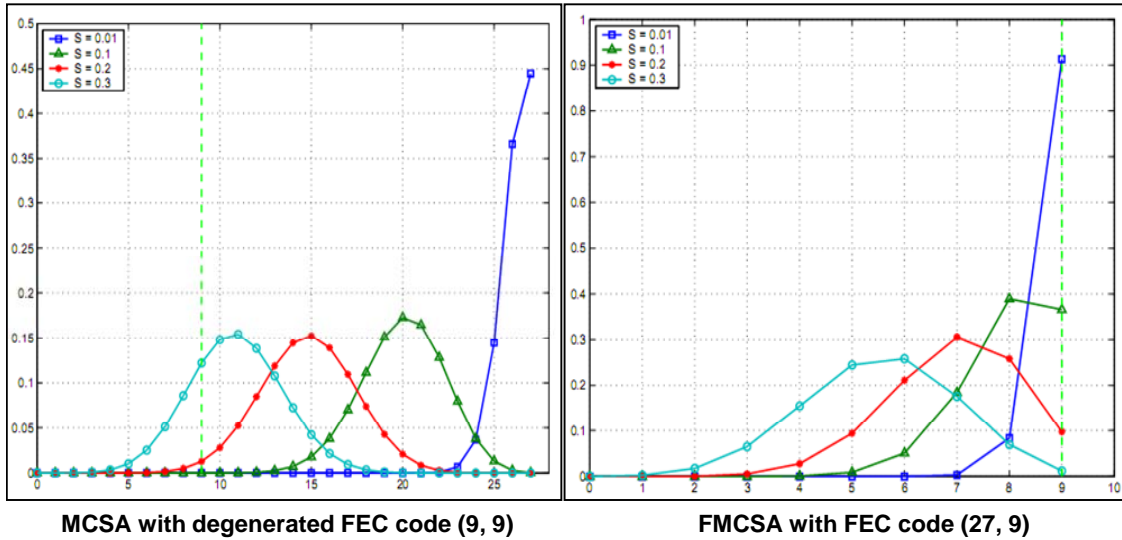
FMCSA, the message can be recovered in the second attempt. While MCSA does not take advantage of this fact, the retransmissions may again incur collisions. Therefore FMCSA can improve the delay performance significantly when compared with MCSA.


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

Figure 4: Distribution of number of received packets in MCSA and FMCSA

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 3). Therefore, using FMCSA can 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.

4. OPNET Simulation Models: DVB-S2 Forward and SAMA+FMCSA+ACM Return

We have developed OPNET models [9] of an enhanced satellite hub and an enhanced VSAT that implement DVB-S2 in the forward channel and SAMA augmented with FMCSA and ACM in the return channel. Figure 5 shows the top level network view of a scenario involving the developed simulation models. Here a single hub serves 1024 VSATs with the communication between the hub and VSAT going through a satellite. A remote workstation is connected via Ethernet to each VSAT. These remote workstations send HTTP requests via the developed VSAT gateway to a server workstation (called *hub_wksn* in the figure) that is connected to the developed satellite hub through a router. We use this scenario in our simulations (see next section).
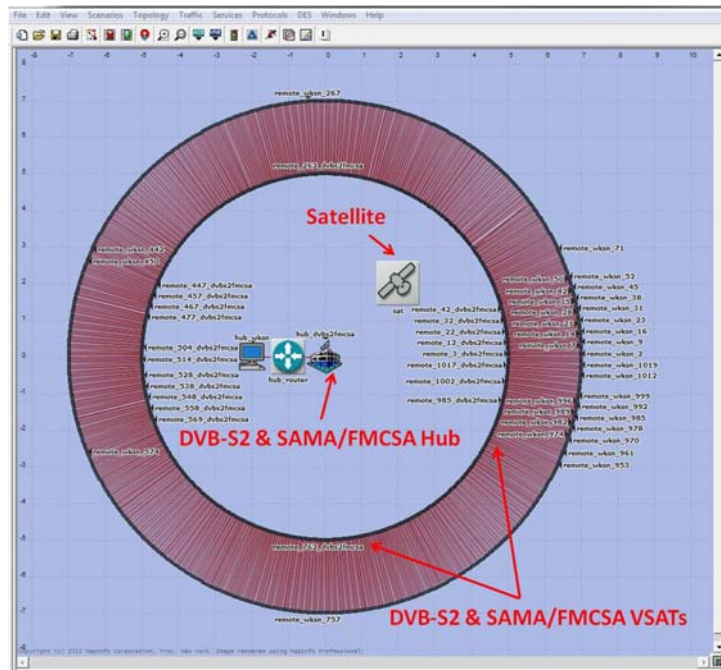
Figure 5: Network with DVB-S2 Forward & SAMA+FMCSA+ACM Return

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Figure 6 shows the forward and return channel parameters. The SAMA+FMCSA+ACM return channel implements the SAMA spreading augmented with FMCSA and ACM. The parameter *"Spreading Factor"* in the figure is the SAMA spreading factor. The parameters *"IP Coderate Numerator"* and *"IP Coderate Denominator"* together specify the FMCSA coderate. The total return channel capacity is set to 6.4 Mbps (with QPSK modulation) which is then divided among 50 unspread channels. The total forward channel capacity is set to 25 times the total return channel capacity for the same modulation.

Figure 7 shows the OPNET state machine implementation of the satellite hub's Medium Access Layer while figure 8 shows the corresponding OPNET state machine implementation of the VSAT internet gateway's Medium Access Layer.
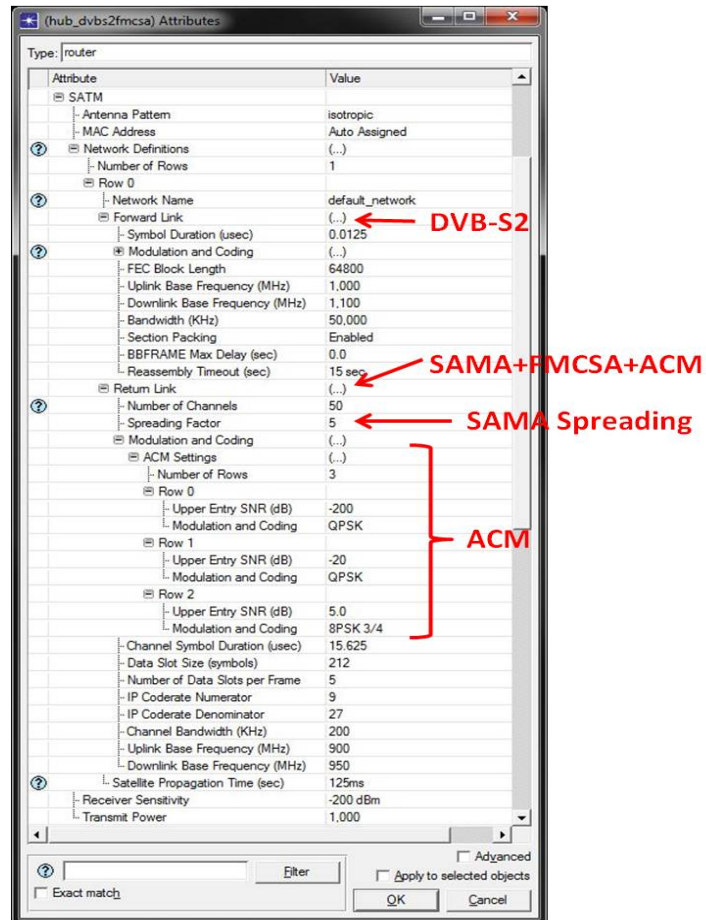

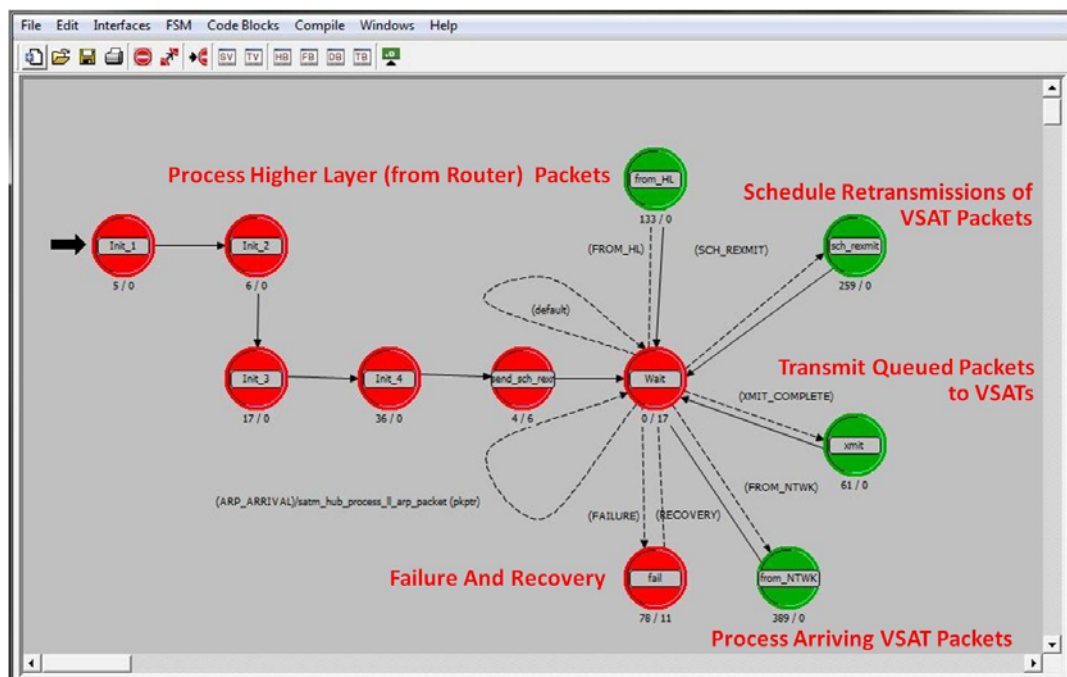**Figure 6: Channel Parameters for DVB-S2 forward & SAMA/FMCSA+ACM return channel**

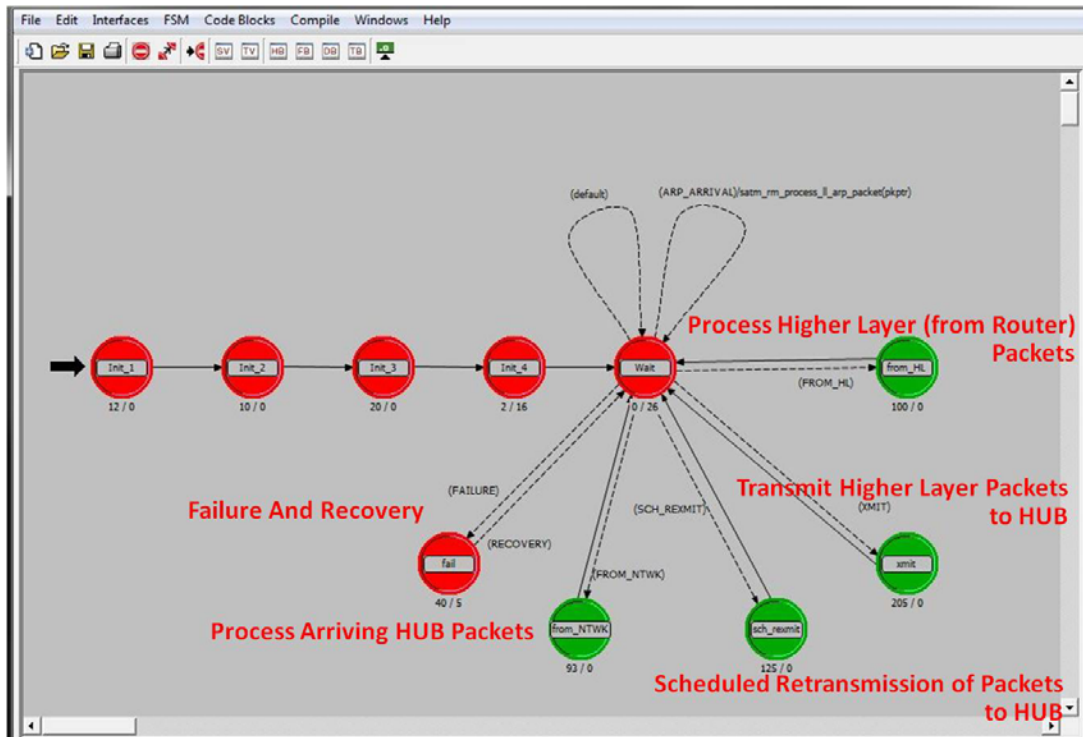**Figure 7: State Machine of the Hub MAC (DVB-S2 and SAMA+FMCSA+ACM)**

Figure 8: State Machine of the VSAT MAC (DVB-S2 and SAMA+FMCSA+ACM)

5. OPNET Simulation Results

In order to test the developed OPNET models of the enhanced SAMA hub and VSAT, we use the scenario shown in figure 5 with the DVB-S2 forward channel parameters and the SAMA+FMCSA+ACM return channel parameters as shown in figure 6. The SAMA+FMCSA+ACM return channel uses a FMCSA (27, 9) code in the simulations and is thus identified by the legend "FMCSA (27, 9)" in the graphs that follow (figures 9 and 10).

Figure 9 shows the average short message (432 byte HTTP request) packet delay for various normalized throughputs (i.e., offered loads) between the enhanced SAMA+FMCSA+ACM system and MCSA (whose delay is equivalent to SAMA alone). We see that the enhanced SAMA system shows much better delay performance especially as the load increases. It is also able to support a higher maximum throughput as seen by the packet delays not blowing up till the normalized offered load is

Figure 9: Enhanced SAMA system and MCSA Simulation Results

0.5 while the packet delays of the MCSA system blow up from 0.4 normalized offered load. The simulation results here match the previous results of figure 3 for plain FMCSA and MCSA.
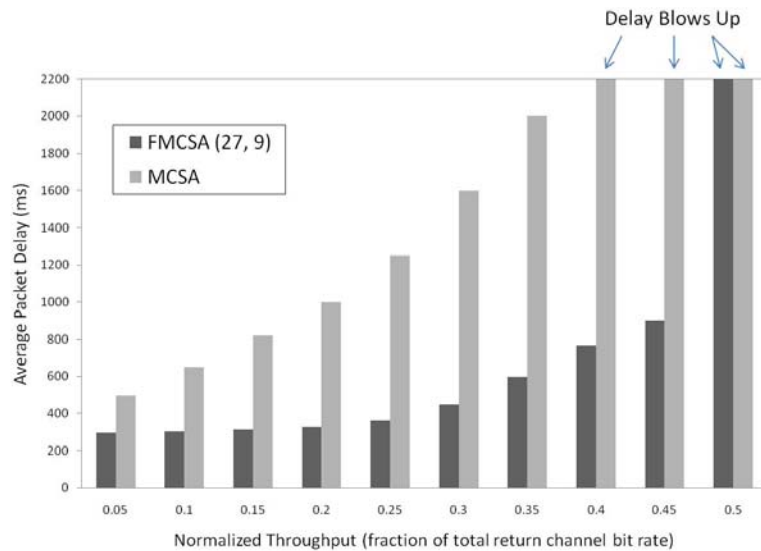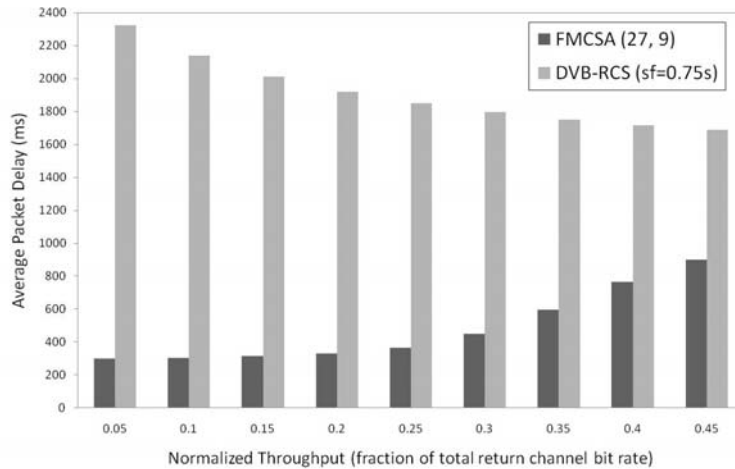
Figure 10 shows the average short message (432 byte HTTP request) packet delay for various normalized throughputs (i.e., offered loads) between the enhanced SAMA+FMCSA+ACM system and a DVB-RCS system. The DVB-RCS system setup in the simulation had a superframe duration of 0.75s and is so annotated in the graph's legend. We see that for low loads the enhanced SAMA system delivers much better delay performance. Note that the decrease in average packet delay of the DVB-RCS system with increasing loads

Figure 10: Enhanced SAMA system and DVB-RCS Simulation Results

(at least up to 0.45). This can be explained by a higher probability of more than 1 packet queuing up at the VSAT between superframes as the load increases and hence the VSAT asking for and being granted more bandwidth to transmit in the next superframe.

6. Conclusion

In this paper, we have described our work on developing and evaluating detailed OPNET simulation models of an enhanced VSAT and an enhanced satellite hub based on Cerona SkySPAN technology with capacity and latency optimizations in the return channel so as to allow significantly higher number of users and a better user experience. We show via OPNET simulations that the enhanced SAMA VSAT with FMCSA and ACM improves the throughput and latency of the SkySPAN SAMA system.

We are currently investigating Dynamic Channel Allocation (DCA) algorithms 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 efficiently utilize the satellite radio resources.

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