PERFORMANCE EVALUATION OF HYBRID SAMA VSAT WITH FMCSA AND RESERVATIONS

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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 a hybrid random access and reservation based 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 a hybrid random access and reservation based Dynamic Channel Allocation (DCA) scheme. The overall goal of the DCA algorithm is to make the system behave like a random access system at low loads for small messages so as to provide low message delay and to behave like a MF-TDMA reservation based system at high loads as well as for real time traffic so as to provide high maximum throughput and a better user experience. The random access protocol used at low loads is SAMA enhanced with Fast Multi-channel Slotted Aloha (FMCSA) protocol. FMCSA combines Multi-Channel Slotted Aloha (MCSA) with packet level forward error correction for new messages and scheduled retransmissions for partially received messages. This protocol increases the maximum possible throughput of SAMA and reduces the delay of multi-slot short messages while providing more robust delay performance with respect to load fluctuations, thus resulting in a much better user experience at low loads. The system transitions into a reservation based system at higher loads and for real time traffic so to support higher maximum throughput and achieve good QoS for real time traffic. The satellite return channel is divided into multi-frequency periodic frames. Each frame has mini-slots used for sending reservation requests in contention mode and larger data-slots used for sending data in either contention mode (FMCSA) or reservation mode (where the HUB allocates data-slots based on requests). We show via OPNET simulations that the enhanced SAMA VSAT with the hybrid DCA algorithm improves the throughput, latency and robustness of the SkySPAN SAMA system. We also compare, via OPNET simulations, the enhanced system with a DVB-RCS system to show the improvements in user experience both in terms of delay and throughput.

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. 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 [9] simulation models of an enhanced VSAT 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 SkySPAN. Section 3 goes over the system considerations and overall system architecture. In section 4, we describe the return channel DCA algorithm used that behaves as a random access system (Spread Aloha Multiple Access (SAMA) [3] and Fast Multi-Channel Slotted Aloha (FMCSA) [4]) at low loads and transitions to a reservation based system at higher loads. We then describe in section 5 our OPNET simulation models of the enhanced VSAT satellite Internet gateway and the enhanced satellite hub that uses DVB-S2 [2] in the forward channel and the DCA algorithm in the return channel. Section 6 presents some results of running the OPNET simulation models developed to show improvements in system throughput and latency. Finally we conclude in section 7.

2. Background and Motivation

The gateway and hub are based on Cerona's SkySPAN technology. SkySPAN currently uses the Digital Video Broadcast via Satellite 2nd standard (DVB-S2) in the forward channel, and Spread Aloha Multiple Access [3] in the return channel. The SkySPAN star topology network (figure 1) consists of the SAMA hub, the space segment and the SkySPAN VSAT. At low loads, the SAMA protocol delivers packets at a third of the latency compared to competing technologies like DVB-RCS (multi-frequency TDMA) [6]. By using spreading, the SAMA system permits the use of very small antennas that can be steered easily to maintain broadband communications in rapidly moving vehicles.

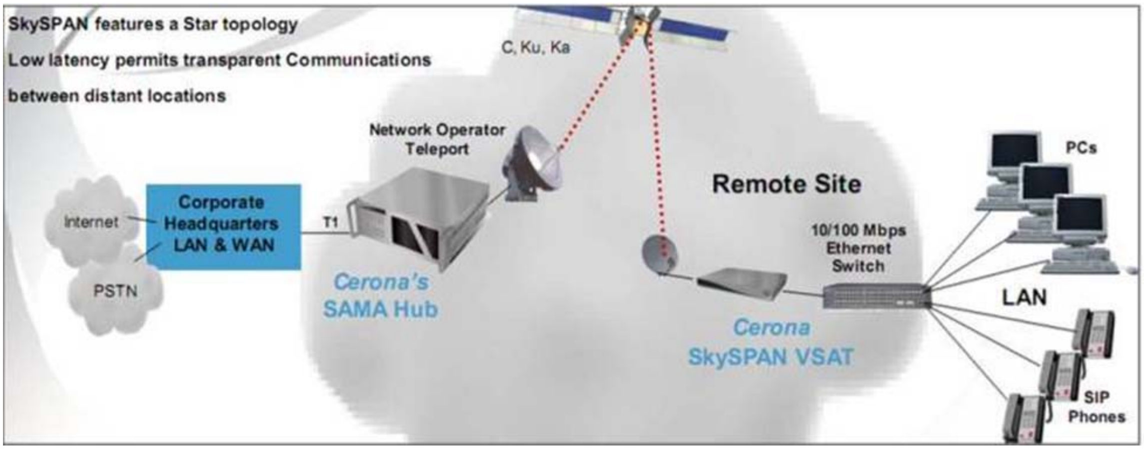

Figure 1: Cerona SkySPAN star topology satellite network

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. In [10], we developed an enhanced SAMA VSAT and hub that uses SAMA augmented with Fast Multi-Channel Slotted Aloha and Adaptive Coding and Modulation in the return channel. Compared to SAMA alone, FMCSA further reduces the latency and supports higher number of users while providing more robust delay performance with respect to load fluctuations, thus resulting in a much better user experience at low loads. 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. In this paper, we further augment the SAMA return channel with a hybrid random access and reservation based Dynamic Channel Allocation scheme with ACM. The overall goal of the DCA algorithm is to make the system behave like a random access system at low loads for small messages so as to provide low message delay and to behave like a MF-TDMA reservation based system at high loads as well as for real time traffic so as to provide high maximum throughput and a better user experience. The random access protocol used at low loads is SAMA enhanced with FMCSA. Thus the DCA return channel promises to deliver high speeds at a third of latency compared to competing technologies like DVB-RCS while supporting higher number of users with better user experience.

3. System Considerations and Overall Architecture

We consider satellite systems that serve as access networks to provide Internet services to fixed and mobile networks as shown in Figure 1. Any such satellite system designed to carry current Internet traffic must be able to support data as well as audio and video traffic. Audio and video traffic over satellite are best (as defined by user perceived quality) carried by allocating some constant bit rate to this type of traffic. Thus there is a need for reserving bit rate in the return channel from the remote users (VSATs) to the central satellite gateway/hub. Internet data traffic, on the other hand, has great variability (i.e., is bursty) both in message size and message arrival times. Higher layer messages are usually split by the Medium Access Control (MAC) layer into multiple packets and sent (separately) in multiple time-slots. It is desirable to deliver short transaction based messages, like those generated by point of sale transactions, in the return channel with the smallest delay possible. To improve remote-user perceived quality when browsing web pages, it is also desirable to send HTTP requests in the return channel with the smallest delay possible. In addition, to improve TCP performance, it is beneficial to send TCP ACKs with as low a delay as possible. As long as the satellite return channel is operating at low channel utilization, a random access protocol like slotted ALOHA provides the best possible delay for such short messages. Thus different types of Internet traffic impose different requirements on the satellite return channel. Hence the return channel protocol should be capable of distinguishing between different internet traffic types and tailoring its behavior to the traffic type.

In order to support mobile users, the return channel needs to support spreading. ACM on the return channel is also desirable in order to enable automatic adaptation of the coding and modulation to changing channel conditions. The system needs to support a large number *U* of remote-users and hence U is much larger than the round-trip delay (*R*) divided by return channel slot time (*T*). This needs to be taken into account when designing the return channel access protocol.

There have been many different return channel satellite access schemes described in the literature [*7,* 8, 5, 4, 11-16]. The ideal return channel satellite MAC protocol for internet traffic that is capable of supporting a large number of remote users should be able to prioritize traffic, tailor its behavior to traffic type, act like a random access protocol at low channel loads and also support high loads when the system should act like a reservation-based system.

The overall system architecture for the forward and return channel is shown in figure 2. Transmitting data from the central hub to a large number of remote VSATs on the broadcast satellite channel is best achieved using Time Division Multiplexing (TDM). Thus the protocol used in the forward channel is DVB-S2 (12) with ACM. The return channel protocol used is a custom Dynamic Channel Allocation protocol that is described in the next section and uses ACM along with spreading.

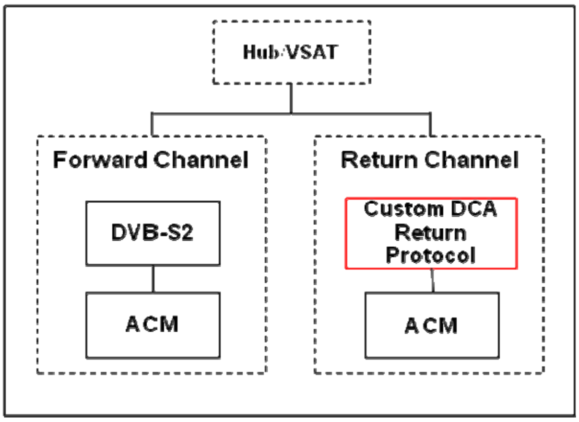

Figure 2: Overall System Architecture

4. Return Dynamic Channel Allocation Algorithm

The overall goal of the return channel DCA algorithm is to make the system behave like a random access system at low loads for small messages so as to provide low message delay and to behave like a MF-TDMA reservation based system at high loads as well as for real time traffic so as to provide high maximum throughput and a better user experience. The random access protocol used at low loads is SAMA enhanced with Fast Multi-channel Slotted Aloha (FMCSA) protocol. 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 and 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 much better user experience at low loads. The system transitions into a reservation based system at higher loads and for real time traffic so to support higher maximum throughput and achieve good QoS for real time traffic.

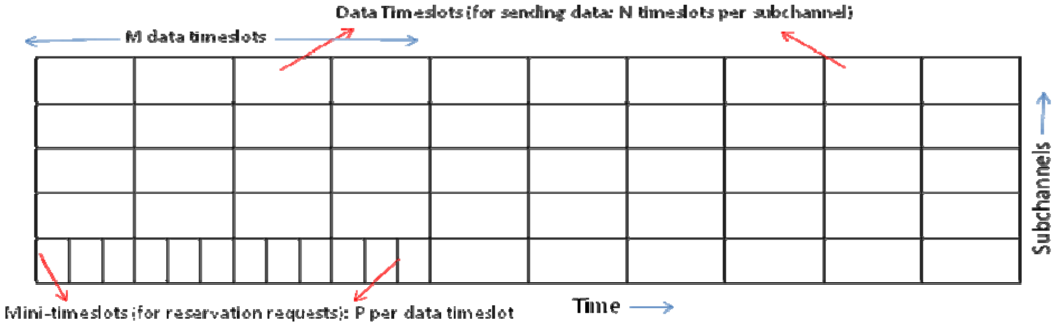

Figure 3: Return Channel Periodic Frame Structure

The satellite return channel from the remotes (i.e., VSATs) to the hub has a periodic frame structure as shown in figure 3. Mini-timeslots are used to send reservation requests in contention mode (Diversity Slotted Aloha (DSA) [15]) while data-timeslots are used to send data in either contention mode (FMCSA) or reservation mode (where the hub allocates data-slots based on requests and some scheduling algorithm). The duration of a data timeslot is chosen to be an integer multiple of the duration of a mini-timeslot. Let the duration of P mini-timeslots be the same as the duration of a data timeslot and let N data timeslots fit in a single subchannel of a frame. M data timeslots are converted into M*P mini-timeslots for reservation requests. The parameter M is a user-configurable parameter.

Each reservation request in a mini-slot can reserve multiple data-slots. Considering a typical HTTP request of 500-800 bytes and using a data-slot of 188 bytes (same as DVB-RCS MPEG2 Transport Stream), each HTTP request typically needs 3-5 data-slots. There must be enough mini-slots allocated in a frame so that the normalized request load (when the data load is around 90 to 100 percent of data portion capacity) in the reservation request portion of the frame is such that most of the reservation attempts go through in the first attempt (the packet loss ratio due to contention should be kept very low around .01 or .001). FMCSA offers no improvement over slotted ALOHA if only single packet messages are sent. Hence the slotted ALOHA system used is Diversity Slotted Aloha where the reservation requests are sent twice in a single frame. For a packet loss ratio of .01, DSA can support normalized load of .05 while for a packet loss ratio of .001, DSA can support normalized load of .02. Retransmissions of the reservation requests is supported via a double retransmission scheme where the retransmitted reservation request is sent twice in two different frames.

At high loads, most of the data-slots will be allocated by the satellite hub and there will be very few, if any, free data-slots. Thus the system at high loads behaves as a reservation system with random access reservation requests. Contention based reservation requests benefit from a traffic model that assumes that at any given time only 10% of the users are active. As long as average return channel load is below some threshold α (between .2 to .4), the system operates as an enhanced SAMA+FMCSA+ACM system. When the average return channel load exceeds the threshold for some hysteresis time *T1*, then the system switches to a reservation based system with random access reservation request mini-slots. The system in reservation mode switches back to FMCSA+SAMA+ACM system when the average return channel load falls below threshold α for a hysteresis time *T2*.

4.1. 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. 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. SAMA uses Direct Sequence Spread Spectrum 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 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” applications and also applies to many commercial environments such as marine, rail and first responder requirements.

4.2. Fast Multi-Channel Slotted Aloha (FMCSA)

In order to improve the delay performance of short multi-timeslot 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 [4]. FMCSA combines MCSA random access with packet level forward error correction (FEC) for new messages (that are sent in mutlitple timeslots) 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 MCSA.

Figure 4 (duplicated here from [10]) shows the average short message (432 byte HTTP request) packet delay for various normalized throughputs (i.e., offered loads) between a SAMA+FMCSA+ACM system (code (*n=27,k=9*)) and MCSA (whose delay is equivalent to SAMA alone) system simulated in OPNET. We see that the enhanced SAMA+FMCSA 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 0.5 while the packet delays of the MCSA system blow up from 0.4 normalized offered load. As described in [4], this 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.

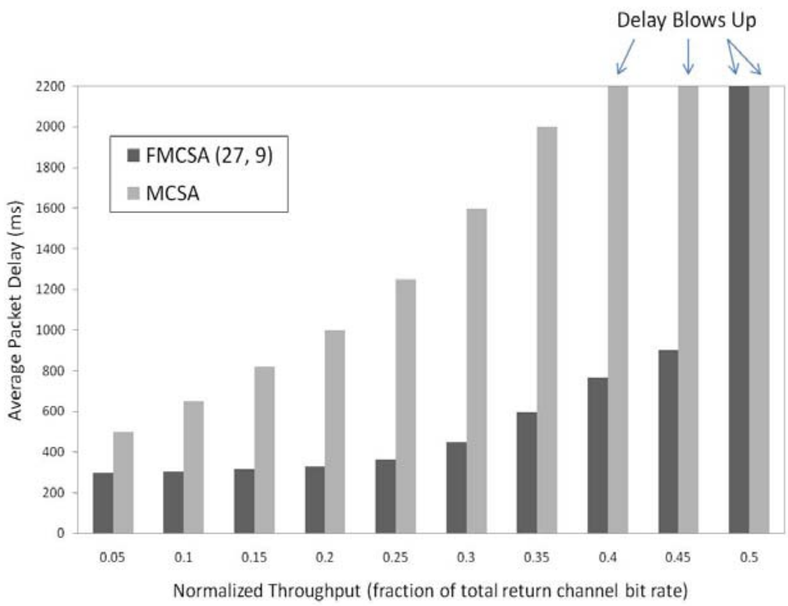

Figure 4: Simulation Results of Average Pkt. Delay v.s. Throughput for FMCSA+SAMA (FMCSA (27, 9)) and MCSA

5. OPNET Simulation Models: DVB-S2 Forward and DCA 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 hybrid DCA with ACM in the return channel as described in section 4. 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).

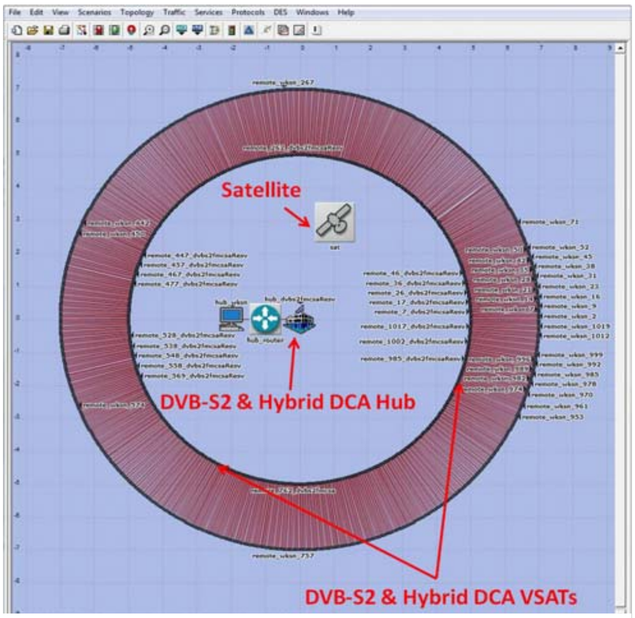

Figure 5: DVB-S2 Forward & DCA Return Network

Figure 6 shows the forward and return channel parameters. The hybrid DCA return channel implements the SAMA spreading augmented with FMCSA and ACM for low loads and transitions to a reservation based system with contention reservation requests when offered load is above "*Offered Load Transition Threshold*" as described in section 4. 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 to be used in FMCSA mode. The parameters "*Reservation Request Size"* and "*Number of Reservation Request Minislots"* specify the reservation request size and number of reservation requests in reservation mode. 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.

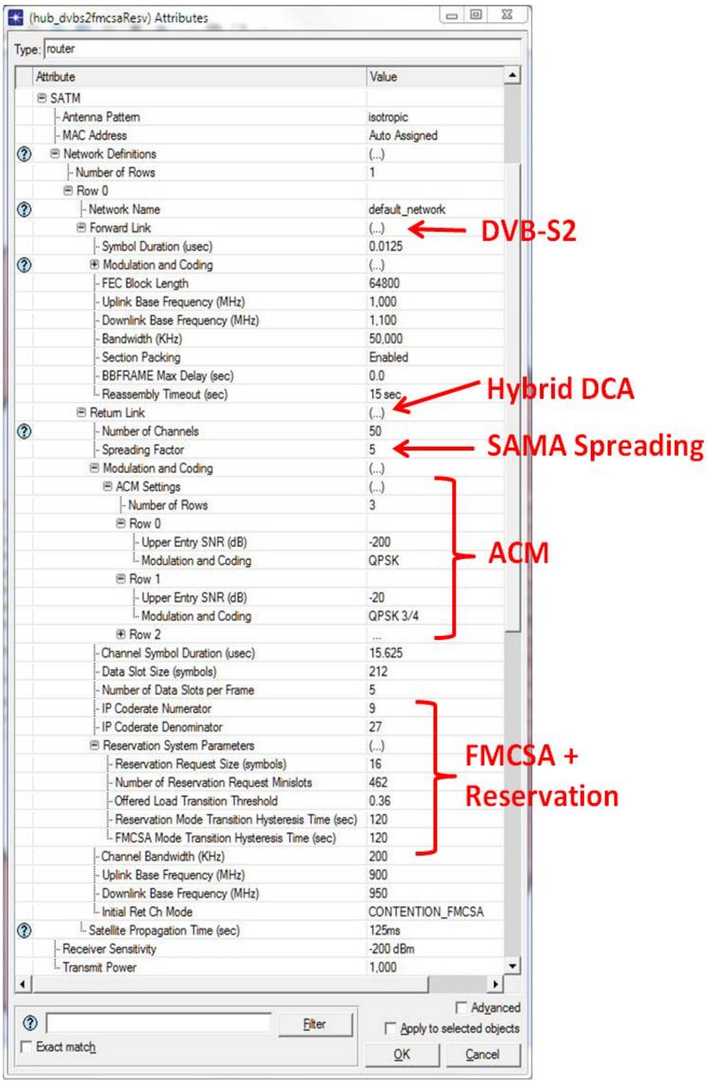

Figure 6: Channel Parameters for DVB-S2 forward and Hybrid DCA return channel

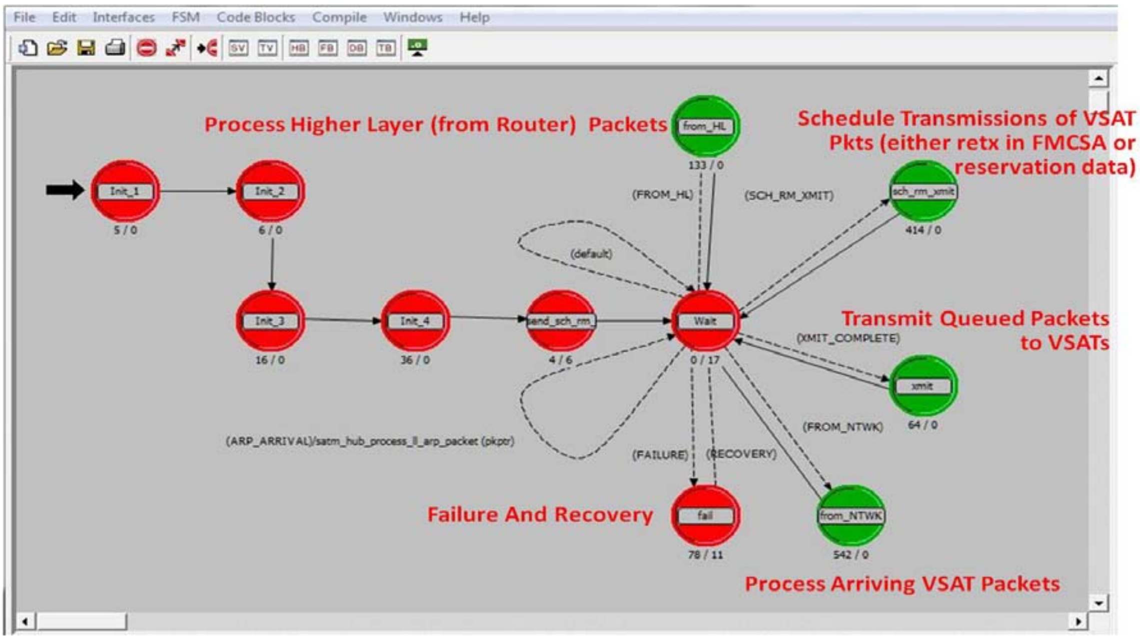

Figure 7: State Machine of the Hub MAC (DVB-S2 and Hybrid DCA)

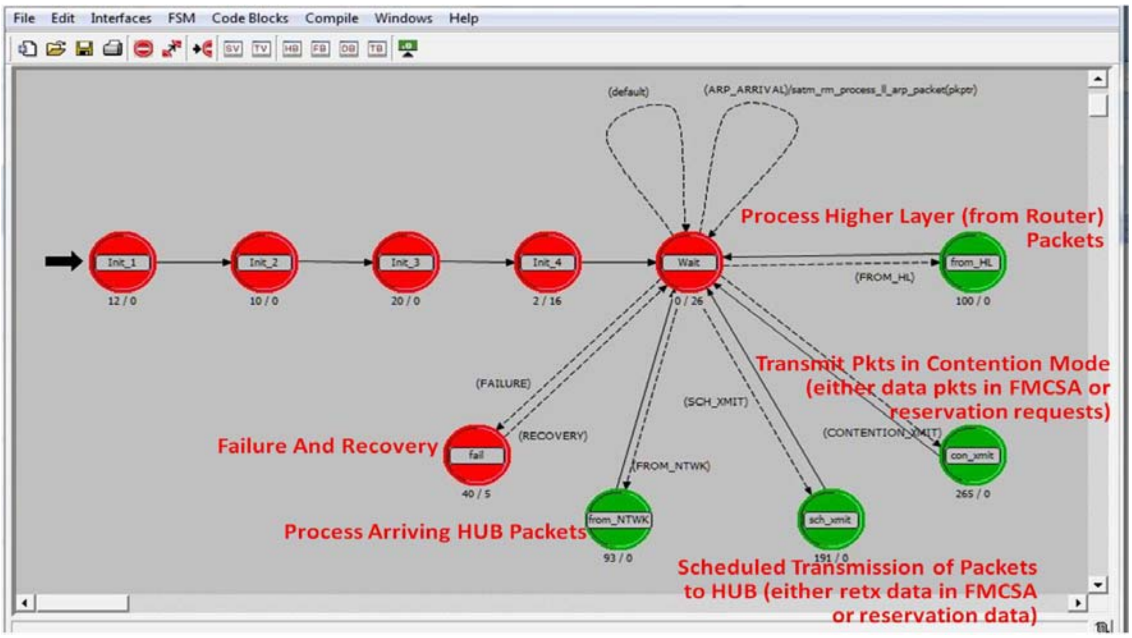

Figure 8: State Machine of the VSAT MAC (DVB-S2 and Hybrid DCA)

6. 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 and the custom DCA return channel parameters as shown in figure 6. The custom DCA return channel protocol uses a FMCSA (27, 9) code at low loads and the return channel switches to a reservation based system if offered load is above 0.36. 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 DCA system and a DVB-RCS system. The DVB-RCS system setup in the simulation had a superframe duration of 0.75. We see that for low loads the enhanced DCA system (in FMCSA mode) delivers much better delay performance; and at higher loads (reservation mode) too the delay is lower than DVB-RCS and remains fairly constant. Note the sharp change in delay as the hybrid DCA system changes from a contention SAMA+FMCSA system to a reservation based system at a threshold of 0.36.

7. Conclusion

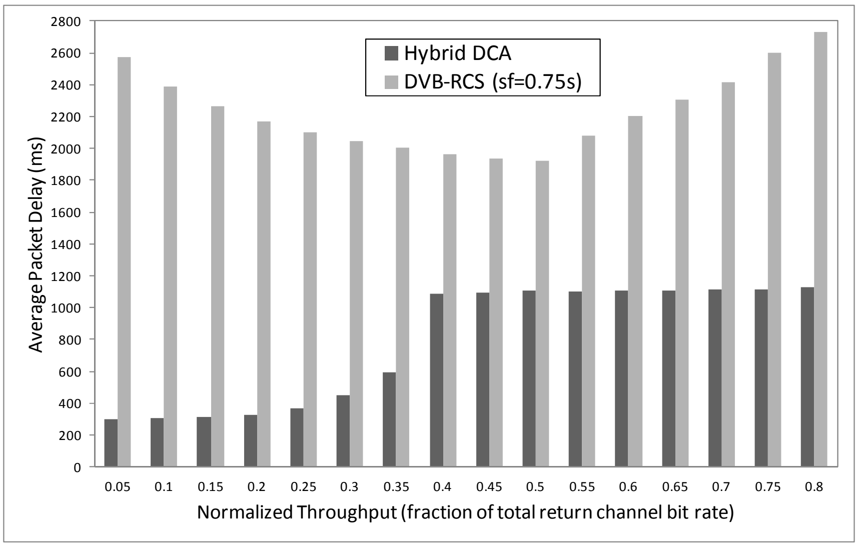

Figure 9: Hybrid DCA system and DVB-RCS Simulation Results

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 a hybrid random access (FMCSA) and reservation based 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 DCA return channel improves the throughput and latency of the SkySPAN SAMA system.

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