TECHNICAL RESEARCH REPORT

Using Commercial Satellites to Provide Communication Support for Space Missions

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Using Commercial Satellites to Provide Communication Support for Space Missions

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***Abstract*- NASA is interested in using commercial satellites to provide broadband communications support for future space missions. In this paper, we describe a large-scale simulation model that we plan to use for detailed performance studies of critical parameters. We focus on the unique challenges we face and how we plan to use simulations to investigate:**

- **the feasibility of using proposed commercial constellations to carry various classes of traffic between ground terminals and near-earth spacecraft.**
- **the performance optimization of such systems.**

I. INTRODUCTION

The start of the deployment of the International Space Station (ISS) has ushered a new era in space exploration. At the same time, advances in communications technology could allow investigators on Earth to enjoy a virtual presence in space[1]. In order to achieve this, there will be a need to provide high quality, broadband communications connectivity in order to enable cost effective global access to experimental data from the ISS and other space missions. NASA is also interested to gradually facilitate broadband Internet services throughout its missions, eventually leading to a scenario where every spacecraft and instrument in NASA's network can have an IP address and a connection to the Internet[2].

Gradual commercialization of space communications operations could enable:

- Reduction in cost for NASA's communication needs;
- Better, faster and easier dissemination of space mission and experimental data directly to the scientists;
- Faster development in the satellite industry that could enable other commercial entities to take part in experiments in space, such as future space habitats and planetary missions.

For these reasons we started an effort to investigate the use of next generation commercial satellite constellations for supporting NASA's needs. As a first step, we have developed a simulation model for this scenario, consisting of: the ISS, models of several commercial satellite constellations, the existing NASA Network and the ground network of candidate commercial constellations. We consider this to be a minimal architecture, because all aspects of the model have been considered, including propagation characteristics, coverage aspects, traffic generation, node movement tracking, hand-off, and connectivity. The performance parameters addressed include:

***Coverage*:** Percent of time that data could be transmitted to the ISS via the commercial system - this includes Static & Dynamic coverage and the effect of Inter Satellite Links.

Throughput: Maximum daily throughput depends on the availability duration (coverage statistics) and the per-channel data rate (link quality).

QoS: QoS is evaluated in terms of availability duration and link quality. Link quality is best described in terms of EIRP and G/T values that are specified in the ISS design and must be provided by the commercial constellation. Available duration can be computed based on the results of the coverage analysis.

Antennas & Terminals: Antenna and terminal characteristics with respect to required link quality are considered. It would be necessary to have an antenna design well suited for covering moving satellites and terrestrial traffic.

II. COMMUNICATIONS SUPPORT FOR THE ISS

A. *Simulation Model*

Our general model consists of the ISS (treated as a satellite in an extremely Low Orbit) with a network of three ground stations. We plan to incorporate along with that detailed models of several proposed constellations, and see how each one performs for specific traffic scenarios. To illustrate our modeling process we describe here two characteristic cases, focusing more on the more challenging MEO case:

- A system with three GEO satellites. This along with the ground network model makes up a basic network similar to NASA's current TDRSS-Deep Space Network (DSN).
- A system with 7 MEO satellites in a ring, based on the proposed Orblink EHF-band MEO system [3].

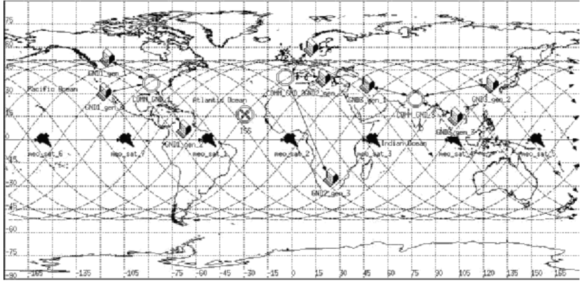

Fig. 1. OPNET network model-MEO Case

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A. Simulation Model Components-MEO Constellation

ISS Module: The ISS is currently modeled as a simple traffic generator. After a random idle period, it creates a file whose size is uniformly distributed. The file is then divided into fixed-size packets and transmitted to the destination address.. No priority or service classes are implemented. The queue_sat module performs simple FIFO queuing, with a packet service time that is chosen to ensure proper flow control. Packets are transmitted only if the strength of the beacon signal received from any satellite is above a threshold value that is a simulation attribute. Continuous monitoring of beacon signal strengths from available satellites ensures correct operation of Pointing, Acquisition and Tracking (PAT) subsystem on-board the ISS. The ISS-MEO handoff modules perform handover of the ISS transmit antenna. Based on the received signal strengths, the ISS_antenna_to_sat is handed off between satellites. Handoff on-board the ISS is performed as hard handoff (break-before-make). ISS_once_proc is responsible for initializing state variables, model attributes and process attributes, and maintains the integrity of the node model over multiple simulation runs.

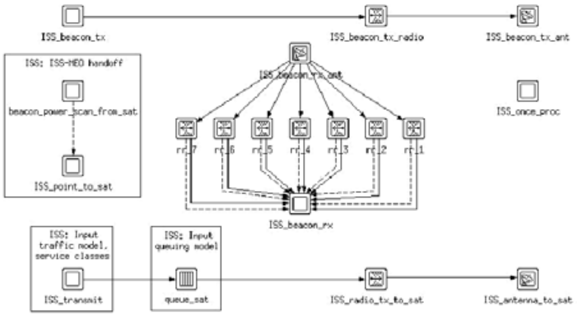

Fig. 2. ISS Module

There is a need to develop a protocol layer structure that will allow us to support multiple services in addition to the present file transfer -- video, long-duration connections, multicast, high-priority data, etc. Protocol support at ISS will ensure that QoS requirements are met for each service type. Complex input traffic models will be developed later to model the distribution of different service applications.

MEO Satellite Module: The MEO network is currently made up of 7 satellites, capable of OBP activity: queuing, routing and handoff. Each satellite maintains continuous connections with its two adjacent satellites, and all 7 satellites form a ring in equatorial orbit at 9000 km. altitude. The meo_point_to_meo module checks and maintains the connections between adjacent satellites. Each MEO satellite has multiple transmit-receive pairs to adjacent satellites, the ISS, and the three ground stations.

When a satellite receives a packet, it identifies it as belonging to commercial or ISS traffic. Commercial traffic is fed into the meo_pk_queue while traffic to or from the ISS is received in the iss_pk_queue. A FIFO queuing discipline is used but later additions to this model will include a priority-based queuing scheme based on QoS specifications for packet streams.

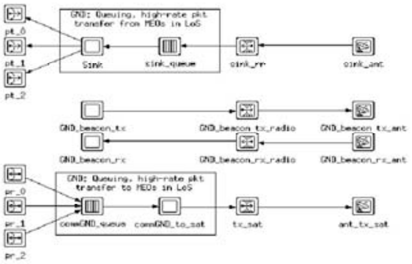

Fig. 3. MEO Satellite Module

The meo_proc processing module then performs shortest-path routing and forwards the packet to next-hop satellite or destination ground station. This is done based on the value in the "destination address" field. From the destination address of the end-user terminal, the satellite determines the closest ground station to the terminal. Continuous location monitoring allows the satellite to know if it is currently in line-of-sight of the destination ground gateway. If so, the satellite downloads the packet to the destination ground gateway. Otherwise, it forwards the packet to one of its neighboring satellites.

Ground Station Module: The simulation model currently has 3 ground stations that continuously monitor the movement of the MEO satellites to ensure correct PAT operation. Each GND station receives, from ground terminals, commercial traffic to be transmitted over satellite to other ground terminals. It also receives ISS traffic to be transmitted to ISS. GND stations also receive return traffic from the MEO network that is made up of ISS and commercial traffic. These packets are received by the sink_rr receiver module. Received packets are queued at the sink_queue to be transmitted to end-users. The sink processing module uses an impartial FIFO de-queuing scheme to remove received packets from the queue and send them to one of the three end-user terminals based on the packet's destination address. All three end terminals are connected to the ground gateway using point-to-point links.

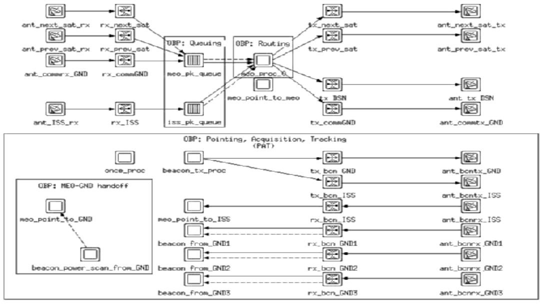

Fig. 4. Node model for GND station

Point-to-point links are also used to receive data packets from the end terminals. A simple queuing model is implemented at present, with intelligence to initiate high data rate transfer of queued packets to satellite during periods of visibility. The bandwidth is shared equally between ISS packets and commercial packets in the commGND_queue module. The commGND_to_sat module periodically checks for LoS to any satellite and initiates high rate transfer from the queue to the satellite.

GND_beacon_tx and GND_beacon_rx modules are responsible for the background beacon tracking operation to ensure that minimal number of data packets are lost due to small and rapidly-changing LoS windows at the ground gateway. The beacon mechanism logically links the ground gateway network with the MEO satellite network.

Advanced bandwidth allocation and queuing models could be used to partition available bandwidth between commercial traffic and ISS traffic, with the partition scheme being a test case.

Ground Terminal/Network Gateway Module: The network model shows 9 ground terminals that are connected to the 3 GND stations (three to each). These terminals can be considered to be network gateways to corporate/local/wide-area networks. Each terminal acts as a source and sink for data traffic to/from other terminals and to/from the ISS. The modules GND_gen and Sink perform these functions at the network end-user terminals.

A simple FIFO transmit queue is shared by both types of traffic. The receiver queue at network gateways performs segmentation/reassembly, MAC-layer packet sequencing, and duplicate packet detection and discarding. SAR operations are performed based on the packet's sequence number. Packet sequencing operations are carried out using an internal queue called the overflow queue, which stores packets that are received out of order. If a packet's sequence number is less than expected, it is discarded as a duplicate. If the sequence number is greater than expected, it is inserted into the overflow queue and the queue is sorted using a bubble-sort technique. The head of the overflow queue is then checked to see if it is the packet with the expected sequence number. This operation is performed in the sink_queue process model.

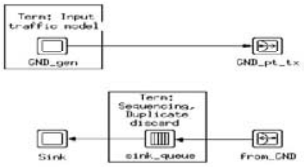

Fig. 5. Model for ground terminal/network gateway

Improved traffic models are planned at transmitters to model multiple traffic types for different service classes and QoS requirements as well as IP (or other network-layer) protocol and basic TCP implementation to provide support for end-to-end QoS guarantees for multiple services.

B. Simulation Model Components-GEO Constellation

In this case, model consists of similar four types of Modules described earlier. Satellite Module of GEO case however is much simpler as the network topology is very simple.

B. Preliminary Results & Discussion

Since we are dealing with a preliminary model at this early stage, we are not yet able to run detailed end-to-end performance simulation runs, so the information we can get a this stage is limited. However, we are currently able to look at some proof of concept runs and verify the correct operation of the different components in the network.

Fig. 6, plots the queue length over a fixed time interval over selected satellites. It shows the variation in load of each satellite. Note that the load on each satellite in this simulation model will converge to the mean over multiple revolutions. Over a single revolution the values will not converge, as the orbital period of the ISS is not a multiple of the orbital period of the MEO network.

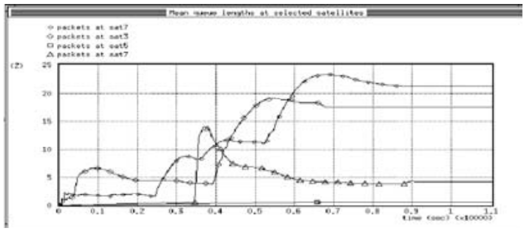

Fig 6. Average OBP-queue lengths at MEO satellites

C. Coverage Analysis

We next turn or attention on some preliminary coverage analysis for two different constellations, using Orblink as the example for the MEO case and Spaceway [4] as the example for a next generation GEO commercial system. The following assumptions apply to the two scenarios we investigate, using the Satellite Tool Kit (STK) package. Satellite antenna is fixed (pointing nadir)-

- Line-of-sight is assumed for access at the satellites (no elevation angle or other constraints are placed on the satellites)
- "complete chain access" means the total time during which any object within the first element in the chain has access to any object in the next and sequential elements in the chain.

It is important to note that these represent the final implementations of the complete constellations as they were described in recent FCC filings. These systems are under development and are undergoing significant changes, and will probably be implemented in several phases. The analysis presented here is only used to demonstrate the methodology and a frame of reference; a detailed modeling of a lot of proprietary details of the final designs needs to be used for a realistic evaluation of the suitability of these systems for this service. We also like to point out that systems that reach an arrangement with NASA to support mission communications will probably accommodate design modifications that would allow them to focus on this task and meet the required quality of service and coverage.

We consider a system consisting of the ISS, Spaceway (GEO), Orblink (MEO) and Ground Stations at Fairbanks, Weilheim, Sioux Falls, McMurdo, Svalbard, Wallops. We assume:

- Tracking ground antennas (targeted on constellation)
- Variable elevation angle
- Fixed cone angle
- Fixed satellite antennas

For the case in which the antennas on the ground station are allowed to rotate and track the commercial satellite during the period which there is acquisition, the antenna by definition moves as to maintain the satellite along the boresight of the antenna. In this situation, the cone angle of the ground antenna is not important; for as long as the center of the antenna has line of sight to the satellite, there is contact. The minimum allowable elevation angle, however, will directly restrict the amount of access obtained. In this scenario, the minimum elevation angle constraint was varied from 0 to 40 deg, and the duration when there is a complete link between the ISS to the commercial constellation to one of the ground stations within one day was calculated.

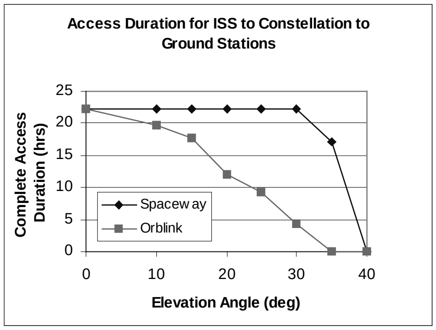

Fig. 7. Access Time Duration Vs Elevation Angle

As can be seen from the graphs and as discussed earlier, constellations with higher altitude will generally have better coverage. In this case, the distribution of the facilities were such that the total duration did not vary until a certain elevation angle, at which the duration drastically drops. We see the interesting properties of having two constellations that are both equatorial, but differ by altitude.

III SUPPORT FOR OTHER MISSIONS

We next turn our attention on an initial study on the coverage issues that need to be addressed in a varity of other near earth typical missions in various altitudes and inclinations. We investigate the use of three proposed satellite constellations for this purpose:

Spaceway: The Spaceway (final) constellation consists of 20 geosynchronous satellites in 15 longitudinal positions[4]. The constellation is designed to provide coverage over populated land areas, so the longitudinal positions of the satellites are not evenly distributed, and instead are chosen to provide more land coverage. The instruments on the satellites in actuality consist of 183 spot beams with a 1.5º field-of-view per beam. Because each satellite is stationary relative to the earth, each beam can be individually pointed to target certain areas on the earth. Because information on the pointing of each individual beam is currently not known, we approximate them with one conic sensor on each satellite with a 7º half-cone angle pointing nadir (towards the center of the earth).

Astrolink: The Astrolink constellation consists of 9 geostationary satellites in 5 orbital positions. For this analysis, only the satellites with the 5 unique orbital positions were used. The antenna is assumed to have a 5º half cone angle pointing fixed at the center of the earth.

Orblink: The Orblink constellation consists of 7 satellites at an altitude of 9,000 km following an equatorial orbit (zero degree inclination). This constellation is approximated in this analysis with an even distribution of satellites around the equator. The antenna on each satellite is assumed to have a 24º half-cone angle pointed towards the center of the earth.

D. Static Coverage Analysis

For each satellite constellation, static coverage analysis was performed by fixing an arbitrary moment in time, and determining the percentage of the earth that has access to one or more of the commercial satellites. This analysis was then repeated for space mission altitudes of 0 km, 300 km, 400 km, and 700 km. Generally, reduction in percentage of coverage is seen with increasing altitude. Figure 8 shows the differences in coverage for the three constellations at 400 km – Spaceway and Astrolink have spotty coverage because of the uneven distribution of the satellites around the equatorial plane.

E. Dynamic Coverage Analysis

This analysis shows the dynamic geometric coverage as the NASA user satellite and commercial satellite constellation are both moving over a period of time. Results are obtained by running the scenario for a 10-day period at 60-second step sizes. One continuous coverage is defined as the period of time that the NASA satellite is in field-of-view with one or more of the sensors on the commercial satellites. Repeated trials were performed for each commercial constellation, with varying cases for the NASA user satellite.

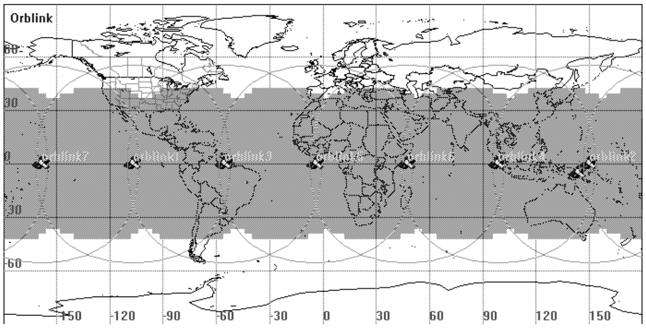

Fig. 8a. Coverage by Orblink at 400 km (65.3%)

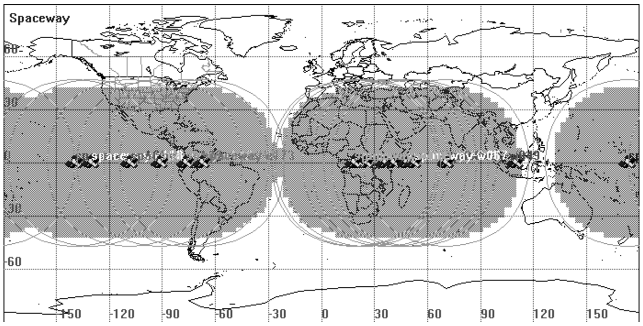

Fig. 8b. Coverage by Spaceway at 400 km (57.7%)

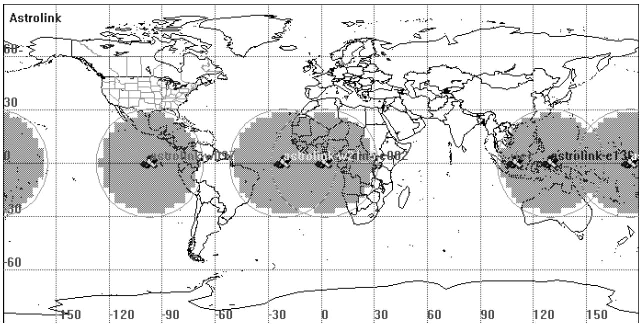

Fig. 8c. Coverage by Astrolink at 400 km (25.6%)

Figure 9 shows the percentage of coverage duration available from the user satellite to each constellation over a 10-day period. The satellite is first varied in altitude from 300 to 700 km at a constant 28.5 deg inclination, then varied from 20 to 60 deg inclination at a constant 500 km. The analysis shows that the inclination of the satellite affects the coverage much more than the altitude, and that the Astrolink constellation has poorer coverage than Spaceway and Orblink. These results can be translated to the types of services that can be supported and the maximum durations of these services, based on the coverage duration, as well as scheduling of services based on the mission location with respect to the satellite constellation and the ground.

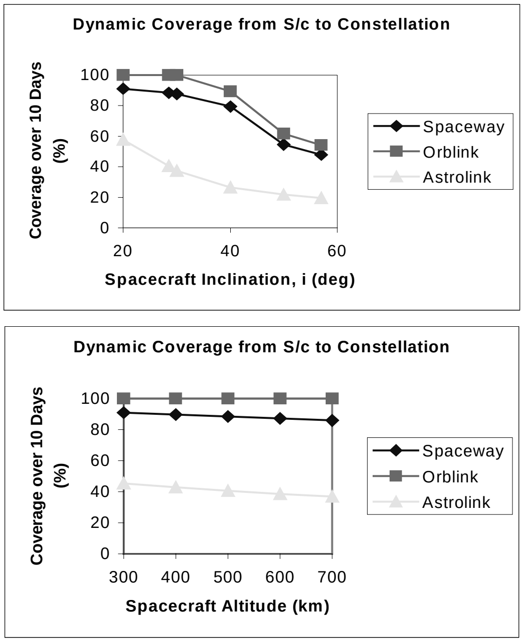

Fig. 9. Effect of mission altitude and inclination on coverage

IV. SUMMARY & FURTHER WORK

We are developing a methodology and a large-scale simulation model to evaluate the feasibility of carrying NASA mission traffic using proposed commercial satellite constellations. The simulation model will allow us to perform detailed studies to quantify the performance of satellite systems for the following test parameters: specific services and their QoS requirements, protocols, traffic models, satellite routing schemes, on-board bandwidth/buffer allocation methods, queuing disciplines, and handoff strategies. We have explained some of the features of the present models. The next major steps in this work will be in modeling the data services and statistics of the traffic that must be supported as well as the protocol modifications that will allow these services to be supported.

ACKNOWLEDGMENT

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