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LEO Satellite Communication Through a LEO Constellation Using TCP/IP Over ATM

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ABSTRACT

The simulated performance characteristics for communication between a terrestrial client and a LEO satellite server are presented. The client and server nodes consist of a TCP/IP over ATM configuration. The ATM cells from the client or the server are transmitted to a gateway, packaged with some header information, and transferred to a commercial LEO satellite constellation. These cells are then routed through the constellation to a gateway on the globe that allows the client/server communication to take place. UBR (unspecified bit rate) is specified as the quality of service (QoS). Various data rates are considered.

INTRODUCTION

The motivation for this research arises from the desire to maintain continuous TCP connections between the NASA terrestrial base, which is the client, and the server on a NASA LEO satellite, regardless of its position over the globe. Two possible resolutions to the problem of global coverage can be considered. The first is the utilization of a number of GEO satellites. The power requirements and launch technology of GEO satellites causes them to be very expensive. Also, the delay involved in communicating across GEO hops is a concern.

A second, and more recent, alternative is the use of an intermediate LEO constellation to provide global coverage. LEO satellites do not have the power requirements of GEOs, and recent launch technologies have allowed LEOs to be positioned at a relatively low cost. Since LEOs are positioned at a much lower altitude than GEOs, much smaller transmission delays and atmospheric interference are experienced.

This paper investigates the use of a commercial LEO constellation as an intermediate network between a terrestrial client and a LEO satellite server. The client at the NASA base in Houston, Texas and the server on a NASA LEO satellite orbiting the Earth, in the same orbit as the Spartan 1, communicate using the satellite constellation [1]. The performance of TCP/IP over ATM between the client and the server are presented. Although current LEO satellite constellations are primarily intended for voice communications and have a low data rate, our intention is to examine them as potential means for providing TCP/IP over ATM communication between LEO mission satellites and terrestrial locations.

SATELLITE NETWORK

The constellation consists of 66 LEO satellites. These LEOs are capable of inter-satellite communication, as well as uplink and downlink ability. The frequency used for uplinks is 29.2 GHz and for downlinks it is 19.5 GHz. The satellites communicate with each other at 23.28 GHz. For all communications, quarternary phase shift keying (QPSK) is used as the modulation scheme. The satellites are in 6 orbits with 11 satellites in each orbit. The LEO constellation uses 12 gateways positioned globally, according to the current Iridium ground facilities [2].

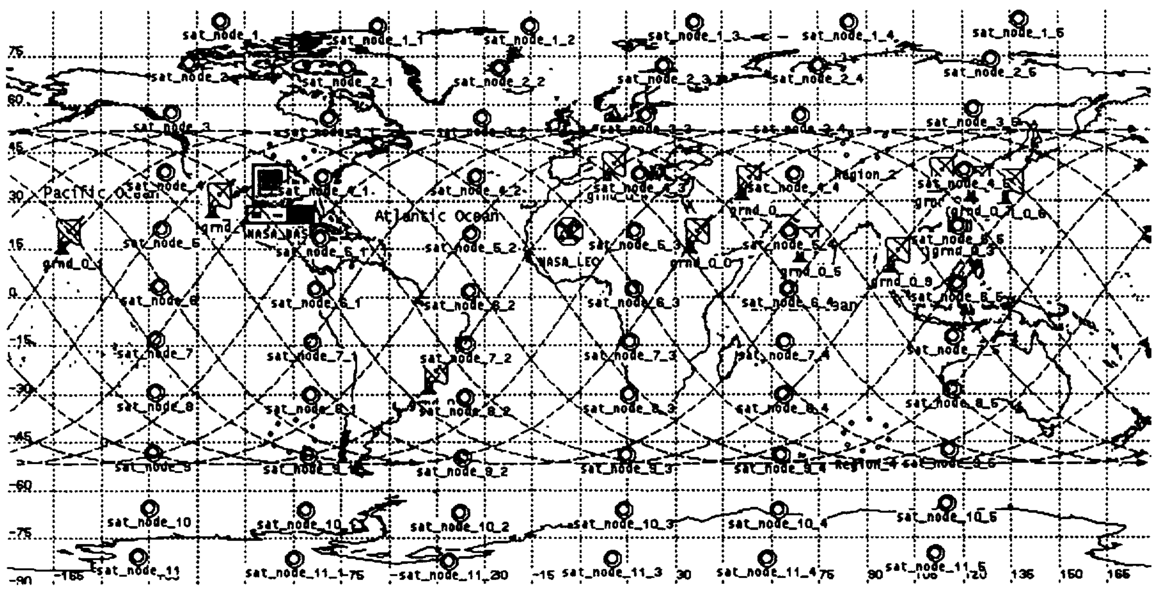

Figure 1

For the purposes of this simulation, the ground stations serve as bridges to and from the LEO constellation. The ground station located near Phoenix, Arizona is connected to the NASA Johnson Space Center in Houston. The overall network is shown in Figure 1. The smaller circular nodes represent the constellation of LEOs. The node represented by the satellite icon is the NASA mission LEO. The twelve terrestrial gateways are represented by receiver dish icons.

FUNCTIONAL DESCRIPTION

A brief overview of the flow of information between the client and the server is as follows.

The NASA base located in Houston, Texas serves as the client node and generates requests. The server resides on a NASA mission LEO satellite that is in orbit to collect mission-related data and transfers information to the NASA base upon request. Both the client and the server processes use a TCP/IP over ATM architecture. The QoS specified by both the client and the server is UBR only [3, 4].

The client generates requests, which are segmented into ATM cells (after IP segments the TCP information into IP datagrams) and transferred to the gateway in Arizona via an optical link. At that point, the gateway adds a few bytes of header information that will allow a traversal across the LEO satellite constellation. This information simply marks the source and the destination of the cells. The cells are routed to the constellation's gateway that is closest to the NASA LEO at that instant. The gateway receives the cells, removes the header information, and transmits the ATM cells up to the NASA LEO, where the ATM cells are reassembled into IP datagrams. The datagrams are then delivered to the TCP layer and on to the application.

The NASA LEO then processes the requests and transmits down to the closest constellation gateway. The gateway then adds the header information and transmits the cells to the LEO constellation. The cells are then routed through the network back to the gateway in Arizona. The header information is removed, and the ATM cells are transferred via the optical link back to the NASA base in Houston, Texas.

The simulation is modeled after a contributed model which is packaged with OPNET Modeler 5.1 [5]. The model, called sat_rte_example, illustrates a technique to subject a LEO constellation to traffic conditions. Additional processes were developed that allowed ATM cells to be effectively transmitted over a LEO constellation. Also, the routing method for the constellation was altered to transfer information across the network more efficiently. The result was a fully functional TCP/IP over ATM hybrid client/server network, which utilized an intermediate LEO satellite constellation.

NODE ARCHITECTURES

The simulation is based on five types of nodes, which are described in this section.

A. Client Node (NASA BASE)

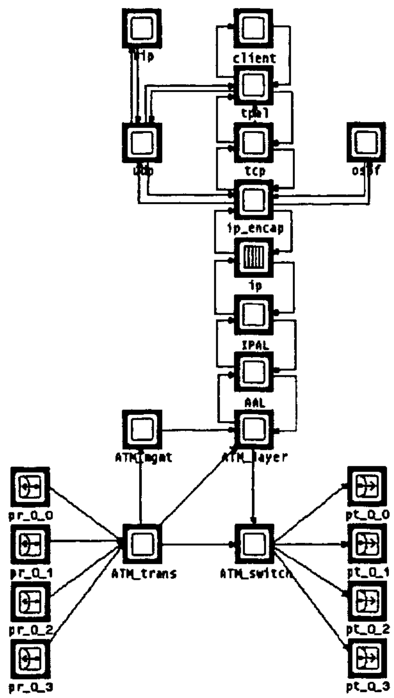

Figure 2

The client node consists of a client process over a TCP/IP over ATM protocol stack. The client process simulates the generation of requests for FTP transfers. The client requests 10 file transfers per hour, with a 50/50 mix of "get" and "put" operations. The average file size is 50,000 bytes. The QoS specified in this simulation is UBR. This QoS will best represent the type of traffic that the network will be subjected to.

B. Server Node (NASA mission LEO satellite)

The server node has the same architecture as the client node. The server process functions over a TCP/IP over ATM protocol stack. The server is configured to service FTP requests. The layers under the server process are exactly the same as those of the client node to ensure a virtual link between the client application layer and the server application layer.

C. Gateway Nodes (Excluding Arizona)

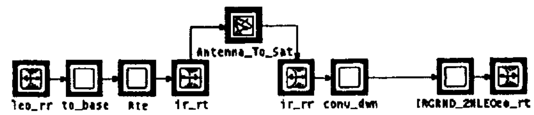

Figure 3

In addition to the gateway in Arizona, which is connected to the NASA base, there are 11 gateways that are capable of receiving and transmitting information to and from the NASA LEO satellite.

If ATM cells are received from the NASA LEO, then the gateways forward the information to the "to_base" process. This process finds the destination gateway (for these nodes the destination will always be the Arizona gateway), attaches the source and destination information to the ATM cells in the form of a header, and forwards them to the "Rte" process. The "Rte" process decides how the cells will traverse the constellation and then transmits to the appropriate LEO satellite.

Cells from the LEO network take different paths. Note that a gateway will only receive cells from the LEO network when it is the closest gateway to the NASA mission LEO. The cells come into the receiver and are forwarded to the "conv_down" process. Here the LEO network header information is removed, which results in the original ATM cell. The ATM cell is then sent to the "IRGRN_2NLEO" process, which finds the NASA mission LEO and communicates with it.

D. Gateway Node in Arizona

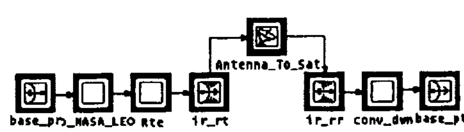

Figure 4

The gateway located in Arizona contains point-to-point and radio transmitters and receivers. If ATM cells originate from the NASA base, the cells are packaged with source and destination header and routing information, and are transmitted to the nearest satellite in the LEO constellation. Note that these cells will always be destined to the gateway nearest to the NASA mission LEO.

If, however, the ATM cells are received from the LEO network, the header information is stripped and the ATM cells are forwarded to the NASA base.

E. LEO Nodes

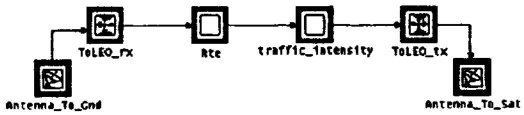

Figure 5

The satellite node is based on the contributed model, "sat_rte_example". Although it has the same structure, the routing is slightly different because it minimizes the number of hops across the LEO network.

The traffic simulation scheme is the same as the contributed model. The model applies a user specified baseline traffic load for various regions over the globe. The LEOs over the regions are then subject to this baseline traffic. The LEOs receive cells, decide whether the cells are to be sent to a gateway or forwarded to the next LEO, react according to the region's traffic condition, and then send the cells to the transmitter.

SIMULATION RESULTS

The simulation results are based on three different scenarios. In Scenario #1, there is no upper bound on the rate at which information is transferred over the LEO network. In Scenario #2, the data rate of the Iridium network (2400 bps) is used. In Scenario #3, the transfer rate of the Globalstar network is used, since it has the next higher data rate among LEO constellations, with a baseline traffic introduced to the network [6].

All simulation results are for 6000 seconds, which is enough time for the NASA mission LEO to orbit the Earth once.

A. Scenario #1 (Unlimited bit rate)

Since there is no upper limit on the rate of transfer over the LEO constellation and the network is not subject to any outside traffic, the transfer rate over the network is optimized. The performance of the FTP service over the client/server connection can be represented by the flow of FTP traffic between the source and the destination.

Figure 6 shows the FTP traffic sent from the client application, and Figure 7 shows the FTP traffic received at the server in bytes/sec.

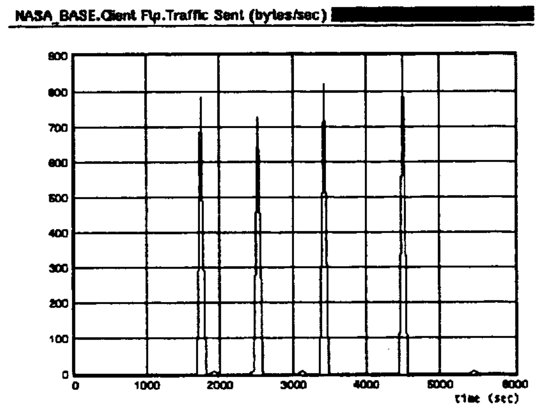

Figure 6

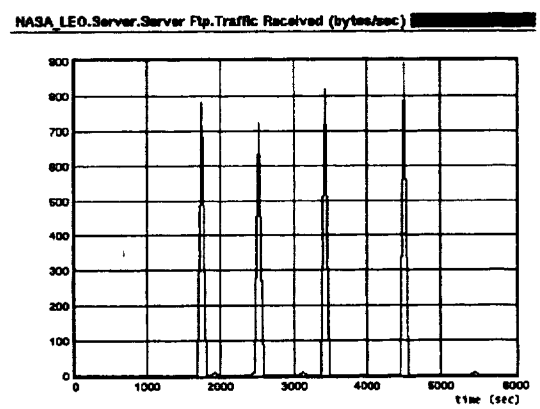

Figure 7

As seen from Figures 6 and 7, the FTP traffic sent from the client is received intact at the server with only minimal delay, indicating that the simulation model is valid.

The delay between the source and destination ATM layers can be observed by monitoring the flow of UBR cells. Figure 8 depicts the delay experienced by the ATM cells from the server to the client.

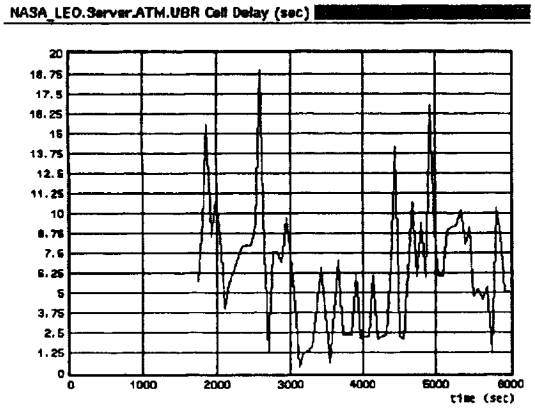

Figure 8

The variations in cell delay are due to the changing communication paths. Also, the major delay points occur when the NASA mission LEO is over regions of the Earth that do not contain terrestrial gateways.

The end-to-end delay for TCP segments between the peer protocols is shown in Figure 9. This delay is for the traffic from the NASA LEO server to the NASA client base.

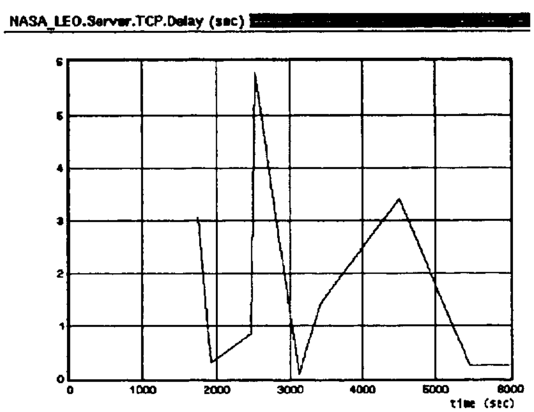

Figure 9

The major delay spike corresponds approximately to the point in time when the NASA LEO passes over the South Pacific Ocean. In this simulation there are no gateways located in this region, resulting in this large delay.

Overall, the network performed as expected. After the TCP connection was initiated, delays were experienced over regions without terrestrial gateways. Since there is no other network traffic involved and there is no upper limit on the transfer rate, the data is transferred between the client and the server with little delay in other regions.

B. Scenario #2 (2400 bps)

This scenario specified an upper bound on the transfer data rate over the LEO network that is equivalent to that of the Iridium constellation (2400 bps). Although there is communication between ATM peer processes, the network did not allow a TCP connection to be established. This is most likely caused by the processing delays involved with the changing network topology and the TCP/IP over ATM architecture. No simulated data is reported for this scenario due to the insufficient data rate.

C. Scenario #3 (9600 bps with network traffic)

This scenario introduces background traffic conditions to the LEO constellation which change relative to the geographic regions of the globe. It is probably more representative of TCP/IP over ATM connections implemented in first-generation LEO satellite constellations.

Figures 10 and 11 show the FTP traffic transmitted by the LEO server and received by the NASA client base, respectively. In contrast to Scenario #1, the data rate limit causes significant delay and loss from end to end.

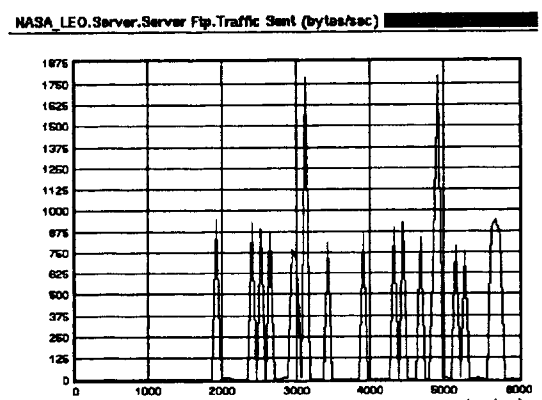

Figure 10

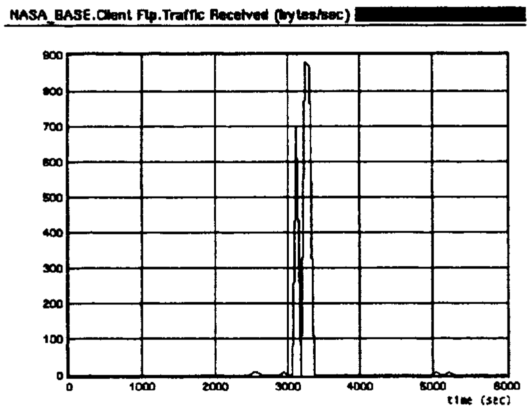

Figure 11

The UBR cell delay for the ATM layer from the LEO server to the terrestrial client is shown in Figure 12.

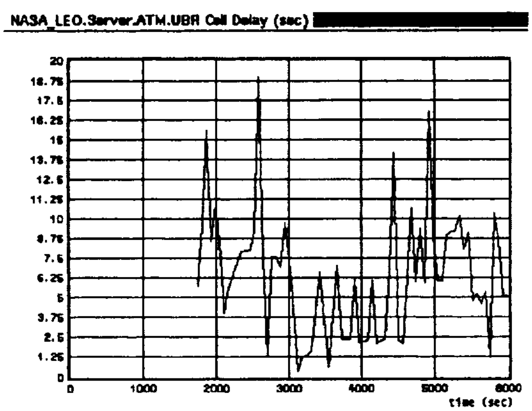

Figure 12

The end-to-end delay for TCP traffic between the LEO server and the terrestrial client is shown in Figure 13.

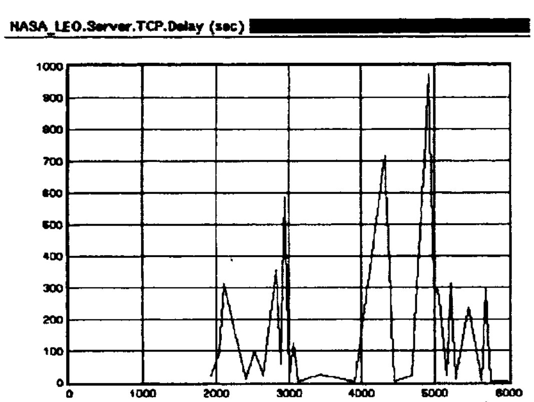

Figure 13

Due to the 9600 bps data rate, the background network traffic, and the changing topology of the LEO satellite network, significant delays are experienced.

CONCLUSIONS

Two conclusions can be drawn from this research. First, the data rate of the LEO constellation is the most limiting aspect of the network. This research determined that a 2400 bps data rate does not provide sufficient bandwith to support the UBR QoS; however, a 9600 bps transfer rate will just support the UBR QoS. Second, a LEO satellite can communicate with a terrestrial base, utilizing a LEO constellation, with performance characteristics that are acceptable given the limitations imposed by the network.

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