TECHNICAL RESEARCH REPORT

A Simulation Study of Enhanced TCP/IP Gateways for Broadband Internet over Satellite

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A Simulation Study of Enhanced TCP/IP Gateways for Broadband Internet over Satellite

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Abstract

The demand for Internet bandwidth has been growing rapidly over the years and the use of high bandwidth satellites has been proposed as one possible solution to meet the increasing demand. However, there are certain performance problems with providing Internet over satellite due to the nature of TCP/IP protocol suite and the satellite link characteristics. In this paper, we describe a simulation study of an architecture for improving the performance of TCP/IP over satellite links. On each end of the satellite link, there are gateways that split the TCP connection so that the satellite link is transparent to the end hosts. The the split TCP connection over the satellite segment is then optimized. TCP congestion control is maintained on each segment of the split connection. We simulated such an architecture in OPNET and present results showing improved throughput over the satellite link.

INTRODUCTION

Various architectures have been proposed for providing Internet over satellite service. The first model is one in which each downlink is an end-point of the network. In this kind of a network, the satellite link is the edge of the network [1] [2]. Therefore the network service providers have the freedom to improve performance of the system, by making any modifications/enhancements without regard to conformace with the rest of the Internet community. In the second model, the satellite link lies in the middle of the network. This architecture imposes tighter constraints on any proposed modifications to the basic protocols being used in the network because though such changes may improve the performance of the satellite component, it might also adversely affect the rest of the network.

In this paper we consider the second model. As shown in Figure 1, the satellite link logically lies between two segments of the internet and passes data transparently from one to the other. In

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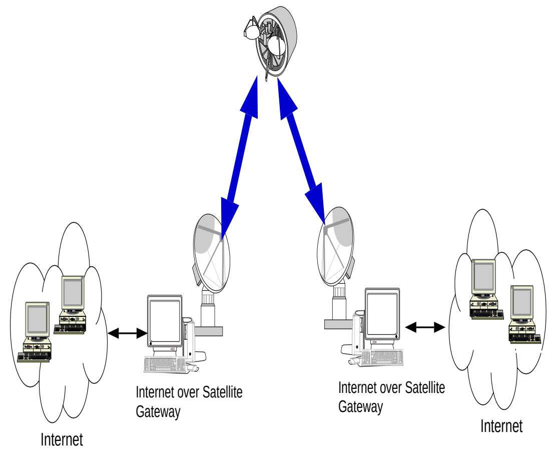

Figure 1: Network Overview

particular, we examine one specific aspect of the Internet over satellite system, namely, the design of the groundstation gateways. The gateways main function is to hide the effects of a satellite link from the rest of the internet. Additionally, gateways can also perform local optimizations between the earth stations(the gateways) to enhance performance.

We claim that such gateways are essential in building a high performance Internet over satellite system. The introduction of the high bandwidth delay product satellite link into a network, using protocols primarily designed for terrestrial networks, creates significant performance degradation. To alleviate this problem, possible solutions include redesigning protocols for high delay bandwidth product links, or the use of proxies and gateways at the edges of such links. We adopted lthe later approach to design special gateways at the edges of the satellite links.

In section 2 we describe the various OPNET components we used in our simulation study and any modifications/enhancements we had to make to them. In section 3 we discuss our simulation architecture and the performance criteria of interest to us in this study. Section 4 describes our simulation results. In section 5 contains our conclusions from this study as well as outlines our future work.

GATEWAY COMPONENTS AND OPNET IMPLEMENTATIONS

The network architecture we are simulating is shown in Figure 1. It consists of two LANs connected across a satellite link via gateways. The gateways are responsible for making the satellite link transparent to end users of the network. These gateways have been enhanced to contain a TCP module which is not present in most routers. Unfortunately, this additional gateway functionality also translates to certain reduction in the speed at which it can process packets. However, our simulation results in the next section justify the advantages of this approach even at the the cost of higher processing delays.

The enhanced gateways, not only implement the standard TCP enhancements proposed in

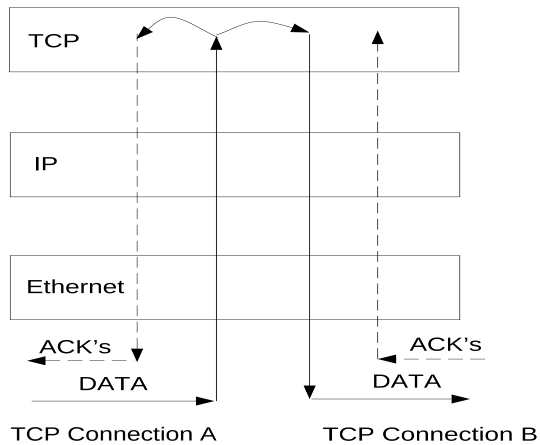

Figure 2: Connection Splitting Implementation

RFC1323 and RFC2018 [3] [4], but also implement TCP Connection Splitting. In the following sections, we will describe our OPNET implementation of the TCP enhancements, as well as our implementation of TCP Connection Splitting.

TCP Enhancements

We implemented the fast retransmit, fast recovery, large windows, SACK and FACK TCP enhancements in TCP model in OPNET. These implementations are described in greater detail in [5].

TCP Connection Splitting

TCP connection splitting has been shown in [6] to provide significant benefits for TCP over satellite. It is conceptually illustrated in Figure 2. The end-to-end connection between end-hosts is split into seperate TCP connections, from end-hosts to gateways, and in between the gateways. It is the responsibility of implementations of TCP connection splitting to ensure that the end-to-end semantics of TCP are maintained. We follow the process flow diagram and description specified in [6] for the purposes of our OPNET implementation. Due to the close mapping between OPNET TCP state diagram specification and real TCP state diagram representation, the task of mapping a linux implementation in [6] to OPNET is greatly simplified This requires modifications to both the IP and the TCP implementations in OPNET.

Packet flow through our modified router is shown in Figure 2. A correct implementation of connection splitting requires that changes be made in three different process models in the OPNET router node model, in the TCP, IP_RTE and the IP_ENCAP process models.

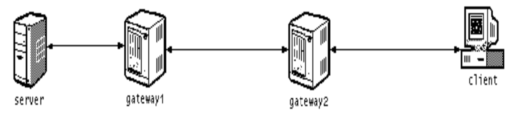

Figure 3: Simulation Architecture

A basic IP router is first enhanced by adding a TCP module to it. Then the IP layer modules are modified so that it passes all packets up to the TCP layer. The TCP layer then performs the connection splitting functionality, by generating an ACK for the received packet, as well as forwarding it to the next segment of the split connection.

The modifications in the TCP layer that support connection splitting include correct connection setup, data transfer, as well as connection closing.

Both the modifications at the IP layer as well as at the TCP layer are provided as attributes which can be enabled and disabled for the purpose of simulation studies.

SIMULATION ARCHITECTURE AND PARAMETERS

We implemented the components described in the previous section in OPNET5.1. The TCP enhanced gateway model is built by adding the TCP module to an existing router model. In addition, we also made changes to relevant process models to achieve desired functionality. Special care was taken to ensure that the modifications to the code were such that simulation attributes could be used to enable/disable the functionality as desired in order to simulate the different simulation scenarios.

The base network model we used is shown in Figure 3. The link between the two gateways has a data rate of a T1 link. A unidirectional delay of 250ms is added to the link when simulating a satellite link. In the cases where the large windows option has been used, the recieve TCP buffers are configured to 195K(default is 64K). This value is chosen as it equals twice the bandwidth-delay product (2*(1.5M(bw)*0.5(rtt)). The window scale factor chosen is 3. In all cases a ftp file transfer is studied. A 50M file is transferred from the server to the client.

We study four simulation scenarios: terrestrial network, satellite network without enhanced gateways, satellite network without enhanced gateways but with large windows used end-to-end, and finally satellite network with enhanced gateways.

The performance criteria of interest to us in this study were:

- aggregated throughput rates on the satellite link
- round-trip time computation by end hosts

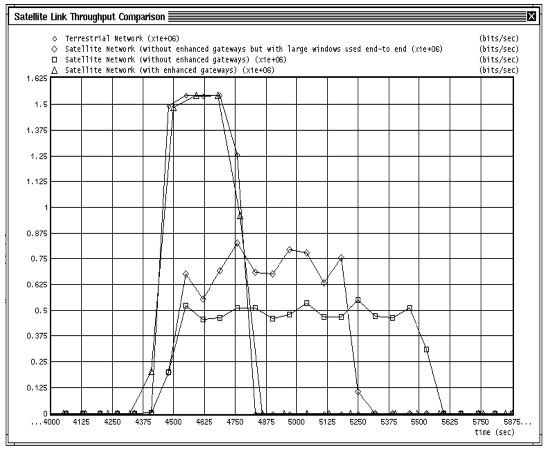

Figure 4: Satellite Link Throughput Comparison

- file download response time seen by clients
- the ability to optimize the satellite link independent of the options used by end-hosts
- increase in load on the routers due to the additional functionality

To compare performance results simulations were run for each of the four scenarios.

SIMULATION RESULTS

In this section we present and discuss simulation results obtained from the Internet over satellite system described in the previous sections.

Satellite Link Utilization

One of our primary performance criteria was the throughput on the satellite link. Figure 4 shows relative performance of different simulation scenarios. The throughtput was measured on the link between two gateways. In the terrestrial case there was no delay on that link, therefore throughtput was high(close to the capacity of the T1 link). When a 250ms delay was introuduced on this link the observed throughtput dropped to 500Kbps(about a third of the capacity of the T1 link). When the large windows option was introduced on the client and server, the observed throughtput improved to 800-900Kbps. Finally connection splitting was enabled on two gateways, and the large windows option was used just between them. In this case the throughput on the satellite link was again close to the capacity of the T1 link. This clearly shows the benefit of connection splitting and the use of TCP enhancements on the satellite gateways.

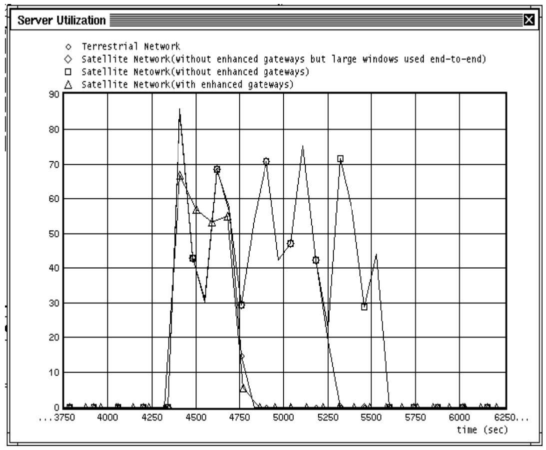

Figure 5: Server Utilization Comparison

File Transfer Rate from Server(Server Utilization)

One issue of interest is the impact that the introduction of satellite gateways in the Intenet may have on the rest of the Internet. In our simulation model, this translates to the impact on the server and the client. Figure 5 shows the server utilization, which is defined as percentage of time for which the server has 100% utilization, for the different simulation scenarios. The shorter the time period for which the server is facing high utilization, the greater its ability to handle more traffic from other sources. Once again we observe that the terrestrial case and the case when enhanced gateways are used show similar utilization curves. They have the shortest duration when compared to the cases when enhanced gateways are not used. The use of enhanced gateways has made the satellite link transparent to the server in terms of utilization.

Round Trip Time Measurements

The performance of TCP is highly sensitive to the measured round trip time. This is the primary reason why TCP performance suffers when a satellite link is part of the network. Figure 6 shows the round trip time measured by the server for different simulation scenarios. In the simple terrestrial case it is close to 150ms. In both cases when the gateways are not used, the presense of the satellite link causes the round trip time to increase to be slightly greater than 500ms. However, when the enhanced gateways are used, the round trip time measured by the server is only 75ms. This implies that the use of the enhanced gateways has removed the negative impact of the satellite link in TCP performance. As the observed round trip time measured by both the server and the client is short they also recover faster from packet loss.

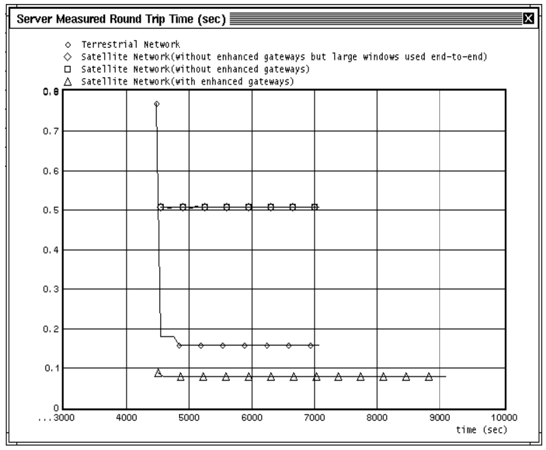

Figure 6: Server Measured Round Trip Time Comparison

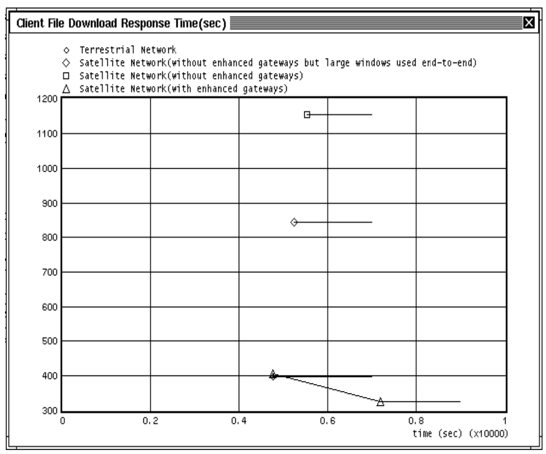

Figure 7: Client File Download Time Comparison

Client File Download Response Time

The file download time is the ultimate user observable criteria. Figure 7 shows the file download response time for different simulation scenarios. As a result of the higher throughput on the satellite link when enhanced gateways are used, we see that the file download time observed by the clients is almost 3-4 times shorter than the case where the gateways were not used. It is 2-3 times faster than the case where large windows was used end-to-end.

Discussion on TCP enhanced gateways

All our results demonstrate the advantages of using TCP enhanced gateways in a network which includes satellite links. The disadvantage of such a scheme is the increased load on the IP layer on the gateways. With our modification, each packet passes through the IP layer twice, to and from the TCP layer. This may cause incoming packets to be dropped and queues to overflow on the gateways. Therefore it is essential that the such an enhanced router have enough processing speed. On the other hand, we can also make the upstream sender slow down when packets are queued via advertised receive window. Currently we are studying the flow control problem inside the gateway.

CONCLUSION AND FUTURE WORK

In this paper we presented our simulation results for an Internet over satellite system using enhanced TCPIP gateways. We showed how the use of such gateways can make the presence of the satellite link transparent to the rest of the Internet. We also showed comparisons with and without the enhanced gateways. Our results shows better throughput, shorter measured round trip time and shorter file download time when gateways are used.

The results presented in this paper constitute our first set of simulation results required to validate our OPNET models. We are currently working on a more thorough simulation study of our proposed Ineternet over satellite system. This will involve adding several client/server networks to the same gateways as well as the use of more realistic traffic such as http and email along with ftp data.

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