DATA COMMUNICATIONS PROTOCOL PERFORMANCE ON GEOSTATIONARY SATELLITE LINKS -- LESSONS LEARNED USING ACTS

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Abstract

The ACTS system has provided the opportunity to closely study the operation of various data communications protocols at speeds of up to 1.536 Mbps (Megabits per second). We performed performance measurements using the TCP/IP protocol suite, particularly the application layer implementations of FTP. In a separate experiment we studied the SNA/SDLC protocol in Normal Response Mode. Our observation of TCP/IP confirms the need for an expanded window size in the flow control mechanism; we also observe that the "Slow Start" algorithm defined in TCP for congestion control purposes plays a significant role in limiting the throughput achievable with TCP/IP. We further report on strategies designed to overcome these protocol limitations without modifications at or below the transport layer. Our study of SDLC suggests a response time degradation of at least two round-trip delay times when a terrestrial circuit is rerouted over the geosynchronous satellite link. Our results permits network designers to assess the applicability of satellites to disaster recovery situations (were some response time degradation is both expected as well as accepted). These results also point towards a series of steps that can be taken to improve the performance of predominantly terrestrial protocols over satellite links.

Introduction

Over the past two years, the ACTS system has been used in numerous detailed experiments and short-term demonstrations, using voice, video conferencing, and a multitude of data communication protocols. We have performed two set of these experiments[1, 2], examining the SNA/SDLC and the TCP/IP protocol families. The operation of the ACTS system has confirmed that its interfaces adhere to the standards they were designed for, and that the physical layer properties of the satellite channel are sufficiently well behaved to make it unnecessary to insert satellite specific transmission devices, translators, or buffers.

The two protocol families investigated here are very important for the business community. TCP/IP is of course well known to Internet users, and has become accepted as the protocol of choice for interconnected LANs, whether or not an Internet connection exists. SNA remains a mainstay of transaction-oriented networks. Business applications of satellite channels will likely involve one or both of these protocols.

ACTS and its commercial successors therefore promise an environment where satellite channels can be easily inserted into primarily terrestrial networks , for backup or recovery purposes or as operational links to otherwise unreachable remote areas. In such an environment new challenges arise. The overall performance of a protocol family and its applications are affected by the characteristics of a satellite channel, especially if these applications and protocols have been tuned for terrestrial operations. All satellite channels exhibit higher bit error rates than typical fiber runs. In addition, geostationary satellites create substantial latency on the channel. One-way delays on a geostationary links are about 250msec.

This paper is intended as a summary of the published work on SNA/SDLC and TCP/IP studies on ACTS. We show the main results of these studies in the next two sections. We then discuss the performance measures which are central to performance at the end-user level. Finally, we identify the protocol components which most affect performance.

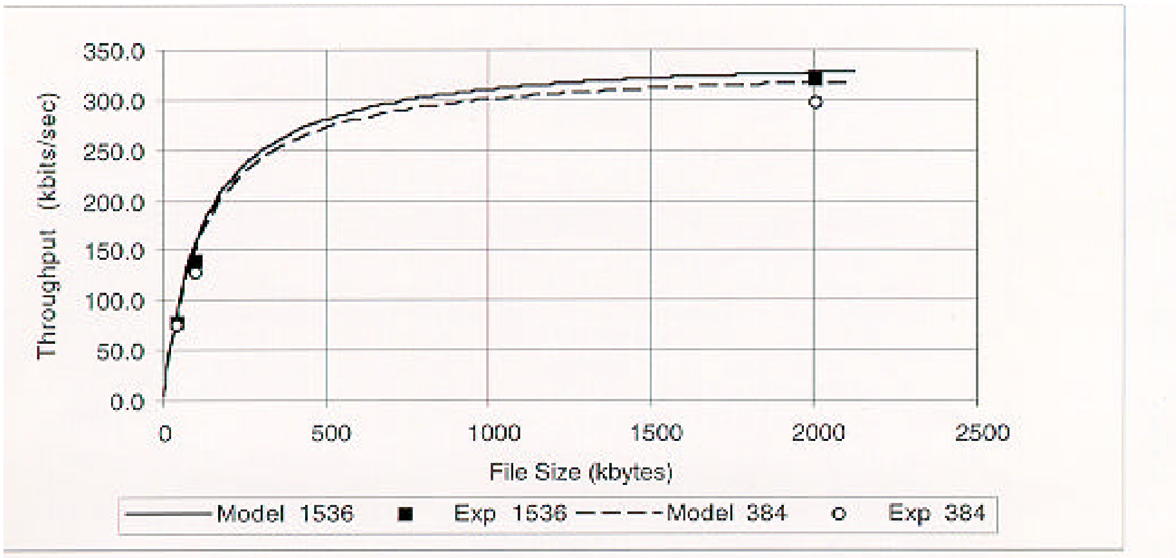

Figure 1: Summary the experimental results obtained for the transfer of various size files at channel speeds of 1.536Mbits/sec (full T1), and 384kbits/sec. Performance is shown as throughput obtained for the transfer of each type of file. Also shown are the results of a model which incorporates the flow control in TCP (a 24KByte sliding window) and the slow start congestion control mechanism.

TCP/IP Performance

To study the TCP/IP, we used ACTS to provide a fractional T1 link between two IP routers. The bandwidth of the link was varied from 64kbps to 1.536Mbps. Each router supported one directly attached 10Mbps ethernet network. Workstations on these ethernet networks were used as clients, servers, and diagnostic tools. The application used for the tests was FTP, for transfers of files between 500KBytes and 10MBytes. Using this configuration allows us to probe various aspects of the TCP transport layer protocol.

Figure 1 shows a summary of the results from our initial study[2]. Experimental throughput is shown as a function of the size of the transferred file. Results for two different channel speeds are shown. Note that there is almost no performance improvement between a 384kbps channel and a full T1. In addition, the performance for small files is substantially poorer than for larger ones. The figure also includes results from a model which incorporates the sliding window flow control and the slow-start behavior of TCP[3, 4]. The reasonable agreement between this simple model and the experiments points to these two factors as the main contributors to the poor performance.

It is important to realize that the performance of the FTP application is being determined by transport layer mechanisms, in this case those incorporated into TCP. A transport layer protocol is not accessible at intermediate nodes (without using a very complex application-level gateway). Therefore, although the satellite channel is indirectly causing the performance degradation, a “fix” cannot be implemented at the link level. An overall change in the protocol is needed. This will of course also affect the terrestrial network. Such protocol changes will therefore be slow since extensive testing will be required.

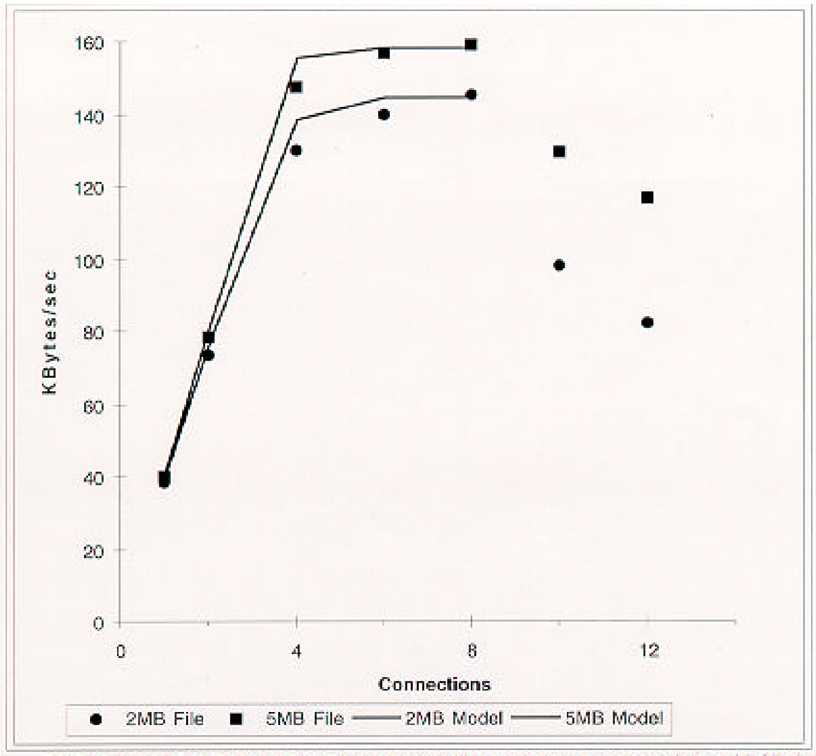

Figure 2 — Performance of 2Mbyte and 5Mbyte file transfers using varying numbers of TCP data

Figure 2 — Performance of 2Mbyte and 5Mbyte file transfers using varying numbers of TCP data connections. The symbols represent experimental measurements, while the solid lines are the result of a model calculation including slow-start, TCP window size, and multi-socket operation.

We have conducted further studies with a modification of FTP[5]. XFTP is able to use multiple TCP connections to transfer a file; this approach has been used by other ACTS experimenters as well[6]. The results prove that this type of protocol change can be very effective in improving performance of the satellite channels. Figure 2 shows the performance of XFTP over a full T1 connection. By using up to 8 TCP connections in parallel we can almost full load the T1 (the peak performance of the tests in figure 2 is about 90% of T1 capacity). Also shown is our model calculation which verifies that the multi-connection approach functions as expected. The reduction of performance past the 8 connection point is caused by packet loss in the routers. This points out the need for further study to insure that applications like this one behave predictably and reliably on terrestrial as well as hybrid (terrestrial/satellite) networks.

Our results further indicate that a careful study of the behavior of TCP and various suggested modifications is needed on satellite channel with non-zero bit error rates. Again, the performance impact of bit errors on the link is based on TCP operation at the transport layer. Different flow control, error recovery, and congestion control schemes will behave differently on satellite channels. Moreover, bit error performance can be changed at the link level by using forward error correction codes. In this case one trades bandwidth for reduced bit error rates.

SNA Performance

To study SNA operation[1, 7], we used ACTS to provide 9.6kbps and 56kbps circuits between a front end processor and one or more cluster controllers. Our test circuits contained a single controller, and a consistent script of transaction requests was used. In addition, we used ACTS to connect production circuits to the front end processor. The performance characteristics of these production circuits during terrestrial operation was well known, and could be compared with the satellite-based operation. The performance figure of merit for these circuits is end-user response time. Table 1 summarizes these results..

	Response Time (sec)
9.6kbps satellite circuit	1.50
56kbps satellite circuit.	1.55
9.6kbps terrestrial circuit.	0.48
56kbps terrestrial circuit.	0.37
Production circuit #9, 9.6kbps, during terrestrial operation .	1.64
Worst case response time for the case above	3.50
Production circuit #9, ACTS test.	4.94
Worst case response time for the case above	11.60
Production circuit #80, 56kbps, during terrestrial operation.	0.55
Worst case response time for the case above	2.40
Production circuit #80, ACTS test.	1.94
Worst case response time for the case above	13.30

Table 1 — Response time measurements on test and production SNA/SDLC circuits.

We note that the satellite test circuits show an increase in response time equal to about two round-trip delay times, consistent with the polling nature of the SDLC Normal Response Mode. [8] . We also observe that response time degradation is more pronounced in the production circuits with larger utilization.

In the case of SDLC, the performance impact of the satellite channel comes primarily from a data link layer operation. However, in a hybrid network with multipoint circuits, intervention even at this level would require changes in the architecture of the entire network. We also note that the SNA protocol stack incorporates handshake mechanisms at higher protocol layers which will impact overall performance. Finally, we want to point out that any response-time sensitive application will be negatively impacted by any channel with large latency.

Conclusions

Our studies suggest that satellite circuits are not necessarily transparent to the end user, even if they can be incorporated into the physical layer of the network without special adaptation equipment. Various protocol features at all levels of the protocol stack may be sensitive to the characteristics of a satellite channel.

For geostationary satellites, the channel latency, possibly combined with bit error rates that are higher than those of terrestrial channels, leads to two types of performance problems.

For some applications, such as on-line conversational systems, the channel latency cannot be overcome. The satellite channel will be a “last resort” choice for the user in these cases. In other cases, particularly the transmission of large amounts of data in a non-realtime context, satellite channels are a very good choice in principle. However, in these cases protocols must be studied carefully to determine their behavior on long latency channels.

Figure 3[9] summarizes various types of applications by there response time and overall throughput requirements. The lightly shaded area shows cases where protocol changes are needed to provide adequate performance. The darker shading shows areas which are inaccessible to satellite circuits due to the latency of the channel.

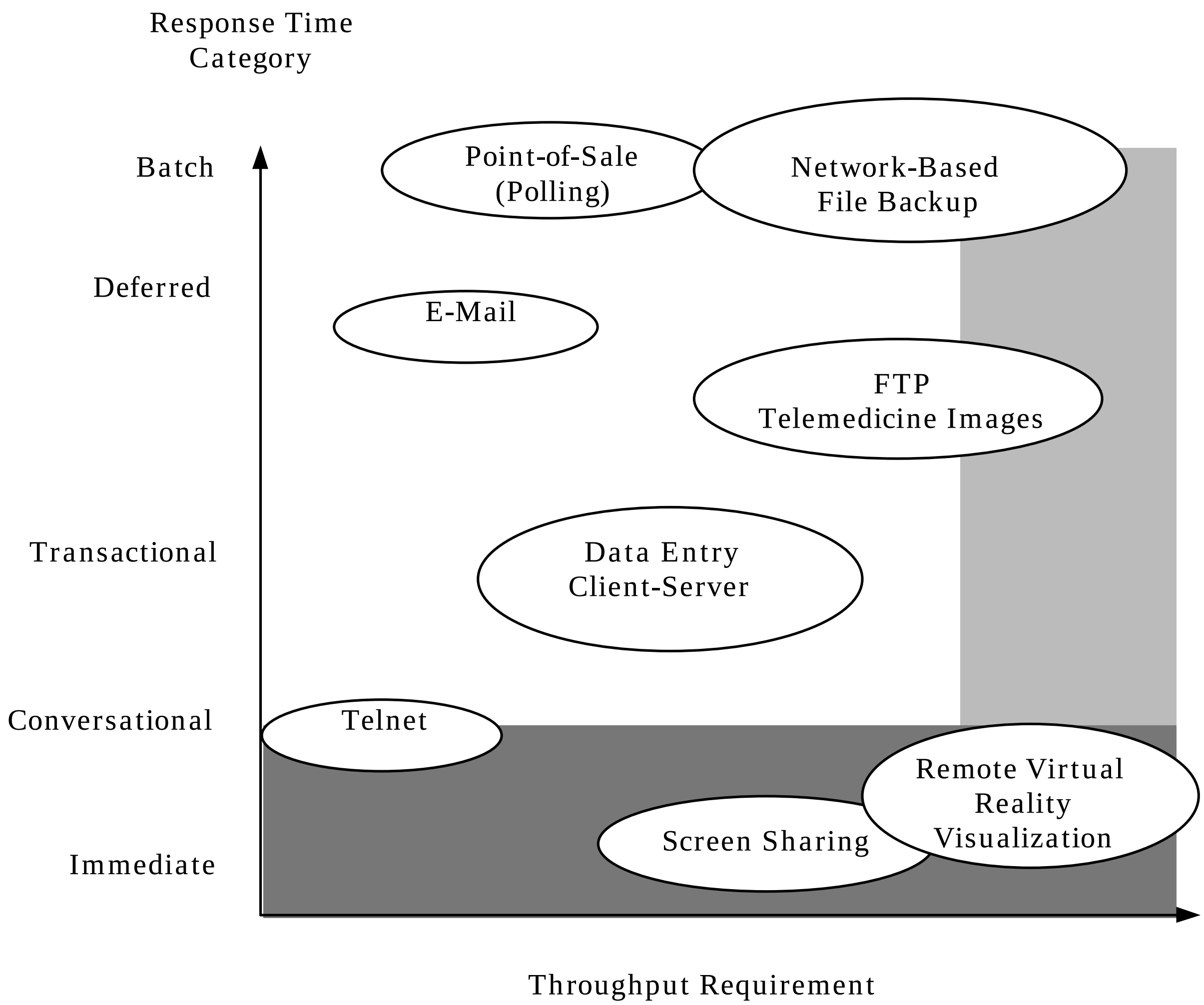

Figure 3 — Summary of throughput and response time requirements of various applications.

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