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Experimental study of channel delay impact on throughput performance of TCP and its extensions in space

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Abstract: Substantially long round trip time (RTT) in space channel hurts TCP interactions between the sending and receiving ends, and limits the usefulness and effectiveness of TCP feedback. Space Communication Protocol Standards-Transport Protocol (SCPS-TP) is a Transmission Control Protocol (TCP) enhancement method aimed at improving its performance in space and interplanetary Internet and is expected to have capability of being feasible applied to experimental evaluation of the effectiveness of SCPS-TP in coping with long channel delay. This paper presents an experimental evaluation of channel delay impact on throughput performance of SCPS-TP over LEO/GEO-stationary space links using a test-bed, compared with the widely deployed TCP.

Key words: Internet protocols, Satellite communication, Channel delay, TCP, SCPS-TP
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INTRODUCTION

As the Internet has been dramatically changing the world, there is an initiative in the commercial and military world to expand the Internet into space environment using Internet-type protocols such as the most commonly used TCP/IP. However the space environment poses a number of challenges in providing reliable end-to-end data communication with a user-specified level of service. Losses due to transmission errors, long round trip times (RTTs), constrained bandwidth, asymmetric link rates, and intermittent connectivity all contribute to severely limit TCP performance. A substantially long RTT in space channel hurts TCP interactions between the sending and receiving sides, and limits the usefulness and effectiveness of TCP feedback from the remote endpoint for space communications. Space Communication Protocol Standards (SCPS) (CCSDS, 1997), developed under the Consultative Committee for Space Data Systems (CCSDS) standards process, is a standardized protocol suite to overcome various space channel problems and provide reliable data transport in space communications. The transport protocol of the SCPS suite, SCPS-Transport Protocol (SCPS-TP) is actually TCP with a set of extensions aimed at improving TCP performance in space environment. It inherits all the relevant features from TCP while modifying others according to the convenience of satellite links.

Some work has been done on performance comparison between SCPS-TP and the commonly used TCP (Durst *et al*., 1997a; 1997c; Horan and Wang, 2001; 2000; Edwards *et al*., 2002; Wang and Horan, 2005a). But no work has been done on evaluating SCPS-TP's ability to cope with long channel delay which is one of the primary features in space communications, especially by comparing it with standard TCP.

This paper describes an experimental evaluation

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of the effectiveness of TCP and SCPS-TP in coping with long channel delay and of the delay impact on their throughput performance over simulated low bit-rate LEO-satellite and GEO-satellite links. The experiments are conducted by running file transfer tests using the Space-to-Ground Link Simulation (SGLS) test-bed (Horan and Wang, 1999; 2002). It is well known that satellite and wireless communication environments show many similarities when observed from the perspective of network protocols. Therefore, the results of this study are expected to be equally applicable for wireless and mobile environments with similar channel conditions.

The rest of the paper is organized as follows. Section II gives a brief description of TCP and SCPS-TP. Section III describes the SGLS test-bed facility and the experimental methodologies used to conduct our experiments. Section IV analyzes the channel delay effects on throughput performance of TCP and SCPS-TP. In Section V, we conclude our study.

TCP AND SCPS-TP

As a highly reliable, widely used transport protocol, TCP performs well in today's Internet, but has some performance problems in space communications due to significant differences between the terrestrial and space environments. The performance of TCP in space communications is mainly limited by data losses from different sources and long round trip channel delays (Durst *et al*., 1997c; Zhang *et al*., 1998). To cope with these limitations, SCPS-TP was developed with a number of extensions and modifications to TCP.

Different from the terrestrial environment where data loss is dominated by link congestion, at least three sources of loss exist in the space environments: link congestion, corruption, and link outage. To overcome these losses from different sources, SCPS-TP uses different congestion control mechanisms. Different from TCP which uses traditional Van Jacobson (VJ) congestion control and assumes that all data loss are caused by link congestion, SCPS-TP can be set to use different congestion controls that treat data loss in different ways (Durst *et al*., 1997c). If we assume that all data loss are caused by link congestion, we set SCPS-TP to run VJ congestion control and call it SCPS-VJ. If we set SCPS-TP to run TCP Vegas congestion control, we call it SCPS-Vegas. SCPS-Vegas distinguishes the loss caused by bit error and congestion.

RTTs in space communications are substantially longer than that in terrestrial Internet environment, hurt TCP interactions between the sending and receiving sides, and limit the usefulness and effectiveness of TCP feedback from the remote endpoint. This causes problems when TCP needs to react to changes in the network, but does not receive feedback about those changes until long after the change had occurred. SCPS-TP addresses this problem by expanding the range of commonly used TCP timer (Horan and Wang, 2000) to allow RTT delays of minutes to hours. SCPS-TP also initializes its retransmission timer based on data from routing structure.

For details of the above and other enhancements of SCPS-TP, refer to (Durst *et al*., 1997a).

EXPERIMENT METHODOLOGIES

This section describes SGLS test-bed and the methodologies used to conduct the experiments.

SGLS test-bed

Fig.1 schematically illustrates the configuration of the SGLS test-bed. Basically, it is a PC-based Virtual Instrument (VI) programmed using the LabVIEW software suite. The hardware topology of the test-bed consists of five PCs including Linux-based file source and sink PCs, the channel error-rate PC and two channel rate-change PCs. File source and sink PCs function as a logical satellite Inter-

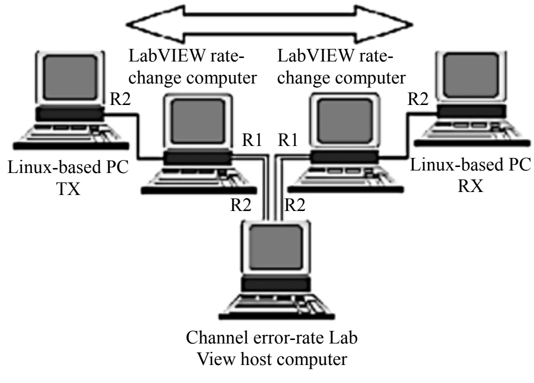

Fig.1 SGLS test-bed hardware configuration

net node and a logical ground station, respectively. The simulator is fully described in (Horan and Wang, 1999; 2002).

Experimental configurations

Fig.2 outlines all experimental factors for the experiments. The experiments are conducted by running File Transfer Protocol (FTP) over TCP/IP and running SCPS-File Protocol (SCPS-FP) over SCPS-TP/IP with two configurations of SCPS-TP, SCPS-VJ and SCPS-Vegas. The SCPS lower layers are configured to not include its networking protocol, SCPS-Networking Protocol (NP), but rather use general IP for a fair comparison. Point-to-Point Protocol (PPP) is used as the link layer framing protocol. SCPS protocol suite is SCPS RI 1.1.48 (Durst *et al*., 1997b) provided by MITRE. IP and PPP are the ones that come from Red-Hat Linux 7.3 which is the operating system running on the two file machines. Specifically, we compare FTP/TCP/IP/PPP, SCPS-FP/SCPS-VJ/IP/PPP and SCPS-FP/SCPS-Vegas/IP /PPP to evaluate the channel delay impacts on their throughput performance. TCP and SCPS-VJ are different protocols running the same congestion control mechanism, traditional VJ congestion control. SCPS-VJ and SCPS-Vegas are the same protocol of SCPS RI but running different congestion controls. VJ congestion control assumes that any data losses are caused by link congestion. In this case, when the transmission has data loss caused by bit error corruption, TCP and SCPS-VJ consider it as congestion loss, reduce their congestion window, and consequently slows down the transmission. In comparison, SCPS-Vegas is configured to treat bit error loss just as corruption loss and does not reduce congestion window and thus maintains its throughput.

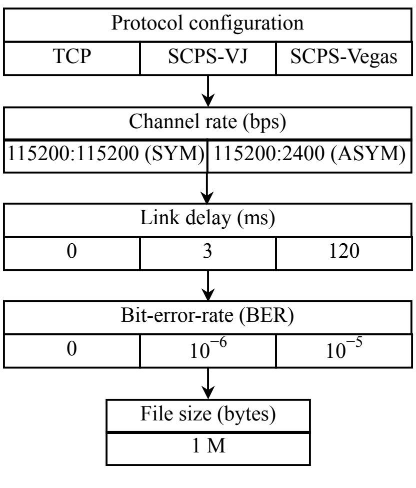

Fig.2 Outline of test factors for the experiments

The SGLS test-bed can be configured to run the experiments with a specified link delay and BER. The channel rates of 115200 bps:115200 bps and 115200 bps:2400 bps simulate symmetric and asymmetric low baud-rate channels in space environment. The link delay of 0 ms, 3 ms, and 120 ms corresponds to no delay, LEO-satellite and GEO-satellite communication links. The BERs of 0, 10^{-6} and 10^{-5} simulate error free, high error rate and very high error rate. Table 1 lists the settings of other configuration parameters in our experiments. The protocol performance is evaluated by conducting file transfer tests with a chosen combination of the test factors and analyzing the averaged file transfer times of 16 runs. See Wang and Horan (2005a; 2005b) for the details of the experiment methodologies.

Table 1 Setting of configuration parameters

Configuration parameter	Test setting
Send buffer size	65536 bytes
Receive buffer size	65536 bytes
Window Scaling option	On
TCP Timestamps option	On
PPP header compression	On
Initial Window Size	3MSS (4344 bytes)

RESULTS AND DISCUSSION

This section discusses the evaluation results of the channel delay impacts on throughput performance of the protocols for both symmetric and asymmetric channels.

Symmetric channel

Fig.3 shows the averaged file transfer times of TCP, SCPS-VJ, and SCPS-Vegas versus BER for each of three channel delays over symmetric channel. To have a nice plot of time versus BER, log10=−7 is used to represent BER=0, i.e. the error free channel. Comparison of the three plots shows that:

(1) For each of the three protocols, the increase of link delay from 0 ms to 3 ms does not affect their performance significantly but the increase from 3 ms

to 120 ms affects their performance significantly, which is reasonable.

(2) Among three protocols, the increase of delay from 3 ms to 120 ms affects the performance of TCP most significantly; at delay of 120 ms, TCP takes the largest file transfer time and SCPS-Vegas takes the least time for all the BERs, indicating SCPS-Vegas is less sensitive than TCP to the increase of channel delay over symmetric channel.

(3) For all delays, the protocols do not show significant performance difference at BERs of 0 and 10^{-6} but when BER is increased to 10^{-5}, the protocols show significant performance difference where SCPS-TP (SCPS-VJ and SCPS-Vegas) shows much less file transfer time than standard TCP.

Considering that the protocols show significant performance difference at BER=10^{-5}, let us directly compare their throughput. Fig.4 shows the throughput comparisons of TCP and SCPS-Vegas for three delays with error rate 10^{-5}. It can be observed the throughput for 0 ms and 3 ms are identical for both the protocols. At channel delay of 120 ms, TCP shows a drastic decrease of throughput compared to SCPS-Vegas. The throughput difference between 3 ms and

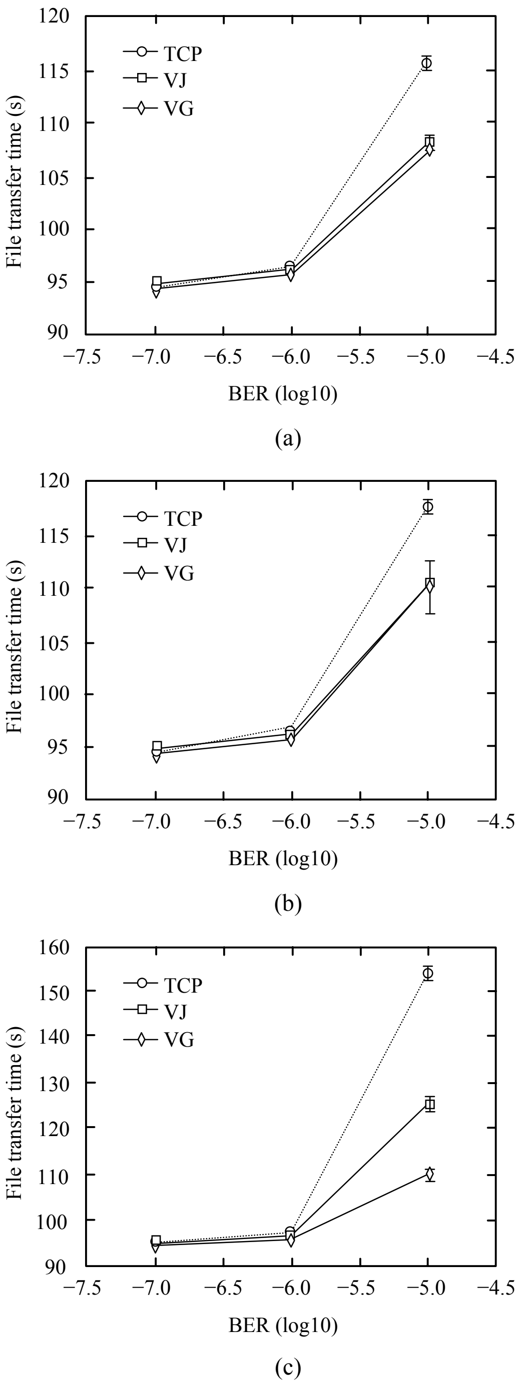

Fig.3 Performance over symmetric channel with 0 ms (a); 3 ms (b); 10 ms (c)

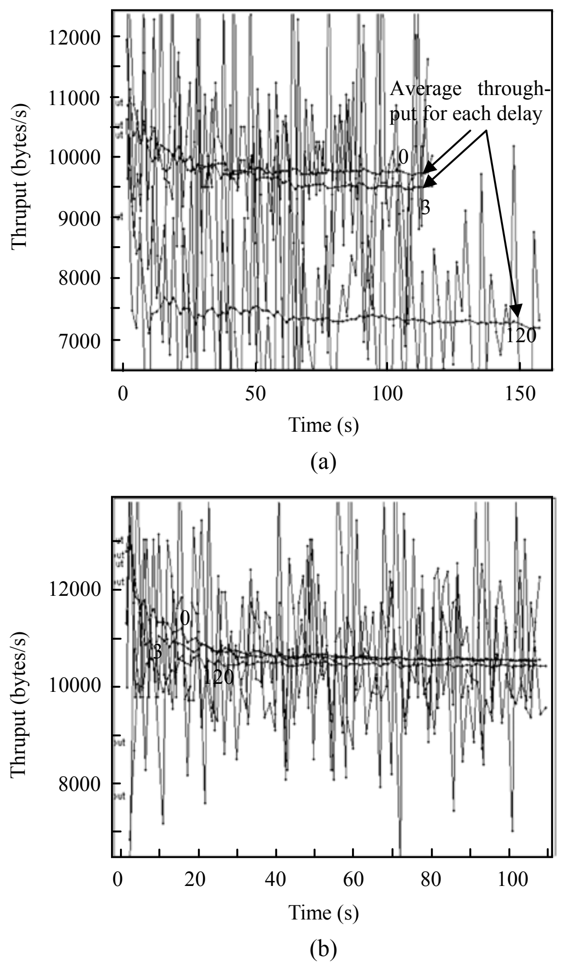

Fig.4 Throughput performances of TCP (a) and SCPS-Vegas (b) over symmetric channel with error rate 10^{-5}

120 ms is about 2400 bytes for TCP while it is only about 250 bytes for SCPS-Vegas. Clearly, the throughput of TCP is affected severely by the increase of delay from 3 ms to 120 ms but not for SCPS-Vegas. This supports our result in the previous discussion that TCP is most sensitive and SCPS-Vegas is least sensitive to the variation of channel delays.

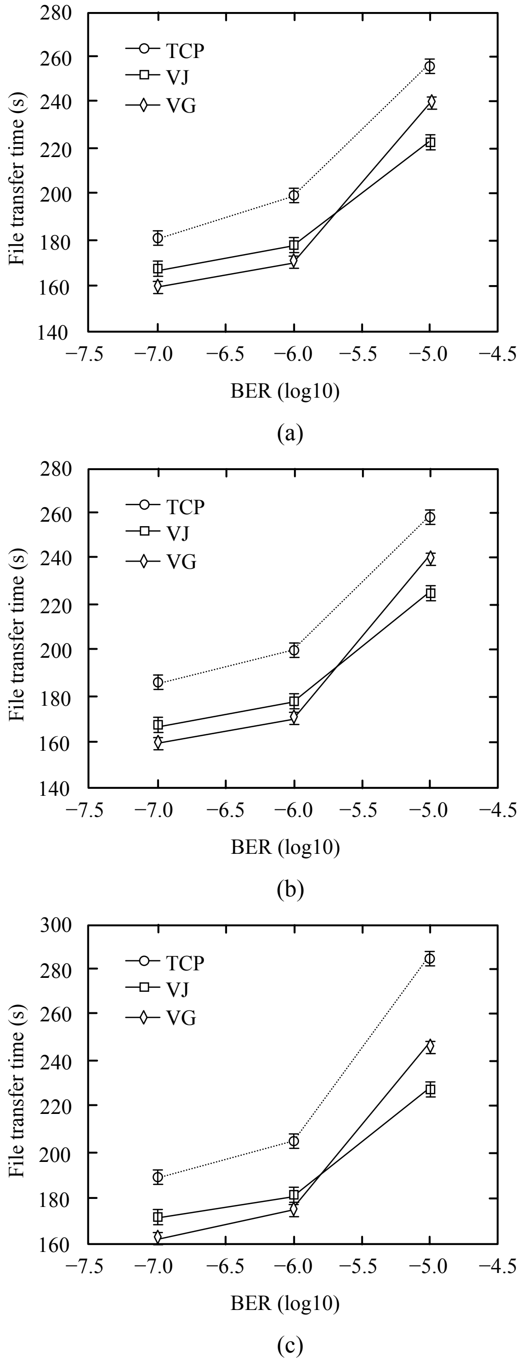

Fig.5 Performance over asymmetric channel with 0 ms (a); 30 ms (b); 120 ms (c)

Asymmetric channel

Fig.5 shows the averaged file transfer times of three protocols versus BER for three channel delays over asymmetric channel. The following observations can be made based on comparison of the three figures:

(1) Different from the case of symmetric channel, for all channel delays, the protocols show performance difference at all BERs and SCPS-TP shows much less file transfer time than standard TCP; at BER of 10^{-5}, TCP shows the largest file transfer time and SCPS-VJ shows the least file transfer time.

(2) All the protocols are equally sensitive to increase in delay from 3 ms to 120 ms except for the case of BER=10^{-5} where the performance of TCP is affected more significantly than the other two.

Fig.6 shows the throughput comparisons of TCP and SCPS-Vegas for three delays at BER=10^{-5}. Similar to the comparisons of symmetric channel, we

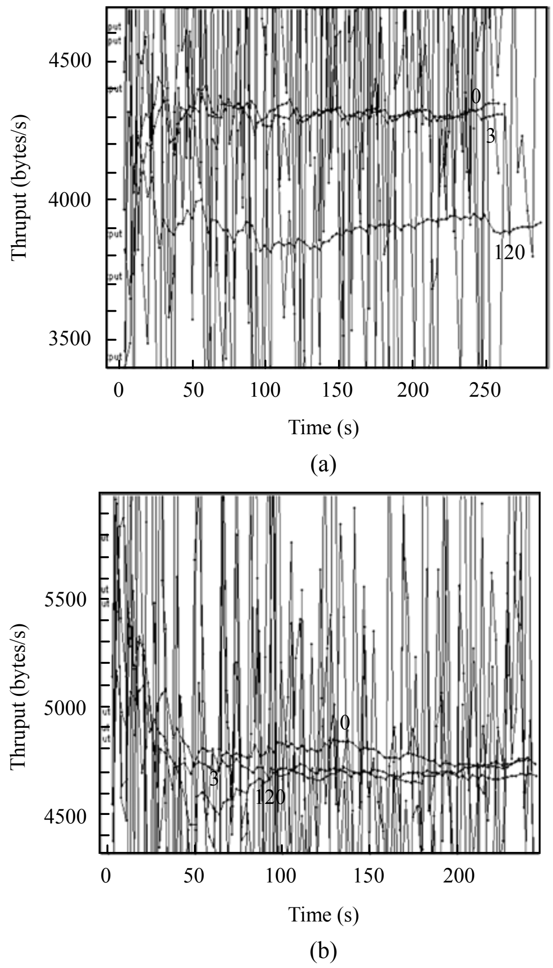

Fig.6 Throughput performances of TCP (a) and SCPS-Vegas (b) over asymmetric channel with error rate 10^{-5}

can observe that the throughput at 0 ms and 3 ms are identical for both protocols. When the delay is increased to 120 ms, the throughput of TCP is decreased by 500 bytes, while the throughput of SCPS-Vegas is decreased by 100 bytes. This indicates that SCPS-Vegas is much less sensitive to the variation of channel delay than TCP/IP for asymmetric channel.

Based on the above discussions of channel delay impacts on the protocols for symmetric and asymmetric channels, the following conclusions can be made:

(1) SCPS-TP protocol shows much better performance than standard TCP over channels with all three levels of channel delays.

(2) SCPS protocol implementation is less sensitive to the variation of link delay than TCP implementation. Among the three protocols, TCP is highly sensitive, SCPS-VJ is moderately sensitive, and SCPS-Vegas is less sensitive, to the change of channel delay. This is true for both channel rates.

The performance advantage of SCPS-TP over TCP over a long-delay channel should be due to the modifications to TCP timer which is expanded to allow RTT delays of minutes to hours as described in Section II. The performance differences between TCP and SCPS-Vegas at high BER should be attributed to the different congestion control mechanisms they use: TCP uses conventional VJ congestion control and SCPS-Vegas uses novel Vegas congestion control. Please refer to Wang and Horan (2005a) for a detailed discussion.

CONCLUSION

This paper evaluates the effectiveness of TCP and SCPS-TP in coping with long channel delay and the channel delay impact on their throughput performance. The evaluations are based on the file transfer experiments over simulated low bit-rate LEO/GEO-stationary space links using the SGLS test-bed. The results showed that SCPS protocol implementation is less sensitive to the link delay variations compared to TCP implementation. Among the three protocols, TCP is highly sensitive, SCPS-VJ is moderately sensitive, and SCPS-Vegas is less sensitive, to the change of link delay.

Based on the experiment results, this paper suggests that a mechanism making the data receiver to adjust adaptively to its acknowledgment (ACK) frequency based on the estimation of RTT may be helpful for better throughput performance over a long-delay channel.

Considering the constraints of satellite channel simulations, similar experiments over realistic satellite links are necessary to verify the above conclusions.

References

CCSDS (Consultative Committee for Space Data Systems), 1997. Space Communications Protocols Specification (SCPS)-Rational, Requirements, and Application Notes. CCSDS 710.0-G-0.3.

Durst, R.C., Feighery, P., Travis, E., 1997a. User's Manual for the SCPS Transport Protocol. WN 97W0000018, Washington C^3 Center, McLean, Virginia.

Durst, R.C., Feighery, P., Zukoski, M., 1997b. User's manual for SCPS reference Implementation Software. WN 97W0000095, Washington C^3 Center, McLean, Virginia.

Durst, R.C., Miller, G.J., Travis, E.J., 1997c. TCP extensions for space communication. *Wireless Networks*, **3**(5):389-403.

Edwards, E., Younghusband, C., Fodil-Lemelin, K., 2002. Performance of SCPS in Complex Networks. Proc. of 20th AIAA International Communications Satellite System Conference.

Horan, S., Wang, R., 1999. Design of a Channel Error Simulator Using Virtual Instrument Techniques for the Initial Testing of TCP/IP and SCPS Protocols. NMSU-ECE-99-002, Vol.1.

Horan, S., Wang, R., 2000. Effects of Networking Configurations on Channel Throughput in Space. Proc. 14th AIAA/USU Conference on Small Satellites.

Horan, S., Wang, R., 2001. Internet-Type Protocol Testing in a Simulated Small Satellite Environment. Proc. of IEEE Conference on Aerospace and Electronic Systems.

Horan, S., Wang, R., 2002. Design of a space channel simulator using virtual instrumentation software. *IEEE Transactions on Instrumentation and Measurement*, **51**(5):912-916.

Wang, R., Horan, S., 2005a. Performance Evaluation of TCP and Its Extensions over Lossy Links in a Small Satellite Environment. Proc. of IEEE International Conference on Communications (ICC), Seoul, Korea.

Wang, R., Horan, S., 2005b. Impact of Van Jacobson header compression on TCP/IP throughput performance over lossy space channels. *IEEE Transactions on Aerospace and Electronic System*, **41**(2):681-692.

Zhang, T., Yan, E., Dao, S.K., 1998. A Measurement of TCP over Long-Delay Network. Proc. 6th International Conf. on Telecom. Systems.