UNIVERSITI PUTRA MALAYSIA

ENHANCEMENT OF TRANSMISSION CONTROL PROTOCOL PERFORMANCE OVER LOW EARTH ORBIT SATELLITE LINKS

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By

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Thesis Submitted in Fulfilment of the Requirement for the Degree of Master of Science in the Faculty of Engineering
Universiti Putra Malaysia

May 2003

To
Mama, Baba, Mona,
my daughters, my husband, Mazin, Maysaa
& all whom I love

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science.

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May 2003

Chairman: Professor Borhanuddin Mohd Ali, Ph.D.

Faculty: Engineering

Recent growth of the Internet has led to the development of Internet services everywhere and over every possible communications medium. Here, Low Earth Orbit (LEO) Satellite has been addressed as a medium for supporting services based on the Transmission Control Protocol (TCP).

Basically, TCP was proposed as a common transport protocol for the Internet. The TCP mechanisms have been modified overtime and almost standardized for wired networks. However, for wireless communications still further modifications are needed for TCP mechanisms. Particularly, in this study an Enhanced Selective Acknowledgement (ESACK) mechanism has been proposed to improve the performance of TCP over LEO satellite links. The ESACK detects the network congestion and adjusts the transmission window by considering losses in two consecutive windows.

By using the network simulator (ns) the overall performance of the TCP ESACK has been compared with that of the TCP SACK over LEO satellite links. The performance metrics include congestion window, effective throughput, end-to-end packet delay and file transmission time. Extensive simulation scenarios have been done using a number of FTP file sizes, two LEO satellite systems at different link error rates, point-to-point and multipoint-to-point connections. The results show that the ESACK provides a higher congestion window than that of the Selective Acknowledgement (SACK), which results in improving the effective throughput as well as reducing the overall file transmission time at the expense of slightly increasing end-to-end packet delay. It can be concluded that the ESACK, with possible slight changes to SACK, improves the performance of TCP over LEO satellite links.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Master Sains.

PENINGKATAN PRESTASI PROTOKOL KAWALAN HANTARAN TERHADAP PENYAMBUNGAN SATELIT

Oleh

MAYADA SALIH ABDALLA MUSTAFA

Mei 2003

Pengerusi: **Profesor Borhanuddin Mohd Ali, Ph.D.**

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Perkembangan teknologi Internet yang terkini menjurus kepada pembangunan perkhidmatan Internet di merata tempat menggunakan segala media komunikasi yang boleh memuat aplikasi Internet. Pada kajian ini dibahas penggunaan sistem komunikasi satelit buruj rendah sebagai media yang mendukung perkhidmatan Internet berasas protokol kawalan hantaran (TCP).

Secara asas, TCP diajukan sebagai protokol umum dalam perkhidmatan Internet. Mekanisme TCP telah diubah suai dari masa semasa dan hampir semuanya mempunyai piawaian untuk perkhidmatan Internet yang mengunakan media berwayar, namun untuk media komunikasi tanpa wayar, mekanisme TCP masih perlu diubahsuai. Dalam kajian ini mekanisme "perakuan memilih tambahan (ESACK)" dianjurkan untuk meningkatkan kecekapan protokol TCP dalam sambungan komunikasi satelit berburuj rendah (LEO). ESACK boleh mengesan kesesakan rangkaian komunikasi dan menyelarakan bukaan jendela penghantaran dengan mengambil kira faktor kehilangan diantara dua jendela yang berturutan.

Dengan mengunakan program simulasi rangkaian (ns) kecekapan penggunaan TCP ESACK pada sistem satelit buruj rendah dibandingkan dengan kecekapan TCP SACK pada sistem yang sama. Kajian metrik yang meliputi jendela kesesakan dilakukan untuk menunjukkan kesan keluaran, pelambatan dan transmisi yang efektif. Beberapa senario simulasi dilakukan secara intensif menggunakan fail-fail yang berbeza saiz terhadap dua buah sambungan satelit buruj rendah yang mempunyai kadar ralat yang berbeza dengan konfigurasi sambungan titik ke titik dan konfigurasi sambungan berbilang titik ke titik. Hasil kajian didapati menunjukkan ESACK menyediakan paras kesesakan jendela yang lebih tinggi berbanding dengan perakuan memilih (SACK), yang mana keluaran efektif diperbaiki dan mengurangkan keselurhan masa penghantaran fail. Dari hasil simulasi rangkain, sistem ESACK didapati mempunyai kekurangan iaitu bertambahnya kesan pelambatan pengiriman paket pada sambungan titik ke titik dan sambungan berbilang titik ke titik. Dapat disimpulkan bahawa ESACK dengan sedikit pengubahsuaian terhadap SACK dapat meningkatkan prestasi TCP dalam sistem satelit buruj rendah.

ACKNOWLEDGEMENTS

I would like to thank everyone who has contributed to this success. Firstly, Prof. Dr Borhanuddin Momd Ali for, accepting me as one of his student, his strong academic's supporting by many ways, creating the association of his graduate students (Broadband-upm) having the sense of one family, and his more patience. Really it is great opportunities that I have had under his supervisory.

Secondly, Dr. Veeraraghavan Prakash and Puan Ratna Zakiah Sahbudin, for being members of the supervisory committee, for helpful suggestions and comments to make the work on the acceptable level.

Thirdly, Dr Ali M Abdelrahman for his assistances especially in equip my computer by Network Simulator (NS), much discussions on different aspects of TCP since the work was just an idea until it has become reality now.

Finally, my parents for all of the love and encouragement they have provided me throughout my life, my daughters Yousra and Ethar. Forever I proud of you.

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LIST OF ABBREVIATIONS

BER	Bit Error Rate
CWND	Congestion Window
ECN	Explicit Congestion Notification
ESACK	Enhanced Selective Acknowledgements
FEC	Forward Error Correction
FIN	Finish
FTP	File Transfer Protocol
GEO	Geostationary Earth Orbit
ISL	Inter-satellite Links
LEO	Low Earth Orbit
MTU	Message Transfer Unit
NS	Network Simulator
RF	Radio Frequency
RTO	Retransmission Timeout
RTT	Round Trip Time
SACK	Selective Acknowledgements
SSTHRESH	Slow Start Threshold
SYN	Synchronization
TCP	Transmission Control Protocol
WWW	World Wide Web

CHAPTER 1

INTRODUCTION

Satellite systems can be considered as an integral part of the third-generation systems due to their ability to provide global coverage and immunity from terrestrial disasters. In particular low earth orbit (LEO) satellite networks have been integrated with terrestrial wired networks to provide communication services for the Internet and mobile users at remote areas. LEO satellite systems have a number of advantages over traditional geostationary earth orbit (GEO) satellite systems, because of relatively low propagation delays and power requirements, resulting from the low orbit altitude. Also LEO satellite networks have a number of advantages over mobile terrestrial networks, due to their ability to provide coverage to land, sea, and air based users [1].

Recent advances in satellite technologies together with fast growth of the Internet have motivated the development of LEO satellite networks such as Iridium and Teledesic systems which perform onboard switching and signal processing, and being interconnected by inter-satellite links (ISL). Iridium provides a low bandwidth service, capable of supporting voice telephony and simple message forwarding services [2]. Teledesic uses fast inter-satellite links and onboard packet switching to provide a high bandwidth and good quality of services similar to that provided by the terrestrial fixed network [3]. On the other hand, the Internet has faced further challenges over satellite providers, since the standard Internet protocols like transmission control protocol (TCP) have been designed primarily for wired networks. Thus several problems may arise when the TCP traffic transport over long link satellite networks [4]. The reasons for that; wireless environments have very different characteristics in terms of latency, jitter, and error rates.

This study introduces the types of satellite constellation networks, and investigates how overall performance of TCP communications carried across such a network can be affected by standard TCP congestion control mechanisms. These mechanisms include slow start with congestion avoidance, fast retransmit with fast recovery and selective acknowledgements (SACK) [5]. Then an enhanced SACK (ESACK) is proposed in this thesis to improve the overall performance of TCP in LEO satellite environment. Finally, the TCP ESACK mechanism is compared with TCP SACK mechanism via extensive simulations, whereby the results obtained showed that the proposed ESACK mechanism improves the performance over the standard SACK mechanism.

1.1 Motivation of the Study

Recently, there has been increasing interest in extending transmission control protocol (TCP) to operate over LEO satellite networks. Building broadband networks based on satellite and wireless Internet technologies is a method of reaching remote and mobile users. For broadband Internet access to continue its fast growth over satellite networks satellite service, providers must overcome the inefficiencies of traditional Internet protocols that degrade the quality of service and inhibit the overall network performance. This motivates researchers to develop a number of proposals for optimising Internet performance over satellite networks.

1.2 Problem Statement

Despite the progress on improving TCP mechanisms there remain some features of the protocol that impair the performance over satellite links. The main problem comes from the fact that the TCP operates on the incorrect assumption by relating any loss to the network congestion. Consequently the TCP responses to the loss by reducing the congestion window which in turn reduces the performance. In satellite communications, packet errors can occur due to atmospheric and environmental conditions, noisy channel disruptions, link outages, signal degradation and interferences. Thus when a loss is actually due to the stress of space rather than the network congestion the TCP unnecessarily reduces the throughput by under-utilizing the link, while the network appears to be slow or inefficient to the Internet over satellite user.

In this thesis the loss indication is addressed as the main factor that affects the TCP performance in LEO satellite environment. The loss may be indicated by large delay variations or handoff due to the relative motion of the LEO satellites, packet transmission errors of satellite links, and/or network congestion. Therefore an enhanced SACK (ESACK) mechanism has been proposed to improve the TCP performance over LEO satellite links by considering loss indications in two consecutive windows before assuming there is network congestion.

1.3 Aims and Contributions

The main objective of this research is to enhance the performance of TCP over LEO satellite networks. This is achieved by proposing an enhanced selective acknowledgements (ESACK) mechanism, which is a slight modification over the standard selective acknowledgements (SACK) mechanism. The contributions of the study could be summarized as follows:

- Identification of the problems that may arise due to the characteristics of LEO satellites, such as those caused by delay variations and handoffs.
- Analysis of the negative impacts of the standard TCP mechanisms on the performance of TCP over LEO satellite networks.
- Proposing of the TCP ESACK mechanism that improves the performance of TCP data over LEO satellite links.
- Modelling and simulating the proposed ESACK and standard SACK mechanisms using a wide range of file transfer protocol (FTP) data files at different error rates. These mechanisms are compared for the TCP performance over LEO satellite links, Teledesic and Iridium systems, where the ESACK mechanism always shows better effective throughput than that of SACK mechanism.

1.4 Organization of the Thesis

This thesis is organized as follows: the introductory chapter justifies the study by stating the problems and identifying the objectives of the research; Chapter 2 surveys standard TCP mechanisms with their impacts on TCP over LEO satellite networks; Chapter 3 describes the research methodology by proposing the TCP ESACK mechanism; Chapter 4 introduces the simulation environment and evaluates the performance of the TCP ESACK over LEO satellite links; and finally Chapter 5 concludes the thesis by highlighting the main features of the TCP ESACK with its performance achievements.

CHAPTER 2

LITERATURE REVIEW

This chapter surveys the advances in satellite technologies, the development in the Internet with the primary focus on the transmission control protocol (TCP) mechanisms and their impacts on the performance of TCP over LEO satellite networks.

2.1 Overview of Satellite Systems

Originally there are two basic types of satellite systems being applicable for TCP; geostationary earth orbit (GEO) satellites and low earth orbit (LEO) satellites. GEOs orbit is approximately 35,000 km above the equator, in which a satellite can stay over the same area of the earth for an indefinite period of time. Each GEO satellite serves one geographical area, and can theoretically cover about 41% of the earth's surface. Companies proposing GEO systems are planning on using between three and fifteen satellites to deliver worldwide services [1].

LEO satellite orbit is between 700 km and 1350 km above the surface of the earth. Each LEO is moving constantly, covering a particular area for around 10 minutes. Because of this, a network of many satellites is required to cover the entire world.

Teledesic and Iridium systems are examples of LEO satellites which have been implemented in this study [2, 3].

2.1.1 General Features of Satellites

Advances in satellite technologies indicate that both satellites (LEO and GEO) will be an essential part of the next-generation Internet (NGI). There are several reasons why satellites will play a key role in the NGI [6, 7]:

- Satellite services can be provided over wide geographical areas including urban, rural, remote, and inaccessible areas (Appendix A).
- Satellite communication systems have very flexible bandwidth-on-demand capabilities.
- Alternative channels can be provided for connections that have unpredictable bandwidth demands and traffic characteristics, which may result in maximum resource utilization.
- Users can easily be added to the system by simply installing the Internet interfaces at customer premises. As a result, network expansions will be a simple task.
- Satellites can act as a safety valve for NGI. Fiber failure or network congestion problems can be recovered easily by routing traffic through a satellite channel.
- Applications such as tele-education, telemedicine, entertainment, etc., can be realized through satellites.

2.1.2 Advantages and Disadvantages of GEO Satellites

Advantages: three GEO satellites are enough for a complete coverage of the earth. Senders and receivers can use fixed antenna positions. Therefore, GEOs are ideal for TV and radio broadcasting. Lifetime expectations for GEOs are about 15 years. GEOs do not require handover [8].

Disadvantages: northern or southern regions of the earth have more problems on receiving these satellites due to the low elevation above the latitude of 60 degrees, i.e., larger antennas are needed. The biggest problem for voice and data communications is the high latency of over 0.25 sec one-way [8]. Because of this latency factor, broadband GEO systems are not as attractive for interactive uses as terrestrial or LEO systems. Also the transmission control protocol/internet protocol (TCP/IP) does not work well with such latency problem. Another potential problem with GEOs is their relatively inefficient reuse of valuable radio spectrum, because of the great distances at which they orbit the earth.

2.1.3 Advantages and Disadvantages of LEO Satellites

Advantages: the great merit of LEO systems is the elimination of GEO's latency problem, because of their relatively close positions to the earth. This is the reason why LEOs were proposed as an alternative to GEOs. Thus, videoconferences can be conducted in true real time, and transmission protocols like TCP/IP may need slight