Evaluation of TCP Versions over GEO Satellite Links

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Abstract—**In this paper an attempt to evaluate the performance of different versions of TCP over satellite link has been performed. The throughput of the protocols has been obtained and some considerations have been made. The considered protocols can be divided in two main categories: terrestrial protocols and satellite protocols. In the first category, the classical TCP Sack protocol has been illustrated because it is a "good-performance" protocol, in addition to TCP WestWood and its modified version, TCP WestWood+, while in the second category Satellite Communication Transport Protocol (SCPS-TP) and Satellite Transmission Protocol (STP) have been shown and compared. The considered protocols have been analyzed on the well-known GEO satellite link. In particular, a classical GEO satellite link and a single connection between two terminals have been considered.**

Keywords—Satellite communications; Terrestrial TCP; Satellite TCP; TCP evaluation

I. INTRODUCTION

The Satellite employment for multimedia application is actually an important research field in telecommunication community. Due to their wide coverage area, satellites play a significant role in global broadband services. Thanks to their intrinsic cost-effectiveness in supporting broadcast and multicast services and their easy setup, satellite systems are particularly well suited to fulfill communication requirements especially in terms of large coverage and long-range mobility. They can also be utilized to cover sparsely populated areas where huge bandwidth resources cannot be provided through terrestrial infrastructures or regions where deployment of terrestrial facilities remains impractical. In this context, the performance of the transport layer, and in particular TCP, is investigated in the literature. Currently, two types of satellites, Geostationary Earth Orbit (GEO) and Low Earth Orbit (LEO) are mostly used for the multimedia applications. The main problem of Satellite TCP regards the fact that TCP is born for terrestrial networks. Then, many characteristics as long as propagation delay of GEO links, high Bit Error Rate (BER), long bandwidth-delay product, frequently handovers of LEO satellites have to be taken into account in the protocol improvement. In this paper an attempt to evaluate the performance of different version of TCP over satellite link has been performed. The throughput of the protocols has been obtained and some considerations have been made using a NS2 simulation environment. Many algorithms have been studied by researchers in order to face these problems. Some solutions involve changes to protocol mechanisms to accommodate the properties of satellite links. These modifications change the basic error-control and flow-control strategies to improve performance.

In this paper a comparison between different TCP versions has been performed in order to analyze the effectiveness of these types of transport protocols over GEO satellite environment. A simplified scenario composed of a source, a receiver and a GEO satellite has been considered TCP considered protocols are the well-known SACK [2], Westwood [3] and Westwood+ [4], satellite SCPS-TP [6] and STP [7,8]. The contributions of this work consist into the investigation and evaluation of the performance of these types of protocols in order to illustrate the STP protocol benefits in comparison with the other satellite and terrestrial TCP protocols. Many simulations are performed and the graphs of throughput in a GEO scenario are shown. The choice of these TCP protocols is for comparison purpose on a satellite network with high bandwidth-delay product (GEO satellite). Westwood, Westwood+, Jersey try to optimize the TCP performance on wireless link updating the *cwin* and *sstresh* parameters using a bandwidth estimation algorithm [3,4,5]. The rest of this paper is structured as follows: related work are shown in Section II, in Section III the main satellite channel issues are discussed; section IV presents a TCP protocols overview and, finally, section V and section VI show respectively performance evaluation and conclusions.

II. RELATED WORK

Related work on the TCP performance applied to Satellite IP networks [3][4] have shown different new mechanisms that try to resolve wireless TCP issues. In the satellite channel, TCP faces the following problems:

Slow Start time: the Slow Start phase proves longer because on this channel there is a long propagation delay that causes a slower congestion window opening and, consequently, a smaller throughput.

High BER: the presence of a high BER causes much packet loss; the sender interprets these problem as a signal of an incipient congestion and therefore the throughput degrades because the congestion window is subjected to unnecessary reduction.

Asymmetric link: as known, the uplink and downlink channel on the satellite are asymmetric between them; this characteristic of the channel causes an overhead of the ACK traffic and therefore a reduction of the bandwidth available for the data traffic.

To address these problems, a lot of simple enhancements have been proposed in the literature [5], [6]. The most important enhancements are: increasing the initial congestion window size from 1 to 4 segments. ECN capable router: this router is capable of notifying the sender of an incipient congestion state. TCP SACK: by utilizing this version of the basic protocol, a sender is capable of recovering from multiple losses in a single RTT. In the literature there are also many versions of the TCP protocol. The most relevant ones are: SCPS-TP [6]: set of extensions on the classic TCP making the protocol capable of reacting correctly towards the aforementioned problems. STP [8]: transport protocol TCP-like studied specifically to have high performance in the satellite environment. TCP Westwood [10] (and TCP Westwood+ [11]): protocol which, through a bandwidth estimation, reduces its congestion window. TCP Jersey [2]: TCP version based on the Westwood scheme, but with a different estimator and with the capability of distinguishing the cause of losses owing to a specific router configuration. TCP Peach [12] (TCP Peach+ [13] and TCP Swift [14]): protocol with two new Slow Start and Fast Recovery algorithms to have a new congestion control scheme with good performance in satellite networks. In [16] authors discuss the performance of TCP-Vegas in Slow Start phase and propose a new pacing method to solve the problem. Also, we suggest using *ssthresh* to avoid premature exit from Slow Start phase. In [17] authors compare the performance of TCP and their implementation of SCPS-TP SNACK (Selective Negative Acknowledgement) over paths with different BER and different delays. They present the improvement in throughput and link utilization when the SCPS-TP SNACK instead of standardized TCP mechanisms are used. In [18] and [21] authors present, TP-S, a novel transport control protocol, introduced for satellite IP networks where, firstly in order to increase the increment speed of Congestion Window (*cwnd*) at the beginning of data transmission, the traditional Slow Start strategy is replaced by a new strategy, known as Super Start. Secondly, a new packet lost discriminated scheme based on IP packets alternately sending with different priority is used in the protocol to decouple congestion decision from errors. Thirdly, bandwidth asymmetry problem is avoided by adopting Modified NACK (M-NACK) in receiving ends, which is sent periodically. They show the goodness of their proposal through simulation results. In [19] TCP-STAR has been proposed to solve problems on delay networks by modifying TCP congestion control method. TCP-STAR achieves high-speed communication by using the estimated bandwidth. In [20] authors propose another TCP version for satellite networks called Cubic, that results to work well in this type of networks.

III. SATELLITE CHANNEL ISSUES

TCP over GEO satellite networks is affected by various problems owing to the fact that TCP is born to operate over terrestrial link where propagation delays are very smaller than satellite one and errors arise for different causes. The main problems are listed in the following [1].

Latency: The latency is composed of three main parts: propagation delay, transmission delay and queuing delay. For connections traversing GEO links, the RTT is about 540 ms.

Slow Start Problems: In the beginning of a new connection, TCP has no info about the available bandwidth on the connection path; thus, it executes the slow start to probe this. This action, in satellite network, causes inefficiency because, i.e. for a small transfer file, the bandwidth is not efficiently used.

Problems Due to Link Errors: Link errors affect two aspects of throughput. First, the corrupted data packets due to link errors must be retransmitted. Second, the TCP sender always assumes a packet loss as the signal of congestion and accordingly decreases its transmission rate. Due to high error rates characterizing satellite links, this assumption may lead to unnecessary decrease in resource utilization, as throughput. This problem is amplified by the long delay characterizing satellite networks.

Problems Due to Bandwidth Asymmetry: Most configurations in satellite communications are bandwidth asymmetric, that is, the bandwidth available in the forward channel is much higher than that in the reverse channel. As a result, ACK packets may congest the reverse channel, and to be delayed and lost. For each of these problems in literature a lot of studies exist. A set of mechanisms are proposed to resolve the specific problems that, often, introduce some problems of different nature. The type of applications that are affected of the TCP satellite issues are real time applications.

IV. TCP PROTOCOLS OVERVIEW

A. *Terrestrial Protocols*

TCP SACK [2]: Multiple packet losses from a window of data can have a catastrophic effect on *TCP* throughput. *TCP* uses a cumulative acknowledgment scheme in which received segments that are not at the left edge of the receive window are not acknowledged. This forces the sender to either wait a roundtrip time to find out about each lost packet, or to unnecessarily retransmit segments which have been correctly received. With the cumulative acknowledgment scheme, multiple dropped segments generally cause *TCP* to lose its *ACK-based clock*, reducing overall throughput. *Selective Acknowledgment* (*SACK*) is a strategy which corrects this behavior in the face of multiple dropped segments. With selective acknowledgments, the data receiver can inform the sender about all segments that have arrived successfully, so the sender needs to retransmit only the segments that have actually been lost.

TCP WestWood [3]: The goal of this protocol is to improve the TCP performance over wired and wireless link through a best bandwidth estimation then the past protocols by improving the congestion control simply by modifying only sender size. For this goal it used a variable called *Bandwidth Share Estimate* (*BSE)* who is estimated at the sender side by sampling and exponential averaging an estimate of instantaneous bandwidth share used by the connection (bandwidth samples are determined from information in ACK packets and from the inter-arrival time between them). By the use of this variable, the reaction of WestWood to a 3-duplicate ACK reception or to a TimeOut action is to decrease the slow start threshold dynamically in accord to BSE in a way to have best performance, expecially over wireless link.

TCP WestWood+ [4]: Westwood+ is a recent TCP version that uses a new algorithm called *additive increase/adaptive decrease* (AIAD) implemented only in the sender size. This algorithm examines the stream of returning acknowledgment packets to estimate the available bandwidth. When a congestion episode happens at the end of the TCP probing phase, the used bandwidth corresponds to the definition of best effort available bandwidth in a connectionless packet network. This bandwidth estimation is then used to adaptively decrease the congestion window and the slow-start threshold after a timeout or three duplicate ACKs instead, i.e. setting slow-start threshold to half of its recent value. Moreover, WestWood+ eliminates the problem of simple WestWood, which overestimated the bandwidth in the presence of ACK compression.

B. Satellite Protocol

Satellite Communication Transmission Protocol (SCPS-TP) [5]:

The SCPS-TP protocol consists of standard TCP augmented by a set of extensions and enhancements that consist of both implementation and specification changes. These modifications each respond to requirements derived from the characteristics of the space environment described above. Some of these TCP modifications have been proposed elsewhere in the literature; however, they targeted environments different from the one we study here, for instance, high-speed networks.

We note that some of the SCPS-TP extensions affect interoperability with regular TCP. Therefore, the use of the nonstandard SCPS-TP options and behaviors is negotiated on connection establishment via a “SCPS-TP capable” option. If the peer TCP endpoint does not return the “SCPS-TP capable” option when it is sent by the connection initiator on the SYN segment, SCPS-TP will behave like regular TCP.

SCPS-TP is able to distingue the cause of a loss and so how to recover from these without obtaining unnecessary throughput by avoiding the congestion-control response and by providing enhanced information about data loss via the SCPS-TP Selective Negative Acknowledgment (SNACK) option. Moreover, SCPS-TP sends ACKs much less frequently than standard TCP does to improve throughput when the ACK channel is highly constrained.

The SNACK option, which is carried on an acknowledgment segment, identifies multiple holes in the sequence space buffered by the receiver. By providing more information about lost segments more quickly, the SNACK option can hasten recovery and prevent the sender from becoming window-limited, thus allowing the pipe to drain while waiting to learn about lost segments. The ability to transmit continuously in the presence of packet loss is especially important when loss is caused by corruption rather than congestion.

Satellite Transport Protocol (STP) [6,7,8]: The transmitter earth station sends data packets and stores them for potential retransmission until they are acknowledged. The transmitter earth station also periodically sends one POLL packet to ask the receiver which packets have been successfully received. The receiver sends a STAT packet as a response. As soon as a packet loss is detected, the receiver informs the transmitter of the packet loss explicitly. Therefore, the bandwidth usage on the reverse channel mainly depends on the polling period, not the transmission rate on the forward channel. In addition, selective negative acknowledgment (here called USTAT) can inform the sender about packet losses within half of an RTT.

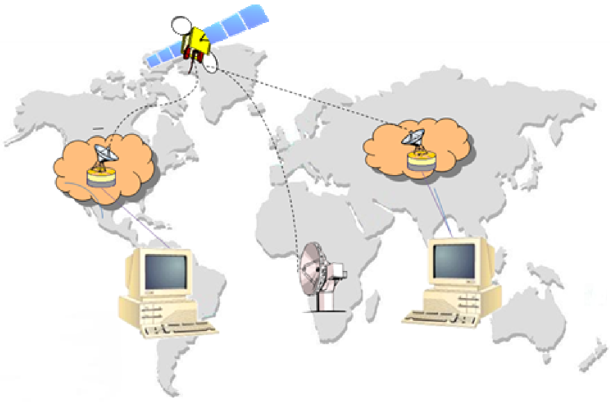

Fig. 1. GEO satellite architecture reference

Standard TCP degrades in Satellite networks because it does not discriminate the causes of packet losses. TCP Jersey is able to reach this purpose [15]. TCP Jersey makes use of a sender enhancement through the adoption of an Available Bandwidth Estimation (ABE) algorithm and ECN-like explicit congestion notification scheme called Congestion Warning (CW). The ABE on the sender-side permits a more accurate estimation of the available bandwidth on the network through ACK rate monitoring. This approach permits an optimal *cwnd* size to be calculated based on the bandwidth estimated value and it is possible to communicate to the sender how to regulate its transmission data rate under a congested network load. The adopted estimator is presented in the following:

$$R_n = \frac{RTTxR_{n-1} + L_n}{(t_n - t_{n-1}) + RTT} \qquad (1)$$

Where R_n*-1* is the bandwidth estimation at the *(n-1)-th* time interval, RTT is the Round Trip Time and L_n is the acknowledged data segment in the *n-th* time interval. Through this bandwidth estimation, the optimal congestion window (*ownd*) in segment units is calculated as depicted below:

$$ownd = \frac{RTTxR_n}{seg\_size} \qquad (2)$$

CW, on the other hand, consists in an ECN-like configuration of network routers so that these routers can advertise the terminals about a congestion situation through an explicit packet marking of the data packets involved. The main advantage of the CW scheme is the discrimination mechanism offered to the sender among data packets lost owing to congestion from frequent link errors present on the satellite links.

V. Performance Evaluation

The performance of the protocols were evaluated through simulations on Network Simulator 2 [-], simulating GEO scenario topology. An FTP transfer between two terminals by using a GEO satellite. The Geo scenario previews a geo satellite with two terminals of which one operates as sender and the other as destination of FTP transfer. In order to improve the TCP performance, increasing throughput, in networks that present high RTT value, it is possible to use greater router buffer and a bigger transmission windows initial value. Moreover, satellite channels present a greater BER in respect to terrestrial channel because of atmospheric conditions, radio frequency interference and signal attenuation. TCP protocol uses loss segments as congestion signal because in satellite networks the main cause of losses is the high BER the standard TCP mechanisms cannot to be used otherwise it will produce a under utilization bandwidth. Another characteristic of satellite link is the link asymmetry that takes to a decrease of arrival ack rate to the sender and then, a slower growth of transmission window. In order to obviate to this problem in a first time a TCP-sack version has been proposed in order to avoid useless retransmissions. In order to improve TCP performance many TCP studies have been performed by researches. Beyond the classical TCP-SACK, the telecommunication community has proposed other protocols as: Westwood, Westwood+, SCPS-TP, STP. The contributions of this work are to investigate and evaluate the performance of these five types of protocols in order to illustrate the better performance of STP protocol that born as a satellite TCP that tries to overcome the issues of the terrestrial TCP. Many simulation are performed and the graphs of throughput in a GEO scenario are shown. The figures, in the following, illustrate results for a satellite links of 2 Mb/s in uplink and downlink with a IP packets size of 1040 bytes for data traffic and an initial congestion window of 20 Kbytes. Note: The SCPS-TP protocol is not totally implemented for the simulations, but it was considered only the SNACK implementation part of this.

Figure 2 shows the decreasing of packets loss percentage on the high delay channel. Comparing only the terrestrial protocol and SCPS-TP, it is possible to note that SCPS-TP protocol performs better than SACK because it introduces the Selective Negative ACK mechanism that permits a lower downlink channel occupation, the same reason for wich it outperforms WestWood+ also. Moreover, the best protocol in this scenario, as we can obtained by analyzing the figure, is WestWood, beacuse his Bandwidth-Extimation algorithm is better than other protocol because it use the ACK information.

Figure 3 shows the same parameters of Figure 2 compared with STP protocol, and is showed that STP outperform previous four protocols in terms of throughput due to the fact that it is born as satellite protocol, and, for this reason, it performs better, i.e. because that it open up it is congestion window than other protocol, and the initial value of this parameter is set roughly to 200 Kbytes. Another benefit to STP in a high *BW*RTD* environment with high losses is that it reports the complete state of the receiver with every *STAT* packet, and that it asks the state of the sended packet by a *POLL* packet, and for this reason the reverse channel is more free for new *SD-pack* transmission.

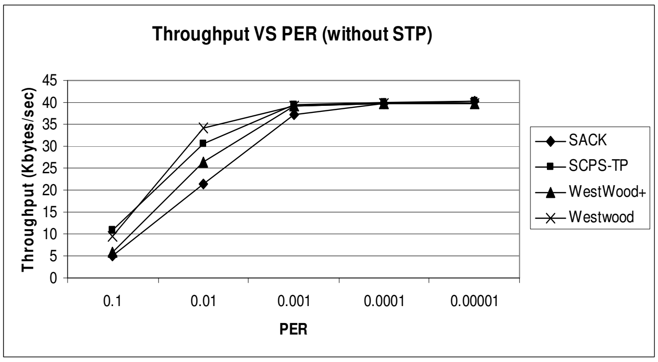

Fig. 2. Example of a figure caption. *(figure caption)*

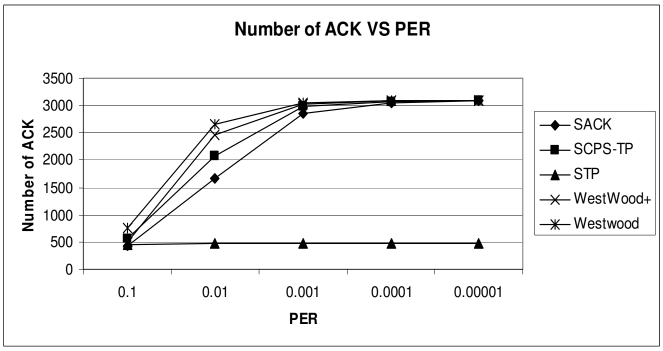

Fig. 3. Example of a figure caption. *(figure caption)*

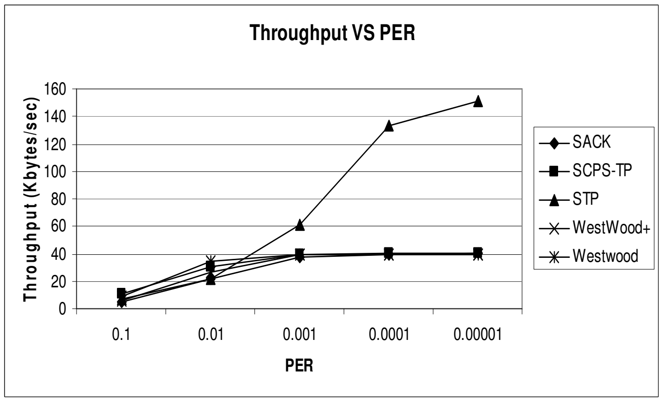

Fig. 4. Example of a figure caption. *(figure caption)*

Figure 4 shows the curve slope of acknowledge number for the five protocols. It is possible to note that the ack number of STP is very lower than other protocols. TCP-Sack and SCPS-TP implements the concept of delayed acknowledgement which reduces the ack number in respect of a classical TCP protocols, but STP with the introduction of four new messages (SD,POLL, STAT, USTAT) reduces furtherly the number of acknowledgement in the reverse channel. Moreover, there is to consider that Westwood and Westwood+ have an higher ACK number than other protocols because these are a fundamental parameter to estimate the available bandwidth and, although this conditions brought to a better throughput, it brought also to an higher utilization of the reverse channel.

TABLE I. SIMULATION PARAMETERS

Parameter	***Value***
Satellite link (Mb/s)	2
Packet Size (bytes)	1040
Congestion Windows (MB)	20

VI. CONCLUSIONS

Satellite communications differ a lot from terrestrial one and this affects the performance of transport protocol layer. While TCP works well in the terrestrial environment, modification is necessary to provide good performance in the satellite environment where the TCP assumption that all packet loss is due to the congestion issues results in a severe performance degradation. In this work a comparison between different types of TCP protocols has been performed in order to show the differences between protocols that, until now, do not have been compared. It has been illustrated that terrestrial protocols in GEO satellite scenario have similar performance while a specific protocol called STP, born for satellite platforms, outperforms, in error links condition, other TCP protocols. The contributions of this work are to investigate and evaluate the performance of a group of protocols in order to illustrate the STP protocol benefits in comparison with the other satellite and terrestrial TCP protocols. Many simulations are performed and the graphs of throughput in a GEO scenario are shown. In the future works it will be possible to study and implement other types of protocols in order to make a exhaustive comparison of transport protocol over satellite networks and, by this studies, it will be possible to propose a TCP version modification in order to introduce a possible protocol candidate to resolve many platform issues.

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