Study of a New Transport Protocol for Satellite Links

Andrea Canhoto and Alessandro Anzaloni

***Abstract*— Characteristics of satellite links, such as long propagation delay (MEO and GEO satellites) and high bit error rate (BER) degrade TCP performance. In this work, we describe and analyze a new transport protocol called STP (Satellite Transport Protocol) proposed by ESA (Europeam Space Agency) to be applied in satellite channels. Through OPNET Modeler 10.5A, we simulated a transfer data between two ground stations using a GEO satellite link. We simulated different values of BER in the channel and measured the throughput obtained by TCP and STP. In all cases, STP reached better performance than TCP.**

***Keywords*—STP, TCP, satellite systems, performance**

I. Introduction

The demand for broadband communication and for accessing the service from anywhere, accelerate the development of wireless communication technologies, such as satellite communication systems, which came to be used in the provision of Internet services.

Satellite systems have some advantageous characteristics in respect to wired networks. Among its properties, there are the following: broadcast capability, the possibility of reaching geographically remote areas with little or no terrestrial infrastructure and the ability to provide mobility to users.

Most of the applications on the Internet, such as FTP, HTTP, and Telnet, use the TCP (Transmission Control Protocol) as the transport layer protocol. Originally, this protocol was developed to operate in wired networks, where transmission error rates are small and packet losses are mainly caused by network congestion.

In satellite links, features as large propagation delay (especially for MEO and GEO satellites), and high bit error rates (BER) in the channel reduces TCP performance. This occurs because TCP can not distinguish the cause of packet losses (network congestion or transmission error) and reacts to all losses reducing the transmission rate in the channel.

Proposed solutions can be classified into two categories:

1) Black Box solutions: TCP protocol is modified in the end terminals and the rest of the network components are not accessible;

2) Complete Knowledge solutions: modifications can be applied to any network component, not only to end terminals.

Black Box proposals present modifications to TCP. In general, the authors propose changes to TCP algorithms in face of packet losses and a less conservative behavior at the beginning of the connection [13], [14], [15], [16], [17].

Complete Knowledge solutions suggest new algorithms and protocols to be implemented in the satellite portion. The aim is to isolate the satellite link from the wired portion of the network. With this, a specific transport protocol can be used in the satellite channel, while TCP is maintained at the end terminals. The great delay and packet losses in the satellite link are treated locally, reducing their impact on the TCP performance [5], [6], [7], [8].

In this work, we describe and evaluate the STP protocol, proposed by ESA, in a black box approach. STP implements a new flow control algorithm, in order to maintain the highest possible transmission rate in the network and to efficiently use the resources available to the communication. Also, the SACK (Selective Acknowledge) option [10] is adopted to recover more quickly from multiple packet losses.

At the author's knowledge, the only existing documents about STP are [9] and [18], where there is a description of the protocol. To date, no performance analysis of this protocol has been achieved.

It is important to clarify that the protocol proposed in [19] and [20] is just a homonym acronym. It implements different procedures from those presented in this work. Basically, the transmitter sends packets to the receiver and stores them for potential retransmission. Error recovery is based only on a selective retransmission mechanism similar in concept to the TCP SACK option (but not equal to it) and there are no timeouts. Periodically, transmitter and receiver exchange control messages and so the transmitter may know which segments were correctly received. When an out-of-order segment arrives at receiver, it can immediately send to the transmitter an explicit negative acknowledgement requesting immediate retransmission. At the transmitter, when it receives this request, the specific packet can be retransmitted.

Indeed, in [19] and [20], the authors propose some modifications to TCP's flow control. The transmitter maintains the slow-start algorithm, but uses an initial congestion window greater than 1 MSS (Maximum Segment Size). The congestion window grows exponentially until the receiver's window is reached or congestion is detected (either

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by packet loss or explicit notification). In occurrence of congestion, the transmitter decreases the congestion window by ½ and initiates the congestion avoidance phase. However, different from what occurs in TCP, the slow-start phase is never re-entered, since the protocol doesn't use timeouts.

In this work, our aim is to evaluate the STP [9], [18] performance in a simulated satellite network and compare the achieved results with those obtained by TCP in the same simulation scenario.

Using the software OPNET Modeler 10.5A, we have simulated a data transfer between two earth stations using a GEO satellite channel. In each simulation, the BER of the satellite link has a different value, ranging from 0 to 10^{-10}. We have compared the performance of STP and TCP, taking as performance parameter the throughput obtained by each protocol. In all simulations, STP achieved better performance than TCP, reaching a throughput value of up to 131.64 times the throughput obtained by TCP.

This work is organized as follows: in Section 2, we describe the STP protocol and the new flow control algorithm implemented; in section 3 there is a brief description of the simulation software; in section 4, we show the performed simulations; in section 5, we show the achieved results. Finally, in section 6, the obtained conclusions are presented.

II. STP – SATELLITE TRANSPORT PROTOCOL

STP is a new transport protocol developed by ESA to be applied in networks containing satellite links. To open and close a connection, STP adopts the same procedures implemented in TCP, whose description can be found in [12].

This new protocol adopts the sliding window mechanism to control the data flow in the channel and it doesn't use TCP Slow-Start and Congestion Avoidance algorithms. In order to recover more quickly from multiple packet losses, it uses the SACK (Selective Acknowledgment) option defined in [10].

In the sliding-window mechanism, it is defined the maximum number of segments that can be transmitted before receiving an acknowledgment (ACK). This number of segments represents the transmission window size. For each received ACK, the window "slides" over the range of available sequence numbers and new segments can be transmitted.

Using the SACK option, the receiver can tell the transmitter which segments were received out of order. With this information, the data sender can perform the retransmission of discarded segments. This mechanism makes more efficient the retransmission of various segments of the same transmission window.

Satellite networks have a great product Bandwidth x Delay. This value, called "pipe", indicates the amount of data that the transmitter can send without waiting for a response (ACK) from the receiver. The delay in this product corresponds to the round-trip propagation delay (RTT-Round Trip Time) on the satellite link.

To fill with data the entire satellite link and maintain a continuous data flow, the adopted transmission window in a connection shall be greater or equal to the available pipe.

$$pipe(bits) = BW(bps) x RTT(s) \qquad (1)$$

Furthermore, the transmitter can not send more data than the value of the window informed by the receiver (*awnd*-advertised window).

Therefore, to determine the effective transmission window (W_{STP}), the STP sender must consider these two parameters and takes the least of them:

$$W_{STP} = \min[pipe, awnd] \qquad (2)$$

For each received ACK and/or SACK, the STP transmitter sends new data segments and/or retransmits the discarded segments, in accordance with its transmission window size given by equation (2).

STP also uses a timeout mechanism, that is, a timer is associated for each sent segment. This indicates the period of time during which the transmitter waits for an ACK. If this timer expires, the segment should be retransmitted.

Every transmission, the STP transmitter sends the largest amount of data as possible. With this new procedure, STP can better react to losses in the satellite link, because it doesn't reduce dramatically the transmission rate in the channel in front of packet discards, as occurs with TCP.

III. OPNET SIMULATOR

OPNET Modeler is a network simulation software, which provides a development environment for the modeling, simulation and performance analysis of communication networks [21].

It employs a hierarchical modeling structure divided into three levels: network model, node model and process model.

The *network model* represents the network topology, composed by communication devices (in OPNET called nodes) and links that can be deployed in a geographical context. To create a network model, the Network Editor is used.

The *node model* represents the internal architecture of communication devices, such as routers, workstations, satellites and so on. The Node Editor allows creating node models, which are composed by interconnected modules. Some modules, referred to as processors and queues, are programmable via their process models.

Process models are defined in the Process Editor. They describe the behavior for programmable modules, and may represent protocols, algorithms, applications and queuing policy, for example.

In our work, the STP protocol has been implemented as a new OPNET process model into a processor module called "stp". Also, we have developed the satellite object used in simulations and we have included one wireless interface to a gateway object and to a workstation object (both presented in OPNET library), in order to provide communication between the satellite and the earth elements (base station and workstation B in the simulation scenario).

IV. SIMULATIONS

With the software OPNET Modeler 10.5A, we have implemented the simulation scenario shown in Figure 1. In this scene, two ground stations communicate themselves through a GEO satellite channel.

In simulations, the workstation A sends data to a base station, which guides for the satellite and it sends the data to the workstation B. The satellite link has a transmission rate of 1Mps, a round-trip propagation delay of 530 ms and variable BER.

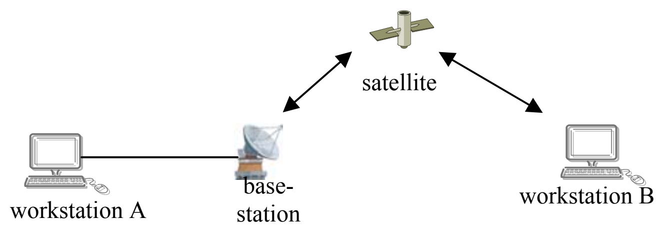


Figure 1. Simulation Scenario

At the transport layer, it was adopted the TCP and STP protocol. For the network layer, it was used the IP protocol and for the link layer any access method is implemented, since there is no dispute for the channel. In this case, the layer 2 protocol only holds the data transfer between network and physical layers. The QPSK modulation is employed.

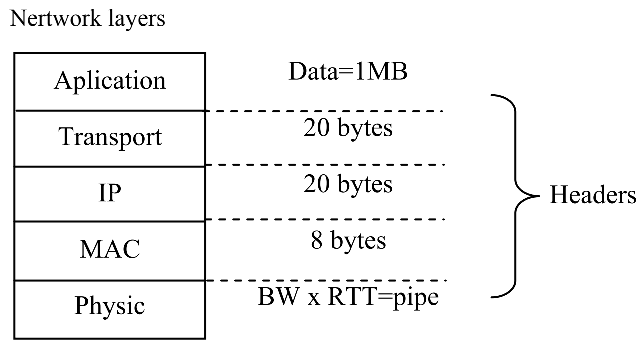
We have adopted the TCP Reno protocol with Fast Retransmit, Fast Recovery and SACK. The configured values of RTO (Retransmission Timeout) are: initial RTO is equal to 1.0s, minimum RTO is equal to 0.5s and maximum RTO is equal to 64s, which are the values commonly used in operational systems.

We have implemented an infinite receiver buffer. So, the STP transmission window (W_{STP}), calculated by the equation (2), is equal to the pipe. We have used a constant W_{STP} equal to 63000 bytes of data. The calculation of this value is shown in Figure 2. The RTO value is fixed in 0.55s, which is slightly higher than the RTT of the channel.

For both protocols (TCP and STP) we used segments of 1000 bytes (MSS - Maximum Segment Size) and the application is the transfer of 1Mbytes of data from workstation A to workstation B. This period of time is counted from the moment when workstation A sends the first data segment until the time it receives the ACK related to the last transferred data segment.

V. RESULTS

To compare the performance of STP and TCP in the implemented scenario, we defined the "goodput" (bits/s) statistic which corresponds to the ratio between the amount of sent data (without headers) and the time provided for such transfer. It is not considered the time spent to open and close the connection. It is important to note that the parameter "amount of sent data" used to calculate the "goodput" statistic is equal to 1MB, which corresponds to the configured application.



BW = 1Mbps; RTT = 0,53s; MSS = 1000 bytes
1 (MSS) + headers = 1048 bytes
pipe = BW x RTT = 530.000 bits = 66.250 bytes

$$W_{STP} = \frac{pipe(bytes)}{1048bytes} = 63{,}21 segments$$

$$W_{STP} = 63000bytes$$

Figure 2. Evaluation of STP transmission window (W_{STP})

Different values of BER were simulated: equal to 0, 10^{-4}, 10^{-6}, 10^{-8} e 10^{-10}. The obtained results are present in Table 1 and in Figure 3.

It is observed that the performance of STP is always higher than that of TCP. In Table 2, it is shown the ratio between the "goodput" of both protocols.

TABLE 1.
"GOODPUT" ACHIEVED BY STP AND TCP S FOR EACH VALUE OF BER

BER	0	10^{-10}	10^{-8}	10^{-6}	10^{-4}
STP goodput	847.034,34	846.201,77	798.264,27	475.729,14	**
TCP goodput	663.473,45	581.610,67	93.003,11	3.586,60	**

Even when there is no packet loss in the channel (BER = 0), TCP achieves less performance than STP. This is because TCP maintains a conservative behavior during data transfer phase, through the use of slow-start and congestion avoidance algorithms [11, 12].

TCP transmitter waits for ACKs from the receiver to adjust the transmission rate in the channel. The long propagation delay of the satellite link slows the receipt of ACKs, increasing the time needed for the transmitter to achieve maximum flow of the channel.

STP initiates the data transfer using a transmission window of 63000 bytes and maintains it constant during all connection life. For each received ACK, new data can be transmitted. With that, STP can best fill the channel and it reaches greater "goodput" than TCP, almost 28% above (BER = 0).

There is much less variation in the "goodput" achieved by STP than that obtained by TCP when the values of BER vary between 10^{-10}, 10^{-8} and 10^{-6}, which shows that the STP is more robust than TCP, in respect to packet losses in the satellite channel. Still, it should be noted that the higher the BER in the channel, bigger is the difference between the "goodput" reached by STP and TCP.

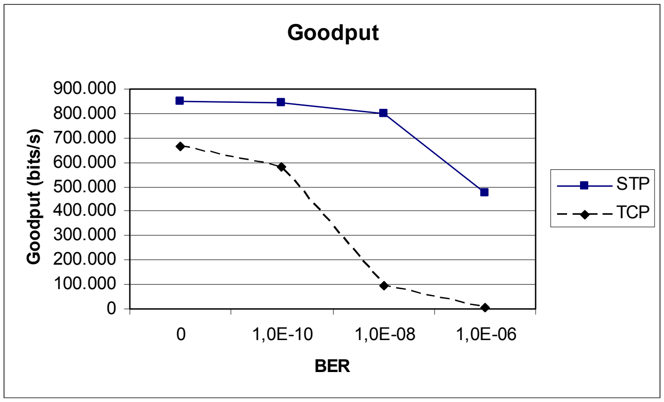


Figure 3. Goodput obtained by STP and TCP for different values of BER

When BER is 10^{-4}, neither of the two protocols has finished the application. That is because with the high BER in the channel, the transport protocol needs to retransmit the segment various times, until it reaches the limit of six (6) retransmission attempts. When this occurs, the connection is aborted. The limit of six (6) retransmission attempts is the amount employed in the TCP and it was kept in STP.

TABLE 2. RATIO BETWEEN THE "GOODPUT" OBTAINED BY STP AND TCP FOR EACH VALUE OF BER

BER	**0**	**10^{-10}**	**10^{-8}**	**10^{-6}**	**10^{-4}**
$STP_{goodput}/TCP_{goodput}$	1,28	1,45	8,58	132,64	**

VI. FINAL CONSIDERATIONS

In this work, we have presented the STP protocol and have evaluated its performance in a simulated satellite channel. To date, no performance analysis of STP had been achieved.

The aim of this work is to evaluate the STP performance in a simulated satellite network and compare the results with those obtained by TCP in the same scenario.

STP doesn't employ slow-start and congestion avoidance algorithms used by TCP and it adopts a new flow control mechanism, in order to maintain the highest transmission rate in the channel during all communication. Moreover, it uses the SACK option to deal with multiple packet losses.

Using the software OPNET Modeler 10.5 A, we have simulated a data transfer between two ground stations across a GEO satellite channel. In each simulation, we used a different value of BER and we compared the *"goodput"* statistic achieved by STP and TCP. It was adopted the TCP Reno with Fast Retransmit, Fast Recovery and SACK. It was implemented the following values of BER in each simulation: equal to 0 (lossless channel), 10^{-10}, 10^{-8}, 10^{-6} and 10^{-4}.

In all examined cases, STP presented really better performance than TCP, with a "*goodput*" from 1.28 to 132.64 times the "*goodput*" obtained by TCP.

Indeed, it should be noted that the higher the BER in the channel, bigger is the difference between the "*goodput*" reached by STP and TCP. This fact shows that the new flow control mechanism of STP makes it less sensitive to packet losses on the satellite link than TCP.

Considering these initial results, we have noted that STP is a good alternative as a new transport protocol for a satellite channel and it is important to further investigate it, for example to analyze the STP behavior in presence of network congestion.

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