The Use of Split-Connection in Satellite Networks
Andréa de Fátima Ferreira Canhoto*, Alessandro Anzaloni*

*ITA - Instituto Tecnológico de Aeronáutica – Brazil
andreafc@ita.br
anzaloni@ita.br

Abstract: In this paper, we discuss the use of the split-connection mechanism in networks involving satellite links. Many researches adopt this procedure in order to isolate the satellite channel from the wired portion of the network, which make possible to maintain TCP protocol in the end-users, while in the satellite link another protocol may be implemented, more suited for the wireless link characteristics, such as long propagation delay and high bit error rate. Though simulation using the software OPNET Modeler 10.0A, we have analyzed the impact of packet losses in the satellite channel, with different values of bit error rate, in the establishment of the end-to-end connection when split-connection procedure is adopted. In this study, we have assumed the Satellite Transport Protocol (STP) proposed by European Space Agency as the transport protocol for the satellite link and the CCSDS AOS recommendation as the Data Link protocol. Simulation results demonstrate that high bit error rate in satellite systems in conjunction with the long propagation delay may prevent the establishment of the end-to-end connection due to TCP implementations of several operational systems (Windows).
Key words: bit error rate, CCSDS, RTO, satellite, split-connection, STP.

1 Introduction

With the increasing use of satellite for data communication, a lot of researches have been made in order to achieve the best utilization of the channel.

Considering the need to provide Internet services, satellite systems must support Internet protocols.

Many Internet applications, such as HTTP, Telnet and FTP, utilize the TCP – Transmission Control Protocol – as the transport protocol, whose algorithms (Slow Start and Congestion Avoidance) are well suited for wired networks (Stevens, 1997).

However, satellite links have different characteristics from wired links, which results in a poor TCP performance in wireless channels.

In wired links, the common cause for packet losses is network congestion. While in satellite links losses are mostly related to transmission error.

In fact, TCP may not distinguish between these losses. It interprets all of them as caused by congestion and reacts activating its congestion control algorithms, reducing its transmission rate. As a consequence, TCP presents a low performance when applied to a satellite channel (Barakat & al., 2000, Metz 1999, Partridge & al., 1997).

The two major factors that degrade the behavior of TCP are long propagation delay and high bit error rate (BER).

To solve this problem, many works have been made in order to propose improvements to TCP or even a new transport protocol for use with satellite networks (Durst & al., 1996, Peng & al., 2001, Allman & al., 1999, Allman & al., 2000).

A lot of proposals adopt the mechanism called “split connection”, which consists of partitioning into segments the end-to-end connection between a sender and a receiver, involving wired and satellite networks. With this procedure, the satellite link can be isolated from the wired portion and new protocols more adequate for link characteristics can be applied to it.

Indeed, split-connection makes it possible to maintain the TCP protocol in the end users, which implies in fewer changes in the network in order to support the improvements added.

In the split-connection, each segment of the network corresponds to a sub-connection of the end-to-end connection between end-users. To establish the end-to-end connection, all sub-connections must be opened too.

In this work, we present STP (Satellite Transport Protocol) proposed by ESA (European Space Agency), which adopts the split-connection mechanism. Indeed, we investigate the impact of propagation delay and bit error rate of a satellite channel in the establishment of the end-to-end connection, considering the TCP
implementation of some operational systems (Windows).

Using OPNET Modeler 10.0A software, we simulated a satellite link with data rate of 1 Mbps and BPSK modulation, using the following protocols: STP for the transport layer, IP (Internet Protocol) for the network layer and CCSDS AOS recommendation (see section 5) for the Data Link layer.

Though simulations, we investigated the packet losses in the satellite channel for different values of bit error rate and how they impact the establishment of the end-to-connection when split-connection is adopted.

This work is organized as follows: Section 2 describes the split-connection procedure and its advantages. Section 3 presents the STP protocol proposed by ESA and considered in this study. Section 4 discusses some important aspects for the establishment of the end-to-end connection considering the split-connection, a satellite link and TCP implementations on some operational systems. Section 5 defines the CCSDS Data Link recommendation and Section 6 discusses the simulation results.

2 Split-connection

Many works have been made in order to develop a transport protocol more suited for a satellite channel, which has characteristics, such as high bit error rate and long propagation delay that degrade the TCP performance when applied to this link.

TCP was designed to operate in wired networks, where congestion is the major cause of packet losses. However, in wireless links, many losses occur due to transmission error.

As TCP can not distinguish the reason for packet losses, it interprets that all are caused by congestion and activates its congestion control algorithms – Slow Start and Congestion Avoidance – reducing the transmission rate. This results in a low end-to-end TCP performance in wireless channels.

Many works have pointed out the behavior of TCP in satellite links and many proposals have been made to improve its performance. A lot of them adopt the split-connection mechanism.

In a split connection, the network between two end users is divided into (wired) terrestrial portion and a satellite one.

Each part of the network corresponds to a sub-connection of the end-to-end connection. Of course, the establishment of the end-to-end connection implies in opening all respective sub-connections.

With split-connection, it is possible to isolate the satellite link from the wired portion and apply in it a new transport protocol more suited for links characteristics in order to obtain a better end-to-end performance, while the standard TCP is maintained in the end-users.

Improvements to TCP or other transport protocols have been proposed in many publications following the split-connection philosophy (Henderson & al., 1999, Peng & al., 2002, Stepanek & al. 2002, Zhu & al., 2003).

3. STP - Satellite Transport Protocol


STP implements algorithms distinct from those adopted in TCP, which must result in a better performance in satellite links.

At the ESA project, it is assumed a hybrid network with a terrestrial portion and a satellite one, as shown in Figure 1.

In this architecture the split-connection is adopted. So the end-to-end connection is divided into parts. In the parts corresponding to the terrestrial networks, TCP is maintained, while in the satellite link STP is implemented.

For each part of the network, a sub-connection is established. The relay between the sub-connections is made by the gateways (Gateway A and Gateway B in Figure 1) that convert TCP segments into STP segments and vice-versa.

Figure 1. Network with terrestrial links and a satellite link.

The establishment of the end-to-end connection implies in the establishment of a sub-connection for each part of the network.

STP adopts the same “three-way handshaking” procedure used by TCP to open a connection (Tanenbaum, 2003), where each pair of entities involved in the establishment of a connection changes three segments indicating the intention to open a connection.

The changing of TCP/STP segments in the proposed architecture for the establishment of the end-to-end connection is depicted in Figure 2.
In this proposed architecture, the end users (Host A and Host B) implements TCP protocol, while the gateways uses TCP in the wired link (link between Host A and Gateway A and link between Host B and Gateway B) and STP protocol in the satellite channel (link between Gateway A and Gateway B).

As illustrated in figure 2, to establish a connection between the end users, the Host A initiates the “three-way handshaking” with Host B (black segments in the figure).

At first, Host A sends the SYN1 segment to Host B. When SYN1 arrives at Gateway A, it forward the segment to Gateway B, which forward the segment to Host B.

When the SYN1 segment arrives at Host B, it generates an ACK_SYN1 segment to Host A indicating the arrival of SYN1 and the intention to open a connection too.

When Gateway B receives the ACK_SYN1, it then opens a (TCP) sub-connection with Host B, which is illustrated by the blue segments in figure 2. After this, it forwards the ACK_SYN1 to Gateway A.

With the arrival of the ACK_SYN1, Gateway A starts to open a (STP) sub-connection with Gateway B, indicated by green segments in figure 2. And then it sends the ACK_SYN1 to Host A.

When Host A receives the ACK_SYN1, it opens a (TCP) sub-connection with Gateway A (red segments) and sends the ACK1 segment to Host B.

So, the end-to-end connection, and all sub-connections involved are established.

In the satellite link, during the phase of connection establishment, if the SYN1 or ACK_SYN1 segment is lost, the gateways are not responsible to retransmit them. The retransmission of these segments is made by Host A or Host B.

During this phase, the gateways only retransmit the segments involved in the establishment of the STP sub-connection (green segments in figure 2).

4. The use of split-connection

In the proposed STP architecture, TCP is maintained in the terrestrial network while STP is implemented in the satellite channel.

As described in the earlier topic, to open the end-to-end connection, all sub-connections involved must be established too. The procedure adopted by STP is the same three-way handshake used in TCP, as is shown in Figure 2.

In the proposed scenario shown in Figure 1, the end-users Host A and Host B are running TCP protocol. So, when Host A wants to send data to Host B, it first sends a SYN segment to Host B to indicate the intention to open a connection with it.

When a SYN segment is sent, the sender starts a timer called RTO (Retransmission Time Out timer) and waits for an acknowledgement (ACK segment) from the receiver during this period. According to the arrival or not of the respective ACK, RTO is adjusted through the Jacobson’s algorithm and Karn’s algorithm (Comer, 2000, Jacobson, 1988, Tanenbaum, 2003).

If the sender receives the respective ACK, the new RTO value is calculated in function of the measured round-trip time. If the ACK doesn’t arrive, the sender duplicates the RTO and retransmits the segment.

RFC (Request For Comments) 1122 and RFC 2988 specifies some limits to be used in RTO implementations, as for example “initial RTO” and “maximum RTO” (Braden, 1989, Paxson & al., 2000).

Table 1 illustrates some parameters related to connection establishment and RTO timer adopted in TCP implementation for several Windowa operational systems (OPNETWORK, 2003).

<table>
<thead>
<tr>
<th>Operational System</th>
<th>Initial RTO (s)</th>
<th>Maximum RTO (s)</th>
<th>Maximum Connection Attempts</th>
</tr>
</thead>
<tbody>
<tr>
<td>NT (3.5/4.0)</td>
<td>3</td>
<td>64</td>
<td>3</td>
</tr>
<tr>
<td>Win 98</td>
<td>3</td>
<td>64</td>
<td>3</td>
</tr>
<tr>
<td>Win 2000</td>
<td>3</td>
<td>64</td>
<td>3</td>
</tr>
<tr>
<td>Win XP</td>
<td>3</td>
<td>64</td>
<td>3</td>
</tr>
</tbody>
</table>

In Table 1, the “Initial RTO” parameter represents the initial value used for RTO by the sender. The “Maximum RTO” parameter is the maximum value that RTO may assume, since it is adjusted during the communication as described earlier.

The operational systems specified in Table 1 adopt
the limit of 3 attempts to establish a connection.

So, in order to open a connection, the sender generates a SYN segment and waits for an ACK during 3 seconds ("initial RTO"). If the SYN or the respective ACK is lost, the RTO will expire. Then the sender retransmits the SYN and now waits for an ACK during 6 seconds (duplicates the RTO). Again, if another loss occurs, RTO will expire. So, the sender tries to open the connection for the third and last time, with the same procedure, now adopting a RTO of 12 seconds.

As the considered scenario involves a satellite link, with long propagation delay and high bit error rate, the delays introduced in conjunction with packet losses may cause successive RTO expiration in such a way that the limit of 3 connection attempts is achieved and the end-to-end connection is not opened.

Of course, the wired link introduces delays to the communication. However, in this work we consider that the propagation delay of the satellite link is significantly bigger than others delays (processing or transmission delays in any link and propagation delay in wired link). So they can be ignored.

Though simulations, we analyze the influence of satellite channel in the establishment of the end-to-end connection in the referred scenario illustrated in Figure 1. For this, we simulated different bit error rates and collected the average and maximum number of retransmissions, which reflect the occurrence of losses in the satellite link.

In this work, we analyze the phase of connection establishment, considering the split-connection mechanism and the STP protocol in the satellite channel.

Observing Figure 2, we verify that for the limit of 3 attempts to establish a connection, imposed by TCP implementations in the operational systems mentioned in Table 1, if the SYN1 or ACK_SYN1 segment is lost in three successive attempts, the connection will not be opened, since the gateways don’t retransmit these segments and so the RTO in the end user will expire.

5. CCSDS Data Link

In this paper, we have adopted the Consultative Committee for Space Data Systems (CCSDS) recommendation for Space Data Link standard.

CCSDS is an organization formed by many member Space Agencies, as for example European Space Agency (ESA), National Aeronautics and Space Administrations (NASA), British National Space Centre (BNSC), Canadian Space Agency (CSA) and Agenzia Spaziale Italiana (ASI).

Periodically, member Space Agencies and other observer agencies meet to address data systems problems and propose technical solutions.

CCSDS have specified the Advanced Orbiting Systems (AOS) Space Data Link protocol. AOS is a Data Link protocol for use in transferring any data over ground-to-space, space-to-ground or space-to-

Figure 3. CCSDS Layers x OSI Layers

AOS uses Transfer Frames of fixed-length, determined for a particular physical channel during a particular space mission. Each Transfer Frame is composed by a header which provides protocol control information and a fixed-data field which carries higher-layer data units.

The Synchronization and Channel Coding Sublayer provides three additional functions: synchronization, error-control coding and pseudo-randomizing. The two later functions are optional.

To guarantee synchronization, the recommendation specifies an Attached Sync Marker (ASM). ASM consists of code symbols attached to Transfer Frames (coded or not coded). Its length varies from 32 bits to 192 bits, depending on the use or not of error-control code and which codification is adopted.

CCSDS Recommendation for AOS Space Data Link Protocol and for TM Synchronization and Channel Coding describe in details all services provided by the AOS protocol, the fields of Transfer Frames and all functions and code methods specified for the Synchronization and Channel Coding sublayer (CCSDS, 2003 (a), CCSDS, 2003 (b)).
In this paper, we have assumed that the Data Link layer (considering the two sublayers) adds a header of 36 bytes to data received from higher layer.

6. Simulation Results

The simulation was made using the OPNET (Optimum Network Performance) Modeler 10.0A software.

The simulation scenario implemented is shown in Figure 4. It corresponds to the satellite link of Figure 1.

Figure 4. OPNET Simulation Scenario

In this study, we analyze the communication between the two Gateways (A and B), considering different values of bit error rate (BER) in the channel.

For each BER, we verified the average and maximum number of retransmissions, which reflects the occurrence of packet losses. With this value, it is possible to analyze if the limit of three connection attempts imposed by the operational systems mentioned in Table 1 would be achieved and if a connection between two end-users involving the specified satellite channel would be established.

We assumed the proposed STP architecture and CCSDS AOS recommendation as the Data Link protocol. Also, in our simulations, retransmissions are implemented in the Data Link Layer not in the transport layer.

For our simulation, we consider that AOS Data Frame (without data field) plus the Attached Sync Marker (ASM) from Synchronization and Channel Coding sublayer result in a Data Link header of 36 octets.

It was simulated a satellite channel of 1 Mbps and BPSK modulation. For transport and network layers, STP and IP (Internet Protocol) protocols are assumed.

As described earlier, in phase of connection establishment, STP implements the same “three-way handshake” procedure used by TCP. So the segments involved during this phase are all of 20 bytes. Indeed, the IP protocol adds a header of 20 octets to the STP layer data.

With STP, IP and CCSDS Data Link layers, we have frames of 76 bytes send to the physical layer.

In this work, we simulated the sending of a SYN segment from Gateway A to Gateway B and the receiving of the respective ACK_SYN segment generated by Gateway B.

Through these simulations, we can analyze the occurrence of packet losses in the satellite link.

As explained earlier, if at least three retransmissions are observed in the link, which represents the occurrence of 4 packet losses in the satellite link, and if these segments are the SYN1 and ACK_SYN1 segments of figure 2, the limit of 3 connection attempts imposed by the operational systems will be reached and the end-to-end connection will not be established.

Table 2 shows the results obtained for different values of bit error rates.

Table 2 – Number of retransmissions for BPSK modulation and different values of BER.

<table>
<thead>
<tr>
<th>BER (average)</th>
<th>SNR - Signal to Noise Ratio (dB)</th>
<th>Average number of retransmissions</th>
<th>Maximum number of retransmissions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,3x10^-3</td>
<td>5,0</td>
<td>235</td>
<td>255</td>
</tr>
<tr>
<td>1,2x10^-3</td>
<td>5,99</td>
<td>14</td>
<td>98</td>
</tr>
<tr>
<td>7x10^-4</td>
<td>6,99</td>
<td>2,3</td>
<td>22</td>
</tr>
<tr>
<td>2x10^-4</td>
<td>8,0</td>
<td>0,3</td>
<td>6</td>
</tr>
<tr>
<td>2x10^-5</td>
<td>9,0</td>
<td>0,03</td>
<td>2</td>
</tr>
</tbody>
</table>

From table 2, we verify that for satellite channels with SNR equal to 5 dB or 6 dB (BER equal to 1,3x10^-3 or 1,2x10^-3) the connection between two end-users using the split connection mechanism won’t be established for the mentioned Windows systems. That is because the average number of retransmissions obtained indicates a great number of packet losses. This implies that the limit of three connection attempts will be achieved and consequently the connection won’t be opened.

For SNR equal to 7 dB or 8 dB (BER equal to 7x10^-4 and 2x10^-4 respectively), were observed an average number of retransmissions less than 3, which make it possible to open the end-to-end connection. However the maximum number of retransmissions is bigger than the limit of 3. So, it is still possible to not establish the end-to-end-connection.

For SNR equal to 9 dB (BER = 2x10^-5) or bigger, the number of retransmission s were always less than 3, so for this value of BER the connection will always be established for the referred operational systems.

From our simulations, we have verified that in researches for developing a transport protocol applicable for satellite links in which the split connection mechanism is assumed, it is important to consider the bit error rate of the wireless link, because it will cause packet losses that can prevent the
establishment of the end-to-end-connection for some operational systems.

Conclusions
In this work we have presented the split-connection procedure that is greatly used in many researches related to the development of a transport protocol for a satellite link.

The STP architecture proposed by European Space Agency is described and some aspects of satellite channel characteristics are discussed.

Though simulation using the OPNET Modeler 10.0A software and considering TCP implementations in some Windows operational systems, we have analyzed how packet losses in the satellite link, with different values of bit error rate, can impact the establishment of an end-to-end connection, when split-connection mechanism is implemented.

The obtained results have demonstrated that for satellite systems with high bit error rate, in the order of $10^{-3}$ and $10^{-4}$, the end-to-end connection may not be established. For less bit error rates, it doesn’t represent a problem.

So, when the split-connection procedure is adopted in the development of protocols for satellite links, it is important to analyze the limitations imposed by the TCP implementations in the operational systems and also the bit error rate of the satellite link because they can prevent the establishment of the end-to-end connection.

Acknowledgment
The authors wish to thank ATECH Corporation for providing the software OPNET Modeler 10.0A used in this work.

References


