A New TCP Bandwidth Estimation Protocol for Satellite Networks

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***Abstract*—Satellite communications represent an important slice of the global communications sector thanks to their broadcast nature. Unfortunately, TCP used on satellite links suffers from a number of well-known performance issues, especially for high altitude satellites with longer delays. In this paper, a new TCP protocol is proposed. This new protocol arises after a careful study of the various protocols present in literature that try to resolve the typical satellite issues. Our TCP protocol is called Available bandwidth adaptable Transport Protocol (ATP) and it takes the advantages of two TPC protocols proposed in literature: Satellite Transport Protocol (STP) and TCP Jersey. In particular, it consists of a reviewed version of STP protocol with the addition of the TCP Jersey Bandwidth Estimation algorithm called Available Bandwidth Estimation (ABE). In order to show the goodness of the proposed protocol we have performed some comparisons between ATP, STP, TCP Jersey and another TCP protocol called Satellite Communication Transmission Protocol (SCPS-TP).**

Keywords—TCP; Satellite; ATP; TCP Jersey; STP; SCPSC-TP

I. INTRODUCTION

Due to their wide coverage area, satellites play a significant role in global broadband services. The management of applications that require end-to-end QoS constraints in satellite networks arises the problem of the transport layer performance and in particular of TCP. Such platforms can augment terrestrial services especially in remote areas, where the terrestrial infrastructure remains too expensive for deployment and start up. DVB-RCS satellite networks on Ka band have achieved great success [1][2] by providing direct broadband access to user requiring specific multimedia applications. In these scenarios, TCP plays a critical role. It is important to investigate the role of TCP also in HAP platforms [3] and the contribution in call admission control phase [4] especially for multimedia traffic. Unfortunately, when used with satellite links, TCP suffers from a number of well-known performance issues, especially for higher data rates and high altitude satellites with longer delays [5][6]. Long delays increase the duration of the slow start interval, because the slow start process depends upon the Round Trip Time (RTT) of the connection. Estimating the RTT dynamically, the interval between the sending of a packet and the receipt of its acknowledgement, is a key function in many reliable transport protocols. Such estimations are used to ensure that data is reliably delivered. If a packet remains unacknowledged for too long time, it is assumed to have been lost and it is retransmitted. The loss characteristic of the link creates more problems. The flow-control mechanism of TCP relies on lost packets as indicators of congestion. While this assumption is true for wired networks, it fails for many wireless links including satellites. So when the TCP connection experiences relatively frequent losses from link-level errors, TCP performance degrades [5][6]. Another issue is the asymmetric channel that previews the bandwidth available in the forward channel to be much higher than that in the reverse channel. This channel asymmetry means that ACK packets may congest the reverse channel, and then they can be delayed and/or lost. Many algorithms have been studied by researchers in order to face these problems. Some solutions involve changes to the protocol mechanisms to accommodate the properties of satellite links, others propose new protocols studied purposely for satellite networks. In our work we propose a novel protocol, called Available bandwidth adaptable Transport Protocol (ATP), that arises after a careful study of the various protocols present in literature that try to resolve the typical satellite issues. In particular ATP takes the advantages of two TPC protocols proposed in literature: Satellite Transport Protocol (STP) [1] and TCP Jersey [6]. STP is projected so as to provide a TCP-like operation, avoiding the issues typical of satellite links and offering an optimal behaviour. TCP Jersey makes use of a sender enhancement through the Available Bandwidth Estimation (ABE) algorithm and ECN-like explicit congestion notification scheme called Congestion Warning (CW). The paper is organized as follows: section II gives a brief overview of the related work; STP and TCP Jersey is presented in section III; some observations of STP and TCP Jersey are summarized in section IV; the proposed TCP algorithm is presented in section V; section VI describes the performance evaluation; and finally, conclusions are summarized in the last section.

II. RELATED WORK

Related works on the TCP performance applied to Satellite IP networks [7][8] 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 [9],[10]. 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 [10]: set of extensions on the classic TCP making the protocol capable of reacting correctly towards the aforementioned problems. STP [12][13]: transport protocol TCP-like studied specifically to have high performance in the satellite environment. TCP Westwood [14] (and TCP Westwood+ [15]): protocol which, through a bandwidth estimation, reduces its congestion window. TCP Jersey [6]: 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 [16] (TCP Peach+ [17] and TCP Swift [18]): protocol with two new Slow Start and Fast Recovery algorithms to have a new congestion control scheme with good performance in satellite networks. In [20] 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 [21] 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 [22] and [25] 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 [23] 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 [24] authors propose another TCP version for satellite networks called Cubic, that results to work well in this type of networks.

III. STP AND TCP JERSEY OVERVIEW

In this section a brief overview of TCP protocols considered as the basis of our idea is introduced.

A. Satellite Transport Protocol (STP)

STP [12] is a protocol developed appositely for satellite networks. It is projected so as to provide a TCP-like operation, avoiding the issues typical of satellite links and offering an optimal behavior. The satellite link issues considered by this protocol are: variable RTT, link asymmetry and performance degradation due to link errors. STP, like TCP, provides a reliable and byte oriented service to applications [13]. The sender transmits a packet on the network and stores it for future retransmissions until its ACK is not received. This protocol makes use of negative ACK through a packet enumeration and, on the contrary of standard TCP for wired networks, only the explicitly requested packets will be retransmitted without adopting any retransmission timers. The main difference between TCP and STP is in the acknowledgment method. TCP sends an ACK for each received data packet while in STP the sender forwards an acknowledgment request to the receiver on a periodical basis. In this case, after the reception of this explicit acknowledgment request, the receiver will notify received packets and further gaps in the ordered data sequence. Further, the receiver, in STP, can request on its behalf, the retransmissions of not received data packets. The combination of these strategies leads to a lower use of the bandwidth on the reverse channel and an increasing speed of loss recovery. For this purpose STP uses four packet types: SD: data packet; POLL: acknowledgment request at receiver; STAT: response of receiver at POLL message; it contains the buffer state at the receiver with any gaps. USTAT: autonomous request of retransmission sent from receiver to the transmitter; it indicates one or more packet losses in the ordered data sequence at the receiver. It is interesting to observe how the USTAT also reduces the POLL/STAT messages exchange (typically 3 POLL for one RTT). It is important to specify that USTAT is sent after receiving a certain number n of data packets.

B. TCP Jersey

Standard TCP degrades in Satellite networks because it does not discriminate the causes of packet losses. TCP Jersey is able to reach this purpose [19]. 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:

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

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:

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

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.

IV. Observations on STP and TCP Jersey

On the basis of the observed behavior of the two considered protocols, it is possible to make some observations. The benefits of the STP protocol are the following. Partial Slow Start: STP stays in the Slow Start phase just at the beginning of the connection; after verifying the *cwnd>ssthresh* condition, it goes in the Congestion Avoidance phase. Transmission Timer Independence: this leads to benefits because the comeback in the Slow Start phase can be eliminated (this situation is avoided by the STP). Thus, the sensitivity of the RTT variation cannot affect the system performance, because the transmission timer expirations are not considered. Better use of the reverse channel: the acknowledgment STP scheme based on the receiver request (POLL/STAT) determines advantages on the reverse channel because the ACK traffic overhead is reduced. Thus, this approach can also provide a solution to the link asymmetry problem. Negative ACK usage: applying the selective negative ACK (USTAT) permits the data loss to fast recovery and to reduce the POLL/STAT packet exchange rate contributing to the reduction of traffic on the reverse channel. These characteristics show as it is better to project a protocol specific for Satellite rather modifying the standard TCP protocol. However, an accurate protocol analysis shows some drawbacks listed below to be corrected. USTAT is not fully used from the STP sender. For example, the following info could be carried inside the USTAT packet: Packet timestamp: the current RTT value is updated just when a STAT packet is received. However, if this updating could be done also when a USTAT packet is received, the RTT estimation will be more accurate and so a better management of timer for the transmission of the POLL (3 for each RTT) could be obtained. The higher sequence number packet info: USTAT carries the info about the highest sequence number packet received from the destination in a ordered data sequence. This means, in the case in which a packet with a higher sequence number in comparison with sequence number of the last received ACK is observed, that also in the presence of data loss, the destination received other packets and so it could increase its transmission window. No discrimination on the causes of data losses: the STP sender, after the reception of a STAT with gap info or a USTAT, is not able to discriminate the causes of data loss and it considers the data losses as due to network congestion reducing the transmission window to half of its size. Concerning TCP Jersey, the drawbacks will not be introduced ,because they are similar to those of the standard TCP. TCP Jersey performs better than standard TCP in Satellite networks because the ABE algorithm and the CW on the router permits the discrimination of the congestion losses from erroneous satellite link losses.

V. Available bandwidth adaptable Transport Protocol (ATP)

From the previous observations it is clear how the development of a new TCP protocol specific for Satellite networks is better than the extensions or modifications of an existing TCP projected for wired networks. For this reason, we prefer to adopt STP as the basis of our work. However, STP presents the issues cited in the previous section. In order to eliminate the problems of STP it is possible to introduce some simple modifications in the USTAT message on the sender side and to adopt a bandwidth estimation algorithm such as that adopted by TCP Jersey to discriminate the causes of data losses. Thus, our proposed protocol called Available bandwidth adaptable Transport Protocol (ATP) is based on the STP but the estimation algorithm is introduced in its basic mechanism and the USTAT info is better used. The USTAT modification permits info to be obtained from the sender side useful for congestion window management and RTT updating in order to regulate the transmission timer of POLL packets in an efficient manner. On the other hand, the introduction of the ABE algorithm needs modification by router for the CW support and the receiver to become ECN-capable. On the basis of the STAT packet reception with losses or USTAT with congestion detection, the sender can request the opening or closing of its congestion window. The reception of an un-marked packet, both STAT packet with losses and USTAT, is interpreted as a link error and it will not determine a window closing. On the other hand, when the USTAT or STAT packet is marked, this means a congested network and the congestion window needs to be closed. In the case of the congestion window decreasing, the reduction will be finer, because it is possible to consider the optimal threshold value calculated on the basis of the ABE algorithm. If the congestion window size is below this threshold value a decrease of the congestion window is non-useful because the network is below its saturation level; in the case in which this threshold is exceeded, a great reduction of the congestion window is necessary. At this point it is verified if the actual window half size exceeds the threshold. If this value is greater than threshold the congestion window should be reduced to this value (threshold), while, in the case that it is lower, the window size can be reduced to half of its actual size in accordance with the classic TCP for wired networks. This policy of window decreasing leads to better performance because the discrimination between data losses due to link errors or network congestion permit to correctly decide whether it is suitable to reduce or to leave the window size unaltered.

A. ATP Flow Chart

The protocol behavior is presented in Figure 1, where the modifications made to the STP protocol in order to make the bandwidth estimation of TCP Jersey are indicated through rectangles. The automa is from the sender side. The variables used in the flowchart and STP protocol are the following: *cwnd*: congestion window; *ssthresh*: Slow Start threshold; *advance*: acknowledged segments number; *congested*: boolean variable, it is set to 1 to indicate congested network; ECN: boolean variable set to 1 from CW router if the networks notifies congestion; *seq*: highest sequence number acknowledged in the USTAT packet; *highest_ack*: highest sequence number acknowledged at sender in a STAT or USTAT packet. The functions are the following: *opencwnd(advance)*: increase *cwnd* of advance segment number; *rtt update( )*: RTT updating; *reset()*: agent creation;

reduce_to_est_rate( ): reduce *ssthresh* to the more suitable value according with available estimated bandwidth. If it is necessary, also *cwnd* is reduced. The main automa states are BEGIN (connection start), SENDING SD + 3 POLL x RTT (sending state) and ABE COMPUTATION. The automa stays in the sending state until the reception of a packet from receiver: in ATP this event determines a verification of packet header to see whether ECN is equal to one or not. If ECN is set to 1, the network routers notify the congestion state and the variable congested is set to 1.

In this way the mechanism of congestion detection through the network router is introduced. After this control the automa goes into the ABE COMPUTATION state where the available bandwidth is estimated through the ABE estimator. Also in this case a different management is effected according to the type of received packet.

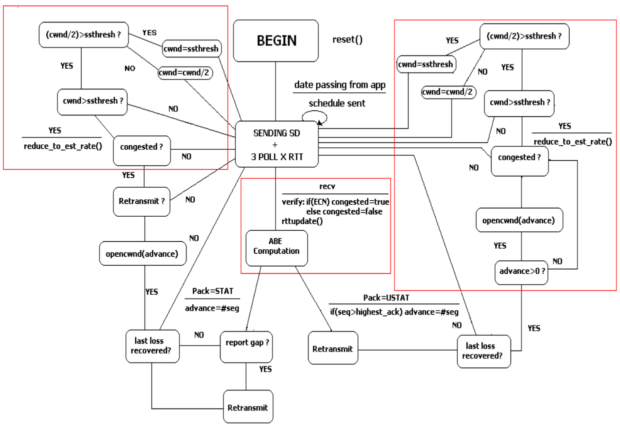

Fig. 1. Flow Chart of ATP

STAT packet reception

The STAT packet reception determines the same behavior as STP. After the setting of the advance variable, it is verified whether some gaps are detected. If they are detected, the lost segments will be re-transmitted, otherwise the system will go into the next state of the flow chart. In this state it is verified whether the previous loss has been recovered. If it is recovered the system will go back into the sending state, otherwise the window of the agent will be opened by an amount equal to advance. As in STP, it is verified whether the STAT packet will cause re-transmissions. If re-transmissions are verified, on the contrary of STP, more accurate window size reduction based on the ABE algorithm will be effected, otherwise the system goes back into the sending state. When the network notifies traffic congestion, window closing becomes necessary and, for this purpose, the function *reduce_to_est_rate()* is recalled. At this point, it is verified also whether the window should be reduced and this can happen if the optimal threshold is verified. In this case, it is verified whether the window size needs to be reduced by half or whether the procedure of resizing the TCP Jersey could be effected.

USTAT packet reception

The next step is the verification of the advance state. If it is greater than 0, *cwnd* is increased by the advance otherwise, as in the case of STAT reception, the state of congested variable is verified. If this variable does not present the network congestion state, it means that it is not necessary to close the congestion window, otherwise it needs to be resized in the same way as analysed for the STAT packet.

VI. Performance Evaluation

A. Simulation Scenario

The simulation scenario used for validating our idea and for comparison purpose is the ns-2 simulator. The simulated network consists of two terminals (transmitter and receiver) connected to a GEO satellite. The TCP protocols considered in this system are: ATP, STP, TCP Jersey and SCPS-TP. No standard TCP such as SACK was considered, because the comparison would not be useful considering the different SACK mechanisms or other standard TCP protocols suitable for wired-networks, but not performing well in satellite networks. We considered more interesting to compare some solutions appositely developed for Satellite networks. The parameters considered in the performance evaluation comparison are: Data throughput at receiver: it is the ratio between the number of data packet received at the destination and the considered time interval. ACK throughput at sender: it is the ratio between the number of ACK received at the transmitter and the time interval. Number of ACK at sender: number of ACK received at the transmitter. The GEO satellite presents the following characteristics; 2Mbit of bandwidth in uplink and down link; Internal queue with CW and a buffer size of 50 packets. Two ground stations are collocated at the Berkley coordinate (in up-link toward the satellite) and Boston (in down link from the satellite). On the down-link channel is inserted a packet loss probability (packet error rate – PER) variable in the range [0,001-10] percent. An FTP connection for data transfer of ten minutes (600 sec.) as duration is considered.

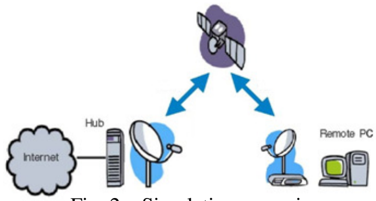

Fig. 2. Simulation scenario

B. Simulation Results

In the following the results obtained. The data throughput at the receiver for different considered TCP protocols is depicted in Figure 3. It is interesting to see how ATP presents a higher throughput in comparison with SCPS-TP and TCP Jersey. This is due to the better network state info carried by USTAT and to the more precise polling that allows a good estimation of the RTT value. Further, when the PER is higher, ATP also outperforms the STP, because our proposed protocol makes use of the ABE inherited by TCP Jersey that permits a better management of the congestion window. An index related to the reverse channel utilization is presented in Figure 4 and Figure 5. A good management in the satellite networks consists in a lower utilization of the reverse channel for ACK traffic. For this purpose, the throughput of received ACK is depicted in Figure 4. As it is possible to see, the throughput is lower for ATP and STP in comparison with the other considered TCP protocols and this is due to the better acknowledgment method (STAT/USTAT) proposed. Through this improvement on the reverse channel, it is possible to use the satellite link for other data traffic. This result can be confirmed in Figure 5 where the ACK number is lower for ATP and STP as expected.

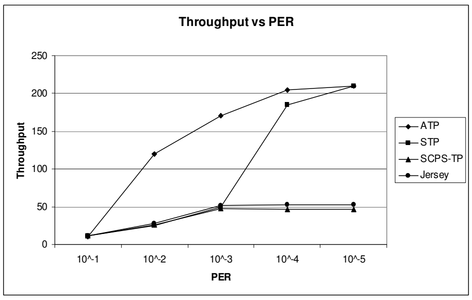

Fig. 3. Throughput data vs. PER

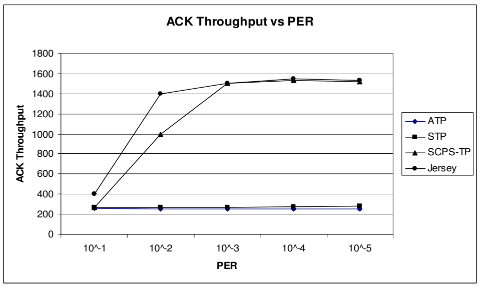

Fig. 4. Throughput ACK vs. PER

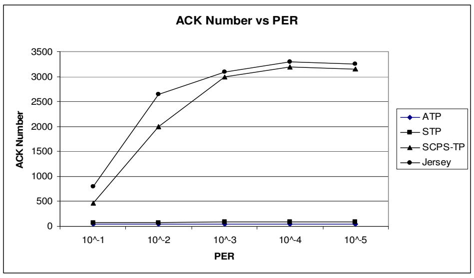

Fig. 5. Number of ACK vs PER

VII. CONCLUSIONS

In this paper it has been proposed a new Satellite TCP protocol. After having performed a deep study on TCP protocols present in literature we have chosen two enhanced protocols, STP e TCP Jersey. In particular our protocol, called Available bandwidth adaptable Transport Protocol (ATP) consists in a reviewed version of the STP protocol. ATP introduces more info in the USTAT packet in order to better regulate the sender side, the congestion window and the RTT estimation. Further, it introduces the ABE algorithm and the CW on the TCP Jersey router in order to know the degree of congestion in the network. It has been shown that our proposal outperforms other TCP protocols through a set of simulative campaigns conduced in a well-known network simulator such as NS-2.

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