Wireline TCP Options Behaviour in the GPRS Network

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Abstract: The General Packet Radio Service (GPRS) system will provide an easy adaptation to applications running in the Internet like WWW, FTP and e-mail. These applications work with the TCP protocol, a protocol that evolves by constantly adopting more functions and options. We analyze the TCP SACK and Timestamps options performance in a busy GPRS network. Due to the highly variable delays of the busy GPRS network analyzed, the SACK option is beneficial, but the Timestamps option degrades the performance.

I. Introduction

The General Packet Radio Service (GPRS) system developed to work with the GSM infrastructure is basically a packet switching system via radio, that in comparison with the 9.6 Kbps data transmission rate of GSM, can offer peak data rates of more than 100 Kbps. The majority of services GPRS will offer is Internet [Kalden00]. This means that a close interaction between the GPRS protocols and the TCP/IP Internet protocols is necessary for a good performance of the Internet applications. The Transport protocol TCP performs very well in a fixed network environment in which the majority of losses are due to congestion, but not in a wireless environment where packet losses can appear when the signal fades. Some enhancements for the TCP protocol in wireline networks, like TCP Selective Acknowledgments option, SACK [Mathis96], and TCP Timestamps option [Jacobson92] have been proposed, even though these TCP options were designed in principle for enhancing the performance of the TCP protocol in wireline networks.

According to our knowledge, however, none of these techniques have considered the particular circumstances of a cellular system. In wireless networks such as GPRS, packets have losses due to high bit error rate values caused by poor propagation conditions as well as long delays. Even though the TCP performance over GPRS is analyzed in reference [Meyer99] to the case of only one mobile user, there is still room to study the performance improvement of the enhanced TCP protocols in a cellular system. In particular, the paper analyzes the performance of the TCP SACK and TCP Timestamps options in a GPRS environment under realistic conditions.

The rest of this paper is organized as follows: Section II presents a brief description of the TCP proposals for wireless networks Section III describes the simulator structure used for the study presented in the paper. In Section IV simulation results are given, and finally, conclusions are derived in section V.

II. TCP in Wireless Networks

TCP is a protocol initially designed for working in fixed networks, where the main problem is the congestion. Therefore TCP has mechanisms to avoid sending useless segments into the network when a congestion situation is detected. However, the problems in wireless networks vary: bursty packet losses, high packet delays depending on the wireless network, variable throughput, etc. Then, in the literature there have been some proposals which enhance the TCP performance in wireless networks. According to [Ludwig00] they can be divided into the following categories (Figure 1):

End to end mechanisms: These proposals don't make changes to intermediate nodes and can modify the TCP protocol in the Fixed Host (FH) [Bansal99] and sometimes also in the Mobile Host (MH).

The Explicit Loss Notification mechanism for example [Balakrishnan97] differentiates the congestion problem in the fixed network from other types of packet losses. Some of the TCP RFCs like SACK and Timestamps are in this group. With the SACK option the TCP receiver informs the TCP sender about all the segments that arrived correctly. The Timestamps option allows the TCP sender to collect more RTT samples, so the RTO value would be more accurate.

Split protocol [Bakre97]: It makes two different TCP connections, one from the FH to the Base Station, and the other from the Base Station to the MH. It breaks the end-to-end TCP semantic.

Snoop TCP protocol [Balakrishnan97]: It consists in having an agent installed at the Base Station which makes local retransmissions on the wireless paths depending on the type of Acknowledgments (ACKs) received from the MH and on local timers. Snoop hides the TCP sender in the FH from losses in the wireless link. When the Snoop agent detects a loss, it retransmits the lost TCP segment to the MH, waits for the corresponding ACK and sends it to the FH before the FH realizes there has been a packet loss.

Cross Layer Signalling: The link or network layers at intermediate nodes or at the MH inform the TCP sender at the FH about the state of the wireless link (loss packets, handovers, etc.), e.g., in [Caceres95] the TCP sender gets information about the handovers.

Link layer proposals [Parsa00]: With these types of proposals the Base Station makes retransmissions at the radio link layer. They depend on the type of radio link protocols used for each wireless network.

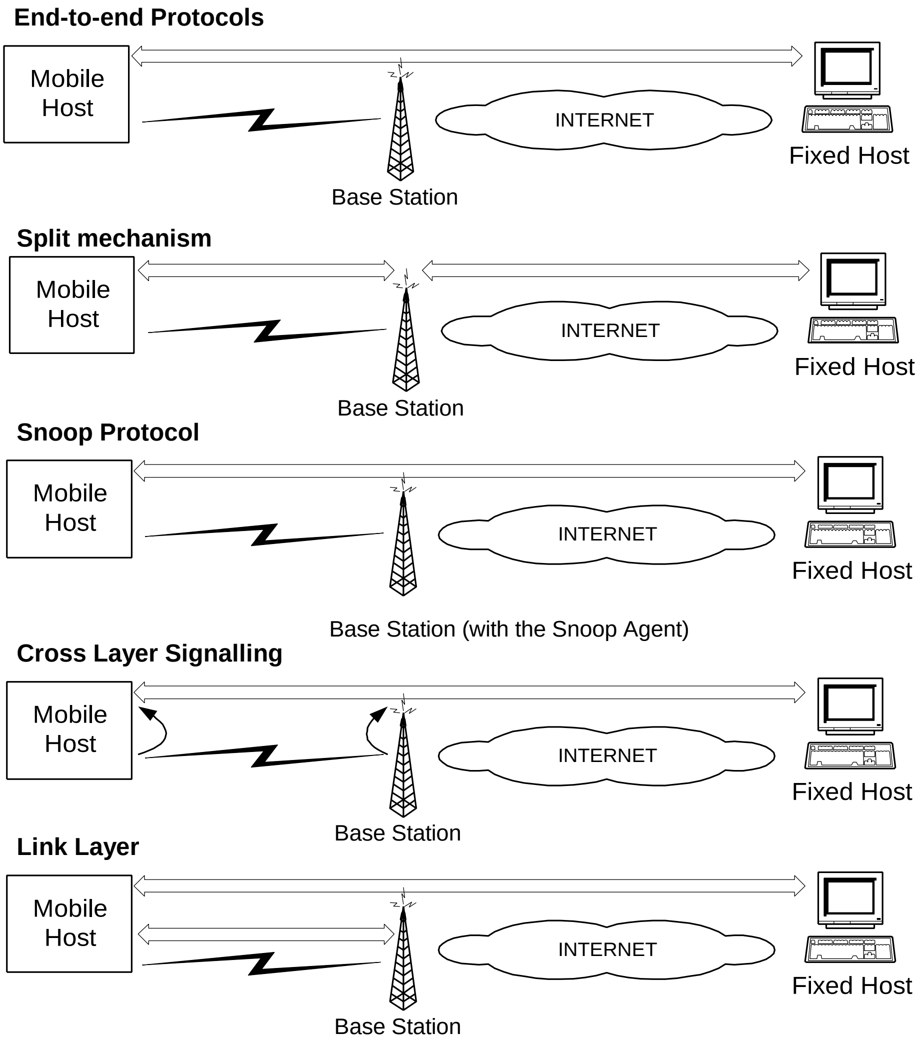

Figure 1: Classification of Wireless TCP Proposals.

III. Simulator Structure

The GPRS simulation model has been created with the event driven simulator Cadence Bones Designer. We simulate the FTP transmission of a 512 Kbytes data file from a FTP server attached to the Internet to a mobile station connected to the GPRS network.

We have simulated the behavior of all the main nodes that exist in the GPRS architecture (Figure 2). A FTP server, with the corresponding TCP and IP layers, models the Fixed Host. TCP-Reno version is assumed. The Internet cloud is modeled by means of the loss packet probability and a delay. The delay is statistically characterized as a gaussian random variable. The GGSN is represented with a router, whereas the SGSN is modeled as a fixed delay that represents the node process delay. The GGSN-SGSN and SGSN-BSS links are also modeled with fixed delays, which take into account the limited link capacities, i.e. 2Mbps and 64 Kbps respectively. The Mobile Host is modeled with a TCP/IP host like the FH.

The radio link is statistically modeled by means of the packet loss probability as well as by the LLC frame delay histogram [Rendon01]. For this study we have assumed a GPRS radio link with 4 PDCHs, Coding Scheme CS4, a C/I relation of 24 dB and 15 Mobile Stations. Three types of bursty traffic have been considered in the GPRS radio link, namely: e-mail, WWW and FTP. We have distributed the type of users in the following form: 50% e-mail, 30% WWW and 20% FTP. The traffic generated for e-mail is similar to the Funet traffic model, whereas the traffic generated for WWW and FTP services has been modeled using the ETSI model [UMTS30.03]. Table 1 summarizes the most important simulation parameters.

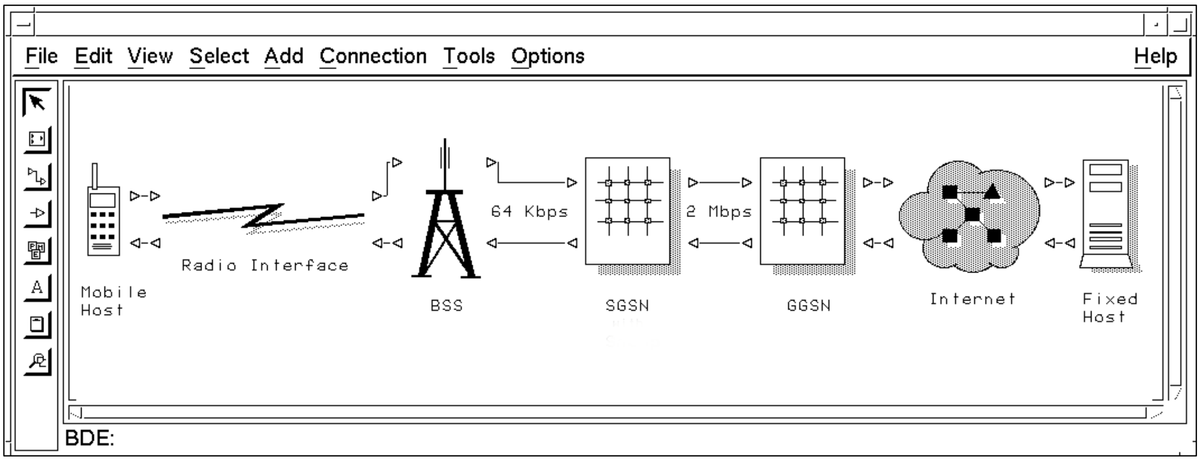

Figure 2: The GPRS simulator constructed with the Bones tool.

Parameter	Value
Max. time waiting for an AGN (access grant notification)	0.1 sec
Max. time waiting for random access attempts per frame	0.3 sec
Max. Time waiting for an acknowledgment	0.1 sec
E-Mail generation frequency	5 messag./hour
WWW pages generation frequency	3 bursts/hour
Number of WWW pages per burst	5 pages/burst
Time between WWW pages	412 sec
Number of frames per WWW page	25 frames/page
Time between WWW frames	0.125 sec
FTP burst generation frequency	6 bursts/hour
PRACH blocks	0; 6
TCP MSS	431 bytes
Mean Internet Delay	100 ms.

Table 1: Simulation Parameters.

IV. Simulation Results

Figure 3 shows the comparison of the throughput of simulations done with the native TCP Reno, the TCP Reno with the SACK option, the TCP Reno with the Timestamps (TS) option and the TCP Reno with the SACK and Timestamps options. From the results we can observe the following:

a) With the Timestamp option the throughput is degraded. Using the TCP Reno with the Timestamps option the throughput degrades 3.85%, and working together with the Timestamp and SACK options the throughput degrades 6.88%

b) The throughput is enhanced when the SACK option is used. Without the Timestamps option the throughput is enhanced 9.09% in comparison with the TCP Reno, and when the TCP uses the Timestamps option, it is enhanced only 1.58%.

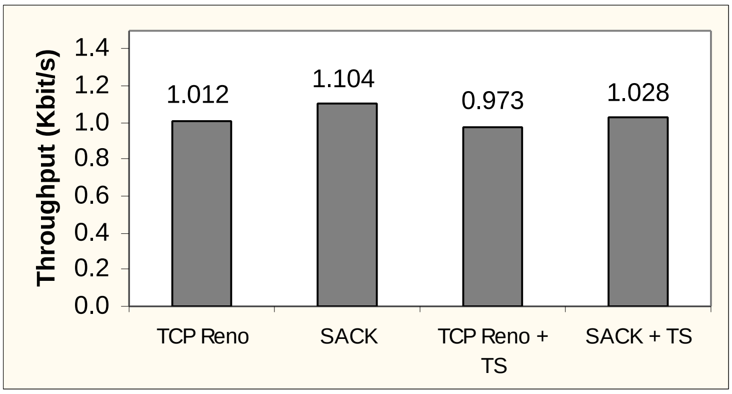

Figure 3: Throughput comparison.

In order to explain these results, we can use Table 2 which shows the percentage of retransmissions done by each option. The data-driven retransmissions correspond to retransmissions done when the TCP sender receives a certain number of Duplicate ACKs (DUPACKs). Timer-driven retransmissions occur when a timer at the TCP sender triggers after a certain time (RTO).

Retransmissions (%)	TCP Reno	SACK	TCP Reno + TS	SACK + TS
Data-driven	2.99	3.30	3.31	3.46
Timer-driven	11.24	1.73	12.47	8.75
Total	14.23	5.03	15.78	12.21

Tab1a 2: Retransmissions

IV.1 TCP Reno

Considering that the PER value of the GPRS radio channel is for this case 2.3%, a retransmission percentage or 14.23 is very high. This high percentage is due to the Timer-driven retransmissions (11.24%). The GPRS radio channel has highly variable delays, which cause variable values of the calculated RTT values and therefore of the calculated RTO values, as can be seen in Figure 4. With these variable values of RTO the timers at the TCP sender trigger frequently, retransmitting then unnecessary TCP segments.

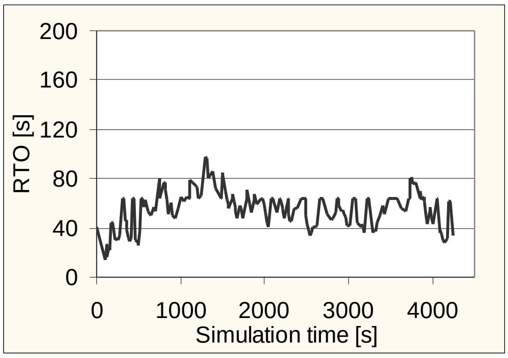

Figure 4: RTO evolution (TCP Reno)

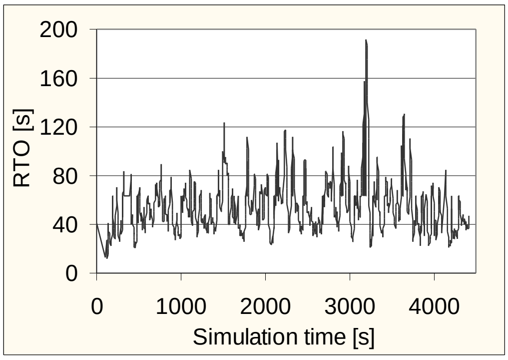

Figure 5: RTO evolution (with Timestamps option)

IV.2 SACK Option

When the SACK option is activated, this percentage of timer-driven retransmissions passes from 11.24% to only 1.73%. A TCP sender with the SACK option cancels the timers of the segments it knows the TCP receiver has correctly received. This is the main reason why the throughput with the SACK option is enhanced. Figure 6 illustrates this point.

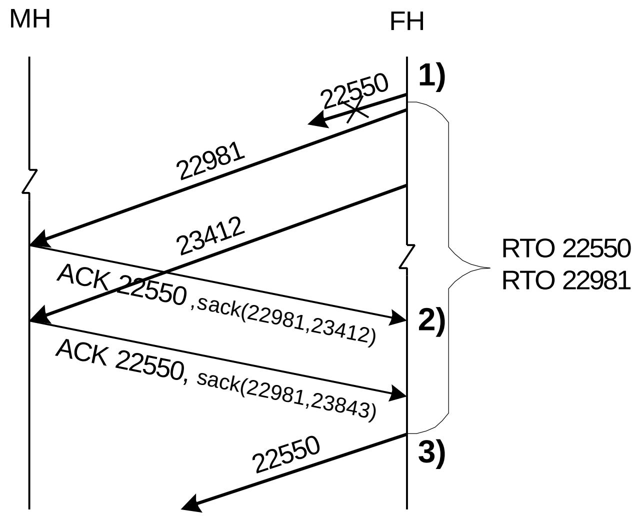

Figure 6: Example of SACK behaviour

1) The Fixed Host sends segments 150002550 (22550) and 1500022981 (22981), but segment 22550 gets lost in the GPRS radio channel.

2) The Mobile Host (MH) gets segment 22981 and sends an ACK 22550 indicating that it has the segment 22981, but not segment 22550. The timer of the segment 22981 is cancelled at the FH.

3) The timer of the segment 22550 triggers and it is retransmitted. Without the SACK option the segment 22981 would have been retransmitted at the same time.

IV.3 Timestamps Option

When the Timestamp option is activated, each transmitted packet is timemarked. Then the TCP sender has more samples to calculate the RTT value. However, due to the highly variable delays of the GPRS radio interface, the RTO values fluctuate very quickly and as a result the timers trigger more frequently (12.47% without the SACK option and 8.75% with the SACK option). Figure 5 shows the evolution of the RTO values with the Timestamps option. Notice that the RTO value can range from 20 s. to 120 s. or even 200 s. (ten times the minimum value). As a result of these rapid time fluctuations, the throughput degrades with the Timestamps option.

When TCP uses SACK and the Timestamps options together, the throughput is less than using only the SACK option. The Timestamps option enhances the number of inappropriate Timer-driven retransmissions and this behaviour cancels the benefits of the SACK option.

V. Conclusions

In order to prevent the losses due to congestion, TCP has a congestion control mechanism that is based in the RTT. However, when this RTT value is not fixed by congestion problems but for losses and delays introduced by the radio channel, the congestion control mechanism degrades quickly the system performance. In particular, due to the variable delays of the GPRS radio interface the RTO values are not accurately calculated. Therefore, the timers located at the TCP sender in the FH trigger frequently, causing unnecessary retransmissions that degrade the performance.

The information contained in the SACK option avoids the unnecessary retransmission of segments that arrived correctly at the Mobile Host, therefore enhancing the transmission throughput. On the contrary, the Timestamps option generates more RTT samples, so that the RTO values vary more. These variable RTO values cause precipitated and unnecessary retransmissions, degrading then the performance.

Acknowledgments

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