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Measured TCP performance in GPRS link adaptation

By

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Abstract:

This paper presents the results of measured TCP performance in the LA process during the deployment of GPRS CS1 and CS2 coding schemes and after the activation of two more coding schemes, CS3 and CS4. The measurements are carried out in one of the commercially deployed live GPRS networks in Malaysia, using end-to-end FTP file transfer application for the assessment. Tracing at the GPRS air interface is done simultaneously. The results show that TCP works well in the LA process and can adapt to the frequent switching between the coding schemes without any problem. The average throughput is increased by 23% for urban areas owing to the activation of higher coding schemes and aided by TCP tuning. It is also shown that throughput is limited by the current coding scheme used and good channel condition is necessary to optimize TCP performance.

Keywords:

GPRS, TCP, performance, link adaptation and coding scheme

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1. Introduction:

General Packet Radio Service (GPRS) [1], [2] is a packet-switched extension of Global System for Mobile communications (GSM) network that offers access to data services such as Internet applications to mobile users anywhere, anytime, as long as they are within its coverage areas. GPRS provides the link between the wireless GSM network and the wired external packet-switched data networks (PDNs) that hosted the Internet applications. With GPRS, the available data rate is between 36.2kbps to 85.6kbps with four time slots allocation.

Internet applications for example web surfing, e-mail and file transfer rely on Transmission Control Protocol (TCP) [3] as a reliable transport for data transfers. It is a connection-oriented, packet-switched transport method that delivers data in small segments or packets. TCP ensures ordered, error-free data delivery with its sequence numbering and acknowledgment systems together with retransmission of loss packets and checksum evaluation. Additionally, it provides data flow control through its congestion control mechanisms.

TCP is originally designed for data transfers across wired, fixed networks. With the implementation of GPRS, TCP traverses the wireless mobile network which is a different environment from the wired network. The varying radio conditions expose data transfers over the wireless GPRS network to transmission errors. Accordingly, four GPRS coding schemes, CS1 to CS4, are defined and employed to protect data from these errors. Switching between the coding schemes is dynamically done through a process called link adaptation (LA). The LA process may cause some impacts on the performance of Internet applications over live GPRS network. This issue has not been specifically addressed in the previous studies conducted on TCP performance in GPRS network [4], [5], [6].

This paper evaluates the TCP performance throughout the LA process in one of the commercially deployed GPRS networks based on the initial coding schemes employment CS1 and CS2, and after the activation of higher coding schemes, CS3 and CS4. This is accomplished by incorporating TCP packet captures in GPRS drive-test measurement. TCP tuning is done as well to optimize the performance. It is shown that TCP can adapt to the varying radio conditions well by its stable performance in the LA process. The throughput improvement is moderate at best and is limited by the current coding scheme used. The results obtained are only relevant to the particular GPRS network being assessed, thus may not apply to all GPRS networks in general.

The rest of the paper is organized as follows: section 2 gives the overview of GPRS LA process together with GPRS parameters setup as implemented in this commercial network. Section 3 outlines briefly the TCP tuning done. In section 4, measurement set up is presented. The results obtained are discussed in Section 5. Finally, the conclusions of the study are given in Section 6.

2. GPRS LA Process and Parameters Setup:

Table 1 gives the GPRS coding scheme with the associated throughput per time slot. In bad channel condition with high anticipated transmission errors, a stringent coding scheme is used that will give the highest protection to the data during transfer but at the expense of reduced throughput. Higher coding schemes offer less protections and are applied during better channel conditions, thus yielding higher throughput.

Table (1): *GPRS coding scheme and associated throughput*

CODING SCHEME	THROUGHPUT (kbps)
CS1	9.05
CS2	13.4
CS3	15.6
CS4	21.4

The radio quality determines the appropriate coding scheme to be utilized. Since radio quality fluctuates over time, the coding schemes also keep on changing according to the varying conditions. In live network, the LA process or the switching between these different coding schemes is done by the network based on the radio conditions as reported by the mobile or based on measurements done by the network itself.

Table 2 provides the main GPRS Reliability class 3 parameters setting for the network under evaluation in two separate measurements, Measurement 1 (M1) and Measurement 2 (M2). Since measurements are done in a live network, there is no control over some of the GPRS parameters that are dynamically changed to adapt to the network conditions at the time. These include the LA process and time slot allocations. Four downlink time slots are allocated for GPRS but at anytime especially during congested or peak hours, they can be assigned to voice traffic which is given the priority over data. For this network, frequency hopping is not enabled.

Table (2): *GPRS parameters setting*

MEASUREMENT 1 (M1)	
GPRS Network Parameter	**Setting**
LLC Mode	Unacknowledged
RLC Mode	Acknowledged
Downlink Time Slot Allocation	4
Channel Coding	CS1, CS2
MEASUREMENT 2 (M2)	
GPRS Network Parameter	**Setting**
LLC Mode	Unacknowledged
RLC Mode	Acknowledged
Downlink Time Slot Allocation	4
Channel Coding	CS1, CS2, CS3, CS4

Tracing at the GSM/GPRS air interface will keep track on time slot allocation and coding scheme usage together with the mobile's operating modes.

3. TCP Tuning:

TCP operations depend greatly on the operating system at client's and server's ends. For this evaluation study, both client and server use Microsoft Windows XP Professional SP2 that supports modern TCP implementation with slow start, congestion avoidance, fast retransmit and fast recovery algorithms [7]. In addition, Selective Acknowledgement (SACK), window scaling and timestamp options are also supported.

To optimize TCP performance in the wireless GPRS network, TCP tuning is done at the client and/or the server ends according to the recommendations in RFC 3481 [8]. The main TCP parameters tuned with the associated values are presented in Table 3. These TCP parameters are adjusted to accommodate the low bandwidth, high delay GPRS network.

Table (3): *Tuned TCP parameters*

TCP PARAMETER	VALUE	HOST	REMARKS
Window Size	64kB	Client & Server	Based on Bandwidth Delay Product (BDP)
Path MTU Discovery	Enabled	Server	For Maximum Transmission Unit (MTU)
SACK	Enabled	Client & Server	Acknowledging non-contiguous packets
Timestamps	Enabled	Client & Server	More and better RTT samples

GPRS Bandwidth Delay Product (BDP) is around 1 – 5kB [8] hence the 64kB window size is sufficient and window scaling option is not required. To determine the TCP Maximum Segment Size (MSS), Path MTU Discovery option is enabled. SACK option is turned on to provide acknowledgments for non-contiguous or out-of-order data packets. This will prevent the sender from retransmitting successfully received packets which can affect the throughput. Timestamp option gives the benefit of obtaining more Round-Trip Time (RTT) samples including for the retransmitted data packets. By default, Windows XP Pro uses the initial send window of two segments size.

4. Measurement Setup:

As mentioned, two separate measurements are carried out, M1 and M2. M1 is done during the implementation of CS1 and CS2 only, and M2 is performed after the activation of CS3 and CS4. A few locations are selected for the measurements involving different network scenarios such as indoor, outdoor, moving and stationary.

File Transfer Protocol (FTP) application is used to assess the TCP performance. A 500kB file download is carried out from the server to the client as per Figure 1. At both server and client ends, Wireshark [9] is used to capture the TCP packets exchanged. The captures are then analyzed using tcptrace [10]. Concurrently, TEMS Investigation [11] is run at the client side to capture on GPRS air interface using a class 10 (4 Downlink + 2 Uplink) mobile phone. This supports four time slots for downlink data transfer.

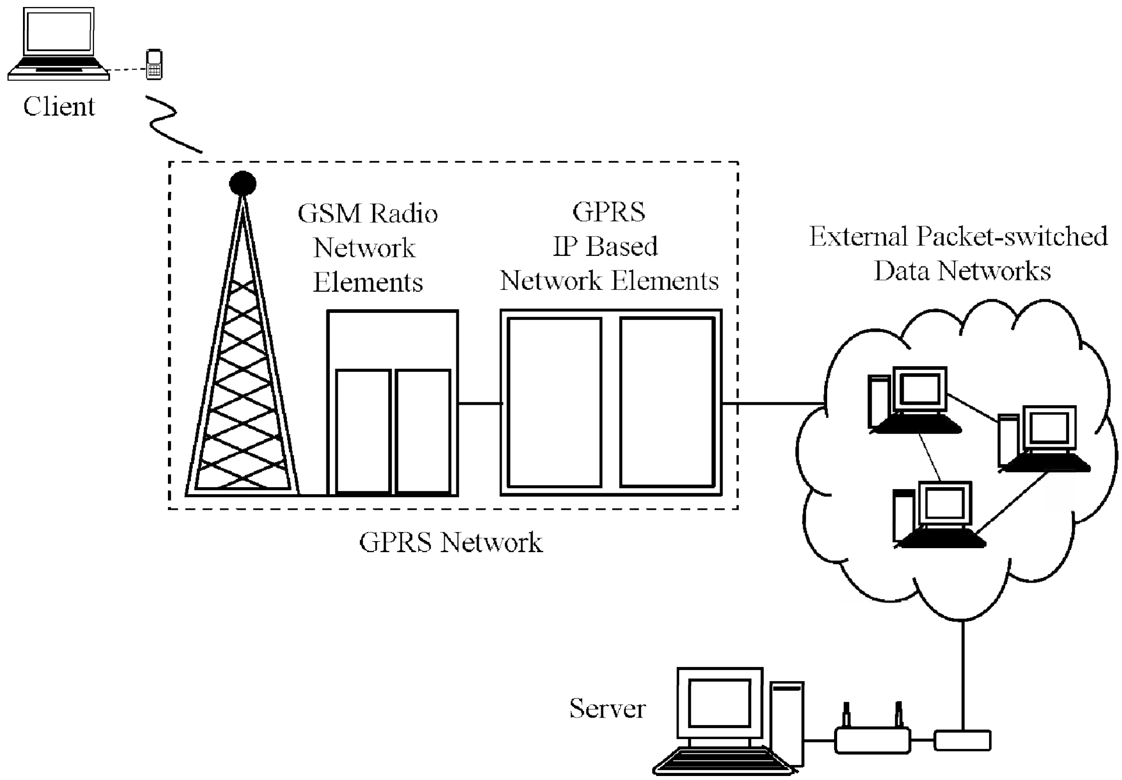


Figure (1): *Measurement setup*

5. Measurements Results:

Figure 2 presents the comparison on the client's overall throughput obtained from both measurements. The highest CS data rate is according to CS2 and CS4 with four time slots allocations. The average throughput is computed based on transmitted data bytes over transfer time excluding headers.

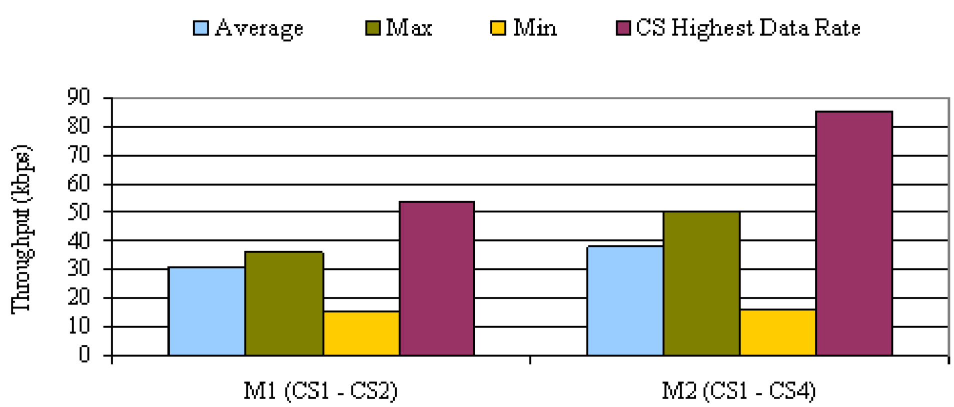


Figure (2): *Client downlink overall throughput*

The average throughput for M1 is 31kbps which is about 57% of CS2 data rate. For M2, the average throughput is 38kbps which corresponds to 44% of the CS4 data rate. The increase in average throughput is approximately 23%, compares to the increase in the highest available data rate that is around 60%. Maximum throughput achievable is 36kbps for M1 and 50kbps for M2. These values are well over 50% of the CS2 and CS4 data rates respectively. The LA process is between two coding schemes in M1 and in M2, it is between four coding schemes. Therefore, in M1, the average throughput values are closed to the maximum throughput achievable. On the other hand, in M2, there is a significant difference between the average throughput and the maximum achievable since the variance between the data rates are greater. Both measurements obtain similar minimum throughput which is around 15 – 16kbps.

The throughput improvement observed in M2 is owed to the activation of higher coding schemes CS3 and CS4. The percentage ratio of the increase in average throughput to the increase in the highest available data rate is 23:60. This indicates that the available high data rate provided by the activation of CS3 and CS4 is still underutilized i.e. less than 50%. It will be shown that this is due to the CS1 dominant usage during data transfers.

Figure 3 splits the overall throughput into throughput based on different network scenarios. For M1, the average throughput is seen to be stable for all scenarios, ranging between 26kbps to 33kbps. For M2, the average throughput is between 33kbps to 42kbps and also stable for all scenarios. The average throughput increase for each scenario is 20% in outdoor stationary, 28% in outdoor moving and indoor stationary and 21% in indoor moving. The increase is also observed as almost even for all scenarios. The different scenarios represent different channel conditions that directly influence the LA process. This shows that TCP adapts well to the LA process without problems. Frequent switching between the coding schemes especially in M2 does not affect TCP which is substantiated by the constant throughput observed. This is illustrated in Figure 4.

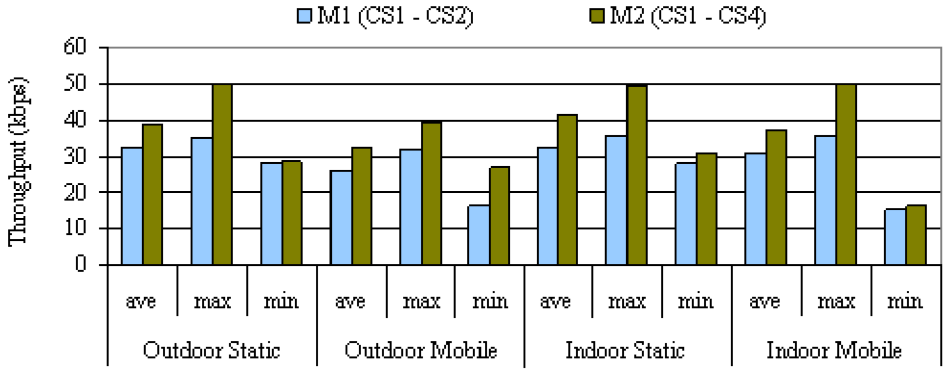
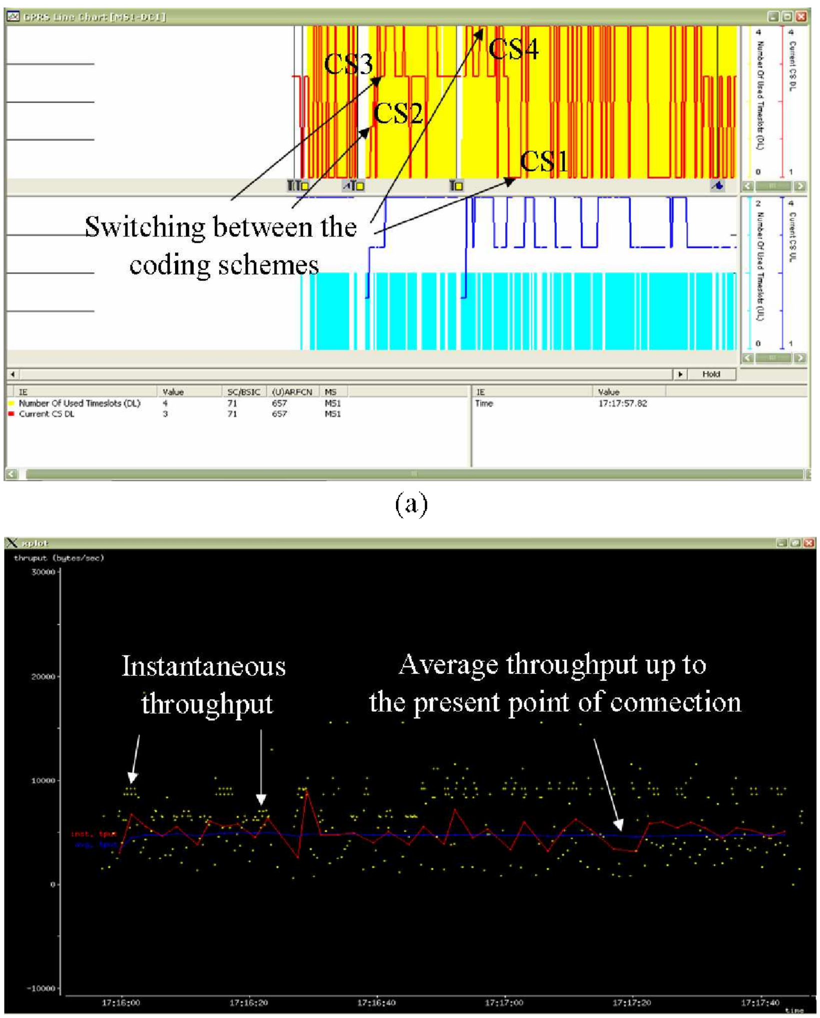


Figure (3): *Client downlink throughput based on network scenarios*



(a)

(b)

Figure (4): *(a) LA process (b) Corresponding TCP throughput*

TCP handles data packet loss by retransmission mechanism. Very few packets are lost during a cell reselection process or during temporary absence of radio resources which are seen in all scenarios. If these occur in succession, the total of lost packets would be substantial. Prolonged bad channel condition is another reason for retransmissions. These are shown in Figure 5. Packet loss reduces throughput in a way that it lengthens the transfer time due to retransmissions.

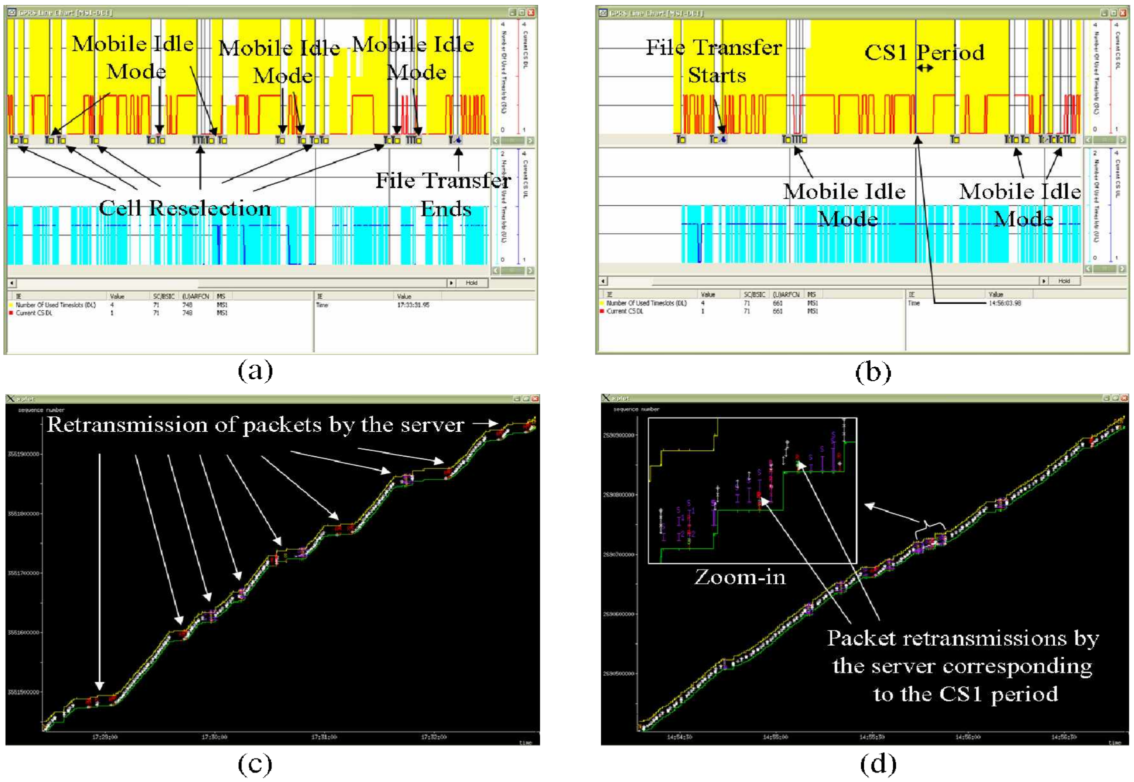


Figure (5): *(a) Successive mobile idle mode and cell reselections (b) Prolonged bad channel condition (c) Successive retransmissions (R) (d) Retransmissions (R) during CS1 period*

Figure 6 represents the overall current coding scheme usage and time slot allocations for M1 and M2. It is shown that in both measurements, CS1 dominates half of the coding scheme usage during transfer time. This affects the overall average throughput that manages only to reach more or less 50% of the highest available data rate with four time slots allocation. Combined with packet loss, throughput is further compromised. The availability of four time slots for most of the data transfers shows that there is minimum contention with voice traffic and ensures throughput is not further affected.

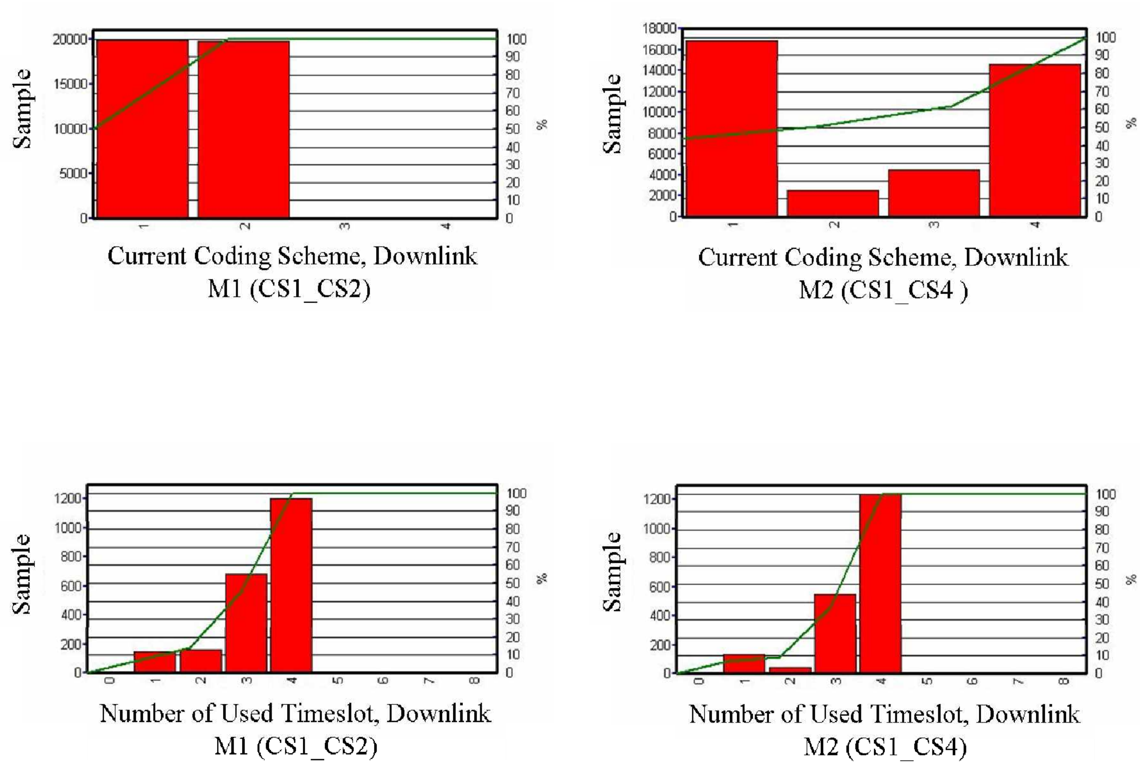


Figure (6): *Overall downlink current coding scheme usage and time slot allocations*

6. Conclusions:

TCP works well in the LA process and can cope with the frequent switching between the coding schemes without any problem. The activation of higher coding schemes means the switching process is done between four schemes compares to only two schemes previously. This shows that the varying radio conditions do not give significant bad impact to TCP mechanisms. On the contrary, the four schemes activation helps to increase TCP performance which is demonstrated by the increase in average throughput seen in all network scenarios. TCP throughput is largely governed by the current coding scheme in used. To fully utilize the high data rate provided by CS3 and CS4 coding schemes, the network operator must ensure good channel conditions.

The constant average throughput observed for every scenario also shows that TCP can adapt well to mobility in GPRS and is able to retain its reliability under various network conditions. TCP is seen to be affected only by temporary absence of radio resources during mobile idle mode, cell reselections and rarely, persistent bad channel conditions where packet loss is common.

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