Performance Evaluation of Retransmission Mechanisms in GPRS Networks

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***Abstract* - This paper studies the performance of the three retransmission mechanisms (i.e., RLC/MAC, LLC and TCP) in a General Packet Radio Service (GPRS) network accessing the Internet. This assessment is done through the end-to-end performance evaluation of Internet applications such as HTTP and FTP over GPRS. A simulation platform including client Mobile Stations, Base Station Subsystems, GPRS Support Nodes, servers and an Internet backbone was implemented in OPNET. The low transmission rate and high radio link error rate over the air interface of a GPRS network affect the overall system performance greatly. Simulation results show that whereas the RLC/MAC block retransmission mechanism is crucial to increase the link utilization efficiency, LLC layer user-data retransmission is not necessary for TCP traffic over GPRS.**

I. Introduction

General Packet Radio Services (GPRS), as a major component of GSM Phase II+ [1-3], aims at providing public packet-switched data services over the existing GSM wireless network infrastructure. GPRS is mainly intended to provide better services for Internet applications compared to the existing circuit-switched data services of GSM [4]. To support packet-switched services, additional network elements have been devised, namely GPRS Support Nodes (GSNs). The Gateway GSN (GGSN) acts as a logical interface to external packet data networks. The Serving GSN (SGSN) is responsible for the delivery of packets to the mobile stations (MSs) within its service area, via base station systems (BSSs) serving individual cell sites. The GPRS protocol stack is shown in Fig. 1.

GPRS defines two retransmission mechanisms to ensure an acceptable level of data transmission reliability. One retransmission scheme is used at the RLC/MAC layer [5, 6], between the MS and BSS as shown in Fig. 2. The second retransmission policy operates at the LLC layer [7], between the SGSN and MS.

An evaluation of TCP performance over GPRS with UNACK LLC mode [8] showed that TCP and GPRS could be harmonized. In this paper we complement [8] in several ways. First, we include the LLC layer retransmission performance study that was not considered in [8] and give more insights into the protocol interactions. Secondly, we provide the performance evaluations of more realistic applications (HTTP/FTP with random session arrival, session ending and traffic density etc.) on a more realistic simulation platform with features of wireless link sharing/congestion and temporary block flow (TBF) establishment, etc.

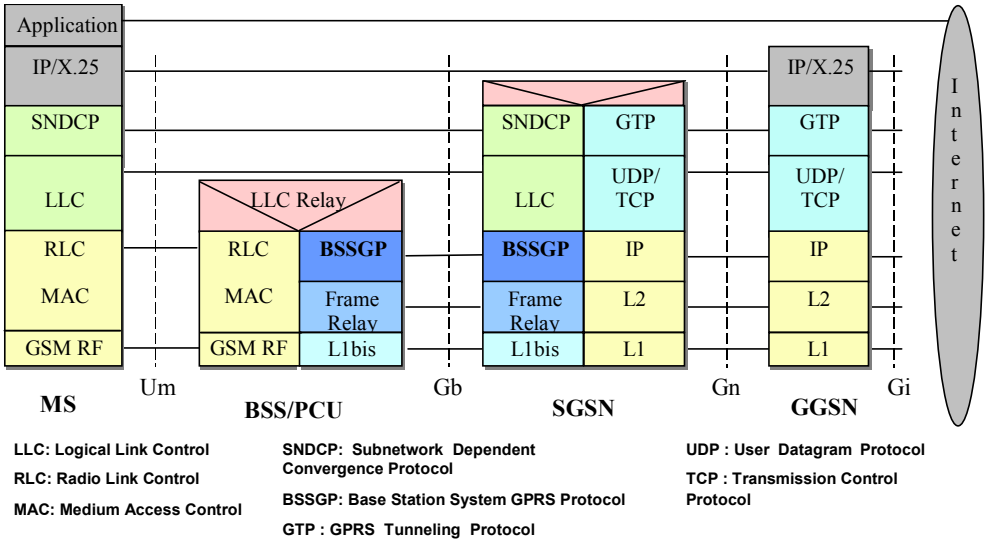

Fig. 1. GPRS protocol stack.

Since these applications (HTTP/FTP) run over TCP, effectively we have three levels of retransmissions for these applications over GPRS, as shown in Fig. 2:

1. End-to-end between the MS and the server (TCP layer),
2. Between MS and SGSN (LLC layer),
3. Between MS and BSS/PCU (RLC/MAC layer).

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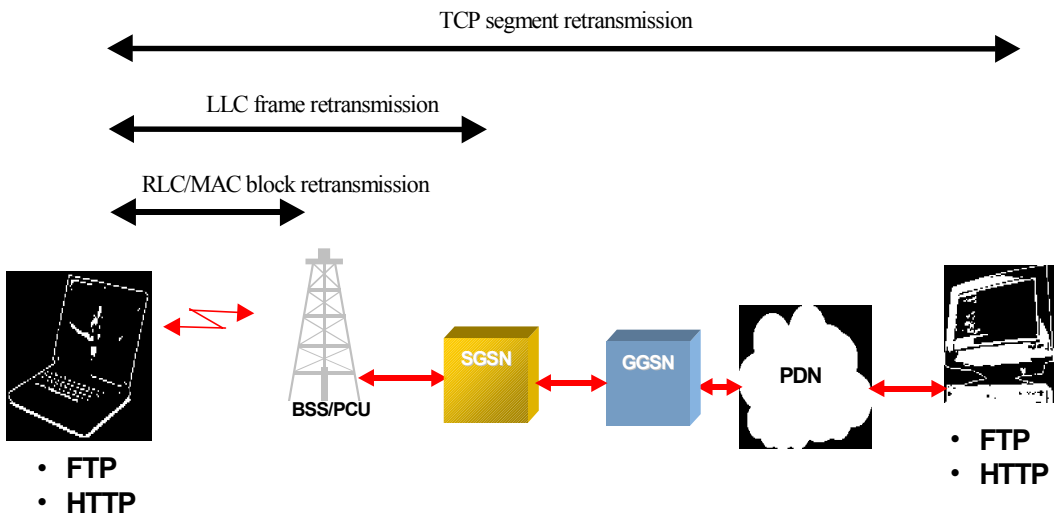


Fig. 2. The three levels of possible retransmissions for TCP traffic over GPRS.

II. Retransmission Mechanisms

A. TCP Retransmissions

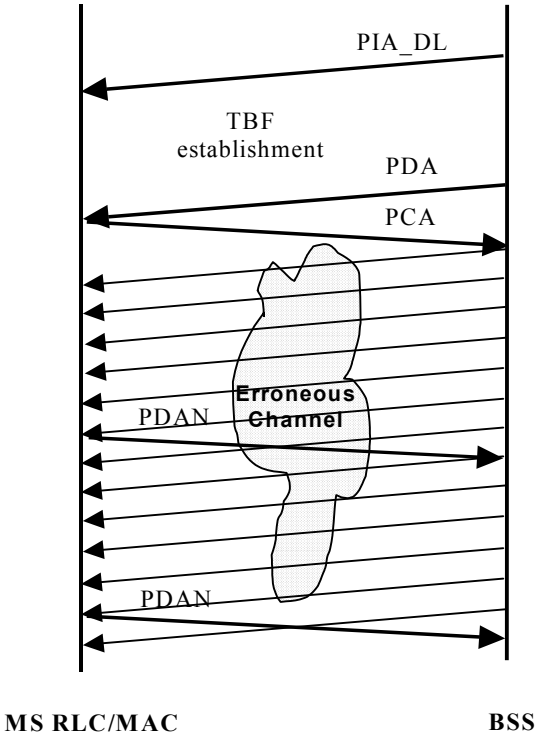
TCP, a standard Internet protocol for ensuring end-to-end reliability between communicating peer nodes, is the transport protocol used by the FTP and HTTP applications. TCP provides a sliding window based ARQ (Automatic Repeat Request) functionality including an adaptive time-out mechanism for ensuring reliable data transmission.

B. LLC Retransmissions

LLC retransmissions are performed between the SGSN and MS in the LLC layer for confirmed information transfer (I format frames). The LLC retransmission mechanism uses a retransmission timer to initiate retransmissions and a window to control the maximum number of sequentially numbered I frames that may be outstanding (i.e., unacknowledged) at any time.

C. RLC Retransmissions

GPRS can utilize a reliable Radio Link Control (RLC) layer protocol, where the RLC blocks are used as the retransmission unit between the BSS and MS. In the downlink (uplink) direction, an LLC frame is sent to (from) the mobile in the form of RLC blocks, which pass through the noisy wireless channel. The transfer of RLC blocks is controlled by a selective repeat ARQ mechanism. After receiving RLC blocks the receiver (MS or BSS) returns ACK/NACK messages periodically (Fig. 3). The sending side only retransmits the RLC blocks that are received in error or lost.



PIA_DL: immediate assign for downlink
PDA: packet downlink assign
PCA: packet control ack
PDAN: packet downlink ack/nack

Fig. 3. Downlink RLC/MAC operations in GPRS.

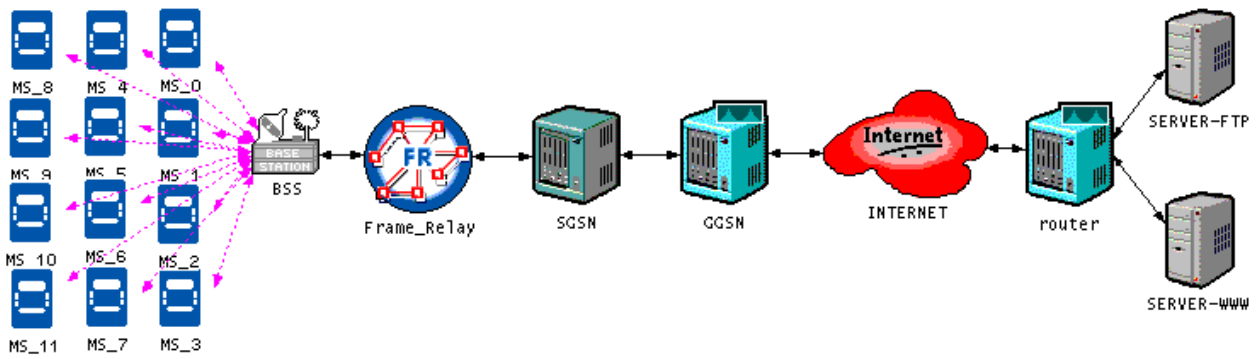


Fig. 4. GPRS simulation model in OPNET.

III. Performance Evaluation

A. Simulation Model

The simulation model (Fig. 4) incorporating the MS, BSS, SGSN/GGSN, Internet backbone, router and server models, has been developed in the OPNET environment.

1) Application models

The most popular Internet applications, HTTP and FTP, are employed for end-to-end performance evaluation.

The HTTP application is characterized by a hierarchical model which parameters include web page rate, page size, object size and max connection number. Web page rate is the rate at which a client session requests HTML pages. It is modeled as an exponential distribution. Page size is the total number of subordinate objects retrieved through a single page access. It is modeled as an exponential distribution with a base value of one. Object size is the average size in bytes of the objects which are transferred from the HTTP server to the HTTP client. The object size is modeled as an exponential distribution. Max connection number is the maximum number of transport-layer connections used by the HTTP client for communications with the HTTP server.

The adjustable traffic parameters for the FTP model are file transfer rate and file size. File transfer rate is the generation rate for FTP sessions (modeled as a Poisson process). Exactly one file is transferred (either file "get" or file "put") in each session. File size is the average size of the file to be downloaded (modeled using a normal distribution).

2) Mobile Station

There are multiple MSs that are served by a single BSS. Each MS includes both LLC and RLC/MAC layers. For sending the RLC/MAC blocks from BSS to an MS, a TBF is first established as explained in the following sub-section.

3) BSS

In this simulation model a single BSS serving multiple MSs is considered. In the downlink direction, when the BSS receives an LLC frame for transmission to an MS, it first establishes a TBF. After successful TBF establishment, the frames pending transmission are fragmented into fixed size RLC blocks. The RLC blocks are transmitted over the air, with random losses according to a specified block error rate. The MS sends PDAN (Packet Downlink Ack/Nack) acknowledgment messages after receiving every 6th or 12th (settable) RLC data blocks. The TBF establishment and data transfer between MS and BSS is shown in Fig. 3. Fig. 5 shows the sequence number of RLC block sent at specific time instants, with the red dot indicating a loss, which is subsequently retransmitted.

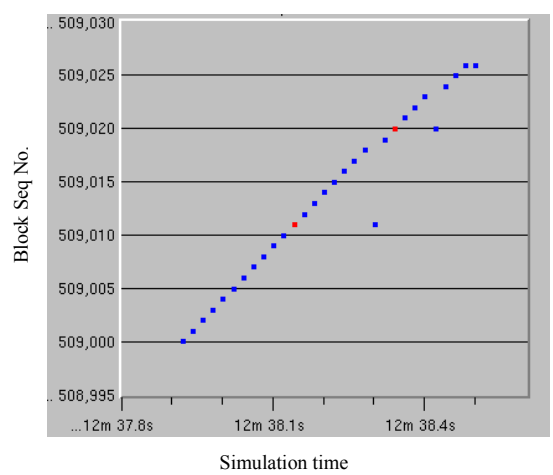


Fig. 5. Re-transmissions of RLC blocks in simulation.

When the PCU receives an LLC frame from the SGSN, it checks if there is any downlink timeslot available. If there is a timeslot available, it will choose one LLC frame from the queue to begin the process.

4) SGSN/GGSN

The LLC layer of SGSN incorporates the retransmission functionality in the acknowledgement mode. Both non-acknowledgement operation and acknowledgement operation

are implemented in the SGSN. GGSN is simply modeled as a router.

5) Internet model

The Internet is modeled by a node with configurable random IP packet delay and losses. It drops the packets according to a specified probability. When a packet comes, a random number uniformly distributed between 0 and 1 is generated to determine if the packet is dropped or not. It also delays the packet transmission:

Delay = K + Erlang (mean, 2)

where, K is a constant term, Erlang (mean, 2) is a random variable calculated using Erlang Distribution of order 2 and mean value "mean".

6) Router/server/frame relay

These models are taken from OPNET standard library.

B. Simulation Scenarios

The simulation assumptions are as follows:

- 4 to 24 MSs.
- 7 packet data traffic channels (time slots).
- Coding scheme: CS-1.
- MS timeslot capability = 1.
- The delay for establishing a TBF is random between 0.7-1.05 sec.
- Maximum number of RLC block retransmissions = 3.
- RLC block error rate =2.5%.
- Maximum number of LLC frame retransmissions N200 = 3.
- Retransmission timers T200, T201 = 10 sec.
- Maximum number of outstanding I frames kD = 16.
- The packet drop rate in the Internet node is 1%, the random delay is 0.05 + Erlang (0.005, 2) sec.
- FTP application,
  - mean file transfer rate = 30 files/hour,
  - mean file size = 25000 bytes/file.
- HTTP application,
  - mean web page rate = 40 pages/hour,
  - mean page size = 5 objects/page,
  - mean object size = 6300 bytes/object,
  - max connection number = 4.

In terms of the retransmission mechanisms, the three simulation scenarios shown Table I are considered.

TABLE I: SCENARIOS OF DIFFERENT COMBINATIONS OF RETRANSMISSION METHODS

Scenario	TCP retransmission	LLC retransmission	RLC/MAC retransmission
1	√		
2	√		√
3	√	√	√

C. Simulation Results and Discussions

In the simulations, the goodput (the actual effective bytes received by the application layer) of FTP and HTTP applications are measured and compared graphically in Fig. 6 - Fig. 9 between the three scenarios. Fig. 6 and Fig. 8 depict the total goodput of all the MSs with HTTP and FTP applications, respectively. Fig. 7 and Fig. 9 give the average goodput of one MS.

In the first scenario shown in TABLE I, retransmissions occur only at the TCP layer. It provides a very poor performance in terms of the channel utilization. This is due to the lossy wireless channel. Even with TCP retransmissions, most data packets are lost.

Scenario 2, where RLC/MAC as well as TCP retransmissions are utilized, provides a much better performance. Using RLC/MAC in the retransmission mode provides the TCP layer with a more reliable radio link, resulting in a better overall performance.

Scenario 3 has retransmissions at the all three levels (LLC, RLC/MAC and TCP). The simulation results show that the addition of LLC retransmissions does not help much in improving the goodput of the applications. In some cases, it even can slightly worsen the performance. The reason can be attributed to the interactions between the LLC and TCP retransmission timers. Most often the retransmission of an LLC frame causes a TCP time-out and retransmission of the associated TCP segment. Therefore, while the LLC frames are still in the SGSN waiting to be re-sent to the MS, the associated TCP segments are also retransmitted, causing duplicated transmissions and wastage of wireless channel resources.

From the simulation results, it is also observed that there is an optimum offered load (in terms of the number of MSs) that maximizes the effective throughput of the network. This means that increasing the number of users (client-servers) utilizing the GPRS network beyond a certain point may effectively reduce the effective throughput of the system. This is due to the high number of TCP connections (for transmitting small objects/files) that occasionally leads to congestion, and the slow start characteristic of TCP.

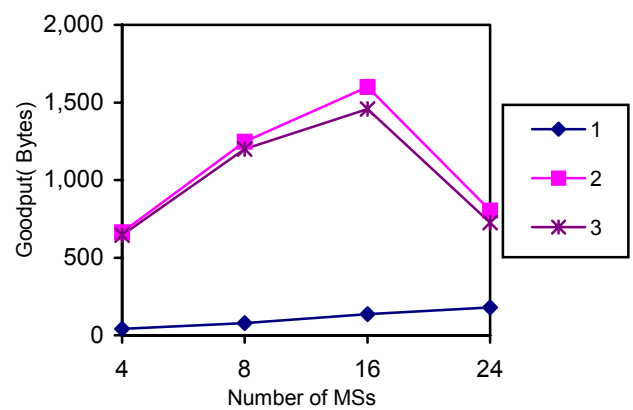


Fig. 6. Total goodput of HTTP application.

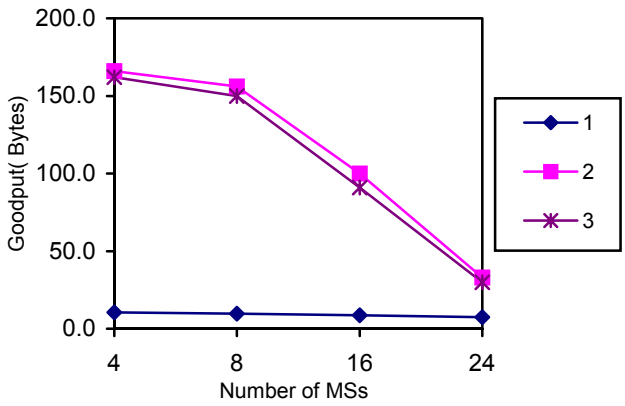


Fig. 7. Average goodput of HTTP application.

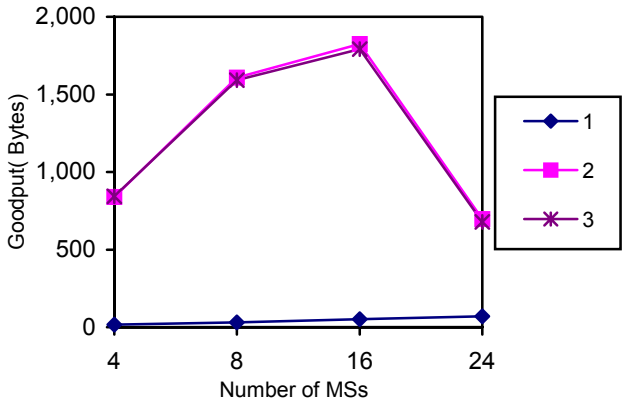


Fig. 8. Total goodput of FTP application.

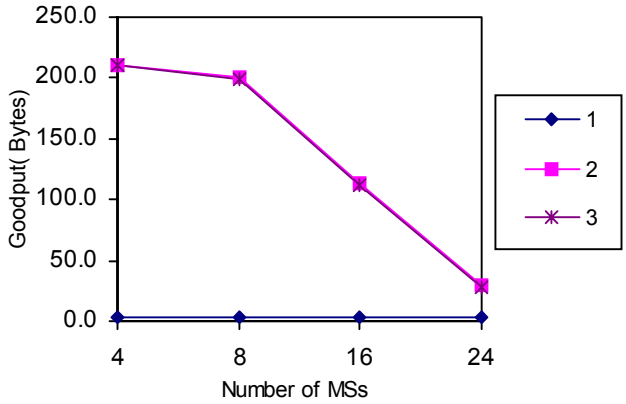


Fig. 9. Average goodput of FTP application.

IV. Conclusions

In this paper we have examined the interactions of the three retransmission mechanisms over GPRS. This is done through analyzing the end-to-end performance of HTTP and FTP over a GPRS network interconnected to the Internet. The three levels of retransmissions in the GPRS-Internet network environment includes:

1. TCP layer retransmissions,
2. LLC retransmissions, and
3. RLC/MAC retransmissions.

Simulation results show that for TCP traffic over GPRS, RLC/MAC retransmissions can substantially improve the system performance, while LLC layer retransmissions are unnecessary at best, and degrade the system performance at worst. The reason can be attributed to the LLC and TCP timers interactions. Most often both the TCP and LLC layers retransmit the lost packets resulting in waste of the radio channel resources.

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