Performance of LLC and TCP on GPRS Uplink with RLC Slot Level Retransmission

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Abstract— **In this paper, we evaluate the performance of the logical link control (LLC) layer and the Transmission control protocol (TCP) layer in General Packet Radio Service (GPRS) networks. We evaluate the uplink throughput and delay performance of GPRS-LLC protocol with radio link control (RLC) layer using block level retransmission (BLR), as defined in the current GPRS standards, and compare it with that of using slot level retransmission (SLR) at the RLC. We investigate the optimum choice of parameters (e.g., number of retransmission attempts) for the ARQ schemes at the RLC and the LLC layers. Our results show that it is more beneficial to do the error recovery by allowing more retransmissions at the RLC layer than at the LLC layer. We show that SLR performs better than BLR. We also study the impact of SLR on the TCP performance.**

I. INTRODUCTION

General Packet Radio Service (GPRS) is a packet mode wireless system that has been standardized to operate on GSM infrastructure, by introducing new packet support nodes (GSNs) and associated protocol stacks [1]. A portion of the radio resources (channel frequencies) in an existing GSM system may be dedicated for packet data services using GPRS. Alternatively, GPRS and GSM services may dynamically share the same radio resources. Thus, GSM voice services and GPRS data services can co-exist on the same GSM infrastructure. The protocol stacks at the Mobile Station (MS), Base Station Subsystem (BSS), SGSN, and GGSN in GPRS are shown in Figure 1. In this paper, we are concerned with the performance of *Logical Link Control* (LLC) layer and TCP layer on the GPRS uplink. The LLC peers are at the MS and the SGSN [2].

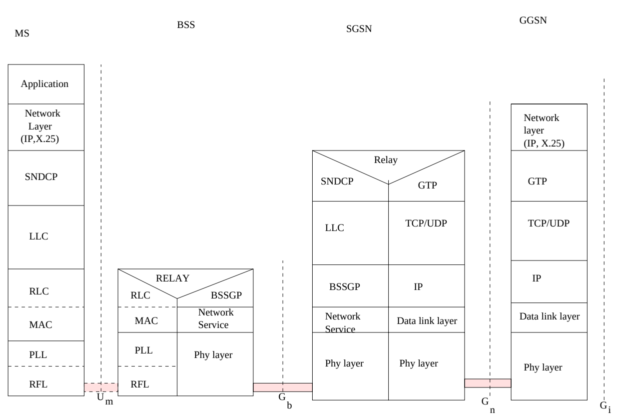

Fig. 1. GPRS protocol architecture

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In our earlier work [3], we have analyzed the performance of the RLC/MAC layers in GPRS. In this paper, we extend this work and investigate the performance of LLC and TCP layers on the GPRS uplink. The performance of automatic repeat request (ARQ) mechanisms at the LLC and RLC layers in GPRS has been analyzed in [4], but without considering the uplink request-reservation dynamics of the MAC layer. Here, we evaluate the performance of the LLC layer protocol in GPRS, considering the uplink request-reservation mechanism with slot level retransmission (SLR) in RLC [5]. We compare this performance with that of using block level retransmission (BLR) at RLC, as defined in the current GPRS standard. We investigate the optimum choice of parameters (e.g., number of retransmission attempts) for the ARQ schemes at the RLC and the LLC layers. Our results show that it is more beneficial to do the error recovery by allowing more retransmissions at the RLC layer than at the LLC layer. We also show that SLR performs better than BLR. We evaluate the throughput performance of TCP with error recovery in LLC and RLC layers. The effect of SLR on the TCP throughput performance is also studied.

The rest of the paper is organized as follows. In Section II, the GPRS LLC layer is described. The system model is described in Section III. Section IV provides the throughput-delay performance of the LLC layer. In Section V, we describe the TCP simulation model and discuss the TCP throughput performance results. Conclusions are given in Section VI.

II. LLC LAYER

The LLC layer operates between the MS and the SGSN, and provides a logical link between them. Packet data units (PDUs) from higher layers (IP layer) are segmented into variable size LLC frames (see Fig.2). The functions of LLC layer include link level flow control and ciphering. The LLC layer can operate either in an unacknowledged mode or in an acknowledged mode. In the unacknowledged mode of operation, the LLC layer does not attempt recovery of erroneous frames. LLC frames, erroneously received or otherwise, are passed on to the higher layers. In the acknowledged mode, the LLC layer provides an ARQ mechanism to retransmit erroneous LLC frames. A Frame Check Sequence (FCS) is used provided in each LLC frame to detect frame errors. A retransmission count variable $N200$ is defined [6]. The LLC is reset and error recovery is passed on to higher layers (e.g., TCP) if frames errors could not be recovered within $R_{llc} = N200$ retransmission attempts.

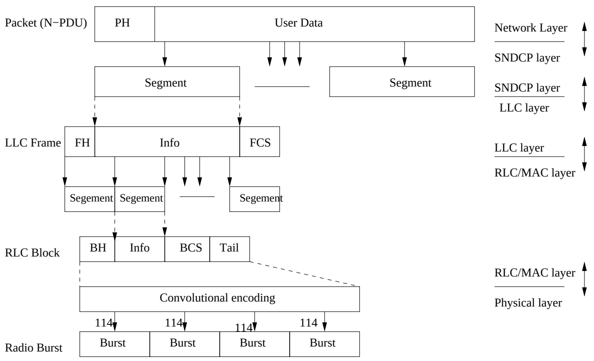

Fig. 2. *Network layer PDU segmentation into LLC frames, RLC blocks, and MAC bursts.*

III. System Model

We consider a single cell GPRS system with M, $M \geq 2$ uplink channels and N mobile users. Each channel corresponds to a frequency-time slot pair in the mobile-to-base station direction. Out of M channels, L, $1 \leq L < M$, channels are used as packet random access channels (PRACH), and the remaining $M - L$ channels are used as packet data traffic channels (PDTCH). Typically, slot TS0 in all GSM TDMA frames on a given frequency can form a PRACH. Likewise, on a given frequency, slot TS1 in all GSM TDMA frames can form PDTCH-1, slot TS2 can form PDTCH-2, and so on. The mobiles use PRACH to send their resource requests to the base station (BS) on a contention basis. The BS can assign either one slot per frame (single slot operation) or multiple slots per frame (multi slot operation) to the mobiles requesting resources. Here, we consider single slot operation. The RLC/MAC layer models given in [3] are used in this study.

We evaluate the throughput and delay performance of the GPRS LLC layer through simulations. We assume the following in the simulation model.

1. The network layer PDU arrival process is Bernoulli with arrival probability, λ, in each slot. A new network layer PDU is accepted only after the completion of the transfer of the previously accepted PDU.
2. The length of the PDU (including LLC/RLC headers and checksums), in number of LLC frames, is geometric with parameter g_f, $0 < g_f < 1$. Each LLC frame is assumed to consist of 5 RLC blocks. Each RLC block occupies 4 slots.
3. Loss of request packets on PRACH is only due to collision.
4. Retransmission attempts of request packets following a collision on PRACH (or non-availability of PDTCH) is geometrically delayed with parameter g_r, $0 < g_r < 1$.
5. Propagation and processing delays are assumed to be negligible. This assumption can be valid in *single slot* operation, where the response from the BS can be within one TDMA frame time itself.

The RLC layer, in acknowledged mode, attempts to recover erroneous RLC blocks using a selective repeat ARQ by attempting retransmissions upto R_{rlc} times. If RLC block errors are not recovered within R_{rlc} retransmission attempts, control is passed on to the LLC. Instead of block level retransmission at the RLC, slot level retransmission at the RLC can be employed [3],[5]. The LLC layer, in acknowledged mode, employs another ARQ which attempts retransmissions upto R_{llc} times, in case of LLC frame errors. If an erroneous LLC frame is not recovered within R_{llc} retransmission attempts, the link layer is reset and re-established. We assume that this reset and re-establishment delay is RESET_DELAY in number of slots. A question in this regard is what is the optimum choice of the values of R_{rlc} and R_{llc} for the ARQs in the RLC and LLC layers. The following section provides the performance results at the LLC layer for different values of R_{rlc} and R_{llc}.

IV. LLC Layer Performance

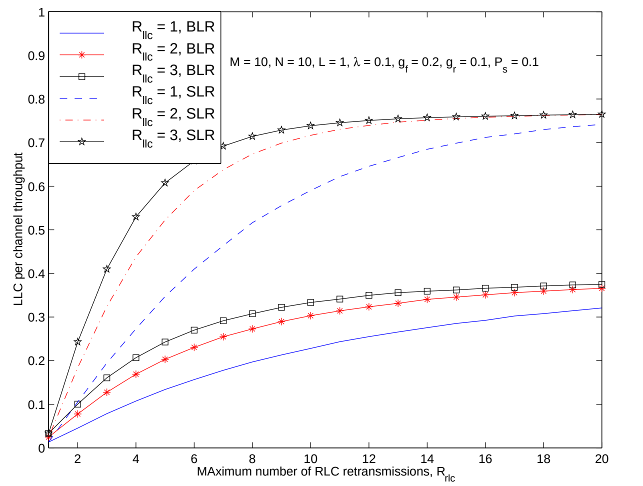

Fig. 3. *LLC average per channel throughput versus maximum number of RLC retransmissions,* R_{rlc}. $N = 10$, $M = 10$, $L = 1$, $\lambda = 0.1$, $P_s = 0.1$, $g_r = 0.1$, $g_f = 0.2$.

The per channel throughput at the LLC layer as a function of maximum number of RLC retransmission count, R_{rlc}, is plotted in Fig. 3, for $N = 10$, $M = 10$, $L = 1$, $\lambda = 0.1$, $g_r = 0.1$, $g_f = 0.2$, and RESET_DELAY = 200 slots. Both block as well as slot level retransmissions at a slot error rate of 0.1 is considered. The R_{llc} values considered are 1, 2, and 3. We define the throughput at the LLC layer as the average number of successful LLC frames. We observe from Fig. 3 that, for a fixed R_{llc}, the throughput increases as R_{rlc} is increased. By increasing R_{rlc} we try to recover erroneous blocks in the RLC layer itself rather than giving up the entire frame (that contains erroneous blocks) to the LLC. We also observe that as R_{llc} is increased, throughput increases. When R_{llc} is small, LLC *resets* occur frequently. A reset makes the channel to stay idle for RESET_DELAY slots. Hence, the per channel throughput at the LLC is less for small values of R_{llc}. By increasing R_{llc}, we try to avoid too many LLC resets. This gives a better performance in throughput. We also note that SLR at the RLC performs better than BLR.

The delay performance at the LLC layer is plotted as a function of R_{rlc} in Fig. 4, for the same set of parameters in Fig. 3. From Fig. 4, we observe that, for a fixed R_{llc}, the delay decreases as R_{rlc} is increased. Also, for a fixed R_{rlc}, increasing R_{llc} increases throughput and decreases delay. If R_{rlc} is

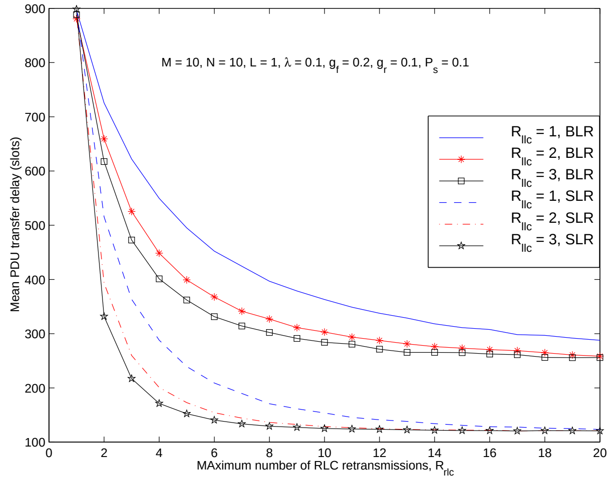

Fig. 4. *LLC mean PDU transfer delay versus maximum number of RLC retransmissions, R_{rlc}. $N = 10$, $M = 10$, $L = 1$, $\lambda = 0.1$, $P_s = 0.1$, $g_r = 0.1$, $g_f = 0.2$.*

too small to recover an erroneous block, then the entire LLC frame that contains the erroneous block is retransmitted. When R_{rlc} and R_{llc} are both small, then LLC resets will occur frequently, which will increase the PDU transfer delay. Thus, for small R_{rlc}, the delay performance improves by increasing R_{llc}. However, when R_{rlc} is large enough (e.g., > 10), the delay performance for R_{llc} = 2 or 3 is approximately the same. This is because almost all the erroneous RLC blocks are recovered in the RLC layer itself and there may not be much need for LLC retransmission.

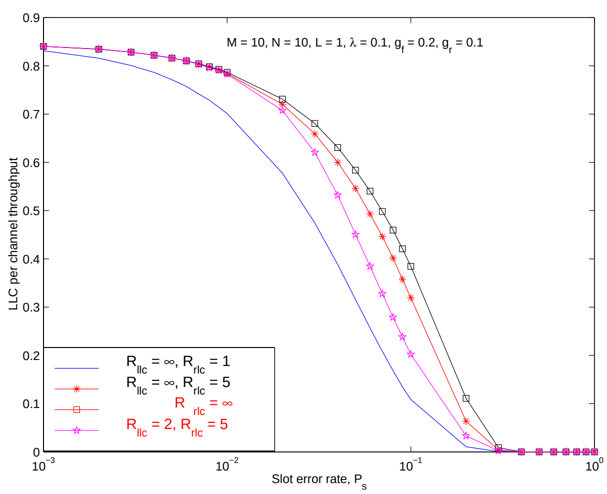

Fig. 5. *LLC average per channel throughput versus slot error rate, P_s. $N = 10$, $M = 10$, $L = 1$, $\lambda = 0.1$, $g_r = 0.1$, $g_f = 0.2$. BLR at RLC.*

The effect of slot error rate on the per channel throughput and delay performance at the LLC is shown in Figs. 5 and 6, for M=10, N=10, $L = 1$, λ=0.1, $g_r = 0.1$, $g_f = 0.2$, and for various combinations of R_{llc} and R_{rlc}. We consider the block level retransmission here. In Figs. 5 and 6, ($R_{llc} \to \infty$, $R_{rlc} = 1$) corresponds to the case where the stack has no RLC and has a persist-until-success LLC, and $R_{rlc} \to \infty$ corresponds to persist-until-success RLC and no LLC. Note that the absence of RLC ($R_{rlc} = 1$) gives the worst case performance even if R_{llc} is taken to ∞. Also, complete recovery at the RLC itself ($R_{rlc} \to \infty$) gives the best performance. This indicates a larger value of R_{rlc} than R_{llc} is beneficial in terms of performance.

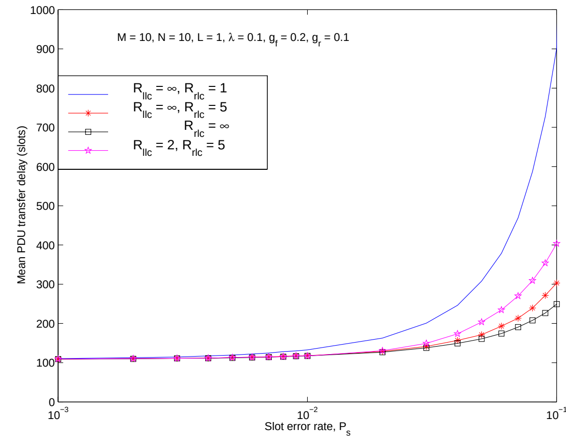

Fig. 6. *Mean PDU transfer delay versus slot error rate, P_s. $N = 10$, $M = 10$, $L = 1$, $\lambda = 0.1$, $g_r = 0.1$, $g_f = 0.2$. BLR at RLC.*

It is noted that the normalized per channel throughput in Figs. 3 and 5 can be converted into equivalent effective data rates as illustrated in the Appendix.

V. TCP Performance

Transmission Control Protocol (TCP) is a well known transport layer protocol in the Internet [7]. TCP is a reliable, connection-oriented protocol which is widely used in popular applications like http, ftp, telnet, etc. Several studies have analyzed the performance of TCP on wireless, but without considering ARQ in the link layer [8],[9],[10],[11]. Here, we estimate throughput performance of TCP in the data transfer phase, on the GPRS uplink with the associated LLC/RLC/MAC layers. For a description of TCP data transfer phase, refer [10].

It is difficult to describe the Internet traffic using classical traffic models. The reason for this is a significant probability for very long sessions, very long interarrival times between sessions and packets of very large size. Heavy tailed (long tailed) complementary cumulative distribution functions (CCDF) *Pareto*, *Weibull*, *hyperexponential* or *power law* are used to describe these measures [12]. In our simulation, we consider an ON-OFF traffic model, such as the web and e-mail traffic. The OFF period distribution is modeled to be a Pareto distribution, for the reasons given above. The classical Pareto distribution with shape parameter β and location parameter a has the CDF

$$F(x) = P\{X \leq x\} = 1 - (a/x)^{\beta}, a, \beta \geq 0, x \geq a, \qquad (1)$$

with the corresponding probability density function:

$$f(x) = \beta a^{\beta} x^{-\beta-1}. \qquad (2)$$

We assume one TCP packet to consist of five LLC frames, and each LLC frame contains 536 bytes. So the TCP packet size is 536 × 5 bytes. An LLC frame is segmented into 25 RLC blocks, each of size 4 GSM slots (see Fig. 2 for PDU segmentation). We consider 20 TCP sessions each sending TCP packets to some hosts in an external Packet Data Network (PDN).

The simulation programs of all the protocol layers, including TCP layer are written in C. The simulation is carried out for one million slots.

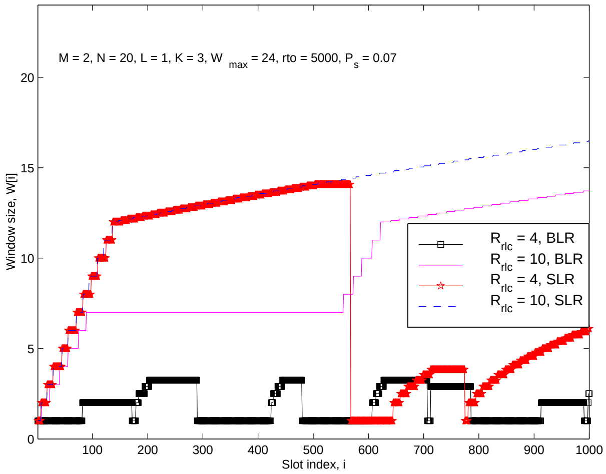

Fig. 7. *Evolution of TCP window size, $W[i]$, versus slot index, i.* $M = 2$, $N = 20$, $L = 1$, $R_{llc} = 3$, $K = 3$, $P_s = 0.07$, $W_{max} = 24$, $rto = 5000$.

Figure 7 shows the evolution of window size, $W[t]$, as a function of time for a slot error rate (P_s) of 0.07, $N = 20$, $L = 1$, $K = 3$, $R_{llc} = 3$, W_{max} of 24 TCP packets, and a round trip timeout value of 5000 slots. The window evolution of four different cases are plotted: a) BLR with $R_{rlc} = 4$, b) BLR with $R_{rlc} = 10$, c) SLR with $R_{rlc} = 4$, and d) SLR with $R_{rlc} = 10$. In Fig. 7, a comparison between $R_{rlc} = 4$ versus $R_{rlc} = 10$ for both BLR and SLR indicates that the window size is more open for $R_{rlc} = 10$ than $R_{rlc} = 4$. This is because for $R_{rlc} = 4$ the recovery of erroneous blocks can be incomplete and this can result in more TCP timeouts and fast retransmits, which shrinks the window size to 1. Since larger instantaneous window sizes are good for achieving high throughput, the choice of parameter value $R_{rlc} = 10$ is preferred over $R_{rlc} = 4$. Also a comparison between BLR and SLR for $R_{rlc} = 10$ reveals that SLR results in a significantly better performance at the TCP layer. The window evolution behaviour in Fig. 7 results in a TCP throughput performance shown in Fig. 8.

Figure 8 shows the throughput performance of TCP as a function of slot error probability, P_s, for different values of R_{rlc}. The following system parameters are taken: $M = 8$ PDTCHs, $N = 20$ users, $L = 1$ PRACH, $R_{llc} = 3$, fast retransmit parameter (K) = 3, maximum advertised window size (W_{max}) = 24 TCP packets, and a round trip timeout value of 5000 slots. We observe that as R_{rlc} is increased, throughput increases, as expected. When R_{rlc} is large, more erroneous blocks are retransmitted and recovered in the RLC layer itself rather than leaving them to LLC or TCP to recover by retransmitting the LLC frame or entire TCP packet. We also observe that the RLC slot level retransmission offers a better throughput than the block level retransmission.

Figure 9 shows the throughput performance for different values of M, for $R_{rlc} = 10$, $N = 20$, $L = 1$, $K = 3$, $W_{max} = 24$, $R_{llc} = 3$, and a round trip timeout value of 5000 slots. We find that as M is increased throughput increases. If the number of PDTCHs, M is less, a successful request may not get an

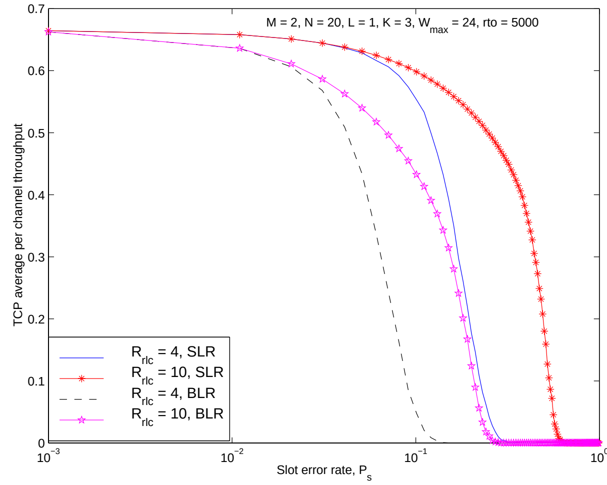

Fig. 8. *TCP throughput performance as a function of P_s and R_{rlc}.* $M = 2$, $N = 20$, $L = 1$, $R_{llc} = 3$, $K = 3$, $W_{max} = 24$, $rto = 5000$.

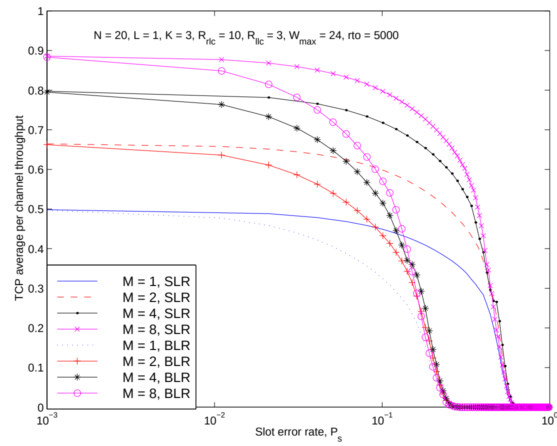

Fig. 9. *TCP throughput performance as a function of P_s and M.* $N = 20$, $L = 1$, $R_{rlc} = 10$, $R_{llc} = 3$, $K = 3$, $W_{max} = 24$, $rto = 5000$.

available PDTCH and will be backlogged. As M is increased the successful requests will see an available PDTCH with high probability and hence the throughput increases as M increases. For a given arrival rate, if M is increased beyond a certain value then the throughput decreases. This is because, the channels remain idle most of the time. This behaviour is illustrated in Fig. 10.

Figure 11 gives the throughput as a function of fast retransmit parameter, K, for $M = 8$ PDTCHs, $N = 20$ users, $L = 1$ PRACHs, maximum advertised window size (W_{max}) of 24 packets, and a round trip timeout value of 5000 slots. We observe a small performance improvement as K is decreased from 3 to 1. This is because, if the error rate is high or errors are bursty, then the receiver may not get $K = 3$ *duplicate acks* before TCP timeout. The receiver in that case *times out* and initiates the *error recovery* mechanism. Since the channel remains idle from the point where the packet in the upper edge of the TCP transmitter window is sent to the point where timeout occurs, the throughput is less. By reducing K we try to initiate *error recovery* sooner. The reduction of fast retransmit threshold is expected to improve significantly performance when the errors are bursty [11].

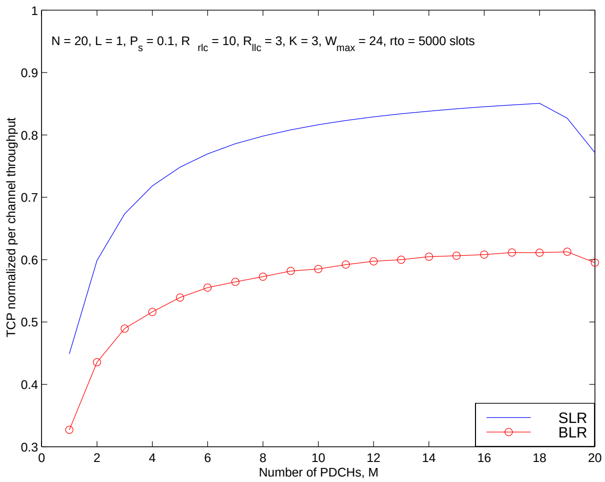

Fig. 10. *TCP throughput performance as a function of* M. $N = 20$, $L = 1$, $R_{rlc} = 10$, $P_s = 0.1$, $R_{llc} = 3$, $K = 3$, $W_{max} = 24$, $rto = 5000$.

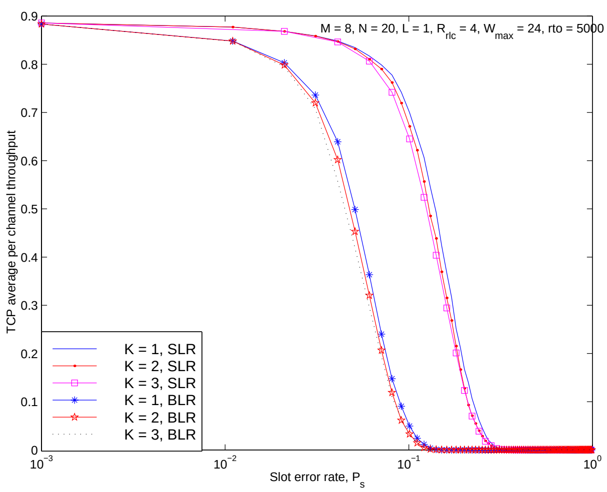

Fig. 11. *TCP throughput performance as a function of* P_s *and* K. $M = 8$, $N = 20$, $L = 1$, $R_{rlc} = 4$, $R_{llc} = 3$, $W_{max} = 24$, $rto = 5000$.

VI. Conclusions

We investigated the performance of the LLC and TCP layers in GPRS networks. We evaluated the uplink throughput and delay performance of GPRS-LLC protocol with RLC layer using BLR and compared it with that of using SLR at the RLC. Our results showed that it is more beneficial to do the error recovery by allowing more retransmissions at the RLC layer than at the LLC layer. Maximum retransmission attempts of about 10 at the RLC layer and 2 or 3 at the LLC layer are shown to provide good performance. Substantial increase in TCP throughput is possible by increasing the maximum allowable number of retransmissions (R_{rlc}) at the RLC layer. Given a large value of R_{rlc}, the fast retransmit parameter, K, does not have much impact on TCP throughput performance

Appendix

We can compute the effective data rate at LLC (or TCP) in Kbps from the normalized LLC (or TCP) throughput, using the relation

$$\eta_c(\text{Kbps}) = \eta_c \cdot \frac{n_{inf} * PL * FL - OH}{PL * FL * BL * 4.615} \text{ Kbps},$$

where

- η_c represents the normalized per channel throughput at the LLC layer (or TCP),
- η_c(Kbps) represents the effective data rate in Kbps at the LLC layer (or TCP),
- n_{inf} represents the number of information bits in each RLC block including the IP/LLC header and checksum,
- PL represents the TCP packet length in terms of number of LLC frames (for LLC, PL = 1).
- FL represents the LLC frame length in terms of number of RLC blocks,
- BL represents the RLC block length in terms of number of GSM slots, and
- OH represents the number of overhead bits per LLC frame (or TCP packet).

Note that the 4.615 in the denominator of the above expression accounts for the one slot duration which is equivalent to one TDMA frame length of 4.615 ms.

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