Performance Analysis of Varying the Link Adaptation BLER Switching Point in EGPRS

W. Featherstone and D. Molkdar
Motorola GSM Applied Research,
16 Euroway, Blagrove, Swindon, Wiltshire, SN5 8YQ, United Kingdom
W.Featherstone@motorola.com & Davood.Molkdar@motorola.com

Abstract- *This paper examines the impact of the choice of the link adaptation BLER switching point on the performance of Enhanced General Packet Radio Service (EGPRS) Phase I, with the aim of determining the optimum switching point. The analysis is carried out by considering outputs from a system level simulator and a system dimensioning and planning tool. Results are presented for both LA and IR for a range of LA switching points. A GSM macro-cellular environment, having an interference limited 4x3 re-use pattern, was chosen. The mobiles operate with perfect receivers in a variety of radio channel conditions.*

I. INTRODUCTION

Radio packet data bearers have been and are being standardised across the world to provide efficient data services and enhance the capacity of existing technologies such as GSM. In GSM, a new packet data service, GPRS [1], is currently being deployed for commercial use. Since the standardisation of GPRS, a new data service to enhance both GSM circuit switched and GPRS has also been standardised in ETSI SMG2. This is known as EDGE, Enhanced Data Rate for Global Evolution. EDGE enhances both circuit (ECSD) and packet switched data services (EGPRS). EDGE standardisation consists of two main phases; Phase I and II. EDGE Phase I standards, aimed at non-real time services using EGPRS and real time services using ECSD, have been finalised (Release 99). EDGE Phase II standards are aimed at real time services via packet data bearers and circuit switched bearers.

GPRS and EGPRS have been designed with a plurality of coding schemes, CS1 to CS4 and MCS1 to MCS9 respectively. Each code has a different level of robustness to the channel conditions experienced. Like GPRS, EGPRS uses link quality control (LQC), specifically link adaptation (LA), to optimally select the code that matches the channel conditions, both at call establishment and during data transfer. In addition to LA, the LQC in EGPRS also includes Incremental Redundancy (IR), which significantly improves the link performance. The need to adapt the code selection arises from the time varying nature of the radio channel. Code selection and reselections are made according to a set of prescribed system operating constraints that are typically based on a switching block error rate (BLER). The choice of switching BLER is critical in maximising the system performance of EGPRS, in terms of throughput and delay. The EGPRS standards stipulate that the operating BLER to be used for equipment testing is 10% in the majority of cases and 30% for the higher MCSs and selected channel conditions [4]. The motivation for higher operating BLER is to increase the percentage coverage of the higher coding schemes; however, this may be undesirable due to the impact on system performance. Therefore, although the standards specify the test operating BLER, they do not indicate what BLER thresholds should be used for the LA BLER switching point, or whether the same thresholds should be used under all channel conditions and for all coding schemes; this is left as an implementation issue.

This paper focuses on the issue of selecting the optimum LA BLER switching point, in terms of the system performance of EGPRS Phase I. The choice is investigated using both a link level based system-dimensioning tool as well as an RLC/MAC system level simulator, in both pure LA and hybrid LA/IR mode. The RLC protocol used is an improved protocol developed by the authors within the scope of the Standards specifications, which considerably increases the feasible operating BLER. The performance is quantified in terms of the system throughput, average user throughput and delay. The GSM interference limited macro-cellular environment using a 4x3 re-use pattern is used in the performance evaluation.

The paper begins in section II with an overview of EGPRS and the features specifically related to this paper. In Section III, the simulation tools are described, followed by Section IV, which describes the simulation scenarios and results. Finally, Section V summarises the conclusions.

II. OVERVIEW OF EGPRS

There are many new features introduced in EGPRS Phase I [1-3], which have resulted in higher data rates at link level and higher spectral efficiency at system level. These have been achieved, primarily, by major modification of the GPRS specifications at the physical and RLC/MAC layer. At the physical layer nine new coding schemes have been introduced. At the RLC/MAC layer: different RLC/MAC header information elements; IR; larger ACK/NACK window size; new quality reports and a host of new signalling information elements have been added.

A. EGPRS Physical Layer

The physical layer of EGPRS Phase I is described in reference [5]. Briefly, there are nine coding schemes of which five, MCS-5 to MCS-9, use 8-PSK and the remaining four, MCS-1 to MCS-4, use GMSK. Furthermore, each coding scheme has up to 3 puncturing schemes, with each representing the same radio block. The punctured blocks can

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be decoded independently or combined together to provide coding gain in IR mode. The variety of code rates and two modulation schemes with their varying degrees of robustness enable operation across a cell designed for GSM speech. Table 1 provides the details of the code rates together with the user data rate per time slot for each coding scheme.

MCS	User rate [Kbps]	Code Rate	Header Code Rate	Family
9 (8-PSK)	59.2	1.0	0,36	A
8 –	54.4	0.92	0,36	A
7 –	44.8	0.76	0.36	B
6 –	29.6	0.49	1/3	A
5 –	22.4	0.37	1/3	B
4 (GMSK)	17.6	1.0	0.51	C
3 –	14.8	0.85	0.51	A
2 –	11.2	0.66	0.51	B
1 –	8.8	0.53	0.51	C

Table 1: EGPRS Data and Code Rates

B. EGPRS RLC/MAC Layer

The RLC/MAC layer determines the performance of a user at system level. The responsibilities of this layer include segmentation of LLC PDUs into RLC blocks, ARQ, LQC and resource scheduling [3]. LQC is essential in maintaining the QoS between a user and the network and in allocating the optimum code (LA) that matches the radio conditions for a prescribed system operating condition, e.g. a fixed operating BLER.

In EGPRS, the LA algorithm can be based on various combinations of the parameters available that determine the radio channel condition. Essentially, these parameters, which are contained either in the uplink packet acknowledgement message for downlink data transfer or estimated at the network side for the uplink data transfer, provide an indication of the C/(I+N) ratio experienced by the MS or network respectively. Using this information, the link can be adapted accordingly. The mechanism of re-segmentation has also been incorporated at the RLC/MAC layer by grouping the coding schemes into three families: A, B and C (see Table 1). With this grouping, it is possible to retransmit a block with more robust coding or transmit a new block with less protection by moving down and up a family group respectively.

IR provides redundancy in increments of a radio block. In simple terms, a radio block that has been received in error is stored and is then combined with the next re-transmission of the block, which essentially contains extra redundancy. This process is repeated until a radio block is decoded successfully. The result is that a given coding scheme can be used at a lower C/I [5].

III. Description of the Simulators

The results, presented in his paper, were produced using a link level based system-dimensioning tool and a system level simulator [6].

A. The System-Dimensioning Tool

The link level based system-dimensioning tool takes as its main inputs the link level (physical layer) BLER performance and C/I distribution for the re-use pattern of interest. The tool has a database of the link BLER performance of all EGPRS coding schemes for all radio conditions defined in the standard [4], along with the C/I distribution for various re-use patterns, e.g. 1x3 and 4x3. These are used to derive a large number of statistics including the percentage coverage, throughput, spectral efficiency, and bandwidth requirements. The parameter of particular interest when considering the choice of the LA BLER switching point is the average user throughput across the cell, where throughput is calculated as:

$$T_{Ave} = \sum_{i=1}^{9} \Big[EffCov(MCS_i)_{BLER(Switch)i} \times R_{MCS_i} \times \frac{(1-BLER(Switch)_i)+(1-BLER(Switch)_{i+1})}{2} \Big],$$

where $BLER(Switch)_i$ and $BLER(Switch)_{i+1}$ represent the BLER of MCS_i at the specified switching point, e.g. 30%, and the BLER of MCS_i at the switching point of the MCS_{i+1} (for i = 9, BLER is zero for i+1) respectively. R_{MCSi} is the user data rate of a given coding scheme as shown in Table 1, e.g. 59.2 Kbps for MCS-9. The tool can be operated under LA or IR mode and is also capable of investigating the impact of other factors such as diversity gain and the degradation due transmitter and receiver imperfections.

B. System Simulator

The system level simulator, used to produce the results presented here, is specifically designed to evaluate the peer-to-peer performance of the Radio Link Control (RLC) layer and Medium Access Control (MAC) layer. This is achieved by modelling comprehensively all aspects of the data transactions as specified in the RLC/MAC GSM specification [3]. The RLC protocol used is an improved protocol developed by the authors within the scope of the Standards specifications, which enables system operation at high BLER. This is achieved by increases the frequency of polling for acknowledgement in proportion to the operating BLER.

The results are evaluated by considering the throughput and delay statistics as a function of LA BLER switching point. The simulator takes several input parameters, the most significant of which are the physical layer performance of each coding scheme for a given radio condition, in terms of the BLER performance [5] and the C/(I+N) distribution across the cell area resulting from the selected re-use pattern. For each scenario considered, the cells are populated with users who have perfect receivers and receive e-mails under a TU50-NoFH radio condition.

For the results presented in this paper the following input parameters were selected; downlink only data transfer on dedicated channels, with 7 time-slots available for data transfer. The mobiles used single slot operation and were assumed to be static during a TBF, operating with a fixed C/(I+N) that was known and hence the optimum (according to the LA algorithm) MCS was selected for transmission. The scheduling algorithm employed was FIFO and then fixed allocation was for file transfer, such that transmissions occur on a block-by-block basis, in the assigned timeslots until completion. Files were generated according to the e-mail traffic model (truncated Cauchy distribution with median, dispersion and maximum of 0.8, 1.0 and 10k bytes, respectively) [7]. The input load is defined as average percentage of cell loading, e.g. 50% loading means on average 50% of time slots are occupied.

- **LA algorithm:**

Scheme 1: Fixed operating BLER as the criteria for code switching. Highest MCS is selected that satisfies the BLER threshold (labelled, LA max MCS).

Scheme 2: The MCS is selected that satisfies the BLER threshold and offers the maximum the throughput for the observed C/(I+N), (labelled, LA max thro).

- **Incremental Redundancy:**

Scheme 1 uses LA scheme 1 for code selection (labelled, LA max MCS) and scheme 2 uses LA scheme 2 for code selection (labelled, IR max thro).

Both IR schemes are termed hybrid LA/IR as LA is used for code selection and IR is used for re-transmissions, which implies that re-transmissions are sent in the next puncturing scheme. P1 is used for the initial transmission in both LA and IR mode.

C. System Simulator Output Parameters

The simulator generates a large number output parameters, those used in this paper are:

- **Delay statistics**

Delay is defined here as the time between the birth of an MS and the time that its last block is successfully acknowledged. Thus, the delay includes the transmission time and queuing delay. The delay statistics at a given input load are the average user delay and ninetieth percentile user delay. This is the 90% point of the delay cumulative distribution (CDF).

- **Throughput**

Throughput is not directly related to the delay since the inactivity time by the user is not taken into account, i.e. it is an indication of when the resources are allocated to a user. Both, the average user throughput and the system throughput are presented.

The average user throughput considering the assumptions made in this paper is estimated as follows:

$$AverageUserThroughput = \frac{1}{N}\sum_{i=1}^{N}\frac{FileSize(i)}{TransmissionTime(i)}.$$

N is the number of files (users) served during the simulation duration. The throughput calculation for each user is equivalent to:

$$Throughput = \left[\frac{Total\ No.\ RLC\ Blks\ At\ LLC}{Total\ No.\ of\ RLC\ Blks\ Tx-ed}\right] * R_C,$$

where R_C is the average data rate during the TBF, because the transmission time only accounts for the time that resources are allocated to an MS.

The system throughput is defined as the sum of all data transmitted during the simulation divided by the simulation duration:

$$SystemThroughput = \frac{\sum_{i=1}^{N} FileSize(i)}{SimulationDuration}.$$

IV. RESULTS

The main objective of this study is to evaluate the impact of the choice of LA BLER switching point of EGPRS. The GSM macro-cellular environment has been selected, using a 4x3 re-use pattern. This re-use pattern represents the BCCH carrier planning with no frequency hopping and no power control.

The following path loss model is used to estimate the C/I

$$Path\ Loss = 126 + 37\log(d) + X(std),$$

where d is distance in Km and $X(std)$ = 8dB is the standard deviation of the lognormal distribution.

D. System-Dimensioning Tool Results

The first set of figures examine the impact of the LA BLER switching point using the link level based system-dimensioning tool, described in section 0. The results presented are the average user throughput across the cell, which the system-dimensioning tool derives from the link level performance curves and the C/I distribution. Figure 1 demonstrates the impact on average user throughput for LA switching point of between 5 and 50% BLER. It is apparent that the optimum switching point is different for each channel type and that, typically, as the mobile speed increases the higher the optimum switching point. However, the optimum switching point for TU3-noFH, TU50-noFH and HT100-noFH channel conditions are close, at BLERs of 25%, 20% and 25% respectively. Figure 2 shows the performance of IR under the same channel conditions, the curves for average user throughput have a similar form. In IR mode, the optimum switching point for TU3-noFH, TU50-noFH and HT100-noFH channel conditions are at BLERs of 33%, 33% and 54% respectively. This demonstrates how the code combining afforded by IR enables a higher operating BLER than LA. The IR switching BLERs can be converted into effective BLER using the following expression [8]:

$$BLER_{eff} \approx \frac{BLER_{switch}}{1 + BLER_{swich}}.$$

The result is that the effective BLER switching points are 25%, 25% and 35%, which demonstrate close correspondence to the optimum switching point in LA mode. The last figure from the system-dimensioning tool is Figure 3, where the performance in LA and IR mode is compared. It is apparent that the average user throughput is higher in IR mode, 37.7 Kbps compared to 36.5 Kbps for TU50-noFH and

34.6 Kbps compared to 32.4 Kbps for HT100-noFH channel conditions.

E. System Simulator Results

As was stated in section 0 only the TU50-noFH channel condition was simulated using the system level simulator. Figure 4 depicts the average user throughput for various LA BLER switching points for the four LA and IR techniques. The degradation in average user throughput at the system level, compared to that estimated by the system-dimensioning tool, arises due to the protocol overheads imposed by the RLC/MAC layer, for example due to the wasteful transmission of pending acknowledgement blocks. It is apparent that maximising the throughput rather than the MCS used offers a higher throughput for both LA and IR. In pure LA mode, when using the highest MCS (max MCS) the system exhibits the same behaviour as with the system-dimensioning tool, in that there is an optimum LA switching point. This is not the case when maximising the throughput (max thro) as the MCS that maximises the throughput is always selected rather than the highest MCS. The result is that as the LA BLER switching point increases a maximum throughput is reached and the curve flatteners. This point is reached at a BLER switching point of 25%, resulting in an average user throughput of 28.6 Kbps. In hybrid LA/IR mode, the throughput peaks 29.1 Kbps and 29.2 Kbps respectively for the "max MCS" and "max thro" scheme at a BLER switching point of 40%, which equates to an effective BLER of 29%. The reason IR scheme 1's (max MCS) average user throughput does not degrade at high BLER can be attributed to the protocol implementation, which enables the benefits of code combining, in IR mode only, to be realised at higher BLER.

Figure 5 shows the corresponding system throughput for a 30% loading level where, as with the average user throughput, the system throughput increases with an increased BLER switching point. Although there are fluctuations in the curves it is apparent from Figure 6 that these are minor in comparison to the impact of system loading on system throughput.

Figure 7 and Figure 8 show the average and ninetieth percentile delay obtained from the system level simulator, for a system loading of 30%. The delay at a this loading level is dominated by the transmission delay rather than the queuing delay, hence the figures at this loading level enable the transmission delay between Pure LA and Hybrid LA/IR to be compared. As expected, the curves are proportional to the reciprocal of the average user throughput curves, because as throughput increases delay decreases, when delay is dominated by transmission delay rather than queuing delay.

V. Conclusions

In this paper, the impact of the choice of LA BLER switching point in EGPRS has been examined using both a link level based system-dimensioning tool and a system level RLC/MAC simulator. The simulation results presented were the downlink throughput and delay performance of EGPRS Phase I in a GSM interference limited macro-cellular environment. The cell configuration examined was a 4x3 re-use pattern, which was assumed to be the BCCH.

It has been shown that, although the optimum switching point varies according to the channel condition, the system level performance of EGPRS is less affected by the choice of switching point when the choice of MCS is based on maximising the throughput. This is so long as it exceeds the optimum BLER switching point derived from the link level performance. However, it should be noted that such a performance is based on the improved protocol implementation proposed by the authors, which increases the frequency of polling for acknowledgement with increasing operating BLER. Consequently, LA and IR can be operated at higher BLER without degrading the system or user throughput. Without this enhancement both the performance of LA and IR degrade as the operating BLER increases. This is, primarily, a result of lost ARQ messaging. Furthermore, operating at excessively high BLER, results in an increase in the signalling overhead required for the additional ACK/NACK messages. Therefore, in order to maximise the system performance, while keeping the signalling overhead low, a BLER switching point of 25% and 33% maybe used in LA mode and IR mode, respectively; note that, 33% equates to an effective BLER of 25% in IR mode. The suggested BLER is low enough that, even if there are inaccuracies in the channel estimate, the system in general will not operate at excessively high BLER.

VI. References

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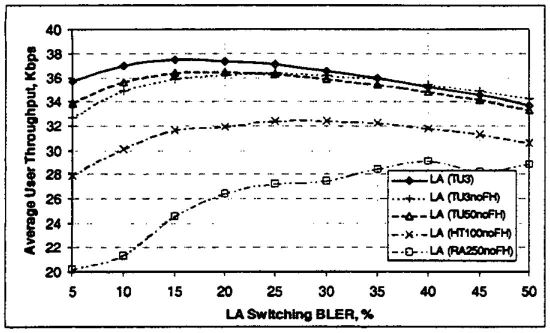

Figure 1: Average User Throughput in LA mode for various Channel Conditions

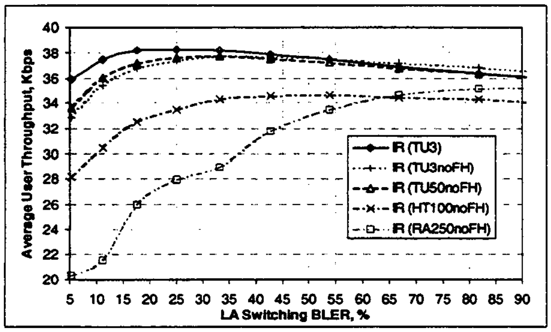

Figure 2: Average User Throughput in IR mode for various Channel Conditions

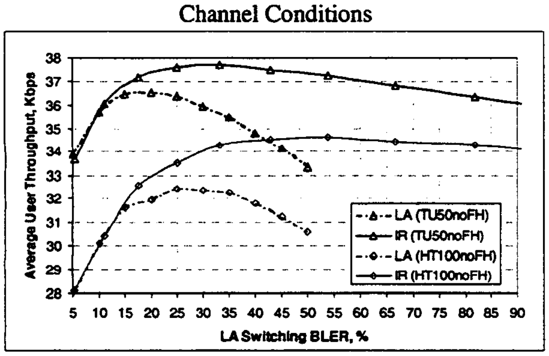

Figure 3: Average User Throughput comparing performance in LA and IR mode

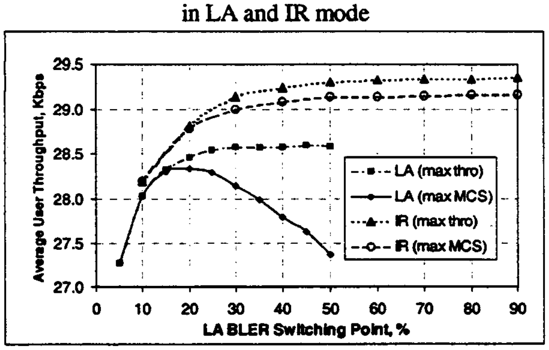

Figure 4: System Level: LA vs. IR Average User Throughput

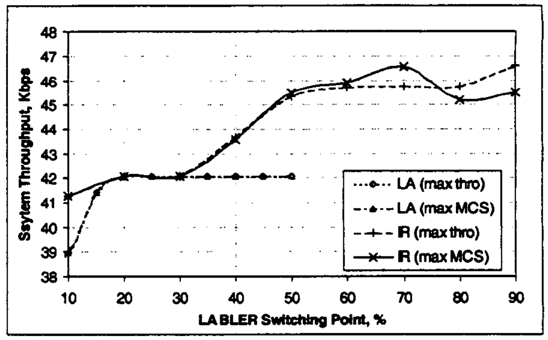

Figure 5: System Level: LA vs. IR System Throughput, 30% loading

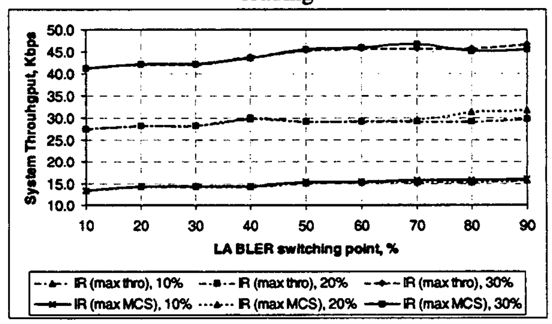

Figure 6: IR system level performance for various loading and LA BLER switching points

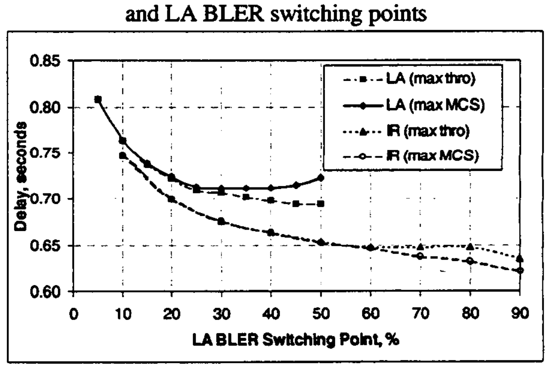

Figure 7: Average Delay at 30% loading

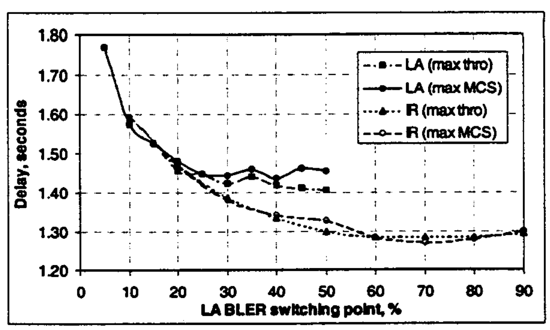

Figure 8: Ninetieth percentile Delay at 30% loading