Effect of Slot Allocation Mechanisms on the Performance of Link Adaptation

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ABSTRACT

The performance and operation of Link Adaptation depends on the channel quality dynamics. Since such dynamics are influenced by the mechanisms used to assign free slots in a TDMA system, this paper investigates the effect that different slot allocation mechanisms have on the Link Adaptation performance. In particular, this study considers a random and a sequential slot allocation mechanism.

1. INTRODUCTION

Link Adaptation (LA), initially developed as a 3G technique [1], has been identified as a key technology for evolved GSM systems such as the Adaptive Multi-Rate codec (AMR), General Packet Radio Services (GPRS) and Enhanced Data rates for GSM Evolution (EDGE). The basic principle of LA is to assess the channel conditions and then use a transport mode, from a set of predefined options, which is optimised for these conditions.

The LA performance depends on the accuracy of the channel quality measurements and the ability of the system to adapt to channel quality variations. This ability is determined by the LA updating period, which defines how regularly a decision is made on the most suitable transport mode. A study analysing the LA performance for various updating periods under different operating conditions affecting the channel quality has been reported in [2]. The LA performance and operation are also dependent on the dynamics of the channel quality variations and how predictable such variations are. The operation of LA is based on time averages of the channel quality over the last LA updating period. Large and fast variations of the channel quality will lead to unreliable channel quality estimates producing wrong mode selections by the LA algorithm. Such wrong decisions can decrease the LA performance [2]. The channel quality dynamics can be influenced by the mechanism used to assign free channels (or slots in the case of TDMA systems). In particular, studies such as [3] have proposed to exploit the flexibility in which slots can be allocated in packet based systems to shape the interference within a system. The idea behind such proposals is to benefit the performance of LA and other adaptive techniques by producing more stable link quality conditions.

This paper investigates the effect that different slot allocation mechanisms have on the performance of Link Adaptation applied to the GPRS radio interface (the GPRS standard does not impose any particular mechanism to allocate free slots in a TDMA frame). In particular, this study considers a random and a sequential slot allocation mechanism and the impact that these two mechanisms have on channel dynamics and therefore the operation and performance of LA. While the random slot allocation mechanism assigns randomly free slots in a frame, the sequential slot allocation mechanism assigns free slots sequentially from the start of the frame.

Figure 1 illustrates the operation and effects of the random and sequential slot allocation mechanisms. The sequential slot allocation mechanism increases the probability of a slot being occupied at the start of a frame and therefore it also increases the chances of having co-channel interferers for these slots. Although this behaviour will increase the interference level, the number of interferers a user might experience is less variable than in the case of the random slot allocation mechanism, which might in turn create more stable channel quality conditions.

The aim of this paper is therefore to compare the performance of LA under both slot allocation mechanisms and analyse whether the expected increased interference level created under a sequential slot allocation mechanism can be compensated with a reduction in the number of mode changes and therefore with a more stable operation of the LA algorithm. This study has been conducted for packet data transmissions in a GPRS-like system.

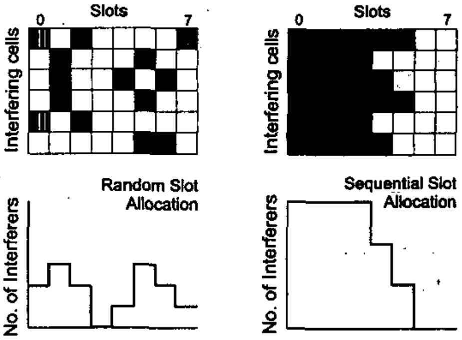

Figure 1: Random and sequential slot allocation mechanisms

2. GENERAL PACKET RADIO SERVICE

Prior to transmission, GPRS data packets are segmented into smaller data blocks across the different GPRS logical layers, with the final logical unit being the Radio Link Control (RLC) block [4]. A RLC block is then transmitted over four bursts in consecutive TDMA frames. The work here presented concentrates on the two lower layers of the GPRS protocol stack, i.e. the RLC/MAC layer and the physical layer.

The RLC/MAC layer provides services for information transfer over the physical layer of the GPRS radio interface. The Medium Access Control (MAC) function of the RLC/MAC layer defines the procedures that enables multiple users to share a common transmission medium, which may consist of several physical channels. The efficient multiplexing of users in the downlink should be ensured by a scheduling mechanism. The RLC function of the RLC/MAC layer is responsible for backward error correction of erroneously delivered RLC blocks by means of a selective retransmission mechanism.

The physical layer is responsible for data unit framing, data coding and the detection and correction of transmission errors by means of a Forward Error Correction mechanism. Four channel Coding Schemes, CS1 to CS4, are specified for the GPRS packet data traffic channels. Each scheme has been designed to provide different resilience to propagation errors under unfavourable radio conditions. The different error correction capabilities of each CS make the payload transmitted in a RLC block dependent on the CS used as shown in Table 1. Therefore, the different coding schemes offer a trade-off between throughput and coding protection, paving the way for the application of dynamic LA to GPRS.

Scheme	Code rate	Payload	Data rate (kbits/s)
CS1	1/2	181	9.05
CS2	≈2/3	268	13.4
CS3	≈3/4	312	15.6
CS4	1	428	21.4

Table 1: GPRS channel coding parameters

3. SIMULATION MODELS

In order to ensure high accuracy and to account for sudden channel quality variations, an event-driven simulator working at the burst level has been implemented. The simulator models the dynamic behaviour of the channel quality in terms of the Carrier to Interference Ratio (CIR).

3.1 System modelling

A cellular network of equally sized 3-sector macro cells, with a cluster size equal to four, has been considered. Within the network interference produced by first and second tier of co-channel interferers is considered. Each cell has a radius of 1km and each sector has been assigned two carriers. Although mobility has been implemented, handover between sectors has not been considered. The boundary effects have been removed by using a wrap-around technique.

The simulator concentrates on the downlink performance. The system load is varied by changing the number of users in the system, with each user operating for the complete duration of the simulation. Only single slot transmissions have been considered. Users are assigned channels in a first-come-first-served basis and the channel is kept until all its data has been correctly transmitted. An ARQ protocol, following the GPRS specifications, has been implemented to request the retransmission of erroneous blocks. A perfect feedback of the ARQ report with no RLC block loses has been assumed. The ARQ window size is equal to 64 RLC blocks. An ARQ report is sent after transmitting 16 RLC blocks [2]. Although the current GPRS standard does not contemplate CS changes for retransmissions, such changes have been considered in this work so that results are not conditioned by GPRS limitations.

Pathloss is predicted using the Okumura-Hata model. Although the Okumura-Hata model was based on measurements done for distances greater than 1km, the model can be extended for distances below 1km as indicated in [5]. The shadowing has a log normal distribution with a standard deviation of 6dB and a decorrelation distance of 20 meters. Fast fading has also been included in the system level simulations as explained in Section 3.3. Power Control (PC) or Slow Frequency Hopping (SFH) mechanisms have not been implemented in the results reported. PC and SFH directly affect the operation of LA and therefore the use of both techniques together with LA would require the definition of an algorithm describing how they should interact. Since the definition of such algorithm is out of scope of this work, PC and SFH have not been considered here.

3.2 Traffic modelling

Two different traffic sources have been considered for this study, WWW browsing and email, with the traffic type evenly distributed among users at 50%. No channel partition has been applied between the two services and results are collected individually for each type of traffic from the central cell. Both traffic sources have been implemented as an ON/OFF model. The WWW model considered uses a separate TCP connection to transfer each file, or object, in a web page. The email size distribution is bi-modal as emails are also used to transfer files. For both traffic models, the transmission of a new packet cannot start until the previous transmission has finished, i.e. all the data has been correctly received. The active transmission time will hence depend on the channel quality conditions. More detail on the traffic sources implemented can be found in [2].

3.3 Link to system level interface

In order to reduce the complexity of system level simulations, the effects at the physical layer are generally included by means of Look-Up Tables (LUTs). Since block errors depend not only on the mean block quality but also on the quality distribution among the four bursts used to transmit a RLC block, a link to system level interface working at the burst level has been implemented using the simulation tool detailed in [6]. This interface is composed of two sets of LUTs, as illustrated in Figure 2. The interface requires as input from the system level the mean CIR experienced in a given burst. LUT-1 extracts the burst quality for the measured CIR. The burst quality is represented by mean of the Bit Error Rate (BER). LUT-1 represents a cumulative distribution function (cdf) of the BER for a given CIR. A random process is then used to generate the actual BER from the corresponding cdf. The purpose of this procedure is to model the effect of fast fading on the BER through a random process thereby including the fast fading at the system level. The BER is then estimated for the four bursts used to transmit a RLC block and LUT-2 maps the mean BER and the standard deviation of the BER over the four bursts to a corresponding Block Error Rate (BLER) value.

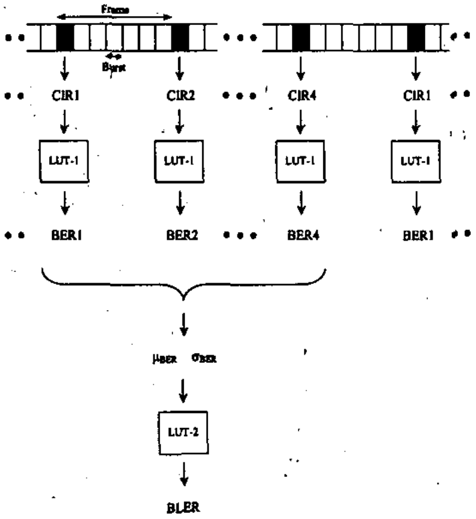

Figure 2: Link to system level interface

4. LINK ADAPTATION ALGORITHM

The basic principle in LA is the estimation of channel conditions and the choice of a CS that is optimised for these conditions. Since this work is based on non-real time data services, a CS is considered to be optimum if it maximises the throughput, defined as:

$$Throughput = R_{CS} \times (1 - BLER_{CS}) \qquad (1)$$

with R_{CS} and $BLER_{CS}$ being the data rate and BLER for a given CS. The LA switching thresholds define the boundaries between the regions where each CS is optimum. In this work, these boundaries are defined as a collection of points, each representing a combination of mean and standard deviation of BER values. An example of the throughput performance used to define the LA switching thresholds is illustrated in Figure 3.

The LA algorithm uses the quality measurements over the previous updating period to decide on the optimum CS. The mean BER and the standard deviation of the BER over a block for each transmitted block during the last updating period are filtered to get the channel quality estimation necessary for the LA algorithm. A filter with a rectangular shape has been applied throughout and a fixed initial coding scheme, CS4, has been selected at the start of each new data transmission.

5. SIMULATION RESULTS

This study is comparing the effect of different slot allocation mechanisms on the LA performance. As explained in Section 1, this comparison is realised in terms of the throughput performance and the number of CS changes. The throughput performance is represented by means of the cdf of the throughput, which allows the assessment of the performance of an LA algorithm for the whole range of bit rates. The throughput is measured per user and is defined as the total number of bits successfully transmitted over the air interface divided by the radio transmission time. As a result, the throughput does not take into account the time a user has been waiting to get access to a channel. In this case, the throughput is measured over intervals of four seconds whenever the user is active. The throughput is collected for all users in the centre cell and the cdf of the throughput is therefore used to provide an indication of the system performance.

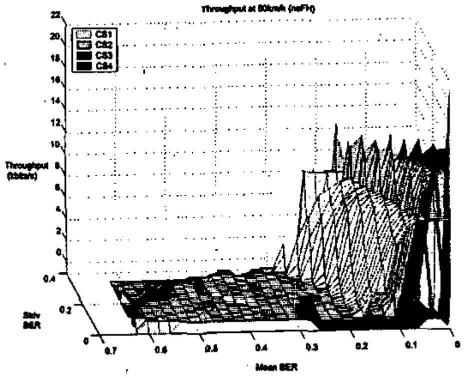

Figure 3: Throughput performance and LA switching thresholds

The study has been conducted for loads of 8, 16, 24 and 36 users per sector. These loads represent an average bandwidth occupancy of 20%, 45%, 67% and 93% respectively. The results presented in this paper correspond to the WWW traffic, users moving at 50km/h and an LA updating period of 100ms (i.e., five RLC blocks). In order to ensure results with good statistical accuracy, each simulation scenario (i.e., considering a different load) simulates the transmission of > 30 × 10^6 RLC blocks in the central cell.

Figures 4 to 7 show the throughput performance for the various loads considered. It can be observed from these figures that as the load increases the performance under both slot allocation mechanisms converge. The channel occupancy increases under high loads and therefore when a user requests a channel to transmit there is a small number of available channels to choose from. As a result both slot allocation mechanisms operate nearly identically, which explains their close performance under high loads. On the other hand, the effect of the load on the performance of each slot allocation mechanism differs. While the performance under a random slot allocation mechanism is clearly affected by the load in each sector this is not the case for the sequential slot allocation mechanism. As this allocation mechanism assigns slots sequentially from the start of a frame, the first slots of a frame experience the conditions of a highly loaded system. The load has therefore a much smaller effect on the performance of the sequential slot allocation mechanism.

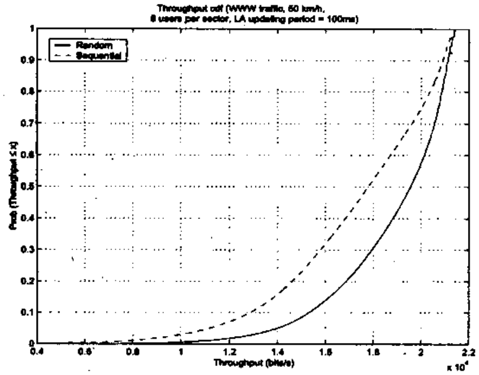

Figure 4: Throughput cdf (8 users per sector)

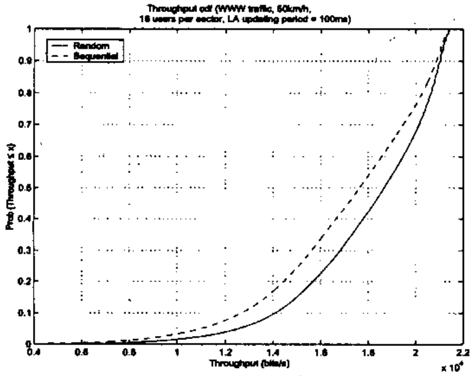

Figure 5: Throughput cdf (16 users per sector)

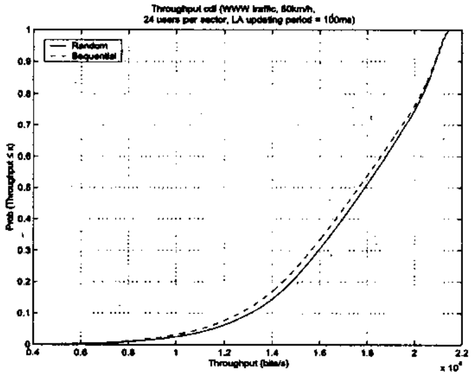

Figure 6: Throughput cdf (24 users per sector)

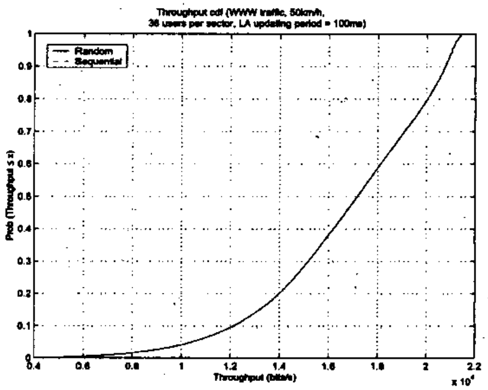

Figure 7: Throughput cdf (36 users per sector)

Figures 4 to 7 clearly show that under low and medium loads the operation of LA is improved with a random slot allocation mechanism. The increased interference level result of the sequential slot allocation mechanism is the origin of this difference in performance. Figure 8 represents the cdf of the CIR obtained for a load of 16 users per sector. While an average CIR of around 24 dB characterises the operation of the random slot allocation mechanism, this average value is reduced to around 21.5 dB in the case of the sequential slot allocation mechanism.

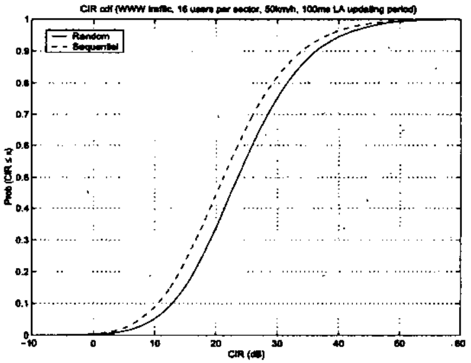

Figure 8: CIR cdf (16 users per sector)

The results presented so far have shown that the increased interference level experienced under a sequential slot allocation strategy degrades the throughput performance of the LA algorithm.

The next step is to check whether the operation of the sequential slot allocation mechanism produces more stable radio link quality conditions and reduces then the number of CS changes.

Contrary to what might be expected a higher number of CS changes are also experienced under a sequential slot allocation mechanism. Table 2 compares the number of CS changes obtained, for both slot allocation mechanisms, under all the different loads. As explained in Section 4, the boundaries between the regions where each CS is regarded as optimum are defined as a function of the BER for the link to system level interface considered. The number of CS changes is therefore dependent on the variability of the BER experienced while a user is active.

	Load=8	Load=16	Load=24	Load=36
Random	2.212	2.54	2.778	2.962
Sequential	2.797	2.842	2.843	2.962

Table 2: Average number of CS changes per second

Figure 9 illustrates the standard deviation of the BER measured over intervals of 100ms when the user is active. This figure shows that the radio link quality conditions are actually more variable under a sequential slot allocation mechanism, which explains the higher number of CS changes compared to a random slot allocation mechanism. For example, under a random slot allocation mechanism, 75% of the samples reported in Figure 9 experienced a standard deviation of the BER lower than 0.018. This value is increased to 0.038 with a sequential slot allocation mechanism. This effect has been observed to be independent of the particular measurement window size since a similar conclusion was obtained when the BER was measured over intervals of 25ms, 50ms and 150ms.

The higher variation of the radio link quality conditions under a sequential slot allocation mechanism is due to the lower CIR conditions experienced with this allocation mechanism. As depicted in Figure 10, lower CIR values actually increase the variability of the BER, which explains the higher variability of the radio link quality conditions experienced under a sequential slot allocation mechanism and the resulting higher number of CS changes. Table 2 also illustrates the different effect of the load on the number of CS changes for both slot allocation mechanisms.

7. CONCLUSIONS

The operation of LA is based on time averages of the channel quality. The performance of an LA algorithm is therefore dependent on the dynamics of the channel quality. These dynamics can be influenced by the mechanisms used to allocate free slots in a TDMA system. In this context, this paper has investigated the effect that different slot allocation mechanisms have on the LA performance. The study conducted has revealed that slot allocation mechanisms maintaining a more constant number of interferers at the expense of a higher interference level decrease the LA throughput performance and also increase the number of CS changes thereby contributing to a less stable operation of the LA algorithm. This increase in the number of CS changes is due to the lower CIR conditions at which these slot allocation mechanisms operate.

The interaction of LA with slot allocation mechanisms has only considered here simple mechanisms that do not use any particular information to allocate channels. Other allocation mechanisms that use information to actually provide the channels could be studied in order to improve the LA performance.

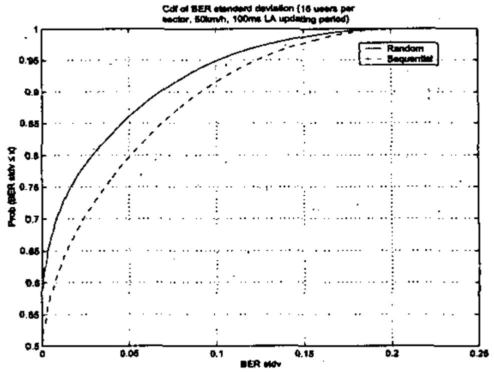

Figure 9: Cdf of the standard deviation of BER (16 users/sector)

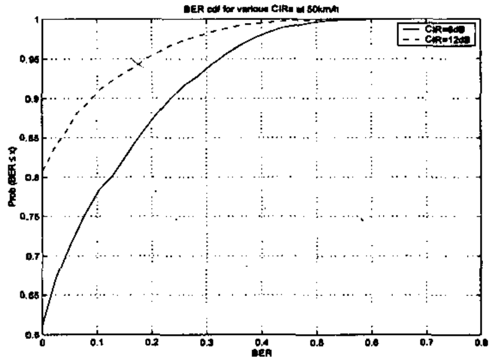

Figure 10: BER cdf at 50km/h for various CIRs

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