Performance of Link Adaptation in GPRS Networks

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Abstract

In GPRS four coding schemes have been defined with different degrees of data protection. The selection of fixed one for a certain packet transmission would lead to a throughput loss if the channel quality conditions vary during the connection, therefore, a link adaptation algorithm based on a BLER estimation is proposed and analyzed. The BLER is calculated from the acknowledgement messages reported by the receiver, so the acknowledgement frequency impacts the link adaptation, and therefore, is to be studied in the present article. The resulting link adaptation algorithm has been analyzed with a dynamic network simulator, under different frequency reuse patterns and frequency hopping strategies. Furthermore, the mean user throughput for the fixed coding schemes and for link adaptation has been estimated from GSM network reported measurements, and a network operator planning tool.

1. Introduction

Into the way towards the Third Generation of Mobile Communications, GPRS (General Packet Radio Service) has become a key step for those applications that require wireless data communication. In the RLC/MAC layer of GPRS four coding schemes (CS1, CS2, CS3 and CS4) have been defined with different degree of data protection [1] with the purpose of adapting the transmission of the data radio blocks to the different quality conditions.

In [3] was shown that the performance of every coding scheme strongly depends on the channel quality conditions, so if a fixed coding scheme was selected the variation of the channel quality conditions during the connection would lead to a performance loss. The aim of link adaptation is to update the coding scheme according to the channel quality variations.

The proposed link adaptation algorithm is based on [4], using the Block Erasure Rate as the channel quality indicator. The transmitter obtains the channel quality information from the acknowledgement messages containing information of the successfully received radio blocks. Thus, the acknowledgement messages frequency influences the link adaptation algorithm. But, besides link adaptation, the packet data transfer adds some constrains to the acknowledgement frequency. So the acknowledgement frequency must be studied in order to reach a compromise that fulfill the requirements of both.

The link adaptation algorithm is analyzed under different frequency reuse configurations, frequency hopping strategies and compared to the fixed coding schemes performance.

Moreover, an estimation of the mean user throughput based on network reported quality measurements as RXQUAL and RXLEV is achieved to investigate the potential mean user throughput in a live network. An estimation of the user throughput geographic distribution is carried out by using a network operator planning tool and the operator's carrier frequency database.

This paper is organized as follows: Section 2 describes the packet data transfer in the RLC/MAC layer and the main details of the coding schemes. Section 3 studies the optimum acknowledgement message frequency. Section 4 describes the proposed link adaptation algorithm and its related channel quality estimation. In sections 5 and 6, the simulated network model is described, and the link adaptation simulation results are exposed and commented. In section 7, the user throughput estimation based on network measurements and the planning tool is achieved, and finally in section 8 some conclusions and remarks are presented.

2. RLC/MAC Model of Operation

The RLC/MAC layer is in charge of adapting the packet oriented transmission to the GSM physical layer. The uplink and downlink packet transfer procedures are handled by the RLC/MAC layer independently. The performance of GPRS networks strongly depends on the RLC/MAC layer

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operation and its efficiency and flexibility to manage the available radio resources. Therefore, the RLC/MAC model of operation is to be discussed here.

Following the description given by [5], the RLC/MAC block transmission between the mobile station (MS) and the base station (BSS) is divided into two steps:

- In the first step the network allocates the channel resources required for the packet transmission. Either the MS or the BSS can initiate the packet resource allocation by a packet transfer access or a packet transfer paging respectively. The process is concluded with a downlink Packet Assignment Message, whereas the BSS includes the list of available Physical Packet Data Channels (PDCHs) for the packet data transfer. For more details see [5].

- In the second step the packet data transfer between the MS and the BSS is carried out. The packet data transfer proccess is described next.

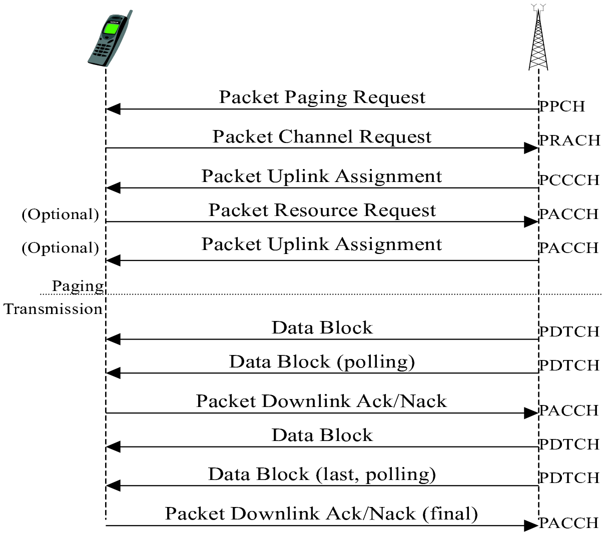

Figure 1. Downlink Data Transfer Example as described in [5]

2.1. Packet Data Transfer

The packet data transfer [1] procedures vary from the uplink to downlink case.

In uplink packet data transfer the MS monitors the downlink RLC/MAC blocks, and, when it is polled by the BSS, the MS starts the uplink packet transmission. The sequence of transmitted data blocks is numbered by a Block Sequence Number (BSN). After a certain period, the BSS sends an Uplink Ack/Nack message that acknowledges all correctly received RLC/MAC data blocks within a certain window k. If block errors occur during the uplink transmission, a negative acknowledgement is included in the Uplink Ack/Nack message by the BSS, and a selective ARQ mechanism is applied, so the erroneous blocks are retransmitted. In uplink packet data transfer, the network decides when to send an Uplink Ack/Nack message.

The downlink packet data transfer is slightly different from the uplink case since the BSS can transmit to the MS on the allocated PDCHs whenever needed. The BSS requests the MS for Downlink Ack/Nack messages by polling it. The MS sends the acknowledgement of the correctly received blocks, and finally, the BSS retransmits the erroneous ones. The downlink packet transmission is represented in figure 2.

The performance of the packet transmission depends on frequency of the Ack/Nack messages. A too frequent acknowledgement could lead to a waste of capacity, while the too infrequent acknowledgement could stall the transmission. The acknowledgement frequency will be treated in section 3.

2.2. Coding in the Physical Link Layer

The RLC/MAC data block transfer is subject to bit transmission errors due to the radio channel conditions. With the purpose of error detection and correction, the Physical Layer applies FEC coding to the RLC/MAC data bits. This coding is one of the main features of GPRS, and can be accomplished by means of four different channel coding schemes (CS1 to CS4). The coding schemes can be characterized as follows:

- CS1 is the same coding as applied for the Slow Associated Control Channel (SACCH), and consists of half rate convolutional coding.

- CS2 and CS3 are punctured versions of the same coding applied for CS1.

- CS4 does not apply convolutional coding at all.

Table 1 summarizes the details about the GPRS channel coding schemes.

The four coding schemes have been defined with different degrees of data protection with the purpose of adapting the transmission of the RLC/MAC data blocks to the different channel quality conditions. The more data protection

Scheme	Coding Rate	Paylaod	Max. Throughput
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. Coding parameters for the GPRS coding schemes

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[1] Unacknowledged mode for RLC/MAC operation is not considered here.

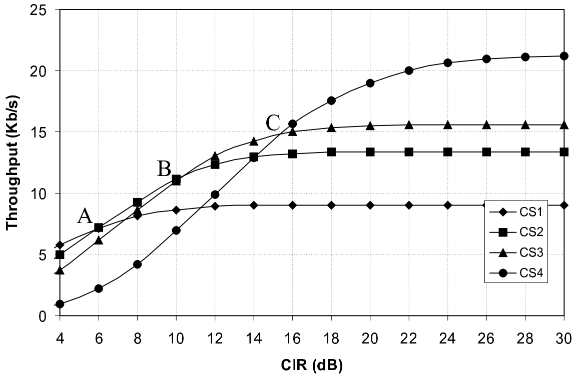

Figure 2. Throughput vs CIR for the 4 Coding Schemes with Ideal Frequency Hopping and TU3 km/h channel model

is applied by the schemes the more redundance is included and, therefore, more number of errors can be corrected. But, on the other hand, the more coding is applied the less quantity of data bits can be borne per data block and, thus, the lower throughput can be reached. Hence, there is a channel coding trade-off between low data protection and few retransmissions as a function of the CIR.

Figure 2 shows the throughput of every coding scheme as a function of the Signal Power-to-Interference Power Ratio (CIR) in a frequency hopping scenario and channel model TU3 km/h by [3]. As it can be seen in the graphic, the throughput of every coding scheme strongly depends on the CIR, and under good channel conditions every coding scheme reaches its maximum throughput and, therefore, CS4 gives the best performance. But under poor channel conditions, the coding schemes with more data protection show better performance.

The impact of frequency hopping on the throughput varies depending on the applied coding. Table 2 shows the mean CIR gain when using frequency hopping for the different coding schemes at several RLC/MAC Block Erasure Rates (BLER) with a channel model TU3 km/h (described in [6]). As it can be seen in the table, for the potential poor users with low CIR, and therefore, using more data protection (i.e. coding schemes CS1-CS2), frequency hopping offers some mean CIR gain at low BLER, while for the potential good users with high CIR (using CS3 and mainly CS4), no hopping gain but loss is achieved by frequency hopping.

Coding Scheme	BLER		
	1%	10%	20%
CS1	6.5 dB	4.0 dB	1.7 dB
CS2	3.2 dB	1.3 dB	-0.1 dB
CS3	2.4 dB	0.2 dB	-1.1 dB
CS4	-2.4 dB	-3.5 dB	-4 dB

Table 2. Frequency Hopping Gain for the GPRS coding schemes

The hopping loss is more significant in CS4 due to the lack of coding that characterizes this coding scheme.

3. RLC/MAC Data Blocks Acknowledgement Procedure

As commented in section 2 the RLC/MAC performance depends on the frequency of the Ack/Nack messages exchanged by the BSS and the MS during the packet data transfer.

In acknowledged packet transfer the transmitter (MS or BSS) shall have an associated acknowledge state array called V(B). V(B) is an array of 128 elements indicating the acknowledgement status of the k previously transmitted blocks, whereas k is the acknowledgement window with a size of 64 blocks. The acknowledge state variable, known as V(A), contains the BSN of the oldest RLC/MAC block that has not been positively acknowledged by the receiver (BSS or MS). All the elements in the V(B) array are indexed relative to the variable V(A) modulo 128. The send state variable V(S) holds the next in-sequence RLC/MAC block to be transmitted.

On the other side, the receiver includes in the Ack/Nack message a received block bitmap (RBB) to indicate the status of the last k received blocks. After the Ack/Nack message reception, the transmitter updates the V(B) array according to the received block bitmap (RBB).

The transmitter shall always transmit the oldest RLC/MAC data block with a negative acknowledgement in the V(B) array. If no RLC/MAC data block with a negative acknowledgement exists in the array V(B), the next two scenarios can occur:

- if [V(S)<V(A)+k] modulo 128, the RLC/MAC block with BSN = V(S) is transmitted.
- if [V(S)=V(A)+k] modulo 128, the transmission gets stalled, and the blocks not acknowledged yet are retransmitted beginning by the oldest one.

3.1. Uplink Acknowledgement Strategy

In uplink packet transmission, the BSS decides when to send an Ack/Nack message, so the acknowledgement frequency could be based on the detected RLC/MAC block errors.

3.2. Downlink Acknowledgement Strategy

In downlink packet transmission, if the BSS polls the MS too infrequently the transmission may get stalled leading to a reduced throughput. To study the polling frequency a simple model of a downlink packet transmission between the BSS and a single MS has been analyzed. The Block

Erasure Rate (BLER) is considered constant during every transmission, and single slot capabity is supported by the MS. The model assumes that Ack/Nack message can not be erased. Nevertheless, this is not critical for realistic BLERs since a new one can be issued after a time out. Different polling periods have been compared to the ideal case where the stalling constrain is disabled for several BLERs. The simulation length is 10.000 RLC/MAC blocks long for all the periods and BLERs. The resulting normalized throughput as a function of the BLER is depicted in figure 3. As it can be seen in the graphic a very infrequent polling period (for example 64 radio blocks) induces a throughput loss up to 40% due to the transfer stalling. But if the MS is polled frequently enough (for example 16 radio blocks), the window stalling is hardly reached for all the block erasure rates, leading to a situation close to the ideal one. Therefore, the transfer stalling introduces a maximum bound to the polling frequency.

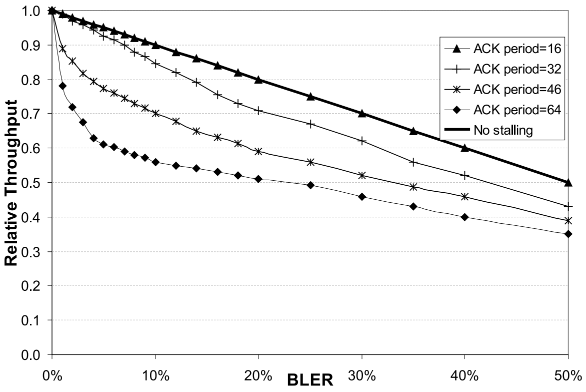

Figure 3. Polling Frequency Loss

On the other hand, in downlink packet transmission, a too frequent polling could lead to a throughput loss. This can be explained following figure 4, which represents the BSS RLC/MAC block sequence transmission. After several data blocks, the BSS decides to poll the MS. The polling block is sent out later due to internal processing at the BSS. After a certain delay, the BSS receives the corresponding Ack/Nack message, and then, it starts the retransmission of the erroneous blocks. If the BSS polls again the MS before the end of the retransmission, the subsequent Ack/Nack message would negative acknowledge the same data block erasures, and therefore, the BSS would retransmit the negative acknowledged blocks more than once, resulting in a waste of capacity. Thus:

$$N_{Poll} \geq N_{Ack} + N_{Retx} - N_{Proc} \tag{1}$$

whereas N_{Poll}, N_{Ack}, N_{Retx}, and N_{Proc} are respectively the number of blocks between consecutive pollings, the number of blocks since the BSS sends out the polling message until it receives the Ack/Nack message, the number of retransmitted blocks, and BSS processing delay measured in number of RLC/MAC blocks. Assuming a periodic polling period, the mean number of retransmitted blocks is the block erasure rate multiplied by the number of blocks between two consecutives pollings:

$$\begin{aligned} N_{Poll} &\geq N_{Ack} + BLER \cdot N_{Poll} - N_{Proc} \Rightarrow & (2) \\ N_{Poll} &\geq \frac{N_{Ack} - N_{Proc}}{1 - BLER} & (3) \end{aligned}$$

which can be used as a minimum bound of the polling period. For example, for an Ack/Nack message delay of 8 blocks, a BSS processing delay of 3 blocks and BLER = 50% as a worse case, the polling period should be no shorter than 10 blocks.

4. BLER Based Link Adaptation

In the mobile radio channel the quality conditions vary during the connection between the MS and the BSS. The aim of link adaptation is to select the most suitable coding scheme according to different channel conditions reaching for every CIR the maximum possible throughput.

For the proposed link adaptation algorithm, the employed parameter to estimate the channel quality is the Block Error Rate (BLER), since the CIR estimation can not be accurately reported by the MS in GSM ([7]).

Whenever an Ack/Nack message is received, the BLER is computed over a set of RLC/MAC data blocks called averaging window. The optimum averaging window size is closely related to the data blocks acknowledgement procedure, and will be treated further. After the Ack/Nack message reception, if the estimated BLER in the previous averaging window overcomes a concrete threshold the coding scheme is modified in the following data blocks. The thresholds are obtained from the BLER in the intersection points *A*, *B*, *C* in figure 2; for example if the transmitter (MS or BSS) is coding the RLC/MAC data blocks with CS4, and, after the Ack/Nack message reception, the estimated BLER in the last averaging window is higher than the threshold calculated for the point *C*, the coding scheme is updated to CS3 in the next RLC/MAC data blocks.

The threshold can be calculated using the following expression:

$$\mathrm{Thr} = (1 - \mathrm{BLER}) \cdot \mathrm{Thr}_{\mathrm{max}} \tag{4}$$

where *Thr* is the throughput of a coding scheme, and Thr_{max} is the maximum achievable throughput for that coding scheme. Therefore the BLER is:

$$\mathrm{BLER} = (1 - \frac{\mathrm{Thr}}{\mathrm{Thr}_{\mathrm{max}}}) \tag{5}$$

filling the throughput at the intersection points and the maximum throughput for every coding scheme gives the thresholds. The resulting thresholds reach BLER values up to

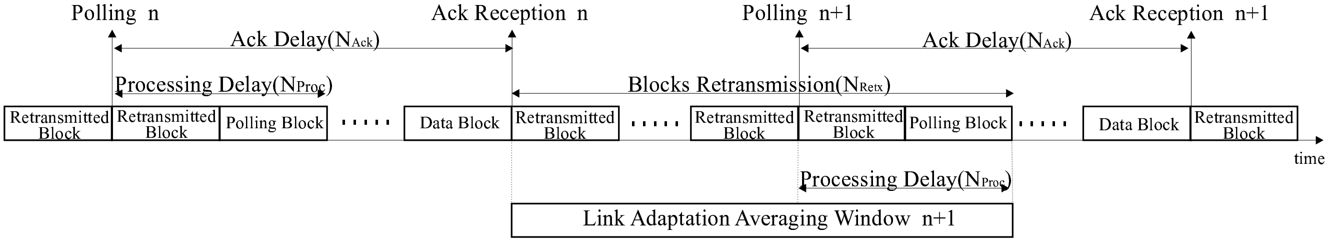

Figure 4. Downlink Mobile Station Polling Procedure

40%, but in order not to increase excessively the number of retransmissions, which could lead to a transmission stalling, the maximum threshold values are limited to 20%. Figure 5 depicts the coding scheme update, and the corresponding BLER thresholds.

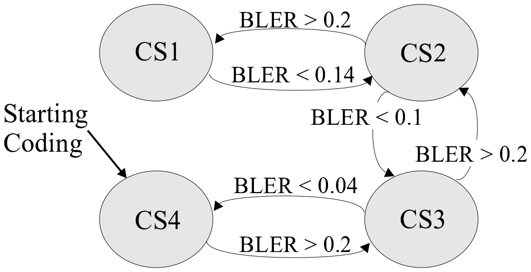

Figure 5. Coding Scheme Update and Corresponding BLER Thresholds

The optimum averaging window size may vary from uplink to downlink packet transfer. In uplink data transfer, the averaging window can not be longer than the number of blocks between two acknowledgements messages. Otherwise, different data blocks in the same averaging window may have employed different coding schemes, and the BLER computation could not be compared with the above mentioned thresholds. On the other hand, the largest number of blocks used for the BLER calculation, the more accurate estimation can be achieved. So, a good choice is to set the window size equal to the number of blocks between two consecutive acknowledgements. As it was commented in section 3, in uplink data transfer, the BSS can vary the acknowledgement messages rate depending on the detected data block errors. Nevertheless, link adaptation adds some constrains to the acknowledgement frequency. If the number of blocks between two consecutive Ack/Nack messages is too short, the resulting BLER resolution is too rough, and if it is too large the link adaptation algorithm becomes very slow.

In downlink packet data transfer, the averaging window size is determined when fixing the periodic polling frequency (see figure 4). When the BSS receives and processes the Ack/Nack message n+1, the BLER calculation over the averaging window n+1 allows to select the most suitable coding scheme for the following RLC/MAC data blocks. The averaging window can not comprise data blocks before the previous acknowledgement message (Ack/Nack message n in figure 4), since they may have employed a different coding scheme. Obviously, the averaging window can not include data blocks after the polling one, because the MS has not received those blocks when it generates the acknowledgement message. Following the example in previous section, if the polling period is set to 16 blocks and the acknowledgement delay (N_{Ack}) and the processing delay (N_{Proc}) are assumed to be around 8 and 3 blocks respectively, the resulting averaging window can be set to 11 blocks long.

5. GPRS Network Model

The performance of the BLER based link adaptation algorithm has been evaluated in a dynamic network simulator.

The analyzed network model consists of a 36 sites regular grid, with 3 sectors at each site, and 4 transceivers per sector. Two frequency reuse patterns (1/3 and 3/9) are simulated, with 27 frequencies for traffic channels, and 12 frequencies for the BCCH (the rest of the time slots in the BCCH frequency also bear GPRS traffic). The first reuse pattern is simulated using radio frequency hopping, and the second one using non hopping, base band hopping and radio frequency hopping. Distance attenuation is modelled by the formula 35log(d). The shadow fading is modelled as a log-normal process with standard deviation equal to 6 dB, and the multipath fading corresponds to fast fading in a typical urban (TU) scenario (see [6]). The receiver physical layer modelling is derived from [2]. Only downlink data transfer is simulated.

The traffic model simply assumes that the data packet arrival to the RLC/MAC layer in each cell is Poisson distributed, and the arrival rate is dimensioned to allow a maximum blocking of 2%. The packet length is exponentially distributed with a mean size of 100 Kbits. No multislot operation is implemented.

The packet transfer paging is not simulated. Two versions of the link adaptation algorithm are simulated. In the first one, all the coding schemes are available and the initial coding scheme is CS4, and in the second one, only CS1 and CS2 are available being the last one the initial coding scheme. The averaging window size is set to 11 blocks. The elapsed time between the polling block transmission and the Ack/Nack message reception is assumed to be 0.

6. Network Simulation Results

The selected measurement to evaluate the performance of the BLER based link adaptation algorithm is the average throughput per packet.

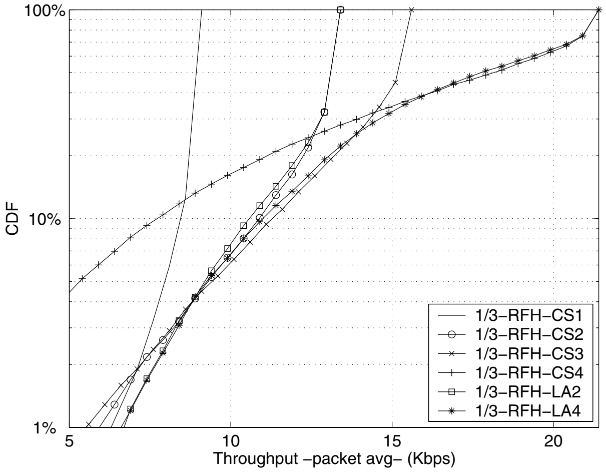

Figure 6. CDF of the Packet Mean Throughput for 1/3 reuse and RF frequency hopping

Figure 6 depicts the cumulative density function of the throughput for the 1/3 reuse pattern, radio frequency hopping (RFH), and all the coding schemes and proposed link adaptation algorithms with two (LA2) and four (LA4) schemes available. In the upper part of the graphic can be seen that in 60 % of the packets the coding scheme with less data protection (i.e. CS4) reaches higher mean throughput than the rest, but on the other hand, for low values of the CDF the more coding is applied the better throughput is obtained. The link adaptation curve with the four coding schemes available (LA 4) follows at every outage the throughput of the coding scheme with best performance. The link adaptation algorithm when using just two coding schemes performs very similar to CS2, and only for low throuhgput its behaviour is influenced by CS1.

Table 3 depicts the packet average throughput at 1% and 10% of the CDF for the reuse patterns 1/3 and 3/9, and for non hopping (NH), base band hopping (BBH), and radio frequency hopping (RFH). The comparison between both frequency reuse patterns clearly shows that the 3/9 reuse outperforms the 1/3 one due to its lower level of interference. Therefore, the coding schemes with more data protection become more relevant for the 1/3 reuse, and for example at 10% outage CS1 still achieves higher throughput than CS4 for this reuse.

Coding	1/3 RFH		3/9 BBH	
Scheme	CDF at 1%	CDF at 10%	CDF at 1%	CDF at 10%
CS1	6.4 Kbps	8.4 Kbps	7.4 Kbps	8.8 Kbps
CS2	6 Kbps	10.9 Kbps	8.3 Kbps	12.4 Kbps
CS3	5.5 Kbps	11.3 Kbps	7.5 Kbps	13.5 Kbps
CS4	1.9 Kbps	7.7 Kbps	3.7 Kbps	12 Kbps
LA2	6.7 Kbps	10.6 Kbps	8.1 Kbps	12.2 Kbps
LA4	6.6 Kbps	11 Kbps	8.2 Kbps	13.3 Kbps
	3/9 NH		3/9 RFH	
	CDF at 1%	CDF at 10%	CDF at 1%	CDF at 10%
CS1	7 Kbps	8.7 Kbps	7.2 Kbps	8.8 Kbps
CS2	8.3 Kbps	12.3 Kbps	8.1 Kbps	12.4 Kbps
CS3	8.5 Kbps	13.6 Kbps	8.3 Kbps	13.5 Kbps
CS4	5.4 Kbps	13.7 Kbps	4.1 Kbps	12.3 Kbps
LA2	8.1 Kbps	12 Kbps	8.4 Kbps	12.2 Kbps
LA4	8 Kbps	14 Kbps	7.8 Kbps	13.6 Kbps

Table 3. Packet Average Throughput at 1% and 10% of the CDF

The comparison between different frequency hopping strategies at 1% outage shows that non hopping offers more throughput for CS3 and CS4, while frequency hopping offers more throughput for the rest of the coding schemes. At higher outage, CS4 still reaches higher throughput with non hopping than with frequency hopping, but the rest of the coding schemes do not show any significant difference between both strategies. In the case of link adaptation with all the coding schemes available, the non hopping strategy outperforms base band frequency hopping due to the influence of CS4. But when only two coding schemes are available the result is the opposite mainly due to the hopping gain offered by CS2 at low block erasure rates (see table 2). Nevertheless, this effect is expected to be inverted at very low outage because the hopping gain is significantly reduced at higher block erasure rates. Obviously, radio frequency hopping shows a performance between base band hopping and non hopping because the traffic load allocated in the BCCH carrier does not hop. Even though the results are in favor of non hopping, for stationary users under bad link quality conditions, frequency hopping could lead to a performance improvement since some of the bursts belonging to the same RLC/MAC block could hop to frequencies with potentially better quality conditions.

7. Estimation of GPRS Mean Throughput in a Live GSM Network

It is important for a network operator to have a good estimate of a service (e.g. GPRS service) before implementing it in the network. The present investigation tries to evaluate the potential GPRS mean throughput in a live GSM network by means of two different approaches. The GSM network [2] is a high traffic intensity area in Denmark.

The first method estimates the mean user throughput based on provided channel quality (RXQUAL and RXLEV) from a live GSM network, being measured and reported every 0,48 sec. If these measurements reports are compared with GPRS link simulations, an estimate of the mean user throughput in the mentioned GSM network can be made. The second method estimates the geographic distribution of the user throughput in a certain area by using the net-

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[2] from the danish operator SONOFON.

work operator planning tool Planet (by Mobile Systems International). This tool can calculate the signal strength for a given distance from the base station by using BSS data (location, height, radiated power, etc.), map data (e.g. height database) and path loss prediction (the network is considered interference limited by the planning tool). Merging these calculations with a frequency database from the same area, a complete map of CIR can be produced. If these CIR values are compared with GPRS link simulations it is possible to estimate the GPRS mean throughput.

7.1. Mapping Functions

The goal of the mapping function is to predict the mean throughput based on both measurements data (RXQUAL, RXLEV) and predictions from the Planet tool (CIR).

The RXQUAL describes the signal quality in terms of BER, and is correlated with the interference situation but also with the coverage. Each of the 8 RXQUAL values corresponds to a BER interval (max/min BER), and by using results from previous link simulations (by [3]), the corresponding CIR interval (min/max CIR) can be found. The throughput is then encountered for each CIR interval by using the coding schemes performance curves, figure 2 for frequency hopping and the corresponding one for non hopping. Ideal link adaptation is applied under the assumption that the coding scheme giving the highest throughput is selected for every CIR that is to be mapped. Each BER interval is mapped into CIR ones as described above, and assuming that the CIR is equally distributed within the interval, a mean throughput can be calculated for each RXQUAL value.

Figure 7 represents the mapping function from the RXQUAL level to the corresponding throughput. First, it is clear that the case where all four coding schemes are available non hopping shows the better performance than frequency hopping due to the influence of CS4, and second, when only CS1 and CS2 are available, non hopping shows a better performance than frequency hopping for high RXQUAL values, but the opposite behaviour for the rest of the RXQUAL values.

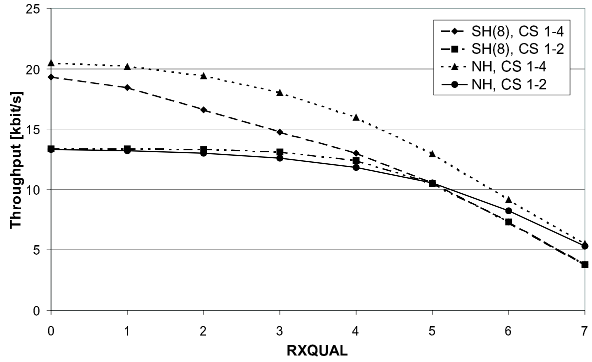

Figure 7. Mapping Function from RXQUAL Levels to Corresponding Throughput

The prediction based on RXLEV measurements analyzes the coverage influence on the reached mean user throughput. Then, the interference is neglected in order to obtain a noise limited throughput prediction. The Signal Power to Noise Power Ratio (CNR) can be estimated from the RXLEV operator reported measurements (signal power information), and the noise floor. The noise floor is assumed to be -113 dBm incluiding a receiver noise figure of 8dB. Matching the CNR intervals to the CIR intervals employed in the RXQUAL based prediction, a correspondence between RXLEV levels and RXQUAL values can be derived, and finally a mapping from RXLEV to user throughput is obtained.

7.2. Mean User Throughput Based on RXQUAL and RXLEV Measurements

The interference and the coverage situation will be examined by using respectively RXQUAL and RXLEV as network measurements. These data are analysed and mapped with the mapping functions described above in order to derive the mean user throughput for the cases using frequency hopping or non hopping and with either 2 or 4 coding schemes. All measurements are taken from a base band frequency hopping network and it is assumed that these data are suitable for deriving the throughput for both frequency hopping and non hopping.

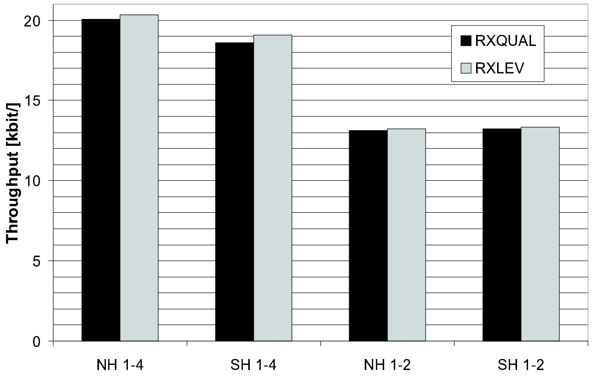

Figure 8. Mean User Throughput from RXQUAL and RXLEV

The mean user throughput from respectively RXQUAL and RXLEV reported mesurements averaged over 24 hours is depicted in figure 8. The figure reveals that the best throughput is obtained with no hopping applied using 4 coding schemes, and hardly no difference for using 2 coding schemes. This gain in throughput by using all coding schemes is primarily the impact of using CS4. Another conclusion is that, although the studied area is a high traffic zone, hardly no difference can be appreciated between the RXQUAL and the RXLEV estimation, so the user throughput is mainly coverage limited.

7.3. Prediction of Throughput Coverage

A fairly good estimate of the throughput quality of a GPRS service is its geographic distribution in a given area, and this can be visualized with throughput coverage maps. As it was commented above, the developed method predicts the mean user throughput in each pixel of a map based on the wireless network plannig tool Planet. The whole process is shown in Figure 9.

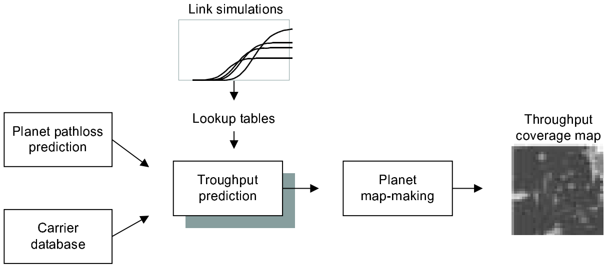

Figure 9. Diagram of the Throughput Prediction Algorithm and its Inputs and Outputs

The GPRS traffic can be allocated on the BCCH carrier, on the TCH carrier(s), or on both. The difference between allocating it on the non hopping BCCH and the random hopping TCH's is investigated.

First, when only CS1 and CS2 are available the mean throughput when allocating GPRS traffic only on the non hopping BCCH frequency is 13.1 Kbps, and when doing it on a hopping TCH the mean throughput is 13.0 Kbps, which is a very small difference. When enabling the four coding schemes, if the GPRS traffic is allocated on the non hopping BCCH the mean throughput is 20.3 Kbps, and if it is done on a hopping TCH the mean throughput is 18.7 Kbps, which is a larger difference.

The distribution of the coding schemes over the pixels is plotted in figure 10, which confirms the fact that allocating GPRS traffic on the non hopping BCCH outperforms the traffic allocation on the hopping TCH.

The reasons why the mean user throughput in a certain pixel performs better with the non hopping BCCH than with frequency hopping are the better BCCH planning, thus having a higher mean CIR, and the influence of CS4. Radio frequency hopping is proposed as a solution to meet the requirements of both speech users, which can be allocated on the hopping TCHs, and the GPRS users, which can be allocated on the non hopping BCCH channel.

8. Conclusions

The proposed link adaptation algorithm based on the BLER as the channel quality indicator, computes this BLER from the acknowledgement messages. The exposed arguments in section 3 have shown that in dowlink data transfer the polling (requesting for the acknowledgement) period should be delimited within a certain range, whose maximum (around 16 RLC/MAC blocks) is determined by the transfer stalling, and whose minimum (around 10 RLC/MAC blocks) is determined by multiple packet retransmissions. With a downlink polling period within the mentioned range (for example 16 radio blocks), the link adaptation averaging window is fixed (for example to 11 radio blocks).

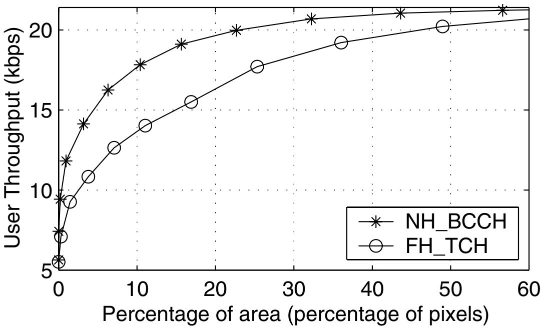

Figure 10. Throughput Distribution over Test Area

Network simulations have shown how link adaptation obtains the maximum possible performance in each link, by selecting the most suitable coding scheme depending on the quality radio conditions. The comparison between different reuses has shown that the throughput is highly sensible to the interference level, and therefore higher frequence reuses perform better. Regarding frequecy hopping, the network simulations have shown that, in general, non hopping outperforms frequency hopping mainly due to the influence of CS4. The estimation of the mean user throughput based on quality measurements and a planning tool has confirmed the previously stated conclusions, proposing radio frequency hopping, so the GPRS traffic can be allocated on the non hopping BCCH, and the rest of the speech user can be allocated on the remaining hopping physical channels.

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