On the Effect of Correlation in Multislot Link Layer Analysis for GPRS

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Abstract

The General Packet Radio Service (GPRS) is due to be implemented in current mobile networks, introducing a whole new range of mobile data applications and services. Considerable effort has been devoted to test its capabilities and system performance. Previous GPRS link layer studies have assumed the allocation of a single slot per frame. However, multiple slots may be allocated to a single user. The aim of this paper is to study the impact of potential correlation on the GPRS multislot link layer performance.

1. Introduction

The General Packet Radio Service (GPRS) [1] has been developed as a standardised system for the provision of packet data services for both evolved GSM and TDMA/136 networks. Its higher bandwidth efficiency compared to circuit switched systems, such as GSM, is due to the introduction of "capacity on demand" and the statistical multiplexing of users in a single slot. GPRS also provides increased data rates through the allocation of multiple slots to a single user, reaching a maximum peak rate of 171.2 kbits/s when considering eight slots per user.

The GPRS performance has been largely studied in the literature. To evaluate its performance, a division is usually made between system [2] and link level [3] studies. The former models a mobile radio network taking into account aspects such as mobility, distance attenuation, shadow fading and the behaviour of interferers. Its output is generally expressed in terms of the distribution of the Carrier to Interference Ratio (CIR). On the other hand, link level studies model the radio link on bit level extracting as output the link quality (e.g., Block Error Rate) as a function of the average CIR. Due to its large simulation time, a single radio link is usually considered. The results for both studies are then merged to analyse the global performance. Usual procedures to interface both levels are to use the link level analysis as a source of information for the system level ([2],[4]). The link level studies are then represented as a set of look-up tables [3] mapping CIR to quality for different sets of operating conditions (e.g., varying the terminal speed, the propagation channel and considering the use of Frequency Hopping). Given a mean CIR for a Radio Link Control block, extracted through the system level analysis, the Block Error Probability is obtained from the set of look-up tables and it is then decided whether a block has been received in error or not.

Considerable efforts have been devoted to improve the interface between both levels for circuit-switched TDMA systems ([5],[6]) and some of them have been migrated to the study of packet based systems such as GPRS or EDGE [4]. In [4], the multipath fading is included on the system level and the RLC block error modelling is refined by not only looking at the mean quality of an RLC block but also at the quality distribution among the bursts used to send the block. The aim of this paper is to analyse the effect of correlation, between slots used to transmit different RLC blocks (see section 3), on link layer results. This effect should even appear when only measuring the mean quality within an RLC block. This last simplified approach has therefore been adopted to model the Block Error Probability in this work.

Present system level studies have only been done using look-up tables obtained through link level studies based on a single slot transmission. This approach assumes that when transmitting RLC blocks on different channels of the same frame, their link level performance (i.e., whether the blocks have been received in error or not) is totally uncorrelated. This assumption can be totally justified when performing studies that are not dependent on the time variability of the system and that average out over time the instantaneous link level performance (e.g., capacity studies [4]). However, when studying adaptive techniques such as Link Adaptation or Power Control the time properties of the link quality are of paramount importance. The aim of this paper will therefore be to analyse the time properties of the GPRS link layer performance when considering a multislot transmission.

This study will take into account the effect of fast fading and correlation between slots.

This paper is organized as follows. In section 2, some background on the GPRS radio interface is provided. The inter-slot and inter-frame correlation, and the approach used to analyse their effect are defined in section 3. The simulation methodology used in this paper is detailed in section 4. The effect of correlation on the multislot link layer performance is then shown in section 5. Finally, conclusions are drawn.

2. GPRS radio interface

Prior to transmission, data packets, received from network layers, are first split into Logical Link Control (LLC) frames. The LLC frames are then segmented into Radio Link Control (RLC) blocks. The resulting RLC data blocks are then coded and block-interleaved over four normal bursts in consecutive TDMA frames. The RLC block's data field length will depend on the channel coding schemes used. Four channel coding schemes, CS1 to CS4, are specified for the GPRS packet data traffic channels [7]. Each scheme has been designed to provide different resilience to propagation errors under unfavourable radio conditions, offering a trade-off between throughput and coding protection. CS1 corresponds to the more robust scheme while CS4 does not use any error correction. CS1 to CS3 are based on a half rate convolutional encoder. However, they differ on the puncturing schemes applied to the output of this encoder. Block Check Sequences are used in all the schemes to facilitate the error detection at the receiver. A common characteristic of the coding schemes is the presence of the Uplink State Flag (USF) in the RLC blocks header. The USF is transmitted in the downlink to indicate which Mobile Station (MS) should transmit in the next uplink slot. The characteristics of the different coding schemes are summarised in table 1.

An efficient utilization of the spectrum is obtained using a multislot channel reservation scheme. Depending on the multislot capabilities of a Mobile Station, the number of available channels and the system load, RLC blocks belonging to one LLC frame can be sent on different physical channels simultaneously and in parallel. Using this reservation scheme, transfer delays can be reduced and the assigned bandwidth can be varied dynamically.

The GPRS standard [8] does not impose the continuity of the allocation of slots from the same frame for a given MS class (even though there are some restrictions according to the multislot capability of the MS). Therefore, the effect of this non-contiguous allocation might influence the already mentioned correlation effect.

Scheme	*Code rate*	*Pre-coded USF*	*Radio Block excl. USF and BCS*	*BCS (parity bits)*	*Tail*	*Coded bits*	*Punctured bits*	*Data rate kb/s*
CS-1	*1/2*	*3*	*181*	*40*	*4*	*456*	*0*	*9.05*
CS-2	*≈2/3*	*6*	*268*	*16*	*4*	*588*	*132*	*13.4*
CS-3	*≈3/4*	*6*	*312*	*16*	*4*	*676*	*220*	*15.6*
CS-4	*1*	*12*	*428*	*16*	*0*	*456*	*0*	*21.4*

Table 1 GPRS channel coding parameters

3. Inter-slot and inter-frame correlation

Previous studies on the GPRS link layer have assumed the allocation of a single slot per frame. However, multiple slots may be allocated and the correlation between contiguous slots may be significant depending on the operating conditions. According to the coherence time, the time to reach a 50% correlation level for fast fading is in the order of 10 GPRS frames at 5 km/h, one frame at 50 km/h, and one slot and a half at 250 km/h, for a mobile system operating at 900 MHz [9]. Therefore, there is a potential correlation between slots transmitting different RLC blocks.

Figure 1 illustrates a multislot user transmitting two RLC blocks in different physical channels of the same frame.

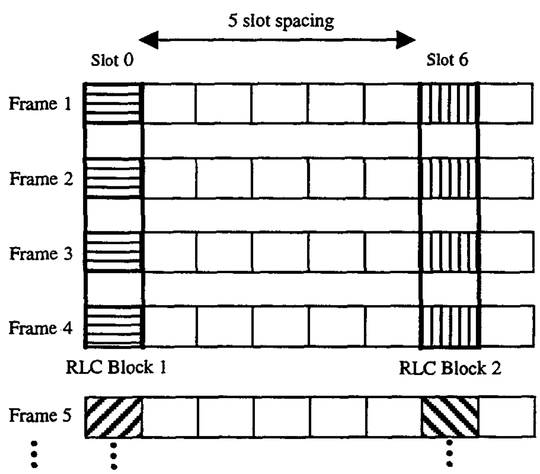

Figure 1 RLC Blocks transmission

Each RLC block is interleaved over four normal bursts in consecutive frames. There is a potential correlation between the RLC block transmitted in slot 0 and the RLC block transmitted in slot 6, according to the coherence time, as already mentioned. This correlation is due to the correlation between slots of the same frame (e.g., between slots 0 and 6 of frame 1) and between slots of different frames (e.g., slot 6 of frame 1 and slot 0 of frame 2). The correlation between slots of the same frame will be termed inter-slot correlation and the correlation between slots of different frames will be termed inter-frame correlation. Both correlations might then influence the post-decoding state (that is, whether a block has been received in error or not) in which the RLC blocks are received. This potential influence is the subject of the study presented in this paper. The spacing between the slots of the same frame used to transmit the different RLC blocks might influence the correlation and its effect will be studied. A spacing of zero slots corresponds to the case in which two RLC blocks are transmitted in contiguous slots of four consecutive frames. Figure 1 corresponds to the case of a five slot spacing between the two physical channels used to transmit the RLC blocks. The maximum spacing is six slots. This study has been confined to the case in which transmission of different RLC blocks, in different channels, starts at the same frame.

What is then important, is whether the traditional packet link quality measure, that is the mean BLER, may be used to study the effect of correlation. According to the GSM standards [10], the radio channel satisfies the criterion for wide sense stationarity for distances of about 10 metres, which is then the case during an entire GPRS frame for speeds of 5, 50 and 250km/h. The first order averages (such as mean and variance) should then be independent of time [11]. Also second order averages, such as cross-correlation, should not depend on time but on the time difference. The wide sense stationarity of the GPRS radio channel is illustrated in figure 2.

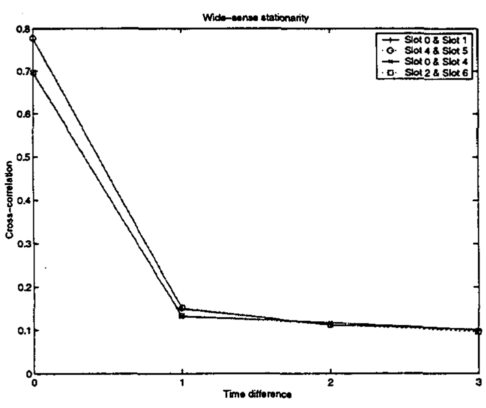

Figure 2 Wide sense stationarity

Figure 2 represents the cross-correlation of the BLER between two physical channels. As it can be seen the separation between the channels selected, and therefore the time difference, has an effect on the cross-correlation but not the particular channels selected. Figure 2 corresponds to a speed of 50 km/h, the same observations apply for the other speeds.

The mean BLER cannot therefore be used to study the correlation as it does not reflect the effect of fast fading and time properties of the GPRS link layer performance. This was also verified by simulation tests, which revealed that the mean BLER is very similar for each slot of a frame.

Then, it is necessary to define new parameters to illustrate the effect of correlation. This paper illustrates this effect by specifying the "Correlation probability", P_c. Let X^i represent the post-decoding state in which a RLC block transmitted in the slot i of four consecutive frames is received. X^i takes the value 1 if the block has been received in error and the value 0 if the block has been correctly decoded. We then define $Pr[1,1]^n$ as the conditional probability that two RLC blocks transmitted in different slots of the same frame are received with error, for a slot spacing n, given that the first block is received in error. Similarly, we can define $Pr[0,0]^n$, $Pr[1,0]^n$ and $Pr[0,1]^n$ as follows:

$$\Pr[0,0]^n = \Pr[X^{i+n} = 0 \mid X^i = 0]$$
$$\Pr[1,1]^n = \Pr[X^{i+n} = 1 \mid X^i = 1]$$
$$\Pr[1,0]^n = \Pr[X^{i+n} = 0 \mid X^i = 1]$$
$$\Pr[0,1]^n = \Pr[X^{i+n} = 1 \mid X^i = 0]$$

The Correlation probability P_c is then defined as the probability that a RLC block transmitted in slot Y will be received, after channel decoding, with the same state as a RLC block transmitted in slot X. Both RLC blocks are transmitted in the same four frames. Considering the example illustrated in figure 1, P_c will represent the probability that RLC block 2, transmitted using slot 5, will be received with error/no error if RLC block 1 is received with error/no error. P_c can then be expressed as follows:

$$P_c^{\,n} = \Pr[0,0]^n + \Pr[1,1]^n$$
$$1 - P_c^{\,n} = \Pr[0,1]^n + \Pr[1,0]^n$$

with $i \in [0,6]$ and $i+n < 7$.

4. Simulation method

An enhanced software version of the demonstrator reported in [12] has been used in order to study the performance of the GPRS Link Layer. This simulator models the transmission chain through the use of a database of error patterns produced with the bit level simulation package COSSAP. Figure 3 illustrates the GPRS transmission chain. Co-channel interference has been modelled as a single continuous strong interferer, following the characteristics of the testbed used by ETSI [10]. The thermal noise at the receiver has also been included.

In [3], the performance was studied for a single slot environment being then able to reuse the errors database used in [12]. For a multislot link layer analysis, a new database has been produced following the ideas developed in [13]. In this case, the interferer is also modelled as a multislot source.

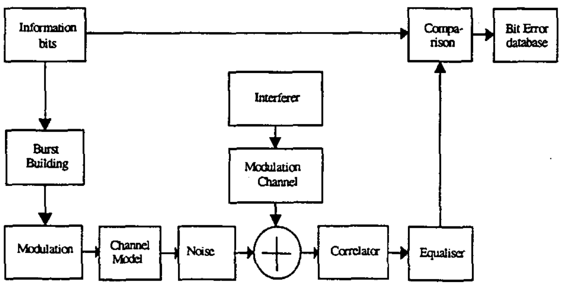

Figure 3 Transmission chain

The GPRS channel coding/decoding functions use the error database as illustrated in figure 4. When simulating the physical layer, the channel coding output is first interleaved and then the radio propagation effects are added. The output of this sum is then de-interleaved before being passed to the channel decoding process. However, de-interleaving the error patterns and adding them to the channel coding output is equivalent. This last solution has been adopted for this simulator for the sake of simplicity.

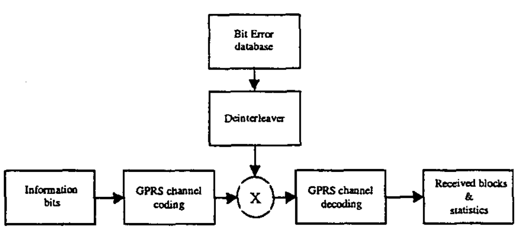

Figure 4 GPRS simulator

The derivation of an error database significantly reduces the simulation time [3] whilst maintaining accuracy of radio link quality representation [13]. In fact, the error database is independent of the data bits transmitted making it possible to be reused whenever the radio path effects have to be taken into account.

5. Effect of correlation

In this section, the effect of correlation on the probability Pc will be analysed and quantified. Its impact for different operating conditions (i.e., different terminal speeds, coding schemes and CIRs) will be presented.

5.1 Assumptions

The simulations have been conducted for a typical urban channel model [10] at speeds of 5km/h and 50 km/h, and for a rural area channel model [10] at 250 km/h. The capacity limiting factor for a cellular system is the co-channel interference. Therefore only simulations for an interference-limited case are considered in this paper. For the purpose of this work, the carrier frequency was set to 900 MHz. The following results assume the same mean CIR during the four consecutive TDMA frames used to transmit RLC blocks, as the effect of fast fading is analysed. A constant CIR might be targeted for the application of adaptive techniques. Such techniques require an interference environment as stable as possible since large and fast variations in CIR might lead to unreliable channel estimates producing a poor performance. In order to avoid an interference scenario with fast and large variations in CIR, resource allocation schemes have been investigated to shape the interference ([14], [15]). The application of Power Control also contributes to produce a stable interference environment.

5.2 Results

In figure 5, the effect of the terminal speed on the probability Pc is shown for a varying spacing between the slots selected to transmit different RLC blocks. This figure corresponds to a CIR of 4dB and the CS2 coding scheme. First of all, it is important to notice that the probability is quite different for the three terminal speeds considered suggesting that P_c has to be taken into account to decide the post-decoding state (block error or not) in which RLC blocks, transmitted on different physical channels, are received. Pc also depends on the spacing between the slots selected. The effect of this spacing varies with the speed. For a speed of 5 km/h, the probability P_c is high and its decrease for an increasing spacing, between the slots selected to transmit different RLC blocks, is not very important. This suggests that the selection of slots to transmit the RLC blocks will not make a significant difference at low speeds. This is explained by the coherence time and the important correlation between RLC blocks, transmitted in different physical channels of the same four frames, at low speeds. For a speed of 50 km/h, a decrease of 8% on the probability Pc is observed when transmitting on channels spaced by six slots compared to when the RLC blocks are transmitted on contiguous slots. This decrease suggests that the correlation between RLC blocks is less important at 50 km/h and the selection of the physical channel has an impact. A speed of 250 km/h represents a different scenario. The coherence time suggested a 50% correlation for only one slot and a half at this speed. From figure 5, it can be observed that the probability initially decreases with the slot spacing but then begins to increase again (when a three slot spacing is reached), possibly due to the increasing impact of inter-frame correlation. The impact of inter-frame correlation becomes higher as the speed increases.

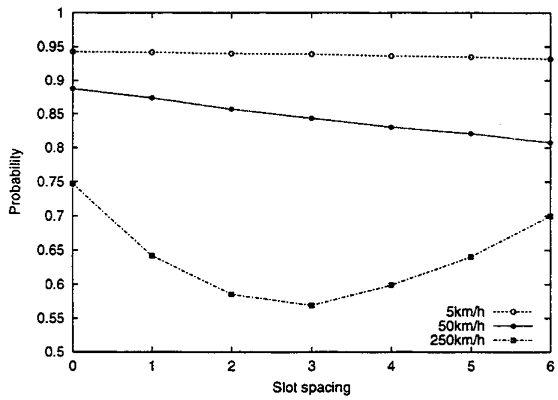

Figure 5 Effect of speed for CIR=4dB and CS2

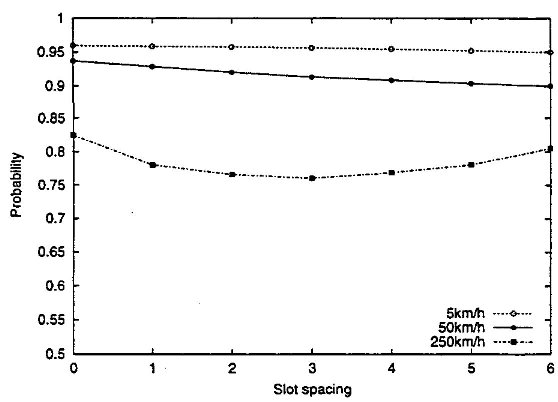

Figure 6 Effect of speed for CIR=10dB and CS2

The probability P_c is also highly influenced by the CIR. Figure 6 corresponds to a CIR of 10dB and also the CS2 coding scheme. It can be noticed that the effect of the spacing between slots selected to transmit different RLC blocks decreases even for high speeds. This is due to the reduction of the effect of multipath fading with higher CIRs. In this case, the high probabilities are produced by the limited number of transmission errors. For higher CIRs (e.g., 18 or 20dB), the probability P_c does not represent any more the effect of correlation.

Another parameter that influences the probability P_c is the error correction capabilities for each coding scheme (CS). Figures 7, 8, 9 and 10 show the evolution of P_c for each CS for varying CIR conditions. Each curve represents a different spacing between the slots selected to transmit various RLC blocks. These figures correspond to a speed of 50 km/h. It is interesting to note that independently of the CS used, the probability P_c first decreases when the CIR increases and then increases. The difference between each CS is the point at which the probability P_c starts to increase. This effect is due to the error correction capabilities of each coding scheme. The probability P_c is increased when the RLC blocks sent in different slots have been both received either in error ($Pr[1,1]^n$) or with no error ($Pr[0,0]^n$). P_c decreases when the RLC blocks have been received with different states, that is when we have $Pr[0,1]^n$ or $Pr[1,0]^n$. For very low CIRs (e.g., CIR = 0dB), the probability is high due to the big quantity of errors and therefore the high value of $Pr[1,1]^n$. When the CIR increases, the number of transmission errors decreases and so does $Pr[1,1]^n$. Each CS copes differently with the errors. When the CS has a strong error correction capability, it will be able to correct more errors and therefore $Pr[0,1]^n$ and $Pr[1,0]^n$ will decrease to the detriment of $Pr[0,0]^n$. This explains why the probability P_c starts increasing for CS1 for smaller CIRs. When the CSs are less robust, less errors are corrected and the probabilities $Pr[0,1]^n$ and $Pr[1,0]^n$ are higher. Only when the CIR has increased to the point where each CS can handle properly the errors, P_c starts to increase. The less robust the CS, the later will the probability P_c start increasing as can be seen in figures 7, 8, 9 and 10. The same observations can be done for the other terminal speeds although the probabilities are different as already illustrated in figures 5 and 6.

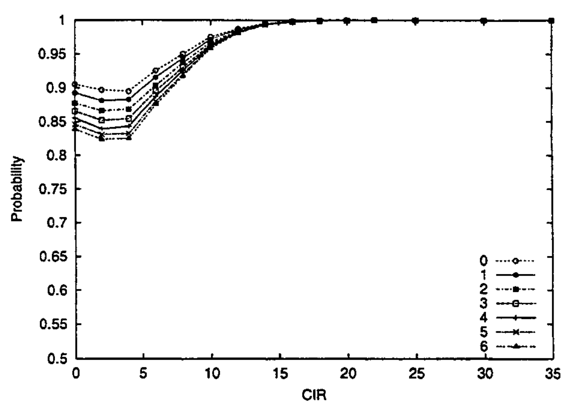

Figure 7 Probability P_c for 50 km/h and CS1

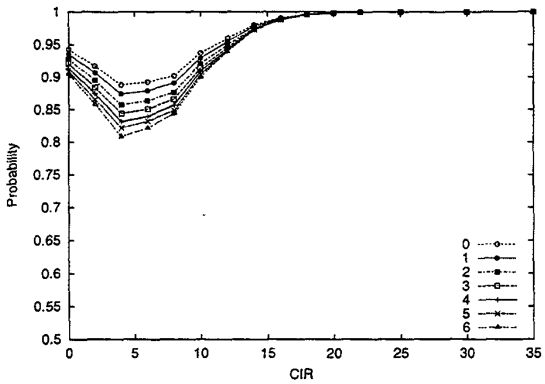

Figure 8 Probability P_c for 50 km/h and CS2

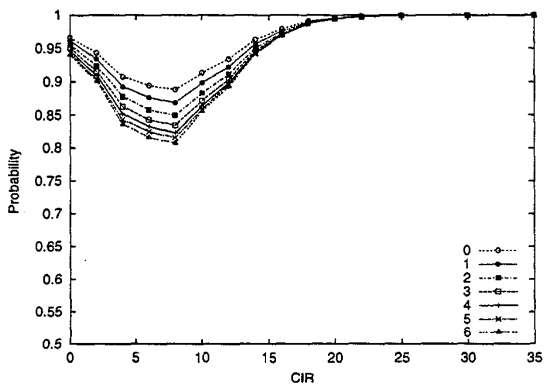

Figure 9 Probability P_c for 50 km/h and CS3

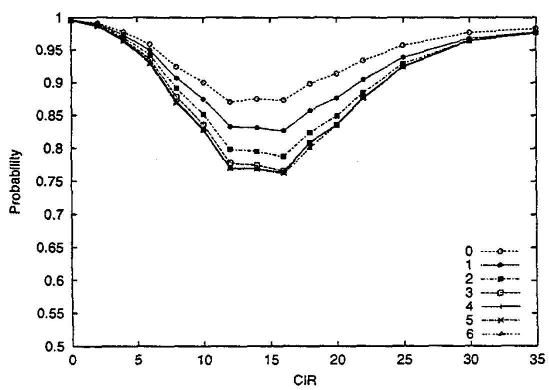

Figure 10 Probability P_c for 50 km/h and CS4

Another view of the effect of the error correction capability is shown in figure 11, which plots the probability P_c for RLC blocks sent on channels spaced by four other slots. Each curve corresponds to a different coding scheme. In this figure, it should be noticed that for low CIRs the less robust CSs have higher probabilities. This is again due to a more important $Pr[1,1]^n$, due to the quality conditions and the fact that the less robust CSs cannot correct the errors. On the other hand, the more robust CSs can handle better transmission errors so $Pr[1,1]^n$ decreases but $Pr[0,1]^n$ and $Pr[1,0]^n$ increase explaining their lowest probability. When the CIR increases the situation is inverted and the more robust CSs provide higher probabilities. This is due to the link quality and their highest capacity to correct the decreasing number of errors occurring.

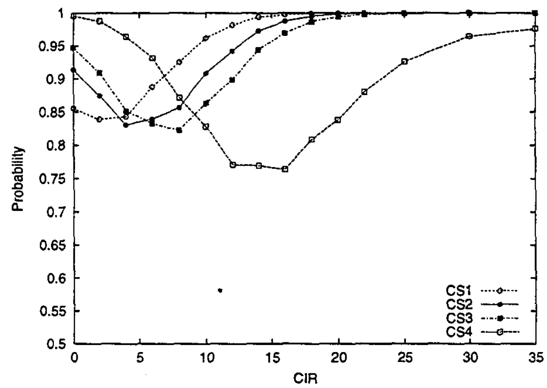

Figure 11 Probability P_c for 50 km/h, a spacing of 4 slots and different CSs

6. Conclusions

This paper has studied the effect of correlation on the GPRS multislot link layer performance. It has been shown that the impact of correlation depends on the operating conditions: terminal speed, robustness of the coding schemes and CIR.

The results presented in this paper suggest a greater accuracy is required in the modelling of the GPRS link level performance when considering a multislot transmission.

The spacing between slots, of a same frame, used to transmit different RLC blocks has proven to be a key parameter. Its influence is particularly important for high speeds. Therefore, the impact of correlation on resource allocation mechanisms in a multislot environment requires further investigation.

Further work would be to use the parameters here studied to model the time properties of the link level performance when considering a multislot transmission.

7. References

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