Impact of Interference on the GPRS Multislot Link Level Performance

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ABSTRACT

The GPRS link level performance has been usually assessed considering the allocation of a single slot per TDMA frame. However, multiple slots may be allocated to a single user in order to increase the transmission bandwidth. This paper compares the GPRS multislot link level performance under two interference scenarios that can be associated with performance bounds. Numerical results show that the interference pattern can have an impact on the link level 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 theoretical peak rate of 171.2 kbits/s when eight slots are assigned at the same time to a single user.

GPRS performance is usually assessed in two stages: system level and link level. The former models a mobile radio network taking into account aspects such as mobility, distance attenuation, shadow fading and the behavior 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 at a bit level providing the link quality (e.g., Block Error Rate) as a function of the average CIR. Due to the 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 results as a source of information for the system level. The link level performance is usually represented as a set of look-up tables [2] 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).

The study of multislot systems has been concentrated on system level analysis. Particular attention has been paid to the MAC operation (e.g., [3]). Current system level studies rely on look-up tables obtained through link level studies based on 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 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], [5]). However, when studying adaptive techniques such as Link Adaptation or Power Control, the time properties of the link quality are of paramount importance. An initial investigation of the multislot link level performance is reported in [6]. This study demonstrated that the link level performance can be correlated under certain operating conditions, with the degree of correlation depending on the terminal speed and mean CIR. The spacing between slots of a same frame used to transmit different RLC blocks proved to have a key influence suggesting that the performance will depend on the particular slots assigned to a user in a multislot transmission. The scenario analysed in [6] considered the same dominant multislot interferer for all transmitting slots. However, in a more typical scenario a multislot transmission might experience interference from the same user in some of the slots, whereas other slots might be interfered by other independent interferers. Therefore, the interference may be distributed on the slots in a number of configurations. Evaluating the link level performance for all of them would be too computationally expensive.

This paper complements the GPRS multislot link level study in [6] by considering two different interference scenarios that provide a lower and upper bound on the correlation of the interferers. The scenario modelling the interference as a single dominant multislot user (scenario studied in [6]) is one of these boundary scenarios. The other scenario, discussed in this paper, models the interference on each individual slot in a multislot transmission as a different, independent user. The comparison will allow the influence of the interference pattern on the multislot link level performance to be assessed.

2. GPRS RADIO INTERFACE

The GPRS radio interface can be modeled as a hierarchy of logical layers with specific functions [1]. Prior to transmission, data packets are segmented into smaller data blocks across the different layers, with the final logical unit being the Radio Link Control (RLC) block. 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 (CSs) 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 unfavorable 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. 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. The GSM standard defines 29 different multislot classes, each one allocating a different maximum number of slots for reception and transmission, and imposing different restrictions [8]. Depending on the multislot capabilities of a MS, 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 multiple slots allocated for either reception or transmission need not be contiguous. However, the multislot class of the MS will limit the combinations and configurations allowed when supporting multislot communications due to for example the type of the MS, the necessity to perform adjacent cell power measurements or any constraints imposed by the service selected. Some examples illustrating these limitations can be found in Annex B of [8]. The effect of the non-contiguous allocation of multiple slots might then influence the GPRS multislot link level performance.

Scheme	Code rate	Payload	Data rate kb/s
CS-1	1/2	181	9.05
CS-2	≈2/3	268	13.4
CS-3	≈3/4	312	15.6
CS-4	1	428	21.4

Table 1: GPRS coding schemes parameters

3. MULTISLOT LINK LEVEL ANALYSIS

The coherence time of the channel [9] is approximately ten 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. There is therefore a potential correlation between signals received in different slots, which might influence the instantaneous link level performance on different slots of the same frame. A multislot transmission scheme assigning two slots from the same frame to a single user is illustrated in Figure 1. The signals received in slots 0 and 6 may then be correlated. This correlation can be due to the correlation between signals transmitted in 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 can 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. The spacing between the slots of the same frame used to transmit the different RLC blocks is an important parameter influencing this correlation. 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.

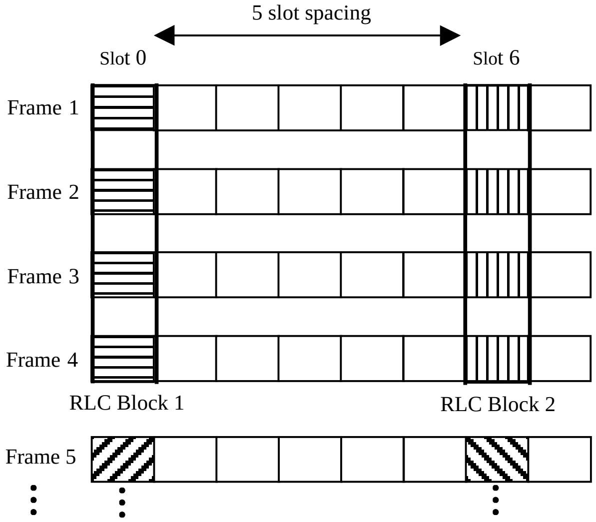

Figure 1: RLC Blocks transmission

The analysis reported in [6] highlighted that the traditional link quality metric, namely mean Block Error Rate (BLER), cannot be used to study the effect of correlation in multislot link level results, as it does not reflect the effect of fast fading and time properties of the GPRS link layer performance. A new parameter termed “correlation probability”, P_c, was specifically defined for this purpose. This parameter defines the probability that a RLC block transmitted in an arbitrary slot, Y, is received, after channel decoding, with same state (error/no error) as a RLC block transmitted in another slot, X, of the same frame. 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. $\Pr[1,1]^n$ is defined 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, $\Pr[0,0]^n$, $\Pr[1,0]^n$ and $\Pr[0,1]^n$ may be defined 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 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 ∈ [0,6] and i+n < 7.

Considering the example illustrated in Figure 1, P_c will represent the probability that RLC block 2 transmitted in slot 5 is received with error/no error if RLC block 1 is received with error/no error.

4. SIMULATION ENVIRONMENT

An enhanced software version of the demonstrator reported in [10] 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 2 illustrates the GPRS transmission chain. The effect of the thermal noise at the receiver has been included.

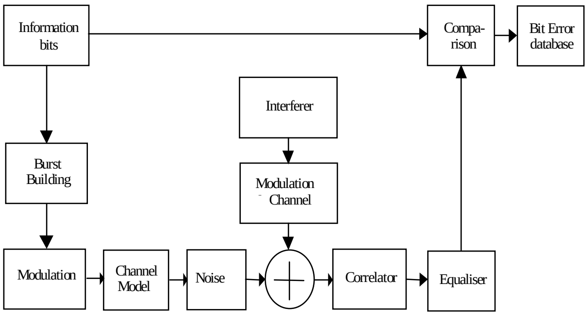

Figure 2: Transmission chain

The GPRS channel coding/decoding functions use the error database as illustrated in Figure 3. 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 here in for the sake of simplicity.

The derivation of an error database significantly reduces the simulation time [2] whilst maintaining accuracy of radio link quality representation [11]. 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.

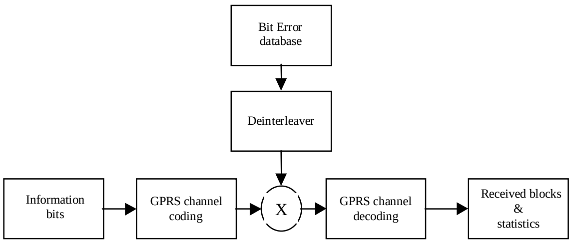

Figure 3: GPRS radio link simulator

The simulations have been performed for typical urban and rural scenarios using channel models following the recommendations proposed in [12]. The impact of the interference has been evaluated for different speeds. Speeds of 5km/h, and 50 km/h have been considered for the urban scenario. The rural environment has been evaluated for a speed of 250 km/h. For the purpose of this work, the carrier frequency was set to 900 MHz.

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. Co-channel interference has been modelled as a single strong random, continuous GSM-modulated interfering signal following the guidelines for the testbed described in [12]. Moreover, in [13] it has been demonstrated that a single interferer generally dominates the interference. The interfering signal is uncorrelated with the transmitting signal.

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 mean CIR might be experienced in highly loaded systems. It might also be targeted for the application of adaptive techniques, which 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. Moreover, a constant mean CIR corresponds to the scenario where the effect of correlation on the multislot link level performance should be stronger. The first step should then be to check whether the correlation has any effect in the link level performance under a constant CIR, as if it is not the case, then it will be very unlikely that it would have any impact under a variable CIR scenario.

As previously explained the aim of this paper is to compare the GPRS multislot link level performance under two reference scenarios that can be associated with performance bounds. The first scenario (Scenario 1), studied in [6], models the interference as a single multislot user. The transmitting slots will hence be all interfered by the same user. The second scenario (Scenario 2) models the interference as eight independent single slot users. The transmitting slots are therefore each interfered by different and uncorrelated users.

5. NUMERICAL RESULTS

This section evaluates and compares the GPRS multislot link level performance, by means of the correlation probability, under the above mentioned reference interference scenarios.

First of all, it is worth noting that the numerical values of the correlation probability differ between the two scenarios under the same operating conditions as depicted in Figures 4 and 5. This is mainly due to the fact that in Scenario 1 the correlation probability is influenced by the correlation within the signal received from the transmitter and by the correlation within the signal received from the multislot interferer. On the other hand, in Scenario 2, the correlation within signals received from the interferers is reduced and the impact of such reduction reflects on the numerical values of the correlation probability.

Despite different numerical values, similar conclusions can be reached for both scenarios regarding the effect of the mean CIR and robustness of the different GPRS coding schemes (CS). Figure 4 and Figure 5 plot the probability P_c, under Scenario 1 and Scenario 2, for all four coding schemes, a slot spacing of four and a speed of 50 km/h. From these figures it can be observed that for both scenarios and independently of the coding scheme applied the probability P_c initially decreases when the CIR is increased but eventually increases after a particular value. 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. 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 $Pr[1,1]^n$, where as $Pr[0,1]^n$ and $Pr[1,0]^n$ increase explaining the decrease in P_c. When the CS has a strong error correction capability, it will be able to correct more errors as the CIR increases and therefore $Pr[0,1]^n$ and $Pr[1,0]^n$ will decrease to the detriment of $Pr[0,0]^n$. When $Pr[0,0]^n$ becomes the dominant factor in P_c, P_c will start increasing again. The point at which this occurs is different for the coding schemes. This is due to the fact that for the same mean CIR as CSs less robust are used, fewer errors are corrected and the probabilities $Pr[0,1]^n$ and $Pr[1,0]^n$ take higher values compared to more robust CSs. Only when the CIR has increased to the point where each CS can handle properly the errors, P_c starts to increase.

On the other hand, the effect of slot spacing on the correlation probability differs between both scenarios for certain speeds. As shown in Figure 6 the slot spacing has a strong impact on the correlation probability under certain operating conditions within Scenario 1. These conditions correspond to the range of average CIRs where the error correcting capabilities of the CSs may or may not correct the transmissions errors (i.e., when neither $Pr[1,1]^n$ nor $Pr[0,0]^n$ are dominant factors in P_c). As shown in Figures 4 and 5 this range of mean CIRs vary with the error correcting capabilities of the coding schemes.

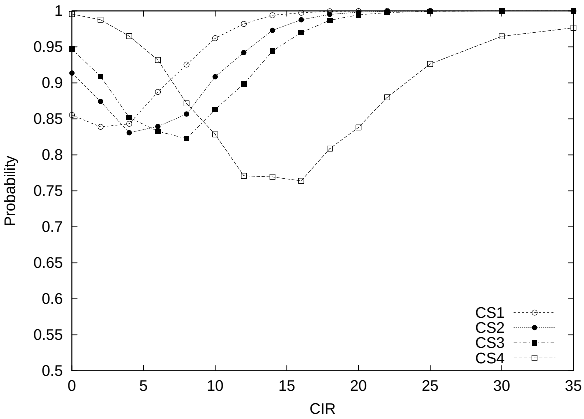

Figure 4: Probability P_c, considering Scenario 1, for 50km/h, a spacing of 4 slots and all the CSs

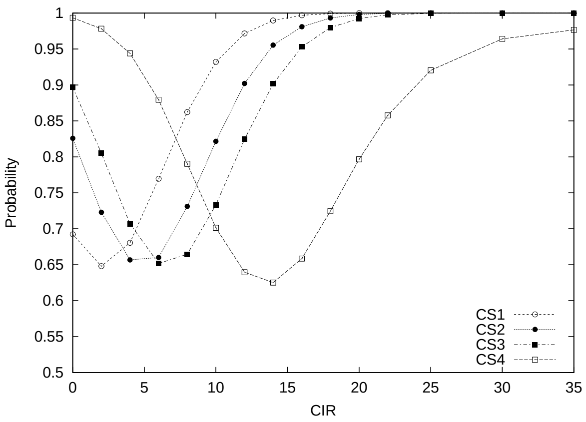

Figure 5: Probability P_c, considering Scenario 2, for 50km/h, a spacing of 4 slots and all the CSs

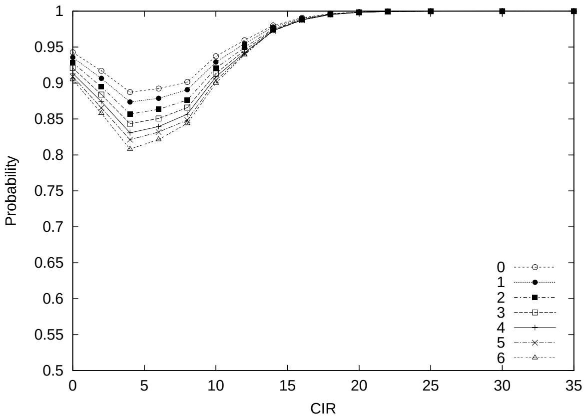

Figure 6: Probability P_c for varying CIRs and slot spacing (at 50km/h and CS2) under Scenario 1

At 5 km/h, the effect of correlation on the link level performance, for both interference scenarios, is such that the slot spacing has no impact on the correlation probability as P_c does not vary across the frame. The particular slots selected for a multislot transmission would then have no impact on the performance for both interference scenarios at 5km/h.

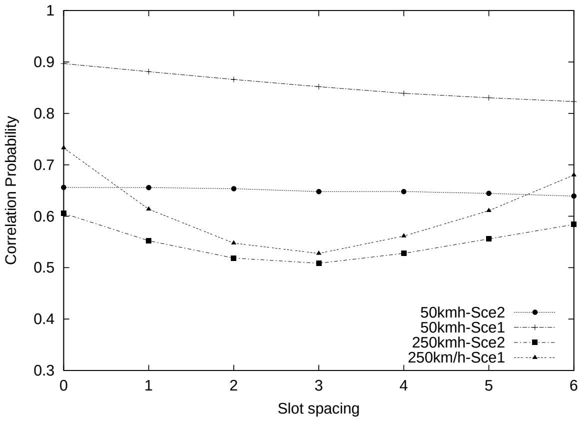

Figure 7: Effect of slot spacing on the correlation probability (CIR=2dB and CS1)

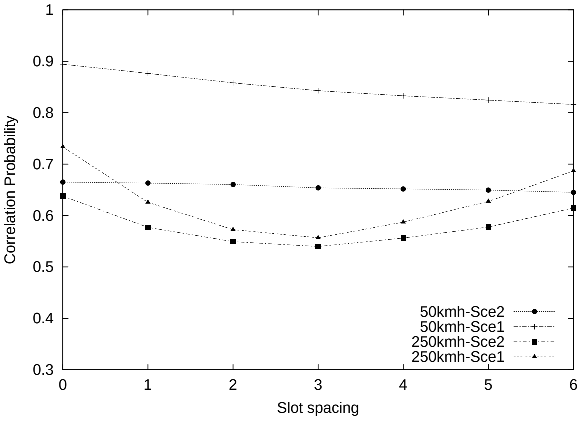

Figure 8: Effect of slot spacing on the correlation probability (CIR=6dB and CS3)

At higher speeds, the slot spacing can play an important role. Figures 7 and 8 illustrate the effect of slot spacing on the correlation probability at speeds of 50km/h and 250km/h for the two interference scenarios. At 50km/h and 250km/h, the slot spacing has a considerable effect on the correlation probability under the interference conditions modelled in Scenario 1. However, this effect is significantly reduced under Scenario 2. In Scenario 1 and considering the operating conditions reported in Figure 7, the difference in the correlation probability between transmitting two RLC blocks with slot spacing equal to 6 or slot spacing equal to 0 is 7.4%, at 50km/h. This difference is reduced to 1.6% under Scenario 2. In Figure 8, this difference is reduced from 7.9% to 1.85% for the same speed. Direct comparison of Figures 6 and 9 reveal that, for the whole range of mean CIRs, the effect of slot spacing is negligible when each transmitting slot is interfered by a different interferer but not when they all are interfered by the same mutislot user. For the less robust coding scheme, CS4, the effect of slot spacing on the correlation probability P_c is also significantly reduced under Scenario 2 (Figure 11) compared to Scenario 1 (Figure 10). However, its effect is still considerable and should be taken into account. At 50km/h and for the majority of the coding schemes, the effect of slot spacing on the multislot link level performance could then be neglected under the interference conditions modelled in Scenario 2. Except for the less robust coding scheme, the link level performance in slots of the same frame will then be independent of the particular slots selected for a multislot transmission.

The case considering a speed of 250 km/h represents a different scenario. From Figures 7 and 8, it can be observed that the correlation 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. At 250km/h and considering the operating conditions reported in Figure 7, the difference in the correlation probability between transmitting two RLC blocks with slot spacing equal to 3 or slot spacing equal to 0 is reduced from 20.5% (Scenario 1) to 9.7% (Scenario 2). In Figure 8, the same difference is reduced from 17.7% to 9.8%. Although the effect of slot spacing is also clearly reduced at 250km/h under Scenario 2, it is still present. Therefore, the particular slots selected for a multislot transmission would still have an impact on the link level performance at high speeds under both interfering scenarios.

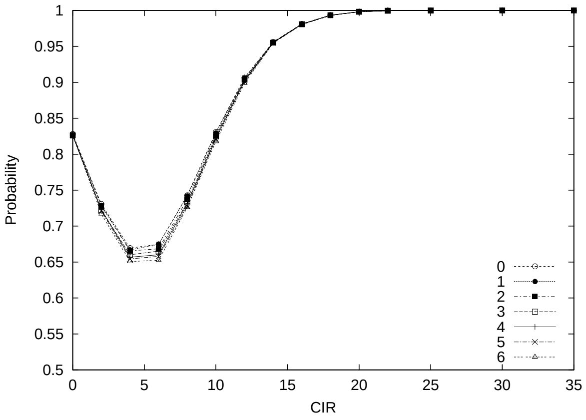

Figure 9: Probability P_c for varying CIRs and slot spacing (at 50km/h and CS2) under Scenario 2

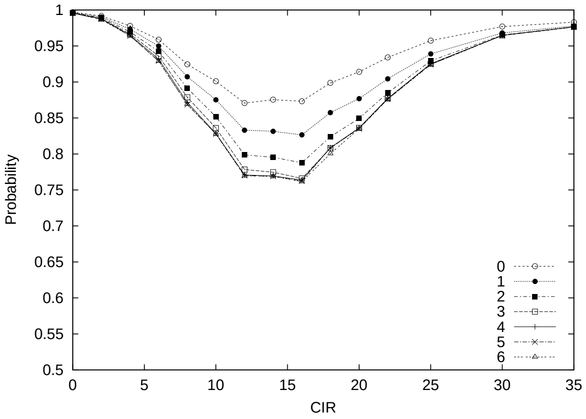

Figure 10: Probability P_c for varying CIRs and slot spacing (at 50km/h and CS4) under Scenario 1

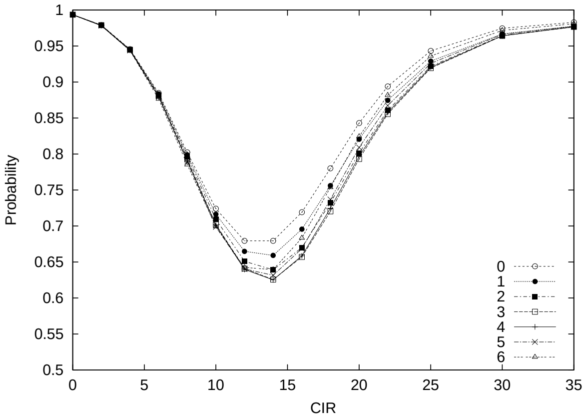

Figure 11: Probability P_c for varying CIRs and slot spacing (at 50km/h and CS4) under Scenario 2

6. CONCLUSIONS

This paper has expanded the analysis in [6] by comparing the GPRS multislot link level performance under two interference scenarios that can be associated with performance bounds. The initial interference scenario described in [6], which considers a single strong multislot interferer, has therefore been augmented to accommodate multiple single slot interferers as part of a new interference scenario. The results demonstrate that the correlation probability is affected by the interference pattern. Also, the effect of slot spacing on the GPRS multislot link level performance is influenced by the interference pattern for medium and high speeds. The results also indicate that when each slot of the multislot transmitter is interfered by a different user, the effect that slot spacing has on the correlation probability, for medium speeds, can be eliminated. In this case, the multislot link level performance across slots of the same frame is independent of the resources allocated. Even though this effect was also clearly reduce for high speeds its influence cannot be neglected.

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