Using Time Advance Information to choose Coding Scheme in GPRS

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***Abstract*- GPRS defines four coding schemes named from CS-1 to CS-4 with different degrees of data protection against transmission errors in the air interface. The former coding scheme is already used in GSM and the others sequentially offer higher throughput rates but less protection. The selection of the best suited coding scheme could be based on link quality estimators but also on more deterministic system parameters as Time Advance information. This paper analyses this latter option and provides results in order to quantify the feasibility of such allocation based on the Time Advance information. Aspects as TA resolution, cell coverage, power control policies and system load are taken into consideration.**

I. INTRODUCTION

The General Packet Radio Services (GPRS) system is intended to upgrade the existing GSM network to a packet switched system. This solution is expected to be one of the key enablers of many applications and services in the way of wireless data access. GPRS implies to add a complete packet-switched core network to the GSM-Network Switched Subsystem (NSS) and leave almost unchanged the GSM Base Station Subsystem (BSS) [1]. The main extension needed in the BSS segment is the Packet Control Unit (PCU) to interface data packets to the GSM-BSS and to control and manage most of the radio related functions of GPRS. The PCU and the GPRS mobile station (MS) use GSM radio resources to exchange data and control information. Particularly, Radio Link Control/Medium Access Control (RLC/MAC) mechanisms are implemented at this level to manage transmission over the air interface. Information transmitted between peer RLC/MAC entities is organized in Radio Blocks (RB). The amount of radio resources that a RB consumes is fixed. However, the amount of useful payload information included in a RB depends on the applied coding scheme.

In GPRS, four coding schemes named from CS-1 to CS-4 have been defined with the purpose of adapting the transmission of the radio blocks to the different quality conditions of the radio channel. The aim is to maximize the throughput of the radio channel by using the most suited coding scheme at each given moment. The optimal choice of the coding scheme depends on the radio channel conditions and more particularly, it could be described as a function of the carrier to interference ratio (CIR).

Link adaptation, that is, the selection of the best fitted coding scheme under certain radio conditions, could be based on radio link quality estimators as Carrier to Interference Ratio (CIR) and Block Error Ratio (BLER) [2-3]. However, whatever the method used to estimate the radio link quality, the time variant nature of the radio channel and also the bursty nature of the GPRS traffic could make difficult to predict with certain accuracy the channel behavior. Most analysis proposing link adaptation based on CIR and/or BLER estimators assume that the radio channel behaves constant during the transmission of a complete traffic burst, or at least during the minimum signaling window needed in order to have a feedback with the quality estimations done at the receiver. In GPRS, scheduling strategies used to share radio resources among mobile users could lead to situations where, specially when the system load is high, RBs assigned to mobile terminals are enough discontinuous in time to neglect correlation between channel conditions. Furthermore, when slow frequency hopping (SFH) techniques are used in traffic channels, the interference from co-channel emitters could change meaningfully from RB to RB. Under such channel behavior where poor correlation conditions exists between consecutive RBs, this paper quantifies the benefits and limitations of considering a more deterministic and static information such as Time Advance (TA) to select the coding scheme or simply in order to be taken into account jointly within other link adaptation criteria. Results are obtained under different conditions as TA resolution, cell coverage, power control and system load.

The paper is organized as follows. Section II provides more details on coding schemes defined in GPRS. Time Advance mechanism is explained in Section III. Section IV describes the model scenario and system assumptions considered in the analysis. In section V results are provided and finally Section VI concludes the paper.

II. CODING IN GPRS

The coding applied by the physical layer in intended to protect data against radio transmission errors. The more data protection the more redundancy is included and, therefore, the less quantity of data bits could be transmitted within the same bandwidth. This trade-off is reflected in the four coding schemes defined in GPRS. CS-1 uses a half rate convolutional code. The CS-2 and CS-3 schemes use the

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same convolutional code but with different degree of puncturing. The CS-4 scheme does not use error correcting coding.

In GPRS data transmitted on the air interface is structured in Radio Blocks. Each Radio Block contains a RLC/MAC data or control unit and consists of 456 coded bits arranged in four consecutive radio bursts. As the size of the Radio Block is kept constant, the coding scheme determines the amount of the useful payload. Table I shows the transmission rates achievable over a Packet Data Channel (PDCH) depending on coding scheme. A PDCH is able to transmit a RB each 20 ms on average. The stealing flags defined in GSM radio bursts are used to discriminate the four coding schemes.

Table I. Transmission rate for the four Coding Schemes defined in GPRS

	Code rate	Payload (bits)	Bit Rate (kbits/s)
CS-1	½	181	9.05
CS-2	≈2/3	268	13.4
CS-3	≈3/4	312	15.6
CS-4	1	428	21.4

As it is shown in Fig. 1 [4], the throughput achievable with each coding scheme depends on the value of CIR. Values plotted in this figure correspond to a Typical Urban (TU) radio channel with MS's speed equal to 50 km/h and ideal SFH. It could also be noticed from the figure that an optimal code allocation could be done for different CIR margins.

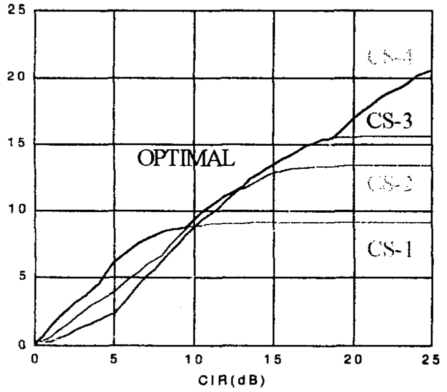

Figure 1. Throughput in kbits/s versus CIR

III. TIME ADVANCE

The Time Advance mechanism compensates the effect of the propagation delay and avoids overlapping transmissions by anticipating mobile station transmission time accordingly. The initial value of TA information is measured at the Base Station each time the mobile transmits on the PRACH (Packet Random Access Channel) and it is notified to the mobile station when radio resources are allocated. Thus, whenever the mobile station transmits its information in normal bursts the initial transmission time is corrected with the TA value.

In GPRS/GSM the resolution provided by TA is limited to one bit period. So, the distance resolution (d_{TA}) given by the TA could be formulated as

$$d_{TA} = \frac{T_b}{2} \cdot c \qquad (1)$$

where T_b is the bit period and c refers to light's speed. Therefore, in GSM, the distance resolution provided by TA in restricted to approximately 550 meters. Results provided in this paper are based on this resolution but they could be directly extended to situations where it was possible to known TA information with further resolution. So, using the 64 values considered in GSM for TA means that the radius of the cell is as large as 35 km. Typical cells with 2-8km radius could take profit of TA values up to 4-16.

GPRS also defines a mechanism to update TA information each 1.92s. This mechanism relays on the transmission of single bursts allocated on purpose within the PDCH multiframe. For instance, considering two consecutive calculations of TA separated 1.92s, the distance between a BS and a MS moving at 100 km/h could change as much as 53 meters in a worst case. This is why we can consider the TA value as a *static* information in a RB time scale. On the other hand, the estimation procedure of TA is considered enough reliable to neglect erroneous TA values.

IV. ENVISAGED SCENARIO AND MODEL ASSUMPTIONS

The simulation model consists of a macrocell deployment scenario with 37 tri-sectored cells distributed around a central Base Station in which results are collected. Mobiles that apply the same TA correction are distributed within a circular ring around their BS. Fig. 2 illustrates such a distribution. The idea behind using TA as a link adaptation criterion is to exploit the correlation between CIR statistics and a particular TA value.

A. Uplink and Downlink CIR statistics calculation

When we consider signal-level based power control in the uplink, the required power to be transmitted from useful Mobile Station to the corresponding Base Station is calculated according to

$$P^{U}_{req} = T_{PC} + L + S - G_L + \Delta_{PC} \qquad (2)$$

where T_{PC} is the target power level, L is the propagation loss, S accounts for the slow shadowing, G_L includes the link

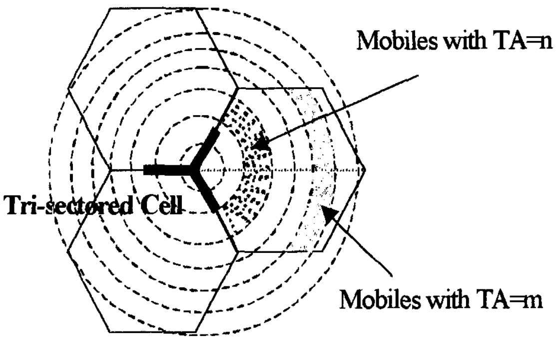

Figure 2. Mobile distribution within a sector depending on TA value.

gains and losses due to antenna pattern, spatial diversity and BS connectors, and Δ_{PC} is an uniform random variable to take into account the discrete step size of the power control. Furthermore, the effect of having a maximum and a minimum transmission power is modeled by calculating the MS transmitted power P_T^U from the expression

$$P_T^U = \min\left(P_T^{\max}, \max\left(P_T^{\min}, P_{req}^U\right)\right) \tag{3}$$

In the uplink channel, interferers are MSs connected to co-channel base stations. Therefore, the interfering power received in the Base Station from a Mobile Station *i* located in an interfering sector could be calculated by the following expression

$$I^i = P_T^i + L^i + S^i - G_L \tag{4}$$

where now L^i refers to the propagation losses between the interferer mobile and the base station of the reference user. The transmission power of this mobile also is calculated according to (2) but considering the base station which the interferer mobile is linked to. Shadowing behaviors in different links are assumed to be not correlated.

Thus, the CIR value is computed according

$$CIR = \frac{P_r^U}{\sum_{\text{int}\, erferes} p \cdot P_r^i + \eta} \tag{5}$$

where η is the receiver noise and p is a random variable that takes into consideration the load of the system. Fixing p=1 means a fully loaded system in which we have an active mobile transmitting in each interferer sector. The interferer sectors are the resulting from assuming a regular reuse pattern K/3· K.

Downlink characterization is similar to the uplink methodology. The main remarkable difference in the downlink is that interferers are always the co-channel BSs.

The propagation loss model is the one defined for Vehicular Test Environment in [5]. For a given frequency band and for a fixed base station antenna height Δh_b, in metres, measured from the average rooftop level, the propagation loss estimated by this model could be formulated as

$$L = L_o + 10 \cdot \mu \cdot \log_{10}(d) \tag{6}$$

where L_o and μ depends on the carrier frequency and Δh_b. Shadow fading S is modeled by a normal process with standard deviation of σ dB. The effect of the multipath fading is supposed to be accounted in the function used to relate BLER to CIR. Table II shows the reference configuration for which results are provided.

Table II. Model parameters.

	Uplink	**Downlink**
Max. TX Power	33 dBm	38 dBm
Min. TX Power	13 dBm	13 dBm
Link Gain	13+0+3-2	0+13+0-2
PC Target	-90 dBm	-90 dBm
PC Step	2 dB	2 dB
Receiver Noise (dBm)	-116.6	-114.6
Propagation Loss (Δh_b=15,f_o=900Mhz)	L_b=120.8,μ=3.76	
Shadowing(dB)	6	
Frequency Plan	1/3	

Monte Carlo simulations are used to collect statistics. In each iteration, a reference mobile is randomly and uniformly distributed within a circular region fixed by a given TA value. Besides, in each interferer sector, a MS is randomly distributed over the whole sector according also to an uniform distribution. Then, CIR calculations are performed in downlink and uplink channels of the reference user.

Fig. 3 plots the cumulative density function (CDF) of CIR values obtained in three specific regions fixed by TA values equals to 1, 4 and 8. The cell radius is 8.88 km and consequently the maximum valid TA is 8. The figure also contains CIR statistics collected in the whole cell, that is, for mobiles located anywhere in the reference sector. It is noticed that CIR statistics depends strongly on the TA region in which they are collected.

B. Coding Scheme based on TA

Once CIR statistics are calculated for each TA value, the mean throughput $\overline{S}_{CS-i}$ achieved with each coding scheme could be obtained from the following expression

$$\overline{S}_{CS-i}(TA) = R_{CS-i}^{\max} \cdot E\left[1 - BLER_{CS-i}(CIR)\right] \tag{7}$$

where $R_{CS-i}^{\max}$ is the maximum rate for CS-i (see Table II), $BLER_{CS\text{-}I}(CIR)$ is the function that relates BLER to the value

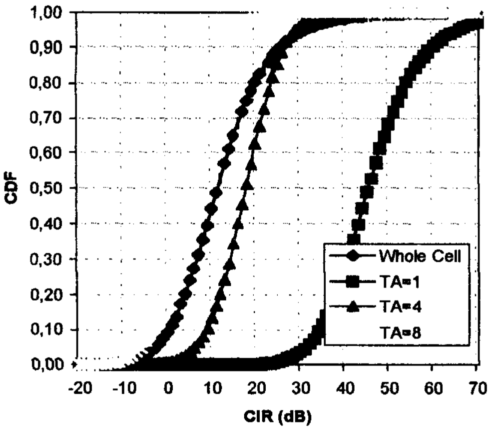

Figure 3. CDF of CIR for each TA-defined region

of CIR depending on coding scheme, and E[.] denotes the computation of the mean value according to the probability density function of CIR. Therefore, $E[1 - BLER_{CS-i}(CIR)]$ indicates the averaged value of non erroneous radio blocks. Each circular ring will have an optimal coding scheme in terms of mean throughput. From (2) it is possible to calculate the mean throughput per sector by means of

$$S_{TA} = \iint_{Sector} \max_{CS-i}(S_{CS-i}(TA)) \cdot dS = \sum_{k=1}^{N_{TA}} \max_{CS-i}(S_{CS-i}(k)) \cdot (2 \cdot k - 1) \cdot \left(\frac{d_{TA}}{R}\right)^2 \cdot \frac{\Delta\theta}{360} \qquad (8)$$

where N_{TA} is the number of different TA values and $\Delta\theta = 120°$ for tri-sectored cells. To evaluate the efficiency of such assignment we can compare the mean throughput achieved in the whole area in case of code allocation per TA value, to the mean throughput in case of an optimal code allocation S_{max} done per unit area. S_{max} could be obtained from evaluating the following expression

$$S_{max} = \iint_{Sector} \max_{CS-i}(S_{CS-i}(r,\theta)) \cdot r dr d\theta \qquad (9)$$

IV. RESULTS

Results in Fig. 4 and Fig. 5 show the throughput achievable with each coding scheme versus the distance to the base station in terms of the Time Advance value. Both cases consider no power control policies. Fig. 4 corresponds to a 4.44 cell radius, that is, 8 different TA values available, and Fig. 5 is obtained for a 2.22 Km cell radius, that is, 4 different TA values. The graph named *TA Adaptive* in both figures provides the maximum value of (7) calculated in each circular ring determined by a given TA. As it could be observed, for each TA value, there is an optimal coding scheme to be used in terms of mean throughput. In the 8 TA value scenario, the allocation based on TA gives a S_{TA}=11.4 kbits/s while a coding assignment done per unit area would provide S_{max}=11.5 kbits/s. On the other hand, the mean throughput provided by the usage of a fixed allocation on the whole cell is calculated to be about S_{FIX}=10.4 kbits/s, being CS-3 the best fitted code in this case. In the 2.22 km radius cell, S_{TA} is 11.5 kbits/s while S_{max} is found to be 11.7 kbits/s. In this case the best fix allocation would be also CS-3 with S_{FIX}=10.6 kbits/s.

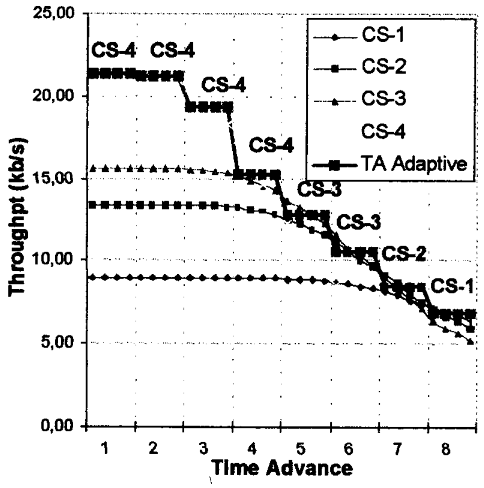

Figure 4. Throughput depending on coding scheme and TA value (cell radius 4.44Km)

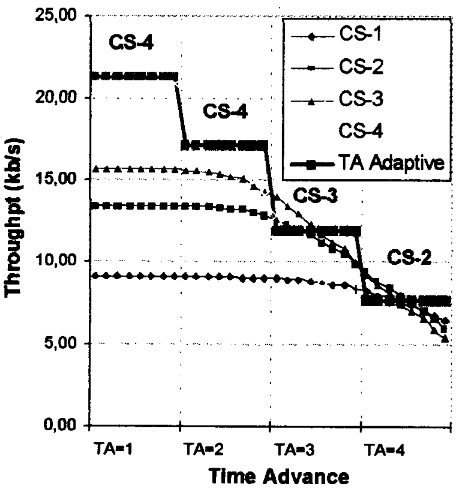

Figure 5. Throughput depending on coding scheme and TA value (cell radius 2.22Km)

Fig. 6 provides S_{TA} depending on TA resolution for both of the above considered cell radius. Besides, the best throughput achieved by a fixed allocation S_{FIX} is also provided. It is shown that practically the whole increase of mean throughput achieved by considering TA information is achieved with TA resolution greater or equal than 4.

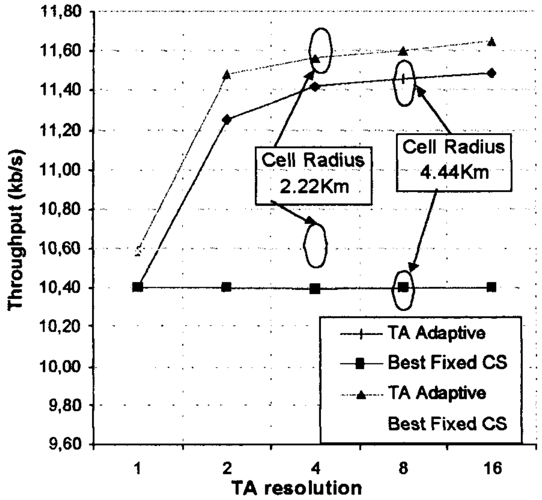

Figure 6. Effect of TA resolution

Finally, Table III provides some results when different parameters to the ones stated in Table II are considered. While the first row correspond to results obtained with the reference configuration, the first column in the following rows indicates the parameter changed in each case. A cell radius of 4.44 radius has been assumed for all the simulations. Basically the table provides in which TA-defined region each coding performs the best. Results are given uniquely for the uplink since it has been found that downlink exhibits the same behavior.

Table III. Coding scheme allocation per TA (1..8)

	CS-4	CS-3	CS-2	CS-1	S_{TA}	S_{max}
T_{PC}=-90dBm	1	2-7	8	-	11,60	11,64
T_{PC}=-100dBm	1-2	3	4-8	-	10,58	10,61
No PC	1-4	5-6	7	8	11,39	11,44
σ=1 dB	1	2-7	8	-	12,73	12,77
σ=8 dB	1	2-6	7-8	-	9,40	9,40
Δh_b=5m (L=129, μ=3.92)	1-3	4-5	6-7	8	10,85	10,90
Reuse 3/9	1-6	7-8	-	-	15,62	15,77
Load 75%	1-2	3-7	8	-	12,34	12,46

It is noticed that power control policies modifies the allocation of the coding scheme per TA since CIR dependence versus distance is altered. However, although coding allocation per TA is shown to be dependent on the power control configuration, the usage of power control, given a specific scenario, is a long term system characteristic. And, as it could be observed from values of S_{max} and S_{TA} in Table III, the allocation done per TA is always close to an optimal allocation in terms of mean throughput done per unit area. Table III also provides results for different environment propagation conditions. If antenna height is reduced to Δh_b=5 m, the mean throughput is reduced but the TA allocation is still suitable. The same effect could be observed when the shadowing deviation σ is modified. In terms of interference, a cellular reuse 3/9 provides a better throughput and TA allocation also provides results close to the best allocation per unit area. Furthermore, when the system load is relatively high (75%-100%) the allocation tables are practically the same. Just in that situations the time between transmitted radio blocks from/to the same mobile could be so important to neglect correlation in radio channel and the information provided by the TA knowledge could be useful to determine the coding scheme to use.

V. CONCLUSIONS

This paper analyses the use of TA information as a criteria in selecting coding scheme in a GPRS system. It is found that the use of TA knowledge could be useful in poor correlated radio channels where conditions could be very different from RB to RB and also in situations where there is no other link quality estimation available, i.e., when a transmission begins. Results are provided to quantify the benefits of such TA allocation in terms of cell radius, time advance resolution and system propagation and interference conditions. It is for further study the analysis of link adaptation algorithms that incorporate TA value is its decision criteria.

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REFERENCES

[1]. Jian Cai and David J. Goodman, "General Packet Radio Service in GSM", IEEE Communications Magazine, October 1997.
[2]. O.Queseth, F.Gressler and M.Frodigh, "Algorithms for Link Adaptation in GPRS", Vehicular Technology Conference 1999, pp. 943-947.
[3]. Pablo José Amegeiras et al., "Performance of Link Adaptation in GPRS Networks", VTC 2000.
[4]. GSM 05.50 v. 8.2.0 Release 1999, "Digital cellular telecommunications system (Phase 2+);Background for Radio Frequency (RF) requirements"
[5]. UMTS 30.03 version 3.2.0, "UMTS; Selection procedures for the choice of radio transmission technologies of the UMTS".