Delay–Throughput Performance of Packet Service in UMTS

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Abstract- *The UMTS W-CDMA radio interface is characterized by great flexibility and a variety of different physical and logical channel types rates and protections are possible, by choosing suitable parameters, such as spreading factors, code rates and ARQ schemes. In this paper we present the results, obtained by a detailed simulation, about the effect of several parameters and system alternatives on the capacity of the downlink shared channel.*

Keywords - UMTS, CDMA, packet service, ARQ, FEC.

I INTRODUCTION

The Universal Mobile Telecommunications System (UMTS) [1, 2] is the third generation mobile communication system developed by ETSI, the European Telecommunications Standard Institute, which will allow the use of a new frequency spectrum and is expected to extend the present GSM service to include multimedia.

Due to the effort of the standardization bodies, the radio interface is characterized by great flexibility and a variety of different physical and logical channel types. For instance, several user rates and protections are possible, by choosing suitable parameters, such as spreading factors, code rates and ARQ (Automatic Repeat reQuest) schemes.

Among the new services offered by UMTS, the packet data service is probably one of the most critical from the system parameters setting point of view mainly because of the characteristics of the code division access scheme adopted at the radio interface.

In the downlink, three different channel types are available for data packets transmission, namely the DCH *Dedicated Channel*, the DSCH *Downlink Shared Channel* and the FACH *Forward Access Channel.*

The DCHs are assigned to single users through set-up and tear down procedures and are subject to closed loop power control that, if used for circuit service such as voice, stabilizes the BER (bit error rate) and optimizes CDMA performance.

The DSCH is a common channel on which several users can be time multiplexed. No set-up and tear down procedures are required and the physical channel on which the DSCH is mapped does not carry power control signaling. However, since the closed loop power control is still required, users that are allowed to access DSCH services must have an associated active DCH.

The FACH is shared by several users to transmit short bursts of data, but, unlike DSCH, no closed-loop power control is exerted and no DCH must be activated to access this channel.

For each one of the above channels, different combinations of spreading factor and code rate can provide the bandwidth and the protection required for different services and environments.

Well known results for real-time circuit traffic show that CDMA with closed-loop power control can be very effective in spectrum exploitation [5]. Its efficiency can be further enhanced by using powerful codes and it has been proved that FEC codes are more effective than spreading codes [6].

With packet service, the effect of direct sequence spreading, FEC codes and closed loop power control is not easily predictable and the optimal combination of codes and spreading factors may be different from circuit service. In fact, data traffic is bursty in nature, and, depending on the number of interfering channels and their power levels, errors can be more efficiently obviated by ARQ techniques than by forward error correcting codes [7, 8].

To understand the roles that the many parameters and system features have on the overall capacity with packet service, we have implemented a detailed simulator of the UMTS downlink.

In Section II we present the system model adopted for simulations and in Section III we discuss the results obtained. Section IV includes some final remarks and concludes the paper.

II SIMULATOR DESCRIPTION

The simulator reproduces a system composed of 49 exagonal cells that lay on a torus surface to avoid border effects. The base stations (BS) are located at the center of each cell and irradiate with omni-directional antennas with unit gain.

A Propagation model

The propagation model assumed in this work follows the guidelines of ETSI [9]. In particular, the relationship between the received power P_r and the transmitted power P_t is given by $P_r = P_t 10^{\frac{\epsilon}{10}} L$ where L is the path loss and $10^{\frac{\epsilon}{10}}$ accounts for the loss due to slow shadowing, being ϵ a normal variate with zero mean and σ^2 variance.

In the following we refer to a macro-cellular environment, for which the cell radius is 300 m, and the path loss L is expressed as

$$10 \log L = -(128.1 + 37.6 \log r)(dB)$$

where r (in meters) represents the distance between the mobile and the base. Furthermore, we assume no fading and shadowing standard deviation equal to 5 dB.

When a new user is generated, its position is chosen randomly over the torus surface and is assigned to the BS with the minimum attenuation. No user mobility is considered.

B Traffic model

We have adopted a basic traffic model with packet calls where users arrive according to a Poisson Point Process of intensity λ, as described in [9]. Each user, upon activation, generates a flow of packets whose length is negative exponentially distributed with mean 3840 bits. The packet flow is composed of a number of packets, geometrically distributed with mean $N_p = 25$, which arrive according to a Poisson Point Process whose intensity is chosen to match a given source speed.

A user leaves the system as soon as the last packet has been successfully transmitted.

C Transmission model

The packets generated by each user are delivered to the RLC (Radio Link Control) layer [4] where they are subdivided into transmission blocks before being queued for transmission. Each transmission block includes an RLC header of 16 bit that also accounts for an ARQ mechanism.

At each frame, set equal to 10 ms, the MAC (Medium Access Control) layer [3] chooses an user queue according to the scheduling mechanism and, after adding a MAC header, sends to the physical layer a number of blocks less or equal to that needed to fill the space available in the frame. Before transmission, the physical layer adds the redundancy bits according to the coding scheme adopted.

Our simulator adds the parity bits required by Convolutional Codes, with 256 states, Constraint Length $K = 9$ and optimal puncturing, whose Bit Error Probability (BER), obtained through link level simulations [10], is shown in Figure 1. In particular we have considered code rates, spreading factors and block sizes such that the bits introduced by rate matching are very few and add overhead, without increasing error protection.

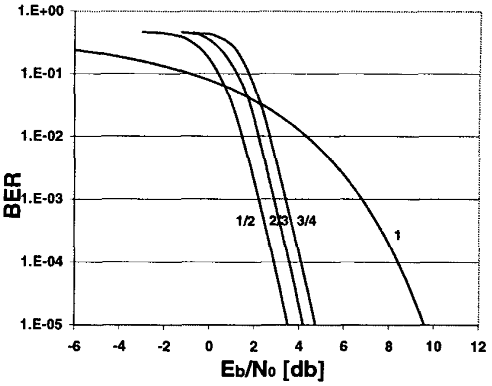

Figure 1: *Bit Error Rate of the convolutional codes adopted in UMTS as function of the bit normalized energy.*

D Receiver model

At the receiving side the carrier to interference ratio is evaluated, for each transmission, as

$$\frac{C}{I} = \frac{P_r}{\alpha I_{intra} + I_{inter} + P_N} \tag{1}$$

where P_r is the received signal strength, P_N is the thermal noise assumed equal to -99 dBm, I_{inter} is the sum of the signal powers received from the other cells, I_{intra} is the sum of the signal powers received from other users within the cell, and α is the loss-of-orthogonality factor that, according to [11], is assumed equal to 0.4.

For each transmission, the normalized bit energy is used to derive the BLER, and the correctness of the transmission is decided testing the value of a normalized random variable against BLER.

In the following, otherwise specified, we will refer to the SIR after despreading, which is defined as SIR=SF × C/I.

Our simulator does not implement an explicit ARQ procedure. Instead, at the end of the transmission, the transmitted block is kept in the transmitting queue if any error occurs and is canceled otherwise. After 10 failed transmissions the block is dropped and the user is declared in outage.

E Power control model

The power control mechanism adopted for DCHs uses two control loops. The inner loop controls the transmitted power to maintain the SIR at the target value, whereas the outer loop controls the SIR target to provide a target BLER. As in our simulation we investigate a service at a time, the corresponding BLER requirement can be assumed constant and therefore we have implemented the inner loop only, treating the BLER target value as an input.

Though UMTS specifications state that power-update requests of ±1 dB are transmitted every time slot (0.625 ms), to simplify the simulator and reduce the run length we have assumed to transmit power updates every frame (10 ms).

DCH power updates, limited within the ±16 dB range, are requested at each frame based on the difference between the SIR target and the SIR evaluated on the last frame.

Each channel can not exceed a transmitted power of 30 dBm, whereas the overall power transmitted by a base station is limited to 43 dBm. [11].

III SIMULATION RESULTS

Due to the complexity of the overall system and the interaction among the system parameters and performance variables do not allow a single and straightforward discussion of the system behavior, in our investigation we have been forced to split the study in several sub-problems and to take simplifying assumptions.

First, the interference generated by DCHs is not taken into account in SIR calculation that determines the performance of the data channel and the power control updates.

With this assumption we have investigated the effect of spreading factor and code rate with the single physical DSCH, and the achievable performance with multiple physical channels.

Since for several values of system parameters we have observed throughput instability, we have introduced a control mechanism based on the well known back-off (BO) mechanism, which limits the instability caused by collisions. We adopted a linear back-off mechanism which inhibits the use of the DSCH in a cell where a collision has occurred while trasmitting the maximum available power.

A Effect of codes and spreading factors

Figure 2 shows the packet average delay versus the throughput when one PDSCH is adopted with SF=4 and for different codes, namely R= 1, 3/4, 2/3, 1/2. In all cases we have adopted the linear back-off mechanism described above and we have used optimal SIR_{target} values for the inner loop power control procedure. In these conditions, the best performance is obtained with a light codes (R= 3/4 and R=2/3). Heavier codes (R= 1/2) achieve a poorer performance since the added redundancy bits provide an excess protection and negatively affect the throughput. The low throughput in the case of no error correction (R= 1) shows that the protection of the spreading process with SF= 4 is not sufficient to fight interference.

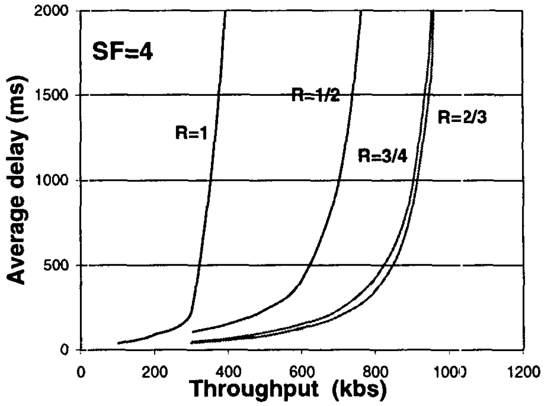

Figure 2: *Average delay versus throughput for SF=* 4 *and different code rates with the basic traffic model.*

In the $R = 1$ case, we have adopted a SIR target of 13 dB as this SIR value provides a BLER low enough to be suitable for ARQ operation. Unfortunately, due to the power limits, the power control is not able to reach this value at high loads, and the BLER results much higher. As channel traffic G increases, the power control drives many sources into saturation causing a sharp increase in the BLER and the BO mechanism intervenes and drastically limits the maximum G.

As the high SIR target is responsible for the bad performance at high $G = 1$, to get better performance we must adopt correcting codes that allow a lower SIR. We have observed that with an $R = 3/4$ code, a 9 dB SIR is enough to guarantee a very low BLER. Even in this case the performance is too bad in $G = 1$ and the BO intervenes limiting G to 0.955. A similar behavior is shown by the code $R = 2/3$, though the G limit is further increased to 0.97. The delay curves for the two latter cases almost perfectly overlap, showing the ability of the BO to keep the system very close to capacity.

Although in the two last cases the reduced SIR target reduces the BLER, the obtained BLER is still much higher than what predicted by Figure 1. The reason is that the power control mechanism can track the SIR at the target value only with slow varying interference, as in the case of circuit service. Differently, with packet service, traffic and interference are bursty and the power control is not able to keep the SIR constant. We have measured SIR standard deviation values in the range 3.7 – 4.3 dB [1]. A consequence of this behavior is that the errors in-

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[1] Throughout the paper, all interference and SIR statistics are evaluated considering logaritmic values

troduced by the radio channel are not independent, but occur in burst when the SIR is too low.

With more powerful codes (R= 1/2), $G = 1$ can be reached and, because of the further reduced SIR target, the BLER is further reduced. However, the benefits of the reduced number of retransmissions, do not compensate the loss of throughput due to the increased code redundancy and the maximum observed throughput is remarkably smaller than that obtained with R= 2/3.

The system parameters configuration with R= 1/2 is very effective in fighting interference, since it allows trasmissions with lower power levels. It's quite clear from figure 2 that the redundancy introduced by the code R= 1/2 limits the capacity of the system, when using a single PDSCH. Under these hypothesis we have studied the performance of the DSCH service when using multiple SF= 8 in a single BS, and a FEC code with R= 1/2.

The performance is significantly improved, as observed in Figure 3, by using 3 and 4 PDSCHs with a SIR target equal to 4 dB, which in this case has shown to be optimal. The BO mechanism intervenes with 4 PDSCHs limiting the maximum G to 0.855. With 5 PDSCHs, the increase in the interference prevails. Here, G is limited to 0.622, and a small instability effect is present despite the BO. The case of 4 channels provides the maximum throughput (1240 kb/s) among those examined.

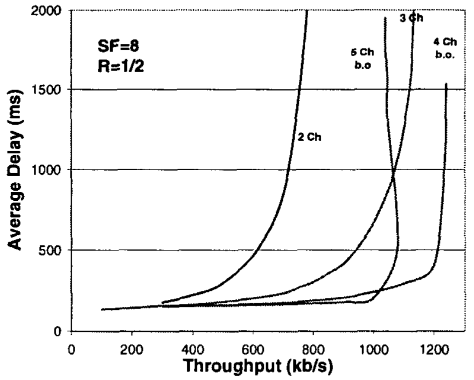

Figure 3: *Average delay versus throughput when a different number of physical channels are used in parallel for* $SF= 8$ $R = 1/2$.

We now consider the interference generated by the DCHs. It is expected that the increased interference caused by all the active DCHs decreases the throughput of the DSCH and causes instability.

To control this phenomenon we have limited to N the number of associated DCHs. Users that arrive beyond this limit are queued and wait for an available DCH.

In our model we have assumed that DCH control channels use a spreading factor equals to 512 and require a SIR target equal to 8 dB in order to grant a BER level low enough on the signalling bits.

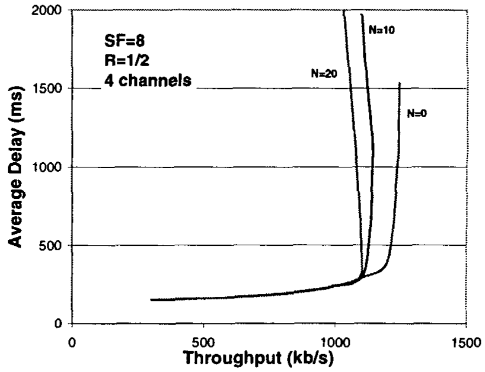

Figure 4: *Average delay versus throughput when a different number of active users is adopted in the case with four physical channels,* $SF= 8$ *and* $R = 1/2$.

Figure 4 shows the effect of N for the optimal case of four channels, SF= 8 and $R = 1/2$. As N is increased, the system reaches an instable behavior due to the high level of the introduced interference.

B Effect of power control

The closed-loop power control in the DSCH, has the drawback of introducing additional interference through the control channels. To evaluate the trade off between added interference and stricter control on the transmitted power we have studied the performance of the FACH (*Forward Access Channel*), which is very similar to the DSCH as far as the processing and the transmission of information is concerned, but do not use a closed-loop power control. We have analyzed two alternative ways of using the FACH channel,

In the first alternative, the "NO-PC" case, no power control is exerted and all users transmit at the fixed level of 30 dBm. In such a channel, users experience different average SIR values, due to their different path loss and shadowing, and, therefore different BLER. To avoid persistent error conditions of users with a bad channel, we have adopted the Random Order scheduling discipline.

In the second alternative, the "OL-PC", we have adopted an open-loop power control mechanism that compensates the different link losses. In this case, the transmitted power is adjusted, within the allowed range, to reach a power level target value.

Figure 5 compares, for SF= 4 and $R = 1/2$, the delay throughput curves of the DSCH channel with $N = 10$ (CL-PC case) with those of the FACH channel in NO-PC and OL-PC cases. The maximum throughput reached in the NO-PC case is quite low (670 kb/s), and 8% of users experience packet loss due to the limit in the number of consecutive retransmissions.

The performance of the OL-PC case depends of the target value of the received power. The best, shown in the figure, has been obtained with a value of −66 dBm. The maximum throughput of OL-PC is 670 kb/s not far from 750 kb/s obtained by the CL-PC. This indicates in the case of a single physical channel the much more complex close-loop power control is provides a marginal improvement and simpler open-loop mechanisms should be preferred. Different is the behavior in the case of multiple physical channels. In this case the closed-loop power control is more effective in controlling SIR variations and achieves much higher throughput. In the case of 4 PDCHs, SF= 8 and $R = 1/2$, shown in Figure 6, CL-PC reaches a maximum throughput of 1200 Kb/s, almost three times as much as OL-PC.

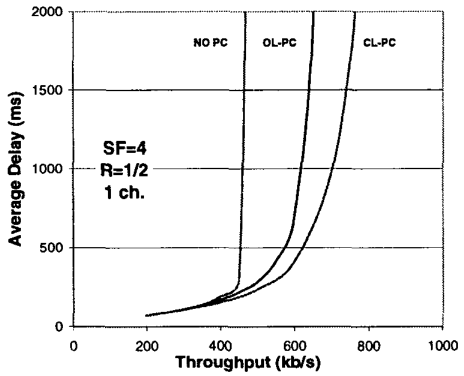

Figure 5: *Average delay versus throughput for cases that adopt different power control schemes in the case SF=* 4 $R = 1/2$ *and one physical channel.*

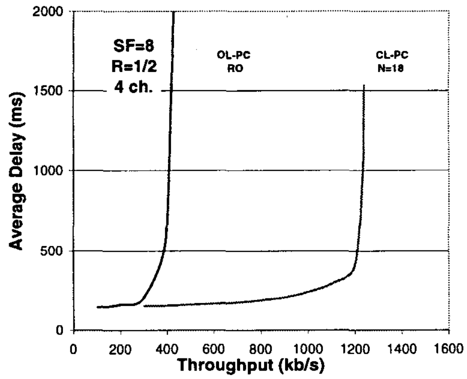

Figure 6: *Average delay versus throughput for cases that adopt different power control schemes in the case with four physical channels, SF=* 8 *and* $R = 1/2$.

IV CONCLUSIONS

In this paper we have investigated the performance of the UMTS radio interface, with packets service, mainly evaluating the maximum throughput achievable on the DSCH with different physical channels configurations and power control mechanisms.

The results show that, when the packet service can use only a single physical channel, the maximum throughput is attained with the smallest available spreading factor, SF= 4, and a light code, $R = 2/3$. In this scenario, we have observed that the closed-loop power control can not efficiently follow the strong interference variations and does not provide a significant gain with respect to the open loop one.

If the use of multiple physical channels is allowed, the maximum throughput is attained by using up to four channels with SF= 8 and $R = 1/2$, despite the new intra-cell interference introduced. This is mainly due to the improved efficiency of the closed-loop power control that, taking advantage of the longer transmission time and of the reduced interference burstiness, better tracks the SIR target.

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