Issues on Packet Transmission Strategies in a TDD - TD/CDMA scenario

Jordi Pérez-Romero, Ramón Agustí, Oriol Sallent, Fernando Casadevall

Dept.de Teoria del Senyal i Comunicacions, Universitat Politècnica de Catalunya (UPC), Barcelona, Spain, email: [jorperez, ramon, oriol, ferranc]@tsc.upc.es

Abstract: *This paper presents a packet transmission scheme that deals with the problems of a TDD CDMA scenario with different levels of frame structure asymmetry in adjacent base stations by distributing the users in the slots depending on their Time Advance. A multiple access protocol and a scheduling algorithm are also proposed to provide a certain degree of Quality of Service.*

1.- Introduction

One of the main goals of the future 3rd generation mobile communication systems will be the provision of different kinds of multimedia services with a certain degree of Quality of Service (QoS) that is to be guaranteed depending on the considered application and its interactivity requirements. In this framework, CDMA packet based networks, such as the considered in the UTRA proposal, provide an inherent flexibility to handle the provision of these services.

UTRA provides two operation modes depending on the duplex technique being used: FDD and TDD. The first one makes use of a DS/CDMA multiple access strategy while the second one applies a combined TDMA DS/CDMA access scheme. The TDD mode gains interest whenever asymmetric services are taken into account, as it would be the case of Internet services, in which a higher amount of information is to be sent in the downlink (DL) direction, while in the uplink (UL) direction only small commands (mainly page requests and TCP acknowledgements) are transmitted. Then, a different number of time slots can be allocated to the DL and the UL, depending on the traffic asymmetry.

When aiming to design a mechanism to provide specific Quality of Service guarantees in a TDD packet environment, different points should be considered. Particularly, new tasks arise that were either not applicable at all or considered in a very simple way because of the circuit-switched nature of the 2nd Generation networks. These are the following:

- *Multiple Access Protocol*: it specifies the way how the users access into the system in order to start the transmission of a set of information packets. Very different kinds of protocols have been studied up to date, and all of them have in common a certain degree of randomness in the access. The higher this degree the higher the flexibility, but the poorer the behaviour when aiming to preserve some requirements such as the maximum access delay. Then, when a certain QoS is to be guaranteed, the randomness needs to be reduced to some extent in order to keep the specified constraints.

- *Scheduling Algorithm*: it specifies the instant when a certain user that has gained access in the system through the multiple access protocol can start the transmission of its information, as well as the spreading factor to use. This mechanism requires to define a prioritisation rule between the users as well as a smart algorithm to distribute the resources among them in order to meet the QoS criteria.

- ***Dynamic Channel Allocation (DCA)*:** this mechanism is responsible for deciding on which resources(i.e., slots and codes) the transmission is to be performed, and it needs to work closely with the scheduling algorithm. It should be pointed out that in a TDD TD/CDMA scenario each slot can receive a different level of interference depending on the transmissions in the serving cell and also in the neighbour cells. This interference can be very important when different asymmetry patterns are considered in adjacent cells. Consequently, some criteria to distribute slots among users need to be defined in order to minimise this effect.

- *Admission Control*: it handles the number of users that may be accepted in the system and thus that can try the access through the defined protocol. This admission control is inherently dependent on the multiple access protocol and on the scheduling algorithm being used. The better the way how these mechanisms operate, the higher the number of users that can be admitted in the system.

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Under this framework, this paper aims to define strategies to cover some of the issues corresponding to the above specified points in the context of a TDD TD/CDMA packet transmission scenario. So, in Section 2, the problem of the interference due to the different asymmetry in adjacent cells is stated and a DCA criterion to distribute users among slots depending on their Time Advance (*TA*) is presented. On the other hand, in Sections 3 and 4, a multiple access protocol, consisting on an adaptation of the ISMA (Inhibit Sense Multiple Access) protocol [1][2] to the TDD scenario, and a scheduling algorithm are proposed, respectively, and in Section 5 some simulation results dealing with the maximum number of allowed users by the scheduling and multiple access protocol in an isolated cell are obtained. Conclusions are summarised in Section 6.

2.- Interference in a TDD TD/CDMA scenario

One of the most important aspects that needs to be considered when evaluating a TDD TD/CDMA scenario is the effect of the different frame structure asymmetry (number of UL and DL slots) in the neighbour cells, which can lead to high interference situations [3]. Figure 1 aims to illustrate this point in a situation where two mobiles are connected to two frame-synchronised neighbour base stations. During a certain slot in the ΔT interval, the mobile connected to BS1 is receiving in the DL while the mobile connected to BS2 is transmitting in the UL. As it is shown, interference affects to both links:

- Mobile to Mobile interference: In this case, the DL of the serving cell may be affected by the UL of the rest of cells. The effect may be different depending on the terminal position respect to its serving cell and the rest of cells. For example, consider in Figure 1 the case of a terminal located at the edge of its serving cell (BS1) and operating in the DL. Assume also that next to this terminal there is another terminal corresponding to the neighbour cell (BS2) which operates in the UL. In such a case, a high power level can be received from the terminal served by BS2 that can damage the reception of the terminal served by BS1 because both of them work at the same carrier.

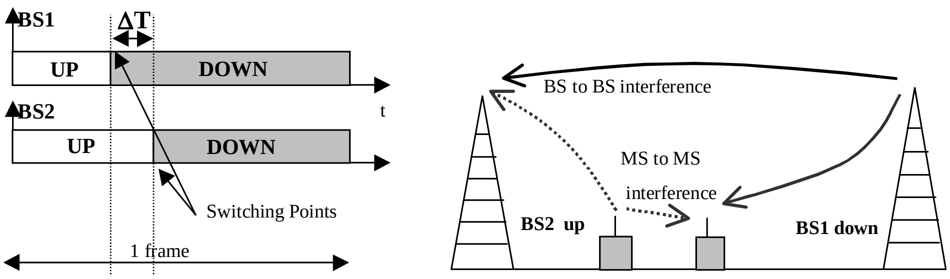

Figure **Error! Unknown switch argument.** *Example of the problem of the different asymmetry in neighbour cells*

- Base Station to Base Station interference*:* In this case, the UL of the serving cell (denoted BS2 in Figure 1) may be affected by the DL of the rest of cells which operate in the same carrier. Note that even if using a different scrambling code, the received power level at the serving base station coming from a base station which is transmitting in the DL can be very high, especially in case of line of sight (LOS) between base stations, and can damage seriously the current transmissions in the UL of the serving base station. In this case the effect is not terminal dependent, and affects equally all the terminals transmitting in the considered slot.

The solution to this interference problem is not a trivial task. Some possibilities would be the use of different frequency bands for neighbour cells or imposing the restriction that all cells must operate with the same asymmetry level, that is, the same slots for the UL and the DL in all the base stations [3]. However, these solutions reduce at a great extent the flexibility and efficiency claimed for asymmetric CDMA systems. In this paper, we propose a mechanism that aims to reduce the effect of this interference without the above drawbacks and that consists on relaying on the co-ordination between the scheduling algorithm and the DCA procedure in order to distribute the resources by taking into account the specified problem.

Particularly, one possibility is to consider the distance of the terminals to the base station in order to decide which is the most appropriate slot to be allocated. Then, those terminals whose distance is higher can be assigned to those slots which are more separated from the switching point in the frame, so that its protection against this kind of interference is higher. Note that the effect of the different asymmetry will be more critical in those slots closer to the switching point. The knowledge about the distance to the base station can be provided by the Time Advance (*TA*), which in a TD/CDMA multiple access system should be provided as an inheritance from the TDMA component. For example, in the UTRA TDD proposal and in the case of synchronisation among UL transmissions, the *TA* resolution is 1/4 chips, which leads to a distance resolution of about 10 m, that can be appropriate to our purposes [4].

Then, according to this method, by considering a 10 ms frame structure such as the one defined in the UTRA TDD proposal [5] composed by 15 slots with a single switching point, for a mobile with time advance *TA* in a cell of radius *R* (m), its suitable UL and DL slots would be:

$$UL\ slot = \left\lfloor \left(1 - \frac{TA \cdot c}{2R}\right) SP \right\rfloor \qquad DL\ slot = SP + \left\lfloor \frac{TA \cdot c}{2R}(15 - SP) \right\rfloor$$

being *SP* the switching point (i.e., the number of the first DL slot in the frame) and c=3.10^8 m/s. $\lfloor x \rfloor$ denotes the highest integer value lower than *x*.

It should be pointed out that this method provides advantages not only to the MS to MS interference, due to the fact that the most interfering users are located closer to their base station, but also to the BS to BS case. In this case, the benefit arises from the fact that, when distributing the DL users in the interfering base station according to their *TA*, a lower power level is required in the problematic slots, as they are assigned to the mobiles which are closer to the interfering BS, thus resulting in a lower interference for the UL of the neighbour base station.

Table I. Simulation parameters

Asymmetry structure	BS1: UL: Slots 0-3, DL: Slots 4-14. BS2: UL: Slots 0-7, DL: Slots 8-14
User density	12.64 users/km^2 [6]
Probability of a user being active	0.7
Power Control	Ideal. Keeps Eb/No constant
Maximum power	BS: 43 dBm. MS: 33 dBm
Thermal Noise power	-103 dBm
Cell radius	1 Km
Eb/No target	5.8 dB for UL, 8.3 dB for DL [6]
Outage condition	Measured Eb/No below Eb/No target
BS to BS propagation model	Free space loss, assuming Line Of Sight with an additional decoupling of 20dB to account for different antenna downtilts
MS to BS propagation model	L=128.1 + 37.6log d(km) with a 10 dB slow fading [6]
MS to MS propagation model	L=128.1 + 37.6log d(km) with a 12 dB slow fading [6]

Trying to evaluate the advantages provided by this method, some simulations have been carried out in a 2 cell scenario with the propagation models and parameters defined in Table I and assuming frame synchronisation between BSs. Each simulation run consists on randomly distributing users in both cells. For each simulation run the outage probability has been calculated for each slot both when selecting the slot for a user by taking into account the TA and when the selection is purely random.

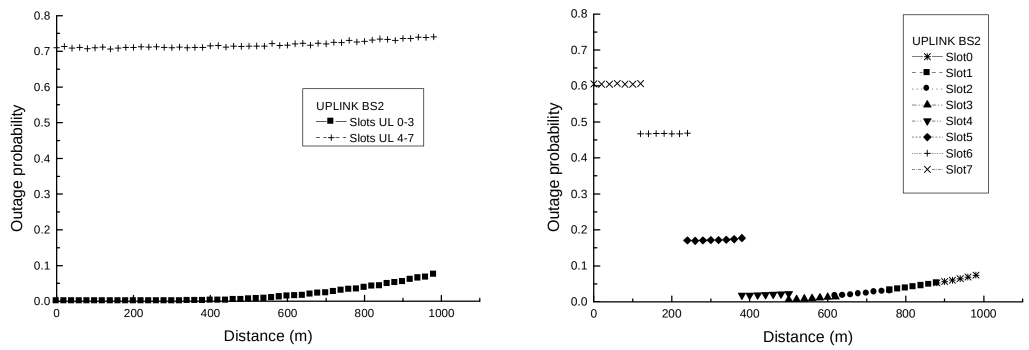

Figure 2.- Outage probability for the UL slots of BS 2 with random distribution (left) or according to TA (right)

The results regarding the outage probability as a function of the distance to the serving BS are shown in figures 2 and 3 for UL slots and DL slots respectively, and the average outage probabilities are presented in Table II. According to the asymmetry pattern of the BSs, shown in Table I, the more problematic slots are those from 4 to 7, as it can be observed in the graphs. Particularly, note that when the random distribution is applied the outage probability is the same for all these slots, with very high values that could lead to consider these slots not available for transmission, specially in the UL case, due to the LOS consideration between base stations. This distribution leads to an overall outage probability (when considering all the slots and all the distances) of about 0.36 for the UL case and 0.06 for the DL case. On the other hand, when considering the distribution according to the TA the outage probability becomes different for each specific slot as those slots that are further away from the switching point are more protected, both in the UL and DL. Particularly, it should be noted the important reduction that is obtained in the outage probability of slots 4 to 6 in the UL of BS2 and slots 5 to 7 in the DL of BS1, and also in the average outage probability, which is around 0.17 for the UL and 0.03 for the DL, approximately half the values obtained in the random distribution case, which confirms the advantages of the proposed method.

Table II. Average outage probabilities

	UL	DL
Random assignment	0.36	0.06
TA assignment	0.17	0.03

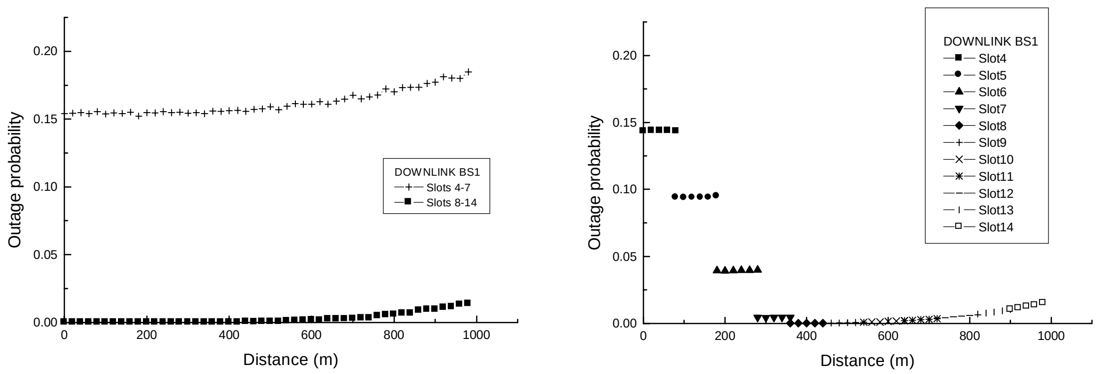

Figure 3.- Outage probability for the DL slots of BS1 with random distribution (left) or according to TA (right)

3.- The ISMA (Inhibit Sense Multiple Access) Protocol

An adaptation of the ISMA protocol is proposed to work in a TD/CDMA environment. According to this protocol, the base station indicates whether or not each resource (slot and OVSF code) is busy, with a total of 15 time slots and 16 OVSF codes [5]. Then, when mobile terminals aim to transmit a certain message, they select, depending on the resource status, one of the free resources and start the transmission if no collision has occurred against another user. Due to the inherent asymmetry of a TDD scenario, there is not any predefined association between an UL and a DL resource, so mobile terminals select in their access procedure both the UL resource and the DL resource, which will be intended to transmit control commands (power control, acknowledgements, scheduling commands, …). The proposed multiple access protocol can thus be subdivided in the following two steps:

1.- According to the status information broadcast by the base station, mobile terminals that aim to start a new message transmission select an UL resource (i.e., a slot and OVSF code pair) and they transmit a packet on it. Together with information regarding the number of packets that are to be transmitted and their quality of service requirements, the slot/code selection for the DL is also indicated.

2.- If the UL transmission has been successful, the base station confirms the access in the selected resource in the DL. It just transmits a packet replying the uplink selection and the downlink selection. Note that if more than one user have selected the same DL resource the BS can indicate a new assignment in its reply, so that each DL resource is assigned to a single user.

After this process has been completed, mobile terminals can start the transmission of their information by following the scheduling commands that will be indicated in the DL resource.

4.- Scheduling algorithm

Once a user has gained access in the system through the multiple access protocol, it must follow the permissions indicated by the scheduling algorithm, responsible of determining who can transmit and the spreading factor that can be applied, in order to manage transmissions according to the QoS that is to be provided to each user. It should be noted that even if a user has successfully selected a resource through the ISMA protocol, it may not have permission to transmit in a given frame. For example, let consider the case of two users that have selected two resources in the same time slot (i.e., each one has a different OVSF code of spreading factor 16). In this case, and due to the characteristics of the considered OVSF codes, if one of them is allowed to transmit at a reduced spreading factor, it would be possible that this fact inhibited the transmission of the other user. This matter points out the importance of a good mechanism that schedules transmissions appropriately.

The proposed algorithm acts in two steps:

1.- *Prioritisation process*: The different users are ordered according to a priority ϕ which depends mainly on the amount of information they require to transmit (i.e., the number of required resources x) and the maximum timeout for this information to be transmitted, according to the considered QoS. The criterion to perform this prioritisation process is based on the algorithm presented in [7]. However, a change has been introduced consisting on the consideration of two timeouts *TO1* and *TO2*, measured in frames, so that when the first one expires for a given user, the prioritisation criterion changes in order to increase even more the priority of this user. This point allows a higher control not only over the maximum delay but also over the delay distribution. Then, the priority ϕ can be calculated as a function of x, the timeouts *TO1* and *TO2*, the number of available time slots N, and the maximum number of simultaneous transmissions in a slot, M (i.e., M=16), by the following expressions:

$$\phi = min\left(N, \frac{\lceil x/M \rceil}{TO1} \right) \text{ if } TO1 > 0 \qquad \phi = min\left(N, \frac{\lceil x/M \rceil (1 + |TO1|)}{TO2} \right) \text{ if } TO1 <= 0$$

2.- *Allocation process*: The different resources are allocated to users depending on their previously calculated priority. Then, for each user the spreading factor and the resources are decided. This procedure works close together with the DCA mechanism in order that the allocated resources are suitable from an interference point of view, as it has been stated in Section 2. Particularly, the following rules are taken into account:

- The UL and DL slots that were selected in the ISMA protocol can be changed in the allocation process according to the TA. The decision of reallocation is taken depending on the difference between the selected slot and the preferred slot according to the TA criterion. If this difference is higher than a certain threshold, the reallocation is performed.

- Depending on the measurements performed in the UL by the base station and in the DL by the mobile terminals, the resource manager can decide that a resource is not appropriate for a certain terminal and thus perform a reallocation procedure. This fact is indicated in the selected DL resource.

Another aspect to consider in order to ensure a certain QoS delay requirement for the packet transmission relays on bounding the UL access delay by means of reducing to some extent the randomness of the access. One way to do this is by making use of a polling mechanism as the one explained in [8]. Accordingly, for those users that have recently performed a message transmission, a reservation of a single resource is made with a certain periodicity. This allows users to enter the system either by following the ISMA procedure or as an answer to a periodical reservation, and thus the access delay is bounded by the polling period.

5.- Simulation results. Definition of the Admission Region.

One of the key points dealing with guaranteeing a certain QoS relays on keeping the number of admitted users in the system (i.e. those that can be involved in the scheduling algorithm) below a certain limit that guarantees a good system behaviour. This limit is related to the maximum degradation in the system performance that can be tolerated, and it can only be determined by evaluating the performance of the scheduling algorithm and the multiple access protocol for different traffic situations. This evaluation yields to the definition of the *admission region,* i.e. the maximum number of users that can be admitted in the system while keeping the QoS guarantees.

In order to illustrate this point, some simulations have been performed with the proposed scheduling algorithm and multiple access protocol when considering two traffic classes: Low Delay users, with a mean bit rate of 4 kb/s in the UL and 10 kb/s in the DL, requiring a maximum packet transmission delay of 50 ms, and Long Delay users, with a mean bit rate of 8 kb/s in the UL and 20 kb/s in the DL, with a maximum delay restriction of 300 ms. In both cases, the traffic generation pattern follows an ON/OFF model with Poisson arrivals in the ON periods. The polling period has been set to 40 ms for Low Delay users and to 290 ms for Long Delay users, according to their delay bounds. For Low Delay users, TO1=30 ms and TO2=50 ms, while for Long Delay users TO1=200 ms and TO2=300 ms. A 10 ms frame structure with 5 UL slots and 10 DL slots has been simulated in a single cell scenario, aiming to evaluate the ability of the packet transmission scheme to manage transmissions under ideal channel conditions. A total of 244 information bits are transmitted in each slot/code pair. One UL slot is reserved for the RACH channel and one DL slot is reserved for the broadcast information, so none of them are used by the proposed packet scheme. The criterion that defines the QoS has been set to a maximum of 5% of packet transmissions with a delay higher than the maximum allowed bound for each service class.

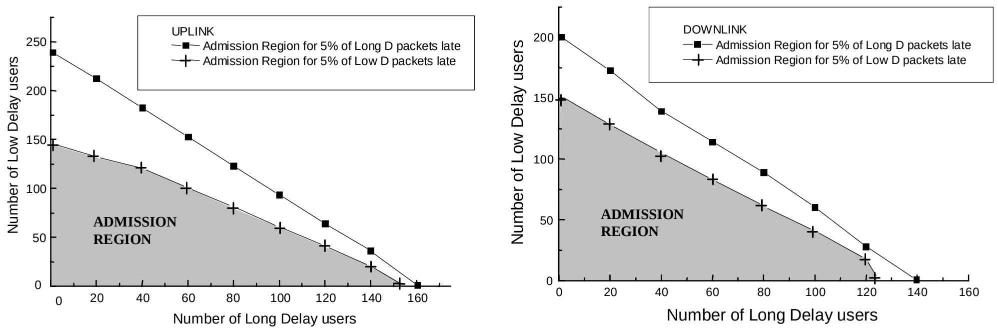

Figure 4.- Admission regions for the Uplink and the Downlink

Figure 4 shows the admission regions for the maximum number of users that can be admitted in the UL and the DL when aiming to meet the specified criterion both for Long Delay and Low Delay users. It should be observed how the higher restriction comes from the Low Delay users, which define the overall admission region as the shaded area in Figure 4. The results in terms of maximum number of users are easily translated in terms of maximum throughput in the system by using the mean bit rate per user. This yields to a maximum overall throughput of 2.89 Mb/s in the DL and 1.38 Mb/s in the UL, corresponding to a 82% and a 88% respectively of the maximum system capacity, which gives an idea of the promising behavior of the proposed scheme.

6.- Conclusions

This paper has dealt with some of the aspects that need to be regarded when aiming to guarantee a certain degree of Quality of Service in a packet transmission TDD TD-CDMA scheme. Particularly a criterion to decide the most suitable slots for every user depending on their time advance has been presented. Simulations have shown that this scheme can greatly reduce the interference due to different asymmetry patterns in adjacent cells. On the other hand, a multiple access protocol and a scheduling algorithm have been proposed and evaluated, obtaining very promising results regarding their efficiency in the use of radio resources.

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