Packet Transmission Strategies to Provide Quality of Service in a TDD-TD/CDMA System

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Abstract - **This paper presents some packet transmission mechanisms dealing with the provision of quality of service (QoS) over the radio interface in a TDD-TD/CDMA scenario such as the one considered for the UTRA TDD proposal in the UMTS system. To this extent, two different multiple access protocols are proposed for such an environment, based on the ISMA and DSA++ approaches, and they are complemented by a polling mechanism that allows a reduction in the access time. A scheduling algorithm is also considered in order to prioritise transmissions to guarantee the specific QoS requirements for the different services.**

I. INTRODUCTION

The provision of different multimedia services to mobile users while at the same time meeting some specific Quality of Service (QoS) requirements has become one of the main goals of the third generation mobile communication systems. To this extent, and taking into account the asymmetric nature of most of these services, an unpaired TDD-TD/CDMA scenario like the one considered in the UTRA TDD proposal for UMTS can provide a more efficient spectrum use for reduced mobility environments than other possibilities based on a FDD approach.

Such a TDD-TD/CDMA scenario is based on a frame structure where each time slot can either work in the uplink or in the downlink direction, while several simultaneous transmissions are allowed in each slot by making use of OVSF (Orthogonal Variable Spreading Factor) codes [1][2]. However, the limited number of these codes introduces a scarcity in the amount of available resources that needs to be handled by the definition of appropriate radio resource management strategies. This point becomes specially critical whenever the considered traffic presents a bursty nature, as it would be the case of most Internet based applications. To this end, packet transmission strategies gain added interest in front of the classical circuit switched mechanisms because of their more efficient use of the involved radio resources.

The provision of specific QoS requirements in such a packet transmission scenario introduces new challenges for the radio resource management field, as there appear several functions that need to be covered which were either not considered or just considered in a simple way under circuit switched environments. These functions are the following, as depicted in Fig. 1:

- ***Multiple Access Protocol***: As in a packet transmission environment users do not have always allocated resources in the uplink, it becomes necessary to specify the way how users can gain access into the system in order to start the transmission of a set of information packets under the control of the scheduling algorithm. The multiple access protocol is then responsible for defining the rules how users perform this access. These protocols have to cope with a certain degree of randomness that can seriously limit the ability of the system to meet the QoS requirements. Then, appropriate mechanisms need to be defined to limit this randomness while at the same time keeping a high flexibility.

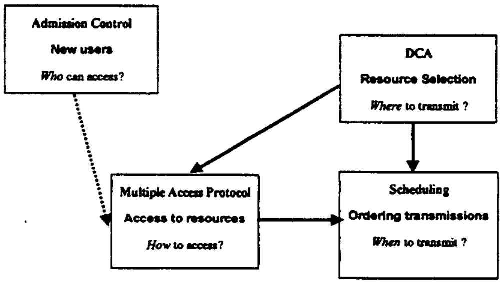

Fig. 1 Interaction between RRM functions

- ***Scheduling Algorithm***: Once users have entered the system through the multiple access protocol, the scheduling algorithm is responsible for defining when the different transmissions can be performed as well as the spreading factor they can use. This mechanism requires to define a prioritisation rule between the users as well as a smart algorithm to distribute the resources among them aiming to meet the different QoS criteria.
- ***Dynamic Channel Allocation (DCA)***: In a TDD-TD/CDMA scenario not all the resources are equal in terms of interference, as there can be time slots which suffer from a higher interference than others, depending on the slot allocation in the different neighbouring cells. To this extent, and in a situation with different frame asymmetry patterns in adjacent cells, interference between mobiles and interference between base stations can arise, which can be specially critical for certain terminals depending on their position with respect to other terminals in the system [3]. One possibility to avoid such an interference relays on having the same asymmetry patterns in adjacent cells [4], but this possibility can highly reduce the flexibility claimed for the TDD scenario to deal with different traffic asymmetries. Then, it

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can be better to try to cope with this interference by allocating slots to terminals depending on some criteria that tries to minimise such an interference. Consequently, the Dynamic Channel Allocation scheme is responsible for deciding which are the most suitable time slots for each terminal according to these criteria. Possible DCA mechanisms relay on a distance criterion and are defined for example in [5][6].

- ***Admission Control***: Once having defined the previous mechanisms, and in order to guarantee the QoS requirements, it is necessary that the number of terminals in the system is kept below a certain maximum that depends on the overall behaviour of the multiple access protocol, the scheduling algorithm and the DCA scheme. Then, the admission control is responsible of keeping this limit when dealing with new users. Note that in a packet transmission scenario, this limit does not correspond to the ***maximum number of simultaneous transmissions***, which in fact is provided by the scheduling algorithm, but to the total number of users whose QoS requirements can be guaranteed, either if they have permission to transmit in a given frame or not.

Under the considered framework, this paper aims to define suitable multiple access protocols and scheduling algorithms for a TDD-TD/CDMA packet transmission scenario. These mechanisms could afterwards be integrated with DCA schemes like the ones proposed in [5][6]. The rest of the paper is organised as follows: Section II deals with the analysis of multiple access protocols, and in particular the ISMA (Inhibit Sense Multiple Access) protocol [7][8] and the DSA++ (Dynamic Slot Assignment) [9] are considered in a TDD-TD/CDMA scenario together with a polling strategy that aims to reduce the randomness in the access. In Section III the scheduling algorithm is analysed and finally in Section IV the performance evaluation is presented. Conclusions are drawn in Section V.

II. MULTIPLE ACCESS PROTOCOLS

As a framework for the definition of the multiple access protocols, we take as a reference the 10 ms frame structure of UTRA TDD, composed by 15 time slots that can be either assigned to the uplink or to the downlink. Each slot can be simultaneously shared by up to 16 users with different OVSF codes with a spreading factor SF ranging from 1 to 16 in powers of 2. Due to the nature of these codes, a terminal transmitting with SF=1 uses the same amount of resources than 16 terminals transmitting with SF=16 [2]. As a result, the resources to manage become essentially the available time slots for the uplink and downlink and also the OVSF codes of SF=16. On the other hand, each frame should contain at least one slot in the uplink direction intended to the random access channel (RACH) and one slot in the downlink direction for the broadcast and synchronisation channels.

A. ISMA-TD/CDMA protocol

The essential behaviour of the ISMA protocol relays on indicating in the downlink the status of the uplink channel, so that terminals only try the access whenever the channel is not busy [7]. When translating this behaviour into a CDMA scenario, the base station should indicate in the downlink the status of the different code sequences, so that terminals only try access to codes that are not busy [8]. In a TDD-TD/CDMA scenario, then, the base station just needs to broadcast the status of the different pairs slot-OVSF codes with a single bit per resource (1: busy, 0: free). Then, the rules specifying the protocol are defined as follows:

1.- For each frame, in slot 0 the base station broadcasts the status of each UL and DL resources. In this slot, other system information not having to do with the protocol can also be transmitted (i.e., pagings, ...).

2.- Once a given terminal wants to transmit a set of packets in the uplink, it just randomly selects a free resource for the UL and transmits its request on it. This request contains its transmission needs (i.e., amount of information to transmit, maximum allowable delay, mobile identifier that should have been previosuly obtained after registering in the system and passing the admission control, ...) together with the selection of a free resource in the DL. This DL resource will be intended to send to mobile control information (i.e., scheduling commands, acknowledgements, timing advance control, ...). Notice that this DL selection is a difference between the FDD case, where one can imagine that each UL code can have a corresponding DL code, and the TDD case, where due to the asymmetry between UL and DL this correspondence is not possible.

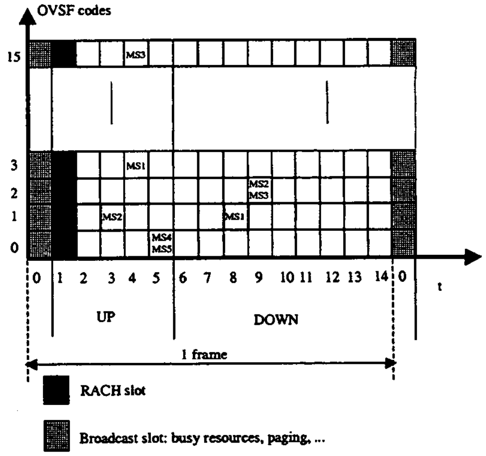

Fig. 2 ISMA-TD/CDMA protocol

3.- After sending the request, the terminal waits for confirmation in the selected DL resource. This confirmation should indicate the mobile identifier as well as the selected UL and DL resources. In the special case of two or more mobiles having selected the same DL resource, this indication can contain their identifiers and assign different DL resources for each of them in the next frame.

4.- The selected resources are broadcast as busy in the next frame and terminals should transmit according to the scheduling commands that are sent on the DL resource, which indicate the SF to use and the allocated resources for each frame depending on the amount of information to send.

5.- If a given access is not confirmed through the selected DL, the involved terminals will repeat the access procedure in successive frames.

An example of the protocol behaviour is shown in Fig. 2. Notice the frame structure, with 4 slots devoted to uplink (apart from the RACH slot, that can be used for example for circuit switching users, registration, ...) and 9 slots devoted to downlink (apart from the broadcast slot). In this example, 5 terminals are trying access. MS1 selects for the UL slot 4 and code 3, and for the DL slot 8 and code 1. This selection is correctly received and acknowledged by the base station in the selected DL resource. On the other hand, MS2 selects for the UL slot 3 and code 1, and for the DL slot 9 and code 2, while MS3 selects for the UL time slot 4 and code 15 and for the DL slot 9 and code 2, the same as MS2. As a result, in the selected DL resource there appear two confirmation messages, one for MS2 and the other for MS3, assigning to one of them a different DL resource for the rest of frames. Finally, MS4 and MS5 try the access in the same UL resource and, as a result, a collision occurs and the base station is unable to identify both requests, that are not acknowledged. Consequently, MS4 and MS5 will try the access in a later frame.

B. DSA++ protocol

Another possible multiple access protocol that fits perfectly in a TDD-TD/CDMA scenario is the DSA++ protocol proposed initially for Wireless ATM [9]. According to this protocol, the frame structure is subdivided into signalling and traffic slots. In the UL signalling slots users transmit requests and in the DL signalling slots the network transmits the resource allocation for the next frame both for UL and DL after having applied the corresponding scheduling algorithm.

When taking into account the UTRA TDD frame structure, as depicted in Fig. 3, a possibility would be to make use of the RACH slot, with up to 8 simultaneous transmissions [1], as an UL signalling slot and the broadcast slot as the DL signalling slot, containing the identifier of the mobile to whom each resource is allocated. Notice that one of the main drawbacks of this scheme is the amount of control information to be transmitted through this signalling DL slot. On the other hand, it offers a high flexibility as the resource allocation can easily changed frame by frame.

C. Polling strategy

When aiming to guarantee specific QoS requirements under a packet transmission scheme, one of the important points to deal with relays on the random nature of the multiple access protocol that users apply to gain access in the system. Due to this random nature, and depending on the ability of the protocol, mobiles could spend a lot of time in the access before they can indicate their needs to the resource manager, responsible for executing the scheduling algorithm, and thus it can be hard to guarantee the required QoS bounds for example in terms of maximum delay.

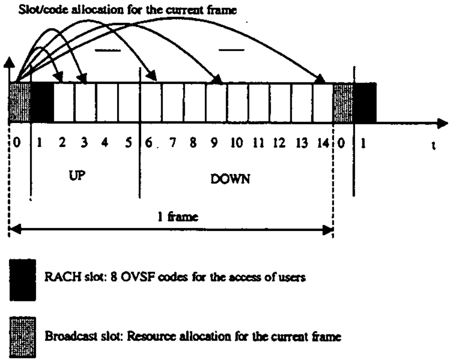

Fig. 3 DSA++ protocol in TDD-TD/CDMA

Under this framework, one possibility relays on reducing to some extent the randomness in the access aiming to bound the maximum access delay. A suitable mechanism for this purpose is to combine the considered protocol with a polling mechanism like the one that we presented in [10] for a FDD scenario. This scheme consists on performing periodical reservations of a single resource (i.e., a slot and OVSF code with SF=16, both for UL and DL) for those users that have recently transmitted a set of packets. If these users have new information to be transmitted they can make use of the reserved resource. In the case that no polling is performed to a user in the current frame, whenever it requires to transmit it should follow the rules of the considered multiple access protocol (ISMA-TD/CDMA or DSA++). Notice that, according to this procedure, the access delay is bounded by the polling period (i.e., the period according to which these reservations are performed). In order to not perform infinite reservations without answer to a terminal that has no more information to transmit, it is required to define as a parameter the maximum number of consecutive pollings without answer that will be devoted to a given user.

III. SCHEDULING ALGORITHM

Once users have gained access in the system through the multiple access protocol, the scheduling algorithm is responsible for deciding which users are allowed to transmit and its corresponding spreading factor or equivalently number of OVSF codes. To this extent, the algorithm should manage efficiently the OVSF codes by taking into account their properties.

The scheduling algorithm essentially works on a frame by frame basis by performing two generic steps, which are prioritisation and resource allocation. The first one just defines some criteria to order the different transmissions while the second one defines the specific resources to be allocated to each allowed transmission.

1) Prioritisation

When aiming to guarantee a specific maximum delay bound for the transmission in the radio interface, a possible prioritisation criterion is given by the following expression, according to the Wisper algorithm, proposed in [11], which fits suitably in a TDD-TD/CDMA structure like the considered here.

$$\phi = min\left(N_s, \frac{\left\lceil {x}/{M} \right\rceil}{TO}\right) \qquad \text{if } TO{>}{=}1 \tag{1}$$

Essentially, the priority ϕ for the request of a given user is computed as a function of the number of available time slots N_s, that depends on the frame asymmetry, on the number of required resources by the user x (i.e., the number of required pairs time slots - OVSF codes), on the timeout or maximum time remaining to guarantee the delay bound TO, measured in frames, and also on the maximum number of simultaneous resources M that a terminal can make use of. By taking into account the specific TDD environment, we can set M=16, because each terminal can transmit with SF=1, and this corresponds to transmit on all the 16 possible resources in a time slot. The value of this priority can be regarded as the number of time slots that should be assigned to the user so that if it transmitted with its maximum capacity, M, the timeout would run completely out.

Depending on the overall load and on their requirements, it may be possible for some packets to experience a higher delay than the maximum allowed one. Consequently, TO may take negative values. In this case, in order to give a higher priority to these users, equation (1) is modified as follows:

$$\phi = min\left(N_s, \lceil x/M \rceil \left(|TO| + 1\right)\right) \qquad \text{if } TO<1 \tag{2}$$

Once the priority has been calculated for a given request, the number of resources N to be allocated if the request was accepted is given by:

$$N = min\left(\lceil \phi \rceil M, x\right) \tag{3}$$

The remaining x-N required resources for that request, if any, are again prioritized as a different request. As a result, after the prioritization procedure, each request is split into other requests each with its corresponding priority ϕ and the corresponding number of resources to be allocated N.

2) Resource allocation

This procedure is executed after having ordered the requests with decreasing priority. For each request, the resource manager has to verify whether or not the number of required resources N can be allocated.

Although the same scheduling algorithm can be applied with both multiple access protocols ISMA-TD/CDMA and DSA++, there are some considerations to be made regarding how resources are allocated:

1) In DSA++ resources can be reallocated on a frame by frame bases, being this allocation signaled through a common control channel. Then, DSA++ does not introduce any restriction to the scheduling procedure.

2) In ISMA-TD/CDMA, once a terminal has gained access in the system, it has pair of resources (UL and DL) that are broadcast as *busy* in the subsequent frames. This information needs to be taken into account by the scheduling algorithm when trying to allocate resources. Then, once resources are to be allocated to a given terminal, the resource manager tries to allocate them in the time slot/ OVSF code selected by the user in its access. In the case that this allocation is not possible due to OVSF codes restrictions (for example because of another user being previously accepted in the same slot with SF=1), the scheduler will try the allocation in a different slot. The result of the scheduling procedure is always signaled through the selected DL resource, indicating the permission to transmit and the allocated resources.

Regarding the polling mechanism, each polling to be performed is considered as an additional request in the prioritization procedure with timeout TO = 1 frame and x=1 resource to be allocated.

IV. PERFORMANCE ANALYSIS

The proposed mechanisms have been evaluated in a single cell scenario with of two service classes, defined as follows:

a) Long Delay users: they allow a maximum delay of 300 ms (30 frames) in 95% of cases. The traffic pattern consists in an ON/OFF model with exponential duration for the activity and inactivity periods with a mean of 1 s. During activity periods, exponentially distributed messages are generated according to a Poisson arrival statistic with a mean offered load per user of 8 kb/s in the uplink and 20 kb/s in the downlink.

b) Low Delay users: they allow a reduced maximum delay of only 50 ms (50 frames) in the 95 % of cases. The traffic model is the same as for Long Delay users but in this case the mean offered load per user is 4 kb/s in the uplink and 10 kb/s in the downlink.

The generated messages are split into fixed length packets with the number of bits that can be transmitted by making use of a single resource (time slot and OVSF code with SF=16), this is 244 bits [1]. Zeros are added if required in order to have an integer number of packets.

The UTRA TDD frame structure is assumed with 5 time slots for the uplink (including the RACH slot) and 10 for the downlink (including the broadcast slot). It has been considered that all the 16 OVSF codes can be simultaneously used in each time slot both in UL and DL. The intracell interference is neglected (by considering the orthogonality of OVSF codes together with joint detection schemes and UL synchronisation through time advance strategies this interference can be highly reduced, leading to orthogonality factors close to 0 [12]) and thus the evaluation focuses on how the joint behaviour of the multiple access protocols and the scheduling algorithm is able to manage efficiently the different resources (time slots and OVSF codes) dealing with the random nature of the considered packet traffic. In any case, the evaluation could be extended by taking into account accurate link level simulations to model the effect of intracell interference.

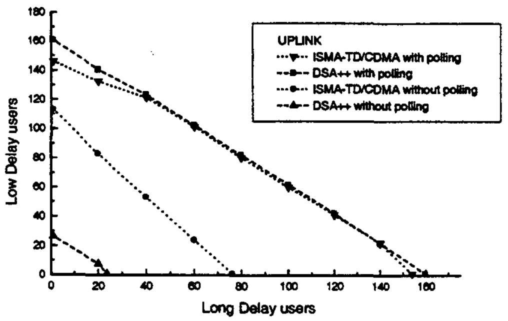

Fig. 4 Admission region for the uplink

The simulations have been performed for the two multiple access protocols with and without polling. The polling period for Long Delay users is equal to 290 ms and the polling period for Low Delay users is equal to 40 ms. Fig. 4 presents the admission region for the uplink (i.e., those combinations of numbers of users that meet the requirement of more than 95% packets with a delay lower than the maximum bound for each service class). There exists an important gain in the admission region when making use of the polling strategy, particularly in the case of DSA++, whose access delay is poorer than that of ISMA-TD/CDMA. In fact, while there exists a high difference in the performance of both protocols when no polling is applied, the difference becomes very small when considering the polling strategy. In this case, the system performance is limited by the behaviour of the scheduling algorithm, that is essentially the same in both cases, rather than by the access protocol.

In turn, Fig. 5 shows the admission region for the downlink. As the multiple access protocol only has effect on the uplink, both protocols have the same behavior. It can be observed how the polling strategy tends to decrease the downlink capacity, although the reduction is much smaller than the increase achieved in the uplink. The reason relays on the fact that each polling requires a reservation in the UL and another one in the DL, while only the UL takes benefit of the reservation in terms of a reduction in the access delay.

V. CONCLUSIONS

This paper has addressed different packet transmission strategies to guarantee quality of service restrictions in terms of delay bounds. The work has focused on the multiple access protocols ISMA-TD/CDMA and DSA++, that have been complemented with a polling mechanism that bounds the access delay. As a result, system performance is limited by the ability of the scheduling algorithm to manage transmissions and not by the random nature of the multiple access protocol. The increase in performance achieved by the polling mechanism in the uplink is at the expense of a certain reduction in the capacity of the downlink. The effect of the polling is more significant with those protocols that have a poorer access delay performance.

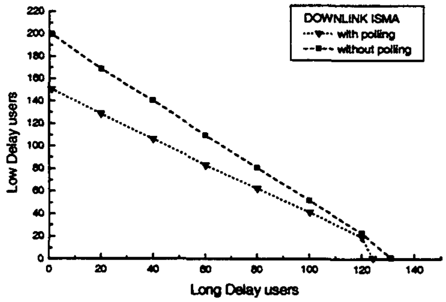

Fig. 5 Admission region for the downlink

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