An opportunistic scheduling with fairness for NRT traffic in presence of RT traffic for UMTS/TDD

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***Abstract*— In UMTS-TDD (Universal Mobile Telecommunications System - Time Division Duplex) the data rates and the service quality (bit error rate, delays) are provided by the Radio Resource Management (RRM). The RRM manages the transmission power, the spreading factor and the orthogonal code assignement. The specifications leave open the choice of the RRM strategy.**
This work proposes a scheme suitable for mixed traffic consisting of Real Time (RT) services and Non Real Time (NRT) services in downlink. For NRT services, in presence of RT services, a channel allocation power-based strategy is combined at the physical layer with an opportunistic scheduling at the Medium Access Control (MAC) layer to minimize Node-B transmitting power and schedule mixed traffic that benefits of a good radio channel and respects Quality of Service (QoS) constraints and fairness rules. The overall RRM strategy minimizes the number of RT rejected calls and the Block Error Rate (BLER) of NRT services.
***Keywords*— UMTS, TDD, scheduling, fairness**

I. Introduction

UMTS TDD systems are intended to provide a global mobility and wide range of applications with different QoS for multimedia communication. Those applications could be divided in two categories: Real Time (RT) applications, with a constant rate and hard requirements on delays (voice, video), and Non Real Time (NRT) applications, with non constant rate, but with soft requirements on delays (web browsing, file transfer). The RRM part is in charge of determining the usage of radio resources in order to satisfy the various QoS requirements. Related works [1] [2] [3] propose various Call Admission Control (CAC) strategies to allocate resources (OVSF codes to be used on time slots) but only in the case of RT (Real Time) applications. In this work, a suitable scheme for mixed application (RT and NRT) is proposed. The RT applications are handled by CAC that allocates a part of the radio resources. The other resources are allocated by the scheduler to the NRT application with respect to QoS constraints and fairness rules.

The novelty of this scheme consists, for the CAC part, in joint minimum-power channel allocation strategy to determine precisely the judicious place to allocate resources for RT and NRT application among slots. For the scheduler, it resides in exploiting two constraints: first take into account the presence of RT applications to determine the available capacity, second take into account the radio link quality in order to reduce the transmission error rate. In the presence of mixed applications, NRT application cannot be scheduled freely in the remaining radio resources because it could break the rules used for CAC. The scheduler has to be aware of the constraints on each time slot in a frame in order to determine the subset of radio resources eligible for soft constrained application. The scheduler has to take also into account the radio channel state to avoid transmitting under unfavorable conditions. This feature is called opportunistic scheduling. This opportunistic method may lead to favor only the flows of terminals that are under favorable radio conditions. To mitigate this effect, a fairness rule is introduced. This rule takes into account the relative priorities of the various flows. As a consequence a joint strategy between the physical layer and the MAC layer to allocate resources for RT and NRT applications may improve significantly the performance. This combined approach holds account of a uniform distribution of the transmitted power in downlink on different slots and adopts a scheduling based on channel state knowledge at the transmitter and complies with a fairness rule ensuring the priorities indicated by QoS.

This article is organized as follows: Part II presents the notion of resource and the Transport Channel architecture. Part III covers the adopted opportunistic scheduling over wireless channels with a statistical fairness rule. Part IV presents the simulation model based on Eurecom UMTS/TDD platform [10]. Part V presents simulations and results and part VI concludes.

II. Architecture

A. Resource

In this document a resource is an orthogonal code at a given slot that carries user data. A resource could be also called a physical channel. At a given TTI (Transmision Time Interval, 1 TTI = 10 ms), a resource could be used by only one user.

B. TRCH: Dedicated Channel and Downlink Shared Channel

A service is transported on a Transport Channel (TRCH). Transport channels are the services offered by layer 1 to the higher layers. A transport channel is defined by how and with what characteristics data is transferred over the air interface. TRCH include the Block Size, the type of error-correcting code, the rate of the error-correcting code, the CRC size (Cyclic Redundancy Check, for error detection) and the maximum puncturing rate. Two kinds of TRCH are usually used for sending data in the downlink: The Dedicated Channel (DCH) and the Downlink Shared Channel (DSCH).

DCH are TRCH that are used to carry user or control information between the Radio Access Network and a User Equipment (UE). A DCH is created at the start of the service. A DCH is mapped onto one or more physical channels. The set of the physical channels allocated to a DCH is indicated in the CCTRCH (coded composite transport channel). The physical channels of a DCH are reserved to this DCH during all the time of the service. RT applications are usually transported on DCH, because they are able to provide a continuous rate. The NRT applications are not transported on DCH. The number of physical channels of a DCH will be computed according to the resource required by the RT service.

DSCH are TRCH shared by several UE (User Equipement) carrying dedicated control or traffic data. In a frame, only one UE is allowed to use a DSCH, but the UE can change at every frame. A DSCH is configured during the Base Station initialization. The number of physical channels of a DSCH is variable. The list of the DSCH and the configuration of the DSCH are indicated to each UE at its initialization. In this document, all the DSCH have three physical channels. The UE of a TRCH is indicated in the TFCI field, in the first physical channel of the DSCH. NRT applications are transported on DSCH. If no more resource for DCH is available, RT application could be transported on DSCH. Two strategies are possible: give the highest priority to the RT applications, or allocate temporarily resource of DSCH as DCH resources, and temporarily remove the concerned DSCH from the DSCH list. The second solution is applied in this article (flexible allocation).

Figure 1 is an example of the resource repartition among DCH and DSCH. Nine slots are reserved for the transport of data on downlink. The Spreading Factor is set to 16, so 16 OVSF code are

OVSF 15	DSCH 21	DSCH 21	DSCH 21	DSCH 22	DSCH 22	DSCH 22	DSCH 23	DSCH 23	DSCH 23
OVSF 14	DSCH 18	DSCH 18	DSCH 18	DSCH 19	DSCH 19	DSCH 19	DSCH 20	DSCH 20	DSCH 20
OVSF 13	DSCH 1	DSCH 3	DSCH 5	DSCH 7	DSCH 9	DSCH 11	DSCH 13	DSCH 15	DSCH 17
OVSF 12	DSCH 1	DSCH 3	DSCH 5	DSCH 7	DSCH 9	DSCH 11	DSCH 13	DSCH 15	DSCH 17
OVSF 11	DSCH 1	DSCH 3	DSCH 5	DSCH 7	DSCH 9	DSCH 11	DSCH 13	DSCH 15	DSCH 17
OVSF 10	DSCH 0	DSCH 2	DSCH 4	DSCH 6	DSCH 8	DSCH 10	DSCH 12	DSCH 14	DSCH 16
OVSF 9	DSCH 0	DSCH 2	DSCH 4	DSCH 6	DSCH 8	DSCH 10	DSCH 12	DSCH 14	DSCH 16
OVSF 8	DSCH 0	DSCH 2	DSCH 4	DSCH 6	DSCH 8	DSCH 10	DSCH 12	DSCH 14	DSCH 16
OVSF 7	DCH	DCH	DCH	DCH	DCH	DCH	DCH	DCH	DCH
OVSF 6	DCH	DCH	DCH	DCH	DCH	DCH	DCH	DCH	DCH
OVSF 5	DCH	DCH	DCH	DCH	DCH	DCH	DCH	DCH	DCH
OVSF 4	DCH	DCH	DCH	DCH	DCH	DCH	DCH	DCH	DCH
OVSF 3	DCH	DCH	DCH	DCH	DCH	DCH	DCH	DCH	DCH
OVSF 2	DCH	DCH	DCH	DCH	DCH	DCH	DCH	DCH	DCH
OVSF 1	DCH	DCH	DCH	DCH	DCH	DCH	DCH	DCH	DCH
OVSF 0	DCH	DCH	DCH	DCH	DCH	DCH	DCH	DCH	DCH
	Slot 0	Slot 1	Slot 2	Slot 3	Slot 4	Slot 5	Slot 6	Slot 7	Slot 8

Fig. 1. Repartition of resource among DCH and DSCH

available by slot. The 8 first resources of each slot are reserved for the DCH. When a DCH is configured, at the start of an RT application, the resources allocated to it are removed from the list of the DCH free resources. The DSCH are configured at the Base Station initialization. Packets are selected from queues and transported by DSCHs according to the scheduling policy.

III. Opportunistic scheduling over wireless channel

A. Wireless channel characteristics

Wireless channels are subject to several propagation effects as reflections, diffractions and scattering which cause time varying characteristics like bursty channel errors, location dependent errors. Consequently, the scheduler needs to know the channel state in order to optimize service scheduling and to give the transmission rigth to users with favorable channel conditions. In our scheme, the scheduler infers the channel state from the measurement reports sent by mobiles, relying on the reciprocity of the channel due to TDD operations.

B. Opportunistic scheduling over wireless channel with fairness rules

Scheduling packets over wire-line is a classical problem in network analysis, contrary to wireless network like UMTS which exhibits a time varying behavior because of the radio channel. In addition, providing transmission of multiple data flows with different QoS constraints over wireless channel represents one of the most important requirements of UMTS networks, consequently we have to design scheduling of mixed services and adopt a judicious strategy to jointly allocate resources for RT and NRT flows. Because of its hard constraints, RT traffic has to be treated in priority by the RRM layer which will allocate resources depending on CAC algorithms. When the power among the slots is controlled by the CAC of a RT application, it is supposed that no NRT application is present. Furthermore, at each TTI, before the use of a DSCH by a NRT application, the CAC controls among the slots of this DSCH, if using this DSCH does not make the power exceed the threshold on the slots. This control takes into account the presence of the RT application. If the use of the DSCH makes exceed the threshold, the DSCH is not used. So the number of DSCH available at a TTI is variable. To allocate the available DSCH, we can adopt different approaches. Many works choose to maximize users rate according to the channel condition in a selfish manner [7]. Unfortunately these approaches could be prejudicial to the users facing unfavorable radio conditions and therefore would never get access to the channel. For this reason, we have to consider some fairness rules to guarantee the access for all users. [9] proposes an interesting approach which combines an opportunistic scheduling based on the channel state and one statistical fairness rule to share access to the channel. In our approach, we follow this method to schedule NRT flows and choose to balance the choice of the flow to be served between channel state and fair channel access according to UMTS QoS priorities. We also take into account the fact that NRT flows will not degrade the rule of uniform distribution of the power adopted by the RRM process for RT flows. The scheduling algorithm selects flows according to the equation developed in [9]:

$$f_{p+1} = argmin_{i \in B(p)} \frac{L_i(p) - K_i(p) + U_i(p)}{\phi_i} \qquad (1)$$

Where $f_{p+1}(p)$ is the selected flow at time p+1, $B(p)$ is the set of backlogged flows at time p, $L_i(p)$ is the Head Of Line (HOL) packet length of flow i, $K_i(p)$ is the flow associated credit updated according to the Credit Based Fair queuing approach [8], ϕ_i is the weight of flow i given by the QoS priorities and $U_i(p)$ is the cost function at time p. In the implementation of this opportunistic scheduling algorithm, the cost function U_i and channel state E_i are related by:

$$U_i = -\beta log(1 - E_i) \qquad (2)$$

Transmission to a user is delayed when he is facing unfavorable radio conditions and has a low credit. During the time when transmission is delayed, his credit is increased. When his credit is high, he is served even if the channel conditions are unfavorable.

By varying the β value of the cost function in equation (2), the importance of the channel state in the service selection algorithm will change. Note that, with β = 0, the scheduling considers only the weight of the services, and not the channel state.

The quality of the fairness could be measured by:

$$\frac{\left(\sum \frac{x_i}{\phi_i}\right)^2}{n * \sum \left(\frac{x_i}{\phi_i}\right)^2} \qquad (3)$$

Where ϕ_i is the weight of the user, x_i is the proportion of traffic given to user i, and n is the number of users. When this ratio is close to 1, the scheduling is fair.

When all the users have the same priority, the formula becomes:

$$\frac{\left(\sum x_i\right)^2}{n * \sum {x_i}^2} \qquad (4)$$

That is the Jain's fairness index [11].

IV. Simulation model

Experiments on the UMTS Eurecom platform have been performed [10]. This platform, which is compliant with the 3GPP specification, offers a Radio Access Network divided into the following layers: RLC (Radio Link Control), MAC (Medium Access Control) and Physical Layer. The RLC receives packets (SDU, Service Data Unit), from the upper layer. It segments them into PDU (Protocol Data Unit) of size 336 bits (320 bits for the data field, and 16 bits for the header). The MAC layer asks a number of PDU from the RLC according to the results of the scheduling. The physical layer is in charge of error correction and detection. The rate 1/2 convolutional code of is used. The resources are configured as in figure 1. Half the resources are reserved to the DCH, and there are 24 DSCH of 3 resources each. Those DSCH could carry one PDU (So an instantaneous rate of 32 kbit/s). There is no limit to the number of DSCH that a user can listen to in a frame. 10 NRT services are set. To evaluate the quality of the fairness rules, the RLC queues of the NRT services are considered full. The DCH is configured at the initialization of the service, after the authorization of the Access Control. A DCH takes resources with respect to the service requirements between the free resources reserved to the DCH. The rate of the RT services is 128 kbit/s. In this configuration, the DCH of a RT service uses 10 resources. The arrival law of the RT applications and the duration of the services have a Poisson law of rate respectively λ = 0.033 and μ = 0.0067. (respectively average time of 30 and 150 seconds). The following channel model is used: a 10 state Markov chain, from the state 0, channel with few error, to state 9, channel of bad quality. The channel state can increase or decrease with increment 1 with a probability of 1/3, and stay at the same state with a probability of 1/3 (It remains in state 0 with a probability of 2/3, and it goes from the state 9 to the state 8 with a probability of 2/3). The state 0 has an Eb/N0 of 3.3 dB, and the state 9 of 1.5 dB. The step between two states is of 0.2 dB. (2) becomes here:

$$U_i = -\beta log(1 - \frac{1}{S_i}) \quad (5)$$

where S_i is the number of the current state. The value of maximum power by slot is normalized to 1.

V. Simulations and Results

A. Scheduling

The 10 services are supposed to have different weights. The first 5 have a weight of 0.081, the next 3 have a weight of 0.108, and the last 2 have a weight of 0.135 (the sum of all the weights is 1). But, the scheduling also takes into account the channel state. Thus, a user with a favorable channel will be preferred with respect to a user with an unfavorable one. The objective is to increase the link reliability. By varying the value β of the cost function in equation (2), the importance of the channel state in the service selection algorithm will change. Note that, with β = 0, the scheduling considers only the weight of the services, and not the channel state. The objective is to assess the performance of the scheduling scheme in terms of BLER while maintaining an acceptable degree of fairness.

Table 1 indicates the average BLER corresponding to PDU Error Rate for a simulation period of $20s$ for NRT services with respect to β. For all β values, the BLER figures given in table 1 are in line with the recommendation of 3GPP specification [12]. The best value is obtained for β = 100 000.

β	Block Error Rate
0	7.9*10 -2
10 000	5.8*10 -2
100 000	2.1*10 -2

Tab. 1. Block Error Rate

Figures 2-4 show the behavior of the scheduler with respect to β. The solid line shows the evolution of the channel state during the simulation time. The bars indicate the number of PDUs served for a given user with respect to the TTI. In figure 2, for (β = 0), the scheduling behavior is similar to a weighted round robin: DSCH are regularly allocated to the service. In figure 3, (β = 10 000),

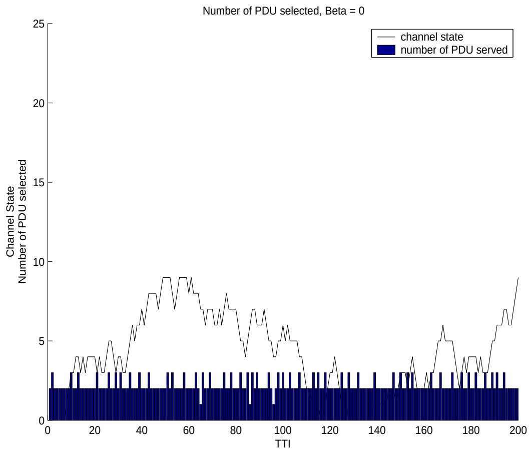

Fig. 2. β = 0

we observe that the service is irregularly served. When the channel conditions are bad, the service could be not served for a short time. However as soon as the channel conditions become little better, the service is allowed to send packets. When the channel of the user is good for a long time, the behavior becomes close to a weighted round robin. In figure 4, (β= 100 000), the scheduling strongly

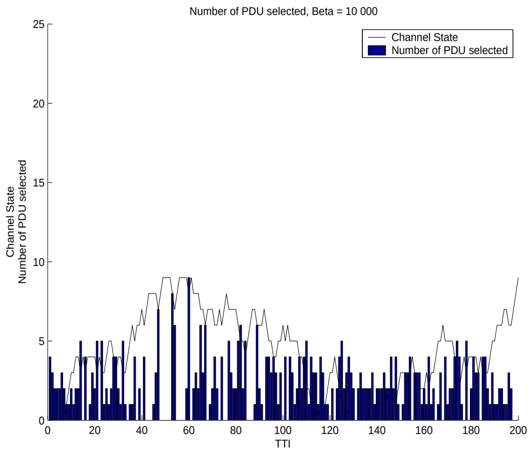

Fig. 3. β = 10 000

follows the channel state. There is an important variation in the way a service is treated over time. When the channel conditions are bad, the appliation is not served for a long time, but when the channel condition becomes better, the service receives a large amount of PDUs (close to the maximum that could be allowed in a frame).

Figure 5 shows the amount of blocks served for two users of same weights. The amount is for a range of 20 TTI. For β = 0, the fairness rule is clearly seen: the two curves stay close. For β = 10 000 and β = 100 000, the transmissions differ, because the users have different channel conditions.

Table 2 indicates the proportion of resources allocated to services. For β = 0, the proportion of resources is very close to ϕ_i: The behavior is similar to Weighted Round Robin. The level of fairness is measured using the index (3). The values of the index are 1, 0.9999 and 0.9975 for respectively β = 0, 10^4 and 10^5. The index shows the behavior of the scheduling is fair.

When the RT applications are allowed to be transported on DSCH, the number of resource available for the NRT applications decreases. But the proportion of resources allocated to the services

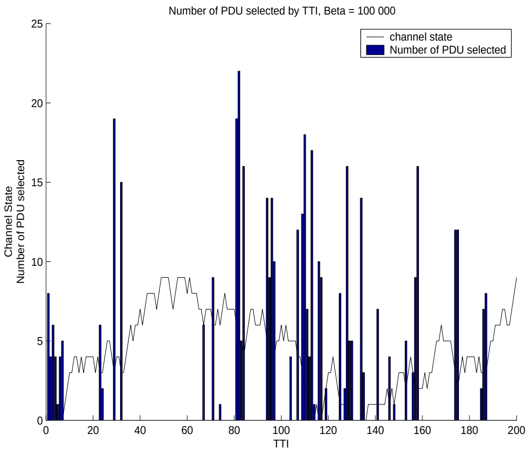

Fig. 4. β = 100 000

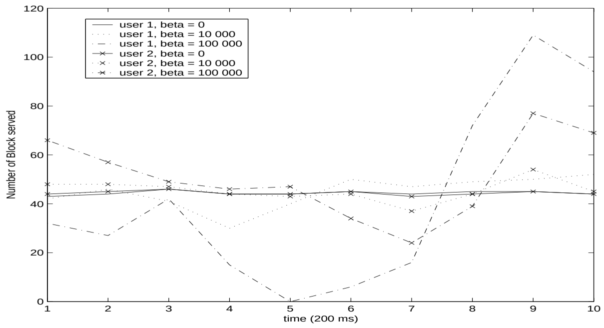

Fig. 5. fairness of the scheduling

is similar at table 2. The flexible allocation does not change the scheduling behavior.

VI. Conclusions

In this paper, we present a joint RRM channel allocation algorithm with an opportunistic scheduling. This algorithm provides guaranteed resources for RT applications and fair scheduling and priortization for NRT applications.

The NRT traffic does not disturb the RT traffic, since the opportunistic scheduling and the CAC are joint. The opportunistic scheduling has a fair behavior and reduces the BLER.

Service Id	β = 0	β = 10 000	β = 100 000
0	0.081	0.082	0.086
1	0.081	0.081	0.087
2	0.081	0.080	0.084
3	0.081	0.081	0.080
4	0.081	0.081	0.078
5	0.108	0.107	0.105
6	0.108	0.108	0.112
7	0.108	0.109	0.109
8	0.135	0.137	0.137
9	0.135	0.134	0.121

Tab. 2. Proportion of resources allocated to service

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