ADMISSION CONTROL FOR DIFFERENT UE-MAC ALGORITHMS IN UTRA-FDD

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Abstract

Radio Resource Management (RRM) entity is responsible for the utilization of the air interface resources in UTRA-FDD and, consequently, the adoption of efficient RRM algorithms is needed to guarantee QoS as well as to provide high capacity. Among the several RRM functions that will help to achieve such objectives, this paper proposes three different MAC strategies applied at UE (User Equipment) level, which are devoted to decide the suitable radio transmission parameters for each connection in the uplink direction. Also, the impact of these algorithms on admission control decisions is studied. Results reveal that for a proper admission control algorithm design, the behaviour of the different UE-MAC algorithms needs to be taken into account.

1. INTRODUCTION

Second generation wireless systems have focused their effort on providing mobile voice applications to the end user with good quality. One of the challenges for 3G wireless network operators is to develop and deploy new marketable and profitable services. For example, to satisfy the growing demand for accessing the Internet anytime, anywhere, Internet services need to be seamlessly extended to mobile terminals. This would require a QoS mechanism on 3G air interface that is optimized for supporting this kind of services. In addition, 3G wireless networks need to support a variety of services including those that are well-defined, as well as those that would emerge in the future. Therefore, the QoS framework for 3G air interface must be flexible and should also be practical, i.e. it should have low complexity of implementation and low volume of control signaling.

Radio Resource Management (RRM) entity is responsible for utilization of the air interface resources and, consequently, the adoption of efficient RRM algorithms is needed to guarantee QoS as well as to provide high capacity. The RRM functions that will help to achieve such objectives include [1]:

1. Admission control: it controls requests for setup and reconfiguration of radio bearers.
2. Congestion control: it faces situations in which the system has reached a congestion status and therefore the QoS guarantees are at risk due to the evolution of system dynamics (mobility aspects, increase in interference, etc.).
3. Mechanisms for the management of transmission parameters: are devoted to decide the suitable radio transmission parameters for each connection (i.e. Transport Format -TF-, target quality, power, etc.).
4. Code management: for the downlink it is devoted to manage the OVSF code tree used to allocate physical channel orthogonality among different users.

The radio interface of the UTRA is layered into three protocol layers: the Physical Layer (L1), the Data link Layer (L2) and the Network Layer (L3). Additionally, the layer 2 is split into two sub-layers, the Radio Link Control (RLC) [2] and the Medium Access Control (MAC) [3]. On the other hand, the RLC and layer 3 protocols are partitioned in two planes, namely the User plane and the Control plane. In the Control plane, Layer 3 is partitioned into sublayers where only the lowest sublayer, denoted as Radio Resource Control (RRC) [4], terminates in the UTRAN. Connections between RRC and MAC as well as RRC and L1 provide local inter-layer control services and allow the RRC to control the configuration of the lower layers. In the MAC layer, logical channels are mapped to transport channels. A transport channel defines the way in which traffic from logical channels is processed and sent to the physical layer. The smallest entity of traffic that can be transmitted through a transport channel is a Transport Block (TB). Once in a certain period of time, called Transmission Time Interval (TTI), a given number of TB will be delivered to the physical layer in order to introduce some coding characteristics, interleaving and rate matching to the radio frame. The set of specific attributes are referred as the Transport Format (TF) of the considered transport channel. Note that the different number of TB transmitted in a TTI indicates that different bit rates are associated to different TF. As the UE may have more than one transport channel simultaneously, the Transport Format Combination (TFC) refers to the selected combination of TF. The network assigns a list of allowed TFC to be used by the UE in what is referred as Transport Format Combination Set (TFCS).

In the above framework, this paper focuses on evaluating several decentralised UE-MAC strategies for the selection of a suitable uplink transmission rate (e.g. a suitable TFC) among the set of allowed values decided by the admission control process (e.g. the TFCS). Section 2 details three different algorithms as well as the admission control approach, which are evaluated through system level simulation in Section 3. Finally, Section 4 summarises the results obtained.

2. UPLINK RRM FUNCTIONS

RRM strategies have to be applied in a consistent way to both uplink and downlink. Focusing in the uplink, 3GPP approach can be divided in two parts:

1. Centralized component (located at RNC): Admission and congestion control are carried out.
2. Decentralized part (located at UE-MAC). This algorithm autonomously decides a TF within the allowed TFCS (TF Combination Set) for each TTI (Transmission Time Interval), and thus operates at a "short" term in order to take full advantage of the time varying system conditions.

2.1. UE-MAC strategies

In order to gain more insight into the decentralized component, three specific MAC algorithms for interactive-like services (e.g. WWW browsing) are proposed and will be evaluated in the next section:

1) Delay-oriented algorithm (TO): This strategy tries to guarantee a specific delay bound for each packet that is transmitted. Taking into account that a certain delay target should be guaranteed, a possibility relays on selecting the TFC that allows the transmission of the information in the buffer within a specified delay target. For example, let assume the delay target is TO ms, a packet of L_b bits is to be transmitted within this delay target and *TBmax* as the maximum number of Transport Blocks allowed in a TTI. In order to transmit these bits in a maximum of TO ms, the minimum number of bits to be transmitted per TTI would be:

$$L = \frac{L_b}{TO} \cdot TTI \tag{1}$$

and the number of transport blocks to be transmitted would be:

$$numTB = \min\left(TB\max, \left\lceil \frac{L}{TBsize} \right\rceil \right) \tag{2}$$

TBsize being the number of bits in a Transport Block for the considered RAB. Consequently, the TFC selected would be the minimum one allowing to transmit *numTB* transport blocks. (1) refers to the sample case that no buffering effects arise. In case that there is more than one packet is in the buffer a weighted expression is used instead of (1).

2) Service credit algorithm (SCr): When a certain mean bit rate should be guaranteed, a new possibility arises that makes use of the "service credit" (SCr) concept. The SCr of a connection accounts for the difference between the obtained bit rate (measured in TB per TTI) and the expected bit rate for this connection. Essentially, if SCr > 0 the connection has obtained a higher bit rate than expected, if SCr < 0 the connection has obtained a lower bit rate than expected. At the beginning of the connection: SCr(0)=0. In each TTI, the SCr for a connection should be updated as follows:

SCr(n) = SCr(n-1) + Guaranteed_rate / TB_size
- Transmitted_TB(n-1) (3)

where SCr(n) is the Service Credit for the n-th TTI, SCr(n-1) is the Service Credit in the previous TTI, Guaranteed_rate is the number of bits per TTI that would be transmitted at the guaranteed bit rate, TB_size is the number of bits of the Transport Block for the considered RAB and Transmitted_TB(n-1) is the number of successfully transmitted Transport Blocks in the previous TTI.

The quotient Guaranteed_rate/TB_size reflects the mean number of transport blocks that should be transmitted per TTI in order to keep the guaranteed mean bit rate. As a result, SCr(n) is a measure of the number of Transport Blocks that the connection should transmit in the current TTI=n to keep the guaranteed bit rate.

Then, assuming L_b bits in the buffer, the number of transmitted Transport Blocks in the current TTI would be:

$$numTB = min\left(\left\lceil \frac{L_b}{TBsize} \right\rceil, SCr(n), TBmax \right) \tag{4}$$

3) Maximum rate algorithm (MR): Selecting the TFC that allows the highest transmission bit rate according to the amount of bits L_b to be transmitted. Thus, the number of transport blocks to be transmitted would be:

$$numTB = \min\left(TB\max, \left\lceil \frac{L_b}{TBsize} \right\rceil \right) \tag{5}$$

2.2. Admission control

In order to point out the impact of the RRM decentralized component on the RRM centralized component, some concepts on admission control are introduced in the following. The admission control procedure is used to decide whether to accept or reject a new connection depending on the interference (or load) it adds to the existing connections. Therefore, it is responsible for deciding whether a new RAB can be set-up and which is its allowed TFCS. Commonly, admission control principles make use of the load factor, which measures the theoretical spectral efficiency of a W-CDMA cell [5]. From the implementation point of view, admission control policies can be divided into modeling-based and measurement-based policies [6]. In case the air interface load estimation is based on measurements the cell coverage is maintained. In case the air interface load is estimated in statistical terms it is the cell throughput which is maintained and cell breathing effects may arise due to the fact that intercell interference can not be directly and precisely included [5]. Similarly, the admission control algorithm can be seen as a three-phase approach [7]: a) Capacity check (receiver-oriented admission), b) Power availability (transmitter-oriented admission), c) OVSF code availability (only downlink).

For an statistical-based capacity check in the uplink case, and assuming that K users are already admitted in the system, the (K+1)th request should verify:

$$(1+f)\sum_{i=1}^{K}\frac{1}{\dfrac{SF_i}{v_i\cdot\left(\dfrac{E_b}{N_o}\right)_i\cdot r}+1}+(1+f)\frac{1}{\dfrac{SF_{K+1}}{v_{K+1}\cdot\left(\dfrac{E_b}{N_o}\right)_{K+1}\cdot r}+1}\le\eta_{\max} \tag{6}$$

$(E_b/N_o)_i$ being the target value for the i-th user, SF_i is the i-th user spreading factor, r the channel coding rate and v_i the activity factor of the traffic source. In the case of the voice service this factor is typically set to 0.67. For interactive services, like www surfing, this factor should be estimated on a service by service basis. According to (6) different admission strategies arise by balancing the following parameters: 1) The spreading factor: by setting SF_i as an estimated average value the user will adopt along its connection time the assumed load will be closer to the real situation at the expense of relying on the statistical traffic multiplexing. In turns, considering SF_i as the lowest SF in the defined RAB covers the worst case at the expense of overestimating the impact of every individual user and, consequently, reducing the capacity. 2) The activity factor of the traffic source: by setting $v_i<1$ the admission procedure can be closer to the real situation of discontinuous activity (typical in interactive-like services) at the expense of relying on the statistical traffic multiplexing. In turns, $v_i=1$ covers the worst case at the expense of overestimating the impact of every individual user and, consequently, reducing the capacity. 3) The overall load level: by setting $\eta_{max}<1$ the admission procedure allows for some protection against traffic multiplexing situations above the average (for example having more active connections than the expected average number, or having more users making use of low SF than the expected number).

Capacity and coverage are closely related in W-CDMA networks, and therefore both must be considered simultaneously. In turns, the coverage problem is directly related to the power availability, so that the power demands deriving from the system load level should be in accordance with the planned coverage and should ensure that the required transmitted power will be lower than the maximum transmitted power allowed and high enough to be able to get the required E_b/N_o target. For a given service, planned load factor and planned coverage probability, the maximum cell radii for assuring power availability along the cell can be obtained. Then, for a given cell radii, the admission process should ensure that the load factor will not overcome the planned value. The load-based admission control expressed in (6) should then be adjusted through $\eta_{\max}$ to manage the statistical traffic multiplexing as well as the dynamic transmission rates employed by the users depending on the UE-MAC TFC selection algorithm for a given intercell interference.

3. PERFORMANCE EVALUATION

The radio access bearer considered for supporting the interactive service has a maximum bit rate of 64 Kbps in the uplink and an associated 3.4 Kbps signalling radio bearer [8]. Possible transport formats are detailed in Table 1. The traffic model considers the generation of activity periods (i.e. pages for www browsing), where several information packets are generated, and a certain thinking time between them, reflecting the service interactivity. The specific parameters are: thinking time between pages: average: 30 s, average number of packet arrivals per page: 25, number of bytes per packet: average 366 bytes, maximum 6000 (truncated Pareto distribution), time between packet arrivals: average 0.125 s, exponential distribution. As the interest of the present paper in what admission control concerns is on the statistical terms in (6), the simulation model includes a cell with radii 0.5 km, perfect power control is assumed for CDMA interference characterisation and intercell interference is represented by f=0.6. From [4] and through some simple rearrangements it is found that for a cell range of 0.5 Km with 95% probability and unity-gain antenna, the load factor must be below 75% when the interactive service at maximum bit rate is considered. Physical layer performance, including the rate 1/3 turbo code effect, is taken from [9]. The mobility model and propagation models are defined in [10], taking a mobile speed of 50 km/h and a standard deviation for shadowing fading of 10 dB.

Table 1. Transport formats of the considered RAB.

TrCH type		DCH
TB sizes, bit		336 (320 payload)
TFS	TF0, bits	0×336
	TF1, bits	1×336 (16 Kb/s, SF=64)
	TF2, bits	2×336 (32 Kb/s, SF=32)
	TF3, bits	3×336 (48 Kb/s, SF=16)
	TF4, bits	4×336 (64 Kb/s, SF=16)
TTI, ms		20

3.1. UE-MAC strategies results

The delay distribution for the different strategies is presented in Figure 2, where SCrX stands for a service credit strategy with a guaranteed rate X Kb/s and TOX stands for the delay oriented strategy with a maximum delay target for each packet of X frames (10·X ms). It can be seen that the delay distribution is quite different for TO and SCr strategies: few packets experience low delay for TO (as the strategy tends to transmit the packet information in the specified delay) while for SCr some packets can be transmitted with a very low delay (for example when the traffic source has been off for some time the terminal is gaining SCr up to the arrival of a new packet).

It can be observed from Table 2 that the MR strategy provides the highest rate per page. It is worth mentioning that since no admission procedure is considered in this simulation, the system is observed under high (but not heavy) load conditions, so that it is possible to observe the behaviour of the different strategies avoiding mixing effects with admission and/or congestion control decisions. In turns, TO reveals to be quite insensitive in terms of bit rate to the specific time-out value due to the fact that this strategy takes into account the buffer occupancy to try to keep the total packet delay (including buffering and transmission time) around TO. Additionally, TO strategy is able to provide a lower delay jitter compared to SCr strategy. On the contrary, since SCr strategy does not take into account the buffer occupancy, it provides a better control of the transmission rate reflected in a low rate per page jitter.

It is found that SCr strategy tends to use high TF (low spreading factor) only after inactivity periods, where the UE is not consuming SCr and is adding SCr every frame. The TO strategy uses high TF more often, as it tends to increase the bit rate to overcome the queuing delay and to satisfy the time-out constraint. In particular, it is found that MR strategy uses TF4 in 80% of the transmissions, while SCr uses TF1 or TF2 in 75% of the transmissions. This difference in terms of how the UE-MAC algorithms behave should be taken into account in the admission control design, as it will be shown later.

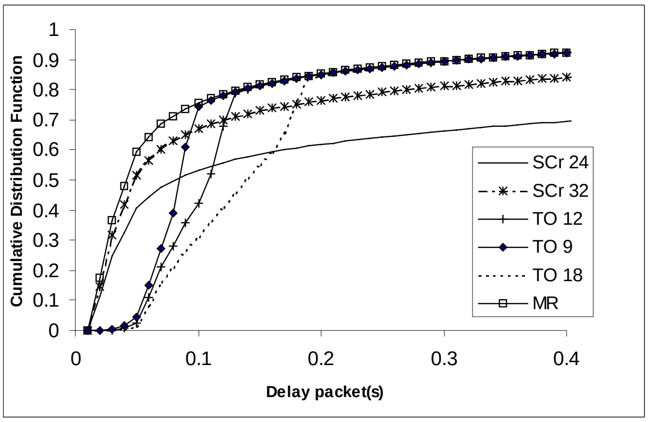

Figure 2. Cumulative delay distribution for different strategies.

Table 2. Delay and rate for different strategies.

	Average packet delay (s)	Packet delay jitter (s)	Rate per page (Kb/s)	Rate per page jitter (Kb/s)
SCr16	1.8	2.28	14.2	2.1
TO18	0.18	0.16	21	12.1
SCr24	0.54	0.95	19	5.0
TO12	0.16	0.16	22.1	11.0
MR	0.12	0.18	23.6	11.3

3.2. Influence of UE-MAC strategies on admission decisions

Table 3 shows the admission probabilities (i.e. the probability that a user request is accepted into the system) for different values of the SF (equivalent to TF) used for admission purposes in (6) and $\eta_{\max}$ for both MR and SCr strategies. The activity factor is assumed to be the average value coming from the traffic model. The criterion for considering the system under a congested situation is when (7) holds for more than 90 out of 100 consecutive frames, revealing that the CDMA capacity has been overcome.

$$(1+f)\sum_{i=1}^{n}\frac{1}{\dfrac{SF_i}{\left(\dfrac{E_b}{N_o}\right)_i}+1}>\eta_{th} \tag{7}$$

If this situation has occurred during the simulation run, it is denoted as Cong in Table 3. However, note that depending on the specific congestion detection and congestion resolution algorithms, the system could or could not continue operating under normal conditions and the interest of the present criterion is only for establishing a basis for comparison purposes.

It can be observed from Table 3 that for a proper admission procedure the characteristics of the decentralized algorithm being applied at UE-MAC layer should be taken into account. For example, if TF2 and $\eta_{\max}$ =0.75 are considered in the admission phase for MR strategy, and since the dynamic behavior of this algorithm tends to use TF4 in most cases, the system enters in congestion with less than 500 users because the admission is too soft. In turns, for SCr the TF considered for admission purposes is much better adjusted to the real dynamic value, so that admission allows for more than 550 users to enter in the system while maintaining a controlled performance: Figure 3 plots the power limitation probability as a function of the distance to the cell site (i.e. the probability that a given user requires more power than the maximum allowed for achieving the target Eb/No), revealing that even at the cell edge this probability is within the coverage probability design. Also, Figure 4 plots the average packet delay again as a function of the distance to the cell site, revealing that no performance degradations are observed as one moves far from the cell site. On the other hand, if TF4 is considered for admission purposes, congestion is avoided on the expense of reducing the admission probability because from the transmission rate point of view the worst case is considered and from the traffic multiplexing point of view $\eta_{\max}$ =0.75 is low enough to absorb traffic fluctuations without causing congestion. Nevertheless, for SCr strategy $\eta_{\max}$ =0.75 is not so suitable because the admission is too strict. It is worth noting that the value for $\eta_{\max}$ eventually allows for a softer or stricter admission as shown in the example in Table 3, where increasing the value up to $\eta_{\max}$ =0.9 improves the performance for SCr strategy with respect to $\eta_{\max}$ =0.75 and TF4 case.

Finally, Figure 5 plots the load factor distribution, showing that it tends to be quite low in the average (i.e. much lower than $\eta_{\max}$). However, due to statistical traffic multiplexing high values may appear, giving an idea about how often the network could be in a congested state.

Table 3. Admission probabilities for different cases.

Number of www users	Admission probability TF2 η_{max} =0.75		Admission probability TF4 η_{max} =0.75		Admission probability TF4 η_{max} =0.9	
	MR	SCr	MR	SCr	MR	SCr
450	1	1	0.98	0.98	1	1
500	Cong.	1	0.93	0.91	1	1
550	Cong.	1	0.84	0.82	Cong.	0.98
600	Cong.	Cong.	0.76	0.74	Cong.	0.93

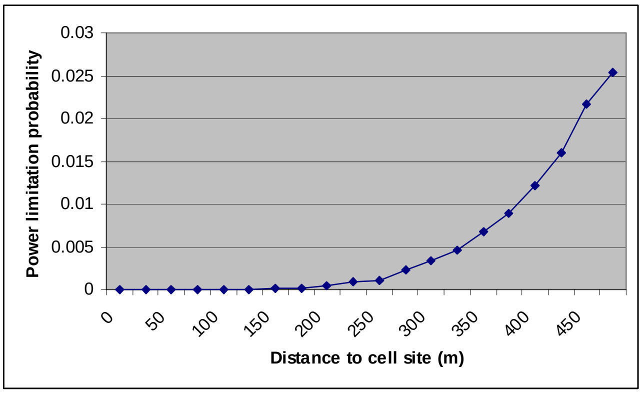

Figure 3. Power demands for 550 www users, SCr and admission based on TF2 and η_{max} =0.75

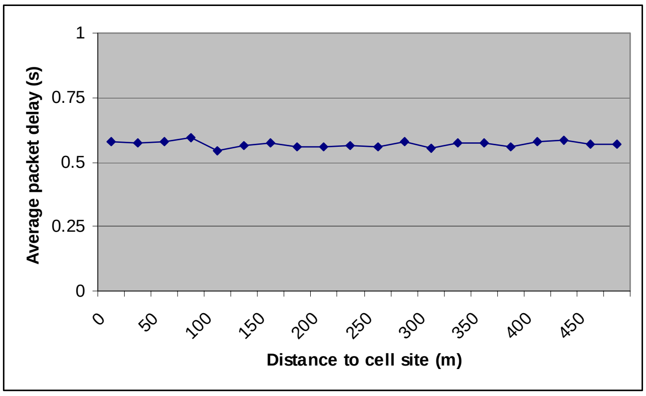

Figure 4. Packet delay for 550 www users, SCr and admission based on TF2 and η_{max} =0.75

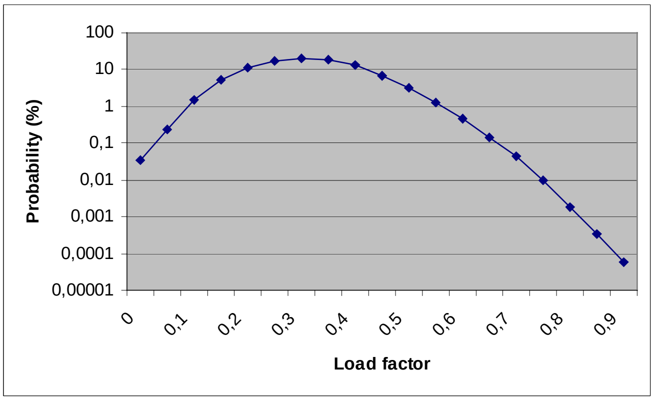

Figure 5. Load factor distribution for 550www, SCr, admission TF2 η_{max} =0.75.

4. CONCLUSIONS

RRM strategies are expected to play an important role in a mature UMTS scenario, as different algorithms may have an impact on the overall system efficiency and on the operator infrastructure cost. Among the several RRM functions, this paper has focused on the UE-MAC component by studying three specific algorithms for interactive-like services. It has been also shown that, since these UE-MAC algorithms in the uplink operate in an autonomous and decentralised way, their behaviour should be taken into account for a proper admission control algorithm design. In particular, the knowledge of the TF distribution used by the mobile terminals has an impact on the admission phase and, consequently, on the spectral efficiency achieved.

5. ACKNOWLEDGEMENTS

This work is part of the ARROWS project, partially funded by the European Commission under the IST framework and by the Spanish Research Council under grant TIC2000-2813-CE.

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