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Admission Control Guaranteeing Quality of Service in Packet Access based Pico-Cellular Networks

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Abstract: *This paper deals with three techniques which can cope with the expected high demand for multiple services in future mobile communication systems. They are: the deployment of pico-cells, dynamic channel allocation (DCA), and packet reservation multiple access. We propose an admission control scheme guaranteeing quality of service in a cellular system which uses these techniques in combination. The performance of packet reservation with admission control and its superiority to circuit reservation is illustrated by simulation results.*

Introduction

In order to satisfy the increasing demand for mobile communications, next generation mobile communication systems like UMTS (Universal Mobile Telecommunication System) or FPLMTS (Future Public Land Mobile Telecommunication System) will offer a wide range of services to users in all environments (rural, urban, indoor).

For these systems the RACE II/ATDMA project developed the air-interface. It is based on the PRMA++ protocol, an adaptation of PRMA (Packet Reservation Multiple Access, Goodman [2]). Building on a system proposition of this group, we study the combination of dynamic channel allocation and packet access protocols in the pico-cellular environment. Dynamic channel allocation is more flexible as fixed channel allocation and can cope better with temporally and spatially varying user densities. Packet reservation multiple access protocols, which allocate resources only in the active periods of the source, profit from the statistical multiplexing gain. The combination of both techniques provokes a continuous rearrangement of system resources ("channels"). Guaranteeing quality of service in this context is a challenging task. We propose two admission control algorithms, which both accomplish this task. We further show that, in an extended cellular network, one algorithm behaves better than the other.

The following section describes shortly the used system model for pico-cellular environments and defines quality of service based on speech clipping. After that we introduce the admission control schemes and then we present a performance evaluation of packet reservation protocols compared to circuit reservation. In this paper we focus on voice transmission, but the general conclusions can be applied to data transmission as well.

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The System Model

The pico-cellular environment is characterized by a complex propagation situation and a strong overlap of coverage areas (Fig. 1). A mobile station is often covered by more than one base antenna. In the following we call these base antennas "Remote Antenna Units (RAUs)". They are linked to the central unit (CU, containing the BSC and BTS) by fiber optic cables. The link is performed on the radio frequency, which makes the RAUs to small, cost-efficient units containing only an optical transceiver and an antenna.

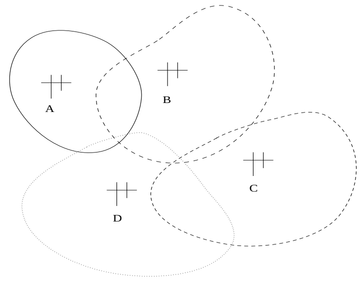


Fig. 1: Picocellular Environment

The idealized system, as presented in [7], uses a path loss propagation model, where the path loss *pl* follows an exponential law ($pl \sim l^{\alpha}$, where l is the distance and α the attenuation constant). This leads to the definition of circular coverage areas. Figure 2 presents an overlay of the coverage areas of the central RAU on the usual hexagonal cell layout. Applying a discrete power control with two power levels, the RAU can set up a communication with any mobile station within the circle with radius R_{LC} when using low power and within the circle with radius R_{HC} when transmitting with high power. The reuse of a communication channel is possible outside the interference area which is defined by the circles with the radii R_{LI} and R_{HI} for the low and high power case respectively. The minimum reuse distance is given by R_{HI}/R_{HC}. When drawing the coverage and interference circles for all other RAUs in the same manner, the service area is parceled out into homogeneously covered zones. Each zone is defined without ambiguity by the set of covering and interfering RAUs and the applied power level.

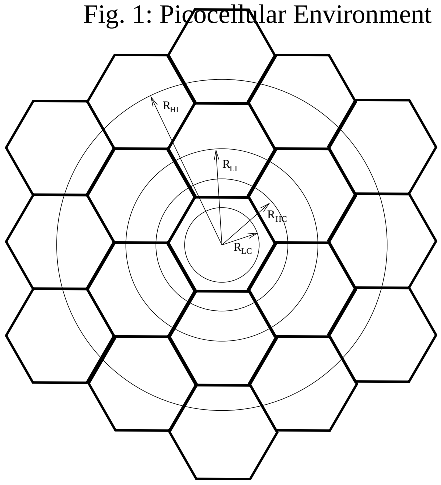


Figure 2: Propagation Model

In order to take advantage out of the overlap of coverage areas all system resources (channels) are assigned dynamically by a centralized algorithm (Dynamic Channel Allocation - DCA) located in the CU. The efficiency of our DCA algorithm and its gain compared to fixed channel allocation (FCA) was already shown in [1]. The algorithm manages the use of the resources in all cells of the service area. Its resource evaluation scheme always chooses the best possible channel in respect to a most dense packing of system resources. It does not demand pernickety frequency planning as a fixed channel allocation algorithm would do, and it copes very well with locally different user densities.

Quality of Service based on Speech Clipping

Brady [4] showed that voice is characterized by *talking* and *silent* periods. Hence, a voice coder with speech activity detection does not produce continuous data. It creates data only during the *talking* periods of a conversation. It is therefore unnecessary to assign a communication channel for the whole duration of the conversation. Packet access protocols like PRMA (packet reservation multiple access) [2] or PRMA++ [5] occupy a channel only during the talk-spurts of a call. As independent conversations create different talking and silent periods, one channel can be used by more than one user (statistical multiplexing).

At the beginning of each talk-spurt a resource must be allocated. In the case that all usable resources are occupied, the demand will be queued. Each time that another communication releases a resource (at the end of a talk-spurt), the queue will be emptied according to a first-come, first-served policy. Queuing results in the loss of speech data, called *front end clipping*. We assume perfect transmission on the radio channel so that no speech will be clipped in the middle of a talk-spurt.

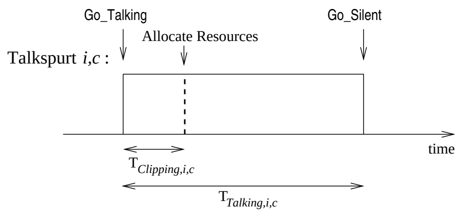


Figure 3: Front End Clipping

The definition of the service quality will be based on the amount of clipped speech.

The number of talk-spurts of a call varies. It depends on the call duration and the individual talk-spurt length. We will refer to the number of talk-spurts of the call

c as $N_{talk,c}$. Let us define the time from the beginning of the i^{th} talk-spurt of call c to the allocation of resources as $T_{Clipping,i,c}$ (front end clipping). The duration of the talk-spurt is denoted as $T_{talking,i,c}$ (Figure 3). These parameters are recorded for each call. In a real system, this can correspond to recording the number of generated and dropped packets. We introduce a clipping parameter, for which the time of all clipping and talking periods is summed up. The following equation defines the **overall clipping ratio R_{clip}**:

$$R_{clip} = \frac{\sum_{c\in\{all\ calls\}} \sum_{i=1}^{N_{Talk,c}} T_{Clipping,i,c}}{\sum_{c\in\{all\ calls\}} \sum_{i=1}^{N_{Talk,c}} T_{Talking,i,c}} \quad (1)$$

A threshold for the capacity of the system can be given by a overall clipping ratio of 1% ([3], [6]). If the overall clipping ratio exceeds this threshold, we will expect the service quality of the system to be not satisfactory.

Admission Control

In the context of circuit reservation (in the GSM system, for example) resources are assigned for the whole duration of a communication. At the call set-up a resource is either available or not. In opposite to that, a packet access oriented system occupies resources only in the active periods of a call. Hence the resource state in such a system changes continuously. In combination with the dynamic resource allocation principle, admission control is therefore an important factor. The quality of service has to be guaranteed for the whole lifetime of a call. We present two admission control strategies that both use a quality estimation of the ongoing communications in order to decide of the admission of a new call.
A simple scheme is the ***Global Admission*** (***Glob_Adm***) control.
It calculates the short-term clipping ratio $A_{global}(t_0)$ over all active calls at the time of a call arrival t_0. Let $i(c,t_0)$ be the index of the last talk-spurt of call c which finished before t_0 and C the set of active calls in the whole service area. With the former definitions we write:

$$A_{global}(t_0) = \frac{\sum_{c\in C} \sum_{i'<i(c,t_0)} T_{Clipping,i',c}}{\sum_{c\in C} \sum_{i'<i(c,t_0)} T_{Talking,i',c}} \quad (2)$$

If $A_{global}(t_0)$ exceeds 1%, the new call will not be admitted. This means, that this admission control scheme blocks new calls, when the quality of already communicating users is not sufficient.
The location where the new call arises is not taken into account.
However, in an extended network, the interference created by a communication is limited to its vicinity. The influence that the admission of a new call has on calls in distant areas is very limited. For this reason we introduce a second admission control scheme, called ***Local Admission (Local_Adm)***. Its admission control parameter $A_{local}(t_0,z)$ will be defined in accordance to equation (2). The only difference is $C'(z)$, which is the set of active calls in the **relevant area**. It depends on the zone z where the new call arises[3]:

$$A_{local}(t_0,z) = \frac{\sum_{c\in C'(z)} \sum_{i'<i(c,t_0)} T_{Clipping,i',c}}{\sum_{c\in C'(z)} \sum_{i'<i(c,t_0)} T_{Talking,i',c}} \quad (3)$$

The relevant area is defined as the union of the coverage areas of all RAUs with which the mobile station could set up a connection. Figure 4 depicts an example: The mobile station 1 is in the intersection of the coverage zones of the RAUs A, B, and C. It could therefore set up a communication with these three RAUs. The relevant area for the local admission control is the united

[3] As our system concept defines a zone as a homogeneously covered area, the position of a mobile is sufficiently exact determined by the zone in which it is located.

coverage area of the 3 RAUs (dyed in gray). Mobile 2 is only covered by the RAUs D and E. Hence, the relevant area in this case is the united coverage area of the RAUs D and E only.
As before, if $A_{local}(t_0,z)$ exceeds 1%, the new call is blocked.

Simulation Results

In the following simulations the service area is chosen to consist of the central cell and 10 tiers of surrounding cells (61 cells altogether). Only one power level is applied. The inter-arrival times of the calls, the call duration and the duration of the talking and silent periods follow a negative exponential law. We set the mean call duration to 100 seconds, the mean talk-spurt duration to 1.4 seconds and the mean duration of a silent period to 1.7 seconds. The number of system resources (or "physical channels") is set to 16.
In a previous study [1] circuit reservation was investigated for this system concept. It was found that the system capacity is limited by the down-link. Hence, we here consider the down-link only.

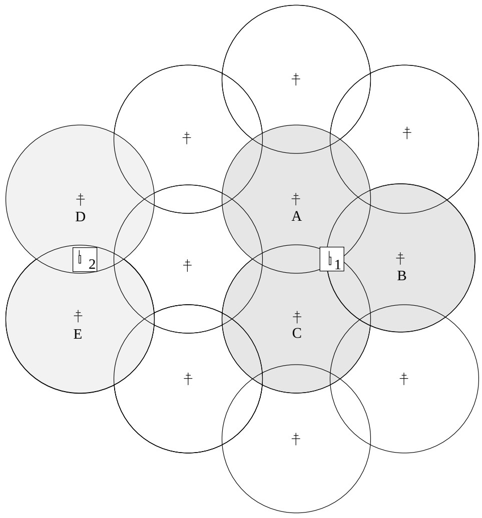
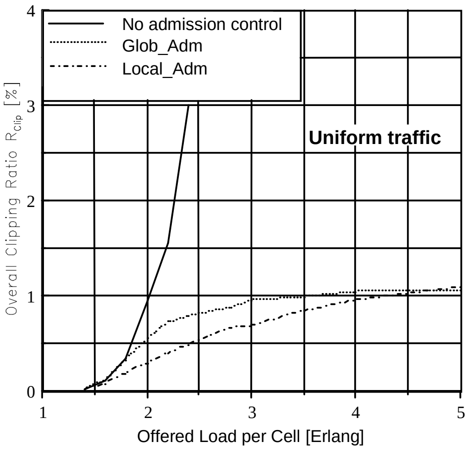
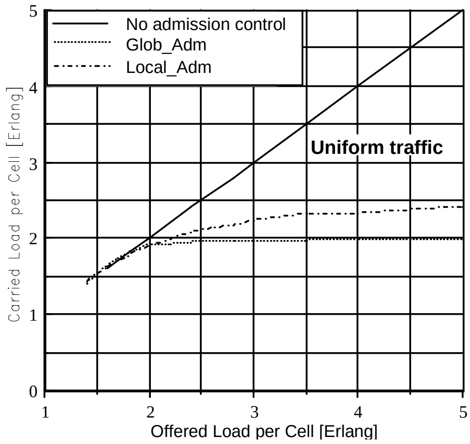


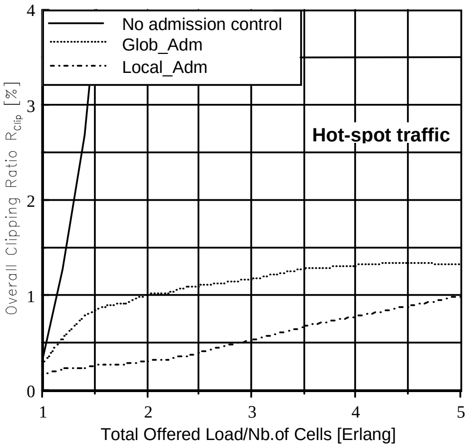
Figure 4: Relevant area

Performance with static users

We investigate the performance of our admission control schemes with static users. We apply a uniform traffic distribution and a hot-spot traffic distribution. The latter concentrates about 50% of the traffic in the central cell and parts of the first surrounding tier, the rest in the outer regions of the service area.
Figure 5 (left, top) depicts the overall clipping ratio R_{clip} for the uniform traffic distribution. Without admission control no quality is guaranteed for the accepted calls. The clipping increases unbounded with the offered load. On the other hand, we see that both admission control schemes respect 1% clipping even for high offered load. The *Local_Adm* strategy offers a better quality than the *Glob_Adm* strategy.







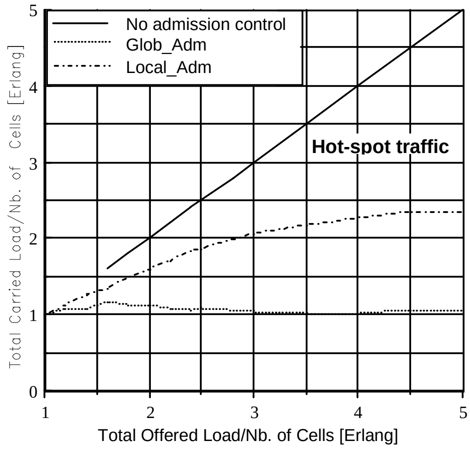


Figure 5: Clipping ratio (left) and carried load (right) for uniform traffic (top) and hot-spot traffic (bottom)

In Figure 5 (right, top) we show the carried load (accepted calls). In the case of no admission control, carried and offered load are of course identical. This curve represents the upper bound for the carried load and is given for comparison purpose only. Both admission control strategies show a limit of carried load. The *Local_Adm* strategy performs better then *Glob_Adm*. It allows to carry a higher load.

The superiority of *Local_Adm* is even more apparent for the hot-spot traffic (Figure 5, bottom). More than the double load can be carried with this strategy. Also for hot-spot traffic, the overall clipping ratio is much lower for the *Local_Adm* strategy than for the global one. The overall service quality is therefore better with the local approach. Furthermore, it is worth noting, that *Local_Adm* allows to carry the same load for both traffic distributions, while *Glob_Adm* can carry only half of the load for the hot-spot traffic distribution.

Packet Reservation compared to Circuit Reservation

In opposite to the previously presented packet reservation strategy, circuit reservation protocols, as they exist in second generation cellular systems, allocate resources for the whole call duration. For admitted calls, the quality of service is always good (front end clipping does not occur). For packet reservation an effective admission control scheme can guarantee a service quality (respecting 1% overall clipping), no matter the distribution of call arrivals. If locally and temporarily the load is high so that users experience a bad quality, new calls are blocked. We simulate a 36 cell scenario (6 tiers). The number of system resources is set to 18 physical channels (one carrier with 18 slots) for the circuit reservation case. For the packet reservation case we dedicate 2 channels for contention purpose (PRMA++ protocol), so that in this case only 16 physical channels are available. In both cases the above introduced DCA algorithm is applied. The traffic distribution is uniform, mobility is not considered.

To compare the two reservation schemes we depict the blocking probability in Figure 6. The results are given for enabled power control (*two power levels*) and disabled power control (*one power level*). Let us measure the system capacity at the 1% threshold of the blocking probability.

Of course, it is not surprising that the capacity of the system is generally higher when applying two power levels compared to one power level. Using low power whenever possible reduces co-channel interference and therefore increases the channel re-use factor.

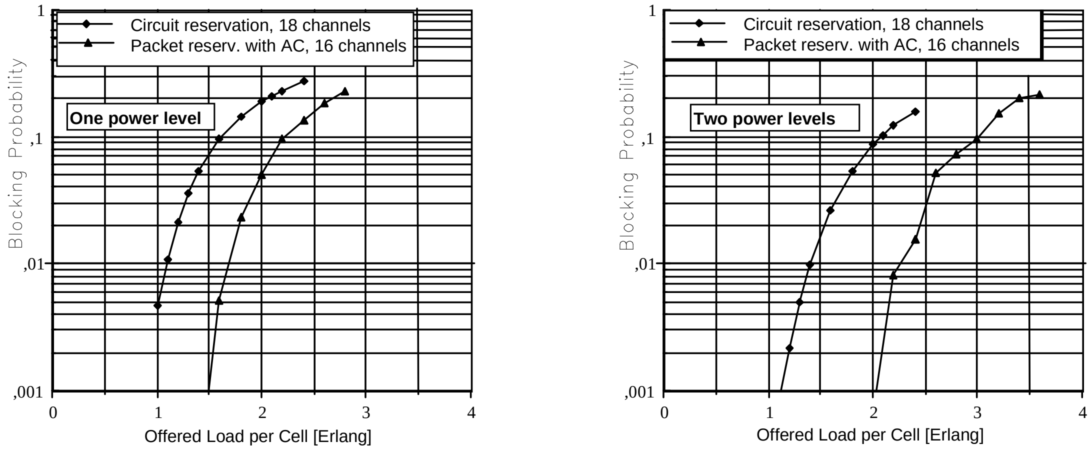


Figure 6: Comparison of Circuit and Packet Reservation

We find that the system capacity for circuit reservation is limited to 1.1 Erlang (1.4 Erlang for two power levels). With packet reservation however, a capacity of approximately 1.7 Erlang (2.25 Erlang for two power levels) is reached. This is a gain for packet reservation of 1.5 to 1.6.

Mobility

In order to test the influence of mobility on our system with packet reservation, we applied a simple mobility model for the uniform traffic distribution. The flow of mobiles entering a zone is kept as large as the flow of mobiles leaving a zone. So the traffic distribution stays uniform, when the call arrivals are uniformly distributed. The simulations show that this mobility model does not change the results already obtained with static users.

In our system the hand-over is performed implicitly by the resource allocation scheme. At the beginning of every talk-spurt the location of the mobile is determined. This position determines the set of covering RAUs at which a resource can be allocated. During a talk-spurt a mobile always keeps the allocated resource (and therefore stays with the same RAU). It is just at the beginning of the next talk-spurt when a hand-over may be executed. This is a justified strategy for the pico-cellular environment. During a talk-spurt (in the mean 1.4 seconds) a mobile station at pedestrian speed will rarely leave the coverage area of a RAU. Because of this implicit hand-over scheme, balanced mobility does not degrade the system performance.

Further studies must deal with the influence of more complex mobility models (moving hot-spots, for example).

Conclusions

Future mobile communication systems will have to offer a wide range of services and will have to support high user densities. Pico-cells, marked by an important overlap of coverage areas, will be deployed. Dynamic channel allocation strategies and packet access protocols promise a gain in capacity and good adaptation to varying traffic loads. How to guarantee quality of service in such a context is a challenging task.

For voice transmission with packet reservation multiple access (PRMA++) we defined quality of service based on speech clipping. We proposed two admission control schemes, which both guarantee quality of service for any offered load and any traffic distribution. In an extended pico-cellular network the local admission control scheme shows better performance than the global one.

The comparison of circuit reservation to packet reservation with guaranteed quality of service shows a capacity gain of 1.5 for the latter.

Even though our study does not deal with data transmission, the developed concept could be applied to it. Depending on the demanded service (fax, short messages or multimedia for example) new quality of service parameters had to be defined (e.g. packet loss, delay). The admission control schemes could then easily be adapted.

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