Admission Control Effects on the Capacity and the Quality of Service in UMTS

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***Abstract*— With the roll out of the Universal Mobile Telecommunications System in Europe the optimization of the capacity and the Quality of Service is becoming an issue. Therefore the task of the Radio Resource Management to control these two aspects has become more important. This work deals with the effects of the admission control, which handles the acceptance of new calls.**

Since the UMTS specification leaves room for admission control algorithms, in this work three different admission control strategies have been extended, newly derived, and were implemented in a UMTS System-Level Software Simulator. Using this simulator the effects of the admission control strategies are investigated in different scenarios, and the results are compared to the case disregarding Radio Resource Management.

The simulations show that all admission control strategies can decrease the number of dropped calls and overload situations. Therefore the Quality of Service is increased for the price of a smaller capacity. The best results are given by the newly derived interference based admission control.

I. INTRODUCTION

After the allocation of the Universal Mobile Telecommunications System (UMTS) licenses in Europe the network operators started with the construction of the third generation mobile networks. This new standard uses the Code Division Multiple Access (CDMA) technique which is different in the behavior compared to the GSM standard. Therefore the Radio Resource Management (RRM) which is crucial to the capacity and the Quality of Service (QoS) in the system needs to be investigated. QoS is measured here in the number of dropped calls and the number of overload situations.

One RRM strategy aspect which influences the QoS of a mobile system is the Admission Control (AC) which handles the acceptance of new calls. If the traffic load is too high, the AC should prevent the system from overload to increase the QoS. Since the UMTS specification [1] leaves room for AC algorithms in this study three different algorithm were developed and investigated.

For the investigation a dynamic UMTS System-Level Software Simulator was developed at the IND at Aachen University [2], whichwas extended in the context of this study to investigate different AC strategies.

Section II characterizes some aspects of the AC and the three algorithms we developed and implemented. In section III general aspects of the simulator as well as the results of the simulations are introduced. Section IV gives a short conclusion.

II. ADMISSION CONTROL

The purpose of the AC is to control new arriving calls in communication networks to prevent overload situations. Therefore the traffic load of the base stations (BS) is limited by the AC to keep the traffic load below the maximum capacity of the BS. The capacity of a BS can be defined as the number or the sum of the data rates of the connections. In our work the definition using the data rate will be used. If the data rate is kept constant for all MSs, the capacity definition using the number of connections is taken (see section III-B). Since the gross data rate, which is the data rate transmitted through the air interface, is considered, the capacity is defined as the total data rate r_{BS}^{max} the BS can handle. In a CDMA system like the UMTS network the capacity is not fixed, but changes with the interference level and is therefore called soft capacity [3], [4]. The task of the AC is to prevent overload situations by predicting the capacity and the behavior of the system after a new connection is established.

In case a mobile station (MS) wants to establish a new connection to a BS, different scenarios are possible:

1) The traffic load of the BS is far below the maximum load. After the MS is connected, a new equilibrium state for the system is calculated.
2) In case the traffic load of the BS is close to its capacity, the connection of the MS could lead to an instable state. Because of the new connection the interference rises and the BS cannot provide the required QoS for all users. In this case the traffic load has to be reduced and a connection has to be dropped. This can be the just new established connection. When this user is disconnected the old state is obtained and the BS has sufficient power to establish the connection again. These oscillations have to be prevented.
3) After connecting the new user and being in the overload situation, it is possible to drop a different user, meaning another connection is disabled. In this case the QoS of the network is decreased.

The task of the AC is to prevent the cases 2 and 3 to keep the system stable and increase the QoS. On the other hand some disadvantages arise with the use of any AC:

- For QoS reasons, connections are kept longer than allowed for the maximum capacity [3]. For the maximum capacity the MS with the smallest path loss to the BS should be connected. But the AC can block a new connection which has a smaller path loss compared to existing connections to prevent the system from an overload situation. Therefore the AC can decrease the maximum capacity.
- When using the AC the probability of a connection being blocked is higher than without AC. But in general a high call dropping probability is worse than a high call blocking probability and therefore this disadvantage can be neglected [5].

The UMTS specification requires AC for Premium and Assured services which assure a certain QoS [1]. Best Effort services which have no guaranteed QoS do not need AC.

Fig. 1 shows the procedure of the AC. The MS requests a new connection at the BS. If the UMTS specification requires AC, the AC compares the actual traffic load of the BS with its capacity. The new connection is then established or blocked depending on the result of the AC.

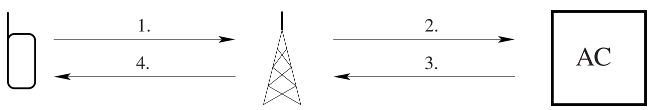

Fig. 1. 1. Request for a new connection
2. If needed, AC checks capacity
3. AC gives back results
4. Connection is either established or blocked

Since the UMTS specification leaves room for different AC strategies and different algorithms using a variety of parameters, this paper focuses on three different algorithms that are developed and investigated in the following.

A. Data rate based Admission Control

The first considered approach for the AC defines a maximum cell capacity based on the number of connections [6]. However, it is only possible to use the number of connections, if all connections have the same data rate r. Since the more general situation with different data rates shall be investigated, the model is extended using the total gross data rate to define the maximum cell capacity. That means, the decision criterion for accepting new calls consists of the data rate of the existing connections r_{BS} and the data rate of the new connection r_{Con}^{new}. The sum $r_{Con}^{new} + r_{BS}$ must stay below the maximum data rate of the BS r_{BS}^{max}:

$$r_{Con}^{new} + r_{BS} \leq r_{BS}^{max} \tag{1}$$

In this decision condition the data rate of the BS and the data rate of the new connection are known in the system. The soft capacity in CDMA systems is the reason that the maximum data rate of the cell is not fixed. It is unknown to the system so that it has to be estimated. In this work the maximum data rate was set to a fixed level, calibrated for each scenario.

This model uses only information of the focused cell for the decision. In this work a new extention is presented which includes the surrounding cells using a certain weight factor w_{BS_i}. The weight factor depends on the geographic properties of the scenario, independent of the position of the MSs in the surrounding cells since the downlink is considered. Therefore the weights are constants setting the influence of the neighboring cells.

High load of surrounding cells rises the interference in the focused cell. Therefore, MSs in these cells are weighted and treated as load. The data rate of the focused cell BS_0 and the weighted sum of the data rates of all surrounding BSs r_{BS_i} has to be less than the maximum data rate of the BS r_{BS}^{max}:

$$r_{Con}^{new} + r_{BS_0} + \sum_{i=1}^{\#BS-1} w_{BS_i} \cdot r_{BS_i} \leq r_{BS_0}^{max} \tag{2}$$

Using this decision condition the data rate based AC establishes or blocks new connections depending on the maximum data rate of the cell. Since the estimation of the maximum data rate of the BS is not straight forward, two alternative new approaches are presented in the following of this work.

B. Interference based Admission Control

Since the capacity of a CDMA system is not a fixed value but depends on the interference in the system, a straight forward approach for AC is to use the interference as the decision criterion for accepting new calls. In the downlink rising interference has to be compensated by increasing power sent by the BS which is shared between all users. This increase in power rises the carrier power and therefore improves the Carrier to Interference Ratio (CIR) which is the main criterion for the quality of the connection. In conclusion, the maximum power of the BS is the factor limiting the capacity of the cell.

In this work a new approach is derived called interference based AC which uses the power of the system as the decision criterion. The maximum power of the BS P_{BS}^{max} is the limiting factor which is fixed. The accumulated power of all connections transmitted by the BS has to be below that limit. Therefore, the decision criterion to accept a new connection consists of the sum of the transmitted power for all M existing connections P_{Con_i} plus the additional BS power in the cell when accepting the new connection P_{Con}^{new} and the maximum power of the BS:

$$P_{Con}^{new} + \sum_{i=1}^{M} P_{Con_i} \leq P_{BS}^{max} \tag{3}$$

The power for the existing connections P_{Con_i} is the power before the new connection is established. Since the new connection increases the interference level for the existing ones, their power will be risen after the new connection is established. This effect is included in the term P_{Con}^{new} which consists of two parts:

$$P_{Con}^{new} = P_{Con(self)}^{new} + P_{Con(other)}^{new} \tag{4}$$

The term $P_{Con(self)}^{new}$ represents the power the new connection needs for itself. The term $P_{Con(other)}^{new}$ is the power rise for the existing connections since the new connection increases the interference level.

Referring to the decision criterion in Eq. (3) the power of the existing connections and the maximum power of the BS are quantities which are known in the network. However, the power of the new connection with its two components needs to be estimated which will be investigated in the following separately for each component.

1) Power $P^{new}_{Con(self)}$ for the new connection itself: The MS requires a certain Target CIR level CIR_{Tar} for the new connection. The power for the new connection is therefore defined as the CIR_{Tar} multiplied by the total interference transformed to the position of the BS by the path loss L. The path loss is defined here as the ratio of the transmitted power and the received power.

$$P^{new}_{Con(self)} = I_{total} \cdot CIR_{Tar} \cdot L \qquad (5)$$

The interference for the new MS consists of the intra interference which originates from the focused cell. The focused BS, BS_0, has M_0 connections using the same scrambling factor as the new connection. In reality, the orthogonality of the different spreading codes of the same scrambling code is not perfect. The factor `Ort` gives the percentage to what extent the spreading codes are orthogonal to each other, so that they interfere with 1-`Ort`. The M_1 connections that use a different scrambling factor interfere to a full extent:

$$I_{intra} = (1 - \mathtt{Ort}) \cdot \sum_{i=1}^{M_0} \frac{P_{Con_i}}{L_{BS_0}} + \sum_{i=1}^{M_1} \frac{P_{Con_i}}{L_{BS_0}} \qquad (6)$$

The path loss L_{BS_j} with $j = 0$ is the path loss to the focused BSs; with $j \neq 0$ the other BSs with N_j connections are indicated. The second part of the total interference is the inter interference, meaning that it originates outside the focused cell. All other parts of the interference sources are modeled as a constant term named thermal interference I_{therm} so that the total interference is:

$$I_{total} = I_{intra} + I_{therm} + \sum_{j=1}^{\#BS-1} \sum_{i=1}^{N_j} \frac{P_{Con_i}}{L_{BS_j}} \qquad (7)$$

2) Power rise $P^{new}_{Con(other)}$ for the existing connections: In the following the effect of the interference created by the new connection influencing the existing connections is investigated. Here the effect on the existing connections of the same cell is considered, neglecting the effect on other cells since the greater path loss to MSs in different cells decreases their influence.

To calculate the power rise for the existing connections the CIR level needs to be the same before and after the establishment of the new connection. Thus, the interference level is predicted for a virtual MS representing all real MSs with a certain path loss. Since in a high traffic load situation the number of MS is so high, the discrete power control will be modeled in this work as one virtual MS with continuous power control:

$$CIR_{Tar} = \frac{P^{old}_{BS}}{I^{old} \cdot L} = \frac{P^{new}_{BS}}{I^{new} \cdot L} \qquad (8)$$

With P^{old}_{BS} the power of the BS before accepting the new call and P^{new}_{BS} the power after the admission. Rearranging Eq. (8) and substituting the new interference by the old one and the power for the new connection adjusted by the path loss gives the new power of the BS:

$$P^{new}_{BS} = P^{old}_{BS} \cdot (1 + \frac{P^{new}_{Con(self)}/L_{BS_0}}{I^{old}}) \qquad (9)$$

Using (9), the power increase $P^{new}_{Con(other)}$ can be calculated, to predict P^{new}_{Con} and used in the decision criterion in Eq. (3):

$$P^{new}_{Con(other)} = P^{new}_{BS} - P^{old}_{BS} = \frac{P^{new}_{Con(self)}}{L_{BS_0}} \cdot \frac{P^{old}_{BS}}{I^{old}} \qquad (10)$$

C. Power based Admission Control

A different and simpler approach based on an empirical formula for the AC which reduces the used CPU time due to the simplified calculation of the power for the new connection compared to the interference based AC uses the same decision conditions introduced as Eq. (3) and is called power based AC. The algorithm to predict the power for the new connection P^{new}_{Con} is simplified compared to the approach discussed earlier. This algorithm should show that it is possible to receive good results with a much simpler approach and to reduce the computation time of the simulator.

The prediction of the power for the new connection is based on the gross data rate of the new connection r^{new}_{Con} which is a function of the spreading factor length of the new connection $l_{SF} = r_{Chip}/r^{new}_{Con}$. The term r_{Chip} is the chip rate which is fixed for UMTS at 3.84 MChip/s. A connection with a higher data rate needs more power than a connection with a small data rate. The other parameter used in the prediction P_{BS}, is the power that the BS transmits. The more power the BS transmits the higher is the intra interference in the cell. This relationship is proportional as long as only one scrambling factor is used. If more than one scrambling factor is necessary, the orthogonality is not given and the interference level rises stronger than with only one scrambling factor.

This qualitative relationship is used to find an empirical solution for the prediction of P^{new}_{Con} which was found in this work by investigating different scenarios close to the maximum capacity of the system. With this estimation of P^{new}_{Con} the decision criterion in Eq. (3) is the working basis for the power based AC.

III. SIMULATIONS

A dynamic Simulator with moving MSs based on the UMTS specification has been implemented. This tool with a Graphical User Interface simulates a scenario with an arbitrary number of MSs and BSs. In each scenario the downlink is simulated on system level. Thus, the connections are not modeled on the bit-exact level but as signal power for themselves or interference for others. The uplink is not considered since the capacity of a CDMA-System is normally limited by the downlink [7].

The path loss model of the simulator is a standard model with a loss exponenet of 3.5 [8] and enables construction of individual 3-dimensional scenarios by positioning BSs, MSs, and different obstacles, each with individual heights. With the needed CIR and the data rate of the MSs, the power the MSs need can be determined.

CDMA systems like UMTS use scrambling and spreading codes to distinguish between different users. Each connection can be identified by its spreading and scrambling code. One scrambling code provides a certain single set of spreading codes which are orthogonal so that different users within a set belonging to one scrambling code do not interfere with each other. As the number of orthogonal codes is limited a new set of spreading codes has to be used, if the number of users is increasing. This second set of codes is orthogonal within the set but interferes with the other sets of codes. When new MSs are connected to a specific BS, the connections use the same scrambling code as long as enough spreading codes are available. When a set of spreading codes is completly used, a second set with a different scrambling code is started.

It is possible to establish the connection between the MS and the BS, if the pilot channel of the BS is received with a certain CIR. If a certain threshold is reached, the user will be connected; when the CIR goes below the threshold the connection will be dropped.

A. Data rate

In a single isolated cell the general function of the AC becomes clear. For this purpose the traffic load of the cell is increased stochastically. The BS connects the new MS as long as it is located in the supply circle, which is the area where the MS receives the pilot channel with a sufficient CIR which is set to a constant threshold. If the AC is used, the supply circle is the area where the AC accepts new MSs. When the traffic load is close to the maximum capacity of the BS, the AC algorithms realize that it is not possible to accept new connections with a high path loss and do not accept these MSs. Therefore the supply circle is reduced and overload situations do not occur.

With this procedure the next simulations are carried out. Using the interference and power based AC algorithms the traffic load of the cell is increased until a MS has to be dropped or no more MSs can be established. These results are compared using no AC until the first call is dropped. It is not useful to investigate the capacity of the data rate based AC, since the maximum capacity is set in this algorithm. These simulations are done using the different possible spreading factors for the MSs.

In Fig. 2 the total data rate of the BS is shown over the spreading factor used by the MS. The simulations are made using a pilot channel power of -20 or -23 dB to show the effects of the pilot power. The figure shows that the smaller the capacity of the BS is the higher the pilot power. The reason is an increased cell radius and therefore more MSs at a greater distance which use more power are accepted. An exception, caused by the discrete number of MSs, can be seen on the left of the diagram, where the simulations include only a few MSs since the data rate of each MS is very high.

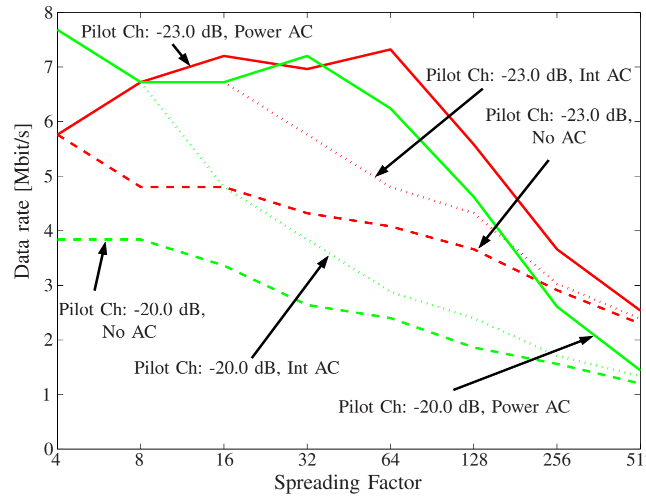

Fig. 2. Simulation in an isolated cell using different AC strategies with different pilot channel powers

Another result from the simulation is that the load is higher using AC compared to not considering AC. The reason is that the AC prevents the connection of an MS that would cause an overload situation. Therefore it is possible to accept connections with a smaller path loss using less resources. This result does not show that the AC increases the capacity of the cell, but that the traffic load of the BS is used up to its capacity without overloading the BS. The highest load can be accepted with the power based AC since the estimation is the most conservative allowing therefore to accept only the call with the lowest path lost.

B. Dynamic Behavior

To investigate the behavior of the AC in realistic scenarios a more complex scenario with 8 BSs is considered. The MSs with a spreading factor length of 64 are not fixed but move with velocities between 5 and 10 m/s to simulate a dynamic behavior of the system. The pilot channel power was selected to -20 dB to give a good coverage of the whole scenario when the traffic load is moderate. The different AC algorithms are rated using the following parameters:

1) **Not connected MSs (%)**: This is the percentage of MSs that are not connected and is therefore a measure for the capacity of the system.
2) **Number of dropped calls** per time duration: A dropped call is defined as an MS that has a connection and looses it not by its own decision.
3) **Overload Situations** of all BSs per time duration: An overload situation is defined when a BS reaches its maximum power. This parameter measures the QoS of the system together with the dropped calls.

Fig. 3 shows the not connected MSs over the number of MSs in the scenario. It is obvious that the number of not connected MSs increases with the total traffic load. Interesting to see is that using AC the capacity of the system is decreased compared to the reference scenario with no AC. This is the price to pay for a better QoS in the system. The interference based AC gives the best results concerning the capacity.

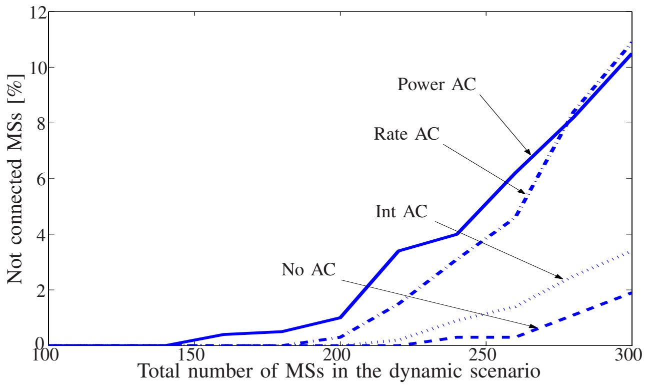

Fig. 3. Not connected MSs with different and no AC

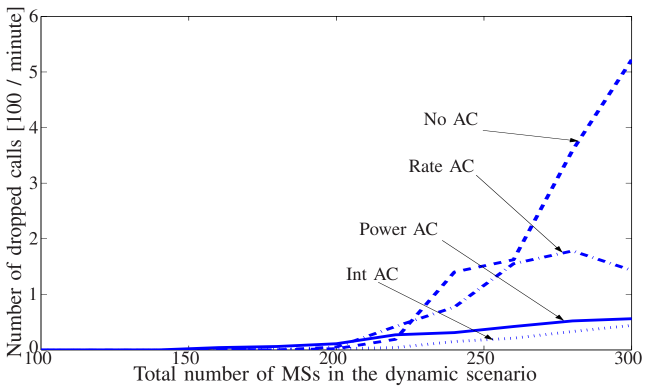

Fig. 4. Number of dropped calls with different and no AC

In Fig. 4 the number of dropped calls is shown. The QoS is increasing in all load scenarios for every considered AC algorithm. The interference based AC again gives the best results followed by the power based AC. In the case without AC the number of dropped calls rises rapidly if the traffic load is high. The AC can keep the number of dropped calls at a certain level with only a small increase as the traffic load rises. Furthermore, the level of dropped calls can be reduced by calibrating the AC to the specific scenario and by using a safety margin. This margin can increase the QoS further for a higher price in capacity. Therefore the simulations here were done without a margin.

Similar results are given investigating the other QoS parameter which counts the number of overload situations shown in Fig. 5. Without AC the number of overload situations increases rapidly with the traffic load. All ACs increase the QoS with the best results using the interference and power based AC.

These simulations show the behavior of the AC. The QoS rises to a certain degree depending on the algorithm for the price of a smaller capacity. The best result is achieved using the interference based AC which increases the QoS to the highest level and reduces the capacity only to a small extent. The power based AC using a much simpler algorithm increases the QoS to nearly the same level but for a higher price in terms of capacity. This shows that it is possible to achieve good results using a simple algorithm. The data rate based AC gives the worst results. Since the results for this algorithm are not as good as the other two discussed, a better prediction of

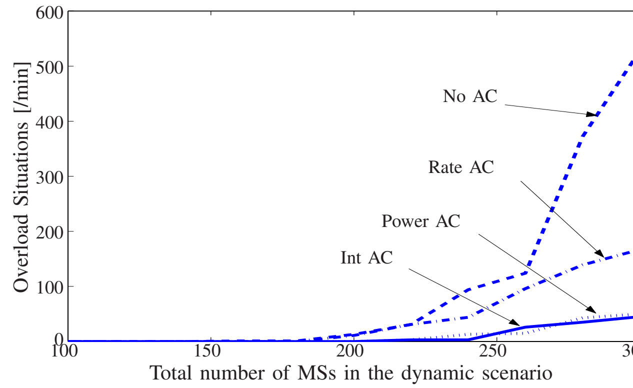

Fig. 5. Number of overload situations with different and no AC

the maximum data rate and a better calibration to the scenarios is needed. This leaves room for further research by adapting the parameters to the scenario.

IV. CONCLUSIONS

This work investigates the impact of three different AC algorithms on the capacity and the QoS in the UMTS network. This is done by comparing the AC strategies to a reference scenario without RRM using a dynamic UMTS-Software simulator.

For all ACs the QoS rises for the price of a lower capacity. The best results are achieved by the interference based AC which analyzes the interference created by a new connection. The algorithm estimates the power increase for the BS and establishes the new connection only if the BS is able to handle the traffic load. The power based AC which is based on the same approach but using a faster and simpler implementation generates nearly the same results for the QoS improvement. However, the capacity is decreased much more compared to the first algorithm. The data rate based AC predicts a maximum data rate which the BS can handle. This maximum data rate is used as a decision criterion for the new connections.

This work shows that a system using AC strategies can improve the QoS. On the other hand a tradeoff of a decreased capacity needs to be accepted. Different strategies and their calibration allow an individual selection of the tradeoff.

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