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UPLINK POWER BASED ADMISSION CONTROL IN MULTI-CELL WCDMA NETWORKS WITH HETEROGENEOUS TRAFFIC

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Abstract—Wideband code division multiple access (WCDMA) is an interference-limited system. When the system operates at nearly full capacity, admitting another user may affect the stability of the system. Therefore, proper Call Admission Control (CAC) is crucial and should balance between Quality of Service (QoS) requirements for the new user and also for the existing users and at the same time keep the accepted traffic as high as possible. In this paper, we investigate this tradeoff in the uplink direction using power-based Multi-Cell Admission Control (MC-AC) algorithm. Multimedia services are considered with different QoS requirements. Different traffic scenarios are considered. Simulation results reveal that MC-AC algorithms have many advantages over single cell admission control in terms of overall stability of the system and total system throughput.

1. INTRODUCTION

WCDMA technology has been established as the main air interface for Third Generation (3G) mobile systems. WCDMA is an interference-limited system where each signal transmitted in the air interface is presented as a wideband noise to the desired signal. Admitting too many users results in a situation where the mutual interference between the connections degrades the QoS for the new user as well for the ongoing connections. Therefore, admission control play a very important role in providing the user with the requested QoS as well as making an efficient use of the available capacity and preventing the system from an outage situation due to overloading.

An ideal CAC mechanism should accept a call if and only if the power control algorithm is able to reach a new equilibrium with a guaranteed good quality of all connections. Interactive call admission scheme is very close to ideal CAC because it allows the new connection to transmit for a trial period during which it takes measurements to determine whether the connection can be tolerated [1, 2]. Unfortunately, these schemes are not practical due to long time consumed to take measurements and decision. In the uplink, received power at Node B is considered the best parameter that reflects the current load in the network. In [3], a simple received power-based admission control was proposed. The measured interference includes both intra-cell and inter-cell interference and the measured values are compared with a threshold. The new attempt is only accepted if the threshold is not exceeded. Acceptance threshold must be carefully tuned to limit the dropping probability. A CAC algorithm using multiple power-based thresholds for multiple services was proposed in [4]. In [5, 6], a predictive received power based CAC has been proposed to reduce the safety margin of the admission threshold by estimating the additional interface due to the new call. In [5], an uplink admission control strategy based on the received wideband interference is introduced. The target of the uplink admission control algorithm is to prevent the overload of the WCDMA system and to guarantee the quality of the existing connections and the planned coverage area of the system. Before a new user is admitted to the system, the admission control algorithm estimates the increase in the total interference level due to a new user. In [6], multi-cell power increase estimation was proposed. This scheme tries to improve the performance of the system by estimating the power increase due to the new user in the serving cell and also in the neighboring cells. In [7, 8] both analytical and simulation models are presented to evaluate the MC-AC algorithm with different traffic scenarios when elastic services (services that allowed to be degraded) are considered. Apart from their bit rate and QoS requirements, service classes are characterized by their slow down factor which is a measure of how elastic the sessions of that class are. They concluded that as the sessions become more elastic, the blocking probability decreases and total system throughput increases at the expense of slight increase in dropping probability.

In this paper, we propose a model to investigate the received power based MC-AC when multimedia traffic is considered with different QoS requirements. The trade off between class-wise blocking and dropping probability is studied. Fast power control is used with admission control after a new user is admitted to bring the system to a new equilibrium state in which every user try to reach its target signal to interference ratio. The rest of the paper is organized as follows: Section 2 introduces the system model and the theoretical assessments that are required to build the simulation environment. The concepts of load factor and noise rise and the relation between them that represents the basis for the admission control decision is described in Section 3. Simulation model is described in Section 4. Simulation results and discussions are presented in Section 5. Finally, concluding remarks are discussed in Section 6.

2. SYSTEM MODEL

Consider an uplink situation in a WCDMA cellular radio system with B base stations and K service classes. Let M_k the number of active mobile stations of class k in the system. The transmitted power vector for the ongoing users of class k is defined as:

$$\overline{P}_{tx} = [P_{tx,1} \quad P_{tx,2} \quad \ldots \quad P_{tx,M}] \tag{1}$$

A signal propagating through any medium will be attenuated. In our model the signal attenuation is captured by the path gain which is the ratio between the power of the received signal and the power of the transmitted signal. It should be noted that the path gain is different from the attenuation. In fact, path gain is the inverse of the attenuation and is less than unity.

The path gain matrix can be constructed as:

$$\overline{H} = \begin{bmatrix} h_{1,1} & h_{1,2} & \cdots & h_{1,B} \\ \vdots & \vdots & \ddots & \vdots \\ \vdots & \vdots & \ddots & \vdots \\ h_{M,1} & h_{M,2} & \ldots & h_{M,B} \end{bmatrix} \tag{2}$$

where $h_{i,j}$ is the uplink path gain experienced between user i and cell j, M is the number of active mobiles in the system. In practical WDMA systems, the path gain parameters can be obtained from the pilot reports that are sent from the UE to the nearest cells and measured at the BS. These reports provide information about the downlink path gain. However, since uplink and downlink path gains only differ because of fast fading, uplink path gain can be obtained.

The total received power at the base station j in any moment can be calculated using matrix notations:

$$\overline{P}_{tot,j} = \overline{P}_{tx}.\overline{H} + P_N \tag{3}$$

where P_N is the background noise power received at the base station. Furthermore, the total received power can be represented as:

$$P_{tot,j} = P_N + P_{own,j} + P_{oth,j} \tag{4}$$

where $P_{own,j}$, $P_{oth,j}$ represent the received power from the mobile stations in the home cell and neighboring cells, respectively. Let us define $p^c_{j,i}$ as the coupling factor between the user i that belong to cell j and the cell c, and it is given by the ratio of the path gain between the user i and the neighbor cell (c) to the path gain to its home cell (j).

$$p^c_{j,i} = \frac{h_{i,c}}{h_{i,j}} \tag{5}$$

From the above definitions, it follows that:

$$P_{own,c} = \sum_{k=1}^{K} \sum_{i=1}^{M_{k,c}} P_{tx,k,i}.h_{i,c} \tag{6}$$

$$P_{oth,c} = \sum\nolimits_{j\neq c} \sum_{k=1}^{K} \sum_{i=1}^{M_{k,j}} P_{tx,k,i} h_{i,j}.p^c_{j,i} \tag{7}$$

Let us assume that the received power from the mobile stations that belong to the same class are equal and denoted P_k. This assumption comes from the fact that closed loop power control is more faster than admission control decision so perfect power control could be assumed. Therefore Equations (6) can be rewritten as follows:

$$P_{own,c} = \sum_{k=1}^{K} M_{k,c}.P_k \tag{8}$$

Each service class is characterized by a required bit rate. When a class k is transmitting at rate R_k, the required target ratio of the received power from the mobile terminal to the total interference is defined as:

$$\gamma_k = \frac{(E_b/N_0)_k}{W/R_k} \tag{9}$$

where $(E_b/N_0)_k$ is the energy per user bit divided by the noise spectral density for class k that is required to meet the QoS requirements in terms of bit error rate taken from the link level measurements and W is the chip rate.

Our key finding is to find the required received power of class k at the base station in order to achieve the predefined target and to express this power as a load increment in the system. The power received at the base station from a user of class k, $P_{rx,k,c}$, has to fulfill:

$$\frac{P_{rx,k,c}}{P_{tot,c} - P_{rx,k,c}} = \gamma_k \tag{10}$$

As the aim of power control in the uplink is to keep the transmitted power of the mobile station at a level that equality in Equation (10) is achieved, the initial transmitted power of the MS is calculated as follows:

From Equations (9) and (10) the required received power of a mobile station of class k at cell c is given by:

$$P_{rx,k,c} = \frac{(P_{oth,c} + P_N).(E_b/N_0)_k}{(W/R_k) - (M_{k,c} - 1)(E_b/N_0)_k} \tag{11}$$

Note that all the parameters in Equation (11) are known: $P_{oth,c}$ can be measured at the base station, $M_{k,c}$ is the number of active MSs of class k including the new one, and hence, the required initial transmitted power for the new arrival i of class k is estimated as:

$$P_{tx,k,c,i} = \frac{P_{rx,k,c,i}}{h_{i,c}} \tag{12}$$

Closed loop power control is executed every 10 ms, so that sufficient iterations are taken after every admission to reach a new equilibrium [9].

3. POWER-BASED ADMISSION CONTROL

3.1. Load Factor and Noise Rise

The admission control algorithm estimates the increase in the total received power due to a new user and decides to accept or reject this user according to the current system state. Load increment due to a new arriving user can be estimated as follows:

Solving for $P_{rx,k,c}$ in Equation (10) gives:

$$P_{rx,k,c} = \frac{P_{tot,c} \cdot \gamma_k}{1 + \gamma_k}$$

Define $P_{rx,k,c} = \Delta\eta_k.P_{tot,c}$ as in [10];

$$\Delta\eta_k = \frac{P_{rx,k,c}}{P_{tot,c}} = \frac{\gamma_k}{1 + \gamma_k} \tag{13}$$

Note that $\Delta\eta_k$ can be interpreted as the fraction of the system load that is generated by a user of class k. Another way of expressing the total received power is to describe it as a rise over thermal noise. It is defined as the ratio between the total received power at the base station and thermal noise:

$$\Lambda_c = \frac{P_{tot,c}}{P_N} = \frac{P_{own,c} + P_{oth,c} + P_N}{P_N} \tag{14}$$

The last equation forms the basis for the admission control decision. The new arrival is admitted if Λ_c remains under a predefined threshold which is determined from the link budget during network dimensioning.

From Equation (13), the total load factor in cell c is defined as:

$$\eta_c = \frac{P_{own,c} + P_{oth,c}}{P_{own,c} + P_{oth,c} + P_N} \tag{15}$$

From Equations (14) and (15) the relation between load factor and noise rise is defined as:

$$\Lambda_c = \frac{1}{1 - \eta_c} \tag{16}$$

Noise rise is the best indicator of the load level at the base station because it has a direct relation with the total power received at the BS (Equation (14)), so it is usually taken as an admission decision parameter.

3.2. Admission Control Criteria

From the previous section we know that Equation (14) represents the basis for the admission control decision. A new user is admitted if the following condition is achieved:

$$\Lambda_{own} < \Lambda_{th} \tag{17}$$

where, Λ_{own} is the noise rise at the own cell after the new user has been admitted and $\Lambda_{own,th}$ is the noise rise threshold. Since it is impossible to exactly predict the noise rise increase before admitting the new user [6], then Equation (17) can be modified to:

$$\Lambda_{own}^{est} < \Lambda_{th} - \Lambda_{hr} = \Lambda_{t\arg et} \tag{18}$$

where, Λ_{own}^{est} is the estimation of Λ_{own}, Λ_{hr} is a head room parameter set as a safety margin to compensate for the estimation errors.

Equation (18) can be extended to multi-cell admission control as follows:

$$\Lambda_j^{est} + \Lambda_{hr} < \Lambda_{th} \quad \forall j | j = 1, 2, \ldots, C \tag{19}$$

where, Λ_j^{est} is the estimated noise rise for cell j and C is the total number of cells. The estimated noise rise for cell c is given by:

$$\Lambda_c^{est} = \frac{P_{tot,c} + \Delta P_{k,c}^{est}}{P_N} \tag{20}$$

$\Delta P_{k,c}^{est}$ is the single cell power increase estimation given in [5] as:

$$\Delta P_{k,c}^{est} = \frac{P_{tot,c}.\Delta\eta_k^{est}}{1 - \eta_c - \Delta\eta_k^{est}} \tag{21}$$

$\Delta\eta_k^{est}$ is given by:

$$\Delta\eta_k^{est} = w.\Delta\eta_{k,o}^{est} + (1 - w).\Delta\eta_{k,u}^{est} \tag{22}$$

where, $\Delta\eta_{k,o}^{est}$ is an overestimation for the load increment, $\Delta\eta_{k,u}^{est}$ underestimate the increment of load and w is a weight parameter. From Equation (13):

$$\Delta\eta_{k,o}^{est} = \frac{1}{1 + \dfrac{W/R_k}{(E_b/N_o)_k}} \tag{23}$$

$$\Delta\eta_{k,u}^{est} = \Delta\eta_{k,o}^{est}.\frac{P_N}{P_N + P_{oth,k}} \tag{24}$$

For multi-cell power increase in a neighboring cell j due to admitting a user i in the cell c is given by [6]:

$$\Delta P_{k,j}^{est} = \Delta P_{k,c}^{est} \cdot \frac{h_{i,j}}{h_{i,c}} \tag{25}$$

4. SIMULATION MODEL

To evaluate the performance of the call admission control schemes considered in the previous section, we have built a simulation environment in MATLAB. The main concern of the simulator is to compare the performance of the single-cell admission control with multi-cell admission control at different traffic distribution and different service classes.

4.1. Network Topology

The topology of the system under consideration consists of seven cells each with inner radius of 850 meter. Each cell is served by one base station, located in its centre and irradiate with omni-directional antennas with unity gain. Multi-antenna can be used to enhance the system capacity [14], but it's out of scope of our research. In order to avoid the border effects, a compensation for the other cell interference is added in the simulation to the cells in the first tier both in homogenous and heterogeneous traffic types as will be described later. As the upper tiers contribute by not more than 3% of the total interference, seven cells are considered in the simulation.

4.2. Propagation Model

The propagation model is characterized by an extensive set of channel qualities that reflects the propagation model, mainly expressed as attenuation. The radio attenuation is composed of two factors, the path loss and the lognormal shadowing. We have adopted the propagation model described in [9, 11] as follow:

$$attenuation = [128.1 + 37.6 \log(r)] + \zeta \,[\mathrm{dB}] \tag{26}$$

where, r (in Km) is the distance between the mobile station and the base station. ξ (in dB) has a normal distribution with zero mean and represents the effect of shadow fading. Furthermore, we assume the shadowing standard deviation σ equal to 8 dB.

A user arriving in the system will choose its serving cell so that the radio propagation attenuation between the UE and the BS of its serving cell is minimized. The model is static, i.e., the UEs do not move. User mobility was disabled in order to better verify the impact of admitted calls on the system, by decreasing the load variation due to users moving from cell to cell. Multi-path fading is not modeled; it is assumed to be averaged out at the receiver input. As described in Equation (5), the path gain is fundamental because it is the basis to calculate the coupling factor. Recall that it is the inverse of the attenuation defined in Equation (26). The effect of antenna design on the path loss was discussed in [16] and an analytical model for outage performance enhancement was discussed in [17].

4.3. Power Control Model

The system under consideration is interference and power limited in the uplink i.e., each mobile station has maximum transmission power. The transmitted power is adjusted at each iteration to maintain the target signal to interference ratio $SIR_{k,tgt}$ for class k. The new power control level is executed every 10 ms and the new power level is evaluated as [11]:

$$P_{tx,k,new} = P_{tx,k,old} \cdot \frac{SIR_{k,tgt}}{SIR_{k,cur}} \tag{27}$$

where, $SIR_{k,cur}$ is the current SIR experienced by the mobile station of class k. If the power control requires a power level higher than the maximum value, the maximum value is adopted. After each power control iteration, the actual SIR values experienced by each user are evaluated. If the SIR is lower than the required $SIR_{k,req}$ for class k, the call is considered in an outage situation. The call is dropped if three consecutive frames suffer from outage. In our simulation, the target value is taken to be greater than the required value by 1 dB to compensate for power control error [11, 12]. A close procedure can be also applied to optical CDMA networks [15].

4.4. Traffic Model

In WCDMA system, there can be a large number of calls with different service classes. There are real time services and non-real time services in the system. When the system has remaining capacity, non-real time services can be served but when a real-time service enter the system, non-real time services may be delayed to create enough capacity for the real-time capacity. Thus, non-real time services are ignored in the proposed CAC scheme.

We assume three real time service classes: high data rate, low data rate and voice service. Each service class needs data rate of 128 Kbps, 64 Kbps, and 12.4 Kbps [13]. The E_b/N_0 values of desired Bit Error Rate (BER) of various services are obtained from [10], see Table 1.

The initial call arrival process to a cell c is modeled as independent Poison process with mean arrival rate λ_c. The call duration is modeled as an exponentially distributed random variable. Two types of traffic distribution are considered in the simulation:

- **Homogeneous case**: in which the users are born with equal probability in any of the seven cells.
- **Heterogeneous hot around case**: in which the load in the central cell is 50% of the load in any of the surrounding cells.

The performance measures of the system that used in the simulation include the following:

Blocking probability: probability of the new call being blocked.

Dropping probability: probability that an ongoing connection cannot maintain its SIR and eventually dropped.

Table 1. Traffic classes.

Service	**Average bit rate (Kbps)**	**Required E_b/N_0(dB)**	**Outage SIR Threshold (dB)**	**Service Example**
Class 1	12.4	5	−19.9	Voice
Class 2	64	4	−13.7	Medium Multimedia, Movie, Music
Class 3	128	3.2	−11.57	Video Conversation

Mean system throughput: the average number of bits successfully transmitted per second.
False accept probability: probability that the accepted user in the home cell will make the load in one or more neighboring cells violate the noise rise threshold and affect the stability of the system.

Table 2. Summarizes the input parameters that have been used in the simulation.

Parameter	**Value**
Cell radius	850 m
Number of cells	7
Chip rate	3.84 Mbps
Base station antenna	Omni directional
Standard deviation of shadow fading	8 dB
Maximum Ms transmitted power	21 dBm
Minimum MS transmitted power	−50 dBm
Uplink thermal noise	−104 dBm
Uplink load threshold (voice only)	0.75
Uplink load threshold (multimedia traffic)	0.85
Noise Rise target range	3.5–6 dB
Weight factor (w)	0.5
Percentage of offered traffic for class 1,2 and 3	0.6, 0.2, 0.2
Call holding time for class 1, 2, 3.	120 sec., 4 min., 4 min.

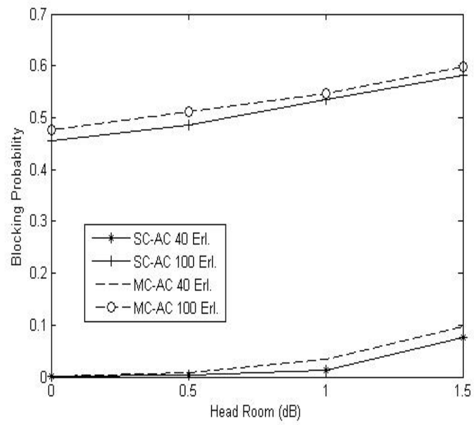

Figure 1. Effect of head room variation on blocking probability with homogenous load.

5. SIMULATION RESULTS

An extensive simulation is carried out to compare the performance of single-cell admission control with multi-cell admission control. We have investigated the performance of both algorithms in two types of traffic conditions; homogenous load and heterogeneous hot around load. In each case, two types of traffic are considered. First, voice only traffic was considered and in the second case simultaneous multimedia traffic of voice, class 2 and class 3 services are introduced.

5.1. Voice Calls in Homogenous Traffic

In this case, voice calls only are considered. The load varies from 10 Erlangs to high load as 100 Erlangs per cell. As mentioned earlier, a trade off exists between blocking and dropping probabilities which are the most important measures of the performance of the system. In order to compromise between these trades offs; a study of the effect of head room described in equation was carried out. Figures 1 and 2 show the dropping and blocking probabilities against head room variation at two different load values that represent low and high traffic at 40 and 100 Erlangs respectively. From these two figures we can see that the dropping probability is greatly improved specially at high load but the blocking probability remains with small changes. As observed, choosing a noise rise head-room equal to 0.5 dB, we can ensure that dropping probability is below 4% even at high load, see Figure 4. Figure 3 shows that the MC-AC is more conservative than Single-

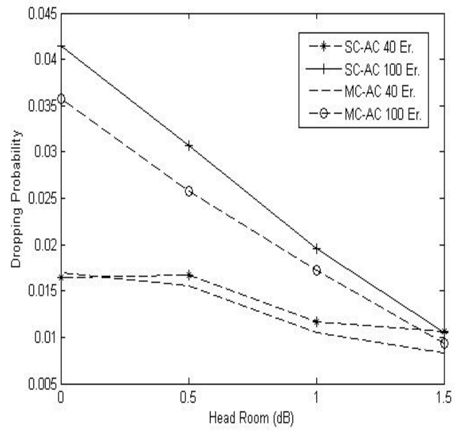

Figure 2. Effect of head room variation on dropping probability with homogenous load.

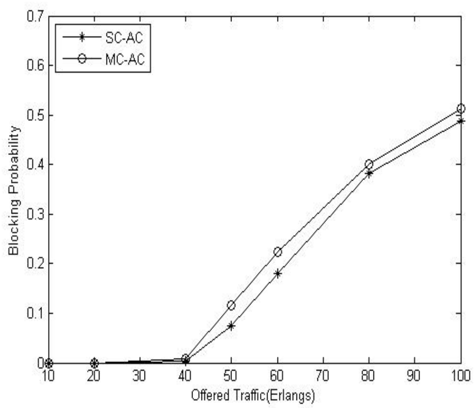

Figure 3. Effect of load variation on voice blocking probability with homogenous load.

Cell Admission Control SC-AC in admitting the new calls because it checks the noise rise increment due to the new call attempt in all cells to ensure that the noise rise threshold is not violated. However, as shown in Figure 4, the dropping probability in case of MC-AC is much lower than SC-AC and improved performance is gained because dropping an ongoing connection is much less desirable than blocking a new attempt. Note also hat although an approximately equal blocking probability difference is obtained in Figure 3, the dropping probability difference becomes larger after 60 Erlangs load.

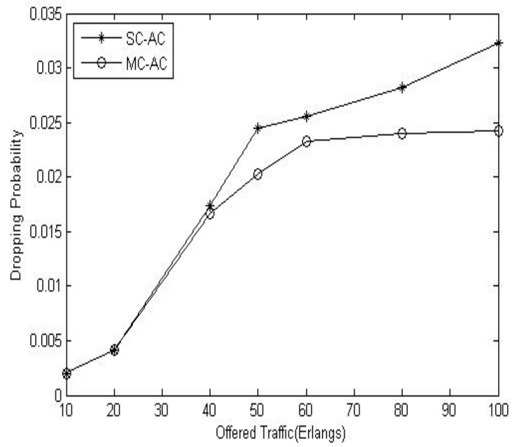

Figure 4. Effect of load variation on voice dropping probability with homogenous load.

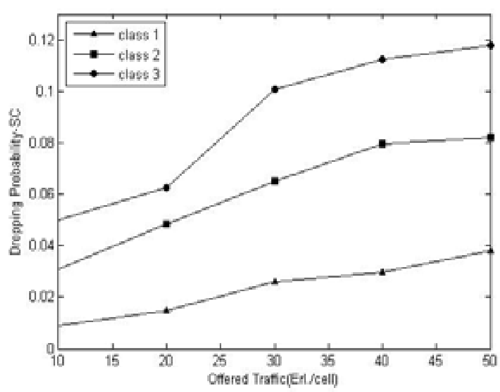

Figure 5. Dropping probability with SC-AC algorithm and homogenous mixed services.

5.2. Multimedia Services in Homogenous Traffic Case

In this case, a mix of the three classes' traffic each with its QoS requirements was considered. Figures 5–8 show the performance comparison between SC-AC and MC-AC algorithms for this case. Comparing Figure 5 and 6, we can see an improved performance in terms of outage probability for each type of traffic. Note that the outage probabilities for class 2 and class 3 traffic are much higher than that for the class 1. The reason behind this is that these services with

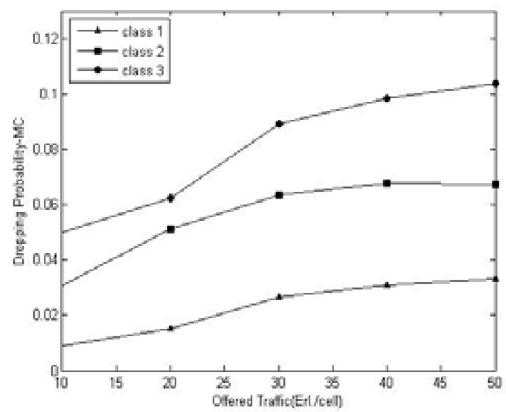

Figure 6. Dropping probability with MC-AC algorithm and homogenous mixed services.

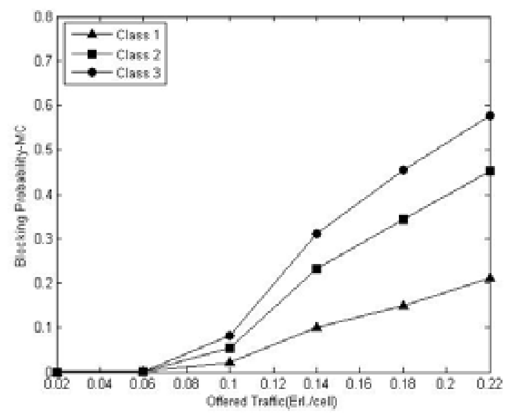

Figure 7. Blocking probability versus load variation with homogenous mixed traffic.

higher bit rates require more transmitted power in order to achieve their target *SIR* and because the system is power limited, higher dropping rate will occur than that of lower bit rate services. At high load, the dropping probability saturates due to a high blocking as shown in Figure 7 which reveals the blocking probability for various services. It can also be seen that services with high bit rates suffer from high blocking probability due to their high load requirements. Figure 8 shows the false accept probability for both algorithms. The false accept probability for MC-AC is very small even at high load.

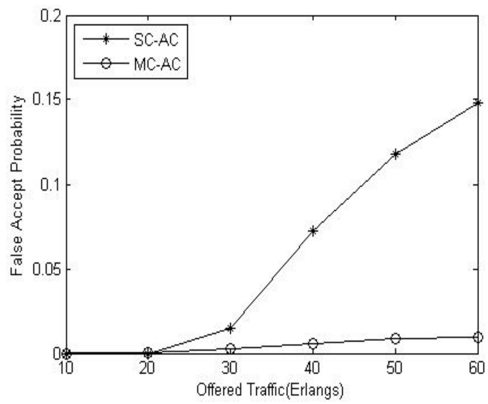

Figure 8. False accept probability versus load variation with homogenous mixed traffic.

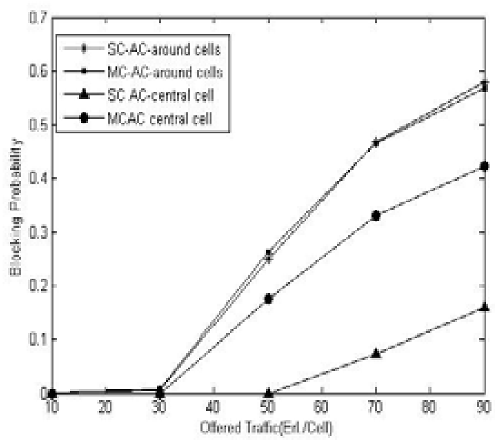

Figure 9. Blocking probability with hot around case with only class 1 users.

This is due to the estimation errors in power increments in serving and neighboring cells [6].

5.3. Voice Calls in Hot around Traffic Case

In this case, a heterogeneous (hot around) voice only traffic was considered. The load in the central cell is half the load in each of the surrounding cells. We observe from Figure 9 that blocking probability in the around cells is the same for both algorithms. In the central cell,

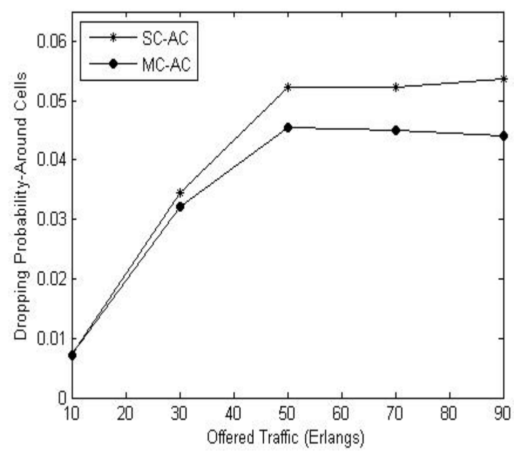

Figure 10. Dropping probability at around cells with only class 1 users.

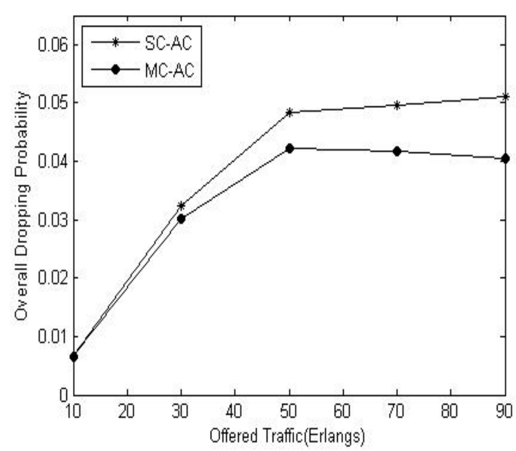

Figure 11. Overall dropping probability with hot around case for only class 1 users.

blocking probability using MC-AC is higher than that of SC-AC as expected. Figures 10–12 show that the dropping probability is lower in case of MC-AC. Figure 12 shows that the dropping probability of the central cell in case of MC-AC remains around 1% even at high load whereas it increases rapidly in case of SC-AC. Comparing Figures 10 and 11 we can see that overall dropping probability and the dropping probability in the around cells are nearly equal. This is because most of the users in the system are located in the coverage area of the surrounding cells.

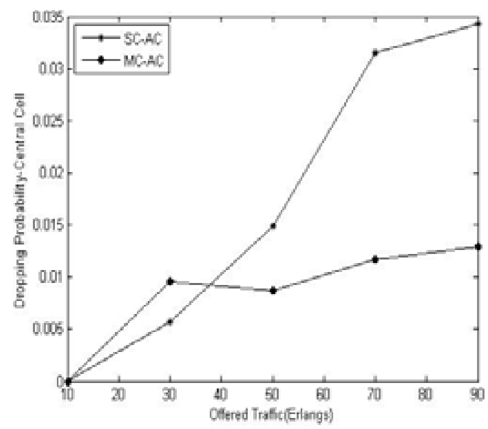

Figure 12. Dropping probability at central cell with class 1 hot around traffic.

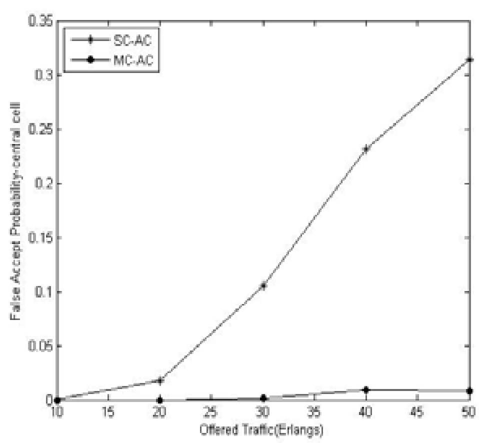

Figure 13. False accept probability at central cell with mixed services.

5.4. Mixed Traffic in Hot Around Case

This case differs from the previous case in that we can investigate the impact of high data rate users in central cell on the neighboring cells specially those users located near the cell border. Comparing Figures 8 and 13, we conclude that false accept probability is larger in case of hot around traffic distributions. This is because the central cell is at a low load so admitting a user with SC-AC algorithm, especially user with high bit rate, make the load in the surrounding cell violates its threshold value with high probability. As seen in Figure 13, this probability is approximately zero with MC-AC algorithm because it checks the status of the current load in all cells. To make the SC-AC behave like MC-AC, the load factor threshold of the central cell should be decreased and this will decrease the capacity of the central cell.

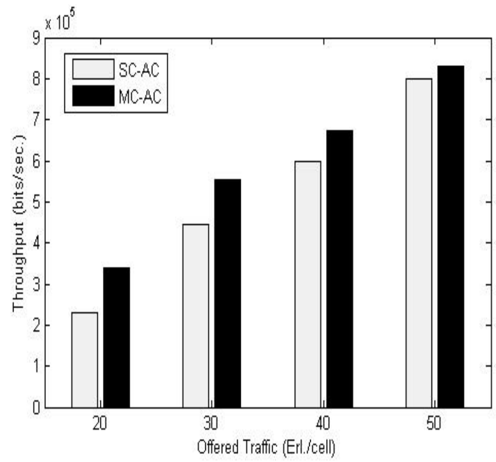

Figure 14. Total throughput in the central cell in case of mixed services with hot around scenario.

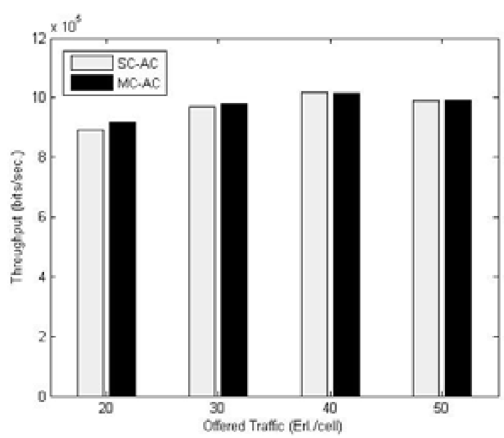

Figure 15. Total throughput at central cell in case of mixed services in homogenous traffic distribution.

For throughput calculation and to make a fair comparison, it is necessary to set the target noise rise Λ_{target} so that SC-AC and MC-AC algorithms give the same dropping probability at different traffic. Figure 14 shows that MC-AC archives approximately 40% increase in the throughput of the central cell at low load with hot around case. At higher loads, this difference decreases due to high blocking. For homogenous traffic, no noticeable capacity gain is achieved as shown in Figure 15.

6. CONCLUSION

In this paper, we have developed a model to investigate the performance of multi-cell admission control when heterogeneous traffic is considered. Simulation results show that MC-AC algorithm has many advantageous over SC-AC in terms of dropping probability, network stability, and total system throughput. A tradeoff between the dropping and blocking probabilities has been discussed. As dropping an ongoing call is more annoying than blocking a new one, dropping probability can be lowered without much increase in blocking probability.

Both homogenous and heterogeneous traffic are considered; it's concluded that more capacity gain is achieved under heterogeneous (hot around) traffic distribution. Finally, results show that high bit rate services suffer from both higher blocking and dropping probabilities, so it can be assumed that these services are with limited coverage.

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