Resource Management in Third Generation Mobile Communication Systems Employing Smart Antennas

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Abstract— Third Generation (3G) Mobile Communication systems will provide enhanced high-speed data, multimedia, and voice services to mobile users. Beam forming techniques have been proposed to increase the spectral efficiency of the wireless channel. In a commercially deployed 3G system, it is likely that the two techniques will co-exist. Resource management in a wireless system should take care of channel impairements and non-ideal antenna patterns. Mobile users moving from one beam to another give rise to resource reallocation issues. In this paper, we propose a resource allocation and management scheme tailored to systems with smart antennas supporting heterogeneous users. The algorithm works by comparing the received power in each beam. Elasticity of user requirements for data services is exploited to provide adaptive QoS to the users, thereby preventing dropping of a call due to user mobility. Simulation results showing the channel and MAI effects on system performance are presented. The throughput advantage obtained using the management scheme is compared to a system without resource management. It is also seen that the throughput of the system increases for a user population exhibiting higher elasticity. In addition the algorithm can be modified to also handle call hand-off.

A. INTRODUCTION

Third Generation (3G) Mobile Communication systems will provide enhanced high-speed data, multimedia, and voice services to mobile users. The integration of such heterogeneous traffic types implies that the network must provide differentiated Quality of Service (QoS). Clearly, the user mix that can be supported at any given time will be a function of QoS requirements and available bandwidth, but in general 3G systems must support much higher data rates than those typical of voice-oriented services. Studies to date have concentrated on improving spectral efficiency – accommodating more data within the same transmission bandwidth. One area that has gained considerable attention from the research community is the exploitation of the spatial domain through antenna beamforming. Systems deploying smart antennas rely on directional beams for reducing the interference from other users. Since CDMA is interference limited, this translates into an improvement in system capacity.

Independent studies have been carried out in each of two areas: performance benefits of employing smart antennas and resource management for 3G systems. The capacity improvement obtained with beam forming was studied by Choi *et al.* [1]; performance improvement from a network perspective has been addressed in [2]. These performance analysis studies have been conducted from the viewpoint of a homogenous (single rate) user population. The resource management problem, on the other hand, has been addressed from an omni-directional antenna point of view. Assuming the use of omni-directional antennas resource management techniques for 3G systems can be found in [3] and adaptive call admission algorithms have been proposed in [4, 5].

In an actual system it is likely that smart antennas will be deployed in order to provide adequate QoS to a variety of user classes. In this environment, it is desirable that the resource management mechanisms be tailored to the use of smart antennas. This paper proposes and evaluates one such resource allocation and management scheme. The key idea is to provide adaptive QoS to users depending on the characteristics of traffic currently present in the cell. Due to the spatial domain considerations introduced by smart antennas, the relative cell characteristics change as the user moves within the cell, causing a change in the service provided to the user in motion. In this paper we propose an algorithm for resource allocation that accommodates elastic and non-elastic traffic, achieving graceful QoS degradation as users move within a cell and interfere with one another.

The paper is organized as follows. In section B we formulate the problem statement and explain the elasticity and satisfaction index of the users. Issues inherent to a wireless link are also explained in this section. Section C describes in detail the model used to study the resource allocation and admission protocols. The elastic call generation, parameters of WCDMA, mobile transmitter, channel modeling and base station receiver are explained in this section. Section D presents the proposed algorithms for resource allocation and resource management and illustrates the performance improvement obtained. Section E discusses the results showing the performance gain of a managed scheme and the effect of elasticity on the performance. Finally, we conclude the paper with some closing remarks and directions of further research.

B. PROBLEM STATEMENT

One major enhancement that is part of the 3G proposal is support for heterogeneous services. We can take advantage of the elasticity exhibited by most data traffic by employing QoS adaptation. The elasticity may be modeled as user requests for a *range* of service levels, from ideal to simply

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tolerable. An appropriate service level is allotted to the user depending on the resources available in the cell. Different metrics have been suggested to measure the user satisfaction[6,7]. In our work, we define a simple metric - Satisfaction Index (SI), a parameter that varies between 0 and 1: 1 corresponds to the best service and 0 to no service being allotted to the user. For a group of traffic flows with similar coding schemes, we adopt a simple definition of the SI as

SI = (Allotted Data Rate)/(Maximum Requested Data Rate) (1)

Note that the SI is a simplified model of user *utility*, the benefit that a user derives from a given service. Utility is a widely used metric in the design and evaluation of pricing mechanisms for networks that support service differentiation.

For the duration of the call, the SI can vary depending on cell conditions. If a call by another user ends, this frees up resources that can be re-allocated to continuing flows, increasing the SI. If a new call arrives, part of the resources is given to the new call, reducing the SI of the current users. This kind of adaptive resource management scheme is proposed in [4] and can be deployed in a system that uses omni-directional antennas as well as one deploying smart antennas.

The data rates supported by a 3G system can be as high as 2Mbps, within a relatively narrow frequency band. Spectrally efficient coding techniques or spectrum enhancement techniques such as beam forming have been proposed to this end. In a base station with smart antennas, managing resources when the users are mobile poses a new challenge. The users can move from the coverage area of one beam to another, giving rise to a condition similar to handoff between cells. With narrow beams the area covered by an individual beam is very low, hence the possibility of a user moving between beams is higher than the probability of his movement between cell boundaries. In addition to that, depending on the channel, the direction of arrival of multipaths can vary. This causes the user to interfere with multiple beams even when the line of sight direction of the user does not change. These factors make management of multiple users in a smart antenna network challenging.

In a commercially deployed 3G system, heterogeneous services and beam forming networks will coexist. This requires a method to perform resource management for heterogeneous users in a smart antenna network. The system must take care of interference caused by a user on multiple beams, movement of user between beams and differences in resource availability in the same cell depending on user location. The algorithm should be robust enough to work in various wireless environments having degradations such as fading, multipath, random scatter, etc.

Our contribution is the development and evaluation of a resource allocation and management scheme tailored to networks employing smart antennas. The evaluation of the algorithm is performed using a simulation model having an integrated medium access layer and physical layer. Since the performance is dependent on the channel conditions, a good model of the physical layer is essential. This includes a model of the mobile transmitter and a 2D rake receiver exploiting the spatial and temporal diversity and accurate channel modeling. The resource allocation and management algorithm is tested on this physical layer framework.

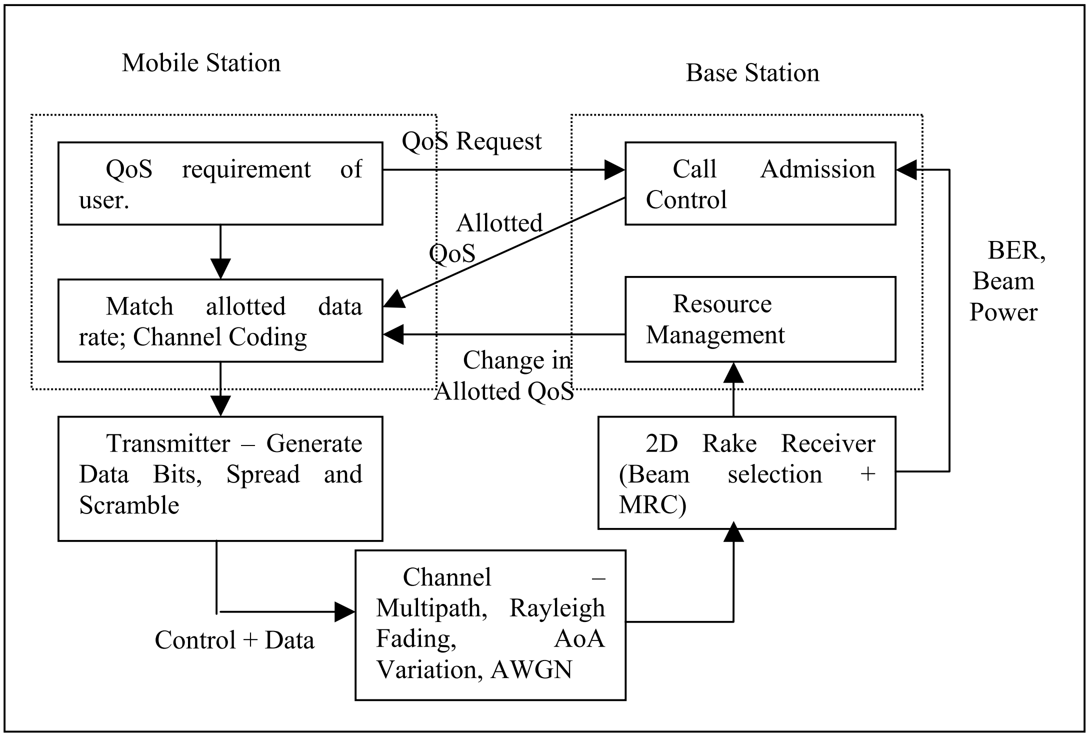

Figure 1. Block Diagram for the proposed system

C. SYSTEM MODEL

We developed a simulation model to assess the performance of the proposed resource management algorithms. The model follows the protocols defined by WCDMA, using Frequency Division Duplexing (FDD) mode of operation as per the 3G standards [8]. The performance of the system depends on a number of characteristics such as channel conditions, multipath profile, antenna beam-forming algorithm, user mobility, etc. The simulation model takes into account all of these parameters and is interfaced with a Medium Access Control (MAC) scheme. The key components of the simulation can be broadly classified into resource request generation model, call admission control, resource management, transmitter model, transmission channel and receiver, as shown in Figure 1. Next, we explain each of these sub-blocks in detail.

Call Generation Model – The different proposed standards (ex. 3GPP, 3GPP2) allow users to experience different QoS based on the type of service requested and the location of users. In the current simulation we assume a connection oriented network model, and the parameters that can be specified by a user when requesting a call are data rate and maximum tolerable bit error rate (BER). Multiple traffic classes are defined based on the data rates and coding schemes; we follow the WCDMA standard in defining these classes. Elastic users specify a range of acceptable data rates, and the system allocates a data rate within that range, depending on resources available for the cell; if not enough resources are available, the call is rejected. Call arrivals and departures follow a Markov model – Poisson arrivals and exponentially distributed service times.

User Location/ User Mobility – In a WCDMA system with smart antennas, there is an additional spatial dimension that can be exploited both in terms of diversity combining and multiple access. In contrast to a system with omni-directional antennas, the call admission in such a system will depend on the location of the users. If two users are co-located, the signals transmitted by them will interfere in the same beam and may cause considerable interference with each other. Hence, we perform resource allotment based on the location of the users. We consider three kinds of users – stationary users (velocity = 0 km/hr); mobile users in an urban environment (velocity = 30 km/hr; angle of movement θ = random, half cosine) and high-speed users (velocity = 120 km/hr; angle of movement constant). A visual representation of these mobility types is shown in Figure 2. The number of users currently in the system is determined randomly, following some pre-specified ratio of number of users for each mobility type.

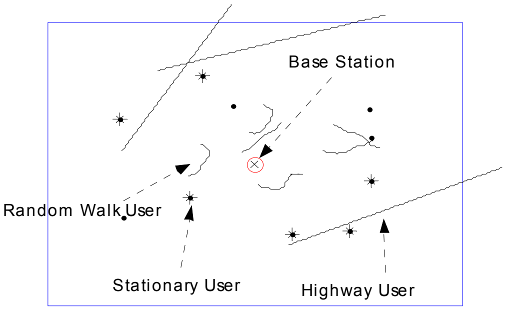

Figure 2. User mobility model

Transmitter Model – The transmitter for the system closely follows the protocol proposed by the Third Generation Partnership Project (3GPP). The transmitted data sequence is spread by OVSF (Orthogonal Variable Spreading Factor) codes. The selection of the OVSF codes depends on two factors: (i) rate of the data sequence to be transmitted and (ii) direction of transmission – uplink or downlink. For the present study, we consider uplink transmission where multiple data rates are permitted. According to the standards, for uplink transmission the same spreading code sequence from the OVSF code set is used. One direct impact of this variable spreading factor is that the lower data rates have longer spreading codes and hence higher spreading gain. However, the higher data rate users will have more stringent BER requirements than the lower rate users. So, the power of the higher rate users must be higher than that of the lower rate users, meaning that resource gradation is performed through power control.

The relationship between the power and data rates for equivalent performance at the receiver can be derived. Consider two flows transmitted at rates R_1 and R_2 with power P_1 and P_2 respectively. The spreading gain associated with the rates are G_1 and G_2. In order to obtain equal performance at the receiver, the energy per bit after despreading should be the same:

$$P_1 G_1 = P_2 G_2 \qquad (2)$$

However, spreading gain G_1 is proportional to spreading factor SF_1. So, equation (2) can be written as

$$P_1 SF_1 = P_2 SF_2 \qquad (3)$$

$$P_1/P_2 = SF_2/SF_1 \qquad (4)$$

Since power in the cell is the limiting factor for a CDMA system, allotting different power is equivalent to assigning different bandwidth for the calls in a bandwidth limited environment.

The data bits after spreading are multiplied with gold codes unique to each user, which gives the required cross correlation properties for the transmitted data sequence. WCDMA assumes asynchronous users and this requires that the transmitted signal have good cross correlation properties.

In the present simulation we are modeling the uplink; Table 1 lists the different parameters associated with the simulation.

Table 1. WCDMA parameters used for the simulation.

Parameter	Value
Chip Rate	3.84 Mcps
Frame Duration	10 ms
Scrambling Code	Gold Codes, 38400 chips
Spreading Codes	OVSF (Walsh) codes, 4- 256
Spreading Factor	4 – 256

Channel Model – In a wireless system, the channel plays an important role in terms of the total data rate that can be supported, interference caused to other users, bit error rate, etc. Since the chip rate of WCDMA is very high (3.84 Mcps), multipath can be resolved most of the time. This means that the signals undergo frequency selective fading. The power delay profiles of the channels used in the simulation are given in Tables 2 (indoors) and 3 (outdoors). The type of channel that the signals encounter is selected based on the distance between the mobile and the base station. In addition, each multipath undergoes Rayleigh fading.

Table 2. Power delay profile for indoor channel.

Delay (ns)	Average Power (dB)
0	0
50	-3
110	-10
170	-18
290	-26
310	-32

Table 3. Power delay profile for vehicular A outdoor channel.

Delay (ns)	Average Power (dB)
0	0
310	-1
710	-9
1090	-10
1730	-15
2510	-20

When smart antennas are used in a system, the Angle of Arrival (AoA) of the signals plays an important role in the resource allocation and further in the resource management scheme. For the present study, the channel implemented is a circular channel model applicable to macrocell conditions. The assumption in such a model is that the base station (BS) is at a greater height than the mobile station (MS) and the scatterers [9]. The Angle of Arrival (AoA) at the BS will depend on the distance between the MS and BS and the radius of scatterers. Measurement studies [10] have been conducted for finding the AoA statistics. The AoA at the receiver from a transmitter at a known location has been measured; the radius of scatterers is found to be in the range of 50-200m [10]. The AoA is modeled by adding the LOS angle to a random value. This random value is generated for each multipath and has the probability density function given in equation 5.

$$f_{\theta a}(\theta_a) = \begin{cases} \dfrac{\pi}{4.9\theta_{a\max}} \cos\left(\dfrac{\pi}{2}\dfrac{\theta_a}{\theta_{a\max}}\right)^{0.475} & -\theta_{a\max} \le \theta_a \le \theta_{a\max} \\ 0 & \text{otherwise} \end{cases} \tag{5}$$

Receiver Model – The smart antennas for the system are deployed at the base station. This provides both space diversity for the received signals and space division multiple access. The antenna forms beams having major lobes in a particular direction. A circular antenna array having N elements is assumed, with the array factor given in equation 6. The beam pattern for a circular antenna array having N elements can be written as [11]:

$$\mathrm{AF}(\theta,\phi) = \sum_{n=1}^{N} \mathrm{A}_n \exp(j\alpha_n)\exp[j\beta\rho_n' \sin\theta\cos(\phi-\phi_n)]$$

$$\alpha_n = -\beta\rho_n' \sin\theta_0 \cos(\phi_0-\phi_n)] \tag{6}$$

In this equation, A_n is the gain pattern of a single element, $\beta = 2\pi/\lambda$ (λ is the wavelength), ϕ_0 and θ_0 are the angles at which the beam will have the maximum gain in the horizontal and vertical planes respectively, α_n is the steering vector, and ρ_n is the radius of the circular array. The beam pattern for this configuration is shown in Figure 3. A circular array is chosen since it has a beam pattern having a major lobe in only one direction.

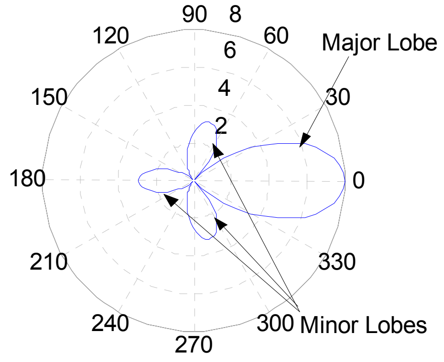

Figure 3. Beam pattern for a circular antenna array with 8 elements.

There are two kinds of directional antenna array systems: (i) a tracking beam system in which the maximum gain point follows the angle of arrival of the user; (ii) a switched beam system where the antenna pattern is fixed. In the present work, we consider the performance improvement obtained by using a switched beam antenna array. The hardware complexity and cost of a switched beam system has been shown to be considerably lower than that of the tracking beam; for a small number of users, the BER performance with a switched beam system is comparable with that of the tracking beam system [1].

The two-dimensional rake receiver combines the signals both spatially and temporally. The rake receiver uses selection combining (choosing the best signal) for space diversity and Maximal Ratio Combining (using a weighted average of the received signals) for temporal diversity. The total power received by each beam is reported to the MAC layer to aid in further decisions for call admission and adaptive resource management.

D. Proposed Resource Allocation and Management schemes

We focus on connection oriented services in 3G systems. In this model, while a dedicated channel is provided to the user, the bandwidth of that channel can change dynamically over time. The system allocates bandwidth to each user depending on the present cell conditions. We first discuss the simple case of the resource allocation strategy for a base station with an omni-directional antenna. This algorithm is then modified for a system with smart antennas, and finally we outline a resource management scheme to monitor the cell due to changes from user movement.

1. Resource allocation for a base station with an omni directional antenna

A first come first serve basis for adaptive resource allocation is considered for the case of a base station with an omni-directional antenna. Resources are allotted to the users based on the current availability of bandwidth under the constraint that the net power does not exceed a pre-defined value. The maximum power permitted in a cell is dependent on the BER requirement of the users. The system supports an arbitrary number of QoS classes, and each class is characterized by a target data rate and coding scheme. Each user defines an ordered list of QoS classes (from least to most desirable) that would meet the user's performance requirements. The power contribution of the user in the cell is predicted by measuring the received power through the control channels. The data rate of the control channel in WCDMA is 15 kbps. Using this information and equation (4), the power level for an arbitrary data rate can be predicted. The algorithm steps are explained below.

Symbol definitions:

TC_i : Traffic class requested by the user
P_{pilot} : Received pilot power
R_{pilot} : Pilot channel data rate
R_{Tci} : Traffic class raw data rate
P_{new_Tci} : Predicted received power for the traffic class TC_i
P_{cell} : Present Cell power
P_{cell_accept} : Cell power if the new call request is accepted
P_{cell_max} : Maximum cell power

Algorithm:

1. User transmits class requests – $[TC_1\ TC_2 \ldots TC_n]$ through the control channels. TC_n is the most preferred class.
2. Base station receives the request and measures the received pilot power. The received power is the sum of all the multipath powers.
3. Set the Call Rejected parameter to True.
4. Repeat the following steps for n down to 1.
5. Calculate the required raw data rate (R_{Tci}) of the class TC_i (depending on the channel coding used).
6. Predict the received power of the class TC_i:
   $$P_{new\_TCi} = P_{pilot} * R_{Tci} / R_{pilot}$$
7. Calculate the received power in the cell if the class TC_i is admitted:
   $$P_{cell\_accept} = P_{cell} + P_{new\_TCi}$$
8. If $P_{cell\_accept} < P_{max}$
   a. Admit traffic class TC_i, set Call Rejected parameter to False.
   b. Inform the user regarding the admitted traffic class.
   c. Exit from the loop.
9. Else loop to step 4.
10. If no class can be accepted, reject the call.

2. Initial resource allocation for a smart antenna system

In a cell with omni-directional antennas, all the users in the cell act as interferers to the rest of the users in the cell. The effect is worsened because of the presence of multipaths, which have the effect of increasing the interference.

In contrast to that, the primary impact of smart antennas on resource admission strategies is due to the direction of arrival of the multipaths. The multipaths from a user can arrive from any direction. The angle of arrival can depend on multiple factors – microcell/macrocell, distance between the base station and the mobile, scatterer radius etc. Depending on the channel conditions, the multipaths can impact the same beam or multiple beams. The effect of the multipaths on the beams is computed from the received pilot channel. Using this information and the power ratio of the required traffic class to the pilot channel, the impact of each traffic class on the beams can be computed. A class that will provide an interference level within the acceptable bounds is accepted. The previous algorithm for the call admission control can then be modified to the one outlined below.

Constants:

M : Number of switched beams

Symbol definitions:

TC_i : Traffic class requested by the user
R_{pilot} : Pilot channel data rate
R_{Tci} : Traffic class raw data rate
$P_{pilot\ beam\_m}$: Received pilot power at beam m
$P_{new\_Tci\_beam\_m}$: Predicted received power for the traffic class TC_i at beam m

P_{beam_m} : Present beam receive power
$P_{accept\_beam\_m}$: Received power at beam m if class TC_i is accepted
$P_{max\_beam\_m}$: Maximum receive power for beam m

Algorithm Description:

1. User transmits class requests – [TC_1 TC_2…TC_n] through the control channels. TC_n is the most preferred class.
2. Base station receives the request and measures the received pilot power $P_{pilot\_beam\_m}$ at each of the beams.
3. Set the Call Rejected parameter to True.
4. Repeat the following steps for n down to 1.
5. Calculate the required raw data rate (R_{Tci}) of the class TC_i (depending on the channel coding used).
6. Iterate steps (a) and (b) for all beams, m = 1…M
    a. Predict the received power of the class TC_i : $P_{new\_Tci\_beam\_m} = P_{pilot\_beam\_m} * R_{Tci} / R_{pilot}$
    b. Calculate the received power in the beam if the class TC_i is admitted: $P_{accept\_beam\_m} = P_{beam\_m} + P_{new\_Tci\_beam\_m}$
7. If $P_{accept\_beam\_m} < P_{max\_beam\_m}$ for all m = 1…M
    a. Admit traffic class TC_i, set Call Rejected parameter to False.
    b. Inform the user regarding the admitted traffic class.
    c. Exit from the loop.
8. Else loop to step 4.
9. If no class can be accepted, reject the call.

3. Resource management for a smart antenna system

The need for continuing resource management occurs in a smart antenna in a similar manner to the requirement for hand-off in a multi-cellular system. The users are allotted power levels depending on the pilot channel strength at the time of arrival of a call; however, the AoA and impact on the antenna array vary as the user moves about in the cell. So if a call is in progress for a sufficient amount of time, two users who were not interacting may start interacting. In a voice oriented network this can cause the call to be dropped. However, for data services, the problem can be circumvented by allotting lower data rates and thereby reduced power to these users when they start interacting. In other words, it is clearly advantageous to have a resource management system that allows for graceful degradation of QoS, rather than a hard decision to drop existing calls. Also note that it is possible that the movement of the users will yield a beneficial effect on system quality, whenever a user moves into an area that ends up generating lower interference to other users. The resource management scheme that we propose acts as outlined below:

Constants:

M : Number of switched beams
U : Total number of users at time of resource management

Symbol definitions:

TC_i : Traffic class requested by the user
$R_{u\_current}$: Current data rate of user u
$R_{\_u\_compared}$: Data rate of the class being compared
R_{Tci} : Alternate traffic class raw data rate
$P_{new\_Tci\_beam\_m}$: Predicted received power for the traffic class TC_i at beam m
P_{beam_m} : Present beam receive power
$P_{accept\_compared\_m}$: Received power at beam m if class TC_i is accepted
$P_{max\_beam\_m}$: Maximum receive power for beam m
$P_{user\_u\_beam\_m}$: Power received from user u by beam m
$P_{no\_user\_u\_beam\_m}$: Power at beam m if user u is absent
$P_{beam\_m\_all\_users}$: Collection of $P_{user\_u\_beam\_m}$ having non-zero received power at beam M
$TC_{\_lower\_i\_user\_u}$: Traffic classes having a lower data rate than the present traffic class for user u
$TC_{\_higher\_i\_user\_u}$: Traffic classes having a higher data rate than the present traffic class for user u

Class Degradation

1. Iterate steps 2 – 11 for all beams m = 1…M.
2. Compare the received beam power, P_{beam_m} to maximum beam power $P_{max\_beam\_m}$.
   If ($P_{beam\_m} > P_{max\_beam\_m}$) continue ;
   else go to step 1.
3. Find the power contribution of all users at beam m:
   $P_{beam\_m\_all\_users} = [P_{user\_1\_beam\_m}, P_{user\_1\_beam\_m}, \ldots, P_{user\_U\_beam\_m}]$
4. Sort $P_{beam\_m\_all\_users}$ with user 1 contributing the maximum power.
5. Iterate steps 6 – 11 for all users u in $P_{beam\_m\_all\_users}$
6. Find the power in the beam if user u is absent
   $P_{no\_user\_u\_beam\_m} = P_{beam\_m} - P_{user\_u\_beam\_m}$
7. Find all the classes requested by the user - R_{TCi}, having a rate $R_i < R_{u\_current}$. This gives the set $TC_{\_lower\_i\_user\_u}$.
8. Sort $TC_{\_lower\_i\_user\_u}$ in the descending order of data rates.
9. Iterate steps 10-11 for all the classes in $TC_{\_lower\_i\_user\_u}$.
10. Find the new power if user u is degraded to a lower traffic class:
    $P_{accept\_beam\_m} = P_{no\_user\_u\_beam\_m} + P_{user\_u\_beam\_m} * R_{\_u\_compared}/R_{\_current}$
11. If $P_{max\_beam\_m} < P_{accept\_beam\_m}$
    a. Reallocate the user to the new class $TC_{\_lower\_i\_user\_u}$.
    b. Compute the new power in all beams:
       $P_{\_beam\_m} = P_{beam\_m} - P_{user\_u\_beam\_m} + P_{user\_u\_beam\_m} * R_{\_u\_compared}/R_{\_current}$
       Use this newly computed value for subsequent calculations.
    c. Add user u to the list of degraded users.
    d. Continue from Step 1.

    Else
    a. Loop to step 9.

Class Upgradation

1. For all users not in the degraded user list, perform steps 2 through 7.
2. Find all the classes requested by the user - R_{Tci}.
3. Eliminate all classes having a rate $<= R_{u\_current}$. This step yields $TC_{\_higher\_i\_user\_u}$.
4. For all TC_i having $R_i > R_{current}$ perform steps 5-8.
5. Find the received power in the beam if TC_i is allotted instead of TC_{allot}.
6. For all beams 1…m, compute:
   $P_{\_compute\_beam\_m} = P_{beam\_m} - P_{user\_u\_beam\_m} + (P_{user\_u\_beam\_m} * R_i / R_{\_current})$
7. If $P_{max\_beam\_m} < P_{\_compute\_beam\_m}$ for all m:
   a. upgrade the user to the traffic class TC_i;
   b. continue step 1 for the next user.

   Else continue from step 4.

The impact of the algorithm can be explained with an example. Consider a cell having 8 beams with the beam pattern given in Figure 3. The major lobes have a 45^0 separation. The base station is located at the origin. There are 3 users in the system, and their characteristics are given in Table 4.

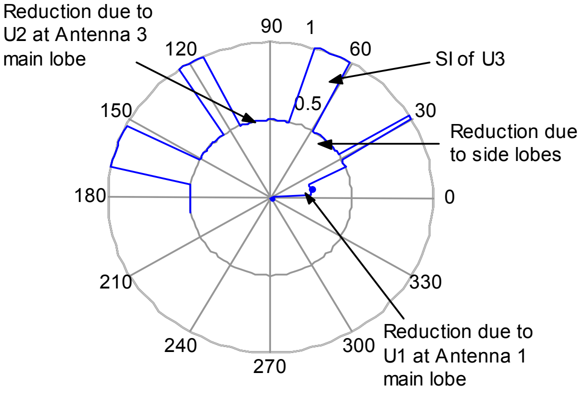

Figure 4. Plot of SI variation with location.

The SI of user U_3 is monitored. The plot of variation of SI with the location is given in Figure 4. It can be seen that the SI increases as the user moves away from the 0^0 location – away from the collocated user U_1. At 45^0, U_3 still influences beam 1 due to the presence of side lobes. However, when the user approaches a position at 90^0, his SI increases to 1, since there are no other users influencing beam 3. When the user moves to the 180^0 position his SI decreases due to the presence of U_2. The effect of beam pattern can also be seen from this example. User U_1 is located at the area serviced by the major lobe of beam 1which has a null at an angle 30^0; similary beam 3 servicing User U_2 and has a null at 30^0. This reduces the Multiple Access Interference (MAI) on user 3 at an angle 30^0, giving a high SI. At 45^0 beams have significant side lobes, hence the presence of U_1 will impact the usable resources of U_3 at this location. If we have an antenna array having a beam pattern with reduced side lobes, SI will not be reduced when the user is in the locations 45^0 and 135^0.

E. RESULTS

In this section, we present the improvement in throughput and in user satisfaction by using the resource management scheme proposed in the earlier section. The effect of multipaths and different data rates in a simple WCDMA system is also shown.

Figure 5 shows the BER performance of a WCDMA system with omni-directional antennas. The BER increases as the number of users increases due to Multiple Access Interference (MAI).

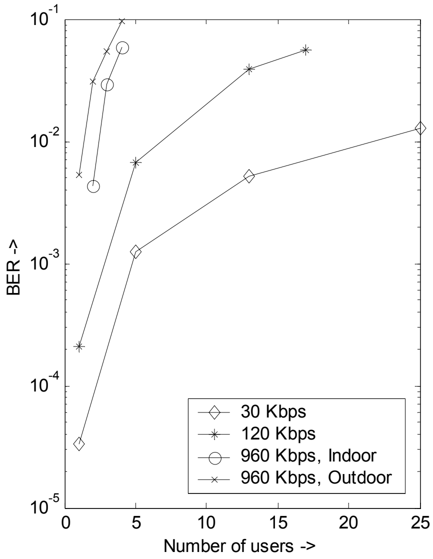

Figure 5. BER performance of a WCDMA system at different data rates and channels

Table 4. User characteristics for the example in Figure 4

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User	Location (R,ϕ)	Velocity (km/hr)	Movement Type	Traffic Classes (No coding scheme is requested.)
U_1	$(1414, 0^0)$	0	Stationary	(960 kbps)
U_2	$(1414,180^0)$	0	Stationary	(480 kbps)
U_3	$(1000,0^0)$	120	Circular	(960 kbps), (480 kbps), (240 kbps), (120 kbps), (60 kbps), (30 kbps), (15 kbps)

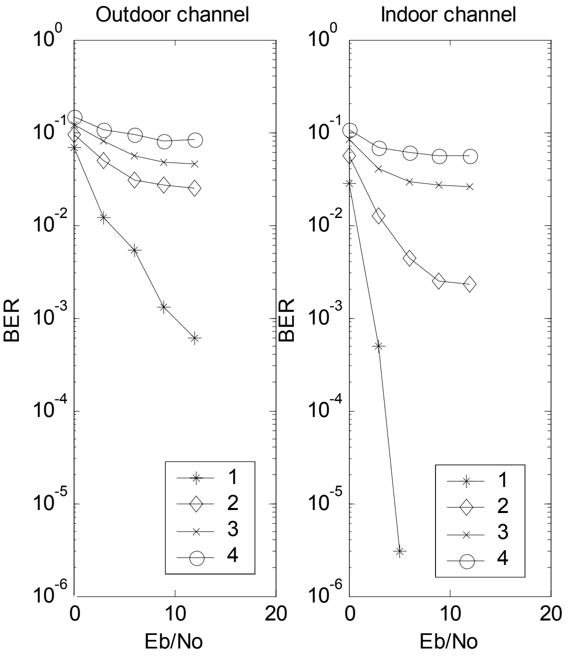

Figure 6. BER plots showing effect of channel profile for a CDMA system

The MAI increases as the data rate increases. Another interesting observation is the decrease in BER for the indoor channel, as shown in Figure 6. This is expected, since the multipaths in the indoor channel do not cause as much interference as the outdoor channel multipaths. These plots shows the interference limited capacity of the CDMA system.

Figure 7 shows the aggregate throughput in a WCDMA system with eight switched beam antennas with and without resource management. The physical layer parameters used in the simulation are given in Table 5. A user population with 20% stationary users, 50% random walk users and 30% high velocity users is considered. The users have high elasticity. The maximum power allowed per beam is varied (equivalent to increasing the capacity since it is a CDMA system). It can be seen that there is a significant gain in using resource management scheme as compared to the case when no adaptive scheme is employed. Equivalently we can notice the increase in the average SI of the user when adaptive resource management is implemented as shown in Figure 8.

Table 5. Phyical Layer Simulation parameters

Scatterer Radius	100 m
Cell Size	2.5 km (square)
E_b/N_0	12 dB
Number of beams	8
Rake fingers	4
Power Control	Perfect

The more elastic the users, the more benefits will be achieved due to the use of an adaptive resource management scheme. This is shown by the increase in aggregate throughput (Figure 9) and average Satisfaction Index (Figure 10) of the users.

F. CONCLUDING REMARKS

With the demand for wireless data communications on the rise, it is anticipated that the need for adaptive QoS and deployment of smart antennas will be widespread. The impairments in a wireless channel are random and less controllable than in a wired channel. When using smart antennas in a system, the cell conditions can change due to the user mobility. Hence there is the need for resource management mechanisms that are tailored to a smart antenna system and take advantage of the elasticity in user requirements. We have proposed a resource allocation and management algorithm that considers the channel effects and instantaneous user locations. This is done by monitoring the power received by the antennas. Through simulation it is shown that the net throughput of a managed system is better than that of a regular system. The resource allocation and management scheme can be modified to include hand off calls also. In such a case, the user entering a cell from an adjacent cell will be treated in the same way as a user entering from the area serviced by another antenna. A few directions for future research include: (i) exploring resource management algorithms for tracking beam antenna arrays; (ii) prioritization of users and employing selective back off for lower priority users; (iii) employing resource reservation protocols; (iv) examining microcell conditions.

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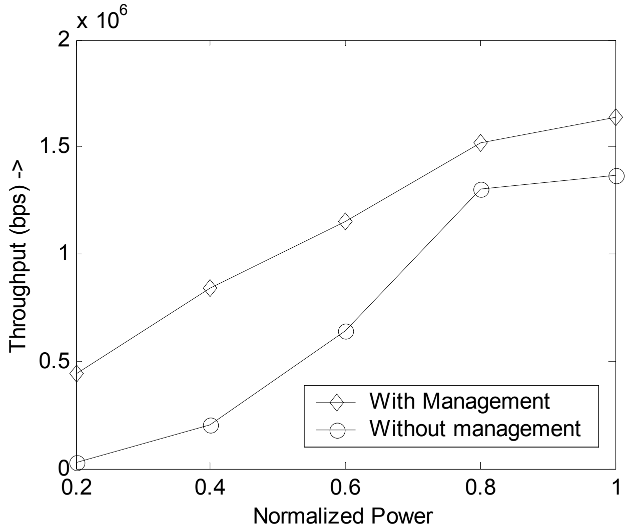

Figure 7. Throughput for a managed and a normal system

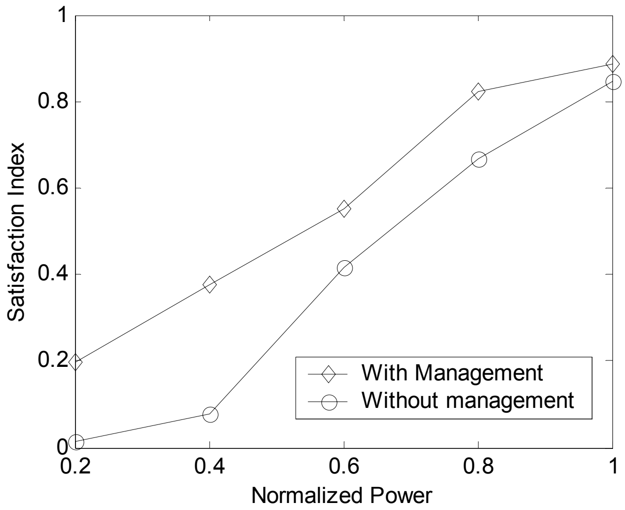

Figure 8. Satisfaction Index for a managed and a normal system

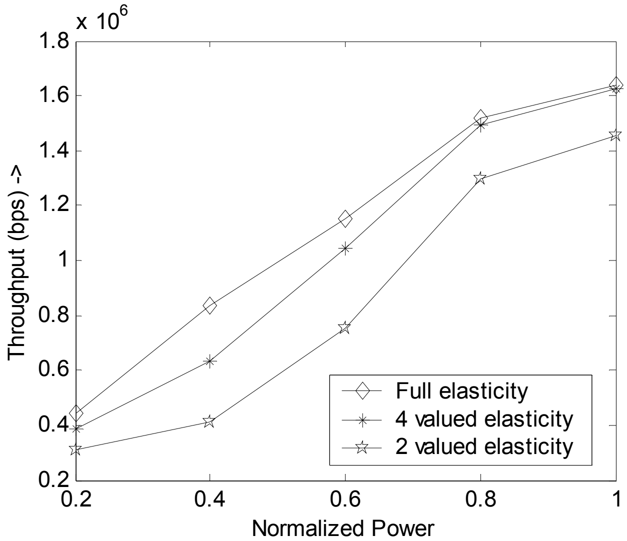

Figure 9. Throughput variation for different user elasticity

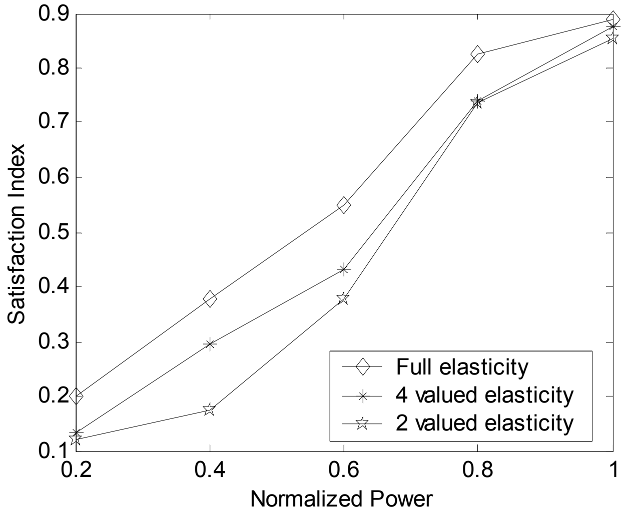

Figure 10. Variation in Satisfaction Index for different user elasticity