Resource Management for Third Generation Cellular Communication Systems

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Abstract—In third generation wireless cellular communication systems, cell sizes are expected to become smaller in order to accommodate high user density and multimedia traffic. Resource allocation schemes will have to be flexible to handle heterogeneous traffic and be dynamically adapted to the time-varying channel and user mobility. In this paper, we propose such a resource management strategy. We introduce the notion of connection group, where a mobile user simultaneously connects to multiple base stations using multiple links. The number of base stations and which base station to connect to are functions of the time-varying channel, mobility, current bandwidth need, and quality of service requirement. Once a call is admitted into the network, the resource management strategy will allow the mobile to dynamically configure its connections in such a way to minimize call dropping probability, maximize signal quality, and increase channel resource utilization efficiency. The performance of the protocol is analyzed in terms of call blocking and dropping probabilities and channel resource utilization. Results show that the proposed resource management scheme can support multimedia traffic with low call blocking and dropping probabilities and high channel utilization efficiency.

I. INTRODUCTION

Issues such as how to assign resources to users with different bandwidth and quality of service (QoS) requirements and how to provide a guarantee of negotiated services have been addressed and researched to some extent in the context of Asynchronous Transfer Mode (ATM) wired networks. The solutions obtained for wired ATM networks can not just simply be applied to wireless networks, because the environment, operation, and the constraints of wireless networks are significantly different from wired networks. In particular, the wireless environment is characterized by impairments and limitations such as frequency selective fading, co-channel interference, limited spectrum and user mobility. The limited radio spectrum allocated for cellular communication and the rapid increase in traffic intensity together imply that macrocells have to be split into many smaller cells to accommodate third generation cellular network traffic. However, as the cell size becomes smaller the frequency of call handoffs will also increase. This will result in higher handoff failure experienced by users. Hence, questions such as 1) How to allocate bandwidth resource to different users in a fair and efficient way such that both blocking and handoff failure of all traffic types are minimized? 2) What admission control procedure should be used to limit the number of admitted calls in order to guarantee on-going calls' QoS? and 3) What redundancy should be added to protect against the fading channel? must be re-addressed and solved.

Past work has largely concentrated only on voice communication. Many channel resource allocation strategies fall into the categories of fixed assignment, hybrid assignment, and dynamic assignment. In many of these techniques, a pool of resource is reserved for handoff calls. Such solution may not be viable in a heterogeneous traffic environment, where the population of mobiles has a diverse collection of bandwidth and QoS needs. In another recently proposed technique [1][3], a new call is admitted into the network only if there is sufficient resource available for it in the current cell and at adjacent cells sometime in the future. A call admitted into the cellular network under this scheme can freely handoff from base station to base station (BS) and enjoy a high quality of service but at the expense of blocking for new calls. Since the direction and the speed at which the mobile moves are unknown, reserving channels at all adjacent cells may waste valuable channel resource. Furthermore, all of these proposed schemes do not take multimedia traffic into consideration.

In this work we propose an Integrated Channel Assignment (ICA) strategy for multimedia traffic. Taking into consideration the impairment and limitation of wireless cellular networks, we integrate factors such as user mobility, bandwidth need, and link quality in design of the resource management scheme. The basis of our proposal is to exploit the small and overlapping coverage area of micro/picocellular architecture, whereby a mobile can be within range of communication to multiple base stations using low power radio transceivers. When a mobile requests a connection, instead of one connection a number of simultaneous connections to multiple base stations will be established. The number of base stations and which base stations the mobile will choose to connect to is a function of the quality of the wireless channel, traffic loading at a given cell and neighboring ones, and user bandwidth need.

With the proposed resource scheme, both blocking and handoff failure probabilities can be significantly reduced. A mobile arriving at a cell, that finds the base station does not have enough resource to support its call, instead of being blocked from entering the network it can borrow resources from neighboring base stations to make the call. This allows a greater statistical multiplexing of resource at all base stations under both uniform and non-uniform traffic loading. Under existing resource assignment schemes, as a user moves away from a BS, bandwidth of the whole call must be obtained at the approaching base station or the call will be forced into termination. Our proposed scheme offers a mechanism of gradual handoff for high bandwidth call, since not all of the connections need to be hand off at once.

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The proposed strategy also provides a means for a mobile to dynamically adapt its connection configuration to the time-varying wireless channel and user bandwidth needs. By monitoring a pilot tone broadcast by base stations, a mobile can re-configure its connection set once the signal of one or more links degrades below a certain threshold. In many instances, a user’s bandwidth need may vary drastically throughout a single session. For example, in web browsing application, one only needs a high speed link in down loading a web page and relatively low bandwidth is required while the user is reading the page. Our proposed scheme allows users to negotiate for more bandwidth (or to give up part of his requested bandwidth) without tearing down the already established connection in order to meet its current need.

This paper is organized as follows. In section II of the paper, we present the network architecture for integrated resource assignment strategy along with the algorithms for call connection, distribution, and handoff and numerical results of performance metrics such as call blocking and handoff failure. The generalized notion of call blocking and handoff failure and mathematical models introduced in section III. We conclude the paper with a discussion of related issues and summarize some on-going research work.

II. ARCHITECTURE OF INTEGRATED CHANNEL ASSIGNMENT SCHEME

We consider a cellular wireless systems where each base station covers a small geographical area. Since the cell size is small, the radiated power requirement is also small and there is considerable overlap in coverage area. Each base station is allocated a set of channels uses omni-directional antennas. Each base station broadcasts a Base Station Status Signal (BSSS) at some power level $P_j$ at all times. The BSSS includes information about the number of available resource at a base station $j$. The signal level $P_j$ serves as a reference for a mobile to determine if the channel can be borrowed and what level of power to transmit on.

In the integrated channel resource assignment scheme, when a mobile requests a connection, instead of one connection a number of simultaneous connections to multiple base stations will be established. Each connection to a base station is configured as a “narrow” band channel, where the term “narrow” band channel could represent neither a fixed frequency bandwidth (FDM), a specific time-slot within a frame (TDM), or a particular code (CDM), depending on the multiplexing technique used. For the remaining of the paper, we will refer to “narrow” band channel as Basic Bandwidth Unit (BBU) and use the two terms interchangeably. For example, in TDM, $C_j = S_j \cdot \tau_j$, where $S_j$ is the link speed (in b/s) and $\tau_j$ is the time duration of a slot for cell $j$. If the bandwidth of a call is $r$ b/s, the call requires $[C_j \cdot r/S_j]$ BBUs.

In Frequency Division Multiple Access (FDMA) and Time Division Multiple Access (TDMA) cellular systems, multiple access is achieved by providing disjoint slots in frequency and time and users in adjacent cells must also be provided disjoint slots; otherwise their mutual interference would be very high. This led to limited frequency reuse due to the minimum reuse distance constraint. In order for a mobile to connect with multiple base stations without introducing additional interference and limiting frequency reuse, we use the notions of channel group and channel borrowing without locking. This is similar to the channel borrowing without locking framework proposed in [2]. To prevent the increase in co-channel interference that will result in channel locking, borrowed channels are used with reduced transmitted power based on the BSSS signal. Therefore, a mobile can use these borrowed channels only in certain region of the cell and only if the signal-to-interference (SIR) meets the requirement of the mobile’s application.

In Code Division Multiple Access (CDMA) cellular systems, all mobiles use the same frequency. The universal frequency reuse applies not only to users in the same cell but also to those in all other cells; and hence no complicated frequency reuse patterns is necessary. To mitigate the effect of handoff failure, a feature called soft handoff is implemented in some CDMA cellular systems. Soft handoff is a process where the mobile establishes a link with the target BS before breaking the link with the serving BS. The mobile acquires a target code channel by continuously searching for a pilot code in order to detect potential candidate for handoff. In the integrated resource management scheme, a mobile communicating with multiple base stations at the same time is equivalent to a mobile transmitting on different CDMA channel number. Although the frequency reuse is 100% in CDMA, borrowing BBUs is equivalent to using multiple channel numbers and the BSSS is the same as pilot code channel in the CDMA context.

In the remaining subsections, we will describe call admission, distribution, and handoff algorithms for the ICA strategy. In our treatment, we assume that there are several classes of traffic sources, where a class-$k$ traffic source has a bandwidth requirement of $b_k \in \{1, 2, \ldots\}$ cK, where $b_k$ is in term of BBUs. Assume that a mobile requesting a connection to the cellular network will run an application whose traffic type belongs to set $K$. Let $\gamma_{\text{avg}}^k$ denote a generic performance threshold required to run the application. This threshold is used for call connection. Let $\gamma_{\text{ho}}^k$ denote the performance threshold below which a new connection must be established. Let $\gamma_{\text{drop}}^k$ denote the minimum tolerable performance threshold for service. If the performance parameter drops below this level, the connection is dropped. The following inequality shows the relation between the performance thresholds:

$$\gamma_{\text{drop}}^k \leq \gamma_{\text{ho}}^k \leq \gamma_{\text{avg}}^k \quad k = 1, 2, \ldots, K \quad (1)$$

The roles that these thresholds play in the call connection, distribution and handoff is discussed in the following subsections.

A. Call Connection Algorithm

A mobile with traffic type $k$, arriving at base station $j$, measures the BSSS transmitted by base station $j$ and other neighboring base stations. Using the BSSS signal, the mobile determine the available BBUs at all the current and all neighboring base stations. Let $C_{ij}^k$ be the current number of BBUs available at base station $j$ that can be used by a mobile at base station $i$ or borrowed by a mobile at base station $i$, where $i, j = 1, 2, \ldots, J$. Note that a mobile can borrow BBUs only if the power that it is expected to transmit on the borrowed channel meets the performance threshold required by its application. Let $\chi$ be the total number of base stations that have the BSSS signals greater than the average performance threshold, i.e., $P_i \geq \gamma_{\text{avg}}^k$. Let $\Theta$ be the sum of the number of BBUs available at all base stations with $P_i \geq \gamma_{\text{avg}}^k$.

The mobile will use the following connection algorithm to determine if it can join the cellular network. First, it will initialize both $\chi$ and $\Theta$ to zero. For each of the neighboring base stations, the mobile will compare the BSSS to the connection threshold $\gamma_{\text{avg}}^k$. If the BSSS is greater than or equal to the connection threshold, it will increment $\chi$ and add the number of available BBUs of that neighboring base station to the total $\Theta$. Once it has completed processing the BSSS of its and all neighboring base stations, the final
value of $\Theta$ will indicate the total available BBUs. If the value of $\Theta$ is greater than or equal to the bandwidth ($b_k$) requested by the call, the mobile is admitted or else it is blocked and cleared from the system. Note that the call connection algorithm is performed in a distributed manner. A mobile will sample the BSSS of each base station that it can hear and make the decision for connection.

B. Call Distribution Algorithm

Once a call is admitted into the system, the mobile has a control of which base station and how many base stations to connect to. The stronger the BSSS of a base station, the higher the probability that the mobile can be connected longer to that base station without requiring a handoff. Since there are multiple base stations that it can connect to, the mobile will first pick those stations that have strong BSSS signals to minimize the occurrence of handoffs and then those base stations that have most available BBUs to reduce the overall network blocking and handoff failure.

Here we propose an uniform call distribution algorithm, where the mobile uniformly distributed its BBU need among base stations. Mobile ranks all base stations in set $\chi$ in the descending order of the base stations status power level and then the list is ranked again in descending order of the number of available BBUs. The mobile will assign one BBU to the first base station on the list and one BBU to the next BS on the list. This continues until all the base stations has been assigned one BBU or there is no more BBU to assign. If there are remaining BBUs at the end of the assignment cycle, the procedure is repeated until there are no more BBUs to be assigned to base stations. Base stations that have no more available BBU at the end of each assignment cycle are eliminated from the list. Once the call distribution algorithm has completed, the mobile will have information on what fraction of total BBUs that it can transmit to each base station.

C. Call Handoff Algorithm

Once the call is admitted into the cellular network, the mobile continuously monitors the power levels of the BSSS on all of its connected ports. When the power level of a link drops below the performance handoff threshold, the mobile will seek new connection(s) at any base station that has available resource or acquire more BBUs from those stations that it already has connections. If no new connection can be established or new BBUs can be acquired before the signal level goes below $\gamma_{drop}$, that connection is dropped. Note that when this event occurs, only that particular connection is dropped, instead of a whole call. For traffic with non-sensitive delay requirement, that portion of the data can be buffered at the mobile unit and transmit at later time when new connection or more BBUs can be obtained.

D. Numerical Results

In this section, the performance of the proposed integrated channel assignment scheme is evaluated in term of new call blocking and handoff failure probabilities and the results are compared to the fixed allocation strategy. Our system model assumes that the new call and handoff rates for all traffic classes are uniformly distributed over the mobile service area. We assume a very large population of mobiles and the average call origination and handoff rates are independent of the number of calls already in progress. We consider that various traffic classes arrive according to an independent Poisson process with rate $\lambda_k$. We assume that the call duration of all traffic types is exponentially distributed with mean $1/\mu_k$. The rate at which the call is hand off and the channel holding time of a call are depended on the velocity of the mobile and the size of the cell. When a mobile crosses a cell boundary, the model assumes that the mobile’s direction change. The direction of travel is assumed to uniformly distributed and independent of speed, where the speed is assumed to be constant. Let $P_{BB}$ be the average fraction of new call of type $k$ that is blocked from entering the system. Let $P_{HD}^{k}$ denote the fraction of handoff attempts that fail for a class-$k$ call.

In the simulation, we assume that there are two types of traffic, a narrowband and a wideband. One can consider a narrowband traffic as a voice call and a wideband traffic as a web browsing session. We assume that the narrowband needs only one BBUs while the wideband traffic requires 6 BBUs. We assume that a cell has a diameter of 1 mile. Mobiles are moving at a speed of $40$ mph. The average length of narrow and wide band calls are 3.5 and 7 minutes, respectively. Each base station is configured to support 24 BBUs and there are 21 base stations deployed in the service area. We simulate the system using equal loading of both narrow and wide band calls in term of number of BBUs. In Fig. 1, we compare the blocking and handoff failure probabilities for fixed channel assignment and our proposed ICA. We denote the narrowband traffic as class 1 and wideband traffic as class 2 and plot both the blocking and handoff failure probabilities as function of traffic loading in term of BBUs. For the fixed channel assignment scheme, both blocking and handoff failures of the narrowband traffic are almost the same since no BBUs are reserved for handoff calls. The handoff failure probability of the wideband traffic is an order of magnitude greater than that of the narrowband traffic. As shown in the plot, the handoff failure probability for class 2 traffic is considerably much higher than that of narrowband traffic. This is because a large number of BBUs must be immediately secured at the arriving cell in order to avoid call dropping.

In going from the fixed channel assignment scheme to our proposed channel assignment strategy, we observe that both the blocking and handoff failure probabilities are reduced significantly. Under medium traffic loading condition, the proposed scheme outperforms the fixed channel assignment scheme by reducing both blocking and handoff probabilities by two orders of magnitude. Importantly, the handoff failure probabilities for both classes of traffic are significantly reduced. The drastic reduction of probabilities results from more efficient usage of BBUs through statistical multiplexing of available resources across different base stations. In Fig. 2, we compare the BBU utilization of fixed channel assignment scheme and our proposed channel assignment scheme, both blocking and handoff failure probabilities for fixed channel assignment and our proposed ICA. We denote the narrowband traffic as class 1 and wideband traffic as class 2 and plot both the blocking and handoff failure probabilities as function of traffic loading in term of BBUs. For the fixed channel assignment scheme, both blocking and handoff failures of the narrowband traffic are almost the same since no BBUs are reserved for handoff calls. The handoff failure probability of the wideband traffic is an order of magnitude greater than that of the narrowband traffic. As shown in the plot, the handoff failure probability for class 2 traffic is considerably much higher than that of narrowband traffic. This is because a large number of BBUs must be immediately secured at the arriving cell in order to avoid call dropping.

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scheme. Under heavy loading condition, the BBU utilization of the proposed scheme is twice of the FCA.

Fig. 2. Comparison of channel utilization for two different channel assignment schemes.

Preliminary simulation results indicate that the proposed ICA strategy can accommodate multimedia traffic in a fair and efficient way. Also, call blocking and handoff failure are reduced for all traffic type under the ICA proposal. In the next section, the generalized notion of call blocking and handoff failure are discussed in the context of channel fading.

III. EXTENSION: GENERALIZED NOTION OF CALL BLOCKING AND HANDOFF FAILURE

In this section we introduce the concept of generalized notion of blocking and handoff failure and set up the mathematical model for the problem. Due to the space limitation, the analysis is not presented here. As mentioned in the introduction section, one advantage of the ICA strategy is that when one of connections is in fade or dropped due to handoff, the whole call is not necessarily effected. In many instances, applications can tolerate a slight decrease in the total required bandwidth for a short period of time without significantly degrade the QoS. Non-delay sensitive applications such as data transfer will see virtually no effect when few of the links are dropped for a short time duration, because data can be buffered and transmitted at later time. For delay sensitive applications such as video conferencing, jitter may be observed in the event of link failure. Although QoS can not be deterministically guaranteed, the effect of few delay jitters is less detrimental than the whole call being dropped.

Due to the multiple link configuration and the flexible mechanism of ICA strategy that allows a call to obtain more or give up BBUs throughout the lifetime of its connection, we have the notion of generalized call blocking and dropping. Since a BBU is a small bandwidth unit, it is possible for a mobile to request more or give up BBUs than the minimum requirement in order to protect against channel fading and handoff failure without a lot of waste of scarce wireless resource. Hence, a call will not be dropped if a few of links have failed. In the context of ICA strategy, dropping of a call only occurs if the number of BBUs goes below the minimum threshold and stays there for a period of time. In the following subsections, we will characterize the wireless channel, formulate the stochastic model that describes the link failure process, and define generalized notion of call blocking and dropping.

A. Connection Model

We assume that a mobile can establish at most $L$ connections at any given time, where each connection is to a different base station. Let $I_n^l$ be the status of the connection to the $l$ base station at time $n$ as seen by the mobile, for $l = 1, 2, \ldots, L.$

$$I_n^l = \begin{cases} 1 & \text{channel is up} \\ 0 & \text{channel is down} \end{cases}$$

We assume that the mobile is moving at a relatively low speed. The channel going up or down is resulted not of inter-cell handoff failure but due to the fading characteristic of the channel. We assume that the channel can be modeled as a first-order Markov process, where

$$P[I_{n+1}^l = 1|I_n^l = 0] = p_d\quad \text{and} \quad P[I_{n+1}^l = 1|I_n^l = 1] = p_u$$

Let $P[I_0^l = 1] = p_u = p_d/(p_d + p_u)$ and $P[I_0^l = 0] = p_d = p_u/(p_d + p_u),$ where $I_0^l$ represents the status of the channel $l$ at the time the mobile joins the network and $p_u$ and $p_d$ are the probabilities that a channel being up or down respectively. We assume that the probability of link failure of all channels are independent and identically distributed. Let $\{Z_n, n \geq 0\}$ represents the number of channels that are up at time $n.$ The probability that there are $j$ links available at the next time instance given that there are currently $i$ links available to the mobile can be expressed as follows:

$$P[Z_{n+1} = j|Z_n = i] = \begin{cases} \frac{\binom{L}{i,j}}{p_u^i (1-p_u)^{L-i}} & i = 0, j \geq 0 \\ \min \{L-j, i\} \sum_{l=i-j}^{\min \{L-j, i\}} \frac{\binom{L-i}{l} p_u^i (1-p_u)^{L-i-l}}{p_u^l (1-p_u)^{L-i-l}} & i \geq j \\ \min \{L-j, i\} \sum_{l=0}^{\min \{L-j, i\}} \frac{\binom{L-i}{l} p_u^i (1-p_u)^{L-i-l}}{p_u^l (1-p_u)^{L-i-l}} & i < j \end{cases}$$

$$P_{g}^{(a,b)} = \binom{b}{a} p_d^a (1-p_d)^{b-a}$$

$$P_{l}^{(a,b)} = \binom{b}{a} p_u^a (1-p_u)^{b-a}$$

where $p_g^{(a,b)}$ and $p_l^{(a,b)}$ are the probabilities that a mobile gains or losses a channels given that there are $b$ channels were down or up in the previous time instance respectively.

Let $Z_0$ represents the number of base stations that a mobile can be connected to at the time the mobile enters the cellular network, and the corresponding probability that it sees $i$ channels being up can be expressed as

$$P[Z_0 = i] = \binom{L}{i} p_u^i (1-p_u)^{L-i}$$

B. Generalized Notion of Call Blocking

Assume that the minimum BBUs required by a call of class $k$ is $M_k - \alpha_k,$ for $\alpha_k \geq 0.$ To prevent a call being dropped due to link
failures, a mobile requests additional BBUs than the minimum required by the application. The additional BBUs are used to meet the mobile’s quality of service requirement in an event if one or more links are down. Note that since a BBU is a very small unit of bandwidth, requiring additional BBUs does not waste scarce wireless resource as compared to the approach proposed in [1] and yet at the same time providing the protection against fading and failure from handoff. For a delay sensitive or strict loss application, $\alpha_k$ can be made larger. For application such as data transfer, $\alpha_k$ can be made small or set to zero. A mobile may wish to join the network even though the number of available BBUs at all base stations may be less than the minimum required BBUs by the application, because the ICA strategy provides a flexible mechanism for it to acquire additional BBUs at a later time.

We assume that the mobile uses the uniform call distribution algorithm as described in section II. Let $a^I_n$ represents the number of available BBUs at a base station $l$ at time $n$. Due to the uniform distribution of BBUs among different base stations, we can assume that the number of available BBUs at all base stations can be approximated as an identical and independent random process. To simplify the analysis, we assume that $\{a^I_n\}$ is identical for all time $n$. Hence, we denote $\{a^I_n\}$ as the number of available BBUs at base station $l$.

Let $\{Y^k_n, n \geq 0\}$ represents the number of BBUs that a call has at time $n$ which can be expressed as follows:

$$Y^k_n = \begin{cases} \min(\sum_{i=1}^{z_n} a^I_i, M_k) & Z_n > 0 \\ \max(n_k, Y^k_n) & Z_n = 0 \end{cases}$$ (7)

Let $n_0$ be the time at which the mobile enters the cellular network. The mobile is admitted into the network if there is enough available BBUs to accommodate its call or $M_k - \alpha_k \leq Y^k_0 \leq M_k$ else it is blocked and cleared from the system. The probability that a call of class $k$ be dropped from entering the system can be easily shown to have the following form:

$$P^k_b = (1 - p_{up})^L + \sum_{z=1}^{L} F^{(z_0)}(M_k - \alpha_k - 1) (L) p_{up}(1 - p_{up})^{L - z_0}$$ (8)

where $F^{(z_0)}$ is the $z_0$-folds convolution of the probability distribution of $F_0$. Although the call blocking probability will be slightly higher than the case when no additional BBUs is required, the mobile application can adjust the parameter $\alpha_k$ that best meets the application QoS at the same time reduces the chance of a call being dropped.

### C. Generalized Notion of Call Dropping

Similar in concept to the generalized call blocking, the call is not considered dropped unless the number of BBUs goes below the minimum threshold requirement and stays there for a period of time. Let us define the following two time sequences: $n^+ = 0, n^- = \min(n : n > n^+_1, Y^k_n < \gamma_k), n^+_2 = \min(n : n > n^+_1, Y^k_n < \gamma_k), n^-_2 = \min(n : n > n^-_1, Y^k_n < \gamma_k), n^+_3 = \min(n : n > n^+_2, Y^k_n < \gamma_k)$, and etc., where $\gamma_k = M_k - \alpha_k$. The time $n^+_1, n^-_1, n^+_2$ and $n^-_2$ and $n^+_3, n^-_3$ and etc. represent those time instances at which the number of BBUs drops below the minimum threshold and those instances at which the number of BBUs reaches above the minimum threshold respectively. Let us define the following sequences: $d^+_1 = n^+_1 - n^+_1, d^+_2 = n^+_2 - n^+_2$, and etc. as the time duration in which the number of BBUs that a mobile has is less than the minimum BBU threshold required by the application. Define $\beta_k$ as the maximum time duration which a call of class $k$ can sustain to have the number of BBUs below the minimum threshold before the call is dropped. Hence, the probability that a call of class $k$ is being dropped can be defined as follows:

$$P^k_d = P[\min_i d^+_i > \beta_k]$$

Its computation is the subject of ongoing work.

### IV. Conclusion

In order to support QoS in third generation cellular communication systems, we have articulated the need for an integrated resource management scheme. We propose a wireless system architecture that alters the relationship between mobile users and fixed base stations. Instead of attaching many mobile users to a single base station, every mobile user interacts and communicates with multiple base stations. The rapidly growing multi-media traffic from mobile users creates one especially challenging problem— that of call handoff. The combination of picocells and high mobility will lead to frequent handoff of high bandwidth streams. How should the available spectral resource be managed to best serve all users? We proposed resource allocation algorithms for the proposed system and studied their performance. We found that even relatively simple algorithms were able to ameliorate the problem of heavy bandwidth users blocking the light users at the same time minimize the blocking and handoff failure and maximize channel utilization efficiency.

We also introduced the mathematical model for studying the generalized notion of call blocking and dropping. The model allows us to study the effectiveness of ICA strategy in preventing a call being dropped due to link failure. Tradeoff study can be performed to understand how much more BBUs need to be requested in order to meet the call’s QoS given certain probability of a channel being down.

The proposed resource management strategy appears to be promising in terms of reducing the blocking and handoff failure and providing protection against harsh fading. Complexities that are introduced by the multiple connections are not discussed here such as synchronization for multiple transceivers and assembly and recording of BBU cells. Since the mobile is connected to multiple base stations simultaneously, additional signalling is required to identify the different links which the mobile uses. Tradeoff study of these issues must be performed.

### REFERENCES

