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ABSTRACT

Hierarchical cellular networks that employ microcells with overlaying macrocells have been proposed to increase the traffic-carrying capacity and circuit quality. Variations in the traffic loads among cells will lessen the traffic-carrying capacity. Moreover, the handoff procedure usually takes place when the call crosses the cell boundary. An ineffective management will increase the system overheads, such as channel switch, data switch, and even network switch. The invetigation proposes an effective load balance and handoff management strategy. This strategy are implemented to solve traffic-adaption   problem that can enhance the   traffic-carrying capacity for variations in traffic. For the management of handoff procedure, our strategy considers the mobility of mobile hosts and the bandwidth utilization in macrocells. It can descrease the number of handoffs and, accordingly, lessen the system overhead. Furthermore, the simulation results are presented to confirm the efficiency of the proposed strategy.

INTRODUCTION

Hierarchical microcell/ macrocell architectures have been proposed [Byungchan 2001, Bo 2001, Chung 2005, Iera 2002, Liu 2005, Li2001, Mar 2000, Shan 2003, Zhao 2005] to increase the traffic-carrying capacity and circuit quality. However, a cellular system has a probability to experience variations in traffic. To provide a high quality communication service for mobile subscribers and to enhance a high traffic-carrying capacity when there are variations in traffic have received much attention [Huang 2004]. Moreover, the handoff procedure usually takes place when the call crosses the cell boundary. In general, the handoff procedure including data tramission, channel switching, and even network switching takes tens or hundreds ms. An effective decrease of the number of handoff procedures that can lessen the system overhead is meaningful.

A geographical area is covered by both of a microcell and a macrocell, where each cell has a base transceiver station (BTS) in its center. Each BTS has a set of primary channels [Chen 2002, Cao 2003, Cao 2000, Katzela 1996]. When a call arrives at an area, this call is first handled by the BTS of a cell. If no primary channels are available in this cell to serve this call, the BTS of the overlaid cell is activated to handle this call. If an available primary channel can be found, this channel is assigned for establishing the communication session of this call. Otherwise, the call is blocked. Accordingly, the number of channels allocated to a BTS will affect the communication quality in this cell and the allocations of system channels among cells will affect the traffic-carrying capacity of a cellular system. A reasonable allocation should provide more channels to each cell with heavy traffic than with light traffic. Otherwise, it will experience that the heavy traffic cells do not have sufficient channels to carry their traffic loads but the light traffic cells have many available channels. Thus, the traffic-carrying capacity of a cellular system is reduced and the call blocking probability arises. To consider real-life networks, the traffic distributions among cells should be changeable according to various conditions. In order to achieve higher channel utilization, when there are variations in traffic, the channel allocations among cells should be effectively reallocated according to current traffic profile.

Each service area is covered by both microcells and macrocells. When a call arrives at an area, the channels of the targeted microcell or the channels of targeted macrocell can be used to handle this call. Many cell selection strategies have been proposed to handle the handoff procedures. Micro-Macro strategy [Zhao 2005] that when a call arrive, the targeted microcell is first to handle this call, if no available channels in this microcell, the overlapped macrocell then are activated to handle this call. The strategy prioritizes the channels of microcells to be assigned to incoming calls. The problem in this assignment is on high-mobility mobile hosts (MHs) that usually crosse the cell boundary will increase the number of handoff procedures. To lessen the load of handoffs, speed-sensitive cell selection strategies are proposed, i.e., high-mobility MHs are prioritized to acquire the channels of macrocells and low-mobility MHs are prioritized to acquire the channels of microcells. However, these strategies can not present a good traffic-carrying capacity [Dazhong 2005, Shan 2003, Zhao 2005].

In light of above discussions, this study presents an adaptive load balance and handoff management strategy. This strategy can dynamically allocate channels among cells according to variations in traffic to solve the traffic-adaptive problem and, accordingly, enhance the traffic-carrying capacity of cellular systems. For the handoff management, the assignment to calls considers the mobility and the available channels of macrocells. The rest of this paper is organized as follows. Section 2 introduces the system model. In section 3, we describe the proposed strategy. The numerical results are given in Section 4. Conclusions are finally offered in Section 5.

SYSTEM MODEL

A microcell/macrocell cellular system is a hierarchical cellular system, where a macrocell overlays a set of microcells. Each cell has a BTS in its center and in which a number of mobile hosts (MHs) are traversing. The mobility of a MH is valuated as Definition 1.

Definition 1: Given a mobile host h, the mobility of h, denoted as $M(h)$, is the number of microcells that h traverse for a specified duration. Mobile host h is termed as a high mobility host if $M(h) > s_h$, where s_h is a speed threshold.

For a microcell or macrocell system, the properties of channel allocations to cells and assignments to calls can be described as follows. A communication session (or a call) can be established if a channel is assigned for supporting the communication between the mobile host and the BTS. Two cells cannot concurrently assign the same channel to calls if their geographical distance is less than $Dmin$; otherwise, their communication sessions interfere with each other. This situation is referred to *channel interference* [Cao 2005, Kateza 1996].

Definition 2: Given a cell C, the set of interfering neighbors of cell C, denoted by $IN(C)$, is: $IN(C) = \{$cell $C' \mid$ the BTSs of cells C and C' operate at the same band and $Dist(C, C') < Dmin\}$, where $Dist(C, C')$ is the geographical distance between cells C and C'.

Cell-based channel set allocations are responsible for allocating each cell C a set of channels $P(C)$, termed as the primary channels of cell C. The primary channel allocations among cells must ensure if channel r is a primary channel of cell C, no other cells in $IN(C)$ can keep this channel as their primary channel. Therefore, Def. 3 is the condition of primary channel allocations. Besides the primary channel set $P(C)$ of cell C, we also use $S(C)$, termed as secondary channel set, to denote other non-primary channels of cell C. $P(C)$ denotes the channels that cell C can assign these channels to incoming calls. Moreover, channel r is available to cell C if r currently is not been assigned to any call in C. Def. 4 accordingly defines the available channels of C.

Definition 3: (The condition of primary channel allocation): Given two distinct cells C and C', where $C' \in IN(C)$, the condition of primary channel allocation between cells C and C' is $P(C) \cap P(C') = \varnothing$.

Definition 4: (Available primary channel): Given a cell *C* with primary channels *P(C)*, the available channels of *C*, denoted as *A(P(C))*, is *A(P(C))*={*r*| *r*∈*P(C)* and *r* is available to *C*}.

The channel allocation to cells must ensure that any two cells whose geographical distance is less than D_{min} do not acquire the same primary channel [Cao 2000]. Accordingly, distinct cells can concurrently assign its primary channels to calls and ensure that these communication sessions do not interfere with one another. In this study, distinct cells can dynamically change their primary channel allocations to satisfy the variations in traffic or in cell-configuration. Let the primary cells of a channel *r*, denoted by *P(r)*, be all of the cells, which contain a primary channel *r* in the system. According to Def. 2, if cell *C* acquires a new primary channel *r*, the original owners of this primary channel *r* in *IN(C)* will be forbidden to keep channel *r* as their primary channel.

Definition 5: The interfering primary cells of channel *r* relative to cell *C* are denoted by *IP(C, r)*, where *IP(C, r)* = *P(r)* ∩ *IN(C)*.

Figure 1: Hierarchical infrastructure network.
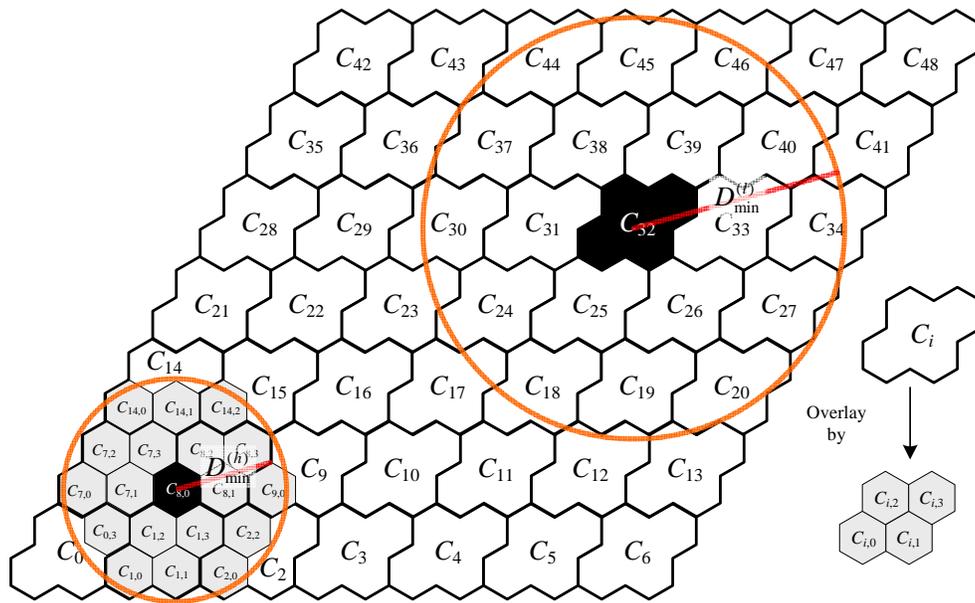
Cells in *IP(C, r)* are the cells that cannot keep channel *r* as their primary channel, when cell *C* acquires a new primary channel. In general, each macrocell C_i overlays with *k* microcells, $C_{i,0}$, $C_{i,1}$,…, $C_{i,k-1}$. For convenience, "$C_{i,j} \in C_i$" is used to denote that microcell $C_{i,j}$ is overlaid by macrocell C_i. Moreover, we also use B_H and B_L to denote the system channels and $D_{min}^{(h)}$ and $D_{min}^{(l)}$ to denote the minimum reuse distances for high-mobility microcells and low-mobility macrocells, respectively. Figure 1 illustrates a cell configuration. Each macrocell C_i overlays 4 microcells: $C_{i,0}$, $C_{i,1}$,…, and $C_{i,4}$. $D_{min}^{(h)}$ and $D_{min}^{(l)}$ are $\sqrt{21}R^{(h)}$ and $\sqrt{21}R^{(l)}$, where $R^{(h)}$ and $R^{(l)}$ are the radiuses of a microcell and a macrocell, respectively. The interfering neighbors *IN(C_{32})* of macrocell C_{32} include macrocells {C_{18}-C_{20}, C_{24}-C_{27}, C_{30}-C_{34}, C_{37}-C_{40}, C_{44}-C_{46}}. If channel *r* is the primary channel of C_{32}, other cells in *IN(C_{33})* cannot keep this channel as their primary channel. The primary channel allocations for microcells are also similar. For instance, these microcells in *IN($C_{8,0}$)* cannot keep the primary channels of $C_{8,0}$ as their primary channels.

SUBJECT STRATEGY

The subject strategy includes a cell-based channel allocation and a call-based channel assignment. The first term is used to allocate each cell C a primary channels $P(C)$. Accordingly, when calls arrived at C, the call-based channel assignment is used to assign channels of $P(C)$ to calls.

Cell-based channel allocation

In this section, we first evaluate the call blocking probabilities of a microcell and a macrocell. Accordingly, two reward functions are defined. These two reward functions consider the call blocking probabilities with traffic loads when a microcell and a macrocell acquire a new primary channel, respectively. Then, we give a primary channel reallocation algorithm in which the reward functions are used to determine the opportune moments for activating the primary channel reallocations.

In a single-band cellular system, Erlang B formula (see (1)) is often used to evaluate the call blocking probability of a cell with the traffic load λ (in erlangs) and the number n of primary channels. In the following contents, notation $\|S\|$ is used to denote the number of elements in a given set S.

$$Prob(\lambda, n) = \frac{\lambda^n}{n!}\left[\sum_{k=0}^{n} \frac{\lambda^k}{k!}\right]^{-1}. \tag{1}$$

Let C_i be a macrocell which overlays microcells: $C_{i,0}, C_{i,1}\ldots$, and $\lambda(C_{i,j})$ be the traffic load in the area covered by microcell $C_{i,j}$. When a call arrives at the area which covered by both microcell $C_{i,j}$ and macrocell C_i, this call is first handled by the BTS of microcell $C_{i,j}$. Therefore, in microcell $C_{i,j}$, the probability that no available primary channels to serve an incoming call equals to $Prob(\lambda(C_{i,j}), \|P_C(C_{i,j})\|)$. Since each macrocell overlays several microcells, the overall traffic load $\lambda(C_i)$ in the covered area of macrocell C_i can be defined as follows:

$$\lambda(C_i) = \sum_{C_{i,j} \in C_i} \lambda(C_{i,j}). \tag{2}$$

$$\mu(C_i) = \sum_{C_{i,j} \in C_i} \frac{Prob\big(\lambda(C_{i,j}), \|P_C(C_{i,j})\|\big) \cdot \lambda(C_{i,j})}{\lambda(C_i)} \tag{3}$$

$$REWARD(C, r) = \big(Prob(\lambda(C), |P(C)|) - Prob(\lambda(C), |P(C) \cup \{r\}|)\big) \cdot \lambda(C) - \\ \sum_{C' \in IP(C,r)} \big(Prob(\lambda(C'), |P(C') - \{r\}|) - Prob(\lambda(C'), |P(C')|)\big) \cdot \lambda(C') \tag{4}$$

$$REWARD(C, r) = \big(Prob(\lambda(C) \cdot \mu(C), |P(C)|) - Prob(\lambda(C) \cdot \mu(C), |P(C) \cup \{r\}|)\big) \cdot \lambda(C) \cdot \mu(C) - \\ \sum_{C' \in IP(C,r)} \big(Prob(\lambda(C') \cdot \mu(C'), |P(C')|) - Prob(\lambda(C') \cdot \mu(C'), |P(C') - \{r\}|)\big) \cdot \lambda(C') \cdot \mu(C') \tag{5}$$

$$\begin{cases} P(C) \leftarrow P(C) \cup \{r\} \text{ and } S(C) \leftarrow S(C) - \{r\}, \\ P(C') \leftarrow P(C') - \{r\} \text{ and } S(C') \leftarrow S(C') \cup \{r\}, \text{ where } C' \in IP(C, r). \end{cases} \tag{6}$$

When a call arrives at macrocell C_i, the probability $\mu(C_i)$ that no available primary channel at its arrived microcell can be defined as (3)

Accordingly, the average traffic load that must be by carried by macrocell C_i using its primary channels is $\lambda(C_i) \cdot \mu(C_i)$. Therefore, the average call blocking probability in macrocell C_i is equal to $Prob(\lambda(C_i) \cdot \mu(C_i), \|P_C(C_i)\|)$.

The reward functions can be used to determine the instant that a cell needs to reallocate its primary channel. Cell C is allowed to request a channel r as its new primary channel only when the utilization of channel r in cell C is larger than in its original owner(s). For convenience, we use *REWARD(C, r)* to present the utilization difference of cell C acquiring a new channel r and the original owners losing their primary channel r. The *REWARD* functions for the primary channel reallocation of microcells and macrocells are defined in (4) and (5), respectively.

According to Def. 2, when cell C acquires a new primary channel r, other cells in $IP(C, r)$ cannot keep channel r as their primary channel. The *REWARD* functions evaluate the utilization, considering the number of primary channels and the traffic loads of cells C and $IP(C, r)$, if cell C acquires a new primary channel and other cell C' in $IP(C, r)$ gives up its primary channel r. The value of *REWARD(C, r)>0* means that the utilization after reallocating channel r to cell C should be larger than the current allocation.

Each cell C periodically detects its traffic loads by counting the number of mobile hosts in the area. If the reward value of a channel r is greater than 0, cell C increases r as its new primary, and the original owners decrease r. The change of primary and secondary channels when cell C acquires a new primary channel is described as (6).

In the initialization, each microcell/ macrocell C is allocated a primary channel set $P(C)$, which must satisfy the condition of primary channel allocations. Then, cell C dynamically performs Steps 1 to 7 to perform channel reallocations in order to maintain its allocation to satisfy both the current cell-configuration and traffic profile. It cannot enhance the traffic-carrying capacity of a service area, if a cell acquires a new primary channel and its overlapped cell gives its primary channel to other cells. To avoid this condition, before cell C activates channel reallocations, C first requests its overlapped cell(s) to forbid their reallocations in Step 1. After the overlapped cells of C accept the request, i.e., the channel reallocations are forbidden to perform in their service areas, they reply to C in Step 2. Then C sends a request to its interfering neighboring cells $IN(C)$ in Step 3 for acquiring their traffic loads and primary channel allocations. In Step 4, after cell C has collected the information, it evaluates the *REWARD* value for each secondary channel r. If *REWARD(C, r) > 0*, cell C has a probability of keeping channel r as its new primary channel by performing Steps 5-7.

There are two cases, including $IP(C, r) \neq \varnothing$ and $IP(C, r) = \varnothing$, when cell C performs Steps 5 and 6. For $IP(C, r) \neq \varnothing$, there are interfering primary cells of channel r and, therefore, cell C performs Steps 5(a) and 6(a) to consult with these cells. Moreover, if there are some competitors in $IN(C)$ raced with cell C in order to acquire the same channel r, these interfering primary cells arbitrate a cell to acquire their primary channel r. For $IP(C, r) = \varnothing$, it represents that no cells contain a primary channel r in $IN(C)$ and, intuitively, cell C can acquire channel r. However, cell C must avoid that other cells in $IN(C)$ simultaneously acquire this channel r. Therefore, cell C performs Steps 5(b) and 6(b) to

consult with each cell in *IN*(*C*) to do the channel reallocation. Cell *C* repeatedly performs Steps 3 to 6 to keep other channels as its new primary channels until no other secondary channel *r′* in cell *C* has positive *REWARD*(*C*, *r′*) value. Finally, cell *C* performs Step 7 to notify its overlapped cells that it has completed its reallocations and the control of performing channel reallocations can turn to its overlapped cells. The detailed operations of each step are described as follows.

Notations: The following notations are used in this algorithm for cell *C*.

− *ReAln*(*C*) contains ″Inactivated″, ″Overlapped ″ and ″Itself″ to denote that the channel reallocations are currently inactivated by both cell *C* and its overlapped cell(s), performed by its overlapped cell(s), and performed by cell *C* itself, respectively.

− *TS*(*C, r*) is a timestamp which is used to determine the order when more than one cell concurrently activates to reallocate the same channel *r*.

− *ChStatus*(*C*, *r*) contains ″Activated″, ″Inactivated″, and ″Ready″ to denote that the reallocation of channel *r* is activated, not activated, and ready to be activated by cell *C*, respectively.

− *Competitor*(*C*, *r*) records the cells in *IN*(*C*), which are competed with cell *C* in order to acquire a new primary channel *r*.

Initialization: Cell *C* contains a primary channel set *P*(*C*) and sets *ReAln*(*C*) to ″Inactivated″. For each channel *r*, cell *C* also sets *ChStatus*(*C*, *r*) to ″Inactivated″, *TS*(*C*, *r*) to 0, and *Competitor*(*C, r*) to $\varnothing$. Then, cell *C* periodically performs the following steps in order to maintain its allocated primary channels to satisfy the traffic distribution.

Step 1: Cell *C* sends a *FORBID*(*C*) message to its overlapped cell(s). When its overlapped cell *C′* has received the *FORBID*(*C*) message, if its *ReAln*(*C*)= ″Overlapped″ or ″Inactivated″, cell *C′* sets *ReAln*(*C′*) to ″Overlapped″ and, then, sends *BeFORBIDDEN* ("True") back; otherwise, cell *C′* sends *BeFORBIDDEN* ("False") back to cell *C*.

Step 2: If each overlapped cell of cell *C* has sent *BeFORBIDDEN*("True") back, cell *C* sets *ReAln*(*C*) to ″Itself″, *ChStatus*(*C, r*) to ″Ready″, *Competitor*(*C, r*) to *Competitor*(*C, r*)∪{*C*}, and performs Steps 3 to 6 to acquire channel *r*. Otherwise, cell *C* performs Step 7.

Step 3: If *ReAln*(*C*)≠″Inactivated″, cell *C* sends a *REQUEST*(*C*) to each cell *C′* in *IN*(*C*) for acquiring the state *X*, where *X*={(λ(*C′*), *P*(*C′*) | cell *C′*∈*IN*(*C*)}. Accordingly, when each cell C′ in *IN*(*C*) receives a *REQUEST*(*C′*), cell *C′* must send a *REPLY*(λ(*C′*), *P*(*C′*)) back to cell C.

Step 4: After acquiring a *REPLY*(λ(*C′*), *P*(*C′*)) from each cell *C′*∈*IN*(*C*), cell *C* can acquire status *X* and, accordingly, calculates *REWARD*(*C*, *r*) for each channel *r*∈*S*(*C*). If *REWARD*(*C*, *r*)>0, cell *C* performs Steps 5 and 6 for acquiring channel *r* as its new primary channel.

Step 5: Cell *C* generates a timestamp *TS*(*C*, *r*) according to the rule in the Lamport's logical clock system and sets *ChStatus*(*C*, *r*) to ″Activated″.

(5a) If *IP*(*C*, *r*)≠$\varnothing$, cell *C* sends *INFORM*(*C*, *r*, *TS*(*C*, *r*)) message to each cell *C′* in *IP*(*C*, *r*).

(5b) If IP(C, r)=∅, cell C sends *INFORM*(C, r, TS(C, r)) message to each cell C' in *IN*(C), where the *INFORM*(C, r, TS(C, r)) messages are used to inform other cells in *IP*(C, r) or in *IN*(C) that cell C wants to acquire channel r.

Step 6: Cell C consults with others for acquiring a new primary channel r. If *IP*(C, r)≠∅, cell C must consult with each cell C' in *IP*(C, r), i.e., Step 6(a); otherwise, cell C must consult with each cell C' in *IN*(C), i.e., Step 6(b).

The message-passing sequence to consult between cells C and C' includes: C first sends *INFORM*() to C' in Step 5; C' replies *REPLY*() back to C in Step 6-1; C sends *RESULT*() to C' in Step 6-2; C' sends *EXCHANGE*() to C in Step 6-3; The primary channel exchange is finished after C receives *EXCHANGE*() from C' in Step 6-4.

<u>Step 6-1</u>: After cell C' has received the *INFORM*(C, r, TS(C, r)) from cell C, cell C' replies ″Req_allow″ or ″Req_deny″ back to cell C based on one of the following three rules and if cell C' sends *REPLY*(″Req_allow″) back to cell C, cell C' sets *Competitor*(C', r) to *Competitor*(C', r)∪{C}.

(R1). When *ChStatus*(C', r)=″Inactivated″ and channel r∈P(C'), it sets *ChStatus*(C', r) to ″Activated″ and sends *REPLY*(″Req_allow″) back to cell C.

(R2). When *ChStatus*(C', r)=″Activated″, for each C″∈*Competitor*(C', r), if *Dist*(C″, C')≥Dmin, it sends *REPLY*(″Req_allow″) back to cell C; otherwise, it sends *REPLY*(″Req_deny″) back.

(R3). When *ChStatus*(C', r)=″Ready″, if *Dist*(C', C)<D_{min} and TS(C', r)<TS(C, r), it sends *REPLY*(″Req_deny″) back to cell C; otherwise, it sets *ChStatus*(C' ,r) to ″Activated″ and sends *REPLY*(″Req_allow″) back.

<u>Step 6.2</u>: If each cell C' in *IP*(C, r) for case (5a) or *IN*(C) for case (5b) replies ″Req_allow″ message back, cell C sends a *RESULT*(r, ″Successful″) back to C'; otherwise, it sends a *RESULT*(r, ″Unsuccessful″) back to C'. (Notably, ″Successful″ means the exchange of primary channel r can be achieved.)

<u>Step 6.3</u>: After cell C' receives a *RESULT*(r, result) message, it performs the following operations:

−   If result=″Successful″, it sets P(C') to P(C')−{r} and S(C') to S(C')∪{r}.
−   Sets *ChStatus*(C', r) to ″Inactivated″; *Competitor*(C, r) to ∅.
−   Sends *EXCHANGE*(r) back to cell C.

<u>Step 6.4</u>: After each cell C' sends *EXCHANGE*(r) back, where C'∈*IP*(C, r) for case (5a) or C'∈*IN*(C) for case (5b), cell C' performs the following operations:

−   If the exchange of primary channel r can be achieved (see Step 6.2), it sets P(C) to P(C)∪{r} and S(C) to S(C)−{r}.
−   Sets *ChStatus*(C', r) to ″Inactivated″ and *Competitor*(C', r) to ∅.

Step 7: After all of the reallocations are completed, i.e., *ChStatus*(C, r)= ″Inactivated″ for each channel r, cell C sends *TURNTO*(C) message to each overlapped cell(s). Moreover, if the overlapped cell C' has received all of the *TURNTO*() messages from its overlapped cell(s), cell C' sets *ReAln*(C') to ″Inactivated″.

Suppose macrocells C_3, C_{14}, C_{18}, C_{22}, C_{33}, C_{37}, and C_{48} in

Figure **1** contain a primary channel r. When macrocell C_i wants to activate the reallocations for keeping channels as its new primary channels, it must ensure that no channel reallocations are currently performed by its overlapped microcell $C_{i,j}$, where $j = 0, 1, \ldots,$ and 6. We assume that after cells C_{23} and C_{32} have performed Steps 1 and 2, both of them evaluate their secondary channel r for positive reward value, i.e., *REWARD*$(C_{23}, r)>0$ and *REWARD*$(C_{32}, r)>0$. Since *IP*$(C_{23}, r) = \{C_{18}, C_{22}, C_{37}\}$ and *IP*$(C_{32}, r) = \{C_{18}, C_{33}, C_{37}\}$, C_{23} and C_{32} perform Steps 5(a) and 6(a). C_{23} sends an *INFORM* message to C_{18}, C_{22}, and C_{37} and C_{23} sends an *INFORM* message to cells C_{18}, C_{33}, and C_{37}. Since $Dist(C_{23}, C_{32}) > D_{min}^{(l)}$, C_{23} and C_{32} can get an *REPLY*("Req_allow") message from $\{C_{18}, C_{22}, C_{37}\}$ and $\{C_{18}, C_{33}, C_{37}\}$. Then, both C_{23} and C_{32} send *RESULT*$(r$, "Successful") to their interfering primary cells of channel r. After their interfering primary cells change channel r as their secondary channel and send *EXCHANGE*(r) back to C_{23} and C_{32}, C_{23} and C_{32} can acquire this new primary channel r. Accordingly, after C_{23} and C_{32} acquired a new channel r, C_{18}, C_{22}, C_{33}, and C_{37} cannot keep r as their primary channel. In this case, both *IP*(C_{43}, r) and *IP*(C_{44}, r) are empty, if either C_{43} or C_{44} activates the reallocation of channel r, it can acquire this channel after consulting with its interfering neighboring cells. If C_{43} and C_{44} concurrently activate the reallocation of channel r, in (R3) of Step 6-1, the cell that contains a smaller timestamp can keep channel r as its new primary channel.

Call-based Channel Assignment

When a call with the targeted MH h arrives at the area of microcell $C_{i,j}$, the system first checks the mobility of h and the available channels of the overlapped macrocell C_i. If h is a high mobility host, i.e., $M(h) > s_h$, and the available channels of C_i are sufficient, i.e., $|A(P(C)) > n_P$, the system assign an available channels of C_i to this call. Then, the system checks the available channels $C_{i,j}$ of microcell $C_{i,j}$. If there are available in $P(C_{i,j})$, the system assigns an available channels of $P(C_{i,j})$ to this call. Otherwise, the system assigns an available channel of $P(C_i)$ to this call. The call is blocked only when no available channels can be found in both of $P(C_{i,j})$ and $P(C_i)$. The formal representation is shown as Figure 2.

**Figure 2: Call-based channel assignment procedure.**
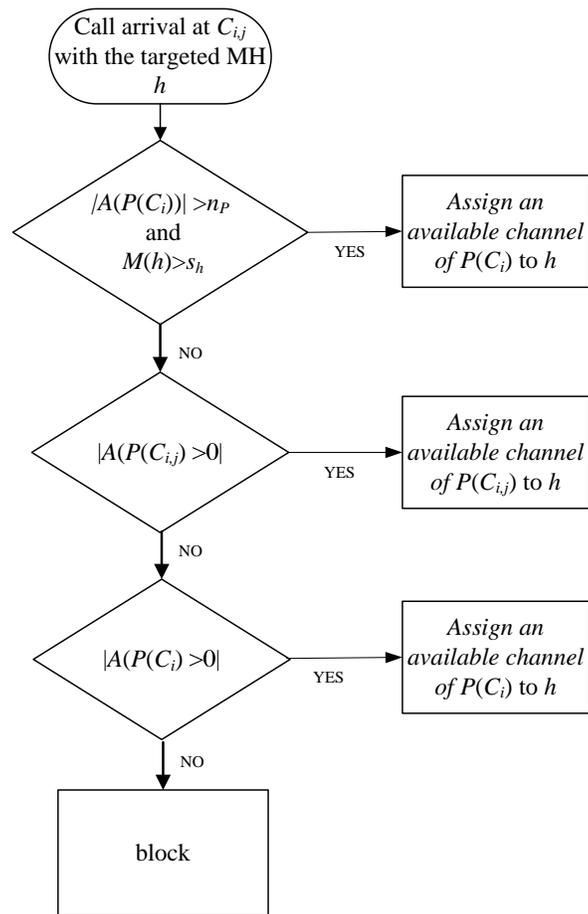
SIMULATION RESULTS

The simulation environment has 49 macrocells, arranged as 7-parallelogram structure, where the radius of a microcell is 100 meters and each macrocell overlaps 4 microcells. The reuse distances $D_{\min}^{(h)}$ and $D_{\min}^{(l)}$ are $\sqrt{21}R^{(h)}$ and $\sqrt{21}R^{(l)}$, where $R^{(h)}$ and $R^{(l)}$ are the radiuses of a microcell and a macrocell, respectively. The frequency bands for microcells and macrocells are 140 and 280 channels, respectively. Initially, each microcell and microcell has 20 and 40 channels, respectively.

The mobility of a mobile host is represented as the speed and is generated according to a random process from 30 to 100 km/hour. The call arrival rate of each MH is generated according to the random process from 2.5 to 4.7 calls/hour and the average call holding time is 3 minutes. In the simulation, our reallocation strategy is first employed to determine the channel allocation among microcells and macrocells. Accordingly, our channel assignment strategy is then to assign channels to incoming calls.

Figure 3 describes the call blocking probabilities of Micro-Macro, Speed-Sensitive, and our strategy under overall calls, handoff calls, and new calls. The results reveal that the adaptive cell-based channel allocation algorithm can make the call-based channel assignment strategy more efficient to utilize the allocated channels. The reason can be described as follows. In other strategies, the primary channel allocation cannot conform to the traffic distributions.
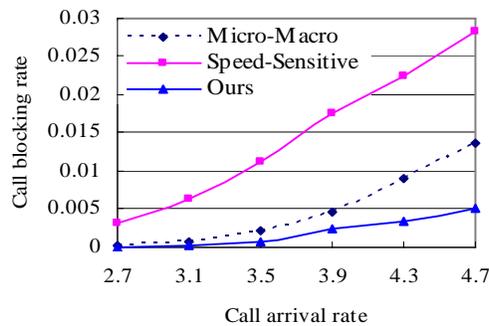
**Figure 3: Call blocking probability.**
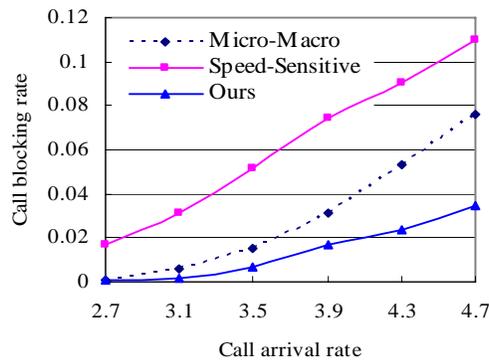
(a) Overall calls
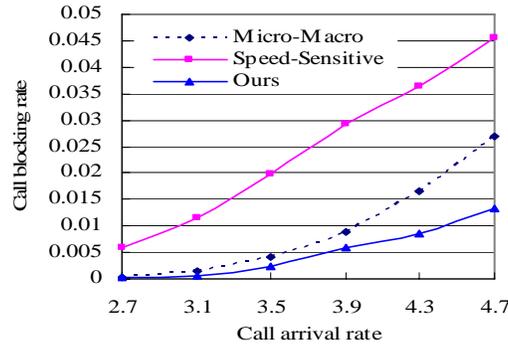
(b) Handoff calls

(c) New calls

Heavy cells cannot acquire sufficient primary channels to serve the incoming calls when other light traffic cells still have some available channels. Our strategy can adapt to the variations in traffic. Therefore, heavy traffic cells have a larger probability to acquire more channels than light traffic cells. Accordingly, the traffic-carrying capacity is larger. Figure 4 describes the average number of handoffs of MHs during one hour. Our strategy presents better performance than Micro-Macro strategy not only the traffic-carrying capacity but also the system overhead.

Figure 4:   Number of   handoffs.
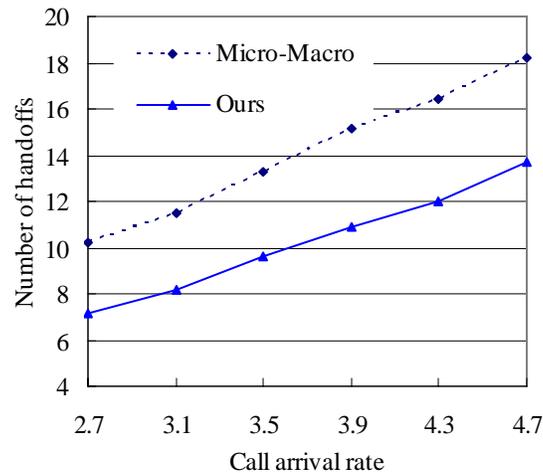
CONCLUSION

The investigation proposed an effective load balance and handoff management strategy. This strategy was implemented to solve traffic-adaption problem that can enhance the traffic-carrying capacity for variations in traffic. For the management of handoff procedure, our strategy considers the mobility of mobile hosts and the bandwidth utilization in macrocells. It can descrease the number of handoffs and, accordingly, lessen the system overhead. Considering ergonomic and economic factors to reallocate channels among cells that can satisfy new trends in the telecommunication industry is one of our future works.

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