An Adaptive Cross-layer Bandwidth Scheduling Strategy for the Speed-Sensitive Strategy in Hierarchical Cellular Networks

JONG-SHIN CHEN[1], MEI-WEN LI[2], NENG-CHUNG WANG[3], YUNG-FA HUANG [4]
[12]Department of Information and Communication Engineering
Chaoyang University of Technology
168 Jifong E. Rd., Wufong Township Taichung County, 41349, Taiwan, R.O.C.
[3]Department of Computer Science and Information Engineering
National United University
1, Lienda, Miaoli 36003, Taiwan, R.O.C.
{[1]jschen26, [2]s9630603, [4]yfahuang}@cyut.edu.tw, [3]ncwang@nuu.edu.tw

Abstract: - Efficient bandwidth scheduling of wireless bandwidth is critical to cellular system performance. Bandwidth scheduling methods can be divided into cell-layer channel allocation and call-layer channel assignment. Previous studies are focused on the latter type of method. Some problems, such as traffic-load variations among base stations (BSs) and BSs failed to provide wireless communication service, are the cell-layer problems and are difficult to handle using the call-layer methods. Therefore, this study presents an adaptive cross-layer bandwidth scheduling strategy for hierarchical cellular networks. This strategy is implemented to solve the traffic-adaptation and the fault tolerance problem according to the speed-sensitive call-layer method.

Key-Words: - Cross-layer, speed sensing, traffic adaptation, and fault tolerance.

1 Introduction

Hierarchical microcell/ macrocell architectures have been proposed [3-4, 6, 9, 12-13, 18-19] to increase the traffic-carrying capacity and circuit quality. A major drawback is that a large number of handoff procedures usually take place when the calls crosse the cell boundary. The large number of handoffs increase will increase the system overheads to do channel switch, data switch, and even network switch. Accordingly, the speed sensitive allocation strategy, termed as the SS strategy, that can decrease the handoff probability was applied [7, 12-13, 15, 18]. However, some system problems such as the imbalance of the traffic loads with the occupied bandwidth or base stations (BSs) failed to provide wireless communication service will lessen the traffic-carrying capacity of the SS strategy. Therefore, providing a traffic-adaptive and fault-tolerant management strategy for the SS strategy is vitally meaningful.

A geographical area is overlapped by both of microcells and macrocells, where each macrocell is covered by a number of microcells. Each cell has a BS to support wireless communications of a number of mobile hosts (MHs). The available system bandwidth for providing wireless communication service is divided into two independent subbands, where one is allocated to the microcell network and the other is allocated to the macrocell network. For each band of a network (the microcell network or the macrocell network), the band is partitioned into a set of non-interfering channels using various techniques such as frequency division, time division, code division, the combination of the techniques. Accordingly, each cell can acquire a number of channels. A communication session (or a call) can be established if enough channel(s) can be allocated for supporting the communication between the MH and the BS. Notably, two neighboring cells can not acquire the same channels. Otherwise, the calls using the same channels at different cells will interfere with other. This situation is referred to channel interference.

Since the channels of two neighboring cells are different, when a call carried by a MH moves from a cell to its neighboring cell, a handoff procedure will take place. In general, the handoff procedure including data tramission, channel switching, and even network switching takes tens or hundreds ms. Since the cell density of a hierarchical network is large, a MH has high probability to cross the cell boundary and needs to do handoffs. To light the handoff problem, the speed-sensitive assignment strategies are applied, 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 to establish the communication sessions.

Each cell has a set of primary channels [5, 10]. When a call arrives at an area, this call is handled by the BS a cell. If no primary channels are available in this cell to serve this call, the call will be blocked. Accordingly, the number of channels allocated to a cell 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.

Efficient bandwidth scheduling of wireless bandwidth is critical to cellular system performance. Bandwidth scheduling methods can be divided into cell-layer channel allocation and call-layer channel assignment. The former type of method is responsible for allocating system channels to cells. Accordingly, when calls arrive at cells, the latter type of method is activated in each cell to assign channels to calls to establish communication sessions. Previous studies are focused on the latter type of method [2, 5, 11-12, 14, 16-17, 22]. Some problems, such as traffic-load variations among base stations (BSs) and BSs failed to provide wireless communication service, are the cell-layer problems and are difficult to handle using the call-layer methods.

In light of above discussions, this study presents an adaptive cross-layer bandwidth scheduling strategy for the SS strategy. This strategy is implemented to solve the traffic-adaptation and the fault tolerance problem according to the speed-sensitive call-layer method.

2 System Model and SS Strategy

This section first presents the system model and, then, using the defined system model to present the SS strategy.

A microcell/ macrocell cellular system is a hierarchical cellular system, where a macrocell overlays a set of microcells. Each cell has a BS in its center to handle the wireless communications of a number of mobile hosts (MHs) in its covered area. The mobility of a MH is valuated as Def. 1.

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

The available system bandwidth is divided into two disjoint sub-bands: B_{micro} and B_{macro}, where B_{micro} is used for the microcells and B_{macro} is used for the macrocells.

For a microcell (or macrocell) system, the given sub-band B is divided into a number of disjoint units (termed as channels). Each cell C is given a subset $P(C)$ of B, termed as the primary channels of C. When a call arrives at C, $P(C)$ is used to serve the call. Two cells cannot concurrently assign the same channel to calls if their geographical distance is less than D_{min}; otherwise, their communication sessions interfere with each other. This situation is referred to *channel interference* [5, 10].

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

According to Def. 2, a cell C with its interfering neighbors $IN(C)$ can not contain the same channel(s) as their primary channel(s). 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 the secondary channel set, to denote other non-primary channels of cell C, where $S(C) = B_{CH} - P(C)$.

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 $P(C) \cap P(C') = \emptyset$.

For cell C, $P(C)$ is used to serve the calls arrived at C. For channels $P(C)$, a channel *ch* is available to C if *ch* currently is not been assigned to any call in C. Definition 4 accordingly defines the available channels of C.

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 $A(P(C))=\{ch \mid ch \in P(C)$ and ch is available to $C\}$.

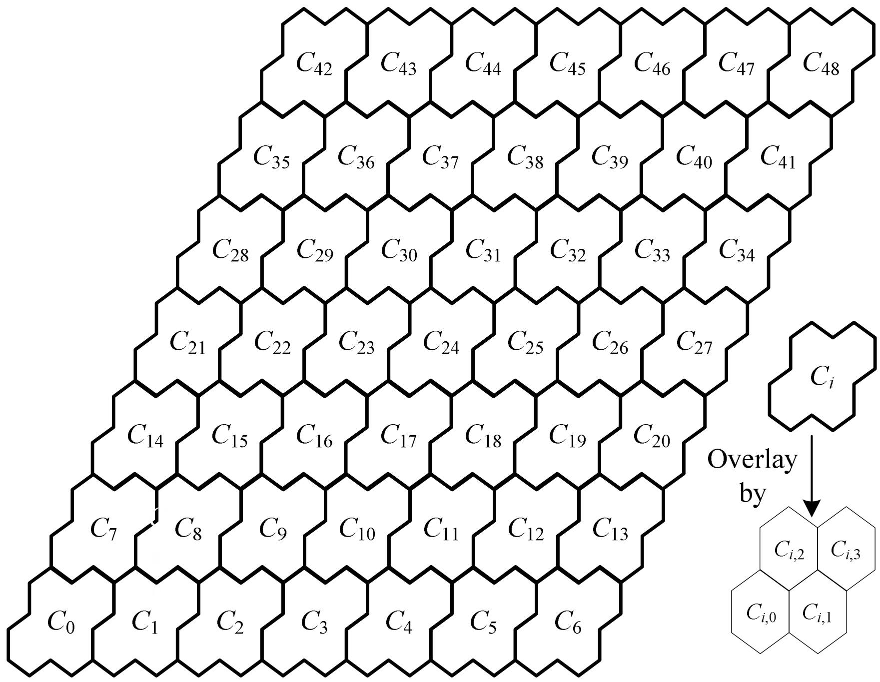

Fig. 1 Hierarchical infrastructure network

In general, each macrocell C_i overlays with k microcells, $C_{i,0}$, $C_{i,1}$,…, $C_{i,k\text{-}1}$. For convenience, "$C_{i,j}\in C_i$" is used to denote that microcell $C_{i,j}$ is overlaid by macrocell C_i. Moreover, D_{micro} and D_{macro} to denote the minimum reuse distances of microcells and macrocells, respectively. Fig. 1 illustrates a cell configuration. Each macrocell C_i overlays 4 microcells: $C_{i,0}$, $C_{i,1}$,…, and $C_{i,4}$. D_{mic} and D_{mac} are $\sqrt{21}r_{micro}$ and $\sqrt{21}r_{macro}$, where r_{micro} and r_{macro} 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_{31}, C_{33}-C_{34}, C_{37}-C_{40}, C_{44}-C_{46}}. If channel ch 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 $IN(C_{8,0})$={$C_{1,0}$-$C_{1,1}$, $C_{2,0}$, $C_{0,3}$, $C_{1,2}$-$C_{1,3}$, $C_{2,2}$, $C_{7,0}$-$C_{7,1}$, $C_{8,1}$, $C_{9,0}$, $C_{7,2}$-$C_{7,3}$, $C_{8,2}$-$C_{8,3}$, $C_{14,0}$-$C_{14,1}$, $C_{15,0}$} cannot keep the primary channels of $C_{8,0}$ as their primary channels.

For any location of a cellular network, there are a microcell $C_{i,j}$ and a macrocell $C_{i,j}$ which can use their primary channels $P(C_{i,j})$ and $P(C_i)$ to handle the arrival calls. For the SS strategy, the procedure to handle the arrival call can be formed as *Fig. 2*. When a call requesting a number c of channels with the targeted MH mh arrives at the area of $C_{i,j}$, there are three cases that mh can acquire the sufficient channels to establish its communication sessions. Otherwise, the call is blocked. In the first case, mh can acquire the primary channels of macrocell C_i that if mh is a high mobility host, i.e., $M(mh) >s_h$, and the available channels of the macrocell C_i are sufficient i.e., $|A(C_i)|> c$. The second is mh can acquire the primary channels of microcell $C_{i,j}$ that if that mh is a low mobility host, i.e., $M(mh) <s_h$, and the available channels of the microcell $C_{i,j}$ are sufficient i.e., $|A(C_{i,j})|> c$. The other is that the available channels of the macrocell C_i are sufficient i.e., $|A(C_i)|> c$ and mh can acquire the primary channels of macrocell C_i.

The SS strategy priorities a high-mobility MH to acquire the channels $P(C_i)$ of a macrocell C_i and a low-mobility MH to acquire the channels $P(C_{i,j})$ of a microcell $C_{i,j}$. The SS can be formalized as Fig. 2. When a call with the targeted MH mh requesting c capacity arrives at the area of microcell $C_{i,j}$, there are 3 cases that the communication session of this mh can be established. Otherwise, the call is blocked.

Case 1: mh is a high-mobility MH and the available channels of C_i are sufficient, i.e., $M(mh) \geq th_H$ and $|A(P(C_i))| \geq c$.

Case 2: mh is a ligh-mobility MH and the available channels of $C_{i,j}$ are sufficient, i.e., $M(mh) > th_H$ and $|A(P(C_{i,j}))| \geq c$.

Case 3: (Not in Cases 2 and 3): The available channels of C_i are sufficient, i.e., $|A(P(C_i))| \geq c$.

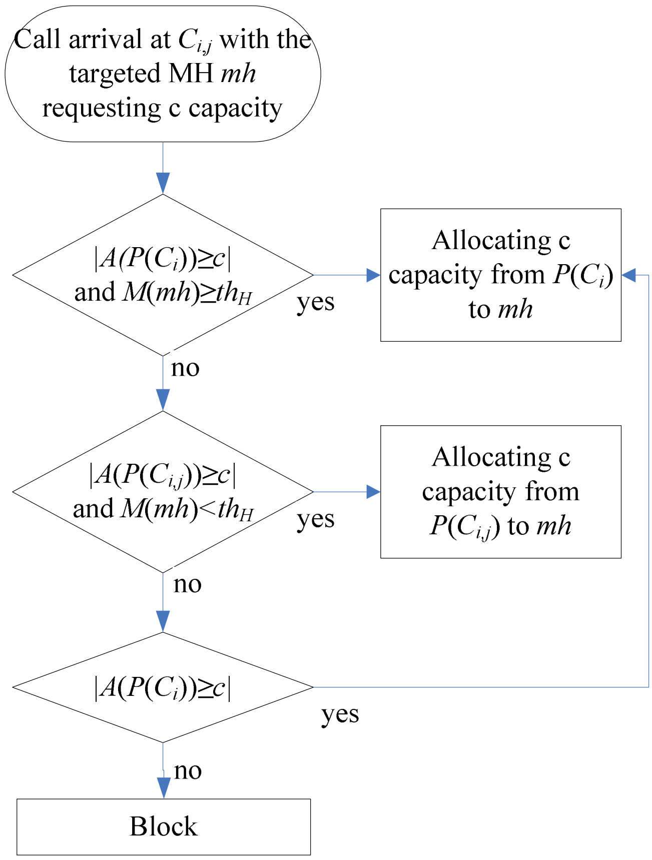

Fig. 2 The SS strategy

Therefore, the allocations of $P(C_i)$ and $P(C_{i,j})$ will affect the performance of the performance of the SS strategy. For the conventional SS strategy, the primary channel allocation is fixed and is difficult to handle the variations in system profiles, such as traffic variations in cells, base station failed to provide wireless services, or wired link failures among cells. In this study, distinct cells can dynamically change their primary channel allocations to satisfy the different variations. Let the primary cells of a channel *ch*, denoted by $PC(ch)$, be all of the cells, which contain a primary channel *ch* in the system. According to Def. 2, if cell *C* acquires a new primary channel *ch*, the original owners of this primary channel *ch* in $IN(C)$ will be forbidden to keep channel *ch* as their primary channel. Definition 5 presents the interfering primary cells $IP(C, r)$ with a channel *ch*, which are the cells that cannot keep channel *ch* as their primary channel, when cell *C* acquires a new primary channel.

Definition 5: The interfering primary cells of channel *ch* relative to cell *C* are denoted by $IP(C, r)$, where $IP(C, ch) = PC(ch) \cap IN(C)$.

For instance in Fig. 1, suppose that cells C_2, C_{11}, C_{20}, C_{22}, C_{31}, C_{40}, and C_{42} have a primary channel *ch*, i.e., $PC(ch) = \{C_2, C_{11}, C_{20}, C_{22}, C_{31}, C_{40}, C_{42}\}$. Since $IP(C_{32}, ch) = IN(C_{32}) \cap PC(ch) = \{C_{31}, C_{40}\}$, if C_{32} acquires *ch* as its new primary channel, C_{31} and C_{40} can not keep *ch* as their channel. Moreover, for C_{41}, C_{47} or C_{48}, since the number of interfering primary cells of *ch* is 0, one of C_{41}, C_{47} and C_{48} can acquire *ch* as its new primary channel.

3 Subject Strategy

Fig. 3 presents the layout of our cell-layer bandwidth scheduling strategy for the call-layer bandwidth scheduling strategy. Our strategy is responsible for allocating system channels to each cell. Accordingly, when calls arrive at this cell, the call-layer strategy is activated to assign the allocated channels to calls to establish communication sessions. When there are variations such as traffic service profile among cells, the cell-layer strategy will be activated, accordingly to the variations, to allocated system channels to each cell. The new allocation is submitted to the call-layer strategy. Then, the call-layer strategy uses the new allocation to carry the traffic.

This strategy uses two allocation condition functions R_{micro} and R_{macro} to valuate the capacity effects of a microcell and a macrocell to allocate a new channel. Accordingly, a distributed channel allocation strategy can be activated to allocate the system channels to meet the variations in traffic profile, service profile, and link-profile.

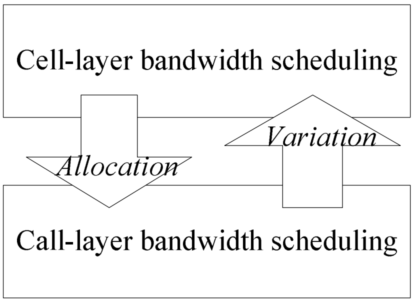

Fig. 3 Layout of the subject strategy

3.1 Allocation condition

The discussion of the condition that a cell can acquire a new channel is presented herein. The condition connects with the traffic of the service area. To evaluate the traffic, we divide the physical service area of a cellular system into a number of units. Each unit contains the covered area of a microcell $C_{i,j}$. The traffic of in the area $C_{i,j}$ is divided into high-mobility traffic $\lambda_H(C_{i,j})$ and low-mobility traffic $\lambda_L(C_{i,j})$.

The SS strategy prioritizes assigning the channels of a macrocell to a high-mobility MH and the channels of a macrocell to a low-mobility MH. Accordingly, the traffic loads of an area of a microcell $C_{i,j}$ is divided into high-mobility traffic $\lambda_H(C_{i,j})$ and low-mobility traffic $\lambda_L(C_{i,j})$, where $\lambda_H(C_{i,j})$ is handled by using $P(C_i)$ of the overlapped macrocell C_i and $\lambda_L(C_{i,j})$ is handled by using $P(C_{i,j})$ of the overlapped microcell $C_{i,j}$.

3.1.1 Microcell With Low-Mobility Traffic

The evaluation of using $P(C_{i,j})$ to carrying the traffic $\lambda(C_{i,j})$ can be represented using Erlang B formula, as shown in (1), in which $|P(C_{i,j})|$ is the number of channels in $P(C_{i,j})$.

Based on (1), the valuation of cell $C_{i,j}$ increasing and decreasing a channel ch can be represented as (2) and (3), respectively. The $incr_{micro}$ ($C_{i,j}$, ch) is used by $C_{i,j}$ to evaluate its capacity effect if it acquires a new channel ch. The $incr_{micro}$ ($C_{i,j}$, ch) compares the channel utilization with the low-mobility traffic $\lambda(C_{i,j})$ before and after acquiring a channel ch, for cell $C_{i,j}$. The $decr_{micro}$ ($C_{i,j}$, ch) is used by the interfering neighbor C of $C_{i,j}$, i.e., $C \in IN(C_{i,j})$, to evaluate the capacity effect if $C_{i,j}$ decreases a channel ch. Therefore, C must take the states of $C_{i,j}$ into consideration. If $C_{i,j}$ currently cannot provide wireless communication service (Service Failure), i.e., $C_{i,j}$ cannot use any channels to carry the traffic, the capacity reduction of decreasing a channel ch is 0. For the No-Failure case, since the current operations of $C_{i,j}$ is normal (No failure), $decr(C_{i,j})$ is set as to compare the channel utilization with and without having a channel ch.

According to Def. 5, if C takes a channel ch as its new channel, the original owners $IP(C, ch)$ of ch must give up ch. The channel transformation among cells can be represented as (4).

According to (2)-(4), the capacity effect of a microcell $C_{i,j}$ acquiring a new channel ch and the original owners giving up ch can be represented as (5). In order to enhance the system capacity, the necessary condition to reallocate a channel ch to $C_{i,j}$ is $R_{micro}(C_{i,j}, ch)>0$.

3.1.2 Macrocell With High-Mobility Traffic

For a macrocell C_i, its allocated channels are prioritized to handle the high-traffic loads $\lambda(C_i)$ presented as (6). The evaluation of using $P(C_i)$ to carrying the traffic $\lambda(C_i)$ can be represented using Erlang B formula, as shown in (7), where $|P(C_i)|$ is the number of channels in $P(C_i)$. Based on (7), the valuation of cell C_i increasing and decreasing a channel ch can be represented as (8) and (9), respectively.

According to (8) and (9), the capacity effect of a microcell C_i acquiring a new channel ch and the original owners giving up ch can be represented as (10). In order to enhance the system capacity, the necessary condition to reallocate a channel ch to $C_{i,j}$ is $R_{macro}(C_{i,j}, ch)>0$.

3.2 Allocation Strategy

The strategy is performed periodically by each cell. The opportunity that a cell performs the strategy can be formally described as follows.

- Partition the set of all cells in a system into G_0, G_1, …,and $G_{cs\text{-}1}$ disjoint subsets, such that any two cells in the same subset are apart by at least a distance of D_{min}. Accordingly, partition the time into T_0, T_1, …, and $T_{cs\text{-}1}$ disjoint time periods (cs is also termed as the *cluster size*).
- The cells in G_i are assigned to perform the channel allocation at time period T_i.

$$EB(\lambda(C_{i,j}), P(C_{i,j})) = \frac{\lambda(C_{i,j})^n}{n!}\left[\sum_{k=0}^{n}\frac{\lambda(C_{i,j})^k}{k!}\right]^{-1}, \text{where } n = \left|P(C_{i,j})\right|, \quad and \quad \lambda(C_{i,j}) = \lambda_L(C_{i,j}). \tag{1}$$

$$incr_{micro}(C_{i,j}, ch) = \Big(\big(EB(\lambda(C_{i,j}), |P(C_{i,j})|)\big) - \big(EB(\lambda(C_{i,j}), |P(C_{i,j}) \cup \{ch\}|)\big)\Big) \cdot \lambda(C_{i,j}) \tag{2}$$

$$decr_{micro}(C_{i,j}, ch) = \begin{cases} \Big(\big(EB(\lambda(C_{i,j}), |P(C_{i,j}) - \{ch\}|)\big) - \big(EB(\lambda(C_{i,j}), |P(C_{i,j})|)\big)\Big) \cdot \lambda(C_{i,j}) & \text{, No Failure} \\ 0 & \text{, Service Failure} \end{cases} \tag{3}$$

$$\begin{cases} P(C) \leftarrow P(C) \cup \{ch\} \\ P(C') \leftarrow P(C') - \{ch\}, \text{ where } C' \in IP(C, ch). \end{cases} \tag{4}$$

$$R_{micro}\big(C_{i,j}, ch\big) = incr_{micro}\big(C_{i,j}, ch\big) \cdot \lambda(C_{i,j}) - \sum_{C_{if} \in IP(C_{i,j}, ch)} decr_{micro}\big(C_{if}, ch\big) \cdot \lambda(C_{if}). \tag{5}$$

$$\lambda(C_i) = \sum_{C_{i,j} \in C_i} \lambda_H(C_{i,j}), \text{where } \lambda_H(C_{i,j}) \text{ is the high-traffic load in the covered area of } C_{i,j}. \tag{6}$$

$$EB(\lambda(C_i), P(C_i)) = \frac{\lambda(C_i)^n}{n!}\left[\sum_{k=0}^{n}\frac{\lambda(C_i)^k}{k!}\right]^{-1}, \text{where } n = \left|P(C_i)\right|. \tag{7}$$

$$incr_{macro}(C_i, ch) = \Big(\big(EB(\lambda(C_i), |P(C_i)|)\big) - \big(EB(\lambda(C_i), |P(C_i) \cup \{ch\}|)\big)\Big) \cdot \lambda(C_i) \tag{8}$$

$$decr_{macro}(C_i, ch) = \begin{cases} \Big(\big(EB(\lambda(C_i), |P(C_i) - \{ch\}|)\big) - \big(EB(\lambda(C_i), |P(C_i)|)\big)\Big) \cdot \lambda(C_i) & \text{, No failiure} \\ 0 & \text{, Service failiure} \end{cases} \tag{9}$$

$$R_{macro}\big(C_i, ch\big) = incr_{macro}\big(C_i, ch\big) \cdot \lambda(C_i) - \sum_{C_{if} \in IP(C_i, ch)} decr_{macro}\big(C_{if}, ch\big) \cdot \lambda(C_{if}). \tag{10}$$

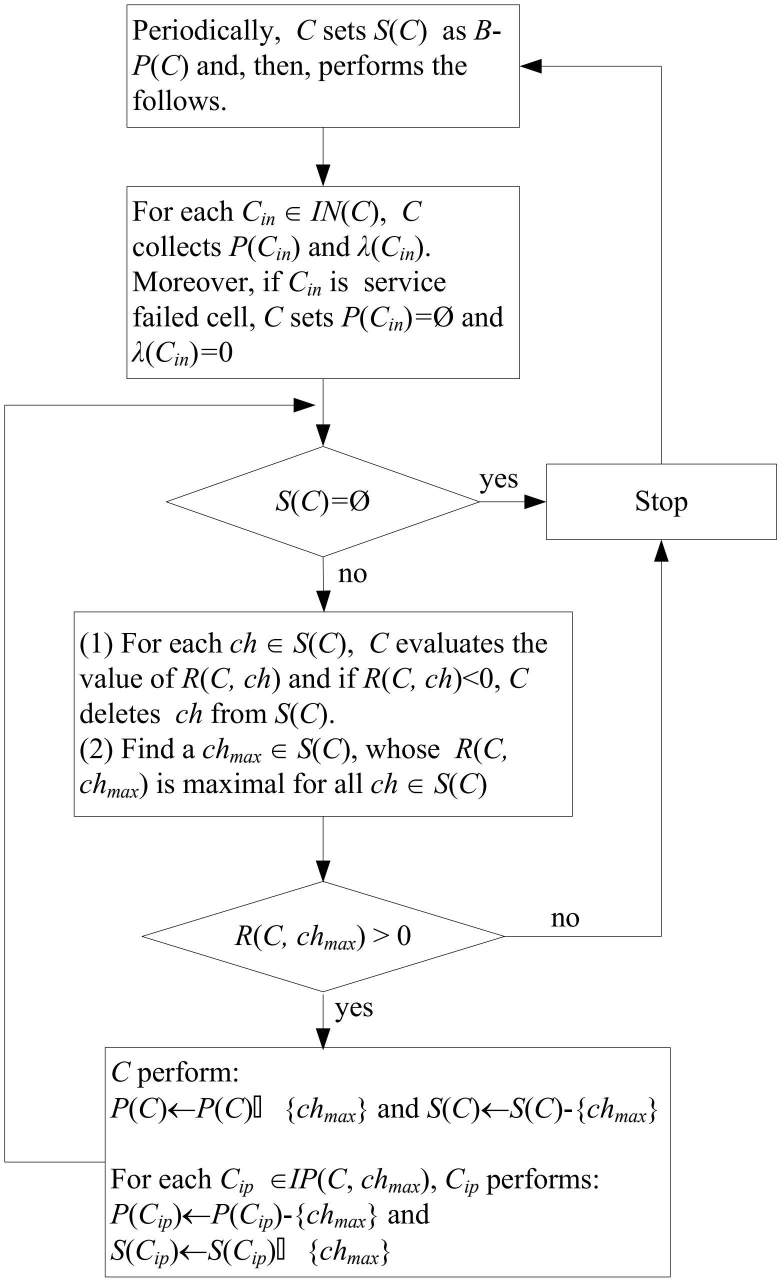

Fig. 4 Allocation strategy

For instance in Fig. 1 with $D_{macro} = \sqrt{21}r_{macro}$, cells $\{C_0, C_1,\dots, C_{48}\}$ can be divided into $G_0, G_1,\dots, G_6$, where $G_0 =\{C_0, C_9, C_{18}, C_{27}, C_{29}, C_{38}, C_{47}\}$, $G_1 =\{C_1, C_{10}, C_{19}, C_{21}, C_{30}, C_{39}, C_{48}\}$, $G_2 =\{C_2, C_{11}, C_{20}, C_{22}, C_{31}, C_{40}, C_{42}\}$, $G_3 =\{C_3, C_{12}, C_{14}, C_{23}, C_{32}, C_{41}, C_{43}\}$, $G_4 =\{C_4, C_{13}, C_{15}, C_{24}, C_{33}, C_{35}, C_{44}\}$, $G_5 =\{C_5, C_7, C_{16}, C_{25}, C_{34}, C_{36}, C_{45}\}$, and $G_6 =\{C_6, C_8, C_{17}, C_{26}, C_{28}, C_{37}, C_{46}\}$. Cells in the same group can perform the strategy at same time period. A cell C that performs our strategy is to evaluate the current variations such as traffic loads and the wireless communication provisions of its interfering neighboring cells $IN(C)$. Accordingly, C reschedules the system channels for $IN(C)$ to meet the variations

The proposed strategy is performed by each cell C, which accords to the current traffic loads and the primary channels of it itself and the each interfering neighbor C_{in} to determine the new primary channels. Therefore, the inputs of the strategy including B, $\lambda(C)$, and $P(C)$, where if C is a microcell (or macrocell), B represents the bandwidth B_{micro} (or B_{macro}) and $\lambda(C)$ represents the low-mobility traffic $\lambda_L(C)$ (or the high-mobility traffic $\lambda_H(C)$). The output of the strategy is channel sets, including C and its interfering neighbor. The formal description of the strategy is shown as Fig. 4.

As follows, we give some examples to describe the methods to handle the variations in traffic profile, link-profile, and service-profile. Suppose, in Fig. 1, the available bandwidth of the macrocell system has 70 channels, denoted as B_{macro}={ch_0, ch_1, …, ch_{69}}. The original primary channel sets of C_{24} is $P(C_{24})$={ch_0, ch_1, …, ch_9}, of C_{29} is $P(C_{29})$={ch_{10}, ch_{11}, …, ch_{19}}, and of C_{18} is $P(C_{18})$={ch_{20}, ch_{21}, …, ch_{29}}. We continually suppose, C_{29} incurs service failure, which cannot provide wireless communications. When C_{24} performs the strategy, C_{24} sets $S(C_{24})$ as $B_{macro} - P(C_{24})$ ={ch_{10}, ch_{11}, …, ch_{69}} and then collects the high-mobility traffic loads λ(-) and the current channel allocations P(-) of $IN(C_{24})$= {C_{10}-C_{12}, C_{16}-C_{19}, C_{22}-C_{23}, C_{25}-C_{26}, C_{29}-C_{32}, C_{36}-C_{38}}. However, since C_{29} incurs service failure, C_{24} sets $P(C_{29})$ as ∅ and sets $\lambda(C_{29})$ as 0. Then, C_{24}, round by round, evaluates $R_{macro}(C_{24}, ch)$ for each ch in $S(C_{24})$. In each round, C_{24} picks up a channel $ch_{\max}$ having the largest positive value and saves $ch_{\max}$ into $P(C_{24})$ and deletes $ch_{\max}$ from each $P(C_{ip})$, where C_{ip} is the original owner of $ch_{\max}$, i.e., $C_{ip} \in IP(C_{24}, ch_{\max})$. In each round, C_{24} also deletes $ch_{\max}$ and other channels with non-positive R_{macro}(-) values from $S(C_{24})$. Until $S(C_{24})$ is empty or any channel in $S(C_{24})$ has non-positive R_{macro}(-) value, the evaluation is stopped. After the evaluation, $P(C)$ denotes the new primary channel allocation of cell C, where C belongs to C_{24} and $IN(C_{24})$. In the evaluation, channels $P(C_{29})$={ch_{10}, ch_{11}, …, ch_{19}}, belonging to a service-failure cell C_{29}, C_{29} cannot use its channels {ch_{10}, ch_{11}, …, ch_{19}} to carry traffic. The $decr_{macro}(C_{29}, ch)$, for ch in {ch_{10}, ch_{11}, …, ch_{19}} will be set as 0 (as shown in (9)), i.e., no capacity effect if C_{29} gives up the channels . For other instance in Fig. 1, suppose $IP(C_9, ch_{39})$={C_8, C_{17}},i.e., in the interfering area $IN(C_9)$ of C_9, C_8 and C_{17} have a channel ch_{39}. Since C_8 has channel ch_{39}, no cells in $IN(C_8)$={C_0-C_3, C_7, C_9-C_{10}, C_{14}-C_{16}, C_{21}-C_{22}} have ch_{39}. When a large number of MHs transfers from the neighbors of C_9, such as C_8 and C_{17} into C_9, C_9 must carry more traffic. The condition will cause the carrying traffic loads with the occupied channels among C_9 and its neighbors unbalanced. Therefore, C_9 has opportunity to acquire more channels from its neighbors. Suppose C_9 performs the strategy and find $R_{macro}(C_9, ch_{39})$>0, C_9 can acquire ch_{39}. The original owners $IP(C_9, ch_{39})$ will give up ch_{39} and transfer to C_9 to balance the traffic transformation. Moreover, for C_0 before transferring ch_{39} to C_9, C_8 is the unique cell having ch_{39}. After C_8 transfers ch_{39} to C_9, no cells in $IN(C_0)$ have ch_{39}, C_0 will acquire ch_{39}.

4 Simulation Results

The simulation environment has 49 macrocells, arranged as 7-parallelogram structure, where the radius of a microcell is 400 meters and each macrocell overlaps 4 microcells. The reuse distances of the microcell system and the macrocell system are $\sqrt{21}r_{micro}$ and $\sqrt{21}r_{macro}$, where r_{micro} and r_{macro} are 400m and 800m, respectively. The frequency bands for microcells and macrocells are 2.24Mb/s and 4.48Mb/s, respectively. The average number of mobile hosts, which locate at the area of a microcell, is 100. It includes 30% high-mobility mobile hosts and 70% low-mobility mobile hosts, generated according the random process. The call arrival rate of a non-calling mobile host is generated according to the random process from 2.20 to 4.95 calls/hour. The environment includes 5 hot microcells. A MH, located at a microcell C, has 2 cases to determine the next location.

Case 1: No hot-cells are closed to C. The probability of moving to each neighboring cell is the same. Case 2: If a hot cell is closed to a hot cell, the probability of moving to this hot cell is 50% and the probability of moving to other non-hot cells is 50%.

The simulation results are demonstrated as Fig. 5-Fig. 8, which include no failure, and 1%, 2%, and 8% of cells failed to provide communication services. In which, "SS" represents the SS strategy without our strategy and "Ours" represents the SS strategy with our strategy. Moreover, "-a" represents the overall call blocking probability, "-h" represents the handoff call blocking probability, and "-n" represents the new call blocking probability.

The results reveal that our strategy is available for the SS strategy and can greatly improve the traffic-carrying capacity. The reason is described as follows. The original cannot handle the cell-layer variations such as the change of the traffic loads among cells or the base stations failed to provide service.

Ours strategy can adaptively tune the bandwidth allocations according the variation of traffic loads among cells. Moreover, when a cell failed to provide service, the neighboring non-failed cells can acquire more primary channels released from the failed cells to light the effect to the system capacity.

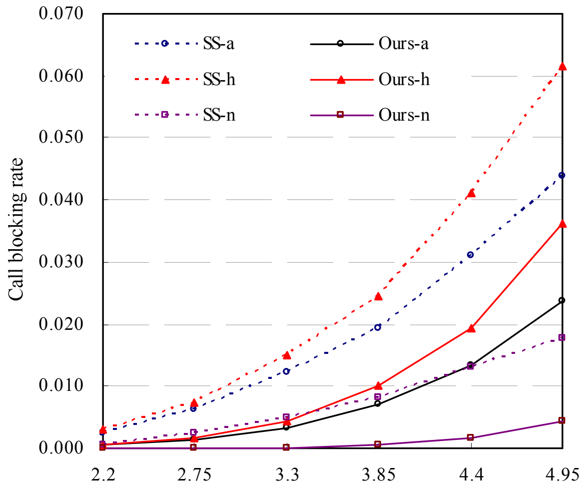

Fig. 5 No failure

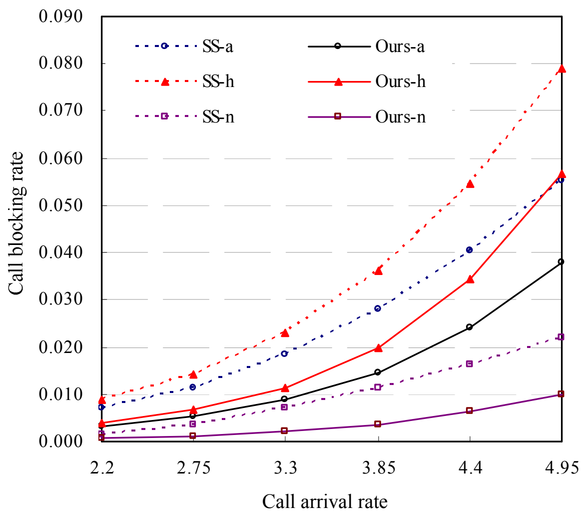

Fig. 6 1% service failure

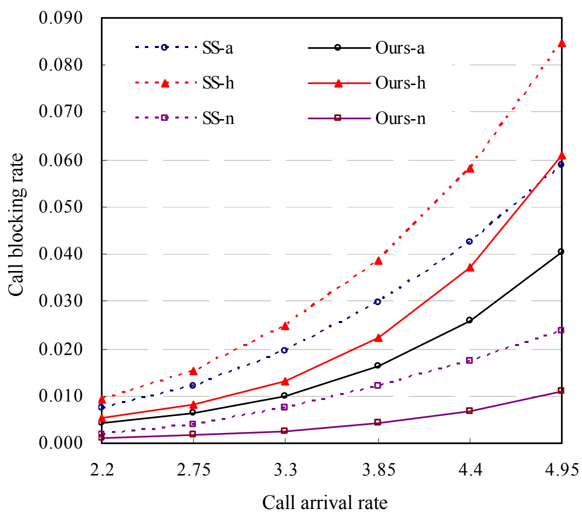

Fig. 7 2% service failure

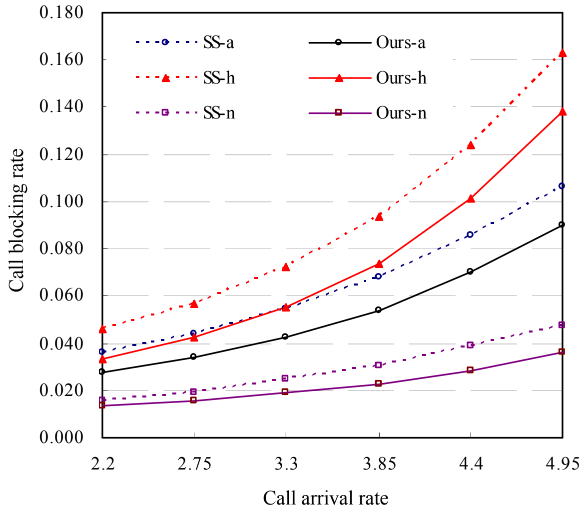

Fig. 8 8% service failure

5 Conclusions

Bandwidth scheduling methods can be divided into cell-layer channel allocation and call-layer channel assignment. Previous studies are focused on the latter type of method. Some problems, such as traffic-load variations among base stations (BSs) and BSs failed to provide wireless communication service, are the cell-layer problems and are difficult to handle using the call-layer methods. Therefore, this study presented an adaptive cross-layer bandwidth scheduling strategy for hierarchical cellular networks. This strategy is implemented to solve the traffic-adaptation and the fault tolerance problem according to the speed-sensitive call-layer method. In microcell/ macrocell cellular systems, when some cells fail to provide communication services, channels in these failed cells can be reallocated to other homogeneous cells and the overlapped heterogeneous cells of failed cells can be assigned more channels. Accordingly, the subscribers still acquire the appreciated communication services even though some cells fail to provide communication services.

The mechanism used in the proposed strategy is from the cell-layer to schedule system bandwidth to handle the variation is system profiles. It can achieve various demands for the mobile communications area by modifying the allocation conditions with more related factors [20-21]. For instance, the charges of providing communication services are one of the considerations for telecommunication markets. For instance, the charges for providing communication services are an important consideration in marketing telecommunication. The charges of calls can be included in the reward function, according to the requirement to maximize the charge to allocate channels to calls. Ergonomic and economic factors will be considered to satisfy new trends in the telecommunication industry in the future.

References:

[1] S. Ali, A. Fakoorian, H. Taheri, and M. Fathi, "Channel management based on maximizing customers' satisfaction and service providers' revenue," *International Symposium on Wireless Pervasive Computing*, pp.702-706, May 2008.

[2] A. Boukerche, K. Abrougui, and T. Huang, "QoS and fault-tolerant based distributed dynamic channel allocation protocol for cellular networks," *IEEE Conference on Local Computer Networks*, pp.59-67, November. 2005.

[3] A. Byungchan, Y. Hyunsoo, and C. Jung Wan, "A design of macro-micro CDMA cellular overlays in the existing big urban areas," *IEEE Journal on Selected Areas in Communications*, vol. 19, Issue: 10, pp. 2094–2104, October 2001.

[4] L. Bo, W. ChengKe, and A. Fukuda, "Performance analysis of flexible hierarchical cellular systems with a bandwidth-efficient handoff scheme," *IEEE Transactions on Vehicular Technology*, vol. 50, Issue: 4, pp. 971 –980, July 2001.

[5] G. Cao, "Integrating distributed channel allocation and adaptive handoff management for QoS-Sensitive cellular networks," *ACM/Kluwer Wireless Networks (WINET)*, Vol. 9, pp. 132-142, March 2003

[6] S. P. Chung and J. C. Lee, "Performance analysis and overflowed traffic characterization in multiservice hierarchical wireless networks," *IEEE transactions on wireless Communications*, Vol. 4, No. 3, May 2005.

[7] C. Dazhong, X. Jing, and W. Peng, "Research on improvement in the handoff performance for high-speed mobile service," *IEEE Canadian Conference on Electrical and Computer Engineering*, pp.1157-1160, May 2005.

[8] L. Huang, S. Kumar, and C.-C.J Kuo, "Adaptive resource allocation for multimedia QoS management in wireless networks," *IEEE Transactions on Vehicular Technology.*, Vol.53, pp. 547-558, Mar 2004

[9] A. Iera, A. Molinaro, and S. Marano, "Handoff management with mobility estimation in hierarchical systems," *IEEE Transactions on Vehicular Technology*, vol. 51, PP. 915-934, September 2002.

[10] I. Katzela and M. Naghshineh, "Channel assignment schemes for cellular mobile telecommunication systems: a comprehensive survey," *IEEE Personal Communications*, vol. 33, pp. 10 -31, June 1996.

[11] S. Kim and P. K. Varshney, "Adaptive fault tolerant bandwidth management framework for multimedia cellular networks," *IEE Proceedings-Communications*, Vol. 152, No. 6, pp. 932-938, December 2005.

[12] B. Li, C. K. Wu, and A. Fukuda, "Performance analysis of flexible hierarchal cellular systems with a bandwidth-effective handoff scheme," *IEEE Transactions on Vehicular Technology*, vol. 50, no. 4, pp.971-980, July 2001.

[13] W. Shan, P. Fan, S. Member, and Y. Pan, "Performance evaluation of a hierarchical cellular system with mobile velocity-based bidirectional call-overflow scheme," *IEEE transactions on parallel and distributed systems*, vol. 14, NO. 1, January 2003

[14] S. Tokekar and N. Purohit, "Performability Analysis of a Fault Tolerant Sectorized Cellular Network," *IEEE Transactions on Annual India Conference*, pp.1-5, September 2006.

[15] A. E. Xhafa, and O. K. Tonguz, "Handover Performance of Priority Schemes in Cellular Networks," *IEEE Transactions on Vehicular Technology*, pp.565 – 577, January 2008.

[16] J. Yang, Q. Jiang, D. Manivannan and M. Singhal, "A Fault tolerant distributed channel allocation scheme for cellular networks," *IEEE Transactions on Computer*, Vol 54, No 5,May 2005.

[17] J. Yang, Q. Jiang and D. Manivannan, "A Fault-Tolerant Channel-Allocation Algorithm for Cellular Networks With Mobile Base Stations," *IEEE transactions on Vehicular Technology*, Vol. 56, No. 1, pp.349-361, January 2007.

[18] Y. Zhang and B.-H. Soong, "Take-back schemes in hierarchical cellular system," *IEEE Globecom*, pp. 31-35, 2005.

[19] F. M. Zhao, L. G. Jiang and H. Y. Bing, "Performance analysis of channel borrowing on hierarchical wireless networks," *IEEE Conf. on IWVDVT2005*, pp. 256 – 259, May 2005.

[20] Shahab Asoodeh, "New Algorithm for Power Control in Cellular Communication with ANFIS," *WSEAS TRANSACTIONS on COMMUNICATIONS*, Vol. 7, January 2008.

[21] Jing-Feng Lin, Guang-Ming Wu and Derchian TsaihIssue, "An Efficient Partition and Matching Algorithm for Query-Set-based

Broadcasting in Multiple Channel Mobile Environment," *WSEAS TRANSACTIONS on COMMUNICATIONS*, Vol. 8, January 2009.

[22] Rekha Patil and A. Damodaram, "A Cross-Layer Based Joint Algorithm for Power Control and Scheduling in CDMA Wireless Ad-Hoc Networks", *WSEAS TRANSACTIONS on COMMUNICATIONS*, Vol. 8, January 2009.