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A dynamic channel-borrowing approach with fuzzy logic control in distributed cellular networks

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Abstract

In this paper, a fuzzy-based dynamic channel-borrowing scheme (FDCBS) is presented to maximize the number of served calls in a distributed wireless cellular network. The uneven traffic load may create hot-spot cells and possibly causes a high blocking rate in hot-spot cells. Most conventional methods use load indices with a threshold value to determine the load status of a cell. However, those exists a ping–pong effect, as loads are around the threshold value. This result causes an unstable system and unnecessary message passing overhead. In addition, the estimation of traffic load is difficult and time-consuming. Thus, an intelligent prediction mechanism is needed. In this paper, we develop a method to predict the cell load and to solve the channel-borrowing problem based on the fuzzy logic control. A new channel-borrowing algorithm with multi-channels borrowing is also presented in this paper. A borrowing mechanism supporting the present facility has been built on the application-level of wireless cellular networks. The FDCBS exhibits better adaptability, robustness, and fault-tolerant capability thus yielding better performance compared with other algorithms. Through simulations, we evaluate the blocking rate, update overhead, and channel acquisition delay time of the proposed method. The results demonstrate that our algorithm has lower blocking rate, less updated overhead, and shorter channel acquisition delays.

Keywords: Dynamic channel borrowing; Dynamic load balancing; Fuzzy logic control; Channel allocation; Wireless cellular networks

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1. Introduction

A cellular system consists of a central switching office, namely mobile switching center (MSC), and a set of cells, each with a fixed base station (BS). Although the concept also applies to radio network controller in 3G systems, a BS directly communicates with all mobile stations (MSs) within its wireless transmission radius. The channel assignment (allocation) problem is an important topic in a cellular system [4]. The objective of the channel assignment of existing results is mainly to exploit the channel reuse factor under the constraint of co-channel reuse distance. Existing results for the channel assignment can be classified into Fixed Channel Assignment (FCA) [3,7,14,16], Dynamic Channel Assignment (DCA) [6,12,17], and Hybrid Channel Allocation (HCA) [8]. The advantage of FCA is its simplicity. However, it does not reflect real scenarios where load may fluctuate and vary from cell to cell.

DCA schemes can dynamically assign/reassign channels and thus are more flexible. In the centralized DCA schemes [15,16], all channels are placed in a pool and are assigned to the new calls as needed, and all the allocate jobs are done by MSC. In the distributed DCA schemes [19], BSs are needed to be involved. HCA techniques are designed by combining the FCA and DCA schemes. In HCA, channels are divided into two disjoint sets: one set of channels is assigned to each cell on FCA basis, while the others are kept in a central pool for the dynamic assignment.

To be more specific, load balancing is the process of redistributing the channels that is submitted to a network of cells so as to avoid the situation where some cells are idle while others are congested (hot-spots). Since the locations of hot-spots vary from time to time, in fact, increasing the bandwidth of a cell can increase the system capacity but not the efficiency to deal with the time-varying imbalance traffic. This is achieved by efficiently transferring channels from lightly loaded cells (cold) to heavily loaded ones (hot).

Conventional strategies of the channel borrowing for the load balancing usually use some fixed threshold values to distinguish the status of each cell [1,5,9,10,16,17]. A cell load is marked as 'hot', if the ratio of the number of available channels to the total number of channels allocated to that cell is less than or equal to some threshold value. Otherwise it is 'cold'. The drawback is that threshold values are fixed. Since load state may exhibit sharp distinction state level, series fluctuation like ping–pong effect may occur when loads are around the threshold. This results in wasting a significant amount of efforts in transferring channels back and forth [1,5]. The load information collection cannot only estimate the time-varying traffic load about the cellular networks, but also provide useful information for making the channels reallocation decisions.

We develop fuzzy rules to determine how to classify a cell to be very hot, hot, moderate, cold, or very cold. A good load information gathering could be able to reflect our qualitative estimates of the current load on a cell, predict the cell load in the near future, relatively stable, and have a simple relationship with the resource indices. In a cellular system, the arrival time of the calls may vary significantly, as the call duration times are vague and uncertain. Due to this nature, using fuzzy system seems to be the best way to approach the problem. The concept of fuzzy number plays a fundamental role in formulating quantitative fuzzy variables. The fuzzy numbers represent the linguistic concepts, such as *very hot*, *hot*, *moderate*, and so on [18].

Traditional channel allocation approaches can be classified into *update* and *search* [2]. The fundamental idea is that a cell must consult all the interference cells within the minimum reuse distance before it can acquire a channel. We adopt the number of available channels and cell traffic load as the input variables for fuzzy sets and define a set of membership functions. In addition, our scheme allows a requesting cell to borrow multiple channels at a time, based on the traffic loads of the cells and channels availability, there by reduce the borrowing overhead further. Our fuzzy logic control consists of four modules: (1) a fuzzy rule base, (2) a fuzzy inference engine, (3) fuzzification, and (4) defuzzification modules [13]. The FDCBS consists of (1) cell load decision-making, (2) cell involved negotiation, and (3) multi-channel migration phases. The structure of a dynamic channel borrowing for wireless cellular network is composed of three design phases by applying fuzzy logic control to them. The cell load decision-making indicates the amount of information regarding the cell as well as the information gathering rules used while making the load redistribution decisions. The goal is to obtain sufficient information in order to make a decision whether the cell load is very hot, hot, moderate, cold or very cold. The cell involves in negotiation, selects the cells to or from which channels will be migrated when the load reallocation event takes place. The multi-channels borrowing pertains to manage the migration of channels from one cell to another [18]. Fig. 1 shows the block diagram of our FDCBS.

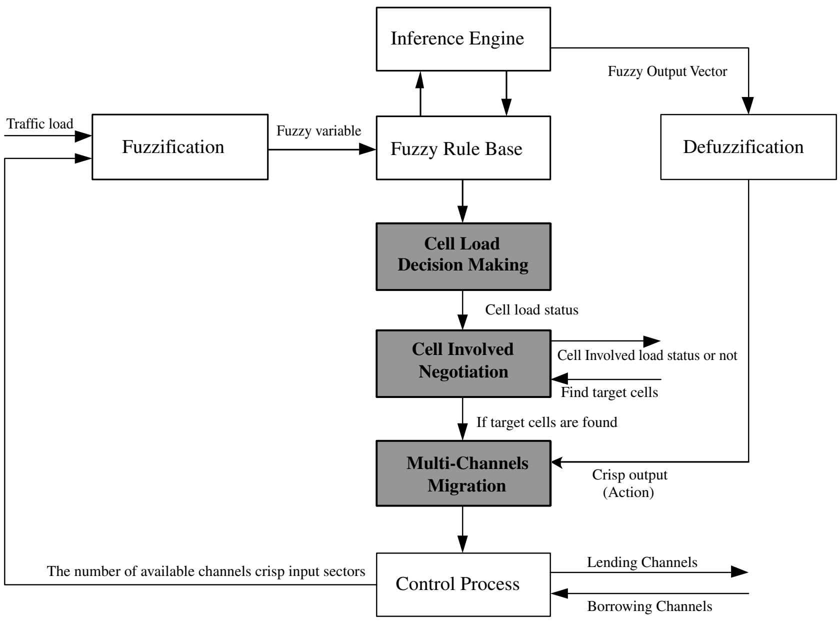


Fig. 1. Block diagram of FDCBS.

The performance of our FDCBS is compared with the fixed channel assignment [7], simple borrowing [3], directed retry [10], CBWL [6], and LBSB [17]. The experimental results reveal that our proposed scheme yields better performance as compared with other conventional schemes. Our fuzzy-based load balancing algorithm not only effectively reduces the blocking rate but also provides considerable improvement in overall performance such as less update message, and short channel acquisition delays. The remainder of this paper is organized as follows. In Section 2, we provide the structure of the fuzzy-based cellular system model. The design issues of our proposed cell load decision-making is described in Section 3. In Section 4, we propose the cell involved negotiation. The new channel borrowing with multichannel transferring scheme is presented in Section 5. Simulation model and results are given in Section 6. Concluding remarks are made in Section 7.

2. Fuzzy-based cellular system model

The cellular system model in this paper is assumed as follows. A given geographical area consists of a number of hexagonal cells, each served by the base station (BS). The base station and the mobile host communicate through the wireless links using channel. Each cell is allocated with a fixed set of channels CH and the same set of channels is reused by those identical cells which are sufficiently far away from each other in order to avoid interference. A group of cells using distinct channels form a compact pattern of radius R. Given a cell c, the interference neighborhood of c, denoted by $\mathrm{IN}(c) = \{c' \mid \mathrm{dist}(c, c') < D_{\min}\}$, where $D_{\min} = 3\sqrt{3R}$ [2]. If N_i denotes the number of cell in the ring i, then for the hexagonal geometry $N_i = 1$ if $i = 0$, and $N_i = 6i$ if $i > 0$.

Partition the set of all cells into a number of disjoint subsets, $G_0, G_1, \ldots, G_{k-1}$ such that any two cells in the same subset are apart from each other by at least a distance of $D_{\min}$ and partition the set of all channels into K disjoint subsets, $P_0, P_1, \ldots, P_{k-1}$. The channels in P_i $(i = 0, 1, \ldots, k-1)$ are called the primary (nominal) channels for the cells in G_i, it is arranged in an ordered list. A channel i is either used (U_i) or *available* (V_i) depending on whether it is assigned to a MS. A channel available for c becomes interfered if it is used by some cell in $\mathrm{IN}(c)$. For convenience, a cell c_i is a primary cell of a channel CH if and only if CH is a primary channel of c_i. Thus, the cells in G_i are primary cells of the channels in P_i and secondary cells of the channels in P_j $(j \neq i)$, the collection of cells in the coverage of the group of the base stations is called a cell *cluster*, as shown in Fig. 2.

In a cellular system, the arrival time of the calls, their call duration time and the message passing overhead among the cells are vague and uncertain. The concept of the fuzzy number plays a fundamental role in formulating quantitative fuzzy variables. These are variables whose states are fuzzy numbers. The fuzzy numbers represent linguistic concepts, such as *very hot*, *hot*, *moderate*, and so on, as interpreted in a particular context. We view this problem as an instance of a more general problem. To transfer a channel from a cell to another cell in order to reduce the blocking rate of the hot-spots, is making decisions under uncertain and vague conditions.

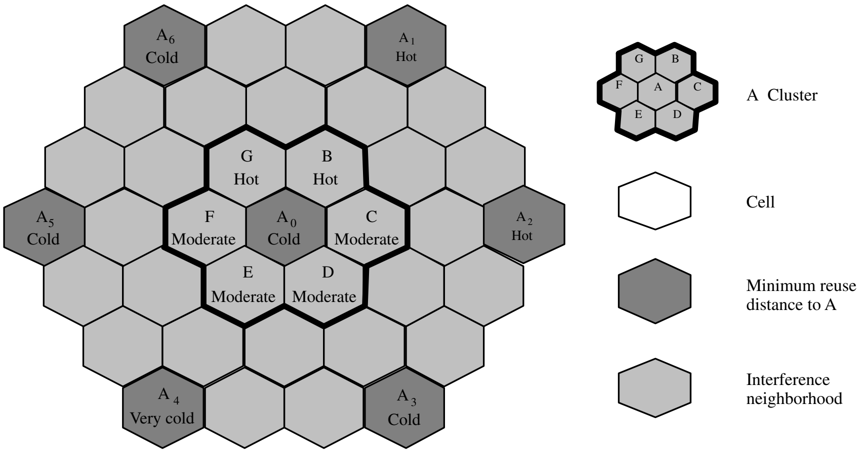


Fig. 2. Hexagonal cellular networks.

3. Cell load decision-making

The cell load collection is one of the most important issues in the cellular system for load balancing approach. This section addresses our strategy of estimating of load status in a wireless cellular network. Such measure is vital for us to determine the most suitable site for migrating channels in order to share the load in the system. This information shall indicate not only the amount of information about the system but also the information gathering rules used in making the load redistribution decisions. We recognize that it is difficult, perhaps impossible; to find an information policy that satisfies all of the above requirements. Moreover, they may be contradictory. But an information may be judged by the degree to which it meets the above criteria. Our proposed scheme seems to be approximating these criteria. This information shall indicate not only the amount of information about the system but also the information gathering rules used in making the load redistribution decisions. This decision indicates various load information which regards with the cellular system. We can construct different available channels membership function, traffic load membership function, and center value for linguistic labels through *fuzzy c-means clustering algorithm* [11] according to various cell's characteristics of system behavior data.

The distributed channel assignment schemes have received considerable attention because of their reliability and solvability. The decision making indicates the significance of various loading that regards with the cellular system. Many researchers use available channel as the single load index for BS in cellular system [15]. Although number of available channel is the obvious factor impacting on the system load, also there are certain other factors influencing the system load, such as call arrival rate and call duration, etc. For the accuracy of evaluating the load state of a cell, we employ the used available channel and traffic load as the input variables for the fuzzy sets. *Fuzzification* function is introduced for each input variable to express the associated measurement uncertainty.

3.1. Fuzzification module

The grades of membership basically reflect an ordering of the objects in fuzzy set A and another way of representing a fuzzy set is through use of the *support* of a fuzzy set. The support of a fuzzy set A is the crisp set of all $x \in U$ such that $u_x(x) > 0$. That is, $\mathrm{Supp}(A) = \{x \in U \,|\, u_A(x) > 0\}$. There are a variety of fuzzy set operations. Among them, three basic and commonly used operations are complementation, intersection, and union. The definitions of *complementation*, *intersection*, and *union* proposed by Zadeh [20] are as follows:

1. The complementation of a fuzzy set A is denoted by $\bar{A}$ and the membership function of $\bar{A}$ is given by $\bar{A}(x) = 1 - u_A(x)\ \forall x \in X$.
2. The intersection of fuzzy sets A and B is denoted by $A \cap B$ and the membership function of $A \cap B$ is given by $A \cap B(x) = \min\{u_A(x), u_B(x)\}\ \forall x \in X$.
3. The union of fuzzy sets A and B is denoted by $A \cup B$ and membership function of $A \cup B$ is given by $A \cup B(x) = \max\{u_A(x), u_B(x)\}\ \forall x \in X$.

These functions are defined on the interval $x \in [a_0, a_6]$, in Eqs. (1)–(5) and $y \in [b_0, b_2]$ in Eqs. (6)–(8) as follows, respectively:

$$\mathrm{VC} = \begin{cases} 1 & \text{when } x \leqslant a_1 \\ (a_1 - x)/(a_2 - a_1) & \text{when } a_1 < x < a_2 \\ 0 & \text{when } x \geqslant a_2 \end{cases} \tag{1}$$

$$C = \begin{cases} 0 & \text{when either } a_1 \leqslant x \text{ or } x \geqslant a_3 \\ (x - a_1)/(a_2 - a_1) & \text{when } a_1 < x < a_2 \\ (a_3 - x)/(a_3 - a_2) & \text{when } a_2 < x < a_3 \\ 1 & \text{when } x = a_2 \end{cases} \tag{2}$$

$$M = \begin{cases} 0 & \text{when either } a_2 \leqslant x \text{ or } x \geqslant a_4 \\ (x - a_2)/(a_3 - a_2) & \text{when } a_2 < x < a_3 \\ (a_4 - x)/(a_4 - a_3) & \text{when } a_3 < x < a_4 \\ 1 & \text{when } x = a_3 \end{cases} \tag{3}$$

$$H = \begin{cases} 0 & \text{when either } a_3 \leqslant x \text{ or } x \geqslant a_5 \\ (x - a_3)/(a_4 - a_3) & \text{when } a_3 < x < a_4 \\ (a_5 - x)/(a_5 - a_4) & \text{when } a_4 < x < a_5 \\ 1 & \text{when } x = a_4 \end{cases} \tag{4}$$

$$\mathrm{VH} = \begin{cases} 0 & \text{when } x \leqslant a_5 \\ (x - a_4)/(a_5 - a_4) & \text{when } a_4 < x < a_5 \\ 1 & \text{when } x \geqslant a_5 \end{cases} \tag{5}$$

$$L = \begin{cases} 0 & \text{when } y \geqslant b_1 \\ (y - b_0)/(b_1 - b_0) & \text{when } b_0 < y < b_1 \\ 1 & \text{when } y = b_0 \end{cases} \tag{6}$$

$$M = \begin{cases} 0 & \text{when either } y = b_0 \text{ or } y = b_2 \\ (y - b_0)/(b_1 - b_0) & \text{when } b_0 < y < b_1 \\ (y - b_1)/(b_2 - b_1) & \text{when } b_1 < y < b_2 \\ 1 & \text{when } y = b_1 \end{cases} \tag{7}$$

$$H = \begin{cases} 0 & \text{when } y \leqslant b_1 \\ (y - b_1)/(b_2 - b_1) & \text{when } b_1 < y < b_2 \\ 1 & \text{when } y = b_2 \end{cases} \tag{8}$$

From Eqs. (1)–(8), we have considered an interval of real numbers and the notation $A = \int_u u_A(x)/x$, and $B = \int_u u_B(y)/y$, where x is the actual input value for the available channel and y is the actual input value for the traffic load, respectively. A is the available channel membership function and B is the traffic load membership function. Let a_i present the center value for linguistic labels of available channel membership function for $0 \leqslant i \leqslant 6$, and let b_i present the center value for linguistic labels of traffic load membership function for $0 \leqslant i \leqslant 2$. The status of A may be very cold (VC), cold (C), moderate (M), hot (H) or very hot (VH) for different value of available channels (x) and the status of B may be low (L), moderate (M) or high (H) for different value of traffic load (y). The fuzzified information is then passed on to the fuzzy inference engine.

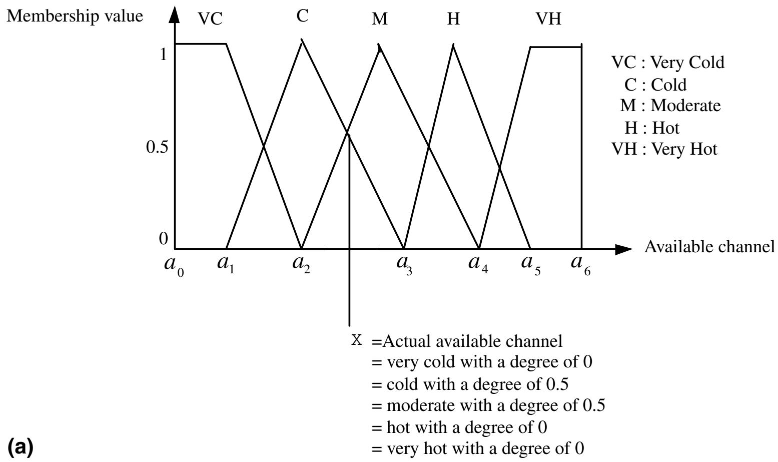
Fig. 3(a) shows membership function for the different values of available channel (see Eqs. (1)–(5)); Fig. 3(b) is the example for the fuzzification of the system parameter for different values of the traffic load (see Eqs. (6)–(8)).

3.2. Fuzzy rule base

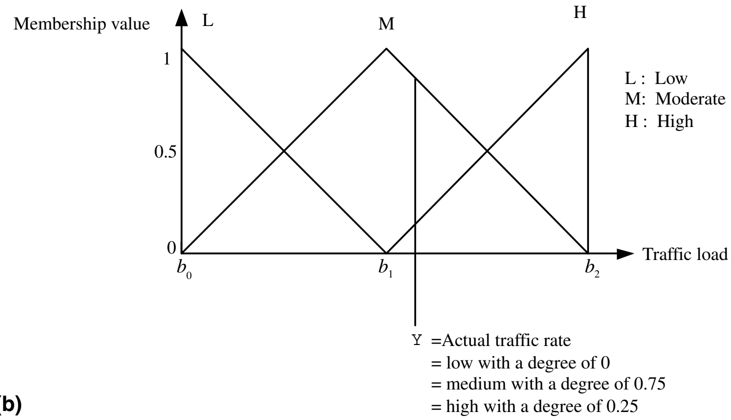
Fuzzy rule base is characterized as collection of fuzzy IF–THEN rules in which the preconditions and consequent involve linguistic variables. This collection of fuzzy control rules characterizes the simple input–output relation of the system. The general form of the fuzzy control rules in case of multi-input–single-output systems (MISO) is:

$$\begin{array}{llcl} \text{Input} & & : & x \text{ is } A' \text{ and } y \text{ is } B' \\ & R^1 & : & \text{IF } x \text{ is } A_1 \text{ AND } y \text{ is } B_1,\ \text{THEN } z \text{ is } C_1 \\ \text{ALSO} & R^2 & : & \text{IF } x \text{ is } A_2 \text{ AND } y \text{ is } B_2,\ \text{THEN } z \text{ is } C_2 \\ & & & \quad\cdots\quad\cdots \\ \text{ALSO} & R^n & : & \text{IF } x \text{ is } A_n \text{ AND } y \text{ is } B_n,\ \text{THEN } z \text{ is } C_n \\ \text{Conclusion} & & : & z \text{ is } C' \end{array}$$

where x, y, and z are linguistic variables representing the control variable and the fuzzy variables taking values in the universes U, V, and W, respectively, and A_i, B_i, and C_i are the linguistic values of the linguistic variables x, y, and z, respectively.



(a)



(b)

Fig. 3. Example for the fuzzification of the system parameter: (a) the number of available channel and (b) the traffic load.

4. Cell involved negotiation

After cell load level of each BS has been decided by the load information, the objective of the cell negotiation is to select the cell to or from which channels will be borrowed when the cell load reallocation event takes place. The traditional channel allocation algorithm in negotiation can be classified into *update* and *search* methods [2]. In the search approach, a cell does not inform its neighbors of its channel acquisitions or releases. When a cell needs a channel, it searches all neighboring cells to compute the set of currently available channels, and then acquires one according to the underlying DCA strategy. In the updated approach, a cell always informs its neighbors whenever it acquires/releases a channel so that each cell knows the set of channel available for its use and underlying DCA strategy. Both approaches have advantages and disadvantages. The updated approach has short acquisition delay and good channel reuse, but it has higher message complexity. In other word, the search approach has lower message complexity, but it has longer acquisition delay and ineffective channel reuse [2]. The fundamental idea of the basic schemes is that a cell must consult co-channel cells, and its cluster cells, before it can acquire channels. When a new call arrives at a hot cell, the FDCBS algorithm is activated requesting its cluster for help, and attempts to borrow sufficient free channels to satisfy its demand.

Our researchers took advantage of fuzzy logic control and presented an enhance version of negotiation scheme, called cell involved negotiation. When the load state is hot, it plays the role of the borrowing channel action; in contrast, it plays the role of the lending channel action when its load state is cold. The moderate cells are not allowed to borrow any channels from any other cells nor lend any channels to any other cells. It is observed that fuzzy enhanced algorithm can enhance the overall system performance effectively. Each BS, an augmented load state table is maintained. The entries of the table are the current load status of every cluster cells as well as the co-channel cells. The cell operation types of load state information exchanges among cells. Each BS keeps the state information of the cells and runs the channel-borrowing algorithm to update load state in period.

4.1. Inference engine

In *inference engine*, the knowledge pertaining to the given control problem is formulated in terms of a set of fuzzy inference rules. There are two principal ways in which relevant inference rules can be determined.

In the above rules, the connectives AND and ALSO may be interpreted as either intersection ($\cap$) or union ($\cup$) for different definition of fuzzy implication. Denote the $\max(\vee)$–$\min(\wedge)$ composition operators. Then we have the following theorem governing the connective AND with one fuzzy control rule to obtain the conclusion. Let us assume that there is one rule R_i with fuzzy implication R_c, the conclusion C' can be expressed as the intersection of the individual conclusions of input linguistic state variables.

$$\begin{aligned}
u_{c'}(w) &= \bigvee_{u,v}\{[u_{A'}(u) \wedge u_{B'}(v)] \wedge [u_{A_i}(u) \wedge u_{B_i}(v) \wedge u_{C_i}(w)]\} \\
&= \bigvee_{u}\left\{[u_{A'}(u) \wedge u_{A_i}(u) \wedge u_{C_i}(w)] \wedge \left[\bigvee_{v}\{u_{B'}(v) \wedge u_{B_i}(v) \wedge u_{C_i}(w)\}\right]\right\} \\
&= \bigvee_{u}\left\{u_{A'}(u) \wedge u_{A_i}(u) \wedge u_{C_i}(w) \wedge u_{B'\circ R_c(B_i;C_i)}(w)\right\}
\end{aligned}$$

where $R_c(A_i, B_i; C_i) = (A_i\text{AND } B_i) \to C_i$.

That is,

$$C' = (A', B') \circ R_c(A_i, B_i, C_i) = [A' \circ R_c(A_i; C_i)] \cap [B' \circ R_c(B_i; C_i)]$$

If the system inputs are fuzzy singletons, $A' = u_0$ and $B' = v_0$, then the results C', derived by employing minimum operation rule R_c and product operation rule R_p, respectively, may be expressed simply as

$$R_c : u_{c'}(w) = \bigvee_{i=1}^{n} \alpha_i \wedge u_{Ci}(w) = \bigvee_{i=1}^{n} [u_{Ai}(u_0) \wedge u_{Bi}(v_0)] \wedge u_{Ci}(w)$$

$$R_p : u_{c'}(w) = \bigvee_{i=1}^{n} \alpha_i \cdot u_{Ci}(w) = \bigvee_{i=1}^{n} [u_{Ai}(u_0) \wedge u_{Bi}(v_0)] \cdot u_{C_i}(w)$$

where α_i denotes the weighting factor of the ith rule, which is a measure of the contribution of the ith rule to the fuzzy control action. If the *max-product* compositions operator $(\cdot)$ is considered, then the corresponding R_c and R_p are the same.

The knowledge pertaining to the given control problem is formulated in terms of a set of fuzzy inference rules. We use five load actions, which are very cold, cold, moderate (stabilize-state), hot, and very hot. This paper, consists of $5 \times 3 = 15$ possible rules as shown in Fig. 4. The two axes of the matrix are for available channel membership function and traffic load membership function. The entries of the matrix represent the effects of the actions to the goal. So an entry matrix of Fig. 4 means that action and individual steps of the FDCBS three design phases.

The BS keeps the load state information of the cells and runs the fuzzy-based channel-borrowing algorithm to borrow free channels from the very cold cells or cold cells whenever it finds any very hot cell or hot cell. The moderate cells are nei-

Traffic load / Available channel	Low	Moderate	High
Very Cold	(Lending) Negative Large (1)	(Lending) Negative Moderate (2)	(Lending) Negative Small (3)
Cold	(Lending) Negative Moderate (4)	(Lending) Negative Small (5)	(Stable) Approximately Zero (6)
Moderate	(Lending) Negative Small (7)	(Stable) Approximately Zero (8)	(Borrowing) Positive Small (9)
Hot	(Stable) Approximately Zero (10)	(Borrowing) Positive Small (11)	(Borrowing) Positive Moderate (12)
Very Hot	(Borrowing) Positive Small (13)	(Borrowing) Positive Moderate (14)	(Borrowing) Positive Large (15)

Fig. 4. Fuzzy rules for channel borrowing/lending control.

ther allowed for reallocation any channels from nor to any other cells nor updated interfering cluster cells.

5. Multi-channels migrating

The new channels migrating with multi-channels transferring can reallocate channels well especially in an unpredictable variation of cell load. Our mechanism for multi-channel transfer calculates the amount of transferred channels by the number of available channels and traffic load. The FDCBS, we have discussed in the last section have a common property; when a requesting cell and a probed cell are decided, the number of reallocated channels is just one channel in each iteration. It is very inefficient if the cell load of two cells differ very much. Our idea is to borrow several channels once instead of only one between two cells. For example, in the next generation multi-media mobile network, a call may need multiple channels at a time. In this idea, we could make the cell load between two cells more balanced. The channel requesting messages transmitted between hot cell i and cold cell j are classified into four categories as follows:

1. Request message, $request(i)$: Message sent by the hot cell i to cluster cells to request the free channels.
2. Reply message, $reply(j, V_j, U_j)$: Message from cold cell j, $j \in cluster$ cells responding to borrow cell i. The message also includes the information on the reserved channels in cell j.
3. Inform message, $inform(i, B_{ij})$: Message sent by borrowing cell i to the lending and the other cells in the *cluster* to inform them about its channel acquisition decision, where B_{ij} is set of channels borrowed by hot cell i from cold cell j. The message also includes the requests of the reserved channels if any.
4. Confirm message, $confirm(j, L_{ij})$: Message sent by cold cell j to borrow hot cell i to inform it the availability of the requested channels that have been reserved at lend cold cell j. Where L_{ij} is the set of confirmed channels lent from cold cell j to hot cell i, and cold cell j can still assign the reserved channels to new arrival calls before sending the confirm message back to hot cell i.

Return to the beginning of the problem, that is, after the requested and selected cells are decided. According to our observation, the number of available channels is the main factor that affects the computing time mostly and it can be divided into two aspects: the available channel and traffic load. Our borrowing mechanism for multi-channel transfer calculates the amount of transferred channels by the traffic load and the number of available channels. The multi-channel allocation pertains to handle the allocation of channels from one cell to another. To accomplish this, we use five load values which are "*Very hot*", "*Hot*", "*Moderate*", "*Cold*" and "*Very cold*", to distinct the difference of cell load on two cells. If one cell is in the "*Very hot*" state; then it will borrow several channels from the cell with "*Very cold*" state. If there are not existing any "*Very cold*" cell, then it would choose the cells with

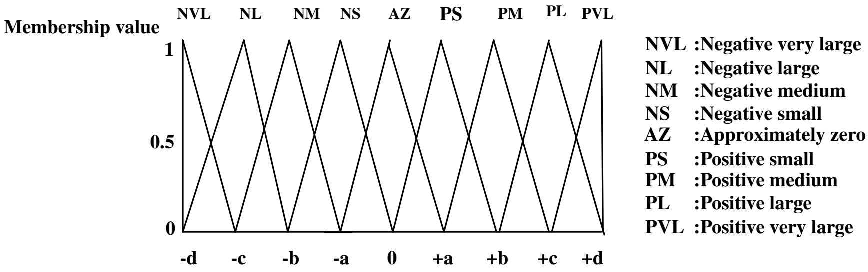


Fig. 5. The membership function of the fuzzy output.

"*Cold*" status. The numbers of borrowed channels are according to the value calculated by fuzzy MAX–MIN composition from the available channels and traffic load. Measurements of input variables of a fuzzy controller must be properly combined with the relevant fuzzy information rules.

5.1. Defuzzification

The purpose of *defuzzification* is to convert each result obtained from the inference engine, which is expressed in terms of fuzzy sets, to a single real number. Defuzzification is a mapping from a space of fuzzy control actions defined over an output universe of discourse into a space of nonfuzzy (*crisp*) control actions. This process is necessary because in many practical application crisp, control action is required for the actual control. Fig. 5 shows the membership function for the channel borrowing/lending a quantity control number of the channel range $[-d, +d]$ of the fuzzy output. The function is defined on the interval $[0, +d]$ for borrowing action, and on the interval $[0, -d]$ for lending action.

We have used the *center of area (COA)* method because it supports software real time fuzzy controls to distinct the difference of load on two cells. This value is calculated by the formula

$$Y^0_{\mathrm{coa}} = \left[\left\lfloor \frac{\sum_{i=1}^{n} W_i * B_i}{\sum_{i=1}^{n} W_i} \right\rfloor - \mathrm{IN}(c) \right]$$

where Y^0_{coa} represent the number of migrate channels, W_i = the antecedent degree of ith control rule and B_i = the consequent center value of ith control rule.

Consequently, the defuzzified value Y^0_{coa} obtained by formula can be interpreted as an expected value of variable. Finally, we obtain

$$\text{Migrate restrict} = \text{Min}[\text{borrowing cell } (Y^0_{\mathrm{coa}}),\ \text{lending cell } (Y^0_{\mathrm{coa}})]$$

6. Experimental results

The problem domain naturally lends itself to simulate using multiple threads since there is a lot of concurrence and global resource management issues in the system.

The simulated model consists of 14 clusters. Each cluster consists of seven homogeneous cells. This experiment has used the number of channels $C = 30$ in a cell, total of $N = 98$ cells in the system. The amount of requested channel, specified of minimum basic channel units (CU) is 30 Kbps of multi-channels migration. We assume $\lambda_o = 100$–2000 calls/h be the call originating rate per cell and $\lambda_h = \lambda_o \times 0.01$–$\lambda_o \times 1$ be the handoff traffic density per cell. We assume that traffic density pattern for performance analysis as λ_h/λ_o, and the $d = 1$ s communication delay between cells, and each handoff and new calls request delay constraint DC = 5 s. So, from the simulation result, the value of traffic load is chosen randomly and nonlinearly. The maximum number of handoff calls are queued 10 for the first class priority and new calls 10 for the second class priority, respectively. Let the density of simulation be 500 peoples per cell and the velocity is from 0 to 100 km/h. We define that the time of the sample interval is 3 min and the sampling time does influence previous one.

In order to represent various multi-media services, three different types are assumed based on the channel requirement and QoS. The duration of calls are distributed by different means for different multi-media traffic types. In our simulation three types of traffic services are assumed: voice service, video phone and video on demand. These types are defined on the channel requirement 30 Kbps, 256 Kbps and interval 1–3 Mbps, respectively. The assumptions of three performance metrics for our simulation study are as follows:

1. *Blocking calls*. If all the servers are busy, and the cell does not succeed to borrow a channel from its cluster cells, then handoff and new calls, generated at this particular cell are stored in the queue, otherwise they get service. If new and handoff calls do not get service of neither free channels nor borrowed channels, then the handoff and new calls are requested. When its waiting time (delay constraint) is over, the calls must be blocked.
2. *Update message complexity*. Each cell needs to communicate with co-channel and cluster cells in order to exchange the set of load state information.
3. *Channel acquisition delays*. The values it acquires before the selected channels, the cell must ensure that the selected channels will not be acquired by any of its cluster cells and interference cells, simultaneously. When a cell receives a channel request from an MS, it assigns a free channel, if any, to the request. Otherwise, the cell will need to acquire a new channel from its cluster cells and then assign channels to the request.

The performance of our fuzzy-based dynamic channel-borrowing scheme (FDCBS) is compared with the fixed channel assignment (Fixed), simple borrowing (SB), and existing strategies like channel-borrowing directed retry (DR), CBWL and LBSB, the experimental results reveal that the proposed channel-borrowing scheme yields have better performance than others. The number of hot cells vs blocked calls have been observed in our scheme.

Fig. 6 compares blocking probability vs traffic arrival rate. Blocking probability is defined as the percentage of calls generated that can be successfully allocated to a channel. It is a key measure of the channel assignment performance. At the base

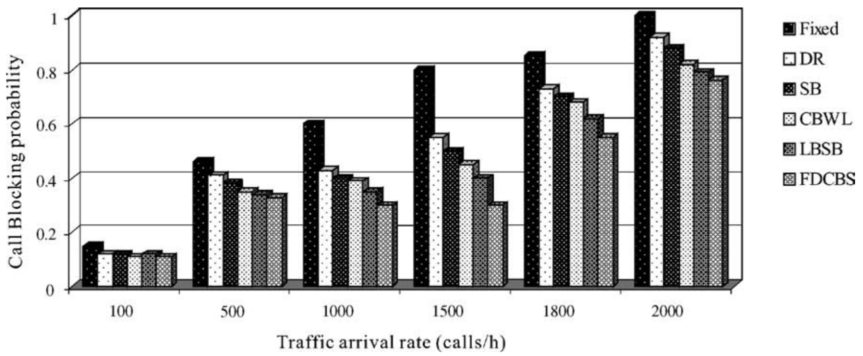


Fig. 6. Compare blocking probability vs traffic arrival rate.

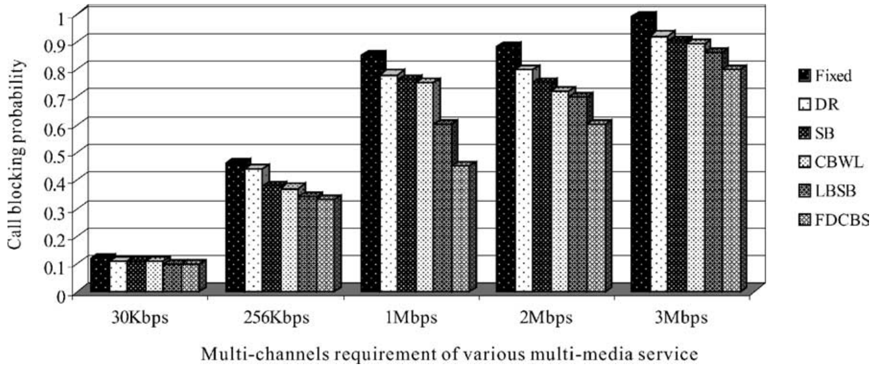


Fig. 7. Compare blocking probability vs multi-channels requirement of multi-media service.

load, all the schemes have low percentage of blocked channel requests, although fixed channel assignment algorithms blocks more than the other methods. When the traffic load increases, the number of blocked channel request also increases. For fixed channel assignment, it increases at faster blocking rate than by using other methods. The reason for this is that a BS can only use its nominal channels. When traffic load becomes hot, nominal channels are used up in many BSs. In cell cluster, while fixed channel assignment algorithms rejects all the new channel requests, the other schemes can handle the imbalance and satisfy new channel requests by borrowing channel from BSs with cold traffic load.

Fig. 7 compares the channel assignment algorithms according to the call blocking probability of channel request for multi-media services. When the traffic load increases, the call blocking rate of channel requests increases at a slower rate than the other schemes. Fig. 8 shows the blocked calls of the six channel assignment algorithms with the number of hot cells. It is observed that with a few hot cells in the system, We find that our proposed scheme has the best performance. In our FDCBS,

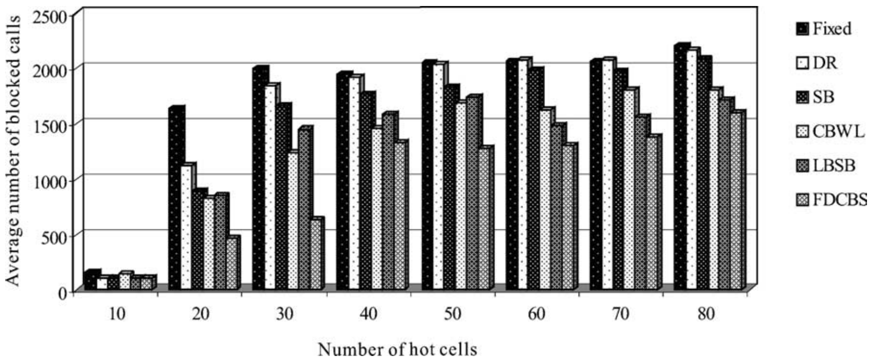


Fig. 8. Compare the number of blocked calls of our scheme with others.

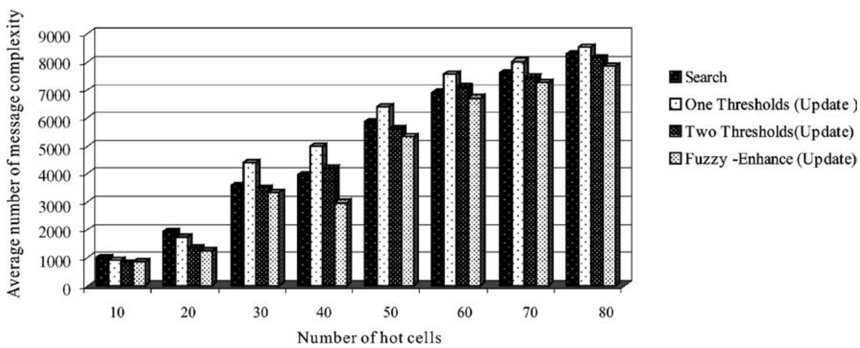


Fig. 9. Compare the average number of update messages overhead of our scheme with others.

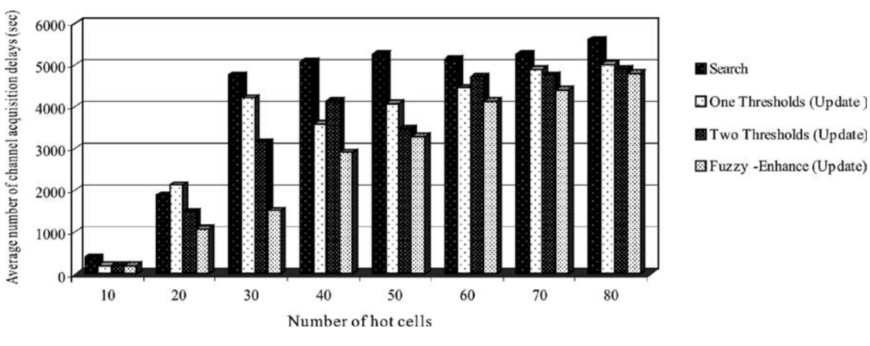


Fig. 10. The channel acquisition delays of various schemes.

when traffic load is hot there will be a lot of channel borrowing at a time for multimedia services, although not as severely channel-borrowing scheme.

Fig. 9 depicts the messages of different channel-borrowing schemes, and we found that our proposed DCA scheme has the shortest updated messages. Especially, our proposed scheme performs well when the number of hot cells are large. The channel acquisition delays is also discussed in our experiment. Fig. 10 shows that our proposed scheme has the shortest channel acquisition delays. This results in a channel allocation scheme with efficient channel use in all traffic conditions.

7. Conclusions

This is the first attempt in formulating the dynamic channel-borrowing problem with fuzzy logic control and with simulation for the various traffic load and number of hot cell nodes. The present paper has highlighted the role of fuzzy logic and its application in wireless cellular networks. In addition, FDCBS has often shown a faster and smoother response than conventional systems. Based on these parameters, a set of fuzzy inference rule is established. Since fuzzy logic control rules are constructed by using linguistic variables, intuitive knowledge is easily integrated into the control system. We believe that a fuzzy decision-making for the control and management cellular networks is more appropriate than the conventional probabilistic models. It also can efficiently determine the suitable cell for borrowing channels. The performance of the proposed scheme is better than that of the conventional schemes on the blocking rate, messages complexity and channel acquisition delays.

References

[1] P.H.J. Chong, C. Leung, A new channel borrowing scheme with interference information for cellular systems, IEEE Vehicular Technology Conference (1999) 1426–1438.
[2] X. Dong, T.H. Lai, Distributed dynamic carrier allocations in mobile cellular networks: search vs. update, IEEE Distributed Computing Systems (1997) 108–115.
[3] J.S. Engel, M. Peritsky, Statistically-optimum dynamic sever assignment in systems with interfering severs, IEEE Vehicular Technology Conference (1973) 1287–1293.
[4] H. Haas, S. McLaughlin, A novel decentralised DCA concept for a TDD network applicable for UMTS, IEEE Transactions on Vehicular Technology (2001) 881–885.
[5] T. Lee, J. Kim, C.S. Hwang, A dynamic channel assignment scheme with two thresholds for load balancing in cellular networks, IEEE Radio and Wireless Conference (1999) 141–145.
[6] H. Jiang, S.S. Rappaport, CBWL: a new channel assignment and sharing method for cellular communication systems, IEEE Transactions on Vehicular Technology (1994) 313–322.
[7] R.J. McEliece, K.N. Sivarajan, J.W. Ketchum, Dynamic channel assignment in cellular radio, IEEE Vehicular Technology Conference (1990) 631–637.
[8] T.J. Kahwa, N.D. Georganas, A hybrid channel assignment scheme in large-scale, cellular-structured mobile communication systems, IEEE Transactions on Communications (1978) 432–438.
[9] J. Karlsson, B. Eklundh, A cellular mobile telephone system with load sharing-an enhancement of directed retry, IEEE Communications (1989) 530–535.
[10] S. Kim, P.K. Varshney, Adaptive Load Balancing with Preemption for Multimedia Cellular Network, IEEE Wireless Communications and Networking Conference (2003) 1680–1684.

[11] M. Krishnamoorthy, M.A. Egan, K. Rajan, Comparative study of a genetic fuzzy c-means algorithm and a validity guided fuzzy c-means algorithm for locating clusters in noisy data, IEEE World Congress on Computational Intelligence (1998) 440–445.
[12] E.H.K. Wu, M.H. Jin, J.T. Horng, A channel allocation algorithm for large scale cellular networks, IEEE Parallel and Distributed Systems (2002) 465–470.
[13] I.b. Turksen, M.R. Emami, A.A. Goldenberg, Development of a systematic methodology of fuzzy logic modeling, IEEE Transactions on Fuzzy System (1998) 346–360.
[14] T.S. Yum, M. Zhang, Comparisons of channel-assignment strategies in cellular mobile telephone systems, IEEE Transactions on Vehicular Technology (1989) 211–215.
[15] S. Mitra, S. DasBit, A load balancing strategy using dynamic channel assignment and channel borrowing in cellular mobile environment, IEEE Personal Wireless Communications (2000) 278–282.
[16] S.K. Sen, S.K. Das, R. Jayaram, A structured channel borrowing scheme for dynamic load balancing in cellular networks, IEEE Distributed Computing Systems (1997) 116–123.
[17] L.P. Shu, J.W. Chen, Dynamic grouping algorithm for cellular communications systems, IEEE Vehicular Technology Conference (1991) 689–692.
[18] Y.T. Wang, A fuzzy-based dynamic channel borrowing scheme for wireless cellular networks, IEEE Vehicular Technology Conference (2003) 1517–1521.
[19] S.H. Wong, I.J. Wassell, Application of game theory for distributed dynamic channel allocation, IEEE Vehicular Technology Conference (2002) 404–408.
[20] L.A. Zadeh, Fuzzy algorithm, Information and Control (1968) 94–102.