A Fuzzy-Based Dynamic Channel Borrowing Scheme for Wireless 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 the hot-spot cells. Most conventional method use load indices with a threshold value to determine the load status of a cell. However, it 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. 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 update overhead, and shorter channel acquisition delays.**

keywords: Dynamic channel borrowing, dynamic load balancing, fuzzy logic control, channel allocation, wireless cellular networks.

I. 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). The concept also applies to radio network controller RNC in 3G systems. A BS directly communicates with all mobile stations (MS) within its wireless transmission radius. The channel assignment (allocation) problem is an important topic in a cellular system. The objective of channel assignment of is mainly to exploit the channel reuse factor under the constraint of *co-channel reuse distance*.

Existing results for channel assignment can be classified into *Fixed Channel Assignment (FCA)* [9][5][16] and *Dynamic Channel Assignment (DCA)* [8][4]. The advantage of FCA is its simplicity. However, it does not reflect real scenarios where load may fluctuate and may vary from cells to cells. DCA schemes can dynamically assign/reassign channels and thus are more flexible. In centralized DCA schemes [11], all the allocation jobs are done by MSC. In distributed DCA schemes, BSs need to be involved.

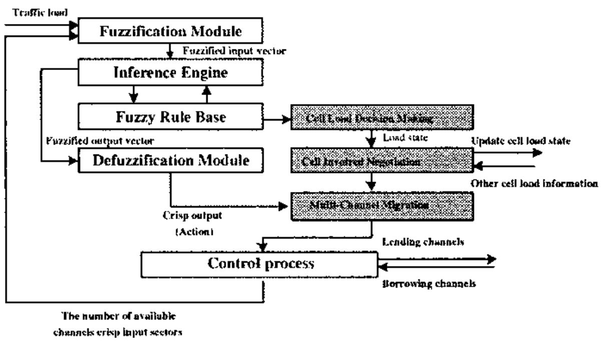

Fig. 1. Block diagram of FDCBS

Recently, *Das et al.* [14] proposed a scheme called load balancing with selective borrowing (LBSB). 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 distinctions, series fluctuation like ping-pong effect may occur when loads are around the threshold. It may waste a significant amount of efforts in transferring channels back and forth [2][10].

The load information collection can not only estimate the traffic load about the systems, but also provide useful information for making channels reallocation decisions. We develop fuzzy rules to determine how to classify a cell as hot or cold. A good load information gathering should be able to predict the cell load in the near future, relatively stable, and have a simple relationship with the resource indexes. In a cellular system, the arrival time of the calls may vary significantly, and their 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 fuzzy numbers play a fundamental role in formulating quantitative fuzzy variables. The fuzzy numbers represent linguistic concepts, such as *very hot*, *hot*, *moderate*, and so on. Traditional channel allocation approaches can be classified into *update* and *search* [3]. The fundamental idea is that a cell must consult all 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 cells traffic loads and available channels, thus further reducing the borrowing overhead. 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 borrowing 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. Fig. 1 shows the block diagram of our FDCBS.

The performance of our FDCBS is compared to the fixed channel assignment, simple borrowing, directed retry [4], CBWL [8], and LBSB [14]. The experimental results reveal that our proposed scheme yields better performance as compared to others. 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 messages, 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 in Section 3. In Section 4, we propose the cell involved negotiation. The new channel borrowing with multi-channel transferring scheme is presented in Section 5. Concluding remarks are made in Section 6.

II. Fuzzy-Based Cellular System Model

The cellular system is modeled follows. A given geographical area consists of a number of hexagonal cells, each served by a base station (BS). Base stations and mobile hosts communicate through wireless links using channels. Each cell is allocated a fixed set of channels 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 forms a compact pattern of radius R. Given a cell c, the interference neighborhood of c is denoted by $IN(c) = \{c' | dist(c, c') < D_{\min}\}$, where $D_{\min}$=$3\sqrt{3}R$ [3]. If N_i denotes the number of cells in ring i, then for the hexagonal geometry $N_i = 1\, if\, i = 0,\, and\, N_i = 6i\, if\, i > 0$.

We partition the set of all cells into a number of disjoint subset, $G_0, G_1, ..., G_{k-1}$ such that any two cells in the same subset are apart by at least a distance of $D_{\min}$. We also partition the set of all channels into K disjoint subset, $P_0, P_1, ..., P_{k-1}$. The channels in $P_i (i = 0, 1, ..., k-1)$ are called the primary (nominal) channels for the cells in G_i, which are arranged in an ordered list. A channel is either *used* or *available* depending on whether it is assigned to a MS or not. A channel available for c becomes interfered if it is acquired by some cell in $IN(c)$. 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

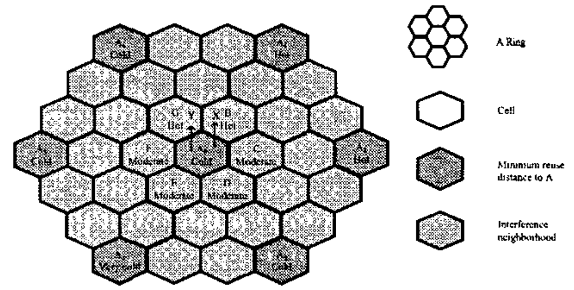

Fig. 2. Hexagonal cellular networks

G_i are primary cells of the channels in P_i and secondary cells of the channels in P_j $(j \neq i)$.

A cell can acquire only available channels, as shown in Fig. 2. The interference neighborhood of a cell may contain as many as 30 cells in the hexagonal cellular network. For example, in the fig 2, the cell B of the system state is hot, and it need to borrow channel x from cell A_0. Meanwhile the cell A_0 of the co-channel cell is A_1, which its system state is hot. The A_0 cannot lend the channel x to the cell B, but another situation, the A_0 can lend to cell G because the A_6 of the system state is cold.

The cell load collection is one of the most important issues in cellular system for load balancing approach. The load information collection denotes not only the amount of cell load about the systems but also the information gathering rules used in making the channel reallocation decision. The goal is to obtain sufficient information in order to make a decision weather the cell's load is hot or not. A good cell load information gathering should be able to predict the cell load in the near future, be relatively stable, and have a simple relationship with the resource indexes, so that its value can be easily translated into that of the expected performance of the network. The advantage of the first approach is the abstraction from the individual channels to a more general estimation of a situation which is described by system state. Thus the decision making must not run all the time; the decision process can be started periodically and dynamically or in dependence on significant changes of system states.

The problem with such methods is that several unrealistic assumptions must be made to make the study feasible. For example in most models exponential distributions for arrival and service times are used. Heuristic techniques usually adopt a threshold used to determine where the load is cold or hot. This binary-state model makes the system load state fluctuate between hot or cold load when the cell load is near the threshold value. It will incur frequent the channel reallocations due to little load change. Simulation techniques have widely been used by researchers. Although it provides more flexibility and freedom, it has its own limitations and drawbacks. For example, the load is usually artificial and predetermined. Some methods use simple queuing model of mobile cellular system [10][8][14]. Those proposed schemes completely ignore other resources than traffic load. Therefore, while it may be reasonable to detect the performance of purely available channels, its utility is questionable for channels that use the other resources of contention. We recognize that it is difficult, or perhaps impossible; to find cell load information that satisfies all of the above requirements. Moreover, they may be contradictory. But cell load information may be judged by the degree to which it meets the above criteria. The proposed scheme seems to be approximating these criteria.

In this paper, the performance of a DCA strategy will depend on how to decide the state information at the BSs [10][3]. An efficient channel assignment strategy should not only consider the present load, but also the load distribution in the recent past based on this information. It should be able to project the load distribution in the near future. The relationship between the communication resources is too complex to define a good rule for estimating the cell load. When the load of a cell increases, some of the channels may be borrowed from a cold cell.

The concept of a 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 spot; is making decisions under uncertain and vague conditions.

III. Cell Load Decision-Making

The decision making indicates the significance of various loading regarding with the cellular system. We can construct different available channels membership function, traffic load membership function, and center value for linguistic labels around through *fuzzy c-means clustering algorithm* [1] according to various cell's characteristics of system behavior data. Many researchers use available channels as the single load index for BS in cellular system [11]. Although the number of available channels is the obvious factor impacting on the system load, there are other factors also influencing the system load, such as call arrival rate and call duration, etc. *Fuzzification* function is introduced for each input variable to express the associated measurement uncertainty.

A. 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, $Supp(A) = \{x \in U | u_A(x) > 0\}$. There are a variety of fuzzy set operations. We consider an

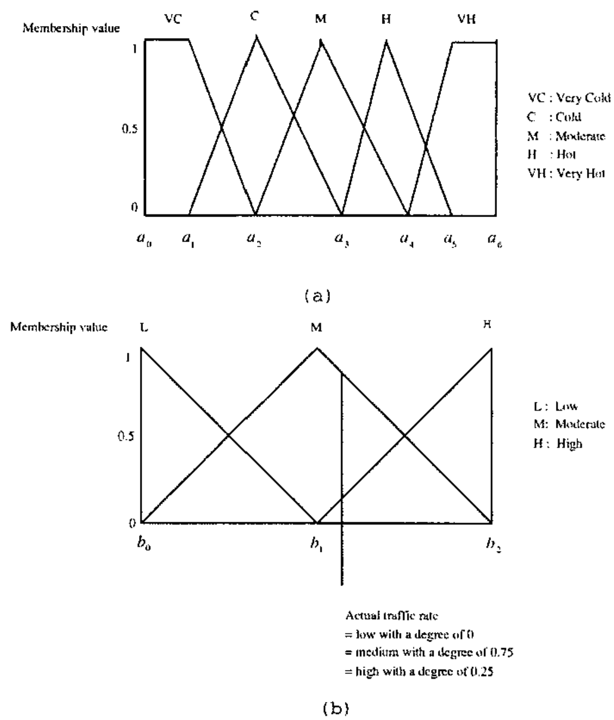

Fig. 3. Example for the fuzzification of the system parameter (a)the number of available channels and (b) traffic load

interval of real number and the notation $A = \int_u u_A(x)/x$. Fig. 3(a) shows membership function for the number of available channel; Fig. 3(b) is the example for the fuzzification of the system parameter traffic load. These function are define on the interval $[a_0, a_6]$, $[b_0, b_2]$ as follows, respectively.

B. Fuzzy Rule Base

Fuzzy Rule Base is characterized a 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:

Input : x is A$'$ AND y is B$'$
R^1: IF x is A$_1$ AND y is B$_1$, THEN z is C$_1$
ALSO R^2: IF x is A$_2$ AND y is B$_2$, THEN z is C$_2$
...
ALSO R^n: IF x is A$_n$ AND y is B$_n$, THEN z is C$_n$
Conclusion : z is C$'$

Where $x, ..., y$, and z are linguistic variables representing the process state variables and the control variable, respectively, and $A_i, ..., B_i$, and C_i are the linguistic values of the linguistic variables $x, ..., y$, and z in the universes of discourse $U, ..., V$

and W, respectively.

IV. Cell Involved Negotiation

The objective of the cell negotiation is to select the cell to or from which channels will be borrowing when the cell load reallocation event takes place. Traditional channel allocation algorithm in negotiation can be classified into *update* and *search* methods [3]. When a new call arrives at a hot cell, the FDCBS algorithm is activated requesting its neighboring interference cells for help, and attempts to import 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.

A. Inference Engine

The knowledge pertaining to the given control problem is formulated in terms of a set of fuzzy inference rules. 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 ($\bigcap$) or union ($\bigcup$) for different definition of fuzzy implication. Denote the max-min composition operators. Then we have the following theorem governing the connective AND with one fuzzy control rule to obtain the conclusion.

V. Multi-Channel Borrowing

Multi- channels borrowing, the new channel borrowing with multi-channel transferring can reallocates channels well especially in an unpredictable variation of cell load. The number of reallocated channels is just one channel in each iteration. It is very inefficient if the cell load of these two cells differ very much. Our proposed idea is why not borrowing several channels instead of only one between two cells whose BS load differ a lot. The difference is that we reallocate several channels instead of only one channel borrowed while making load balancing in each iteration. In this idea, we could make the available channels between two cells more balanced.

To accomplish this, we use five load values to distinct the difference of cell load on two cells; If one cell is in the "*Very hot*" state; then it will borrowing several channels from the cell with "*Very cold*" state. If there are not existing any "*Very cold*" cell, then it would choose several cells with "*Cold*". 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 relevant fuzzy information rules.

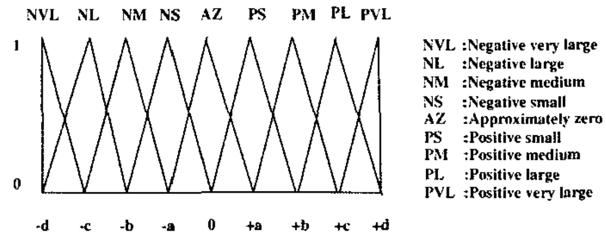

Fig. 4. shows membership function of the fuzzy output

A. 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 crisp control actions. The Fig. 4 shows the membership function for channel borrowing/lending a quantity control number of the channel range $[-d, +d]$ of the fuzzy output. We used *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

$$Y^0_{coa} = \lfloor \frac{\sum_{i=1}^{n} Wi*Bi}{\sum_{i=1}^{n} Wi} \rfloor$$

Where Y^0_{coa} output of fuzzy control

W_i =The antecedent degree of i^{th}control rule

B_i =The consequent center value of i^{th}control rule

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

$$Output\ = Min[borrowing\ (Y^0_{coa}), lending\ (Y^0_{coa})].$$

VI. Experimental Results

The problem domain naturally lends itself to simulation using multiple threads since there is a lot of concurrence and global resource management issues in the system. This experiment used the number of channels $C = 30$ in a cell, and total of $N = 100$ cells in the system.We define that the time of the sample interval is 5 minute, and the sampling time does influence previous one. We assume $\lambda o = 100/hr \sim 2000/hr$ be the call originating rate per cell, and $\lambda_h = (\lambda o \times 0.01 \backsim \lambda o \times 1)$ be the hand-off traffic density per cell. The traffic density pattern for performance analysis as $\frac{\lambda_h}{\lambda o}$, and the $d = 1$ sec communication delay between cells.

The performance of our FDCBS is compared with the fixed channel assignment, simple borrowing, and existing strategies with channel borrowing directed retry, CBWL and LBSB, the experimental results reveal that the proposed channel borrowing scheme yields have good performance better then others. The number of hot cells vs. blocked calls have the observation

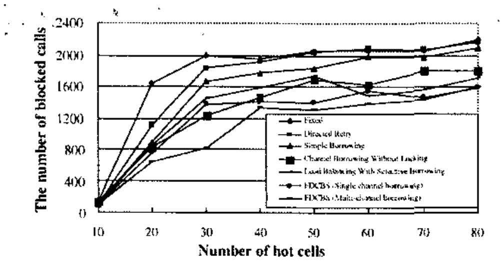

Fig. 5. show the number of blocked calls and comparison of our scheme with others

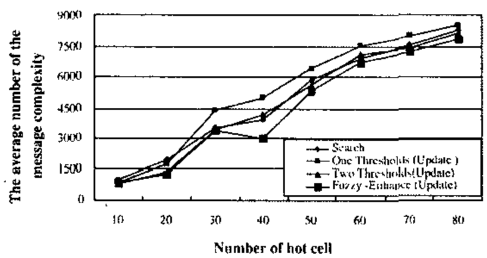

Fig. 6. show the average number of update messages overhead and comparison of our scheme with others schemes

results in our scheme. From Fig. 5, shows the blocked calls of the six channel assignment algorithms with number of hot cells. It is observed that with a few hot cells in the system. We found that our proposed scheme has best performs. Fig. 6 depicts the messages of different channel borrowing schemes, and we found that our proposed DCA scheme has the less update messages. Especially, our proposed scheme performs well when the number of hot cells is large. The channel acquisition delays is also discussed in our experiment. Fig. 7 show that our proposed scheme has the average shortest channel acquisition delays.

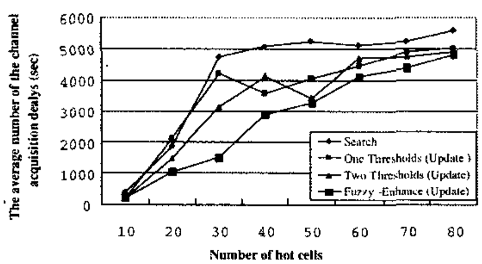

Fig. 7. show the channel acquisition delays of different schemes

VII. Conclusions

Present paper has highlighted the role of fuzzy logic and its application in wireless cellular networks. We have defined methods for collecting system parameters in a fuzzy sense. 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. It also can efficiently determine the suitable cell for borrowing channels. The performance of proposed scheme is better than that of the conventional schemes on the blocking rate and messages complexity and channel acquisition delays.

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