Fuzzy Logic Based Neural Network Models for Load Balancing in Wireless Networks

Yao-Tien Wang and Kuo-Ming Hung

Abstract: **In this paper, adaptive channel borrowing approach fuzzy neural networks for load balancing (ACB-FNN) is presented to maximized the number of served calls and the depending on asymmetries traffic load problem. In a wireless network, the call's arrival rate, the call duration and the communication overhead between the base station and the mobile switch center are vague and uncertain. A new load balancing algorithm with cell involved negotiation is also presented in this paper. The ACB-FNN exhibits better learning abilities, optimization abilities, robustness, and fault-tolerant capability thus yielding better performance compared with other algorithms. It aims to efficiently satisfy their diverse quality-of-service (QoS) requirements. The results show that our algorithm has lower blocking rate, lower dropping rate, less update overhead, and shorter channel acquisition delay than previous methods.**

Index Terms: **Channel allocation, dynamic channel borrowing, dynamic load balancing, fuzzy logic based neural network models, wireless networks.**

I. INTRODUCTION

High spectral efficiency and flexible data rate access are main focus for future wireless networks, as well as the development trend of existing wireless networks toward the next generation. 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, and a BS directly communicates with all mobile stations (MSs) within its wireless transmission radius. The channel assignment (allocation) problem is an important topic in wireless networks [1]–[5]. The base station and the mobile host communicate through the wireless links using channel. 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* [2], [6]. 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 $IN(c) = \{c^{'}|\text{dist}(c, c^{'}) < D_{\min}\}$. If N_i denotes the number of cells 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, $G_0, G_1, \cdots, G_{k-1})$ such that any two cells in the same subset are apart by at least a distance of $D_{\min}$, and partition the set of all channels into K disjoint subsets, $P_0, P_1, \cdots, P_{K-1}$. The channels in P_i $(i = 0, 1, \cdots, K-1)$ are called the primary (nominal) channels for the cells in G_i, and they are arranged in an ordered list. A channel is either used or available depending on whether it is assigned to an MS. A channel available for c becomes interfered if it is used 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 G_i are primary cells of the channels in P_i and secondary cells of the channels in $P_j (j \neq i)$. Existing results for the channel assignment can be classified into fixed channel assignment (FCA) [7], [8] and dynamic channel assignment (DCA) [9]–[11]. The advantage of FCA is its simplicity. However, it does not reflect real scenarios where load may fluctuate and may vary from cell to cell. DCA schemes can dynamically assign/reassign channels and thus are more flexible. In the centralized DCA schemes [12], [13], all channels are placed in a pool and are assigned to the new calls as needed, and all the allocation jobs are done by MSC. In the distributed DCA schemes [6], [12], [14], [15], BSs are needed to be involved.

To be more specific, the channel borrowing for load balancing usually use some fixed threshold values to distinguish the status of each cells [1], [16]. 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-pang 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], [2]. 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).

Due to this nature, using ACB-FNN is the best way to approach the channel borrowing for load balancing 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 [12], [15]. The fuzzy expert system approach has also been applied to forecasting where the advantage of an operator's expert knowledge is used. However, the fuzzy decision wireless network for load balancing requires detailed enhancer [13]. Traditional channel allocation of the negotiation approaches can be classified into *update* and *search* [6]. The fundamental idea is that a cell must consult all the interference cells within the minimum reuse distance before it can acquire a channel. The ACB-

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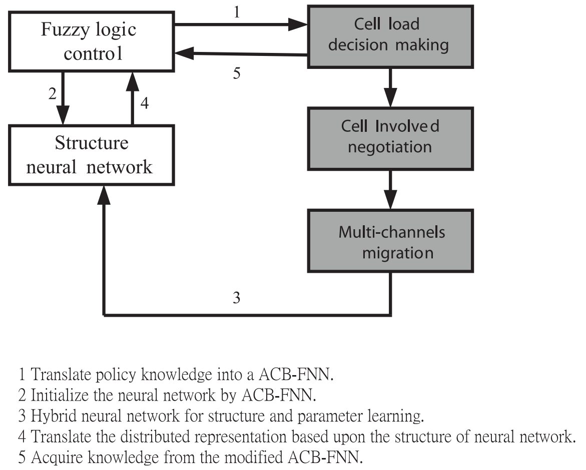

Fig. 1. Block diagram of ACB-FNN.

FNN consists of two modules: Fuzzy logic control (FLC) and neural networks (NN). The ACB-FNN consists of (1) cell load decision-making, (2) cell involved negotiation, and (3) multi-channels migration phases. The structure of a dynamic channel borrowing for load balancing in wireless networks is composed of three design phases by applying artificial NN and FLC 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 they will be migrated when the load reallocation event takes place. Our proposed channel borrowing for load balancing algorithm of the negotiation in wireless networks, where this algorithm can divide these various into three policies: Hot Cell-Initiated, Cold Cell-Initiated, and Symmetrically Cell-Initiated, it will make the system load more balanced than the former ones. 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 channel's availability, thereby reduces the borrowing overhead further. The multi-channels borrowing pertains to manage the migration of channels from one cell to another. Fig. 1 shows the block diagram of our ACB-FNN.

The performance of our ACB-FNN is compared with the fixed channel assignment [8], [14], simple borrowing (SB) [17], directed retry (DR) [4], channel borrowing with out locking (CBWL) [11], and load balancing with selective borrowing (LBSB) [1]. The experimental results reveal that our proposed scheme yields better performance as compared with other conventional schemes. Our adaptive ACB-FNN for load balancing algorithm not only effectively reduces the blocking rate and the dropping 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 II, we provide the structure channel borrowing strategy. The design issues of our proposed ACB-FNN with cell load decision in Section III. In Section IV, new load balancing algorithm with cell involved negotiation. The multi channel migration scheme is present in Section V. Experimental results are given in Section VI. Finally, concluding remarks are made in Section VII.

II. CHANNEL BORROWING STRATEGY

In SB this variant of the fixed assignment scheme proposes to borrow a channel from neighboring cells provided it does not interfere with the existing calls and locked in those co-channel cells of the lending one. In the DR, it is assumed that the neighboring cells and the users overlap region and the main drawback of this scheme include increased number of handoffs and co-channel interference, and also the load sharing is dependent upon the number of users in the overlap region. The CBWL scheme proposes channel borrowing when the set of channels in a cell gets exhausted; but it uses the borrowed channels under reduced transmission power to avoid co-channel interference. Additionally, the facts that only a fraction of the channels in all neighboring cells are available for borrowing. In the LBSB, a cell is classified as "hot," if its degrees of coldness defined as the ratio of the number of available channel to the total number of channel channels allocated to that cell is less than or equal to some threshold value. Otherwise the cell is "cold." Aided by a channel allocation strategy within each cell, it has been presented in that the centralized LBSB achieves almost perfect load balancing and lead to a significant improvement over simple borrowing, directories and CBWL schemes in case of an overloaded wireless access network. In this scheme, it has too much dependency on the central server maintenance of continuous status information of the cells in an environment. The traffic load changes dynamically, leading to enormous amount of updating traffic, consumption of bandwidth and message delays. In this paper, the performance of a DCA strategy will depend on how the state information has been decided at the BSs. Achieving this estimation, however, is difficult and time consuming. The relationship between the communication resources is too complex to define a good rule for estimating the cell load. ACB-FNN, based on a fusion of ideas from FLC and NN, has the advantages of both neural networks such as learning abilities, optimization abilities, and FLC (e.g., human like IF-THEN rule thinking and ease of incorporating expert knowledge). In this way, we can bring the low-level learning and computational power of NN to FLC and also provide the high level, human like IF-THEN rule thinking and reasoning of FLC to NN. Neural networks can improve their transparency, making them closer to FLC, while FLC can self-adapt, making them closer to NN. The typical architecture of FLC includes four principal components: Fuzzifier, fuzzy rule base, inference engine, and defuzzifer [12], [15], [18].

III. CELL LOAD DECISION MAKING

This section addresses our strategy of estimating of load status in wireless networks. Such measure is vital for us to determine the most suitable site for migrating channels in order to

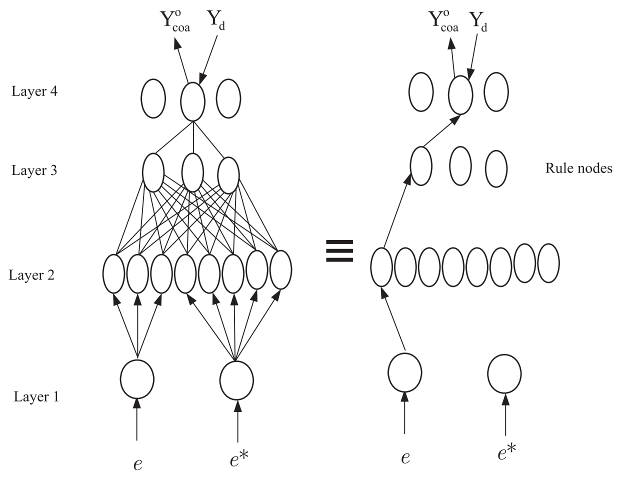

Fig. 2. Hybrid structure parameter learning of the ACB-FNN.

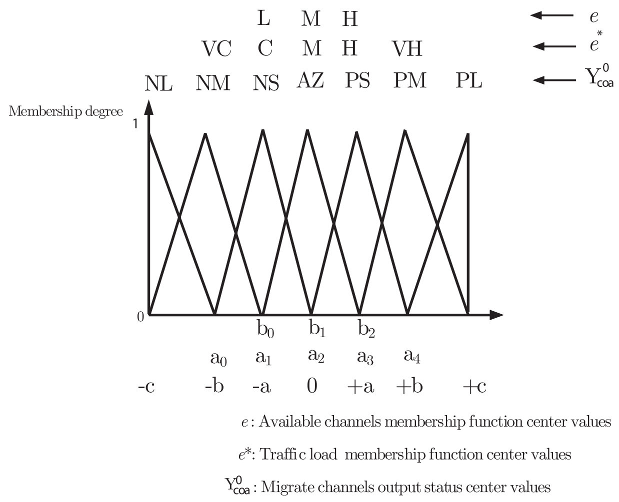

Fig. 3. Membership functions of the fuzzy input and output.

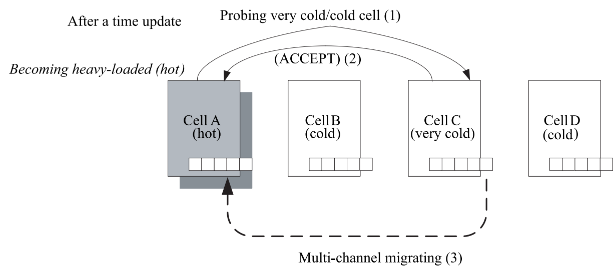

Fig. 4. Example for the hot cell-initiated.

share the load in the system. We can construct different available channels membership function, traffic load membership function. The ACB-FNN has a total of four layers, the nodes in layer 1 are linguistic nodes that represent input linguistic variables, and layer 4 is the output layer. There are two linguistic nodes for each output variable. One is for desired output to feed into the network, and the other is for actual output to be pumped out of the network. Nodes in layers 2 and 3 are term nodes, which act as membership functions representing the terms of the respective linguistic variables, where Y_{coa}^{0} represents the number of migrate channels, and Y_d is our desired output. Fig. 2 shows the hybrid structure parameter learning of the ACB-FNN.

We consider an interval of real number and the notation $e^* = \int_u u_e(a_i)/a_i$, and $e = \int_u (b_i)/b_i$, where e is denoted as available channel and e^* is denoted as traffic load, a_i and b_i are actual input values, respectively. Let a_i present the center value for linguistic labels of available channel membership function for $0 \le i \le 6$, and let b_i present the center value for linguistic labels of traffic load membership function for $0 \le i \le 2$. The status of very cold (VC), cold (C), moderate (M), hot (H), or very hot (VH) for different value of available channels and the status of may be low (L), moderate (M), or high (H) for different values of traffic loads. Fig. 3 shows membership functions of the fuzzy input and output. The function is defined on the interval $[0, +c]$ for borrowing action, and on the interval $[0, -c]$ for lending action.

IV. 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 [6]. Both approaches have advantages and disadvantages. The update approach has short acquisition delay and good channel reuse, but it has higher message complexity. In other words, the search approach has lower message complexity, but it has longer acquisition delay and ineffective channel reuse.

The cell involved negotiation for load balancing algorithm plays the key role of the wireless networks. It needs to negotiate between cells. The algorithm selects the cells to or from which channel will be migrated. In our proposed new load balancing algorithm for wireless networks, the new algorithm can divide these various load balancing algorithms into three policies: Hot Cell-Initiated, Cold Cell-Initiated, and Symmetrically Cell-Initiated (SCI), where it will make the system load more balanced than the former ones.

A. Hot Cell-Initiated

The Hot Cell-Initiated, when a cell becomes very hot or hot after a time update, selects a cell looking for cell load status that is light-loaded (very cold or cold). If it is so, an ACCEPT message is sent back, otherwise it replies with a REJECT message. If the requesting cell is still heavy-loaded when the ACCEPT reply arrives, the lending channel is transferred to the heavy-loaded, otherwise, the channel keeps using locally. Fig. 4 shows an example of the hot cell-initiated. After a time update, cell A does the migration procedure if the load is heavy-loaded by load estimated. Cell C is the probed cell by cell A. If cell C is light-loaded, cell C returns ACCEPT message to cell A. While cell A receives ACCEPT and is still heavy-loaded, cell A will borrow channel from cell C.

B. Cold Cell-Initiated

For the cold cell initiated, the load balancing controller checks the load after every update interval. Once the comple-

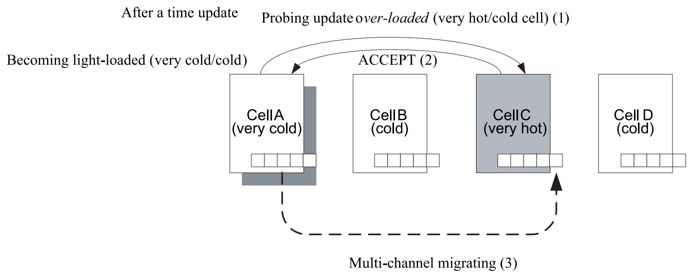

Fig. 5. Example for the cold cell-initiated.

tion of call services brings the cell load status into becoming light-loaded, the cell will probe a select one to check if it is heavy-loaded. When an heavy-loaded cell is found, an ACCEPT message is sent back, otherwise it replies with a REJECT message. The migration of a channel from the probed cell to the requesting cell begins when the ACCEPT message arrives and the requesting cell is still light-loaded. Fig. 5 shows the negotiation and channel migration of this cold cell initiated. While cell A becomes light-loaded after a time period, it probes a cluster cell. Cell C is selected in this example. Because cell C is overloaded, it returns an ACCEPT message to the requesting cell A. cell A is still light-loaded, so it borrows a channel from cell A to cell C.

C. Symmetric Cell-Initiated

Compared with the hot cell-initiated and cold cell-initiated algorithms, in a hot cell-initiated (cold cell-initiated) load balancing algorithm, heavy-loaded cell (light-loaded cell) continues to send unnecessary request messages for load transfer until light-loaded cell (heavy-loaded cell) is found while the system load is heavy (light). Therefore, it yields inefficient inter-cell communications, high message complexity, and high channel acquisition delay. To solve these problems, we propose an improved ACB-FNN and symmetric cell-initiated algorithm for hot cell-initiated and cold cell-initiated load balancing in distributed wireless cellular networks, and define a suitable multi-channel borrowing function. In this scheme, the cells that the request messages are transferred are determined by ACB-FNN. And it decreases unnecessary request messages per channel acquisition, and delay per channel acquisition.

V. MULTI-CHANNELS MIGRATION

The ACB-FNN, 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 loads of these two cells differ very much. Our proposed idea is to borrow several channels instead of only one between two cells whose BS loads differ a lot. For example, in the next generation multimedia mobile network, a call may need multiple channels at a time. We have used the center of area (COA) method because it supports software real time fuzzy controls to distinguish the difference of load on two cells. This value is calculated by the formula

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

where Y^o_{coa} represents 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^o_{coa} obtained by the formula can be interpreted as an expected value of variable. Finally, we obtain

$$\textbf{Migrate channels} = \textbf{Min [borrowing cell } (\boldsymbol{Y^o_{coa}}), \textbf{ lending cell } (\boldsymbol{Y^o_{coa}})].$$

After multi-channels are reallocated, we use hybrid neural network to tune the fuzzy membership function. We define the isosceles triangular membership function of load status, the x_i is an input variable, and the antecedent degree of ith control rule is dependent upon the membership function center value a_i, the membership function width b_i.

$$U_i(x) = \frac{1 - 2|x_i - a_i|}{b_i}.$$

According to the number of migrate channels Y^0_{coa} and the objective error function E, we have

$$E = \frac{1}{2}\left[\left(\left\lfloor \frac{\sum_{i=1}^n w_i \times B_i}{\sum_{i=1}^n w_i} \right\rfloor\right) - Y_d\right]^2.$$

Since the shape of the membership function $U_i(x)$ is defined by the center value a_i and b_i the width, the objective error function E consists of the tuning parameter a_i, b_i, w_i, and η is the learning rate, for $i = 1, \cdots, n$. Hence the learning rules can be derived as follows:

$$a_i(t+1) = a_i(t) - \eta a \cdot dE/da_i,$$
$$b_i(t+1) = b_i(t) - \eta b \cdot dE/db_i,$$
$$w_i(t+1) = w_i(t) - \eta w \cdot dE/dw_i.$$

VI. EXPERIMENTAL RESULTS

The problem domain naturally lends itself to simulate using multiple threads since there are a lot of concurrence and global resource management issues in the system. The simulated model consists of 14 clusters with 7 homogeneous cells each. This experiment has used the number of channels $CH = 100$ 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 $\lambda_0 = 100$ calls/per hour$\sim 2,000$ calls/per hour be the call originating rate per cell and $\lambda_h = (\lambda_0 \times 0.01 \sim \lambda_0 \times 1)$ is the handoff traffic density per cell, and $d = 1$ sec communication delay between cells, and each handoff and new calls request delay constraint ($DC = 15$) seconds. So, from the simulation result, the value of traffic load is chosen randomly and nonlinearly. The maximum numbers of handoff calls are queued 15 for the first class priority and new calls 15 for the second class priority, respectively. Let the density of simulation be 500-*people/per cell*. In order to represent various multi-media services, three different types of traffic services are assumed based on the channel requirement. 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 Mbps to 3 Mbps, respectively. The assumptions of four performance metrics for our simulation study are as follows: **(1) Blocking calls:** If all the servers are busy, the cell does not succeed to borrow a channel from its cluster cells and if its waiting time (delay constraint) is over then the calls must be blocked, otherwise they get service. **(2) Dropping calls:** When an MS moves into a neighboring cell, the call must be transferred to the neighboring BS. This procedure is a hand-off. If a channel can not be assigned at the new BS and the particular cell does not borrow a channel from its cluster cells, then the call generated at this particular cell are stored in the queue, and if its waiting time (delay constraint) is over then the calls must be dropped, otherwise they get service. **(3) Update-message complexity:** Each cell needs to communicate with co-channel and neighbor cells in order to exchange the set of load state information. **(4) 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 ACB-FNN is compared with the fixed channel assignment (Fixed), SB, DR, CBWL, and LBSB. The experimental results reveal that the proposed channel borrowing scheme yields have better performance than others. Fig. 6 compares the channel assignment algorithms according to the new call-blocking probability of channel request for the multimedia services. When the traffic load increases, the call-blocking rate of channel requests increases at a slower rate than the other schemes. Fig. 7 shows the handoff call-dropping probability for various schemes at various multimedia services. The number of multimedia requirements on the horizontal axis has different meanings for voice service, video phone, and video on demand. The ACB-FNN scheme always has lower hand off dropping rate than the existing channel assignment schemes with the same number of channels required. It also indicates that the ACB-FNN scheme can improve performance over the other methods with the number of reserved channels by further reducing the hand off dropping probability.

We compared the performance of proposed method Hot Cell-Initiated, Cold Cell-Initiated, and ACB-FNN (Symmetric Cell-Initiated) is called ACB-FNN (SCI) with a conventional method in this experiment. The experiment is to observe the change of messages required per channel acquisition (messages complexity) when the number of hot cells to be performed is 80. Fig. 8 shows results of the conventional method, when the heavy-loaded cell determines a suitable light-loaded cell, it probing select a cell in distributed wireless networks, and receive the load state information from the co-channel cells. The algorithm determines the selected cell as light-loaded cell, and these cells are repeated until a suitable light- loaded cell is accepted. So, the result of messages complexity shows the fluctuation. In the proposed algorithm, the algorithm shows the fewest updated messages complexity because the load balancing activity performs the ACB-FNN considering the load state when it determines a light-loaded cell. The chosen cell will respond by sending a channel from its transferable channels, or just ignores the message if it is also at a stabilized-state. Our proposed and enhanced ACB-FNN schemes performs especially well when the numbers of hot cells are large, which support multi-channel migration. The channel acquisition delays are also discussed in our experiment. Fig. 9 shows that our proposed scheme has the shortest channel acquisition delays. This results in a channel-borrowing scheme for load balancing with efficient channel use in all traffic conditions.

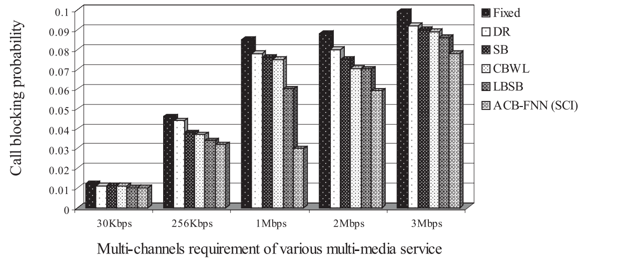

Fig. 6. Blocking probability and multi-channel requirement of multimedia service.

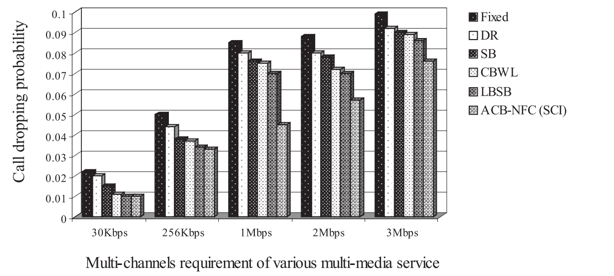

Fig. 7. Dropping probability and multi-channel requirement of multimedia service.

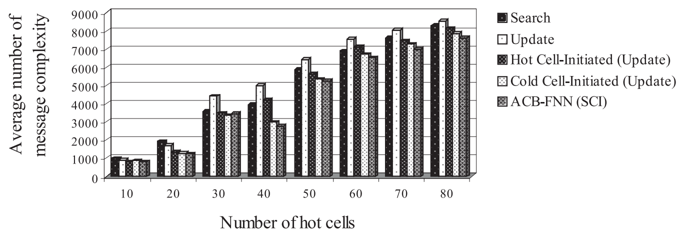

Fig. 8. Average number of update message overhead in our scheme and others.

VII. CONCLUSION

This is the first attempt in formulating the load balancing with ACB-FNN and with simulation for various traffic load and number of hot cell nodes. Present paper has highlighted the role of ACB-FNN and its application in wireless networks. In addi-

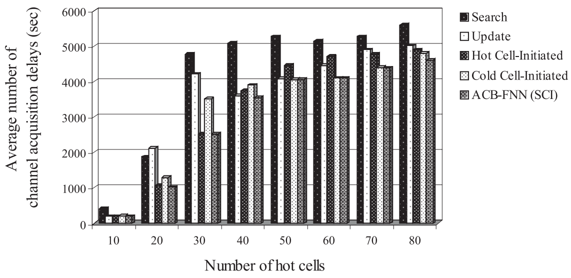

Fig. 9. The channel acquisition delays of various schemes.

tion ACB-FNN has often shown a faster and smoother response than conventional systems. Fuzzy logic and neural networks are complementary technologies in the design of intelligent wireless networks. We believe that a ACB-FNN for the control and management wireless networks is more appropriate than the conventional probabilistic models. The performance of the proposed scheme is better than that of the conventional methods

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