Call Admission Control in Mobile Cellular CDMA Systems using Fuzzy Associative Memory

Rupenaguntla Naga Satish Chandra and Dilip Sarkar

***Abstract*—In a mobile cellular system Quality of Service (QoS) to mobile terminals (MTs) is measured by the Probability of Forced Termination P_{ft} and/or Probability of New Call Blocking (P_b). Since, both cannot be reduced simultaneously, usually keeping the P_{ft} below a designated level DP_{ft} is considered as QoS guarantee to the users of the system. However, P_{ft} is related to system parameters namely, maximum capacity of the cell C, the average new call arrival rate λ, the average call holding time $1/\mu$, and the average cell dwell time $1/\eta$ by complex non linear equations. Therefore, Call Admission Control (CAC) for maintaining P_{ft} at DP_{ft} is a very challenging task. A fuzzy controller is proposed to dynamically maintain P_{ft} at DP_{ft} with changes in system parameters. Also, current cellular networks are employing CDMA as the multiple access technique since it provides much more capacity than other techniques. Interference received at the base station (BS) of a cell is considered in the decision making process of whether to admit a call or not. We describe the CAC criteria used in CDMA cellular networks in this paper. Also, through simulation we show that fuzzy controller can be integrated with other CAC schemes to guarantee QoS to the users.**

***Index Terms*— Call holding time, Cell dwell time, QoS, Fuzzy Associative Memory, Call Admission Control, CDMA.**

I. INTRODUCTION

WIRELESS cellular networks derive their name from the fact that the service area of these networks is divided into a group of cells, with each cell being controlled by a Base Station (BS). When a user requests a service from the network through a mobile terminal (MT), the request may be accepted or denied by the CAC algorithm. This denial of service is known as *call blocking*, and its probability is called *call blocking probability* P_b. A MT can move from one cell to another during a service. This requires successful handoff from previous cell to the new cell. As the MT may cross many cell boundaries during the lifetime of a service, failure to get successful handoff at any cell boundary will force the service to end abruptly. This discontinuation of service is known as *forced termination*, and its probability is called *forced termination probability* P_{ft}.

The average lifetime of a call in the system is known as *call holding time* or *call duration* (denoted by $1/\mu$). The average time that a call resides in a particular cell is known as *residence time* or *cell dwell time* (denoted by $1/\eta$). The new calls arrive in a cell at a mean arrival rate of λ calls/sec. The *load* of a cell is the ratio of call arrival rate to call completion rate, $\rho = \lambda/\mu$ Erlangs/cell. The capacity C of a cell, defined as the maximum number of MTs which can be served by a cell such that QoS requirements are met depends on the multiple access technique employed in the cellular network. Cellular systems using CDMA as multiple access technique usually have a higher capacity than those employing FDMA/TDMA since the capacity of networks using CDMA is soft, that is, interference limited; however, that of systems using FDMA/TDMA is hardlimited by the available bandwidth. This is the main reason for employing CDMA in the deployment of third generation wireless networks supporting heterogeneous services. The capacity of a cell using CDMA is given by

$$C = \frac{W/R\alpha}{E_b/N_0} - \frac{N_T W}{S} + 1 \qquad (1)$$

where W is the available bandwidth, R is the data rate, S is the signal strength, α is voice activity, N_T is thermal noise spectral density, and E_b/N_0 denotes the ratio of bit energy to noise power spectral density. For reliable communication, the E_b/N_0 value of the system should be maintained above a certain value.

Since termination of an ongoing call is considered more undesirable than blocking a call which is trying to access the network, we use P_{ft} as measure of *QoS* of the network. Maintainance of P_{ft} at a desired value DP_{ft} is considered as guaranteeing QoS to the users. The P_{ft} of a cellular system varies with various parameters: the capacity of a cell - C, the average call arrival rate - λ, the average dwell time of the call in a cell - $1/\eta$, and the average total duration of calls in the network - $1/\mu$.

$$P_{ft} = f(C, \lambda, \eta, \mu) \qquad (2)$$

An ideal system should adapt itself to the changes in the network occurring in the real-time without degrading QoS and at the same time should have high bandwidth utilization. In section II we review various Call Admission Control (CAC) algorithms with emphasis on a recent CAC — the CAC with constant preblocking. Section III describes the CAC criteria used in CDMA cellular networks. Also, an expression for finding the number of users who can be accomodated in a cell when interference from outer cells is taken into account is presented here. We then propose a novel CAC algorithm that makes use of Fuzzy Associative Memory (FAM) to dynamically adjust the preblocking load value. In section V we present the design of the fuzzy controller for the mobile system. Operation of the entire system is described in section VI with an example. The fuzzy controller is evaluated and its performance results are presented in section VII. It is followed by conclusion in section VIII.

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II. REVIEW OF CAC ALGORITHMS

A survey of literature indicates that CAC algorithms can be classified into non-prioritized and prioritized schemes. Non-prioritized scheme treat both new calls and handoff calls with equal priority. Prioritized schemes, namely Guard Code Scheme and Code Prerequest Scheme, give priority for handoff calls over new calls. In the guard code scheme, a certain number of codes, g known as guard codes, out of C codes are reserved for handoff calls. In the Code Prerequest Scheme, the MT pre-requests a code from the target cell a certain time, known as the reservation time, prior to leaving the current cell.

A. CAC Algorithm with Call Pre-Blocking

This scheme recently proposed in [4], provides the required QoS by controlling the load observed by a cell, irrespective of the actual load of the system. A maximum new call arrival rate, and hence load ρ_m for a desirable value of P_{ft} is determined, either by simulation [7] or by an analytical method [1]. The value of ρ_m is chosen such that, any load above ρ_m fails to keep P_{ft} below desired level. During the operation of the system, the arrival rate and hence the expected load is estimated. If the estimated load is no more than ρ_m *and* the CAC criteria is satisfied, the call is accepted into the system. Otherwise, the load is greater than ρ_m, and only a fraction f_r, of the incoming calls is attempted to be allocated a code. The fraction is calculated as f_r =ρ_m/ρ_0, where ρ_0 is the estimated load. Thus ρ_m can be considered as the effective load entering into the cell although the actual load is ρ_0. The block diagram describing the main components of this system is shown in Figure 1 in solid lines. This scheme can maintain a predefined level of P_{ft}, irrespective of new call arrival rate, provided the call holding time and the cell dwell time remain constant. If the average call holding time and/or the average cell dwell time changes from the default values (which is generally the case in real-world systems), P_{ft} cannot be maintained at DP_{ft} value since P_{ft} increases with increase in average call holding time and P_{ft} decreases with increase in average cell dwell time. The curves labelled "P_{ft} without FAM" in Figure 2 and 3 show the variation of P_{ft} in the system with change in cell dwell time and call holding time respectively. The graphs clearly depict that P_{ft} value is not maintained at DP_{ft} by preblocking scheme when call holding time and cell dwell time change. This shows that any constant value of ρ_m for call preblocking cannot maintain a constant P_{ft} with varying parameters. The limitations of the above schemes show us the need for a system which can adjust ρ_m value with the change in system parameters.

III. CAC CRITERIA FOR CDMA SYSTEMS

Call admission control is a decision making process of whether to allow a call into the system or not. Bandwidth limited FDMA and TDMA networks consider the number of channels and/or timeslots available as the decision making criteria to allow calls into the system. Interference allowed in the link is used as the decision making criterion for CAC in mobile CDMA systems [8]. CDMA systems check whether the total interference received at the BS exceeds the maximum allowable interference, known as Total Interference Margin (TIM), during call admission. It is chosen such that the E_b/N_0 required in the link is satisfied, and is given by Equation 3. When there are N ongoing calls in a cell and a $(N+1)^{th}$ call wants to enter the cell, the BS estimates the Current Interference Margin (CIM) given by Equation 4. The admission criteria (5) for admitting a call into the system is that CIM should be less than or equal to TIM.

$$TIM = (C+1)N_T W \tag{3}$$

$$CIM = I_C \frac{(C+1) - N}{C - N} \tag{4}$$

$$CIM \leq TIM \tag{5}$$

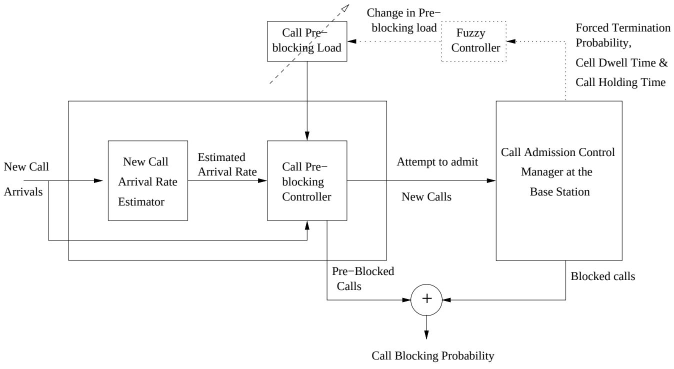

Fig. 1. Block Diagram of a CAC system with Fuzzy Controller

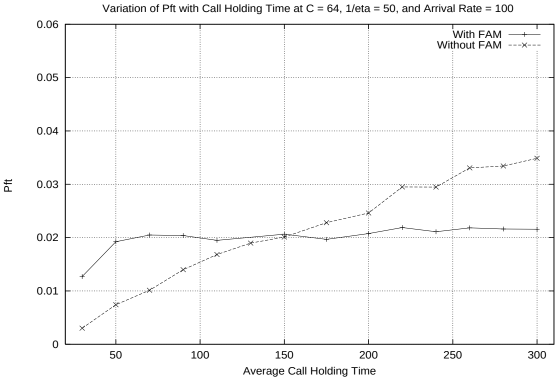

Fig. 2. $1/\eta$ vs P_{ft} at $1/\mu = 150secs, \lambda_0 = 100calls/sec$

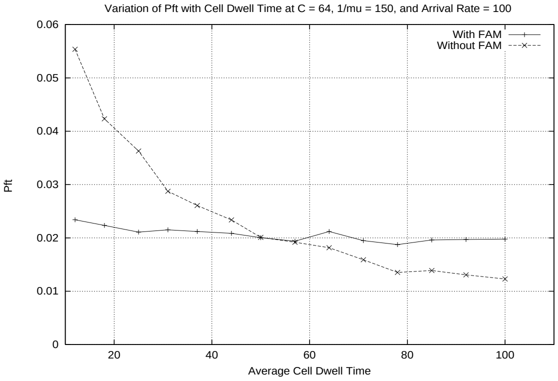

Fig. 3. $1/\mu$ vs P_{ft} at $1/\eta = 50secs, \lambda_0 = 100calls/sec$

In Equation 4, the term I_C denotes the total signal strength that is received at the BS when there are N ongoing calls in the cell. The total signal strength or interference that is received at BS of a cell is equal to sum of the strengths of signals received from the MTs within that cell (Inner Interference - I_i) and from the MTs in the neighboring cells (Outer Interference - I_0). The MTs within a particular cell are power controlled by the BS of that cell such that the BS receives a signal of strength $N_T W$ from the MT. In our study, it is assumed that a BS of a cell receives signal from the MTs within that cell and also from the MTs in the first tier of neighboring cells. Through simulation we found that on an average, the ratio $(I_o + I_i)/I_i$ (denoted by f) is about 1.396. Therefore, I_C can be given by

$$I_C = N\alpha N_T W f \tag{6}$$

A. CDMA System Capacity when Outer Cell Interference is Considered

The maximum capacity (C) of a single cell CDMA system is given by Equation 1. When the outercell interference is considered, the maximum number of users (C_A) who can be allowed into the cell is less than C. We will now give an expression for C_A. From 5 and 6, we have

$$\alpha f N^2 - [(\alpha f + 1)(C+1)] * N + C(C+1) \geq 0$$

if β and γ are the roots of the above in-equation, and $\beta \leq \gamma$, Then

$$N \leq \beta \qquad \text{or} \qquad N \geq \gamma$$

Since $N \leq C - 1$, $N \leq \beta$ is considered and $N = \lfloor \beta \rfloor$ is the maximum number of users in a cell satisfying the admisson criteria when interference from outer cells is also considered. So the maximum number of users who can be allowed in the system when outer cell interference is taken into account is given by
$C_A = \lfloor \beta \rfloor + 1 = \lceil \beta \rceil$
For example, when the maximum capacity of a single cell CDMA system is 64 and voice activity $\alpha = 0.4$, C_A is 63.

B. CAC criteria for Guard Code Scheme

In the Guard Code scheme, since g guard codes, out of C codes are reserved for handoff calls, the TIM is different for new calls and handoff calls. Let $TIM_H(C)$ denote the total interference margin for handoff calls and $TIM_N(C, g)$ denote the total interference margin for new calls when g guard codes are provided. $TIM_H(C)$ is given by Equation 3. If no guard codes are provided, the maximum number of users in a multiple cell CDMA system was found to be C_A (in Section III-A), and the maximum N for which the admission criteria is satisfied such that a new call or handoff call can be allowed to enter the cell is $C_A - 1$. If number of ongoing calls is less than $C_A - g$, only then new calls are admitted. Thus, the CIM value for $C_A - g - 1$ ongoing calls is the $TIM_N(G, g)$. Therefore,

$$TIM_N(C, g) = (C_A - g - 1)\alpha f \frac{(C - C_A + g + 2)}{(C - C_A + g + 1)} N_T W \tag{7}$$

The admission criterion for guard code sheme is

For New Calls

CIM $\leq TIM_N(C, g)$

For Handoff Calls

CIM $\leq TIM_H(C)$

IV. PROPOSED CAC SYSTEM WITH FAM

Figure 1 shows a block diagram of the system employing a fuzzy controller to maintain the P_{ft} at DP_{ft}. The components (shown in dotted lines) have been added to adjust the value of ρ_m for maintaining desired value of P_{ft}. The CAC algorithm employing fuzzy controller to guarantee QoS to the users is designated as the *Dynamic Call Preblocking Scheme*. If P_{ft} is smaller than that of the desired value, ρ_m ought to be increased for better utilization of network resources. On the other hand, if P_{ft} is greater than that of the desired DP_{ft} value, ρ_m ought to be decreased for QoS guarantee. Since P_{ft} and ρ_m are related through a set of complex non-linear equations even for Markovian system, on-line computation of the correct value of ρ_m is practically impossible. Hence, for estimating the acceptable value of ρ_m, we propose to use a fuzzy controller. It is assumed that each cell periodically estimates the average values of cell dwell time, call holding time, and forced termination probability for using them as inputs to the fuzzy controller. The fuzzy controller computes the change in ρ_m value to maintain the P_{ft} at DP_{ft}. This process continues throughout the operation of the system. Thus we have a feedback mechanism which controls ρ_m and in turn P_{ft} dynamically.

Let $P_{ft}[k]$ be the value of call forced termination probability after observation period k. Let the change of forced termination probability, $\Delta P_{ft}[k] = P_{ft}[k] - P_{ft}[k-1]$, between two successive observations be small enough for relating it with that of ρ_m by a linear equation.

$$\Delta P_{ft}[k] = slope \times \Delta \rho_m \tag{8}$$

where *slope* is the slope of the operating curve "P_{ft} Vs ρ_m" for the particular values of call holding and cell dwell times.

Thus, we can calculate $\Delta \rho_m$ from the value of the $slope$ and ΔP_{ft}. Since there will be infinite number of operating curves for infinite combinations of $1/\mu$ and $1/\eta$, we use fuzzy controller to determine the slope of operating curve for a particular combination of $1/\mu$ and $1/\eta$, from the known slope values. We develop a Fuzzy Associative Memory (FAM) for storing a set of rules and an inference mechanism that uses the rules for computing the value of slope.

V. DESIGN OF FAM FOR THE MOBILE SYSTEM

In this section we discuss design of the FAM for our mobile system. It consists of three steps namely fuzzification of the control and solution variables, inference mechanism, and defuzzification. Let the range of average cell dwell time be from dt_{min} to dt_{max} seconds, and that of call holding time be from ht_{min} to ht_{max}. For our experiments, dt_{min} = 8 secs, dt_{max} = 100 secs, ht_{min} = 30 secs and ht_{max} = 300 secs.

A. Fuzzification of Control and Solution Variables

The control variables are the average call holding time and the average cell dwell time. The solution variable is the slope of the curve with ρ vs P_{ft}. To construct the FAM, we define eight fuzzy sets on the control variables and the solution variable. . The fuzzy sets are Very Very Small (VVSx), Very Small (VS*x*), Small (S*x*), Medium (M*x*), High (H*x*), Very High (VH*x*), Very Very High (VVH*x*) and Very Very Very High (VVVH*x*), where *x* may denote HT(Holding Time), DT(Dwell Time) and S(Slope). Fuzzificaton involves scaling and mapping of these input variables to fuzzy sets. This is done by defining the membership functions. The membership functions for call holding times used in our experiments is shown in Figure 4. Note that the interval between ht_{min} and ht_{max} was divided into seven segments whose lengths are a combination of arithmetic and geometric progression. This partioning was based on the study for spacing ρ vs P_{ft} curves evenly. Also, the interval between dt_{min} and dt_{max} is divided into seven segments whose lengths are in geometric progression. For two control variables with eight fuzzy sets each, we get 64 pairs. For each pair we calculate a slope value to constuct the FAM. The calculation of slope involves obtaining a critical load for which P_{ft} is just above DP_{ft} and a critical load for which P_{ft} is just below DP_{ft}. Since DP_{ft} for our study is 0.02, we obtained critical ρ_u and ρ_l loads for P_{ft} values 0.03 and 0.01. Thus, the slope is given by

$$slope = \frac{0.03 - 0.01}{\rho_u - \rho_l} = \frac{0.02}{\rho_u - \rho_l} \qquad (9)$$

The interval between minimum and maximum values of the slope has been divided into seven subintervals following arithmetic progression. An algorithm for computing ρ_u and ρ_l can be found in [1].

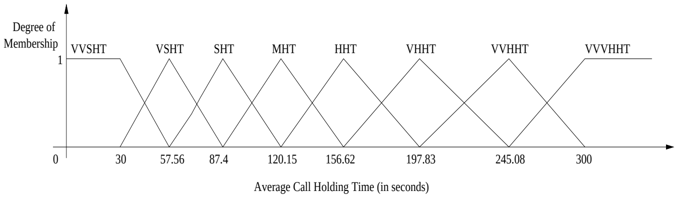

Fig. 4. Membership Functions of Call Holding Time

B. FAM and Inference Mechanism

This involves defining various fuzzy rules which say how the system adjusts solution variable to maintain the desired QoS. In general, a fuzzy rule is of the form

If <fuzzy proposition>, then <fuzzy proposition>

where the fuzzy propositions are of the form, "x is Y" or "x is not Y," x being a scalar variable and Y being a fuzzy set associated with that variable [2]. The number of rules a system requires is related to the number of control variables. As our mobile system has two control variables, each of which is divided into eight fuzzy regions, there are 64 rules for 64 possible input combinations. All these rules are represented in a matrix form with the combination of inputs giving the required outputs. Such matrix forms the *fuzzy associative memory* for the system. The FAM for our system is shown in Table I. As an example, the following rule can be derived from the FAM

if *holding time in VHHT* **&&** *dwell time in HDT*, **then** *slope in VHS*

		HOLDING TIME							
D		VVSHT	VSHT	SHT	MHT	HHT	VHHT	VVHHT	VVVHHT
W	VVSDT	HS	VHS	VVHS	VVHS	VVHS	VVHS	VVVHS	VVVHS
E	VSDT	HS	VHS	VHS	VVHS	VVHS	VVHS	VVHS	VVVHS
L	SDT	MS	HS	VHS	VHS	VHS	VVHS	VVHS	VVVHS
L	MDT	MS	HS	HS	VHS	VHS	VHS	VVHS	VVVHS
T	HDT	SS	MS	HS	HS	HS	VHS	VHS	VHS
I	VHDT	VSS	SS	MS	HS	HS	HS	VHS	VHS
M	VVHDT	VSS	SS	MS	MS	HS	HS	HS	HS
E	VVVHDT	VVSS	VSS	SS	MS	MS	MS	HS	HS

TABLE I

FUZZY ASSOCIATIVE MEMORY FOR MOBILE SYSTEM

C. Defuzzification

Defuzzification involes the conversion of the fuzzy outputs into crisp output. The fuzzy output value of slope which is obtained from the inference mechanism is converted back into the real value based on the definition of the membership functions. We used the centroid method to compute the crisp value of slope ($slope_{crisp}$), given by

$$slope_{crisp} = \frac{\sum_{i \in Z} m_i * slope_i}{\sum_{i \in Z} m_i}$$

where m_i denotes the membership of the control variable slope in the fuzzy set i and $slope_i$ denotes the slope value that has a membership of 1 in the fuzzy set i.

VI. OPERATION OF THE SYSTEM WITH FUZZY CONTROLLER

Operation of the system consists of the following 5 steps

1) Estimation of parameters, namely cell dwell time, call holding time and P_{ft}.
2) Fuzzification of dwell time and holding time.
3) Firing of fuzzy rules using inference mechanism.
4) Estimation of preblocking load slope.
5) Computation of change in preblocking load from the slope.

The new call pre-blocking load value is then used to block the calls entering into the system. All these steps are repeated periodically during the operation of the system in order to maintain the desired P_{ft}.

For real-time estimation of the parameters $\mu, \eta,$ and P_{ft}, there are several factors that need consideration. They include storage requirements, computation power of the BS, and update period – time interval between two successive estimations and parameter updates. If the update period is too long, the BS will require a large storage to save all call related activities. Moreover, the adjustment of ρ_m as the control parameters change is delayed. On the other hand, if update period is too small, estimation errors are too high. Our experiments used 300 seconds for the update period.

Accurate estimation of P_{ft} is the most difficult problem. Especially, when desired P_{ft} value is very small, such as 0.02. During an update period there may be only a few forced terminated calls; even during some update periods no call may be forced terminated. To keep the effect of long observation period and that of small update period, we used what is known as exponential averaging. A fraction α of the observed value of forced termination probability OP_{ft} during the observation period k is added with $(1-\alpha)EP_{ft}[k-1]$ to get Estimated Forced Termination probability $(EP_{ft}[k] = \alpha OP_{ft}[k] + (1-\alpha)EP_{ft}[k-1])$. Thus, the difference between the desired and estimated forced termination is $\Delta EP_{ft}[k] = DP_{ft} - EP_{ft}[k]$ along with the $slope$ value obtained the fuzzy interference mechanism is used to determine the change in preblocking load $(\Delta\rho_m)$ using Equation 8. An example of slope calculation using fuzzy inference mechanism is shown next.

A. *Example Showing the Calculation of Slope*

Let the estimated value of cell dwell time be 40 seconds and that of call holding time be 80 seconds, during an observation period. From our definition of membership functions, a cell dwell time of 40 seconds is 58.4% in fuzzy set HDT and 41.6% in the fuzzy set VHDT. Similarly, 80 seconds call holding time has 24.8% membership in fuzzy set VSHT and 75.2% membership in fuzzy set SHT. These values trigger the following four fuzzy rules from the rule base.

If *Holding Time in VSHT* **&&** *Dwell Time in HDT*, **then** *Slope in SS*
If *Holding Time in VSHT* **&&** *Dwell Time in VHDT*, **then** *Slope in VSS*
If *Holding Time in SHT* **&&** *Dwell Time in HDT*, **then** *Slope in MS*
If *Holding Time in SHT* **&&** *Dwell Time in VHDT*, **then** *Slope in SS*

The firing of these fuzzy rules results in 24.8% membership in set SS, 24.8% membership in set VSS, 54.8% membership in set MS and 41.6% membership in set SS. As both the clauses in the premise of the fuzzy rule are combined with the AND operator, we take the minimum of the degrees of membership. Figure 5 shows the firing of these fuzzy rules. By combining all the four rules, we get the resultant area shown in Figure 6. To combine the rules, we OR them together by taking the larger of the two rules as the value of the combination at each point on the horizontal axis. The crisp value of slope $(slope_{crisp})$ is 0.003275 obtained after defuzzification. This calculated slope value, along with the estimated forced termination probability, is used to find the change in preblocking load $(\Delta\rho_m[k])$ using Equation 8.

VII. EVALUATION OF THE FUZZY CONTROLLER

In this section we discuss the simulation model and results of our simulation. We used wraparound topology with 49 cells to eliminate boundary effect [3]. The mobility of MTs is modeled using a simple Brownian-motion or random walk approximation [5], [6]. A MT can move to any of the current cell's neighbors with equal probability - 1/6 for the hexagonal layout. It is assumed that the trajectories of their motion are not known. We assume that new call arrivals into the network follow a Poisson distribution, call holding and cell dwell times are exponentially distributed. Following the IS-95 specification, W is 1.2288 MHz, and R is 9.6Kbps in our study. We assumed α to be 0.4, E_b/N_o to be no lower than 7dB, and DP_{ft} to be 0.02.

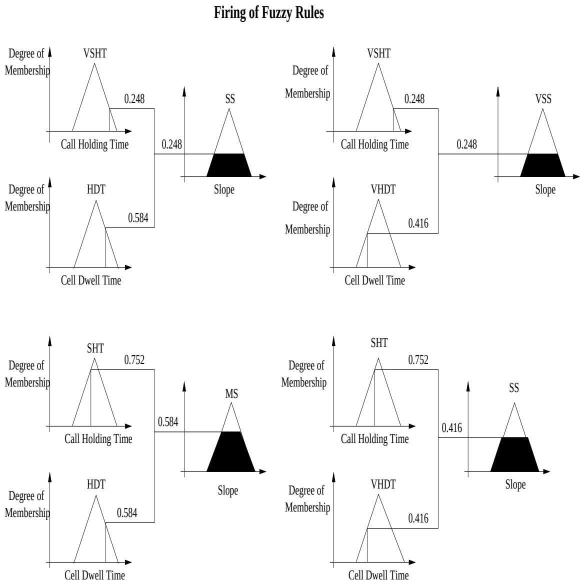

Fig. 5. Firing of Fuzzy Rules

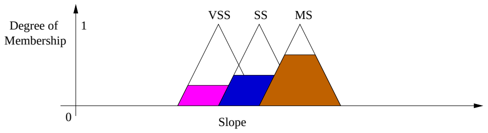

Fig. 6. Aggregation of Fuzzy Outputs to Get the Resultant Area

A. *Results*

Figure 2 shows the variation of P_{ft} with change in cell dwell time $(1/\eta)$. Call holding time and new call arrival rate are kept constant at $150secs$ and $100calls/sec$ respectively. Two curves, one showing the system with FAM and the other without FAM are plotted. The system with FAM shows value of P_{ft} to be very close to DP_{ft} for all values of $1/\eta$ as compared with the one without FAM which shows gradual decrease in P_{ft} with increase in $1/\eta$. This improvement in efficiency is obtained because the extended system adjusts the preblocking load value ρ_m with change in teh value of $1/\eta$. Figure 3 shows the variation of P_{ft} with change in call holding time $(1/\mu)$. Cell dwell time and new call arrival rate are kept constant at $50secs$ and $100calls/sec$ respectively. The figure shows the value of P_{ft} to be again very close to DP_{ft} for all the values of $1/\mu$ for the system with FAM. This can be compared with the system without FAM which shows gradual increase in P_{ft} with increase in $1/\mu$.

Next, we desribe our results when we integrated the fuzzy controller with the guard code and code preblocking schemes. Figures 7, 8, 9 show the variation of P_{ft} with λ, $1/\mu$, and $1/\eta$ respectively for the dynamic call preblocking scheme, guard code scheme with fuzzy controller and code prerequest scheme with fuzzy controller. It can be observed that when fuzzy controller is employed, P_{ft} is maintained at DP_{ft} guaranteeing QoS to the users.

From the above simulations, it is evident that the proposed system functions efficiently in changing traffic conditions. Also, FAM based controller can be integrated with prioritized schemes to guarantee QoS to the users of the system.

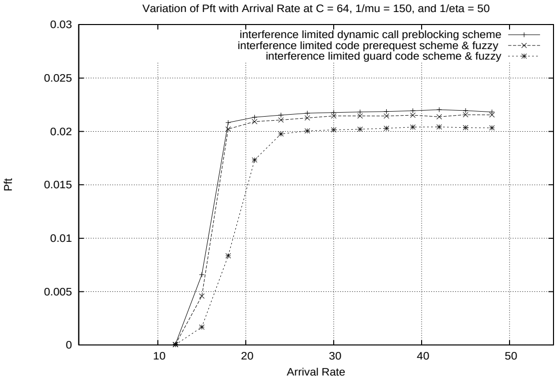

Fig. 7. λ_0 vs P_{ft} at $1/\mu = 150, 1/\eta = 50secs$ with Fuzzy Controller

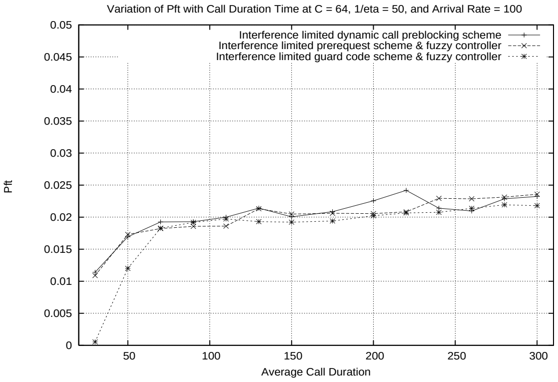

Fig. 8. $1/\eta$ vs P_{ft} at $1/\mu = 150secs, \lambda_0 = 100calls/sec$ with Fuzzy Controller

VIII. CONCLUSION

Call admission control algorithms aim to provide QoS by following a particular strategy in admitting the calls into the system. Prioritized schemes (guard code scheme and code prerequest scheme) and call preblocking scheme, although provide the required QoS at known traffic conditions, fail to reflect the dynamic nature of the system. The constant call preblocking proposed in [4], in particular requires both cell dwell time and call holding time to be constant and controls the actual load coming into the system. The proposed dynamic call preblocking scheme employs a fuzzy controller to maintain P_{ft} at DP_{ft} with changing parameters in the network. Through simulation, we showed that FAM-based fuzzy controller can also be integrated with guard code scheme and code prerequest scheme to maintain the P_{ft} at DP_{ft} guaranteeing QoS to the users. For further extension of this study, one may address the problem of maintaining QoS in the network servicing multiple classes of users with different QoS requirements.

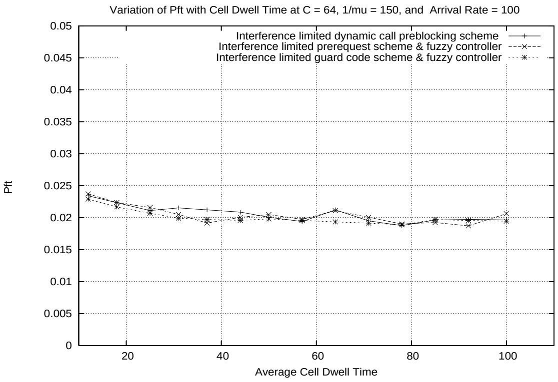

Fig. 9. $1/\mu$ vs P_{ft} at $1/\eta = 50secs, \lambda_0 = 100calls/sec$ with Fuzzy Controller

REFERENCES

[1] Rupenaguntla Naga Satish Chandra. FAM based CAC Algorithms for Interference Limited Mobile Cellular CDMA Systems. Master's thesis, University of Miami, 2003.
[2] Earl Cox. Fuzzy Fundamentals. *IEEE Spectrum*, pages 58–61, 1992.
[3] L.O. Guerrero and A.H. Aghvami. A Prioritized Handoff Dynamic Channel Allocation Strategy for PCS. *IEEE Transactions on Vehicular Technology*, 48(4):1203–1215, 1999.
[4] Satya Kovvuri, Vinay Pandey, Dipak Ghosal, Biswanath Mukherjee, and Dilip Sarkar. A Call-Admission Control(CAC) Algorithm for providing Guaranteed QoS in Cellular Networks. *International Journal of Wireless Information Networks*, 10(2):73–85, 2003.
[5] Y.B. Lin, L.F. Chang, and A. Neorpel. Modeling Hierarchical Microcell/Macrocell PCS Architecture. In *Proceedings of ICC, (Seattle, WA)*, pages 405–409, 1995.
[6] A.D. May. *Traffic Flow Fundamentals*. Prentice Hall, 1990.
[7] Sivaramakrishna Mopati and Dilip Sarkar. Call Admission Control in Mobile Cellular Systems Using Fuzzy Associative Memory. In *Proceedings of the ICCCN03*, 2003.
[8] Sungmoon M. Shin, Cheol-Hye Cho, and Dan Keun Sung. Interference-Based Channel Assignment for DS-CDMA Cellular Systems. *IEEE Transactions on Vehicular Technology*, 48(1):233–239, 1999.