Chapter 3
Call Management in a Cellular Mobile Network Using Fuzzy Comparators

The current literature on mobile communication usually considers the channel assignment and the call admission control as two independent problems. However, in practice these two problems are not fully independent. This chapter attempts to solve the complete problem by employing a fuzzy comparator, which compares the membership of two fuzzy measurement variables to take decisions about call admission, satisfying the necessary constrains of channel assignment. Two alternative approaches to handle the problem are addressed. The first approach is concerned with the development of a fuzzy to binary mapping of the measurement variables to decision variables. The latter approach deals with fuzzy to fuzzy mapping, and then employs a fuzzy threshold to transform the fuzzy decisions into binary values for execution. A performance of both the call management techniques are studied with the standard Philadelphia benchmark and the results outperform reported results on independent call admission and channel assignment problems. The results further envisage that the latter approach is better than the former with respect to resource utilization, adaptability to the network conditions and insensitivity to load variations.

3.1 Introduction

With the rapid increase in the utilization of mobile cellular network, the call management has become an important problem. Existing techniques for call management cannot fully support the necessary user-services, such as minimization of network congestion, minimization of call drop and hard handoff. This chapter however attempts to solve the above problem with an objective to minimize hard handoff [1] and call blocking and increase the call-service. The problem addressed here is unique and new as it attempts to solve two basic problems of call management, including call admission control and channel assignment as a single (and interrelated) problem. It is apparent that the two problems coexist in mobile system, but has been solved independently to minimize the complexity of the overall problem [2-17].

Informally speaking, the call admission control (CAC) is concerned with the allocation of calls waiting for service. In a wireless network, the whole service coverage is partitioned into several continuous areas, each of which is called a

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cell. In each cell, a Base Station (BS) performs the central role to coordinate and relay all communications. A Mobile Station (MS) may initialize a connection request (new call) to the BS (Fig. 3.1). The CAC takes necessary decisions to accept or block the request. In case of successful initial access, the MS will roam freely with the active connection. When the MS reaches the boundary of the cell with an ongoing call, it issues the handoff request to a neighbouring cell to avoid call drop. This connection request is well known as handoff call.

The CAC module is also responsible for acceptance or rejection of the handoff call connection request. Since it is more undesirable to terminate a call in progress than to block a new call connection request, higher priority is normally given to handoff call in CAC strategy.

The common bottleneck to the call management is due to the high call congestion, which causes high call blocking and channel interference. One standard approach to solve the problem of congestion is to enhance reuse of the channels, which, however, in turn increases channel interference and decreases the quality of service (QoS). The chapter, therefore, considers channel assignment problem to resolve the call management problem.

First mobile radio system was introduced by American police department in 1921, which used the bands just above the present AM radio bands. The first commercial mobile telephone service was introduced by AT&T and Southwestern Bell in 1947, which had the cellular concept to increase the reuse frequency of channels though the then technology, could not cope up with the concept. In mid 1960s bell system introduced Improved Mobile Telephone Services (IMTS) which improved the frequency reuse. Their cellular network was divided into a number of circular or hexagonal cells and each had a centrally located base station and a number of radio channels.

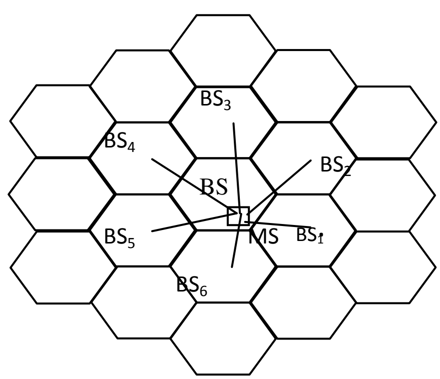


Fig. 3.1 Cell structure of wireless network

The radio channels can be a frequency, a time slot or a code sequence. The mobile devices communicates to each other with the help of a radio frequency through the base station and the base stations communicate through the Mobile Switching Centre (MSC), while MSCs communicate each through the Public Switched Telephone Networks (PSTN) shown in Fig. 3.2.

When a user starts or receives a call, he may move around in the cells of a network with the unfinished call and the network may have to handoff or transfer the call from cell to cell without the knowledge of the user. Historically, the evolution of mobile technology can be divided into 4 generations.

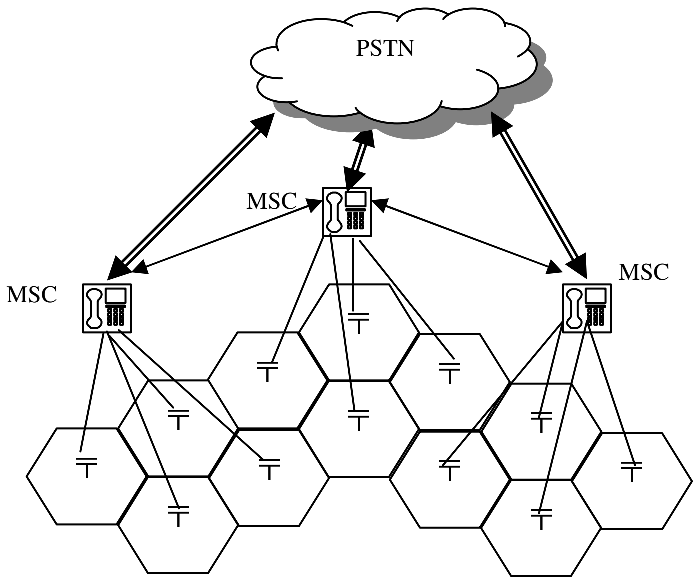


Fig. 3.2 A Typical Cellular Network

- 1G—the analog systems with major service provided was the voice transmission.
- 2G—switching to digital technology for transmission of voice and some limited data in low cost and higher capacity system.
- 3G—introduced multimedia transmission and global roaming in homogeneous network system
- 4G—extended global roaming in heterogeneous systems

Due to the increase in use and complication in technology in mobile networks, the QoS became an issue of utmost important. The Call Admission Control (CAC) mechanism is essentially needed to ensure the QoS provision by restricting the resource of the network to prevent the congestion as well as the degradation of channels currently in use. The basis concepts involved are given as follows.

1. ***Channel assignment scheme:*** How the calls and channels are managed by each cell using different reuse constraints [38]-[49].
2. ***Handoff scheme:*** How the calls are transferred from one cell to the other.

There are two types of handoff, hard and soft [23], [27]-[37].

a. ***Hard handoff:*** The old link breaks and the call drops before the new link are generated.

b. ***Soft handoff:*** When the new channel is obtained, the call is transferred from the old channel to the new thereby causing no break in link.

3. ***Call block and drop:*** [23]-[26]

a. ***Call block:*** When due to the circumstances a new call cannot be assigned to a channel.

b. ***Call drop:*** When due to the hard handoff an ongoing call gets disconnected.

Common performance measuring criteria used to solve the CAC problem includes:

1. ***Efficiency:*** higher network resource utilization
2. ***Complexity:*** computational complexity of CAC
3. ***Overhead:*** exchange of information with neighbour cells
4. ***Adaptability:*** effect of changing network condition
5. ***Stability:*** insensitivity to short term increase in traffic.

3.1.1 Review

There has been a considerable work done in the field of call admission control in recent few years. In 2005, Jue proposed a CAC in wideband CDMA network using fuzzy logic [2]. In this paper, the model proposed was a mapping from fuzzy to crisp. The fuzzy estimator for bandwidth introduced by this scheme calculates the intra-cell bandwidth, inter-cell bandwidth and the residual bandwidth for both home and neighbour cells.

First, it [6] assumes that velocity has only two values, which, however, is not realistic. Second, it considers that the acceptance or rejection of calls solely depends on the bandwidth. Third, reuse of the already used channels is not taken care of in turn compromising the efficiency. Further, computing the bandwidths of all cells over the iterations and exchanging the information among neighbouring cells is time-consuming. Finally, the effect of change in network condition is not considered and the changing traffic load is ignored.

In 2005, another Outage-based fuzzy call admission controller with multi-user detection for WCDMA systems was proposed by [7]. Here the main concern of the fuzzy model was to estimate the signal to noise ratio. The system dose not takes care of channel reuse. Each time computing the probability makes the system computationally complex. The effect of changing load is also not handled. The mobility condition of the mobile device is also not considered.

In 2006, a Neural Fuzzy Call Admission and Rate Controller for WCDMA Cellular Systems providing Multirate Services were proposed in [8]. Here, an adaptive network based fuzzy controller system is proposed using *type1* and *type2* probabilities. The system doses not consider soft handoff and dose not guarantee QoS under heavy traffic. The mobility condition of the mobile device is also not considered.

In 2006, another performance analysis of call admission control in WCDMA System with Adaptive Multi Class Traffic based on Fuzzy Logic was proposed [9]. Here the quality of service and interference is not taken care of properly.

3.1.2 Significance of the Work

The call admission control problem, addressed here, is realized by two alternative schemes shown in Fig. 3.3. Both the schemes include a fuzzy logic module for decision making about the call rejection/acceptance and also consider the channel allocation for the accepted call. The call admission decision is undertaken by considering the present dynamic scenario of the allocation matrix defined as

$$A = [f_{i,j}]$$

where, $f_{ij} = 1$, if the j-th channel in i-th cell is assigned to a call,
$= 0$, otherwise.

The feasibility of channels for allocation is determined by an additional channel allocation module with the consideration of compatibility matrix defined as

$$C = C_{j,k} = \begin{cases} 4, & \text{satisfying cosite constraint between j and k channel in came cell} \\ 3, & \text{satisfying adjacent channel constraint between j and k channels} \\ 2, & \text{satisfying co-channel constraint between j and k channels} \\ 0, & \text{no interferance between channel j and k} \end{cases}$$

Additional input parameters of the call admission control include hotness (degree of congestion) velocity of the mobile and its distance from the base station. It is noteworthy that in conventional call management, the feedback module through channel assignment is not considered.

The first approach undertaken to solve the problem considers a modelling from fuzzy measurements to binary decisions about call admission. The second approach is concerned with a mapping of fuzzy measurement to fuzzy control decisions [51] about call admission using Takagi-Sugano (T-S) fuzzy logic [18].

A study with the standard Philadelphia benchmark with 21 cells confirms that the proposed method outperforms most, if not all, techniques for call management and channel assignment uniquely. Summarizing, the main features of the work are listed below:

1. Minimization of call block or existing call drop, ensuring the fidelity of the network.
2. Usage of efficient channel assignment strategy for minimization of interference and ensuring quality of service.
3. Considering and solving the real world situation, where the mobile stations are moving and hence creating ambiguity in their location.
4. Reduction in the level of congestion.
5. Creating an effective MS to BS as well as global environment for better mutual understanding between the cells and enhancement of overall performance.
6. The proposed scheme utilizes both cell occupancy and mobility, and hence is expected to be more efficient.
7. The schemes are uniform cell based, and hence simple in nature.

Decision time is proactive and fast, based on a priory and feedback parameters.

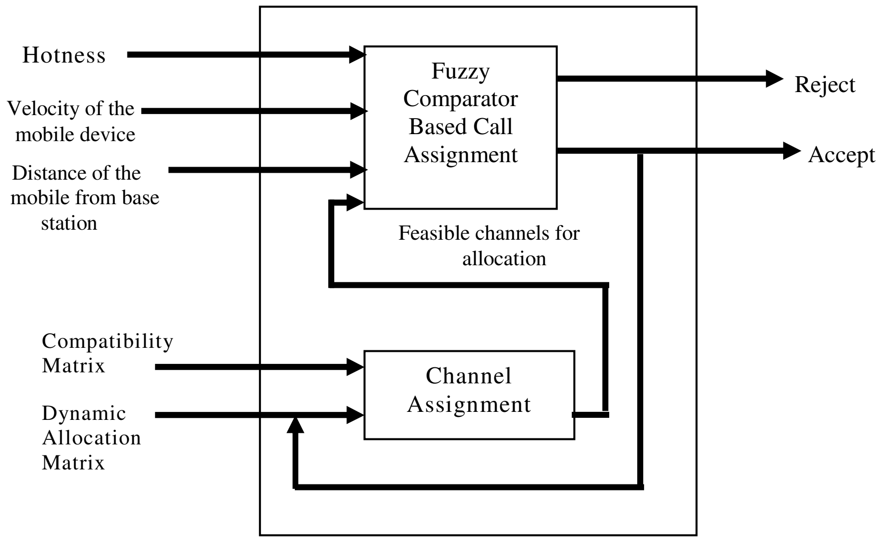


Fig. 3.3 The proposed call management

3.2 Rule Based Call Management

The chapter employs two distinct kind of fuzzy rules for decision making in automated call management in cellular network. The first set of rules maps fuzzy measurements into binary decisions about call management. The procedure applied for fuzzy decision making is different from the classical fuzzy logic. It is needless to mention here that classical Mamdani based fuzzy reasoning, maps fuzzy measurements onto fuzzy conclusions using fuzzy relations. In the present context, however, the decisions are derived based on condition checking of fuzzy linguistic variables as stated in the antecedent part of the fuzzy logic [18-20].

The second category of rules, however, is similar to classical Takagi- Sugano type, which includes an evaluation of the blocking, assignment, dropping or soft handoff membership of a call in a given cell. A fuzzy threshold is then used to transform the fuzzy decisions into binary decisions. Typically, in our experiment we presume the threshold to be 0.5; consequently when the membership obtained by firing the rules exceeds 0.5, the decision is given in favour of the fuzzy linguistic decision variable. If the consequent parts of the rule include blocking of a call, and the membership of call blocking exceeds 0.5, the call is blocked. The extension of classical fuzzy logic to derive binary decisions using thresholds is referred to as fuzzy threshold logic in this chapter.

3.2.1 Fuzzy to Binary Decision Rule Based Call Management

In this section, we briefly outline the principle of fuzzy to binary mapping using a set of rules with fuzzy propositions in the antecedent clause, and binary decision variable in the consequent part. Such policy of adoption is needed to improve system performance without increasing complexity of the reasoning algorithm.

Let $x_1, x_2, ...x_n$ and $y_1, y_2, ...y_n$ be fuzzy linguistic variable, and $\mu_{A_j}(x_j)$ and $\mu_{B_j}(y_j)$ be the membership of the variable x_i and y_i to lie in the set A_i and B_i respectively. Let d_k be a decision variable, which can hold two values: true or false. It is needless to mention that $\mu_{A_j}(x_j)$ and $\mu_{B_j}(y_j)$ lie in [0, 1]. The general form of the fuzzy rule we used are given below.

Type 1 rule:

$$IF\, \mu_{A_i}(x_i) < \mu_{B_i}(x_i)\, AND \mu_{A_k}(y_k) < \mu_{B_k}(y_k)\, AND \, ...$$
$$THEN\;\; d_k \;is\; true.$$

Type 2 rule:

$$IF((\mu_{A_i}(x_i)\; OR (\mu_{A_j}(x_j) > (\mu_{A_k}(x_k))\; AND\; (\mu_{A_j}(y_j) > \mu_{B_j}(y_j))$$
$$THEN\; d_k \;is\; false.$$

The inequality (<) in type 1 rule could be reversed (>). The OR in type 2 rule means the maximum of the membership. For example, $\mu_{A_j}(x_j)$ OR $\mu_{B_j}(y_j)$ is same as Max[$\mu_{A_j}(x_j)$, $\mu_{B_j}(y_j)$]. The decision d_k should be true or false. The parameters defined below will be used in the rest of the chapter.

Definition 1: Hotness is defined here as the number of calls waiting to be serviced at a given time instance. If total no. of incoming calls in $cell_i$ is N_i, and T_i is the total time of calls in $cell_i$ being serviced, then hotness of $cell_i$, denoted by hot_i, is measured by

$$hot_i = \frac{N_i}{T_i}.$$

Definition 2: Availability is defined here as number of free channels in a cell i. Given $f_{i,j} = 1$, if the jth channel in cell i is free. Then the availability of cell i denoted as avl_i, is measured by

$$avl_i = \sum_j f_{i,j}\ .$$

Definition 3: Feasibility is a parameter used to check the viability of channel assignment to a incoming call in a given cell. To test the feasibility of assignment of channel j to an incoming call in cell i, when the channel k of cell i is already in service, ∀ k, we define a measure of feasibility by $feas^j$, using the soft constraints for channel assignment indicated in [42], where

$$feas^j = \sum_k (C_{j,k} - |f_{i,j} - f_{i,k}|).$$

If $feas^j > 0$ then the j-th channel is assigned to an incoming call in cell i. Otherwise, the assignment is abandoned.

Definition 4: Velocity is defined as the velocity with which a MS is moving while in service and is denoted as *vel*.

Definition 5: Distance is defined as the distance of the moving MS from the BS and is hereafter referred to as *dist*.

3.2.2 Fuzzy Membership Evaluation

In call management, the parameters like availability, hotness, velocity of the mobile device and distance from the base station are always dynamically fluctuating with time. Construction of rules for all possible values of the parameters becomes tedious, and also not suggestive as matching of the if-part of the rules with measured value of parameters for a large no of rules takes excessive time, and thus not amenable for execution in real time. One approach to reduce the matching time is to partition the parametric space into intervals, and check the existence of a measured parameter in intervals. Such crisp partitioning is permissible as long as a particular value of a parameter in the if-part of a rule is independent (with respect to decision) over the other parameters in the if-part of the same rule. Fortunately, this is taken care of in fuzzy sets, as it allows overlapping among the partitions in individual parametric space. The parameters: hotness, availability, velocity, and distance here are encoded (fuzzified) in three scales HIGH (hereafter HI), LOW (hereafter LO) and MEDIUM (hereafter MED), while feasibility is encoded into two fuzzy scales: HIGH and LOW. Fig. 3.4 shows the fuzzy membership curve of all the parameters stated above.

3.2.2.1 Fuzzy Rules for Call Admission

The rules used in the present context are given here with justifications below.

1. IF $(\mu_{HI}(avl_i)\ OR\ \mu_{MED}(avl_i)) > \mu_{LO}(avl_i)\ AND\ (\mu_{HI}(feas^j) > \mu_{LO}(feas^j))$

   THEN assign new call to j[th] channel.

2. IF $(\mu_{LO}(avl_i)$ OR $\mu_{MID}(avl_i) > \mu_{HI}(avl_i))$ AND
   $(\mu_{HI}(feas^j) > \mu_{LO}(feas^j))$AND $(\mu_{\mathrm{HI}}(hot_N) > \mu_{\mathrm{LO}}(hot_N)$
   OR $\mu_{\mathrm{MED}}(hot_N))\ AND\ (\mu_{HI}(avl_N) > \mu_{LO}(avl_N)$ OR $\mu_{MID}(avl_N))$

THEN block the cell.

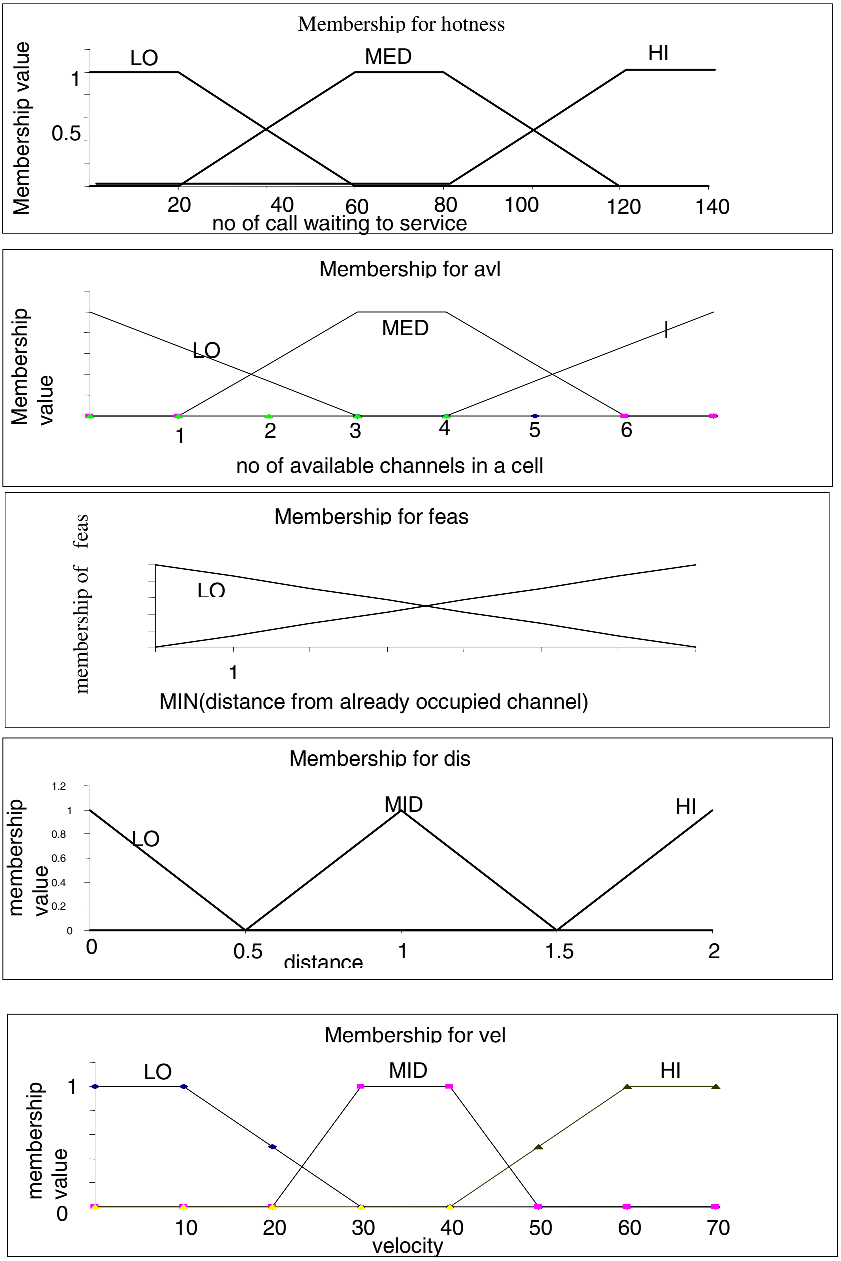


Fig. 3.4 Fuzzy membership of all the variables

In rule 2, N denotes the neighborhood of cell *i*

1. $\text{IF}(\mu_{LO}(avl_i)\ \text{OR}\ \mu_{MID}(avl_i) > \mu_{HI}(avl_i))\ \text{AND}$
   $(\mu_{HI}(feas^j) > \mu_{LO}(feas^j))\text{AND}(\mu_{HI}(hot_N) > \mu_{LO}(hot_N)$
   $\text{OR}\ \mu_{MED}(hot_N))\ \text{AND}(\mu_{HI}(avl_N) > \mu_{LO}(avl_N)\ \text{OR}\ \mu_{MID}(avl_N))$

   THEN search new neighbor N and do Soft Handoff

2. IF $(\mu_{HI}(vel) > \mu_{MID}(vel)\ OR\ \mu_{LO}(vel))$
   $AND\ (\mu_{FAR}(dis)\ OR\ \mu_{MED}(dis) > \mu_{NEAR}(dis))$

   THEN drop the call

3. IF $(\mu_{HI}(vel)\ OR\ \mu_{MID}(vel) > \mu_{LO}(vel))\ AND$
   $(\mu_{MED}(dis) > \mu_{FAR}(dis)\ OR\ \mu_{NEAR}(dis))\ AND$
   $(\mu_{LO}(avl_i)\ OR\ \mu_{MID}(avl_i) > \mu_{HI}(avl_i))\ AND$
   $((\mu_{HI}(feas^j) > (\mu_{LO}(feas^j))$

   THEN do SHO

4. IF $(\mu_{LO}(vel) > \mu_{MID}(vel)\ OR\ \mu_{HI}(vel))\ AND$
   $(\mu_{FAR}(dis)\ OR\ \mu_{MED}(dis) < \mu_{NEAR}(dis))$

   THEN the call carries on with existing channel.

Rule 1 asserts that if a cell has good number of available channels and any of the channels has a high feasibility to accept the call then assigns the call to that channel.

Rule 2 states that though the cell has good number of free channels but the feasibility of assigning the call to them is low then search for such channels in the neighboring cells N. If no such cell exists then block the call.
Rule 3 states that if in a cell good numbers of free channels are available but none fits the feasibility criteria then search the neighboring cells' channels. If any of the cell has such channel do SHO to that channel.

Rule 4 states that in a situation where the receiver is moving very fast and is at the boundary of the cell drop such call.

Rule 5 states that if velocity is high to medium and distance is medium from base station and there is neighboring cell with feasible channel then SHO to that channel

Rule 6 states that if the speed is very slow and is very near to the base station, do not change the channel.

3.2.3 Fuzzy to Fuzzy Mapping for CAC

At the time of assigning a channel to a call, the most important factor to be taken care of is to ensure the QoS, satisfying the feasibility criteria. In case the channels satisfy the feasibility criteria, they are fit for new assignment. In fuzzy to binary mapping, only the fittest channel in a cell is used for new assignment. Determination of the fittest channel there has been performed by selecting the channel with the highest grade of fuzzy membership of High-feasibility set. But in case of fuzzy to fuzzy mapping, the decision variable is fuzzy and is connected with the measurement variables: feas, avl, hot, vel and dis through fuzzy relations.

In order to arrive at a binary decision from the estimated fuzzy decision variable, a threshold is considered, exceeding which the decision is considered true, and else it is regarded false. So a channel with lesser feasibility than the highest is also favoured, if the membership of the decision variable exceeds the threshold. As a result, more channels are in use at a time than in the previous mapping scheme. But choice of suitable threshold ensures that the soft constraints are not violated ensuring QoS.

The fuzzy rules in the present context are Tkagi-Sugeno type, but the reasoning mechanism we introduced here is considerably different from classical Takagi-Sugeno model [3], [4].

The general form of rules used includes

Type 1:

$$\begin{aligned}
&if\,(\mu_{A_i}(x_i)\ OR\ \mu_{A_j}(x_j) > \mu_{A_k}(x_k)\\
&AND\ (\mu_{B_j}(y_j) > \mu_{B_k}(y_k)),\ \forall j\\
&AND\quad ..\ ....\ ..\\
&Then\ d_l\ is\ with\ truth\ value\\
&\mu_c(d_l) = max\{(\mu_{A_i}(x_i),(\mu_{A_j}(x_j)\} * \max_j\{\mu_{B_j}(y_j)\}
\end{aligned}$$

where A_i, A_j, A_k, B_j , B_k and C are fuzzy sets in respective universe discourses. The "*" denotes product of the arguments on both side of it.

Type 2:

$$\begin{aligned}
&if\,(\mu_{A_i}(x_i)\ OR\ \mu_{A_j}(x_j) > \mu_{A_k}(x_k)\ AND\\
&(\mu_{B_i}(y_i) > ((\mu_{B_j}(y_j)\ OR\ (\mu_{B_k}(y_k)),\ \forall i\\
&OR\ ((\mu_{C_j}(z_j) > \mu_{C_k}(z_k)),\ \forall j\ AND\\
&(\mu^N_{A_i}(x_i) > ((\mu^N_{A_j}(x_j)OR(\mu^N_{A_k}(x_k))),\ \forall i)\ AND\quad ....\\
&Then\ d_l\ is\ with\ truth\ value\\
&\mu_D(d_l) = min[1,\ max\{(\mu_{A_i}(x_i),(\mu_{A_j}(x_j)\} * \max_j\{(\mu_{B_j}(y_j)\} +\\
&\qquad + \max_j\{(\mu_{C_j}(z_j)\} * \max_i\{(\mu^N_{A_i}(x_i)\}]
\end{aligned}$$

where A_i, A_j, A_k, B_i, B_j, B_k, C_j, C_k, and D are fuzzy sets in respective universes. The conjunctive antecedent clauses' contribution to decision variable is realized using product (*), while the contribution of to disjunctive clauses is realized in decision variable by summation (+) operation.

The fuzzy implication rules given below use a decision variable for un-serviced call (hereafter abbreviated as uc) in five fuzzy sets ASSIGNMENT (hereafter ASSIGN), BLOCK, SOFT-HANDOFF (abbreviated as SHO), DROP, and CONTINUE (abbreviated as CONT).

3.2.4 Fuzzy Rules Used and Justification

1. IF $(\mu_{HI}(avl_i) \text{ OR } \mu_{MID}(avl_i)) > \mu_{LO}(avl_i)$
   AND $(\mu_{HI}(feas^j) > \mu_{LO}(feas^j))$

Then assign new call to j[th] channel with membership

$$\mu_{ASIGN}(uc) = max\{\mu_{HI}(avl_i), \mu_{MID}(avl_i)\} * \max_j\{\mu_{HI}(feas^j)\}.$$

Membership of assignment is expressed in terms of availability and feasibility, and if the membership value exceeds a threshold of 0.5 then the channel j of cell i is assigned to the call, and rejected otherwise.

2. IF $(\mu_{HI}(avl_i) \text{ OR } \mu_{MID}(avl_i) > \mu_{LO}(avl_i))$ AND
   $((\mu_{LO}(feas^j) > \mu_{HI}(feas^j))$ AND
   $(\mu_{\mathrm{LO}}(hot_N) > \mu_{\mathrm{HI}}(hot_N) \text{ OR } \mu_{\mathrm{MED}}(hot_N))$

   THEN block the cell with membership of block as

$$\mu_{BLOCK}(uc) = \min[1, \mu_{LO}(avl_i) * \max_j\{\mu_{LO}(feas^j)\} + \max_N\{\mu_{LO}(hot_N)\}].$$

It is clear from the above expression that membership of call blocking is a function of memberships of low availability and low feasibility or low hotness, and the call is blocked if the membership of call blocking exceeds a threshold = 0.5.

3. *IF* $(\mu_{LO}(avl_i) \text{ OR } \mu_{MID}(avl_i) > \mu_{HI}(avl_i))$
   AND $(\mu_{HI}(feas^j) > \mu_{LO}(feas^j))$
   OR $((\mu_{\mathrm{HI}}(hot_N) > \mu_{\mathrm{LO}}(hot_N) \text{ OR } \mu_{\mathrm{MED}}(hot_N))$
   AND $(\mu_{HI}(avl_N) > \mu_{LO}(avl_N) \text{ OR } \mu_{MID}(avl_N)))$

THEN search new neighbor N and do Soft Handoff with membership given by

$$\mu_{SHO}(uc) = min[1, max\{\mu_{MID}(avl_i), \mu_{LO}(avl_i)\} * \max_j \{\mu_{LO}(feas^j)\} + \max_N \{\mu_{LO}(hot_N)\} * \max_N \{\mu_{HI}(avl_N)\}].$$

Membership of SHO is expressed in terms of inadequate availability of feasible channels in the cell and the hotness of the neighbors and availability of feasible channels in such neighbors and is accomplished if the membership value exceeds threshold=0.5

4. IF $(\mu_{HI}(vel) > \mu_{MID}(vel) \text{ OR } \mu_{LO}(vel))$ AND $(\mu_{FAR}(dis) \text{ OR } \mu_{MED}(dis) > \mu_{NEAR}(\text{dis}))$

THEN drop the call with membership as

$$\mu_{DROP}(uc) = \mu_{HI}(vel) * \max\{\mu_{FAR}(dis), \mu_{MED}(dis)\}.$$

Membership of drop is expressed in terms of high velocity and the distance away from the BS and the call is dropped when membership value exceeds a threshold=0.5.

5. IF $(\mu_{HI}(vel) \text{ OR } \mu_{MID}(vel) > \mu_{LO}(vel))$ AND
$(\mu_{MED}(dis) > \mu_{FAR}(dis) \text{ OR } \mu_{NEAR}(\text{dis}))$
$OR\ ((\mu_{HI}(avl_N) > (\mu_{LO}(avl_N) \text{ OR } \mu_{MID}(avl_N))$ AND
$((\mu_{HI}(feas^{N_j}) > (\mu_{LO}(feas^{N_j})))$

THEN do SHO with membership

$$\mu_{SHO}(uc) = min[1, max\{\mu_{HI}(vel), \mu_{MID}(vel)\} * max\{\mu_{MED}(dis)\} + \max_N\{\mu_{HI}(avl_N)\} * \max_j\{\mu_{HI}(feas^{N_j})\}]$$

The membership of SHO is expressed in terms of higher range of velocity with medium distance of MS from BS and availability of feasible channels in near neighbor and is done if membership value exceeds the threshold =0.5.

6. IF $(\mu_{LO}(vel) > \mu_{MID}(vel) \text{ OR } \mu_{HI}(vel))$ AND
$(\mu_{FAR}(dis) \text{ OR } \mu_{MED}(dis) < \mu_{NEAR}(\text{dis}))$

THEN carry on with existing channel with membership $\mu_{CONT}(uc) = \mu_{LO}(vel) * \mu_{NEAR}(dis)$.

The membership CONT is expressed in terms of low velocity and nearing distance of MS from BS and is accomplished if membership value exceeds threshold=0.5.

3.3 Computer Simulation

Here we have considered two different decision schemes for assignment or rejection of a call in a channel. Though the decisions are estimated differently, the antecedents are same in both the cases. Hence the same call management strategy is used in both the case which is described below.

3.3.1 Principles of Call Management Strategy

In a network every cell contains channels, some of which are busy in servicing calls, while the rest are free. When a new call arrives in a cell, it is to be assigned to the free channels of the cell, satisfying the soft constraints of channel assignment. If the cell does not have such free channels, the neighboring cells are searched for free channels, and once found they are assigned to the calls. If no such channels are available in near neighbors (adjacent six cells) then the call is rejected.

This, however, is valid as long as the MS are static. But in case the MS starts moving during a call service, it may move out of the cell. To avoid call drop, a new channel from the current cell needs to be allocated when the MS moves out of the cell. If no such channel is found, the call is dropped. The time of search is considered and if the MS is moving out of the cell very fast the call is dropped. If it is moving slowly and is well within the range of the BS then the channel in use continues the service.

In the time of call assignment the calls generated due to SHO are given higher priority over new ones, to maintain the QoS of on-going calls. The calls which are occupying the channels for long time are forcefully dropped to free the channels for reuse. The call management strategy is proposed based on the above considerations.

3.3.2 Call Management Strategy

1. A new call arrives in the cell.
2. If it is a new call, set SHO flag to 0 else (if it is due to handoff) set to 1.
3. Check if the call is moving or static; if moving repeat from step 10.
4. Drop all the calls with call time more than T, and set all the free channels due to call drop and hang-ups available; and refresh the dynamic allocation table and hotness table.
5. Check the availability of the channels in the cell and list all the available channels with the membership of avl.
6. Check the feasibility of the available channels and find the membership of feas.
7. If membership of avl and feas both are high, then assign the call to that channel of the cell, and start counting call time (so as to measure call duration to drop long calls by strategy 4) and go to step 1.
8. If feas is not high, search the highest feasible channel in the near neighbour with highest avl, and if found do SHO; start counting call time and go to step 1.

9. If no such cell found satisfying step 6, block the call and go to step 1.
10. Find the membership of vel and dis.
11. If vel and dis both are low, the channel used for call service is retained in the cell, and go to step 1.
12. if vel is med or high and dist is med, then find the membership of avl for the neighbours, and go to step 7.
13. If both vel and dist are respectively high and far, then drop the call and go to step 1.

The membership curves of the variables are given in Fig 2.4.

3.3.3 Sample Runs for Fuzzy to Binary

The strategy of call admission has two modules (Fig. 3.5). One describes the call admission when the MS are static the other describes the same when the MS are moving. Three specific cells are taken to demonstrate the rules are described in Table. 3.1.

Table 3.1 Measurement of System Features Following the Above Definitions

No of cell	vel	dist	avl	hot	feas
7	5	1	5	55	1,2,4,5
21	55	.4	6	60	1,2,4,5,6,7
9	55	1.6	5	103	1,2,4,5,7

The first module is described in Fig. 3.6a. Here at a particular instance of time when a call arrives in the cell the membership of hotness is calculated using hotness curves. Then the membership or availability of channels in the cell as well as the membership of feasibility of the channels are calculated. Then rules are fired on the basis of membership values, and a binary decision is obtained.

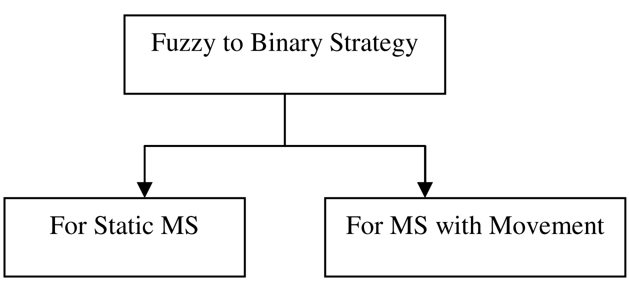


Fig.3.5 Block diagram for fuzzy to binary strategy

RULE1:

IF$(\mu_{HI}(avl_i)$ *OR* $\mu_{MID}(avl_i) > \mu_{LO}(avl_i)$ *AND*$\mu_{HI}(feas^j) > \mu_{LO}(feas^j))$

Assign new call to chanel j in cell i

RULE2:

IF $(\mu_{HI}(avl_i)\ OR\ \mu_{MID}(avl_i) < \mu_{LO}(avl_i))\ AND$

$(\mu_{HI}\ (feas^{\ j}) < \mu_{LO}\ (feas^{\ j}))\ AND(\mu_{HI}(hot_N)\ OR\ \mu_{MID}(hot_N) < \mu_{LO}(hot_N))$

Block the call

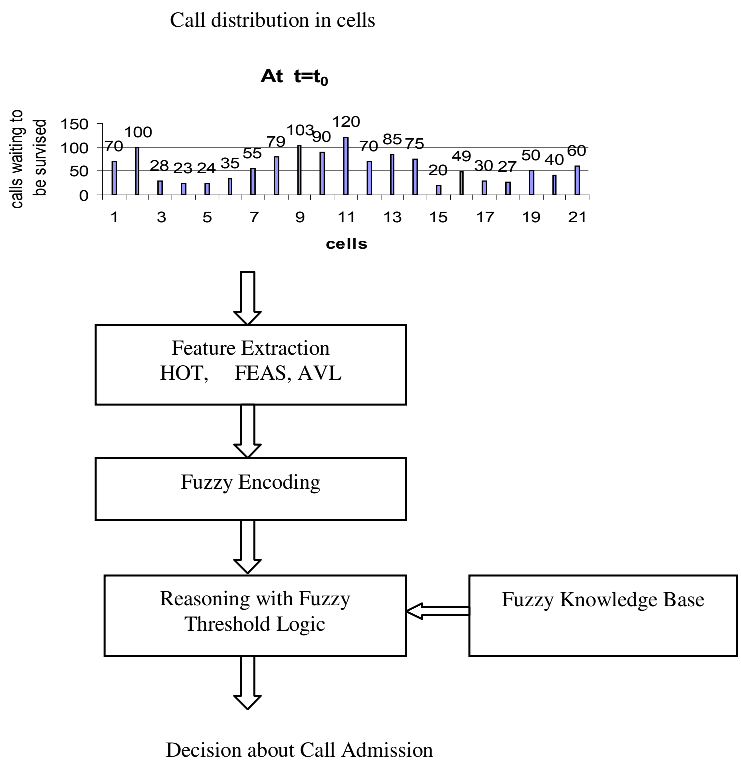


Fig. 3.6a Module describing static call service

RULE3:

IF $(\mu_{HI}(avl_i) < \mu_{MID}(avl_i)\ OR\ \mu_{LO}(avl_i))AND\ (\mu_{HI}\ (feas^{\ j}) < \mu_{LO}\,(feas^{\ j}))$

$AND\ (\mu_{HI}(hot_N) > \mu_{MID}(hot_N)OR\ \ \mu_{LO}(hot_N))AND\ \ \mu_{HI}(avl_N) > \mu_{lo}(avl_N)$

$OR\ \mu_{MED}(avl_N)$

Search new neighbour N and do SHO

RULE 4:

IF $(\mu_{HI}(vel) > \mu_{MID}(vel)\ OR\ \mu_{LO}(vel)\ )AND\ (\mu_{FAR}(dis)\ OR\ \mu_{MED}(dis) > \ )$

$\mu_{NEAR}(dis)$

DROP THE CALL

RULE5:

$$IF(\ \mu_{HI}(vel)\ OR\ O\mu_{MID}(vel)\ >\ \mu_{LO}(vel))\ AND\ (\mu_{FAR}(dis)\ OR$$
$$\mu_{NEAR}(dis)\ ) < \ \mu_{MED}(dis) AND\ (\mu_{LO}(avl_N)\ OR$$
$$\mu_{MID}(avl_N)\ \langle\ \mu_{HI}(avl_N)\ of\ nbd\,(N) AND(\mu_{HI}(feas^{j}) > \mu_{LO}(feas^{j}))$$
$$DO\ SHO$$

The module in Fig. 3.6b is the second part of the scheme proposed by us. Here the situation is considered when the MS starts moving inside the cell or may move out of the cell as well. In such case the membership value of velocity of MS as well as the membership of distance from base station is also important to arrive at a decision, and hence they are also considered together.

In addition, the availability of channels in the neighbouring cell as well as feasibility of using such channels are equally important in decision making. Depending on all such membership values the rules are fired to get a binary decision for the course of action to be followed.

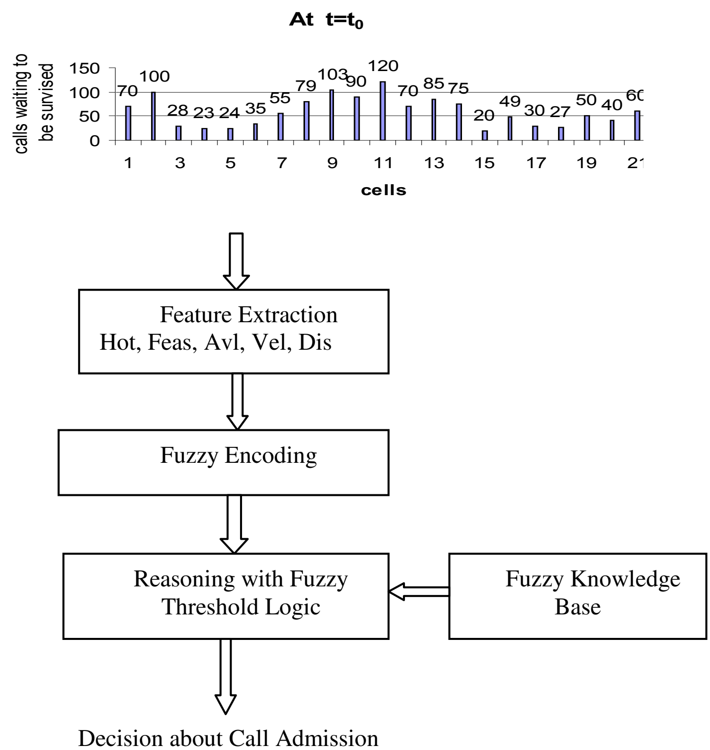
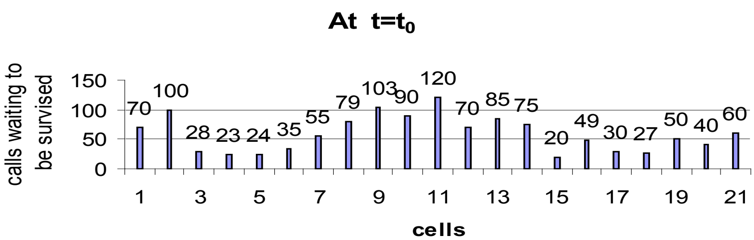


Fig. 3.6b Module describing call service when MS in in motion

3.3.4 Numerical Examples

Let us find out how the system works in a situation where three cells say, the 9th, 11th and 5th are having static calls at an instant $t = t_0$. By calculating the membership value, we find the following facts which are shown in Fig. 3.7a.



MEASUREMENT OF SYSTEM FEATURES

CELL NO	HOTNESS	AVAILABILITY	FEASIBILITY
9	103	5	1,2,4,5,7

Fig. 3.7 When a new call is generated in cell 9

Example 1: Let us consider the network in a situation given in Fig. 3.7
From the Fig 3.7 we can see that the membership value and the curves of availability is given in Fig. 3.7a.

Avl=5	
LO	0
MED	0.5
HI	0.333

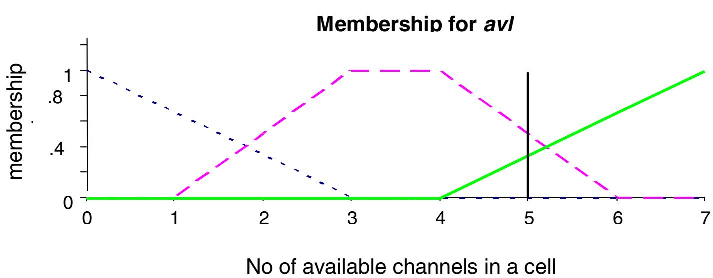


Fig. 3.7a Membership curve for avl

From Fig. 3.7a, it is evident that $\mu_{HI}(avl) > (\mu_{MED}(avl) OR \mu_{LO}(avl))$

The fuzzy membership calculation of hotness is given in Fig. 3.7b.

From Fig.3.7b it follows that $\mu_{HI}(hot) > (\mu_{MED}(hot) OR \mu_{LO}(hot))$

Then the feasibility of the free channels are considered. Fig. 3.7c below demonstrates the feasibility of all the free channels mentioned in Fig.3.2a

Hot=103	
LO	**0**
MED	**0.425**
HI	**0. 575**

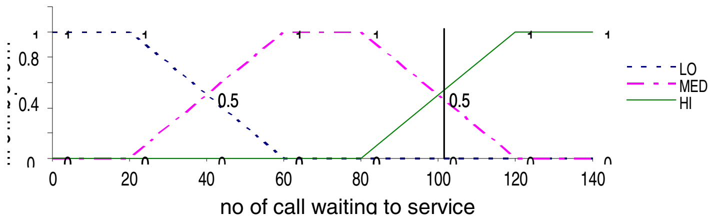
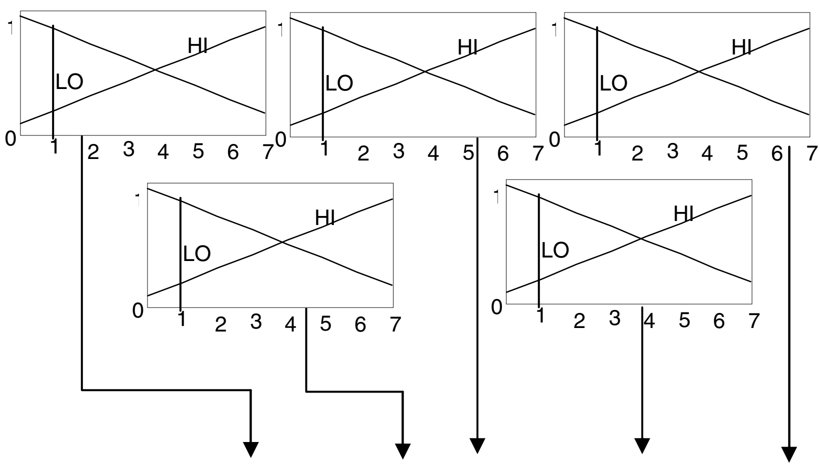


Fig. 3.7b Membership curve for hot in cell 9

From Fig. 3.7c we can conclude $\mu_{LO}(feas^{j}) > \mu_{HI}(feas^{j})\ \forall j \in \{1,2,4,5,7\}$

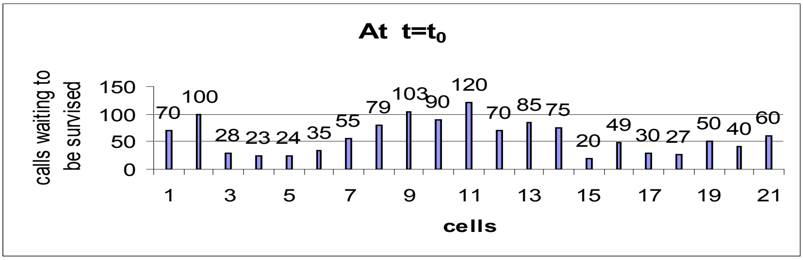


Channel μ	1	2	4	5	7
LO	0.714	0.8568	0.8568	0.8568	0.8568
HI	0.2856	0.1428	0.1428	0.1428	0.1428

Fig. 3.7c Membership curve for feasibility of all available channels

So in the given condition stated above when a new call is generated in cell 9 then all the conditions trigger Rule 2 and the call is blocked. All the tables hereafter are refreshed.

Now consider cell 11 given in Fig. 3.7d



MEASUREMENT OF SYSTEM FEATURES			
CELL NO	HOTNESS	AVAILABILITY	FEASIBILITY
11	120	6	1,2,4,5,6,7

Fig. 3.7d When a new call is generated in cell 11

It is evident from Fig. 3.7e that $\mu_{MED}(avl) > (\mu_{HI}(avl) OR \mu_{LO}(avl))$

The hotness satisfies the condition $\mu_{HI}(hot) > (\mu_{MED}(hot) OR \mu_{LO}(hot))$ shown in Fig. 3.7f.

avl = 6	
Memb. LO	0
Memb.MED	0
Memb. HI	.85

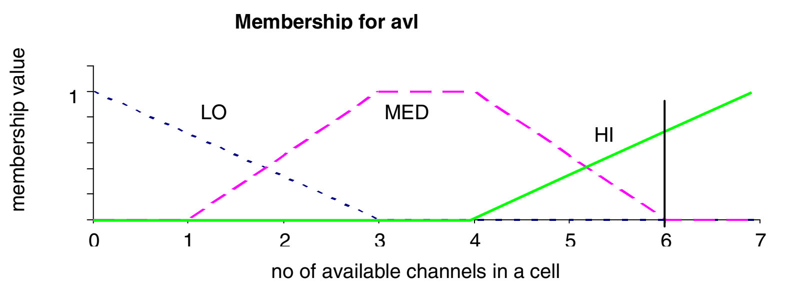


Fig. 3.7e Membership curve avl of channels in cell 11

	Hot=120
LO	**0**
MED	**0**
HI	**1**

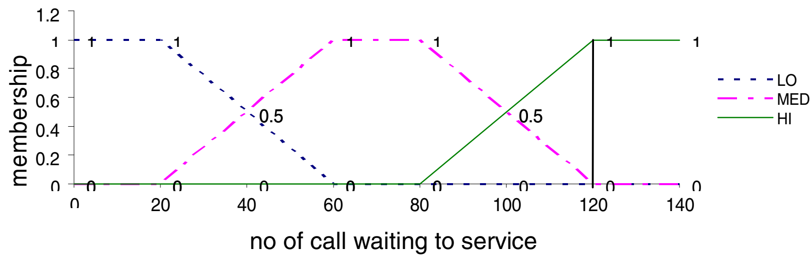
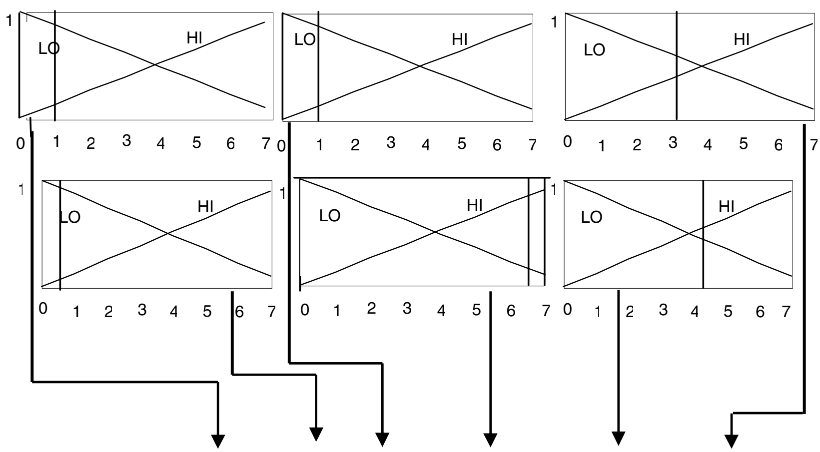


Fig. 3.7f Membership for hotness =120

The feasibility as shown in the Fig. 3.7g shows that $\mu_{HI}(feas^6) > \mu_{LO}(feas^6)$ and for other j $\mu_{LO}(feas^j) > \mu_{HI}(feas^j)$.

So when a new call arrives in cell 11 the 6th channel satisfies all the conditions of rule. Hence the new call is assigned to the 6th channel of cell 11.



Channel / μ	1	2	4	5	6	7
LO	0.71	0.86	0.86	0.14	0.43	0.57
HI	0.28	0.14	0.14	0.86	0.57	0.43

Fig. 3.7g Membership curve for feasibility of all available channels in cell 11

3.4 Fuzzy to Fuzzy Model

In the fuzzy to fuzzy scheme, the 1st module given in Fig. 3.6a, 2.6b is almost the same as the module given in Fig. 3.8. The notable change incorporated here is the output which is fuzzy instead of binary. Hence depending on the input values, the rules are fired and the membership values for un-serviced calls are generated. Depending on the membership values for assign, SHO and reject the call admission decision is taken. A thresholding is done to arrive to the decision.

No of cell	vel	dist	avl	hot	feas
7	5	1	5	55	1,2,4,5

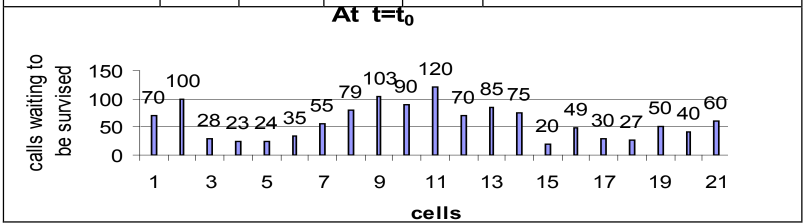


Fig. 3.7h Membership for cell 7

Example2: Let us consider a caller starts moving in the 7th cell as shown in Fig.3.7h

1) In 7th cell the following conditions are satisfied

a) $\mu_{HI}(hot) > (\mu_{MED}(hot)\ OR\ \mu_{LO}(hot))$

b) $\mu_{MED}(avl) > (\mu_{HI}(avl)\ \mathrm{OR}\ \mu_{LO}(avl))$

c) $\mu_{LO}(feas^{j}) > \mu_{HI}(feas^{j}) \quad \forall\, j \in \{1,2,4,5,6\}$

d) $\mu_{LO}(vel) > (\mu_{MED}(vel)\ OR\ \mu_{HI}(vel))$

e) $\mu_{MED}(dist) > (\mu_{FAR}(dist)\ OR\ \mu_{NEAR}(dist))$

Hence rule 6 is fired and all the tables are refreshed.

2) In 21st cell the following conditions are satisfied

a) $\mu_{HI}(vel) > (\mu_{MED}(vel)\ OR\ \mu_{LO}(vel))$

b) $\mu_{MED}(dist) > (\mu_{FAR}(dist)\ OR\ \mu_{NEAR}(dist))$

c) $\mu_{HI}(avl_N) > (\mu_{MED}(avl_N)\ OR\ \mu_{LO}(avl_N))$ for N=17,20

d) $\mu_{HI}(feas^{6}) > \mu_{LO}(feas^{6})$ in N=17

Hence rule 5 is fired and 6th channel of neighbour 17 is assigned with the call. All the tables hereafter are refreshed.

3) In 9th cell the following conditions are satisfied

a) $\mu_{HI}(vel) > (\mu_{MED}(vel)\ OR\ \mu_{LO}(vel))$

b) $\mu_{FAR}(dist) > (\mu_{MED}(dist)\ OR\ \mu_{NEAR}(dist))$

Hence rule 4 is fired and call is dropped.

The Table 3.2 Shows all the membership values of all variable in the three given cells.

Table 3.2 Membership Value for all the variables when MS is moving

Cell No	7	21	9
Hot	μ_{LO}=0 μ_{MED}=.425 μ_{HI}=.575	μ_{LO}=0 μ_{MED}=.425 μ_{HI}=.575	μ_{LO}=0 μ_{MED}=.425 μ_{HI}=.575
Avl	μ_{LO}=0 μ_{MED}=.5 μ_{HI}=.333	μ_{LO}=0 μ_{MED}=0 μ_{HI}=1	μ_{LO}=0 μ_{MED}=.5 μ_{HI}=.333
Vel	μ_{LO}=1 μ_{MED}=0 μ_{HI}=0	μ_{LO}=0 μ_{MED}=.25 μ_{HI}=0.75	μ_{LO}=0 μ_{MED}=.25 μ_{HI}=.7
Dist	μ_{LO}=0 μ_{MID}=1 μ_{FAR}=0	μ_{LO}=.2 μ_{MID}=0 μ_{FAR}=0	μ_{LO}=0 μ_{MID}=0 μ_{FAR}=.2
feas	μ^1_{LO}=.714 μ^1_{HI}=.2856 μ^2_{LO}=.8568 μ^2_{HI}=.1428 μ^4_{LO}=.8568 μ^4_{HI}=.1428 μ^5_{LO}=.714 μ^5_{HI}=.2856	μ^1_{LO}=.714 μ^1_{HI}=.2856 μ^2_{LO}=.8568 μ^2_{HI}=.1428 μ^4_{LO}=.8568 μ^4_{HI}=.1428 μ^5_{LO}=.714 μ^5_{HI}=.2856 μ^6_{LO}=.4284 μ^6_{HI}=.5712 μ^7_{LO}=.5712 μ^7_{HI}=.4284	μ^1_{LO}=.714 μ^1_{HI}=.2856 μ^2_{LO}=.8568 μ^2_{HI}=.1428 μ^4_{LO}=.8568 μ^4_{HI}=.1428 μ^5_{LO}=.8568 μ^5_{HI}=.1428 μ^7_{LO}=.8568 μ^7_{HI}=.1428 μ^1_{LO}=.714 μ^1_{HI}=.2856

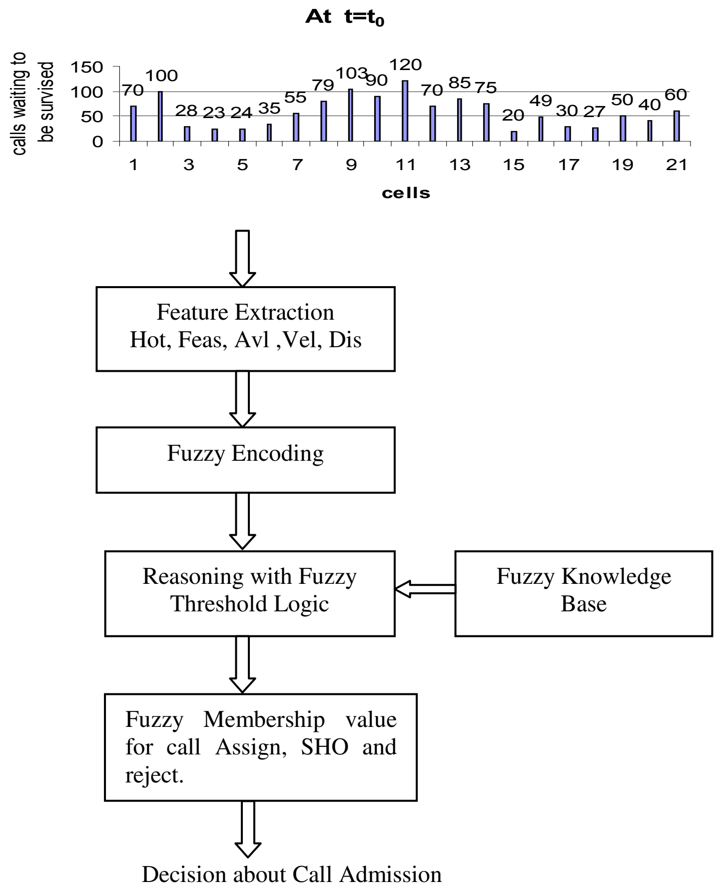


Fig. 3.8 Module describing call service for fuzzy to fuzzy model

3.5 Experiments and Simulation

For simulation we have considered a situation where

1. No. of cells = 21
2. no of channels in each cell= 7
3. Minimum reuse distance in a cell(cosite) $C_{i,i}$=4
4. Co channel constraint $C_{i,m}$=2
5. Adjacent Channel constraint $C_{i,m}$=3
6. minimum call arrival in a system= 21
7. maximum call arrival in a system = 150
8. base station separation= 2 km
9. minimum call hang-up in a cell =1
10. maximum time before call drop in a hot cell= 1 hr
11. maximum velocity= 70 km/hr(city traffic)

At $t = t_0$, 27 calls were serviced and 4 calls were rejected. But the change of hotness may be different due to the hang up of calls by the users. Fig. 3.9b. shows a sample run and how the hotness changes and calls getting serviced in the processes. It is seen that the number of calls serviced increases steadily over the time.

3.6 Results and Interpretation

We define call assignment and call rejection probability to measure the performance of our proposed system of call management.

Let

N_a be the number of calls assigned in a cell,
N_s be the number of incoming calls waiting to be serviced and
N_r be the number of calls rejected.

Then we define call assignment probability and call rejection probability by the following expression

$$P_A = \text{P (call assign)} = \frac{N_a}{N_s} \quad , \qquad P_R = \text{P (call rejection)} = \frac{N_r}{N_s}$$

We first study the performance of the fuzzy to binary and fuzzy to fuzzy algorithm separately.

3.6.1 Performance of Fuzzy to Binary Strategy

In Fig. 3.9 we present a graphical representation of the no. of serviced calls and rejected calls against the total incoming calls. It is apparent from Fig. 3.9 that the system starts with a very few incoming calls, i.e. N_s is low. Naturally, plenty of channels remain free for further call assignment in the cells. Consequently, the call assignment continues to the free channels, and resulting in a significant rise in the number of call assigned (serviced) N_a rises with N_s, when N_r remains constant.

But as Ns increases and the channels get allocated to the calls, free and assignable channels gradually decrease. This happens when N_s exceeds 50(approx) (Fig. 3.9). Then the system experiences congestion and N_r gradually starts increasing whereas N_a gets flatten. Under such situation, the call management scheme starts executing a call drop strategy, where the channels in service for more than a given amount of time are set free. The channels for the normal hang-up (terminated) calls are also set free for subsequent reuse. And the call allocation matrix is refreshed. This dropping and reuse job is repeated in regular intervals. And here after N_a goes on increasing with N_s and N_r flattens.

Table 3.3 provides a situation of network after running Fuzzy to Fuzzy CAC Algorithm

Table 3.3 Call Management in a Network

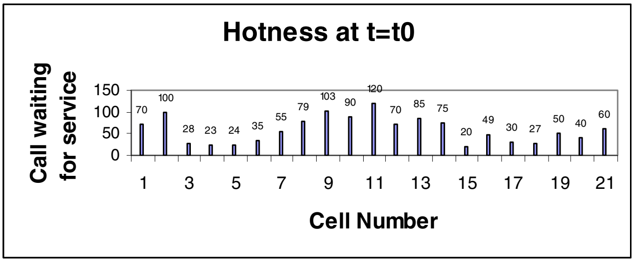
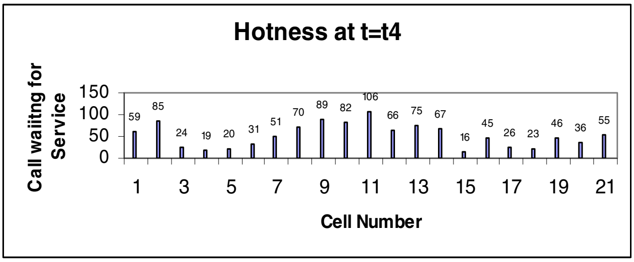
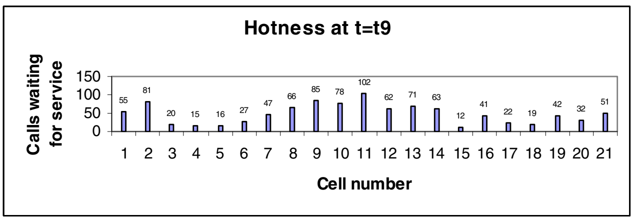
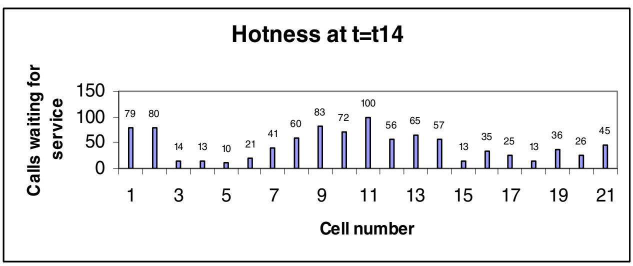
CELL NO.	Call Blocked And Dropped	Soft Handoff	Call Serviced
1		1	
2		1	
3	1		
4		1	
5	1		
6	1		
7		1	
8		1	
9		1	
10			1
11			1
12			1
13		1	
14		1	
15		1	
16			1
17		1	
18	1		
19			1
20			1
21			1
Total	4	10	7

Fig. 3.10 provides a graphical representation of the probability of call assignment P_A and probability of call rejection P_R with increasing number of calls waiting for being serviced N_s. Initially the P_A grows and P_R falls sharply since there are plenty of free channels in the system. Then as N_s increases, the congestion grows and calls start dropping. So P_A starts dropping, and P_R starts growing up. At that point the call management strategy starts dropping long calls repetitively after certain interval of time and reuses the free channels.

Hence, P_A moves up and stays up since the dropping and reuse of channels are repeated in regular intervals. But the slope of P_A flattens up when Ns goes beyond a certain stage (approx 110). This signifies that with limited no. of channels, the configuration indicated in Fig. 3.1, has no more free channels, and thus cannot serve the excessive demand. One way to meet this demand, is to have adequate channels for a given system configuration, so that channels are free even when the call demand is height.

Table 3.4 shows the run of Fuzzy to Fuzzy system in a regular interval.

Table 3.4 Performance of the scheme after certain interval of time

<table>
<tr><th>HOTNESS</th><th>CALL SERVICED</th><th>CALL REJECTED</th></tr>
<tr><td>
</td><td>27</td><td>4</td></tr>
<tr><td>
</td><td>29</td><td>6</td></tr>
<tr><td>
</td><td>34</td><td>6</td></tr>
<tr><td>
</td><td>38</td><td>6</td></tr>
</table>

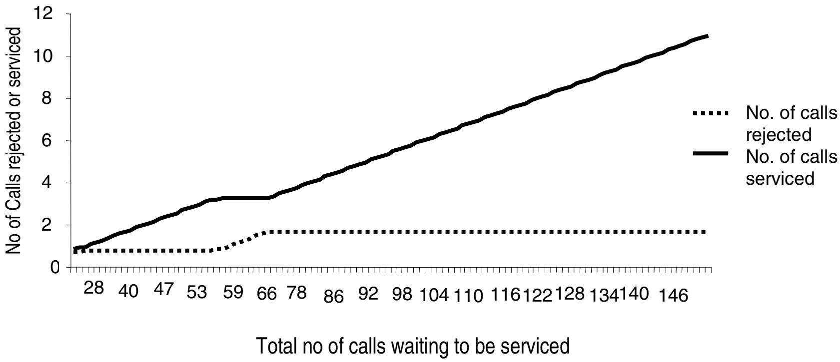


Fig. 3.9 Total number of call dropped and serviced over the time

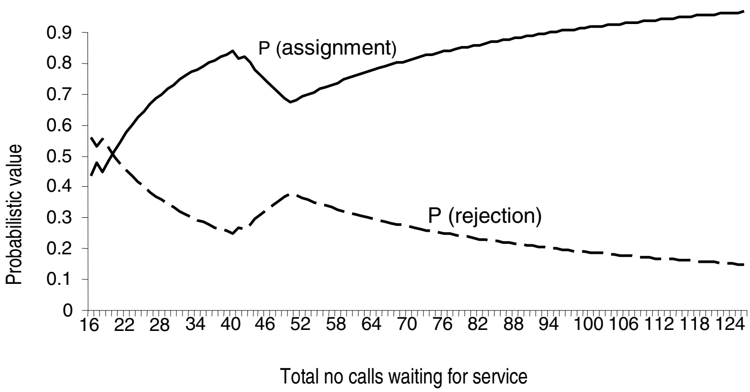


Fig. 3.10 The call- drop probability and call assign probability

3.6.2 Performance of Fuzzy to Fuzzy Strategy

To study the performance of fuzzy to fuzzy decision making in call management strategy, we again have plotted N_a and N_r against N_s in Fig. 3.11. We also plot the P_A and P_R against N_s in Fig. 3.12.

In Fig. 3.11 we see that the congestion is reached much before (around 45) that it was in fuzzy to binary scheme. This is because the fuzzy to fuzzy scheme takes more channels as available for allocating calls.

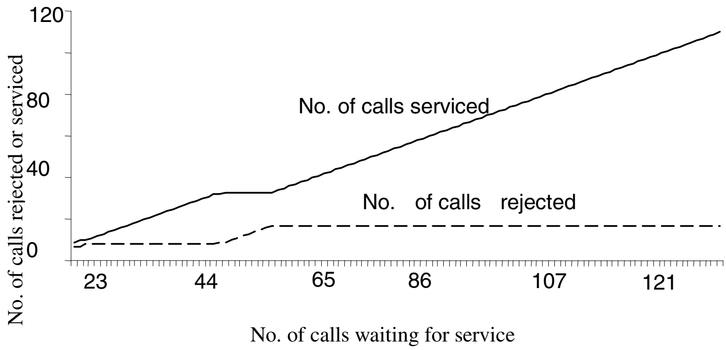


Fig. 3.11 Total number of call dropped and serviced over the time

Fig. 3.12 shows that P_A always stays higher than P_R. This is due to the fact that unlike fuzzy to binary, fuzzy to fuzzy considers more channels as available, using the threshold. Again P_R has a sharp rise, since fuzzy to fuzzy strategy assigns channels faster. The fuzzy to fuzzy strategy takes decision better and hence can handle congestion of higher level.

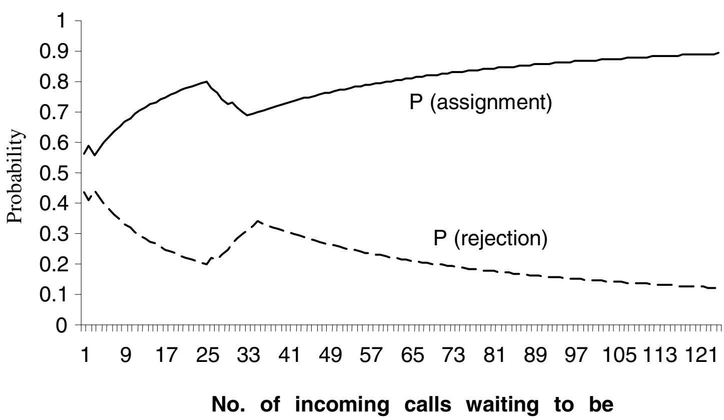


Fig. 3.12 The call drop probability and call assign probability

3.6.3 Comparison between the Methods

Fig. 3.13 shows a comparison between the fuzzy to binary and fuzzy to fuzzy methods in terms of call service. It is observed from this figure that no. of calls assigned (N_a) in fuzzy to fuzzy is always higher than that of fuzzy to binary scheme irrespective of the no. of waiting calls (N_s). Further, the slope of the fuzzy to fuzzy curve is also higher than that of fuzzy to binary.

Lastly, the saturation in the fuzzy to fuzzy system starts at N_s=134, while that in fuzzy to binary takes place at N_s= 120. Finally, the fall-off slope in fuzzy to binary scheme is higher than the fuzzy to fuzzy scheme, indicating that with a little increase in N_s the N_a will have a drastic fall-off in fuzzy to binary mapping scheme in comparison to that in fuzzy to fuzzy mapping scheme.

3.6.4 Call Rejection Threshold for Fuzzy to Fuzzy Module

The experimental shape of the curve for call rejection probability in fuzzy to fuzzy scheme is already explained in Fig. 3.12. In Fig. 3.14, we study the effect of variation of threshold in the fuzzy production rules deciding SHO. An apparent look into Fig. 3.14 reveals that the curves with threshold =0.75 and 0.5 are more or less parallel.

The increase in call rejection probability for increased threshold makes sense following rules1 to 6. The phenomena for threshold =0.25 however is apparently counter-intuitive as it lies between the two other curves, one with less, and the other with more threshold.

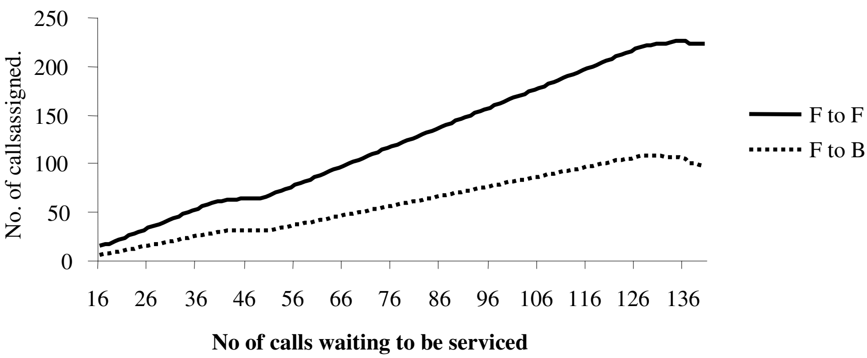


Fig.3.13 Call service in fuzzy to binary and fuzzy to fuzzy methods

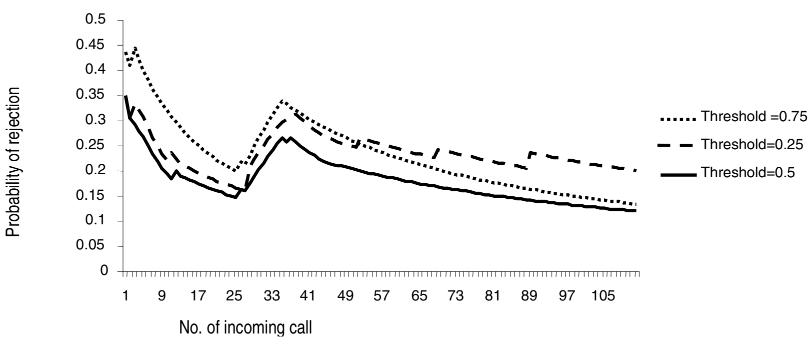


Fig. 3.14 Call rejection probability in fuzzy to fuzzy system with thresholds (0.5, 0.25, 0.75)

A detailed look into the call assignment strategy envisages that for threshold= 0.25 the feasibility condition, i.e. soft constraints, for channel assignment failed to be satisfied, giving rise to this phenomenon. A threshold of 0.5 seems to be an optimum choice as manages to satisfy the feasibility condition in one end and reduces the call rejection probability in the other end.

To compare the performance of our system with classical FCA [50] and DCA, we consider the call rejection probability of these two schemes in [2]. Reconstructing the same, and merging them with our results, we obtain Fig. 3.15. It is clear from Fig. 3.15 that both DCA and FCA have a high call rejection probability when no. of calls waiting for serviced (N_s) is very low. But it may be noted that the same cellular configuration can manage to handle almost double waiting calls, even with a significantly low call rejection probability. Thus our proposed scheme shows far better ability in reducing call block.

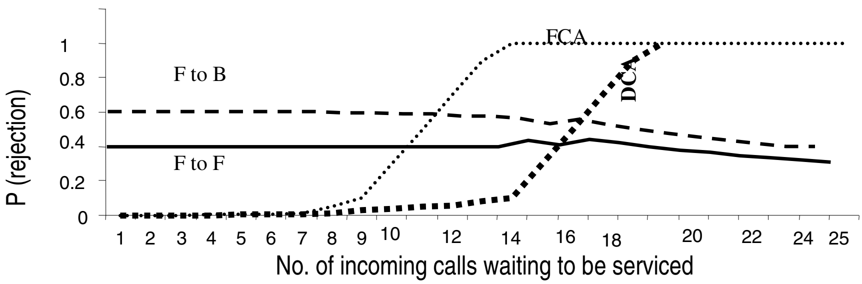


Fig. 3.15 Comparison of call drop probability in channel assignment problem

3.7 Conclusions

The proposed scheme is unique in its approach in combining Channel assignment with Call admission control, which is considered as two different areas of study. By implementing such concept we are able to minimize the interference in terms of co-channel, adjacency channel and co-site constraints, and could be able to ensure quality of service (QoS). Also the scheme implements reuse of channel strategy combined with forceful dropping of long calls, which improves the condition of a heavy traffic network and helps in avoiding congestion considerably. Not only the static calls, but the calls where the MS's are in a move, are also considered and are provided with proper service to minimize the drop of an ongoing call while moving. It has also taken care of the changeable conditions, including availability, feasibility, and hotness of a dynamic network. With all these aspects it gives a better result in managing calls than most of the existing systems.

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