Performance Analysis of Call Admission Control in WCDMA System with Adaptive Multi Class Traffic based on Fuzzy Logic

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Summary

Resource management is one of the most important engineering issues in 3G systems where multiple traffic classes are supported each being characterized by its required quality of service (QoS) parameters. Call admission control (CAC) is one of the resource management functions, which regulates network access to ensure QoS provisioning. Call Admission Control is employed to decide whether to accept or not a new service request and its goal is to admit a higher number of service requests while at the same time guaranteeing the required QoS for every already active connection. CAC in CDMA systems is classically based on Interference or Signal to Interference Ratio estimates and threshold comparisons. Traditionally, a CAC scheme should explore a set of measured parameters to make the decision of accepting or rejecting a requesting call. This type of control scheme makes little or no allowance for measurement uncertainties. However, in the wireless system, due to user mobility, dynamic QoS requirements and varying channel conditions, the measurements obtained are, in general, not accurate. Furthermore, it is also difficult to obtain the complete statistics of input traffic. As a result, the decision has to be based on the imprecision and uncertain measurements. To this end, fuzzy logic provides an approximate but effective means of describing the behavior of the systems that are too complex and not easy to tackle mathematically. Having the nature of coping with uncertainty and imprecision problems, fuzzy logic is expected to provide a good solution to the development of a call admission control scheme. The fuzzy CAC scheme analysed in this paper takes into account the mobility information of the new user requesting connection and already existing users, the type of service request (real time or non-real time) and the load factor which is calculated from the intra-cell interference and the inter-cell interference at the base station.. The QoS requirement of the non real time traffic is reduced to accommodate more number of real time traffic users to improve the performance of the admission control scheme. Simulation results show that the fuzzy based CAC scheme performs better than the fixed CAC schemes without fuzzy in terms of new call blocking and handoff call dropping probabilities.

Key words:
New Call Blocking Probability, Handoff Call dropping Probability, Grade of service.

1. Introduction

Call Admission Control in CDMA cellular networks has been specifically addressed as a means of managing interference (load control) to ensure efficient QoS support, as the capacity of CDMA systems is interference-limited. CAC directly controls the number of users in a cell in order to keep the interference under a tolerable limit so that an adequate radio link performance and required QoS for each user can be maintained. This clearly indicates that there is a trade-off between the system capacity and the overall communications quality, that is, GoS(Grade of service) and QoS in effect. In general, due to the time-varying soft capacity of CDMA systems, the decision of CAC exhibits an error in both directions: to accept and to reject. The CAC strategies investigated in the literature are roughly classified into two types: one is based on the number of users[1],[2] and the other is based on the interference level [3],[4]. These types are referred to as number-based CAC (NCAC) and interference-based CAC (ICAC), respectively.

In number-based CAC schemes considered for single-service or integrated voice/data CDMA systems, the priority is given to voice users and the packet transmissions of data users have to adapt to the remaining system capacity. The capacity index of the voice/data users, i.e., the maximum number of voice/data users that can be accommodated in the system simultaneously, is specified. Thus the operation of number-based CAC schemes is quite similar to the fixed-assignment FDMA/TDMA systems. In interference based call admission control scheme, the total interference at the base station is estimated at the time of new call arrival and the admission decision is made based on the result of comparison of this estimated interference with the predefined threshold. In SIR-based CAC schemes[2] introduced for a single-service CDMA cellular system, the effects of the radio propagation, call-arrival process, and traffic distribution among cells were taken into account. The residual capacity, defined as the maximum number of additional calls that the BS can handle while keeping the system-wide outage probability below a certain threshold, is defined. The residual capacity was calculated periodically according to the received SIR measurement at the BS. Two distributed SIR-based CAC algorithms were proposed by the authors. In the first algorithm, the SIR measurement in the local cell alone was used for making the admission decision and in the second algorithm the

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SIR measurements in all the adjacent cells were also considered.

In the paper [3], K. Kim & Y. Han analysed the performance of the call admission control algorithm in CDMA system for multi rate traffic by taking the received power as the admission parameter. In effective-bandwidth-based CAC schemes[8] proposed for CDMA cellular networks, the effective bandwidth of each call is estimated based on the inter-cell and intra-cell interference and the admission decision is made based on comparing the existing bandwidth with the total effective bandwidth of all the calls including the new call. The previous interference-based CAC schemes are extended to accommodate multi-class users in CDMA mobile multimedia systems. Thus, before accepting a new call, the current level of multiple access interference(MAI) is measured. If it is larger than a certain threshold 'MAIMAX', then the call will be blocked; otherwise, the call will be accepted. The threshold 'MAIMAX' is determined by the outage threshold set for each user class. Two CAC schemes were presented: local and global. The local scheme bases its decision on MAI measurements of the local cell without considering the impact of a new call on the adjacent cells. This can cause quality degradation to the adjacent cells, especially in the case of non-uniform traffic distribution where the traffic load of the local cell is light and that of the adjacent cells is high. The global scheme overcomes such problems by considering the impact of a new call on the residual capacity of the adjacent cells. In this case, the CAC scheme is capable of adapting to the traffic conditions and distributing radio resources among the cells in an efficient manner. This, however, comes with more complexity and overhead due to a larger amount of measurement, processing, and signaling required for keeping track of the global system states.

Thus CAC limits and regulates the number of users admitted into the network under the constraints of network capacity and resource allocation strategies. Efficient CAC schemes can enhance the system capacity and service quality cost-effectively. In advanced multimedia cellular networks, the success of service deployment also depends on network capabilities in providing differentiated QoS to meet a wide range of customer demands. CAC schemes are vital for supporting the two-fold objective of cellular networks operation: (i) to deliver the required QoS; (ii) to provide operators freedom in controlling the payload and group behavior of traffic classes regarding the required services as well as subscriber classes for optimizing network utility and revenues. In the wireless system, the decision made by the call admission controller is to be based on the imprecision and uncertain measurements due to user mobility, dynamic QoS requirements and varying channel conditions. Having the nature of coping with uncertainty and imprecision problems, fuzzy logic is expected to provide a good solution to the development of a call admission control scheme. This paper is organized as follows: section II describes the system model and the admission control algorithm. Section III explains the basics of fuzzy logic and the fuzzy system model of the call admission control. In section IV, simulation parameters and the results are analysed. Section V concludes the paper and it highlights the advantages of the fuzzy based admission control algorithm.

2. System Model

2.1 Call Admission control Algorithm

A wideband CDMA cellular system with hexagonal cells of equal size is considered. Each cell contains a centrally located base station (BS) with an omni directional antenna and the same radio spectrum is reused in all the cells.

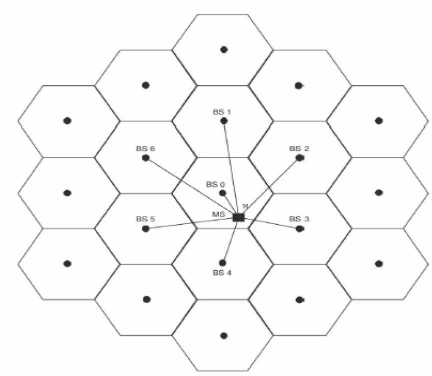


Fig. 1 Cell Structure.

The mobile stations (MS) communicate with their home BSs via the air interface, and all the BSs are connected to a mobile switching center (MSC), which is in turn connected to backbone wire line network. Separate frequency bands are used for the forward and reverse links, so that each BS experiences interference only from the MSs. The focus is placed on the CAC process for the reverse link. In the forward link, each BS broadcasts a unique pilot signal to the MSs. The pilot signals from different BSs are distinguished by different scrambling codes. The MS can detect the pilot signal from any BS when the strength of the pilot signal is above a certain level. Prior to transmission, an MS monitor the received pilot signal power levels from nearby BSs, and chooses its home BS according to the maximum received pilot signal power. It is assumed that MSs, BSs, and MSCs are properly designed such that, while tracking the signal from the home BS, an MS searches for all the possible pilots and maintains a list of all pilots whose signal power levels are above a prescribed threshold. This list is transmitted to the MSC periodically through the home BS. The MSC uses this information to make a decision on when handoff should start and also to estimate the mobility of the users.

When a call request arrives, the MSC uses the mobility information of all the mobile users in the cell and also in the neighboring cells together with their traffic characteristics, to calculate the resources utilized by all the active calls, to estimate the resource requirement of the new call and also to make reservation for the handoff calls. Then it finds the resource availability to accommodate the new call without degrading QoS of the calls already in service. The figure.1 shows a uniform grid of hexagonal cells, where the MS under consideration is located at point M. For simplicity of presentation, we will focus on the mobility information and the interference introduced by the MS at its home BS (denoted as BS_0) and at the six neighboring BSs in the first-tier (denoted as BS_1, BS_2, ... BS_6). Let $d_l(t)$, l = 0,1…6, denote the distance between the MS and BS_l at time t. It is assumed that, with a properly designed transceiver, the channel disturbance is mainly due to shadowing and path loss.
The local mean of the pilot signal power from BS_l received at the MS can be expressed as [12]

$$a_1(t) = \gamma_1 \left[\frac{d_1(t)}{D_0} \right]^{-r} .10^{\varepsilon 1(t)/10} + \nu_1(t) \qquad (1)$$

where γ_l is a constant proportional to the transmitted signal power, r is the path loss exponent; D_0 is the close-in reference distance that is determined from measurements close to the transmitter, and $\varepsilon_l(t)$ in dB at any t is a Gaussian random variable (with zero mean and standard deviation σ_s) characterizing the shadowing phenomenon. For $l \neq k$, $\varepsilon_l(t)$ and $\varepsilon_k(t)$ are independent random processes. If the transmit power levels of all the pilot signals are the same, then $\gamma_l = \gamma$ for l = 0,1…6. $\nu_l(t)$ represents background noise power and multiple access interference (MAI) from the information-bearing signals in the forward link to all the MSs. When there are a large number of users in the system, the MAI can be modeled approximately by a Gaussian random process. Similarly, in the reverse link, the propagation loss $\Lambda_l(t)$ from the MS to BS $_l$ is proportional to the product of the r^{th} power of distance and a log-normal component characterizing the shadowing phenomenon, given by

$$\Lambda_l(t) = d_l^{\,r}(t).10^{\zeta_l(t)/10} \qquad (2)$$

where $\varsigma_l(t)$ in dB at any t is a Gaussian random variable with zero mean and standard deviation σ_s. For the MS at point M in figure.1, suppose at time t, the received power of the signal from this MS at its home base station BS_0 is $P_{r,0}(t)$, then the received power of the signal from this MS at the neighboring BSs can be expressed as

$$P_{r,l}(t) = P_{r,0}(t) \left[\frac{d_l(t)}{d_0(t)} \right]^{r} .10^{(\varepsilon_l(t) - \varepsilon_0(t))/10} \qquad (3)$$

where l = 1,2,….6

In the wideband CDMA cellular system, soft handoff is adopted since it can extend CDMA cell coverage and increase reverse link capacity. Soft handoff happens when an MS moves into the overlapping cell coverage area of two or more BSs. The pilot channel's bit energy to noise-plus-interference density ratio $(E_b/I_0)_p$ is used as the handoff measurement quantity. For simplicity, it is assumed that, in soft handoff, an MS is connected to two nearest BSs with strongest pilot signals, while it is power controlled by the BS that requires it to transmit at the smaller power. Consider that an MS moves into the soft handoff region from cell l to cell k. If cell k does not have enough resources to accept the handoff call when the MS moves out from the overlapping region, the call has to be dropped to guarantee the QoS of the existing calls in cell k. It should be mentioned that, during the soft handoff, the signal transmitted by the MS is received at both the BSs. With selection diversity at the receiving end, the required transmitted power of the MS (and, hence, the system resource) is reduced as compared with that in the hard handoff situation.
The SIR of each and every connection depends on the power emitted by mobile users, inter-cell and intra-cell interferences and the thermal noise. The transmit power of the mobile station can be calculated from the SIR requirement of the user, which is given by,

$$\left[\frac{E_b}{N_0} \right]_i = \frac{W.P_j}{\upsilon_j R_j \left(I_{Total} - P_j \right)} \qquad (4)$$

where W is the chip rate, P_j is the received signal power from user j, υ_j is the activity factor of user j, R_j is the bit rate of user j and I_{Total} is the total received wideband power including thermal noise power in the base station. Solving the above equation for P_j gives

$$P_j = \frac{1 . I_{Total}}{\left[1 + \frac{W}{\left[E_b / N_0 \right]_j \nu_j . R_j} \right]} \qquad (5)$$

The load factor Lj of an j[th] active mobile is,

$$L_j = \frac{1}{\left[1 + \frac{W}{\left[E_b / N_0 \right]_j \nu_j . R_j} \right]} \qquad (6)$$

The total interference at the base station receiver for a user is the interference from the users in own cell and neighboring cells[6].

When a new user enters into the system, the call admission controller of the system first checks whether this connection requires real time service or non real time service. If it requires real time service, then it checks the resource availability in the home cell and also in the neighboring cells after reserving sufficient resources for the handoff calls. The reservation will be updated periodically and also at the time of new call arrival. If the system has enough resources, the call will be admitted otherwise the data rate of the non real time service calls will be reduced to the possible extent to accommodate the new call. If the new connection requires non real time service, this call will be admitted with full rate when the system has enough resource. If the system does not have enough resource, it will be admitted with half rate or even with quarter rate. The non real time call will be blocked only when the system can not provide the service even with this reduced rate. This will happen when the system is heavily loaded with more number of real time service calls. The resource requirement and availability are measured in terms of signal to interference ratio. Since call dropping is more annoying than call blocking the handoff calls must be given higher priority. The reserved resources are used only by the handoff calls. Since the amount of resource reserved for handoff calls is based on the mobility estimation, the resource utilization is also improved.

3. Fuzzy Based Call Admission Control

3.1 Basic concepts of Fuzzy logic

In the Aristotelian logic a classical set can be defined as a set with a crisp boundary. For example, a classical set A of real numbers greater than 6 can be expressed as

$$A = \{x | x \geq 6\}$$

There is a clear and unambiguous boundary "6": if x is greater than this number it belongs to the set A, otherwise x does not belong to the set.

On the contrary, in the Fuzzy logic a set is defined without a crisp boundary. The transition from "belong to the set" to "not belong to the set" is gradual, thus representing the truth grade related to the definition of the concept. This smooth transition is characterized by the so-called 'Membership Functions' that give set flexibility in modeling commonly used linguistic expressions, like "the temperature is hot" or the "weather is warm". A Fuzzy System consists of a Fuzzifier, an Inference Engine, a Fuzzy Rule Base and a Defuzzifier. The Fuzzifier transforms the values of the input parameters into the fuzzy linguistic terms through a set of Membership Functions. These fuzzy linguistic terms are the inputs of the Inference Engine, which will perform the logic inference according to the Fuzzy Rule Base. The Fuzzy Rule Base is constructed by the expert knowledge of the phenomenon (admission control, in this paper). The Defuzzifier converts the results of the inference into the usable values for admission decisions.

The Fuzzy Reasoning, also known as "approximate reasoning", it is an inference procedure that derives conclusions from a set of fuzzy rules and known facts. It can be divided into four steps:

- Degrees of compatibility: compare the known facts with the antecedents of fuzzy rules to find the degrees of compatibility with respect to each antecedent Membership Function.
- Firing strength: combine degrees of compatibility with respect to antecedent Membership Functions in a rule using fuzzy AND or OR operators to form a firing strength that indicates the degree to which the antecedent part of the rule is satisfied.
- Qualified induced consequent Membership Functions: apply the firing strength to the consequent Membership Functions of a rule to generate a qualified consequent Membership Function.
- Overall output Membership Function: aggregate of all the qualified consequent Membership Functions to obtain an overall output Membership Function.

These four steps are employed in the fuzzy inference system shown in the following section.

3.2 Fuzzy system Model for CAC

The Fuzzy Call Admission Control model used in this paper is shown in the figure. 2

The inputs parameters are,

S : Type of service request(Real time or Non-real time)
M: Mobility information of the new user.
I_{Total}: Total interference in the cell, i.e. the inter-cell and intra-cell interference.
L: Available load.

The corresponding fuzzy linguistic term set is,

T(S) : { High-RT, Low-NRT}
T (M): {low, medium, high}
T(L): {low, Medium, high}

The output linguistic variable, denoting the acceptability of the new call is,

T(*D*): {Strongly Rejected, Weakly rejected, Weakly Accepted, Strongly Accepted}.

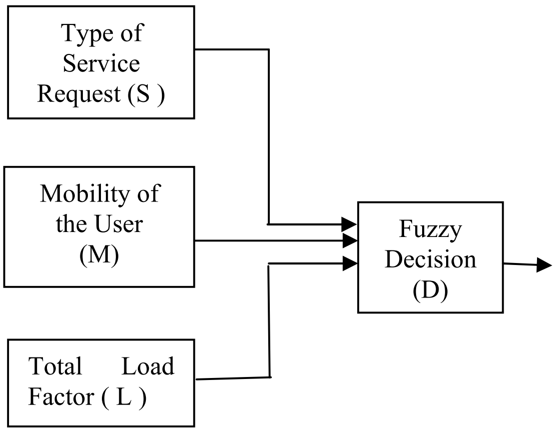
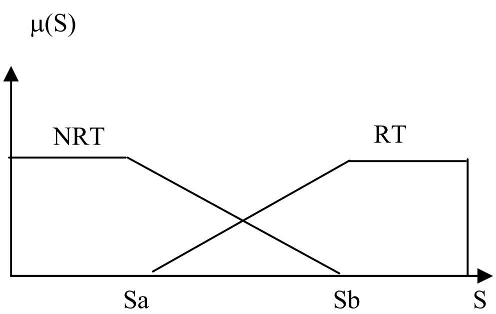


Fig. 2 Fuzzy System Model.

The relative membership functions are shown in Figure..3. The coefficients Sa, Sb, Ma, Mb, Mc, La, Lb, Lc, Ld, Da , Db, Dc, Dd are the fuzzy set ranges of S, M ,L and D respectively.

On the basis of the above fuzzy set, the Fuzzy Rule Base has been constructed and the rules for the admission criterion are listed in Table-1. Fuzzy inference algorithm is based on the Mamdani model.



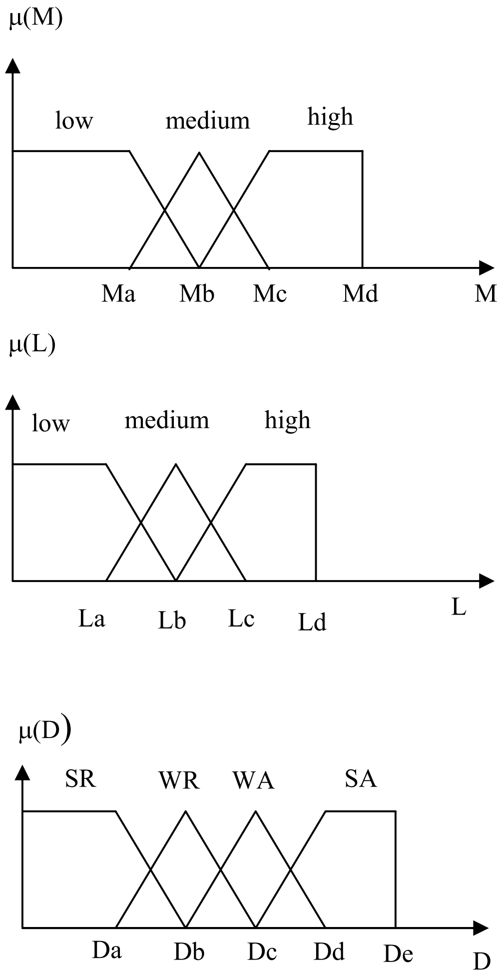


Fig. 3 Fuzzy membership functions.

R- Strongly Rejected WR-Weakly Rejected
WA-Weakly Accepted SA-Strongly Accepted

3.3 Propagation Model

The macro cell propagation model, valid for urban and suburban environment is employed. Path loss L is then expressed according to [10] as follows:

$$L = 128.1 + 37.6 \text{ Log } (R) + \text{Log } (F)$$

where R is the distance (in meters) between mobile and Node B.

Log(F) represents the loss due to fast fading, F being a Gaussian random variable with zero mean and 10 dB standard deviation.

Table 1: Fuzzy Rules

Fuzzy Rule	Type of Service Request (S)	Mobility of the User (M)	Total Load Factor (L)	Fuzzy Decision (D)
1	High	Low	Low	SA
2	High	Medium	Low	A
3	High	High	Low	WA
4	High	Low	Medium	A
5	High	Medium	Medium	WA
6	High	High	Medium	WA
7	High	Low	High	R
8	High	Medium	High	R
9	High	High	High	SR
10	Low	Low	Low	SA
11	Low	Medium	Low	SA
12	Low	High	Low	A
13	Low	Low	Medium	A
14	Low	Medium	Medium	WA
15	Low	High	Medium	WA
16	Low	Low	High	WA
17	Low	Medium	High	WA
18	Low	High	High	R

4. Simulation and Analysis

4.1 Simulation Parameters

The performance of the fuzzy call admission controller for the WCDMA system is evaluated through simulation and is compared with the other Signal to interference based CAC schemes without fuzzy logic. The CDMA system having the bandwidth of W= 5 MHz with 7-cell structure is simulated. Each cell has a radius of 2000 meters. There are three traffic classes, each call having a probability of 0.5, 0.1 and 0.4 to be voice, video and data call respectively[11]. The voice and video calls are real time traffic and the data call is the non real time traffic.

The following traffic parameters are used in the simulation:

- The voice activity for the voice call is 0.5 and the transmission rate is 9.6 kbps.
- Each video connection is modeled as the superposition of 19 independent mini ON-OFF sources. Each mini source generates information at the rate of 9.6 kbps during an ON period. The average length is 0.2 sec for each ON period and 0.8 sec for each OFF period.
- Each data connection requires a minimum transmission rate of 19.2 kbps. The required E_b/I_o value is 7 dB for voice and video connections and 9 dB for data connections. The QoS requirement of outage probability is 0.01 for all voice, video and data calls.
- Three mobility classes: a pedestrian (up to 10 Km/hr), medium speed (10 to 45 km/hr) and high speed (above 45 km/hr) are considered.
- The transmitted power from the base station is taken as 125mW.
- SIR threshold for the new calls is 8 dB for voice and video connections and for the handoff calls, it is 7 dB. Hence the SIR margin of 1 dB is reserved to give higher priority for the handoff calls.

In order to generate fuzzy inference rules for estimating the mobility, the total interference and the load factor, membership functions for each fuzzy variable should be determined, and training data are needed. To choose the type and number of membership functions, it is necessary to take into account both computational efficiency and adaptation complexity of the fuzzy inference system. The most commonly used membership functions are Gaussian, triangle, and trapezoid functions. Here in our work, both the triangle and the trapezoid functions are used. Figure. 3 shows the membership functions used in the fuzzy CAC scheme. Table.1 shows the required rules for estimating the decision for the incoming calls entered at the middle base station.

4.2 Analysis

To evaluate the performance of the proposed fuzzy based admission control algorithm, the SIR based admission control algorithm is also studied. In SIR based algorithm, the new call request(voice and video calls) is admitted when the total SIR at the base station at the time of request is greater than the 8 dB and it is 7 dB for handoff calls. For data calls, since they are non real time calls they will be accepted with the data rate depending on the resource availability. The simulation results are plotted and it shows the variation of the new call blocking and handoff dropping probabilities with respect to average number of users in the system for the different mobility and traffic classes.

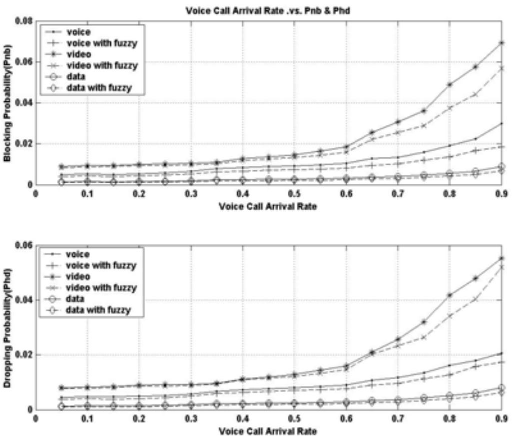


Fig. 4 Voice call arriving rate vs. new call blocking and handoff dropping probabilities of voice,video and data (with and without fuzzy).

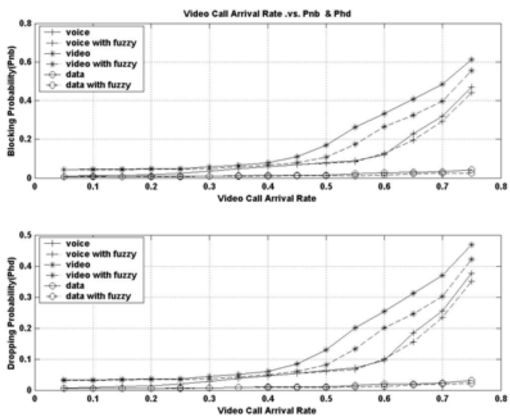


Fig. 5 Video call arriving rate vs. new call blocking and handoff dropping probabilities of voice, video and data (with and without fuzzy).

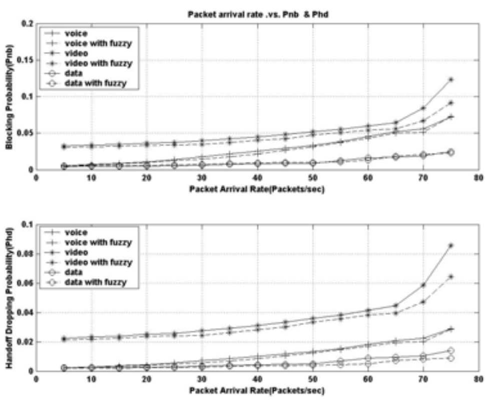


Fig. 6 Data call arriving rate vs. new call blocking and handoff dropping probabilities of voice, video and data (with and without fuzzy).

The figure.4 shows the variations in the blocking and handoff dropping probabilities for the different traffic classes with and without fuzzy with respect to voice call arrival rate. The blocking probability of the video call is high at high loads since it requires more resource than the voice call. The blocking probability of the data calls is constant even at high load because of the rate adaptiveness of the data calls. The figure.5 shows the blocking and dropping probabilities of the various classes with respect to video call arrival rate. The blocking probability of all the call classes are slightly higher than the previous case and it justifies that the resource requirement is more for the video calls. In figure.6 it is found that the blocking probabilities of all the call classes are very less and it is almost constant even at very high packet arrival rate. The performance of the fuzzy based call admission control algorithm is compared with SIR based call admission control algorithm without fuzzy. From the graphs it can be seen that the performance of fuzzy based system for all the traffic classes is improved significantly especially under heavy loads.

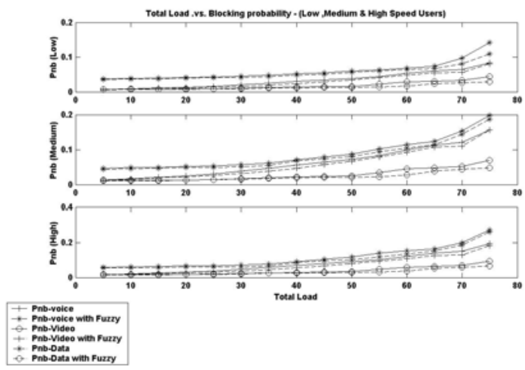


Fig.7 Total Load vs. new call blocking and handoff dropping probabilities of voice, video and data (with and without fuzzy) for Low, Medium and High Speed Users.

The figure.7 shows the variations in blocking and dropping probabilities with respect to the total load in the system for the different mobility of the users. When the mobility of the users is low, most of the calls will be accepted and hence the blocking and dropping probabilities are less. For the medium and high mobility users, the blocking and dropping probabilities are high due to the high SIR requirement for eliminating the effect of fading and also other multi path effects.

5. Conclusion

The fuzzy based CAC scheme for wideband CDMA cellular system, to meet the challenges in CAC due to user mobility, limited radio spectrum, heterogeneous and dynamic nature of multimedia traffic, and QoS constraints has been studied and its performance is analysed in this paper. The fuzzy approach can overcome measurement errors, mobility and traffic model uncertainty, and avoid the requirements of complex mathematical relations among various design parameters. The resource requirement of each call is evaluated in terms of the load factor which depends on the signal to interference ratio requirement and the data rate requirement of the call. The user mobility information is estimated and predicted based on the measurements of the pilot signal power levels received at the MS. The CAC decision is based on the type of call request, mobility of the users and the resource availability, where the handoff calls are given high priority in comparison with new calls via resource reservation. The QoS requirement of the non real time traffic class is reduced to improve the performance of the admission control scheme under heavy load condition. Simulation results show that the fuzzy CAC scheme can achieve QoS satisfaction in terms of the outage probability, and achieve lower new call blocking probability, lower handoff call dropping probability when compared with the SIR based CAC schemes without fuzzy.

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