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Implementation of call admission control scheme in next generation mobile communication networks using particle swarm optimization and fuzzy logic systems

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Abstract

In the present and next generation wireless networks, cellular system remains the major method of telecommunication infrastructure. Since the characteristic of the resource constraint, call admission control is required to address the limited resource problem in wireless network. The call dropping probability and call blocking probability are the major performance metrics for quality of service (QoS) in wireless network. Many call admission control mechanisms have been proposed in the literature to decrease connection dropping probability for handoffs and new call blocking probability in cellular communications. In this paper, we proposed an adaptive call admission control and bandwidth reservation scheme using fuzzy logic control concept to reduce the forced termination probability of multimedia handoffs. Meanwhile, we adopt particle swarm optimization (PSO) technique to adjust the parameters of the membership functions in the proposed fuzzy logic systems. The simulation results show that the proposed scheme can achieve satisfactory performance when performance metrics are measured in terms of the forced termination probability for the handoffs, the call blocking probability for the new connections and bandwidth utilization.

Keywords: Call admission control (CAC); Bandwidth reservation; Wireless networks; Multimedia; Quality of service; Fuzzy logic; Particle swarm optimization

1. Introduction

With the increasing demand for the provision of multimedia applications, such as video on demand (VoD), videoconference, and many WWW-based applications, a great deal of attention is being paid to resource allocation for providing seamless multimedia access in the next generation mobile communication networks (Zahariadis, 2003).

There are two important quality of service (QoS) parameters considered in wireless networks, namely the handoff call dropping probability (CDP) and new call blocking probability (CBP). The CDP denotes the likelihood that an ongoing call is forced to terminate during a handoff process when the allocated resources in the new cell are degenerated to an unacceptable level, while the CBP represents the possibility that a new connection request is denied admission into the cellular networks. Accordingly, one of the most important QoS issues in providing multimedia traffic in wireless networks is to reduce handoff drops caused by lack of available bandwidth in the new cell while maintaining high bandwidth utilization and low new call blocking rate.

Call admission control (CAC), is a mechanism used to administer the quality of service in the wireless network system (Rao, Comaniciu, Lakshman, & Poor, 2004). Since the resource in a wireless network system is limited, the resource management, especially in multimedia application,

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has been a critical problem for years. The CAC mechanism is thus important to manage the constraint resource in wireless communication system. The other method to guarantee the above QoS metrics is resource reservation mechanism and a variety of resource reservation algorithms have been proposed for traditional cellular networks in recent years (Ei-Kadi, Olariu, & Abdel-Wahab, 2002; Oliveira, Kim, & Suda, 1998; Wu, Yeung, & Hu, 2000).

A well-known machine learning technique, fuzzy logic, is employed in this work to compute the expected amount of bandwidth used in the neighboring cells for the handoff calls so that the CDP handoff calls can be effectively reduced. Meanwhile, the fuzzy logic system is also embedded in the call admission controller to block the new calls if a possible congestion situation occurs at the cell that the MH resides. Another machine learning technique, Particle swarm optimization (PSO) technique, is used to adjust the parameters of the membership functions employed in the fuzzy logic systems in order to deal with the volatile characteristics of the cellular systems. The motivation of using fuzzy logic and particle swarm optimization in this work is that the computation of the two techniques is fast and simple, and they have been successfully applied in many areas (Hirota, 1993; Ren & Ramamurthy, 2000).

The remainder of the paper is organized as follows. The primitive call admission control scheme is introduced in Section 2. The adaptive call admission control scheme with fuzzy network traffic load estimator is given in Section 3. Then Section 4 states the bandwidth reservation scheme using fuzzy logic control concept. Section 5 is the simulation results. Conclusions are given in Section 6.

2. Primitive call admission control mechanism

In the wireless mobile communication system, the incoming client is admitted into the system by the granting of the call admission controller. Notably, the available channels are divided into two categories, free channels and reserved channel. The free channels are allocated to the MHs through the resource controller, whereas the size of reserved channels is adjusted by the bandwidth reservation controller. Besides, the traffic in cellular networks is usually categorized into the following two classes in the literature (Oliveira et al., 1998). Class I traffic denotes real-time multimedia traffic, such as interactive audio and video, while Class II is non-real-time data traffic, such as images and text. Since the Class II traffic can torrent unstable bandwidth, portion of the bandwidth allocated to Class II traffic is "borrowed" by new call arrivals and handoff calls that belong to Class I traffic if necessary. When a new call arrival requests a new connection, the CAC algorithm firstly checks whether the desired bandwidth, b_{desire}, requested the MH is satisfied by the available free channels, B_{f}, plus borrowable channels, C_{b}. If the new arriving call is accepted and it belongs to Class I traffic, the embedded resource reservation algorithm will also compute the amount of reserved bandwidth at the appropriate neighboring cells.

Since it is inappropriate to block a handoff call instead of a new call, we further limit the number of new call arrivals to access the system resource by using an adaptive call admission control mechanism in order to reduce the handoff call dropping probability. Whether a new arriving call should be admitted in our algorithm is determined by the following three factors:

- Whether the handoff call dropping probability, P_{hf}, is too high.
- When a cell is hotter, there will be more chances that the MHs at the neighboring cells will handoff to this cell. The hotness of a cell is then defined by:

$$\text{hotness} = \frac{\Delta \text{num}_{\text{MH}}}{\Delta t}, \tag{1}$$

where num_{MH} is the number of the incoming MHs and t denotes time.

- The amount of the free bandwidth available in current cell.

Based on the above consideration, the network traffic load of a cell is estimated by:

$$\text{load} = C \cdot P_{\mathrm{hf}} \cdot \text{hotness} \cdot \frac{1}{B_{\mathrm{f}}}, \tag{2}$$

where C is a constant, P_{hf} denotes the handoff call dropping probability of the cell, hotness represents the hotness of the cell, and B_{f} stands for the unused reserved bandwidth in the current cell. The parameters used in Eq. (2) can be obtained from the base station through simple computation. The computation result of Eq. (2) is then compared with a predefined threshold to determine whether the traffic is overloaded.

While there is a Class I handoff arriving, the CAC algorithm checks if the required bandwidth, b_{desire}, is smaller or equal to the accumulation of the free channels, B_{f}, borrowable channels, C_{b}, and channels reserved by the neighboring cells, B_{r}. It the handoff is admitted, the resource reservation algorithm will be activated to compute the estimated bandwidth at the appropriate neighboring cells when another handoff for the MH occurs in the near future. If the handoff call belongs to Class II traffic, the CAC algorithm allocates the available bandwidth to the incoming handoff if there is any free channel available.

3. Adaptive call admission control mechanism using PSO-tuned fuzzy logic system

3.1. Fuzzy logic call admission controller

The fuzzy logic techniques have been used to solve several connection admission control and channel assignment problems efficiently in ATM and wireless networks in the literature (Hirota, 1993). We thus replace the naive computation of Eq. (2) by fuzzy logic systems to determine whether the traffic at the current cell is overloaded. Meanwhile, we adopt particle swarm optimization technique to adjust the parameters of the membership functions in the proposed fuzzy logic systems.

The fuzzy network traffic load estimator proposed in our call admission control scheme is composed of the following components as described:

- *Fuzzifier*: The fuzzifier performs the fuzzification function that converts three types of input data from the network traffic load estimated scheme into suitable linguistic values which are needed in the inference engine.
- *Fuzzy rule base*: The fuzzy rule base is composed of a set of linguistic control rules and the attendant control goals.
- *Inference engine*: The inference engine simulates human decision-making based on the fuzzy control rules and the related input linguistic parameters.
- *Defuzzifier*: The defuzzifier acquires the aggregated linguistic values from the inferred fuzzy control action and generates a non-fuzzy control output, which represents the estimated network traffic load of the cell.

Notably, the input to the fuzzifier P_{hf} represents the handoff call dropping probability of the cell. The input *hotness* denotes the hotness of the cell, and B_{f} the normalization of the unused bandwidth in the cell.

The membership functions for the handoff call dropping probability of the cell, P_{hf}, where the linguistic variables "low", "intermediate" and "high" give the dropping degree measure of the handoff call dropping probability of the cell. The membership function for the hotness of the cell, *hotness*, is mapped into three linguistic term sets, "cold", "medium" and "hot" and the membership function for the normalization of the unused bandwidth of the cell, B_{f}, is mapped into three linguistic term sets, "low", "medium" and "high" represent the measure of the unused bandwidth. The output parameter of the inference engine, *Load*, is defined as the estimated network traffic load of our network traffic load estimator. The fuzzy linguistic variables for the output are "low", "medium" and "heavy", which are represented the measure of the network traffic load.

Fig. 1 illustrates the reasoning procedure. The rule in Fig. 1 is:

IF the handoff call dropping probability of the cell is intermediate, *AND* the level of the unused bandwidth of the cell is "low", *AND* the hotness of the cell is "low".

THEN the estimated network traffic load of the cell is "medium". Note that the inference rule could be established by network operators.

The non-fuzzy output of the defuzzifier can then be expressed as the weighted average of each rule's output after the Mamdani defuzzification method is applied

$$\mathrm{load}_{\mathrm{BW}} = \frac{\int_{\mathrm{l}} \mu_{\mathrm{A}}(l) l \mathrm{d}l}{\int_{l} \mu_{\mathrm{A}}(l) \mathrm{d}l}, \tag{3}$$

where $\mu_A(l)$ denotes the aggregated output constructed by the connective "*AND*" as shown in the above example is satisfied.

3.2. Particle swarm optimization

Particle swarm optimization (PSO) is a computational intelligence approach to optimization that is based in the behavior of swarming or flocking animals, such as birds or fish. In the PSO, every individual moves from a given point to a new one which is a weighted combination of the individual's best position ever found, and of the group's best position. The PSO algorithm itself is simple and involves adjusting a few parameters. With little modification, it can be applied to a wide range of applications. Because of this, PSO has received growing interest from researchers in various fields.

In this work, we allow each vehicle to execute its individual PSO algorithm. The PSO is used to adjust the two parameters, mean and variance, in the membership functions of the inputs for the fuzzy logic systems.

A summary of the PSO algorithm is given below:

Initialize the swarm of the particles such that the position $\vec{x}_{ij}(t=0)$ of each particle is random within the hyperspace, where $j = 1$–6, denote the values of the two parameters, mean and variance in different membership functions, respectively.

Compare the fitness function of each particle, $F(\vec{x}_{ij}(t))$, which is the packet delivery ratio of each individual during current time period, to its best performance thus far, $pbest_{ij}$;

then

$$\text{(i)} \quad \text{if } F(\vec{x}_{ij}(t)) < pbest_{ij} pbest_{ij} = F(\vec{x}_{ij}(t)), \tag{4}$$

$$\text{(ii)} \quad \vec{x}_{pbest_{ij}} = \vec{x}_{ij}(t). \tag{5}$$

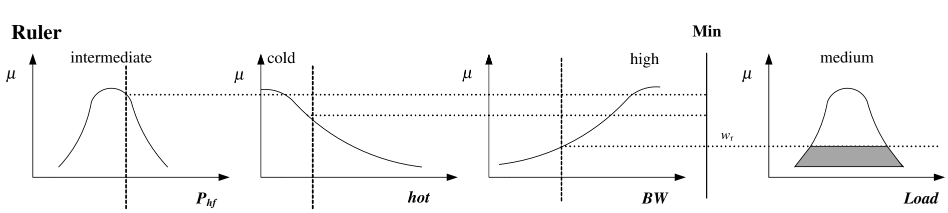

Fig. 1. The reasoning procedure for Madamni defuzzification method.

Compare $F(\vec{x}_{ij}(t))$ to the global best particle, $gbest_j$ if $F(\vec{x}_{ij}(t)) < gbest_j$ then

(i) $gbest_j = F(\vec{x}_{ij}(t))$, (6)

(ii) $\vec{x}_{gbest_j} = \vec{x}_{ij}(t)$. (7)

Revise the velocity for each particle:

$$\vec{v}_{ij}(t) = \vec{v}_{ij}(t-1) + c_1 \cdot r_1 \cdot (\vec{x}_{pbest_{ij}}(t) - \vec{x}_{ij}(t)) + c_2 \cdot r_2 \cdot (\vec{x}_{gbest_j}(t) - \vec{x}_{ij}(t)), \quad (8)$$

where r_1 and r_2 are random numbers between 0 and 1, and c_1 and c_2 are positive acceleration constants, which should satisfy $c_1 + c_2 \leqslant 4$ as reported in Kennedy (1998).

Move each particle to a new position:

(i) $\vec{x}_{ij}(t) = \vec{x}_{ij}(t-1) + \vec{v}_{ij}(t)$, (9)

(ii) $t = t + 1$. (10)

Repeat steps (2) through (6) until convergence.

4. Bandwidth reservation mechanism using PSO-tuned Fuzzy logic system

The representative bandwidth reservation schemes in the literature (Ei-Kadi et al., 2002; Oliveira et al., 1998; Wu et al., 2000) anticipate that a Class I connection request will make a handoff into one of its neighboring cells in the future and thus try to reserve some bandwidth in surrounding cells before the connection request is admitted. Although the above-mentioned bandwidth reservation schemes can effectively reduce the CDP in traditional macrocell wireless networks, however, it will introduce too many overheads among the BSs and waste much bandwidth in microcell cellular wireless systems due to excessively frequent reservation process. In this section, we adopt fuzzy logic controller concept to estimate the reserving bandwidth among the neighboring cells in an effective manner, effectively decreasing the CDP for the multimedia application handoffs, while keeping bandwidth utilization at a reasonable level.

The amount of the reserved bandwidth is determined by the following three factors:

- The speed and the direction that the MH will move to a neighboring cell. The probability of moving to a neighboring cell will be higher if the MH move toward it in a fast speed.
- The current reserved bandwidth for the neighboring cells. The probability of moving to a neighboring cell is proportional to the bandwidth that the neighboring cell reserves.
- The distance of the MH's position to the neighboring cells. There are more chances that the MH will move to the neighboring cell that the MH is closer to.

Based upon the above considerations, the bandwidth reserved in cell B for the MH located at cell A as illustrated in Fig. 2, can be derived as follows:

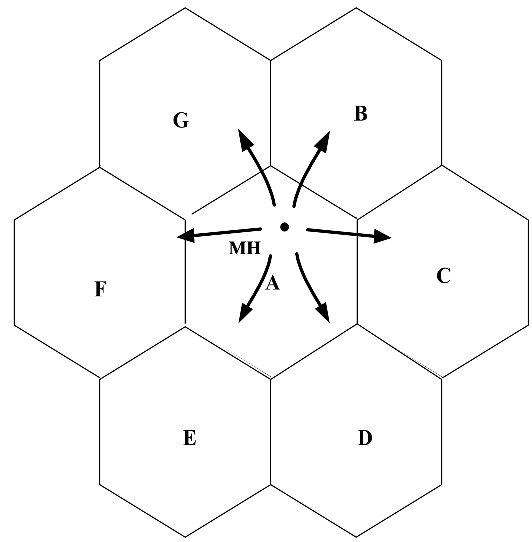

Fig. 2. Hexagonal cellular architecture with a cluster size equal to seven.

$$\mathrm{BR_B} = C \cdot S_\mathrm{B} \cdot \mathrm{BW_{MH}} \cdot \frac{1}{D_\mathrm{B}}, \quad (11)$$

where C is a constant, $\mathrm{BW_{MH}}$ denotes the minimum bandwidth requested by a MH at cell A, S_B represents the speed that the MH moves to cell B, and D_B stands for the distance of the MH's position to cell B. Notably, The parameters $\mathrm{BW_{MH}}$ and S_B can be obtained easily by a simple computation in the base station, and D_B can be acquired based on the location management implemented in the wireless system (Hoare, 1962, Saha, Mukherjee, Misra, Chakraborty, & Subhash, 2004).

The architecture of the proposed fuzzy bandwidth-reserving estimator is quite similar to the fuzzy network traffic load estimator presented in Section 3. Notably, the input to the fuzzifier d represents the normalization of the distance of the MH's position to the neighboring cells. The input P_m denotes the normalization of the current reserved bandwidth for the six neighboring cells, and S the normalization of speed that the MH moves toward the neighboring cell. The output of defuzzifier R_BW stands for reserved weighted factor:

$$R_\mathrm{BW} = \frac{\sum_{i=1}^{27} \mathrm{BW}_i \cdot w_i}{\sum_{i=1}^{27} w_i}, \quad (12)$$

The estimated bandwidth reserved in the target cell, such as cell B as shown in Fig. 2, can be derived as follows:

$$\mathrm{BR_B} = R_\mathrm{BW} \cdot \mathrm{BW_{MH}}, \quad (13)$$

where R_BW stands for the non-fuzzy output, and $\mathrm{BW_{MH}}$ is the minimum bandwidth requested by the MH.

5. Simulation results

To evaluate the proposed call admission control mechanism, a series of simulations are conducted to compare the proposed fuzzy call admission mechanism plus fuzzy bandwidth reservation mechanism scheme (ACAC-FLR), with the primitive call admission control scheme as given by Eq. (2), plus fixed reservation scheme (PCAC-FR), and the scheme without bandwidth reservation (PCAC-NR). Meanwhile, the rate-based borrowing scheme incorporated with the primitive call admission control scheme (PCAC-RBB) (Ei-Kadi et al., 2002) is also compared with the proposed work because it was reported in Ren and Ramamurthy (2000) that the RBB scheme achieves better performance than other representative bandwidth allocation and reservation schemes in the literature, such as the scheme presented in Oliveira et al. (1998).

There are 36 cells included in the simulation environment as shown in Fig. 3. A total of 30 Mbps bandwidth is allocated in each cell. Both classes of the connections are listed in Table 1. Each MH is given a speed characteristic, which decides the time spent in a cell, in order to simulate handoffs. The MH moves randomly to a target cell with a random speed then stays in that cell with a specific time according to its speed and chooses next target randomly with a random speed.

Fig. 4 shows the comparison of call dropping probability (CDP) for multimedia handoffs (Class I), and Fig. 5 illustrates the CDP for combined Classes I and II traffic. We can see from Fig. 4 that the CDP for multimedia handoffs is the lowest for the ACAC-FLR. Besides, the CDP for combined Classes I and II traffic in ACAC-FLR schemes is still lower than the other three schemes as shown in Fig. 5. The PCAC-NR has the worst performance as expected since it does not reserve bandwidth for the handoffs at all. As for the PCAC-RBB scheme, although it uses bandwidth borrowing technique to lower down the CDP for handoffs, its fixed bandwidth reservation mechanism is still inferior to the approach of adaptive bandwidth reservation based on the dynamic change of mobile node conditions as taken in this work.

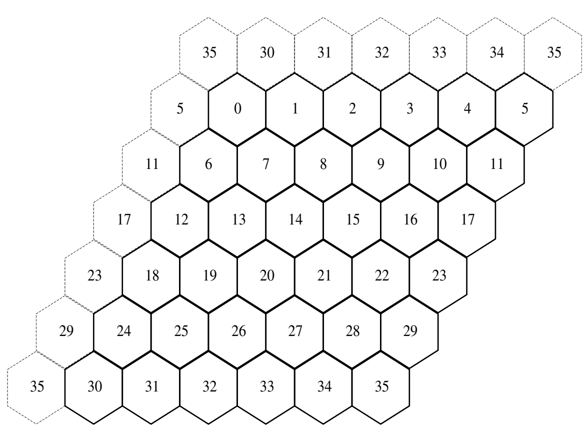

Fig. 3. Cellular topology with 36 cells in the simulations.

Table 1
Multimedia Traffic Used in the simulations

Traffic class	Bandwidth requirement	Average call duration	Example
Class I	30 Kbps	3 min	Voice service
Class I	256 Kbps	5 min	Video-phone
Class I	1–4 Mbps	10 min	Video service
Class II	5–20 Kbps	30 s	E-mail, paging
Class II	64–512 Kbps	3 min	Remote login and data on demand
Class II	1–5 Mbps	2 min	Ftp

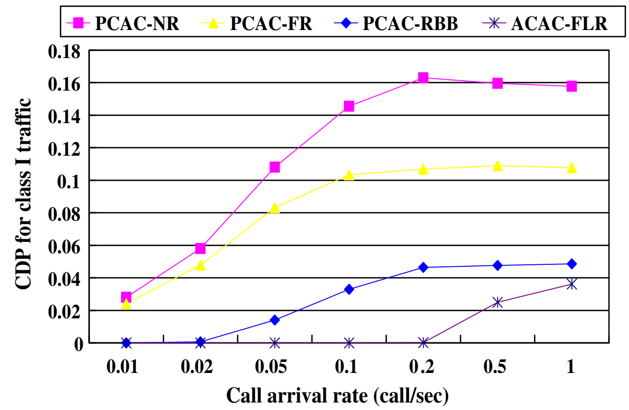

Fig. 4. Call dropping probability for Class I traffic in the four schemes.

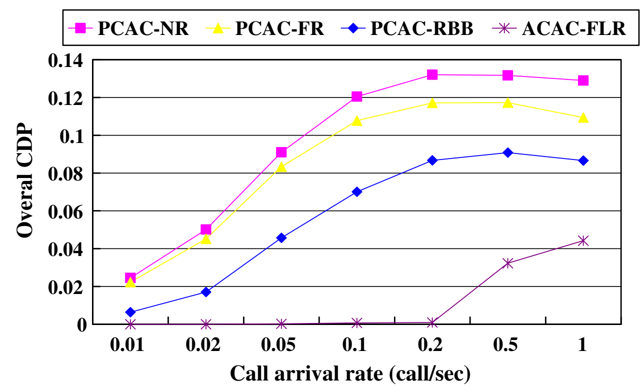

Fig. 5. Call dropping probability for combined Classes I and II handoffs in the four schemes.

Fig. 6 illustrates the CBP for combined Classes I and II traffic. The call blocking probability for the new connections in the ACACp-FLR and the PCAC-RBB schemes is apparently improved by means of the channel borrowing technique. Meanwhile, the effectiveness of fuzzy admission control and bandwidth reservation contributes to the better performance achieved in the proposed ACAC-FLR scheme as illustrated in Fig. 6. The PCAC-FLR scheme has the highest CBP for new connections because it reserves fixed bandwidth for multimedia handoff connections and results in lessened bandwidth available for new connections.

The bandwidth utilization of various mechanisms is given in Fig. 7. Note that the bandwidth utilization is defined as:

$$\frac{\sum_{\text{for each cell}} \text{Used bandwidth of each cell}}{\sum_{\text{for each cell}} \text{Maximum bandwidth of each cell}}. \tag{14}$$

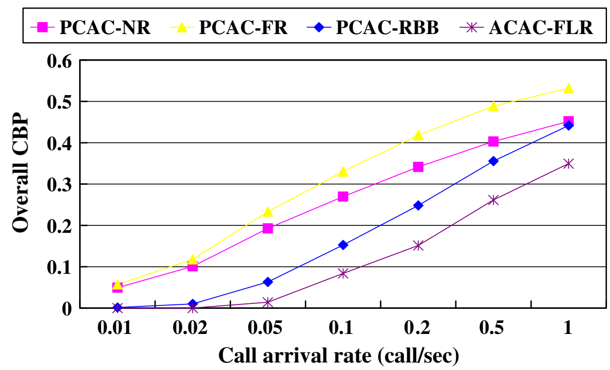

Fig. 6. Call blocking probability for combined Classes I and II traffics in the four schemes.

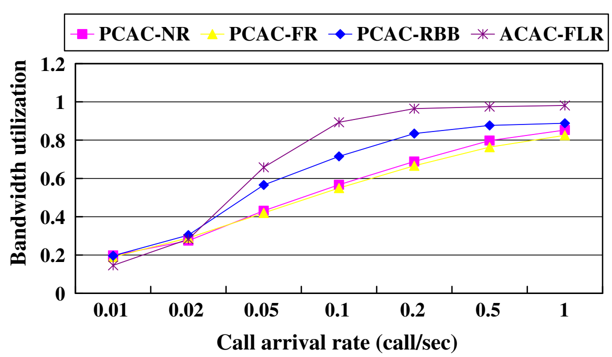

Fig. 7. Bandwidth utilization for the four schemes.

The ACAC-FLR scheme also achieves better performance than the other three schemes in bandwidth utilization due to the efficient usage of adaptive admission control and bandwidth reservation mechanisms. The PCAC-RBB scheme uss bandwidth borrowing technique to achieve higher bandwidth utilization than the PCAC-NR and PCAC-FR schemes. Bandwidth utilization is the poorest in the PCAC-FR scheme since it always reserves fixed bandwidth in each cell which is not necessarily used by the handoffs.

6. Conclusion and future work

In this paper, the adaptive call admission control bandwidth reservation schemes using fuzzy logic controller concept is proposed to reduce forced termination of multimedia handoffs in the mobile wireless communication systems. Fuzzy logic controller concept is employed to determine whether a new arriving call should be admitted and to compute the amount of reserved bandwidth for the handoffs in the expected target cells. Meanwhile, particle swarm optimization technique is adopted to dynamically tune the parameters in the membership function of the fuzzy systems due to the volatile characteristics of mobile wireless networks. The simulation results show that the proposed scheme, the ACAC-FLR, performs better then the fixed reservation (PCAC-FR) scheme, the scheme without reservation (PCAC-NR), and the rate-based borrowing scheme (PCAC-RBB) when call blocking probability for new connections, call dropping probability for the handoffs, and bandwidth utilization are compared. Subsequent research will investigate the feasibility of applying other intelligent tools such as neuro-fuzzy and genetic algorithms into the proposed scheme to improve the accuracy of the motion prediction for the MH.

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