A Timing-Based Bandwidth Allocation Protocol for QoS Provisioning in Multimedia Wireless Networks

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Abstract

In wireless networks carrying multimedia traffic, it becomes necessary to provide a quality of service (QoS) guarantee for multimedia traffic connections. A novel timing-based bandwidth allocation protocol is proposed in this paper as a solution to support QoS guarantees in the multimedia wireless networks. Based on the existing network conditions, the proposed scheme makes an adaptive decision for bandwidth reservation and call admission by employing fuzzy inference mechanism, timing based reservation strategy, and round-borrowing strategy in each base station. The amount of reserved bandwidth for each base station is dynamically adjusted, according to the online traffic information of each base station. Simulation results show that our timing-based bandwidth reservation scheme outperforms the previous schemes in terms of connection-blocking probability, connection-dropping probability, and bandwidth utilization.

1. Introduction

Bandwidth is the most critical resource in mobile multimedia wireless networks and thus, requires mechanisms to efficiently use the available bandwidth. In order to increase the spectrum utilization, microcellular and picocellular networks are deployed. These networks have the inherent problem of rapid handoffs due to smaller coverage areas of cells. This problem leads to higher connection-dropping probability and makes QoS guarantees difficult. Multimedia services impose stringent QoS demands on the wireless networks. One of the most important QoS issues is how to reduce handoff drops due to lack of available bandwidth, so that mobile hosts (MHs) can continue their ongoing sessions [1], [2]. Reserving enough bandwidth for handoff MHs can reduce connection-dropping probability in wireless networks. However, it may lead to high blocking probability of new connections and low bandwidth utilization. Reduction of connection-dropping probability and connection-blocking probability are contradictory. Therefore, new and efficient bandwidth reservation schemes must be developed in the multimedia wireless networks. We must make a tradeoff between the bandwidth utilization and bandwidth reservation such that the connection-dropping probability for handoff connections can be reduced, while the connection-blocking probability for new connections can be maintained at an acceptable level.

Several bandwidth reservation schemes have been proposed to support QoS provision in wireless environments. In [2], the shadow cluster concept is used to predict future resource allocation and to perform bandwidth reservation in wireless networks. In this scheme, the home base station (BS) of an MH informs the BSs of its shadow cluster area about the MH's requirement, position, and movement parameters at call setup time. It requires the exchange of a large amount of detailed knowledge of MHs between the BSs, especially in microcell and picocell wireless systems. This scheme increases too many overheads between the BSs. Moreover, it is difficult to accurately estimate future movement patterns in real wireless environments. A fair resource allocation protocol for multimedia wireless networks is proposed in [1] to provide network users with QoS in terms of guaranteed bandwidth, connection-blocking probability, and connection-dropping probability by using bandwidth reservation and bandwidth borrowing. However, this scheme does not appropriately adjust the reserved bandwidth for each BS in bursts of traffic conditions because the BS uses a fixed reservation mechanism. It reduces the bandwidth utilization and increases the connection-blocking probability. Moreover, when a BS accepts a connection, this scheme may re-distribute the bandwidth allocation for all ongoing connections by using the max-min fairness allocation protocol. However, as MHs increase in the BSs, the QoS guarantees may be reduced for ongoing connections and too many overheads are increased in the BSs of the cellular system because this scheme subjects connections to frequent fluctuations in the allocated bandwidths of MHs.

This paper introduces a novel timing-based bandwidth allocation protocol that supports QoS guarantees in the next generation mobile multimedia wireless networks. In the proposed scheme, each BS makes an adaptive decision for bandwidth reservation by employing fuzzy inference mechanism and timing based reservation strategy. The amount of reserved bandwidth for each BS is dynamically adjusted, according to the on-line traffic information of each BS. The timing based reservation strategy makes the system more responsive to the current traffic conditions, providing efficient bandwidth reservation for the handoff connections. The control of bandwidth reservation is adaptive under overloading traffic conditions, thus can effectively deal with sudden traffic surges.

Multimedia traffic is a combination of both real-time (Class I) and nonreal-time (Class II) traffic. Real-time traffic includes voice and video while data and graphics make up nonereal-time traffic. We design efficient call admission control algorithms for real-time and nonreal-time traffic, according to the different multimedia services. In order to provide the efficient bandwidth re-distribution in a BS, we employ a round-borrowing strategy to reduce the overhead of bandwidth reconfiguration and to satisfy QoS requirements of ongoing MHs in cellular systems. On-line bandwidth reservation scheme does not require prediction of future traffic intensity and user mobility. This approach has significantly lower complexity and system overhead than mobility oriented methods. Our proposed scheme is an adaptive and on-line mechanism. It only requires minimal computational overhead in each BS, and no communication overhead between neighboring BSs to request and release reservations.

The rest of this paper is organized as follows. In Section 2, we present our assumed model of wireless networks. In Section 3, the proposed scheme is illustrated in detail. In Section 4, we present a description of our simulation model and analyze the comparative evaluation results of the proposed scheme through simulations. Finally, some conclusions are given in Section 5.

2. System Model

We consider a mobile multimedia wireless network with a cellular network infrastructure. Each cell contains a BS that needs to allocate and reserve bandwidth for MHs, and communicates with other BSs. In this paper, it is assumed that when an MH requests a new connection or moves into a new cell, the following parameters are provided: 1) The traffic class (I or II). 2) The required bandwidth for the connection. 3) The minimum required bandwidth for the connection. This parameter represents the smallest amount of bandwidth that the connection can be assured of a certain acceptable QoS, e.g., the smallest encoding rate of its codec [1].

In the proposed scheme, we use the fuzzy techniques to reduce the connection-blocking probability and connection-dropping probability, while increasing the bandwidth utilization for QoS sensitive mobile multimedia wireless networks. Fuzzy logic systems have been widely applied

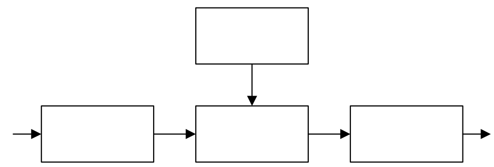

Figure 1. Block diagram of fuzzy system

to deal with call admission control problems in ATM networks [3]. Fuzzy logic controller can incorporate domain knowledge from existing techniques and can be used to control a complex system. The main advantage of fuzzy set theory is that it excels in dealing with real-world imprecision, and the fuzzy approach presents a great ability to adapt itself to dynamic, imprecise, and bursts environments. Figure 1 shows the block diagram of fuzzy system. Information to the fuzzy system first enters the *Fuzzifier*, where it is fuzzified. The fuzzifier is a mapping from an observed input to a fuzzy set with membership function. The fuzzified data is passed to the *Inference Engine*. The Inference Engine matches the fuzzified data against a set of *Fuzzy Rule Base* using inference methods to produce output fuzzy sets. The fuzzy rule base is a control knowledge-base characterized by a set of linguistic statements in the form of "IF-THEN" rules that describe a fuzzy logic relationship between inputs and outputs. The output fuzzy sets are then passed to the *Defuzzifier* which computes a crisp output value by the center of gravity method [4].

3. Proposed Bandwidth Reservation Scheme

3.1 Fuzzy Inference Mechanism

In the proposed scheme, we define two parameters as input fuzzy sets. The fuzzy inference engine utilizes the *CDP* and *BOBI* as input fuzzy parameters, where *CDP* is connection-dropping probability and *BOBI* is the bandwidth rate of *hand-in* and *hand-out* connections within each time interval in the cell. The request for an incoming handoff MH in the cell is called *hand-in* connection and the request for an outgoing handoff MH in the cell is called *hand-out* connection. Let $H_{u,c}$ and $D_{u,c}$, respectively, be the number of hand-in connections and the number of dropping connections within the time interval u in the cell c. The time interval u is $[t_0 - t_l, t_0]$, where t_0 is the current time and t_l is the length of time interval. The *CDP* can be expressed by

$$CDP = \frac{D_{u,c}}{H_{u,c}} . \quad (1)$$

Let $B_{i_m,u,c}$ and $B_{o_n,u,c}$, respectively, be the required bandwidth of the *mth* hand-in connection and released bandwidth of the *nth* hand-out connection within the time interval u in the cell c. If there are M hand-in connections and N hand-out connections within the time interval u in the cell c. The $BOBI$ can be expressed by

$$BOBI = \frac{\sum_{n=1}^{N} B_{o_n,u,c} - \sum_{m=1}^{M} B_{i_m,u,c}}{\max.\left\{\sum_{n=1}^{N} B_{o_n,u,c}, \sum_{m=1}^{M} B_{i_m,u,c}\right\}}. \quad (2)$$

The input fuzzy parameter $BOBI$ represents bandwidth variation of MHs moving into and departing from the cell c within the time interval u. If $BOBI$ is a negative value, it means that the sum of required bandwidths of hand-in MHs is larger than the sum of released bandwidths of hand-out MHs within the time interval u in the cell c. The value of time interval u may be chosen based on the real operation of system (e.g., u = 60 sec).

The fuzzy sets for CDP take the linguistic variables *Low*, *Medium*, and *High* which are represented below by the membership functions μ_{A_1}, μ_{A_2}, and μ_{A_3}, respectively, over the interval [0, 1]:

$$\mu_{A_1}(x) = \begin{cases} 1, & \text{if } x \le 0, \\ (0.25 - x)/0.25, & \text{if } 0 < x < 0.25, \\ 0, & \text{if } x \ge 0.25, \end{cases}$$

$$\mu_{A_2}(x) = \begin{cases} 0, & \text{if } x \le 0, \\ x/0.25, & \text{if } 0 < x < 0.25, \\ (0.5 - x)/0.25, & \text{if } 0.25 \le x < 0.5, \\ 0, & \text{if } x \ge 0.5, \end{cases}$$

$$\mu_{A_3}(x) = \begin{cases} 0, & \text{if } x \le 0.25, \\ (x - 0.25)/0.25, & \text{if } 0.25 < x < 0.5, \\ 1, & \text{if } x \ge 0.5, \end{cases}$$

where $x \in [0, 1]$.

In a similar way, the linguistic variables for $BOBI$ are *Negative*, *Center*, and *Positive* with membership functions μ_{B_1}, μ_{B_2}, and μ_{B_3}, respectively, over the interval [-1, 1]:

$$\mu_{B_1}(x) = \begin{cases} 1, & \text{if } x \le -1, \\ -x, & \text{if } -1 < x < 0, \\ 0, & \text{if } x \ge 0, \end{cases}$$

$$\mu_{B_2}(x) = \begin{cases} 0, & \text{if } x \le -1, \\ (x+1), & \text{if } -1 < x < 0, \\ (1-x), & \text{if } 0 \le x < 1, \\ 0, & \text{if } x \ge 1, \end{cases}$$

$$\mu_{B_3}(x) = \begin{cases} 0, & \text{if } x \le 0, \\ x, & \text{if } 0 < x < 1, \\ 1, & \text{if } x \ge 1, \end{cases}$$

where $x \in [-1, 1]$.

In order to get a crisp output value that gives a calculation of bandwidth reservation for a BS, an output parameter called the reservation-factor is defined. The fuzzy linguistic variables for the output parameter *Reservation-Factor* are *Small*, *Middle*, and *Large* which are represented by the membership functions μ_{C_1}, μ_{C_2}, and μ_{C_3}, respectively, over the interval [-1, 1]:

$$\mu_{C_1}(x) = \begin{cases} 1, & \text{if } x \le -1, \\ -x, & \text{if } -1 < x < 0, \\ 0, & \text{if } x \ge 0, \end{cases}$$

$$\mu_{C_2}(x) = \begin{cases} 0, & \text{if } x \le -1, \\ (x+1), & \text{if } -1 < x < 0, \\ (1-x), & \text{if } 0 \le x < 1, \\ 0, & \text{if } x \ge 1, \end{cases}$$

$$\mu_{C_3}(x) = \begin{cases} 0, & \text{if } x \le 0, \\ x, & \text{if } 0 < x < 1, \\ 1, & \text{if } x \ge 1, \end{cases}$$

where $x \in [-1, 1]$.

Fuzzy logic uses linguistic variables to map the input fuzzy variables to the output fuzzy variable. This is carried out by using fuzzy IF-THEN rules. The input and output fuzzy sets are correlated to produce the fuzzy rules for the inference engine described as follows:

Rule 1: IF *CDP* is *Low* and *BOBI* is *Negative,* **THEN** *Reservation-Factor* is *Middle,*

Rule 2: IF *CDP* is *Medium* and *BOBI* is *Negative,* **THEN** *Reservation-Factor* is *Large,*

Rule 3: IF *CDP* is *High* and *BOBI* is *Negative,* **THEN** *Reservation-Factor* is *Large,*

Rule 4: IF *CDP* is *Low* and *BOBI* is *Center,* **THEN** *Reservation-Factor* is *Small,*

Rule 5: IF *CDP* is *Medium* and *BOBI* is *Center,* **THEN** *Reservation-Factor* is *Middle,*

Rule 6: IF *CDP* is *High* and *BOBI* is *Center,* **THEN** *Reservation-Factor* is *Large,*

Rule 7: IF *CDP* is *Low* and *BOBI* is *Positive,* **THEN** *Reservation-Factor* is *Small,*

Rule 8: IF *CDP* is *Medium* and *BOBI* is *Positive,* **THEN** *Reservation-Factor* is *Small,*

Rule 9: IF *CDP* is *High* and *BOBI* is *Positive,* **THEN** *Reservation-Factor* is *Middle.*

By using the center of gravity method, the crisp reservation-factor can be made. The variation of reservation-factor represents the change in traffic conditions. It not only makes the system responsive to the bursts of traffic conditions, but also gets the bandwidth reservation more efficiently. For example, suppose that we measure two input parameters CDP and $BOBI$ from t_1 to t_5 shown in Table 1. The crisp reservation-factor is dynamically adjusted by employing the fuzzy inference. Figure 2 shows the reservation-factor versus CDP and $BOBI$ in this case. The variation of reservation-factor is from -0.65 to 0.26. It means that the change in traffic conditions is from light traffic load to heavy traffic load. Similarly, Table 2 and Figure 3 show that the traffic load is uniformly distributed. The variation of reservation-factor is only from -0.18 to -0.1. It represents less traffic fluctuations in the BS. The reservation-factor brings an immediate response on the traffic conditions. Hence the proposed scheme makes the

Table 1. Example of bursts traffic

	t_1	t_2	t_3	t_4	t_5
CDP	0	0.03	0.1	0.2	0.25
BOBI	0.7	0.2	-0.1	-0.3	-0.7
Reservation-factor	-0.65	-0.47	-0.18	0.02	0.26

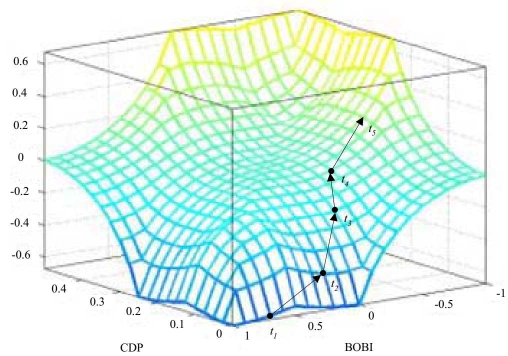

Figure 2. Reservation-factor versus CDP and BOBI (bursts traffic)

efficient bandwidth reservation according to the reservation-factor.

3.2 Timing based reservation strategy

The timing based reservation strategy is employed to calculate the amount of reserved bandwidth based on the crisp reservation-factor and network conditions. The basic idea of this strategy is that a reservation system with lower complexity does not require advance knowledge or prediction of future traffic intensity and user mobility. This strategy makes lower system overhead and causes control decisions of bandwidth reservation in real time. In this framework, the BSs record the requested bandwidths of MHs within each time interval. Let $R_{c_{n+1}}$ denote the amount of new reserved bandwidth for the next time and R_{c_n} the amount of reserved bandwidth at the current time in the BS of cell *c*. Then, the $R_{c_{n+1}}$ can be calculated by

$$R_{c_{n+1}} = \left(\frac{1-\beta_c}{2}\right) R_{c_n} + \left(\frac{1+\beta_c}{2}\right) B_{u,c} , \tag{3}$$

where β_c is the crisp reservation-factor and $B_{u,c}$ is the amount of hand-in requested bandwidth within the time interval *u* in the BS of cell *c*. The reservation-factor controls the relative weights for the recent and past traffic histories. If the mobility of MHs is uniformly distributed, the new reserved bandwidth for the next time in the BS of cell *c* can rely on the current reserved bandwidth (R_{c_n}). However, when the traffic distribution is non-uniform, due to the temporal traffic fluctuations, the new reserved bandwidth for the next time in the BS of cell *c* should depend on recent requested bandwidths of hand-in connections ($B_{u,c}$). We decide the value of β_c by considering the current network traffic conditions. Hence the value of

Table 2. Example of uniform traffic

	t_1	t_2	t_3	t_4	t_5
CDP	0.1	0.1	0.12	0.1	0.12
BOBI	0.2	0.1	-0.1	-0.2	-0.2
Reservation-factor	-0.18	-0.18	-0.12	-0.15	-0.1

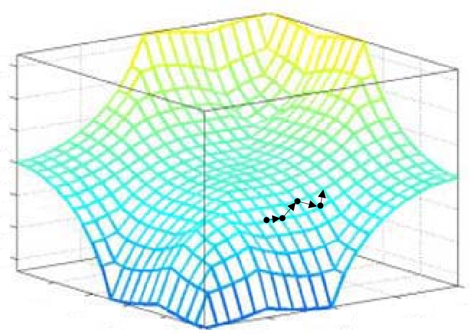

Figure 3. Reservation-factor versus CDP and BOBI (uniform traffic)

reservation-factor β_c can affect the network performance significantly.

For efficient bandwidth utilization, the control decisions of bandwidth reservation must be dynamically adjustable. In our proposed scheme, we take into account the existing network conditions. The amount of reserved bandwidth for each BS is dynamically adjusted, according to the on-line traffic information of each BS. It reserves bandwidth only when necessary. So the BSs make bandwidth reservation efficiently. The timing based reservation strategy makes the system more responsive to the current traffic conditions, providing efficient bandwidth reservation for the handoff connections. Therefore, the connection-dropping probability can be reduced.

3.3 Round-borrowing strategy

A fair resource allocation protocol subjects connections to frequent fluctuations in the allocated bandwidths of MHs [1]. When a BS accepts or releases a connection, this scheme may re-distribute the bandwidth allocation for all ongoing connections. However, as MHs increase in the BSs, it increases too many overheads in the BSs of the cellular system. In order to provide the efficient bandwidth re-distribution in a BS, the round-borrowing strategy is employed to re-adjust the allocated bandwidth of MHs when bandwidth is borrowed or returned.

In this strategy, each BS uses the hand-in times and borrowable bandwidths of MHs to establish a round-queue. When the BS does not have enough residual bandwidth to provide a handoff connection, the borrowable bandwidths of MHs will be borrowed. Thus, the borrowed MHs will temporarily have to give up a certain amount of allocated bandwidth. The borrowable bandwidths of MHs are selected from the round-queue in order, according to the hand-in times of MHs. We employ two pointers to indicate

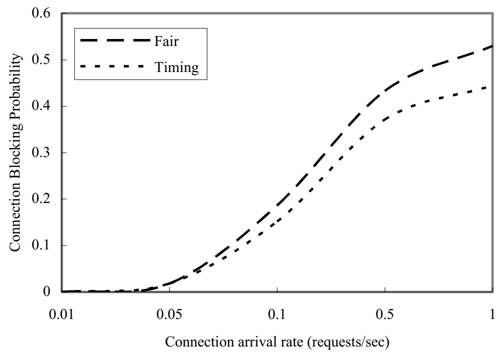

Figure 4. Connection-blocking probability

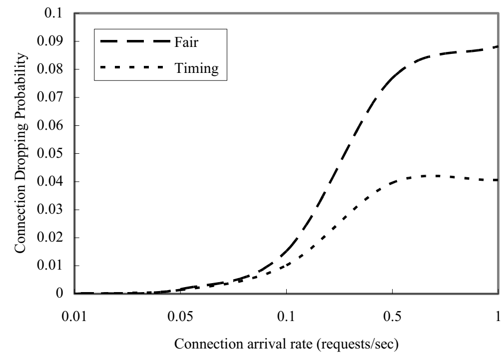

Figure 5. Connection-dropping probability

location of borrowed and returned. On the one hand the borrowed pointer indicates a starting location where the borrowable bandwidth of MH can be borrowed, and on the other the returned pointer indicates a starting location where the borrowed bandwidth can be returned to the MH. We assume that MHs $x_1,\ldots, x_m$ come to the cell in order. Let b_m denotes the borrowable bandwidth of MH x_m, which can be expressed by

$$b_m = B_{x_m} - B_{x_m,min}\ , \tag{4}$$

where B_{x_m} is the required bandwidth of MH x_m and $B_{x_m,min}$ is the minimum required bandwidth of MH x_m. Let W_c denotes the total amount of borrowable bandwidth in cell c. If there are M MHs in the cell c, the W_c can be expressed by

$$W_c = \sum_{m=1}^{M} b_m\ . \tag{5}$$

When an MH terminates, the borrowed bandwidth will be returned. It must be returned to the MHs $x_1,\ldots, x_m$ in order. Hence only a few connections must be re-distributed. This strategy provides the efficient bandwidth re-distribution and reduces the overhead of bandwidth reconfiguration in cellular systems.

3.4 Call Admission Control Algorithms

The main goal of call admission control algorithms are employed to control whether the connections can be served or not. When MH x requests a new connection in the cell bj, the BS of cell bj tries to admit this request by using the available bandwidth. If the available bandwidth is not sufficient for the new connection, the new connection is blocked. Otherwise, the BS of cell bj examines whether the reservation factor is large or not, according to the fuzzy inference. If there is a high reservation-factor (β_{bj}) in the BS of cell bj (e.g., β_{bj} > 0.6), then the new connection will be blocked. Otherwise, the BS accepts the new connection and allocates bandwidth for the new connection of MH x.

When MH x moves from cell bj to the cell bk, the BS of cell bj releases allocated bandwidth of the MH x, and executes the round-borrowing strategy to return the borrowed bandwidth and to re-distribute the allocated bandwidths of MHs. There are two classes of the call admission control algorithms for handoff connection in the cell bk, according to the traffic class of MH x. If the handoff connection of MH x is real-time data traffic, the BS of cell bk checks whether the available bandwidth plus reserved bandwidth (R_{bk_n}) and total amount of borrowable bandwidth (W_{bk}) is sufficient or not. If the minimum required bandwidth for handoff connection of MH x is not sufficient, the BS of cell bk drops the handoff connection of MH x. Otherwise, the BS of cell bk accepts the connection and allocates the corresponding bandwidth for the handoff connection of MH x. If the borrowable bandwidth will be used for MH x, the BS of cell bk executes the round-borrowing strategy to borrow the borrowable bandwidth and to re-distribute the allocated bandwidths of MHs. If the handoff connection of MH x is nonreal-time data traffic, it is dropped only when there is no residual bandwidth for the MH x in the BS of cell bk. If there is not any available bandwidth and borrowable bandwidth (W_{bk}) in the BS of cell bk, the BS of cell bk drops the handoff connection of MH x. Otherwise, the BS of cell bk accepts the connection and allocates the corresponding bandwidth for the handoff connection of MH x. If the borrowable bandwidth will be used for MH x, the BS of cell bk executes the round-borrowing strategy to borrow the borrowable bandwidth and to re-distribute the allocated bandwidths of MHs.

4. Performance Analysis

In this section, we present performance analysis for the proposed scheme. We describe our simulation model and illustrate the simulation results, comparing our scheme with the existing fair resource allocation protocol [1]. In our simulation model we have the following assumptions.

1) The simulation environment is composed of 100 cells and available bandwidth of each cell is 30 Mb/s, each cell keeping contact with its six neighboring cells. The distance between two BSs is 1 km.

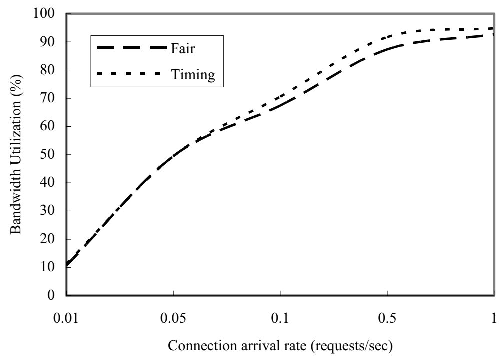

Figure 6. Bandwidth utilization

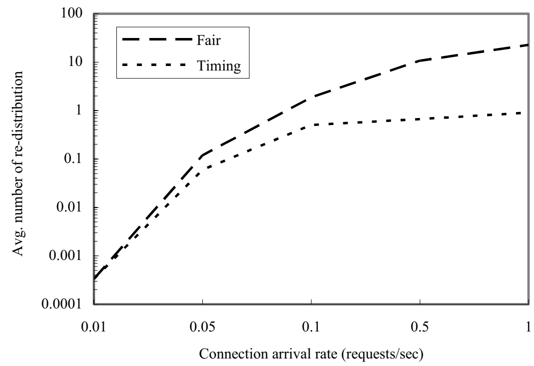

Figure 7. Average number of re-distribution

2) The arrival process for new connection requests is Poisson distribution with rate λ, which is uniform in all cells.
3) In order to represent various multimedia data, six different traffic types are assumed based on bandwidth requirement and traffic class [1].
4) The durations of connections are assumed to follow a geometric distribution with different means for different multimedia traffic types.

Figure 4 shows the connection-blocking probability. When the connection arrival rate is larger than 0.1 requests/sec, it is evident that the connection-blocking probabilities of our proposed scheme are better than that of the fair resource allocation protocol. Figure 5 shows that the connection-dropping probability of our proposed scheme is better than that of the fair resource allocation protocol. Furthermore, as the connection arrival rate increases, it is obvious that the proposed scheme results in lower connection-dropping probability. For example, when the connection arrival rate is 1 requests/sec, the proposed scheme achieves the connection-dropping probability that is approximately 5% lower than the fair resource allocation protocol. The reason for this behavior is that the proposed scheme dynamically adjusts the bandwidth reservation for each BS by using the fuzzy logic systems, providing more efficient call admission control and adaptive bandwidth reservation for handoff connections. Therefore, the connection-dropping probability can be reduced. Figure 6 shows the bandwidth utilization. The fair resource allocation protocol is suitable for the uniformly traffic conditions. However, when the traffic conditions are bursts, this scheme does not appropriately adjust the reserved bandwidth for each BS. Hence the bandwidth is wasted. In contrast, our proposed scheme adjusts bandwidth reservation by using the fuzzy inference mechanism, timing based reservation strategy and round-borrowing strategy, handling bursts of traffic conditions and resulting in high bandwidth utilization. According to the Figure 6, when the connection arrival rate is lower than 0.1 requests/sec, the bandwidth utilizations of two mechanisms are similar. However, when the connection arrival rate increases, the bandwidth utilization of our proposed scheme is superior to that of the fair resource allocation protocol. We also compare the average number of re-distribution per second for each BS with that of the fair resource allocation protocol. Figure 7 shows that our proposed scheme results in lower number of re-distribution by using the round-borrowing strategy. It means that our proposed scheme provides a more efficient bandwidth re-distribution approach and lower system overhead than fair resource allocation protocol in cellular systems.

5. Conclusions

Bandwidth allocation is one of the important components for QoS sensitive mobile multimedia wireless networks. The major advantage of this paper is that our proposed scheme is successfully applied to deal with bandwidth reservation problems and provides better QoS guarantees in mobile multimedia wireless networks. The proposed scheme has significantly lower complexity and system overhead than mobility oriented methods. It not only outperforms the pervious schemes, but is also suitable for the next generation mobile communication systems.

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