Service-Oriented Bandwidth Borrowing Scheme for Mobile Multimedia Wireless Networks

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Abstract

Multimedia applications (audio phone, video on demand, video conference, file transfer, etc.) will be integrated into future mobile communication systems. Bandwidth is the most critical resource in mobile multimedia wireless networks. Due to mobile user mobility and limited bandwidth in the mobile wireless communications networks, the quality-of-service (QoS) guarantee becomes very complicated for multimedia applications. Therefore, the available bandwidth of wireless networks should be managed in the most efficient manner. In order to provide mobile hosts (MHs) with highly satisfying degree of QoS in mobile communication systems, new and efficient bandwidth allocation schemes must be developed. In this paper, we propose and evaluate a novel scheme for bandwidth borrowing in mobile multimedia wireless networks. We employ a service-oriented bandwidth borrowing strategy to reduce the overhead of bandwidth reconfiguration and to satisfy QoS requirements of ongoing MHs in cellular systems. Furthermore, we design efficient call admission control algorithms for different multimedia services. The QoS guarantees can be maintained at a comfortable level in cellular systems. Simulation results show that our proposed scheme outperform the previously proposed scheme.

1. Introduction

The rapid growth in interactive multimedia applications, such as audio phone, video on demand, video conference, and video games has resulted in spectacular strides in the progress of wireless communication systems. Multimedia applications make a great demand for bandwidth and should be transmitted continuously. Since bandwidth is the most critical resource in mobile multimedia wireless networks, it is important to employ mechanisms for efficiently using the available bandwidth. In mobile cellular communication networks carrying multimedia traffic, it becomes necessary to provide quality-of-service (QoS) guarantees for multimedia traffic connections. In order to utilize the radio spectrum efficiently, microcellular and picocellular networks are deployed. These networks have the inherent problem of rapid handoffs due to smaller coverage areas of base stations. This problem leads to higher connection-dropping probability and results in bandwidth resource availability varying repeatedly. Frequent changes in the network traffic make the provision of guaranteed QoS more difficult. Hence, research in the area of QoS provisioning in the next-generation high-speed wireless networks focuses on the integration of resource allocation and admission control policies [1]-[6].

Recently, several bandwidth allocation schemes have been proposed to support QoS provisioning in wireless environments. A rate-based borrowing scheme for QoS provisioning in multimedia wireless networks is proposed in [2] to provide network users with QoS in terms of guaranteed bandwidth, connection-blocking probability (CBP), and connection-dropping probability (CDP) by using bandwidth borrowing. In [1], based on the max-min fairness allocation protocol, a fair resource allocation protocol for multimedia wireless networks is proposed to improve connection-blocking probability, connection-dropping probability, and bandwidth utilization. The fair resource allocation protocol is suitable for MHs with low bandwidth requirements because it relies on the equal share concept and the stringent call admission procedure may not admit many high bandwidth requests in a highly overloaded system. It is unfair for multimedia applications such as video streams and file transfer services. There are some overheads of bandwidth redistribution in [1] and [2]. When a base station accepts a connection, these schemes may re-distribute the bandwidth allocation for all ongoing connections. However, as MHs increase in the base stations, the QoS guarantees may be reduced for ongoing connections and too many overheads are increased in the base stations of the cellular system because these schemes subject connections to frequent fluctuations in the allocated bandwidths of MHs.

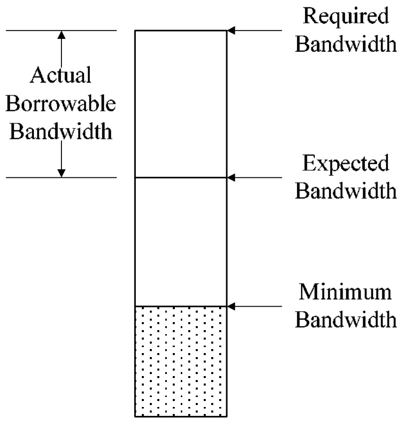

Figure. 1. Bandwidth requirements of a connection.

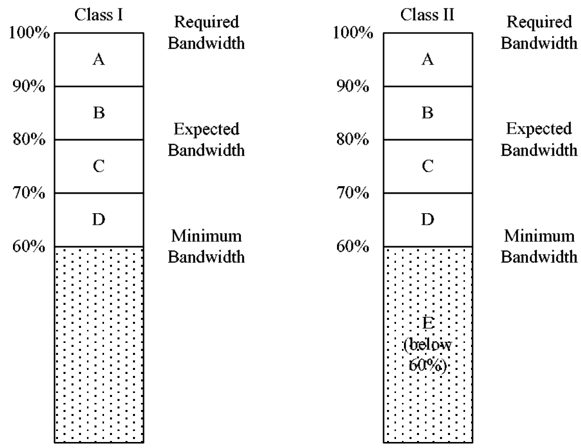

Figure. 2. Satisfying degree of QoS for Class I and II connections.

This paper introduces a novel service-oriented bandwidth borrowing scheme that supports QoS guarantees in the next generation mobile multimedia wireless networks. In the proposed scheme, we classify all multimedia traffic into 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. Also, we provide the efficient bandwidth re-distribution approach in a base station by using the attribute of multimedia traffic. In order to evaluate the overhead of bandwidth reconfiguration and satisfying degree of QoS of ongoing MHs in cellular systems, new measurement method is proposed in this paper.

The remainder of this paper is organized as follows. In Section II, we present our assumed model of wireless networks and describe satisfying degree of QoS. In Section III, we illustrate the proposed scheme in detail. In Section IV, we present our simulation model and analyze the comparative evaluation results of the proposed scheme through simulations. Finally, Section V offers some concluding remarks.

2. System Model

We consider a mobile multimedia wireless network with a cellular network infrastructure. Each cell contains a base station that needs to allocate and reserve bandwidth for MHs, and communicates with other base stations. Base stations are connected to a switching network through wired lines. The establishment and maintenance of connections for MHs in a mobile cellular network is the responsibility of the base station. Two types of connections share the bandwidth of the base station for each cell: new connections and handoff connections. A base station in a cellular network may receive new connections of MHs within its cell and handoff connections of MHs from the neighboring cells. When a connection arrives at a cell where the bandwidth is not available, this situation is called connection blocking for new connections or connection dropping for handoff connections.

In the proposed scheme, it is assumed that when an MH requests a new connection in the current cell or moves into the neighboring 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. The minimum required bandwidth connection is 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 [3].

In the borrowing-based bandwidth allocation scheme [1], [2], it assumes that multimedia applications can tolerate transient fluctuations in the QoS and allows for the temporary borrowing of bandwidth from existing connections in order to accommodate new and handoff connections. The parameters that must be specified in a connection request are the connection class and the required, minimum, and expected levels of bandwidth. The expected amount falls between the required and the minimum, and represents a comfortable working level for the application. The difference between the required and expected amounts of a connection is the actual borrowable bandwidth and the cell may borrow some of this bandwidth from an existing connection in order to accommodate other incoming connections. Fig. 1 illustrates the connection parameters. However, there are some potential problems in the borrowing-based bandwidth reservation scheme. When a base station accepts a connection, these schemes may re-distribute the bandwidth allocation for all ongoing connections by using the borrowing protocol. However, as MHs increase in the base stations, the QoS guarantees may be reduced for ongoing connections and too many overheads are increased in the base stations of the cellular system because this scheme subjects connections to frequent fluctuations in the allocated bandwidths of MHs. In the borrowing-based bandwidth reservation scheme, reducing the overhead of bandwidth reconfiguration and satisfying QoS requirements of ongoing MHs are important issues. The main challenge in the design of an efficient borrowing strategy is to accomplish these two significant requirements. Hence the performance parameters of interest in this paper are satisfying degree of QoS and average number of re-distribution in the base stations.

We classify satisfying degree of QoS for Class I connection into four degrees (A, B, C, and D), and satisfying degree of QoS for Class II connection into five degrees (A, B, C, D, and E). Fig. 2 shows the satisfying degree of QoS for Class I and II connections, where the required bandwidth is defined as 100% satisfying degree of QoS and the minimum bandwidth is defined as 60% satisfying degree of QoS. The expected bandwidth is set at half way between the required bandwidth and minimum bandwidth. In the performance measurement of satisfying degree QoS, we define *average QoS of degree A* (*AQDA*) which is measured for percentage of degree A in all degrees for each traffic class with different connection arrival rate. Let $DA_{t,j}$ and $NA_{t,j}$, respectively, be the number of *degree A* connections and the number of active connections at time t in cell j, where t is measured time from t_a to t_b. If there are J cells in the system, the *AQDA* can be expressed by

$$AQDA = \frac{\sum_{j=1}^{J}\sum_{t=t_a}^{t_b} DA_{t,j}}{\sum_{j=1}^{J}\sum_{t=t_a}^{t_b} NA_{t,j}} \quad (1)$$

3. Proposed Bandwidth Reservation Scheme

The proposed scheme combines service-oriented bandwidth borrowing strategy and call admission control algorithms to guarantee QoS requirements in mobile wireless environments. The service-oriented bandwidth borrowing strategy is employed to re-adjust the allocated bandwidths of MHs. The call admission control algorithms are employed to control whether the connections can be served or not.

3.1 Service-oriented bandwidth borrowing strategy

The borrowing-based bandwidth allocation scheme subjects connections to frequent fluctuations in the allocated bandwidths of MHs [1], [2]. When a base station accepts or releases a connection, this scheme may re-distribute the bandwidth allocation for all ongoing connections. In an extreme case, if only few bandwidths need to be borrowed or returned, all active connections also must be re-distributed the allocated bandwidths in the cell. Therefore, as MHs increase in the base stations, it increases too many overheads in the base stations of the cellular system. In order to provide the efficient bandwidth re-distribution in a base station, the service-oriented bandwidth borrowing strategy is employed to

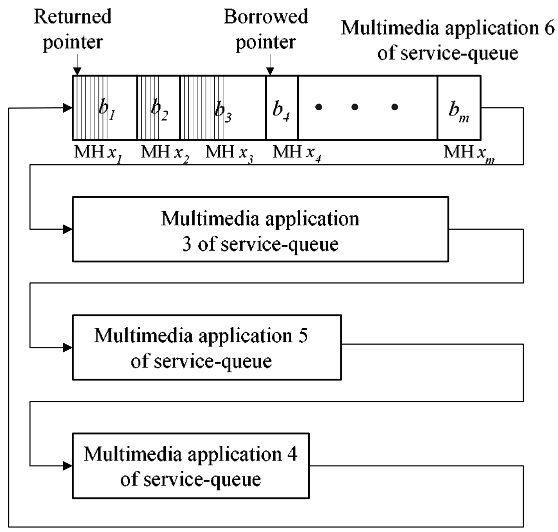

Figure 3. Framework of service-based borrowing.

re-adjust the allocated bandwidth of MHs when bandwidth is borrowed or returned.

The basic idea of this strategy is that a borrowing approach with high satisfying degree of QoS for MHs does not increase the re-distribution overheads in mobile communication systems. In this strategy, each base station establishes several service-queues according to the connection arrival times, borrowable bandwidths of MHs, and multimedia applications. In this paper, we assume six multimedia applications in the simulation model shown in Table I [1], [2], [3]. When the cell does not have enough residual bandwidth to provide a 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. In order to provide high satisfying degree of QoS for ongoing MHs and to decrease the re-distribution overheads in mobile communication systems, the borrowable bandwidths of MHs are selected from the service-queues in order, according to the hand-in times of MHs and multimedia applications. Because the high bandwidth requests also have high borrowable bandwidths, the influence of satisfying degree of QoS for MHs is slight and the number of re-distribution is also small when the borrowable bandwidths are borrowed from the high bandwidth requests. We employ two pointers to indicate 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 $x_1,\ldots, x_m$ are application p traffic and come to the cell in order. Let b_m^p denotes the borrowable bandwidth of MH x_m for application p traffic, which can be expressed by

$$b_m^p = B_{x_m}^p - B_{x_m,exp}^p, \quad (2)$$

where $B^p_{x_m}$ is the required bandwidth of MH x_m and $B^p_{x_m,exp}$ is the expected bandwidth of MH x_m for application p traffic. Let W^p_j denotes the total amount of borrowable bandwidth for application p traffic in cell j. If there are M MHs for application p traffic in the cell j, the W^p_j can be expressed by

$$W^p_j = \sum_{m=1}^{M} b^p_m . \quad (3)$$

In order to maintain a comfortable QoS for each MH, when the borrowable bandwidth must be borrowed, this strategy examines the half total amount of borrowable bandwidths. If the half total amount of borrowable bandwidths is enough for borrowed, the half borrowable bandwidth for each MH is borrowed from the service-queues in order. Otherwise, the total borrowable bandwidth for each MH is borrowed from the service-queues in order. Figure 3 shows the framework of service-based borrowing. This figure illustrates that the borrowable bandwidths of MHs x_1, x_2, and x_3 have been borrowed half borrowable bandwidths from the multimedia application 6 of service-queue. The borrowed pointer points to the borrowable bandwidth of MH x_4. And, the returned pointer points to the borrowed bandwidth of MH x_1. When an MH terminates, the borrowed bandwidth will be returned. It must be returned to the MHs x_1, x_2, and x_3 in order. Hence only three connections must be re-distributed. This strategy provides the efficient bandwidth re-distribution and reduces the overhead of bandwidth reconfiguration in cellular systems.

In order to provide high satisfying degree of QoS for ongoing MHs in the cell, we define *QoS-degree factor* for Class I (or Class II) data traffic within each time interval in the cell. Let $QA^k_{t,j}$ and $QN^k_{t,j}$, respectively, be the number of *degree A* connections and the number of active connections for Class k data traffic at time t in cell j. Let $\phi^k_{t_n,j}$ be the QoS-degree factor of Class k data traffic at time t_n in cell j, which can be expressed by

$$\phi^k_{t_n,j} = \frac{\sum_{t=t_n-l^k_{t_n,j}}^{t_n} QA^k_{t,j}}{\sum_{t=t_n-l^k_{t_n,j}}^{t_n} QN^k_{t,j}} , \quad (4)$$

where t is measured time from t_n - $l^k_{t_n,j}$ to t_n. The $l^k_{t_n,j}$ denotes the length of time interval for Class k data traffic at time t_n in cell j. Initial value of $l^k_{t_n,j}$ may be chosen based on the real operation of system (e.g., $l^k_{t_n,j}$ = 60 sec). The QoS-degree factor $\phi^k_{t_n,j}$ represents rate of degree A connections in all degrees for Class k data traffic at time t_n in cell j. When $\phi^k_{t_n,j}$ < 0.8, it means that over 20% ongoing connections are below degree A for Class k data traffic at time t_n in cell j. This is an important parameter for call admission control in the proposed scheme.

3.2 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 base station of cell bj tries to admit this request by using the available bandwidth plus maximum borrowable bandwidth of MHs in the service-queues. The new connection of MH x is rejected in the cell bj if its expected bandwidth is large than the unused bandwidth plus maximum borrowable bandwidth in the service-queues. Otherwise, the base station of cell bj examines QoS-degree factors. If there is a low QoS-degree factors in the base station of cell bj, then the new connection will be blocked (e.g. $(\phi^{Class\_I}_{bj} + \phi^{Class\_II}_{bj})/2$ < 0.8). Otherwise, the base station of cell bj accepts the connection and allocates the corresponding bandwidth for the new connection of MH x. If the borrowable bandwidth has to be used for MH x, the base station of cell bj executes the service-oriented bandwidth borrowing strategy to borrow the borrowable bandwidth and to re-distribute the allocated bandwidth.

When MH x moves from cell bj to the cell bk, the base station of cell bj releases allocated bandwidth of the MH x, and executes the service-oriented bandwidth borrowing strategy to return the borrowed bandwidth and to re-distribute the allocated bandwidth. 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 base station of cell bk checks whether the available bandwidth plus reserved bandwidth and total amount of borrowable bandwidth ($\sum_{p=3}^{6} W^p_{bk}$) is sufficient or not. If the minimum required bandwidth for handoff connection of MH x is not sufficient, the base station of cell bk drops the handoff connection of MH x. Otherwise, the base station of cell bk accepts the connection and allocates the corresponding bandwidth for the handoff connection of MH x. If the borrowable bandwidth has to be used for MH x, the base station of cell bk executes the service-oriented bandwidth borrowing strategy to borrow the borrowable bandwidth and to re-distribute the allocated bandwidth.

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 base station of cell bk. If there is not any available bandwidth and total amount of borrowable bandwidth in the base station of cell bk, the base station of cell bk drops the handoff connection of MH x. Otherwise, the base station of cell bk accepts the connection and allocates the corresponding bandwidth for the handoff connection of MH x. If the borrowable bandwidth has to be used for MH x, the base station of cell bk executes the service-oriented bandwidth borrowing strategy to borrow the borrowable bandwidth and to re-distribute the allocated bandwidth.

Table 1. Multimedia traffic used in simulation mode

Application	Traffic Class	Bandwidth Requirement	Average Bandwidth Requirement	Connection Duration	Average Connection Duration	Example
1	Real-time	30 Kb/s (CBR)		60 - 600 seconds	180 seconds	Voice Service & Audio-phone
2	Real-time	256 Kb/s (CBR)		60 – 1800 seconds	300 seconds	Video-phone & Video-conference
3	Real-time	1-6 Mb/s (average) 2.5-9 Mb/s (peak) (VBR)	3 Mb/s	300 - 18000 seconds	600 seconds	Interact. Multimedia & Video on Demand
4	Nonreal-time	5-20 Kb/s (UBR)	10 Kb/s	10 - 120 seconds	30 seconds	Email, Paging & Fax
5	Nonreal-time	64-512 Kb/s (UBR)	256 Kb/s	30 - 36000 seconds	180 seconds	Remote Login & Data on Demand
6	Nonreal-time	1-10 Mb/s (UBR)	5 Mb/s	30 - 1200 seconds	120 seconds	File Transfer & Retrieval Service

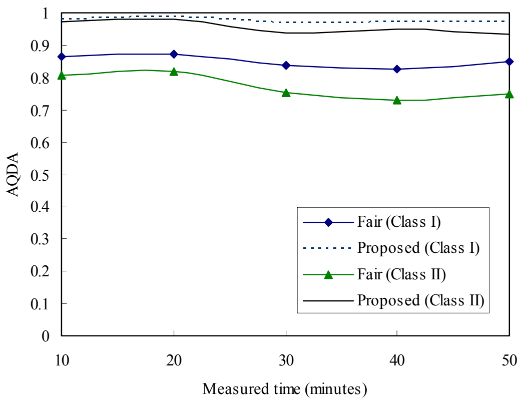

Figure 4. Average QoS of degree A when connection arrival rate = 0.1 requests/sec.

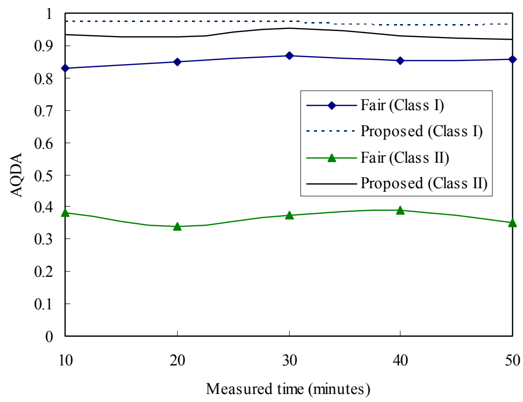

Figure 5. Average QoS of degree A when connection arrival rate = 0.5 requests/sec.

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

Figures 4 and 5 show the *AQDA* for Class I and Class II traffic connections when connection arrival rate = 0.1 and 0.5 requests/sec, respectively. The measured time is from 10 minutes to 50 minutes for each connection arrival rate. It is obvious that our proposed scheme results in higher *AQDA* for Class I traffic and Class II traffic than fair resource allocation protocol. For each connection arrival rate, the *AQDA* of our proposed scheme for Class I and Class II traffic connections is larger than 0.9. Furthermore, there is slight fluctuation in the *AQDA* of our proposed scheme when the measured time changes. It means that the proposed scheme provides better satisfying degree of QoS for ongoing MHs in mobile communication systems. The major reason is that we provide the efficient bandwidth redistribution approach in a base station by using the attribute of multimedia traffic. The influence of satisfying degree of QoS for MHs is slight when the borrowable bandwidths are borrowed from the high bandwidth requests. According to the QoS-degree factors and different multimedia services, we design efficient call admission control algorithms for real-time and nonreal-time traffic. Therefore, our proposed scheme controls the number of MHs, connection blocking and connection dropping appropriately in a base station, providing high QoS requirements in the cellular systems.

We also compare the average number of redistribution per second for each base station with that of the fair resource allocation protocol. Figure 6 shows that our proposed scheme results in lower number of redistribution by using the service-oriented bandwidth

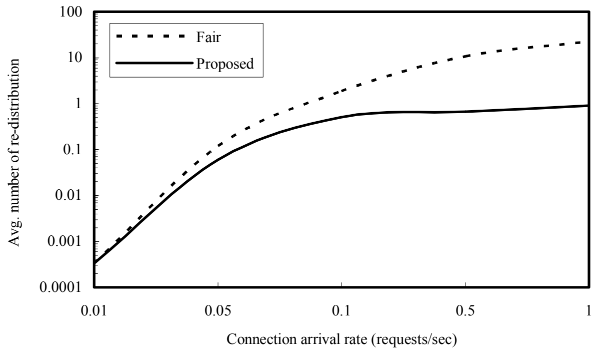

Figure 6. Average number of re-distribution.

borrowing strategy. When the connection arrival rate is larger than 0.05, it is obvious that the fair resource allocation protocol results in higher number of re-distribution in the cellular systems. This is because the fair resource allocation protocol may re-distribute the bandwidth allocation for all ongoing connections when a base station accepts a connection. Also, in this situation, the base station is the more congested because more and more MHs arrive at the cell. Too many overheads are increased in the base stations of the cellular system. In contrast, our proposed scheme leads to slight fluctuations in the allocated bandwidths of MHs. It means that our proposed scheme provides a more efficient bandwidth re-distribution approach and lower system overhead than fair resource allocation protocol. The reason for this behavior is that we rely on suitable arrangement for borrowable bandwidths of multimedia applications to borrowed or returned, reducing the overheads of bandwidth re-distribution in a base station.

Table 2 shows the CBP of two schemes. The CBPs increase in two schemes with increase in the arrival rate of new connection request. However, when the connection arrival rate is larger than 0.1 requests/sec, it is evident that the CBPs of our proposed scheme are better than that of the fair resource allocation protocol. Table 3 shows that the CDP of our proposed scheme is better than that of fair resource allocation protocol. Furthermore, as the connection arrival rate increases, it is obvious that the proposed scheme results in lower CDP. The reason for this behavior is that the proposed scheme provides more efficient call admission control for hand-off connections. Therefore, the CDP can be reduced. Table 4 shows the bandwidth utilization (BU). When the connection arrival rate is lower than 0.1 requests/sec, the BUs of two mechanisms are similar. However, when the connection arrival rate increases, the BU of our proposed scheme is superior to that of the fair resource allocation protocol. This is because the bandwidth allocation of our proposed scheme is determined by using service-oriented bandwidth borrowing concept, resulting in better BU in the cellular systems.

Table 2. Comparison of CBP

Arrival rate / scheme	*0.01*	*0.05*	*0.1*	*0.5*	*1*
Fair	0.0015	0.0181	0.186	0.432	0.529
Proposed	0.0014	0.0180	0.151	0.371	0.445

Table 3. Comparison of CDP

Arrival rate / scheme	*0.01*	*0.05*	*0.1*	*0.5*	*1*
Fair	0.0001	0.0016	0.0152	0.0769	0.0882
Proposed	0.0001	0.0014	0.0101	0.0375	0.0415

Table 4. Comparison of BU (%)

Arrival rate / scheme	*0.01*	*0.05*	*0.1*	*0.5*	*1*
Fair	10.56	49.47	67.43	87.36	92.67
Proposed	11.22	49.42	70.55	91.70	94.89

5. Conclusion

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 provides better QoS guarantees in mobile multimedia wireless networks. Bandwidth borrowing subjects connections to possibly frequent fluctuations in the allocated bandwidths of MHs and decreases the probability that connections will always be provided their desired amount of bandwidth in the base stations. In borrowing-based bandwidth reservation scheme, reducing the overhead of bandwidth reconfiguration and satisfying QoS requirements of ongoing MHs are interesting problems. In this paper, the proposed scheme reaches these two significant objectives.

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