A Fuzzy Bandwidth Allocation Controller to Support Real-time Traffic over Wireless Network

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Abstract — **In this paper, we propose a fuzzy bandwidth allocation controller (FBAC) to support two types of services: (i) restricted time-bounded service (RTBS), such as voice and video services, (ii) loose time-bounded service (LTBS), such as data service in wireless networks. Base on the FBAC, five different request assignment strategies are introduced. Simulation results demonstrate that the fuzzy controller with some proposed assignment strategies obtain high network performance, high fairness as well as an acceptable blocking probability.**

I. INTRODUCTION

In wireless network, many MAC protocols have been proposed about how to guarantee the quality of service (QoS) recently. Typically, slotted based protocols, like R-ALOHA, PRMA [1], ISMA [2], RS-ISMA [3], BRMA [4], reserve slots in the next cycle by pervious contention results. Since each of them does not consider the traffic characteristics, it is hard to exactly match the service requirements or obtain the maximum throughput. Adaptive protocols, such as PRMA/DA [5] and DSAMA [6], dynamic change the slots of different kinds of services to provide better QoS. However, too many kinds of services make the algorithms complexity and need much computing time. To reduce the protocol complexity, we simplify service types into two basic classes: (i) restricted time-bounded service (RTBS), such as voice and video services, (ii) loose time-bounded service (LTBS), such as data service. Each kind of services has its special traffic characteristic, bandwidth requirement and acceptable blocking probability. In order to fully utilizing the bandwidth in wireless network, a flexible bandwidth sharing strategy has to be applied. Although an aggressive bandwidth sharing scheme can provide a better management of network resource, due to the unpredictable fluctuations of traffic flow, the blocking probability of restricted time-bounded service may be violated.

To overcome the problem, we propose a fuzzy bandwidth allocation controller (FBAC) to deal with the bandwidth sharing problem in the wireless network. Based on the FBAC, five different request assignment strategies are proposed to dynamically select proper LTBS requests to serve. Among these strategies, two of them employ another fuzzy strategy switching controller (FSSC) to obtain the best results. The performance of the fuzzy controllers and strategies are evaluated and compared. The simulation results show that the proposed strategies can improve the network performance, bandwidth utilization, fairness. Most important, it has the ability to control the blocking probability of RTBS within an acceptable range as desired. Moreover, the proposed approach is very simple and can be implemented in hardware easily.

The rest of this paper is organized as follows. The system model is given in section II. In section III, we present the functional block diagram of the FBAC. In section IV, five different strategies based on the FBAC for assigning requests are discussed. In section V, the performance measurements, simulation models and results are reported. Finally, some conclusions are given in section VI.

II. SYSTEM MODEL

In wireless networks, channel is often divided into frames with fixed length and each frame is composed of C time slots (i.e., bandwidth is divided into C channels). In such time-division multiple access (TDMA), each time slot can be used by either RTBS or LTBS. According to the characteristics of two types of services, RTBS has higher priority than LTBS and the LTBS may starve when RTBS is overloaded. To prevent LTBS from starvation, a small amount of slots in frame, which is denoted as R, is particularly reserved for the LTBS and the remaining slots in frame can be allocated for either RTBS or LTBS. For simplicity, we denote the former and the latter as the *reserved* slots and the *sharable* slots, respectively. Therefore, the exact number of *sharable* slots is C-R. The channel's allocation of *sharable* and *reserved* slots within a frame in a wireless network is shown as Figure 1.

As described above, when customer issues a request for LTBS, a particular parameter "due-time" is also specified at the same time. This identifies that it is valid only if it is delivered before this specified time. For example, assume a LTBS with transmission time L arrives at time T, the latest timing T' of starting to service is $T+D-L$ if it can be delayed no later than $T+D$.

III. THE FUZZY BANDWIDTH ALLOCATION CONTROLLER (FBAC)

In this paper, the fuzzy approach is adopted to determine how many sharable slots can be temporarily borrowed to serve LTBS without degrading the quality of RTBS. There are two input linguist parameters considered for the fuzzifier in FBAC: the RTBS blocking probability, which is denoted as *rbp*, and the channel free proportion (the ratio of the number of free sharable slots to the total sharable slots), which is denoted as *cfp*. For input parameters, we define the corresponding fuzzy term sets: $T(rbp)$ = {Safe, Normal, Dangerous} and $T(cfp)$ = {Small, Medium, Large}. The selected membership functions for $T(rbp)$ and $T(cfp)$ are the shape of Gaussian-like function (see Figures 2(a) and 2(b)).

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For each membership function, the peak position and the scaling factor are specified according to our knowledge about the system model. (The accepted blocking probability of RTBS is assumed to be 0.02.) The mathematics form of the Gaussian membership function is presented as follows:

$$\mu(x) = e^{-\left(\frac{x-m_i}{\sigma_i}\right)^2} ,$$

where m_i and the σ_i are the peak value and the scaling factor of the ith membership function, respectively. We also define the term set of the output borrowing ratio *br* as *T(br)* = {Small, Medium, Large}. According to the fuzzy set theory, the fuzzy rule base has $|T(rbp)| \times |T(cfp)| = 9$ inference rules (see Table 1). Obviously, if the *rbp* is safe and the *cfp* is high then the *br* is set to large. However, when the RTBS traffic load becomes heavy such that the *rbp* is dangerous, no matter how large the *cfp* is, the *br* is set to small.

In the inference engine, the max-min inference method [7] is used. For the ith rule, the corresponding membership values of these two input variables *rbp* and *cfp* are calculated by $\mu_i(rbp)$ and $\mu_i(cfp)$, respectively. The weight w_i used in defuzzifier is determined by the minimum value between $\mu_i(rbp)$ and $\mu_i(cfp)$. Considering the defuzzifer in FBAC, we employ the singleton method [8] as our defuzzification strategy to reduce the complexity of computation (see Figure 2(c)). For each fuzzy rule, the method will convert the output membership function into a crisp output control value.

The borrowing ration is affected by the blocking probability of RTBS significantly. It is clear that if the *rbp* is dangerous (safe), the borrowing ratio should be small (large). In our case, the peak values for $T(br)$ = {0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9}. When the *rbp* states in normal state, the reason of setting the borrowing ratio to 0.6 is trying to obtain higher bandwidth utilization. The singleton defuzzification method calculates the crisp output value y_l by the following equation:

$$y_l = \frac{\sum_{i=1}^{n} w_i \times p_i}{\sum_{i=1}^{n} w_i} ,$$

where $n = |T(rbp)| \times |T(cfp)|$, p_i is the peak value of the ith output membership function of *T(br)*, and w_i is the weight of the ith control rule. Hence, the number of borrowing sharable slots (*BSS*) are easily obtained by the following equation:

$$BSS = (C-R) \times cfp \times y_l .$$

Although the number of borrowed slots are determined according to the present *rbp* and *cfp*, the way of choosing the LTBS to serve is still has a chance to affect the *rbp*. This is because that once a borrowed slot is occupied by a long-drawn LTBS, it will keep busy for a considerable time. During this period, all incoming RTBS calls may be blocked. Intuitively, a best strategy of choosing the shortest request to serve is able to degrade such influence. However, for the sake of fairness, the earliest arrival request should be served before other requests. Therefore, it is desirable to have an efficient request assignment strategy so that the influence caused by the LTBS could be minimized and the fairness could be achieved at the same time.

IV. FIVE REQUEST ASSIGNMENT STRATEGIES

In this section, five different strategies based on FBAC are proposed for determining which LTBS is chosen to use the borrowed slots. The five request assignment strategies are proposed as follows:

A. Early Request First Strategy (ERFS)

In ERFS, both the reserved and sharable channels, the order of serving requests is based on a simple first-come-first-serve concept. That is, an available channel is assigned to serve the request with the earliest arrival time. It is clear that based on this simple strategy, the fairness criterion is achieved completely. Nevertheless, the assigned request for the sharable channel may take a considerable time before it releases channel. Therefore, the blocking probability of real-time traffic may increase significantly. In order to reduce the blocking probability, the SRFS is proposed.

B. Short Request First Strategy (SRFS)

It is obvious that if the selected request for the sharable slot needs a shorter service time, the blocking probability of RTBS will be reduced. Besides, the blocking probability of the LTBS is also decreased because that the number of serviced calls increases. However, because the SRFS always selects the shortest services from buffer, as a result, almost unserviced requests have a longer service time and the time interval of sharable slots occupied by the LTBS requests will become longer and longer. Consequently, the number of blocked RTBS requests may become larger beyond expectation. The simple way to maintain the *rbp* is to reserve the sharable channels for RTBS instead of sharing by LTBS. However, this contradicts high channel utilization. It is not easy to achieve both at the same time. Another drawback of SRFS is that an earlier arrival request may be postponed by SRFS serving later incoming requests. It is an unfair scheduler. To overcome these shortcomings, an Adaptive SBLR is proposed.

C. Adaptive SBLR

The major concept of the adaptive SBLR is that the **S**hortest service in buffer is assigned for **B**orrowed channel and the **L**ongest service in buffer is assigned for **R**eserved channels. It is expected that the adaptive SBLR will obtain smaller blocking probability of RTBS than that of the SRFS obtained.

D. Fuzzy ERFS/SRFS Strategy (FESS)

A well-behavior assignment strategy should depend on the network status to apply an appropriate strategy. When the blocking probability of RTBS traffic becomes dangerous, the SRFS is applied to shorten the usage time period; otherwise, the ERFS is used to obtain fairness. Based on such concept, the borrowed channels may avoid from domination. Besides, when the RTBS require more bandwidth resources, the sharable slots can be allocated for them quickly. However, it is too hard to precisely classify the dangerous condition. Therefore, an extra fuzzy strategy switching controller (FSSC) is employed to dynamically determine whether the SLFS is more suitable for present network or not.

We note that, in FSSC, two input linguistic parameters *rbp* and *cfp* and the corresponding membership functions are the same as that of FBAC. For the FSSC, we define the fuzzy set of the output switching factor *sf* as *T(sf)* = {Safe, Dangerous} and the membership function of *T(sf)* is shown in Figure 3. The switching factor is used to indicate the status of the network is safe or dangerous. When the switching factor exhibits danger, (i.e., the *rbp* is close to the bounded value 0.02), the network will switch to use the SRFS for controlling *rbp* and channel utilization. Otherwise, the network uses the ERFS to achieve fairness. The fuzzy control rules are shown in Table 2. The crisp output value y_2 of FSSC is also calculated by the singleton defuzzification method.

In order to switch the request assignment strategy, a request assignment mechanism is used in FESS. According to the crisp output value y_1 of FBAC and the crisp output value y_2 of FSSC, the request assignment mechanism switches strategy dynamically and chooses an adequate number of the proper LTBS for serving. Therefore, the FSSC is much flexible to deal with the unpredictable traffic load. In addition, the system performance is also being improved at the same time.

E. Enhanced FESS (EFESS)

In FESS, only one strategy is applied on network at a time, the fairness and the blocking probability can not be improved simultaneously. To obtain a better result, we propose a much flexible strategy, named as Enhanced FESS (EFESS), to apply both strategies on the network at the same time. The concept of EFESS is described in detail as follows. When the capacity of sharable bandwidth is able to deal with the incoming RTBS traffic (which is determined by FSSC), the ERFS can be applied on the borrowed (sharable) slots to obtain fairness. Meanwhile, the SRFS is applied on the reserved slots to decrease blocking probability of LTBS. On the contrary, if the demand of RTBS excesses the entire capacity of sharable bandwidth, the scare borrowed slots should be utilized in a more efficient way. That is, we assign the borrowed slots to serve the requests with the shortest service time. Meantime, the reserved slots serve requests in a function of ERFS.

V. PERFORMANCE MEASUREMENT AND THE SIMULATION MODELS

A. Performance Measurement

Assume the simulation time for the simulation run is *T*. Based on the FBAC, the performances of five strategies are evaluated in terms of the following metrics:

- **RTBS Blocking Probability (RBP)** = the ratio of the number of blocked RTBS requests and the total arrival RTBS requests during a long period of simulation time *T*.
- **LTBS Blocking Probability (LBP)** = the ratio of the number of blocked LTBS requests and the total arrival LTBS requests during a long period of simulation time *T*.
- **Reserved Bandwidth Utilization (RBU)** = the ratio of the summation of busy time intervals of *reserved* bandwidth to serve requests and the total simulation time *T*.
- **Sharable Bandwidth Utilization (SBU)** = the ratio of the summation of busy time intervals of *sharable* bandwidth to serve requests and the total simulation time *T*.

Let **Unfairness Factor (UF)** denotes the number of LTBS requests that are passed the time limit and are dropped by the strategy chooses some later incoming requests to serve. Therefore, the **Network Fairness (NF)** is defined as

$$NF = \frac{SLR - UF}{SLR},$$

where *SLR* is the number of successfully served LTBS requests during the time *T*. A high performance network would require to have small *BP*, high *BU* and high *NF*.

B. Simulation Models

The proposed fuzzy bandwidth allocation controller and five different channel assignment strategies are investigated by simulations. The total number of available channels (time slots in frame) in wireless network is 60 (*C*=60). The numbers of *reserved* time slots are 5 (*R*=5). The acceptable blocking probability of RTBS is set to 0.02. For simplicity, we assume that a buffer with infinite volume is used for buffering all incoming LTBS requests. The request arrival rate of RTBS and LTBS are Poisson distributions with a mean $\lambda_i^{realtime}$ and $\lambda_i^{delayable}$ at the *i*th hour in one day, respectively (see Figure 4). The request length for two kinds of services is an exponential distribution with a mean of *L* minutes. Therefore, the *Network Load* (*NL*) for the network is defined as

$$NL = \frac{\sum_{k=0}^{23}(\lambda_k^{realtime} + \lambda_k^{delayable}) \times L}{24 \times C}.$$

Since $\sum_{k=0}^{23}(\lambda_k^{realtime} + \lambda_k^{delayable})/24 = 4$ and $C = 60$, we obtain a simpler equation: $NL = (4 \times L) / 60$. Therefore, in these following simulation models, NL=1 if L=15. This implies that if mean service time *L* is larger than 15, the traffic load of the network becomes heavy or overloaded. In this paper, the simulation period is 30 days (i.e., T = 43200 minutes) and the parameter *L* is considered from 12 minutes (light loaded, *NL* = 0.733) monotonically increases to 20 minutes (heavy loaded, *NL* = 1.333) in a step of 1 minute and LTBS due-time *D* = 7 hours.

C. Simulation Results

Figure 5 shows the RBPs and LBPs obtained by the ERFS, SRFS, Adaptive SBLR, FESS and EFESS under different mean service time of request when *D* = 7 hours. Figure 5(a) illustrates the LBP obtained by the SRFS is smaller than that of other proposed strategies under different network load level. We can also see that the LBPs obtained by these strategies are almost identical when the network load is light ($L < 15$ *or* $NL < 1$). This is because that under this condition, nearly all the incoming LBTS can be served in spite of which strategy is applied. Intuitively, when the network load becomes heavy ($L \geq 15$ *or* $NL \geq 1$), a larger LBP would be obtained by proposed strategy. We note that the Adaptive SBLR produces a higher LBP when network loaded is heavy. When the network capacity can not deal with the incoming traffic load, the FBAC hardly borrows channels for LBTS. Thus, in SBLR strategy, only the requests with the longest service time have the opportunity to be served. This increases the LBP significantly. Figure 5(b) illustrates the RBPs produced by the ERFS, SRFS, Adaptive SBLR, FESS and EFESS under different network load. Recall that the RBP in the network is required to be bounded beyond a specified value 0.02. In Figure 5(b), the obtained RBPs by all the proposed strategies are obviously bounded beyond 0.02 even when $15 \leq L \leq 17$ (that is, $1.0 \leq NL \leq 1.13$). This implies that the proposed FBAC has the ability to control the RBP efficiently even when the network load is heavy. We also can find that the RBP of the SBLR is slightly better than that of other strategies.

Figure 6 shows the results of reserved bandwidth utilization RBUs and sharable bandwidth utilization SBUs obtained by five strategies under different mean service time L. Since the reserved channels are dedicated for the LTBS, the channels will be fully utilized if the incoming LTBS traffic load excesses the reserved capacity has. In Figure 6(a), we can see that the obtained RBU is almost 1.0 in spite of the mean service time of requests. This is because only five reserved channels are assigned in the simulation model. In Figure 6(b), we can see that the obtained SBU under different mean service time of request is similar to each other. The peak value of the SBU of each strategy occurs when the network loaded is just saturated. If the incoming network load becomes much heavy, the FBAC will slow down the borrowing rate to prevent the blocking probability of RBTS from increasing seriously. However, the SBU is degraded. But, the percentage of SBUs of proposed strategies is still maintained above 75%.

The comparison of Network Fairness (NF) obtained by the five strategies under different mean service time L is shown in Figure 7. Although the SBLR obtains the smallest real-time blocking probability, the drawback is that it performs quite unfair. The unfairness is resulted from the SBLR always selects the shortest and the longest request for the sharable and the reserved channels, respectively. Obviously, the ERFS is the fairest strategy. We note that the proposed FESS and EFESS dynamically switch the ERFS and SRFS strategies to gratify the network requirements. In the worse case ($L = 20$), both the values of network fairness of FESS and EFESS are slightly unfair ($NF \cong 95\%$) when comparing with the ERFS. This shows that the FESS and EFESS obtain an excellent result under different traffic demand.

VI. CONCLUSIONS

In this paper, we design a fuzzy bandwidth allocation controller (FBAC) in the wireless network to provide QoS. Base on the FBAC, we also propose five strategies to select the being served LTBS requests. The simulation results demonstrate that the proposed strategies can guarantee low blocking probability, high bandwidth utilization, and fairness.

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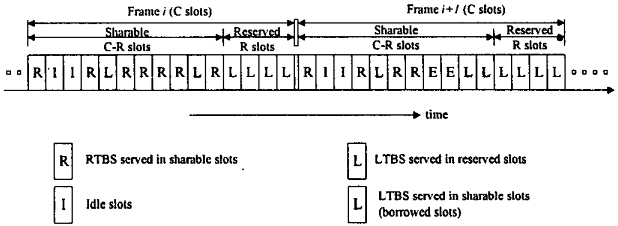
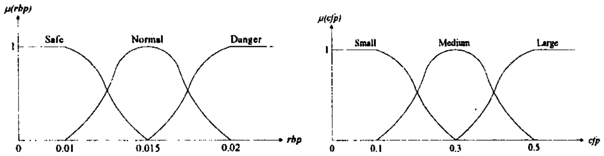
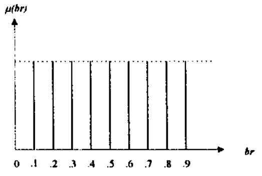


Figure 1. The bandwidth allocation in a wireless network.



(a) *T(rbp)*   (b) *T(cfp)*



(c) *T(br)*

Figure 2. The membership functions of the term sets

Table 1. The fuzzy control rules for borrowing channel.

Rule	*rbp*	*cfp*	*br*
1	Safe	Large	0.9
2	Safe	Medium	0.8
3	Safe	Small	0.7
4	Normal	Large	0.6
5	Normal	Medium	0.5
6	Normal	Small	0.4
7	Dangerous	Large	0.3
8	Dangerous	Medium	0.2
9	Dangerous	Small	0.1

Table 2. The fuzzy control rules for switching strategy.

Rule	*rbp*	*cfp*	*sf*
1	Safe	Large	Safe
2	Safe	Medium	Safe
3	Safe	Small	Safe
4	Normal	Large	Safe
5	Normal	Medium	Safe
6	Normal	Small	Dangerous
7	Dangerous	Large	Dangerous
8	Dangerous	Medium	Dangerous
9	Dangerous	Small	Dangerous

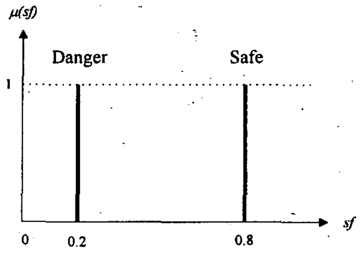
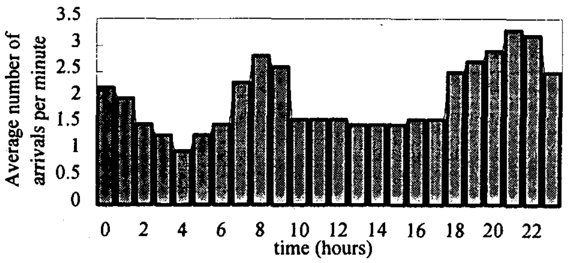
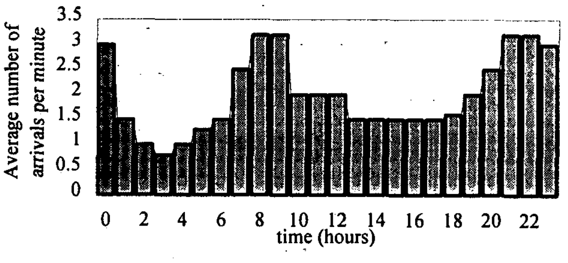


Figure 3. The membership function of the term set *T(sf)*.



(a) RTBS Traffic



(b) LTBS traffic

Figure 4. The average arrival rates for RTBS and LTBS traffic.

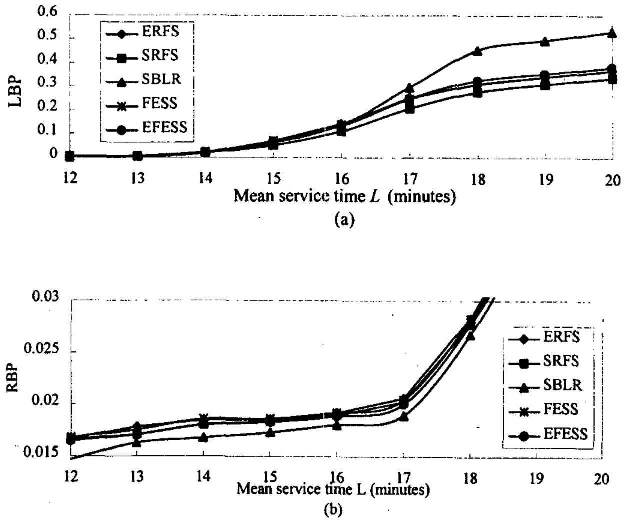


Figure 5. Comparisons of LBP and RBP obtained by the ERFS, SRFS, SBLR, FESS and EFESS under different mean service time *L*.

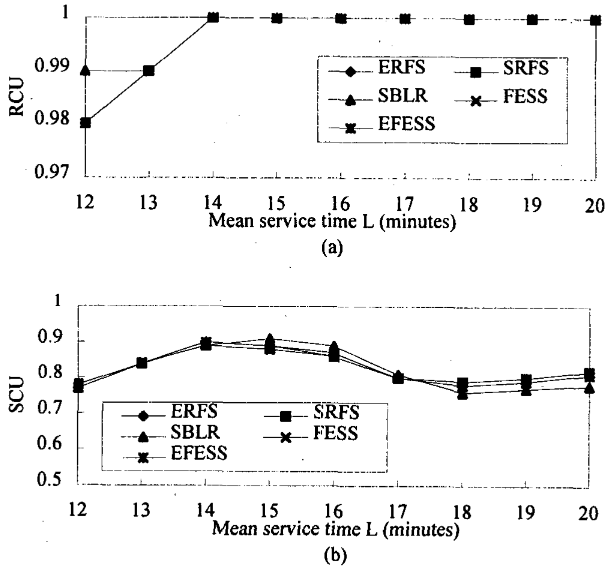


Figure 6. Comparisons of RCU and SCU obtained by the ERFS, SRFS, SBLR, FESS and EFESS under different mean service time *L*.

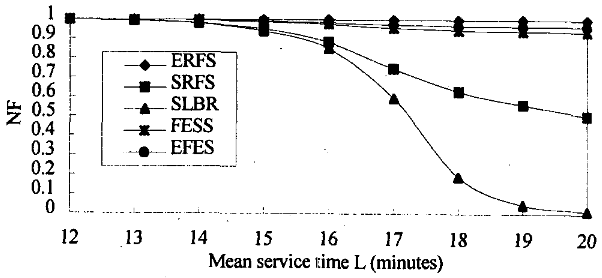


Figure 7. Comparisons of NF obtained by the ERFS, SRFS, SBLR, FESS and EFESS under different mean service time *L*.