Dynamic Bandwidth Quasi-reservation Scheme for Real-time Services in IEEE 802.16e Networks

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***Abstract* — IEEE 802.16e standard did not specify any bandwidth reservation scheme that provides quality of service (QoS) support for real-time services, especially for handover real-time ones. The bandwidth reservation schemes, which were not designed for 802.16e system dedicatedly, could also be applied to it. But their performance is our main concern. In this paper, based on the handover probability and the traffic arrival probability, a dynamic bandwidth quasi-reservation scheme (DBQRS) is proposed to provide QoS guarantee for mobile and fixed wireless real-time multimedia services in 802.16e networks. The corresponding admission control policy is also designed for this scheme. A simulation model is developed to evaluate the performance of the DBQRS using OPNET Modeler. The simulation results demonstrate that the DBQRS not only minimizes the new service flow (SF) blocking rate and the handover SF dropping rate, but also reduces the access delay of new real-time SF and enhances the bandwidth utilization.**

Keywords — bandwidth reservation, admission control, real-time service, broadband wireless access (BWA), IEEE 802.16e, WiMAX, quality of service (QoS).

I. INTRODUCTION

In order to meet the increasing demands of accessing local/metropolitan area networks conveniently and exchanging diverse information rapidly, IEEE 802.16 broadband wireless access (BWA) standards were designed to provide higher capacity, higher data rate at a large area, and support more advanced multimedia services. The latest IEEE 802.16e standard [2] enables mobile station (MS) to roam during services. The mobility of MSs creates handover, which may result in interrupting an ongoing session. Since users are more intolerant of terminating the ongoing real-time services, such as voice and video, than interrupting the non-real-time ones, bandwidth should be reserved for those handover real-time services. However, 802.16e standard did not specify any bandwidth reservation scheme. The defined two-phase activation model for admitting and activating service flow (SF) in the standard [1], which seems to perform bandwidth reservation, is not suitable for real-time services because it does not guarantee real-time services to obtain desired bandwidth. The bandwidth reservation schemes [3][10], which were not designed for 802.16e system dedicatedly, could be applied to it. But their performance is our main concern.

In this paper, a dynamic bandwidth quasi-reservation scheme (DBQRS), which is based on the handover probability and the traffic arrival probability of the corresponding traffic model, is proposed to provide QoS guarantee for mobile and fixed wireless real-time multimedia services in 802.16e networks. In order to increase the throughput and enhance the bandwidth utilization, reserved bandwidth can be temporarily allocated to non-real-time services. From the viewpoints of reserving bandwidth based on probabilities and reserved bandwidth not dedicating to real-time services, we add prefix "quasi" to reservation.

The rest of this paper is organized as follows. In Section II, the contents related to bandwidth reservation in IEEE 802.16e standard are described. The proposed DBQRS for real-time services in IEEE 802.16e networks is presented in Section III and simulation results are discussed in Section IV. Finally, we conclude this paper.

II. RELATED CONTENTS IN IEEE 802.16e STANDARD

A. *Two-phase Activation Model*

The SF, which is the central concept of IEEE 802.16 MAC protocol, provides a mechanism for QoS management. Three basic types of SFs were defined in the standard [1]:

- Provisioned SF is provided by, for example, the network management system;
- Admitted SF has resources reserved by the base station (BS), but the resources are deactivated; and
- Active SF has resources committed by the BS for transport of data packets.

In fact, they correspond to three states of SFs. Only admitted or active SFs can be one-to-one mapped to connections and only active SFs may forward data packets. In the two-phase activation model [1], provisioned SF or dynamically created SF experiences admitted state firstly. Here, resources are reserved for this SF and admission control is performed. Then, the admitted SF is changed into active SF by dynamic service change (DSC) message exchange and the resources are activated, which completes the second stage of the model. The red lines in Fig. 1 represent this process.

But it is not always the case, especially for real-time services. A real-time SF may be provisioned and immediately activated. Similarly, a real-time SF may be created dynamically and instantly activated. In these cases, two-phase activation is skipped and the SF turns into active state directly without experiencing admitted state [1], which is shown by the blue lines in Fig. 1. When the free bandwidth is insufficient, the bandwidth requests of real-time SFs will be rejected.

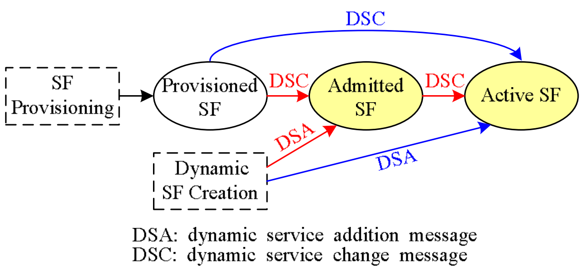

Figure 1. The implementation and skip of two-phase activation model.

B. Consideration for Handover

In 802.16e standard, the serving BS may negotiate over backbone network with the neighbor BSs about the allocation of non-contention-based ranging opportunity for MS [2]. This scheme only guarantees the MS to conduct initial ranging without contention and to enter the target cell easily. The serving BS may notify the MS's intention of handover to the target BS and send MS's information to it over backbone network, which can expedite the handover [2]. However, the ongoing SFs in the MS cannot be guaranteed to get the required bandwidth without suitable bandwidth reservation scheme.

III. The Dynamic Bandwidth Quasi-Reservation Scheme (DBQRS)

Practically, WiMAX (worldwide interoperability for microwave access) is the commercialization of the IEEE 802.16 standard. Because WiMAX is allowed to transmit at high power rates and use directional antennas to produce focused signals, it has a target range of up to 31 miles. But under the mobile situation, since the wireless links are vulnerable, MSs communicating directly with BSs likely will achieve a range of 5 to 6 miles [5]. In contrast, WiFi has a range of only several hundred feet and 3G cellular technology has a range of several thousand feet [4]. Compared with these wireless technologies, 802.16e network has a rather large coverage per BS, in which handover does not occur continually. In other words, the probability of handover is relatively low. In this case, we consider reserving bandwidth for both handover real-time traffics and potential new real-time traffics. Thus, not only the continuity of handover active real-time SF is guaranteed but also the access delay of new real-time SF is reduced and the fairness of admitting new and handover real-time SFs is improved.

The proposed concept of quasi-reservation is derived from two aspects. On the one hand, the bandwidth is reserved for real-time traffic based on the probabilistic estimations of MS's handover and traffic arrival. Thus, a certain bandwidth range may be reserved for the real-time traffics belonging to different MSs simultaneously, not exclusively for a certain one. On the other hand, the quasi-reserved bandwidth does not serve real-time traffic dedicatedly. During the admission control process, the quasi-reserved bandwidth can be available to non-real-time traffic under the condition that the free bandwidth is insufficient and the reserved bandwidth is unused by real-time traffic. The prefix "quasi" differentiates the proposed scheme from the conventional full-bandwidth reservation schemes.

A. Parameter Definitions

In order to describe the proposed scheme, the parameters used in the paper are defined in Table I. Here, $t \in T$ and T is the set of time intervals.

TABLE I. Parameter Definitions Used in the Paper.

M	The number of MSs quasi-reserved bandwidth by BS.
N	The number of the real-time traffic types.
$P_m^{res}(t)$	The probability of MS m requiring BS to reserve bandwidth at time interval t.
$P_{m,n}^{res}(t)$	The probability of the n-type traffic on MS m requiring BS to reserve bandwidth at time interval t.
$P_{m,n}^{arr}(t)$	The probability of the n-type traffic arriving at MS m at time interval t.
$P_{m,n,s}^{arr}(t)$	The probability of s n-type SFs arriving at MS m at time interval t.
$P_m^{ho}(t)$	The probability of MS m handover.
α_n	The weighting coefficient for the n-type real-time traffic.
β_k	The weighting coefficient for MSs in different handover states.
$B_{m,n}$	The reserved bandwidth required by the n-type traffic on MS m.
B_m	The total reserved bandwidth required by MS m.

B. The Proposed DBQRS

Traffics issued from MSs are various. The traffic which is issued and the time when the traffic is issued are stochastic. Moreover, the transmission rate of each multimedia traffic flow changes with time in a random fashion [6]. Therefore, to design the bandwidth reservation scheme based on probability is reasonable.

The bandwidth request and allocation mechanisms in the 802.16 standard specify that bandwidth is always requested on a connection basis and allocated on an MS basis [1][2]. For one thing, the BS collects the connections' bandwidth request information from the same MS, and grants the aggregate bandwidth to the MS. For another, the MS receives the grant and redistributes bandwidth among its connections, maintaining QoS and service level agreements [7]. Hence, the proposed DBQRS performs dynamic bandwidth reservation at BS taking MS as a unit.

Aggregating traffics from several devices, each MS usually has relative steady traffics, not burst traffics [5]. Taking statistics about traffics issued from MS for a certain period of time, we determine the corresponding traffic models. According to these traffic models, the probabilities of the traffic arrivals can be obtained. By the definitions in Table I, we have

$$\sum_{s=0}^{\infty} P_{m,n,s}^{arr}(t) = 1. \tag{1}$$

Then, let

$$P_{m,n}^{arr}(t) = \max\{P_{m,n,0}^{arr}(t), P_{m,n,1}^{arr}(t), \cdots, P_{m,n,s}^{arr}(t), \cdots\}, \tag{2}$$

$$s_{m,n} = \arg\max_{s}\{P_{m,n,0}^{arr}(t), P_{m,n,1}^{arr}(t), \cdots, P_{m,n,s}^{arr}(t), \cdots\}, \tag{3}$$

where $s_{m,n}$ denotes the number of SFs, which maximizes

$P^{arr}_{m,n,s}(t)$. If $s_{m,n}$ = 0, no bandwidth will be reserved for the n-type traffics of MS m.

Bandwidth reservation for the traffic of an MS is related not only to the traffic arrival, but also to the handover situation of the MS. From the multiplication theorem of probabilities, we know

P (*bandwidth reservation for the traffic on the MS*)
= P (*handover of the MS*)
× P (*traffic arrival at the MS* | *handover of the MS*),

where $P(\bullet)$ and $P(\bullet|\bullet)$ denote the probability of the event occurring and conditional probability, respectively. Since the MS handover and traffic arrival at the MS are mutually independent, then

P (*traffic arrival at the MS* | *handover of the MS*)
= P (*traffic arrival at the MS*),

so that

$$P^{res}_{m,n}(t) = P^{ho}_{m}(t) \times P^{arr}_{m,n}(t). \tag{4}$$

The $P^{res}_{m}(t)$ is given by

$$P^{res}_{m}(t) = \sum_{n=1}^{N} \frac{s_{m,n}}{\sum_{n=1}^{N} s_{m,n}} P^{res}_{m,n}(t). \tag{5}$$

Substituting (4) into (5), we obtain

$$P^{res}_{m}(t) = P^{ho}_{m}(t) \times \sum_{n=1}^{N} \frac{s_{m,n}}{\sum_{n=1}^{N} s_{m,n}} P^{arr}_{m,n}(t). \tag{6}$$

It is noted that the identical traffic model with different parameters results in the different values of traffic arrival probabilities. These model parameters change dynamically according to the real situation of traffics issued from each MS in the proposed scheme.

Due to the different handover states as well as the diverse QoS requirements of traffics, we weight these probability values using the different weighting coefficients. On the one hand, three types of real-time data delivery services were defined in 802.16e standard [2]:

- Unsolicited Grant Service (UGS) supports real-time applications generating fixed-rate data.
- Real-Time Variable Rate (RT-VR) Service is designed to carry real-time data applications with variable bit rates, which require guaranteed data rate and delay.
- Extended Real-Time Variable Rate (ERT-VR) Service is similar to RT-VR. Their differences exist in the request/grant scheduling policies. Therefore, we deal with RT-VR and ERT-VR identically in the proposed scheme.

Supporting constant bit rate (CBR) application, UGS is prioritized over RT-VR/ERT-VR. Furthermore, different traffics belonging to the same data delivery service may also have different levels. For instance, within the CBR applications, the traffics with smaller jitter tolerance are given higher priority; within the variable bit rate (VBR) applications, the traffics with smaller delay tolerance are given higher priority. So, based on these priorities, weight $P^{res}_{m,n}(t)$ using the weighting coefficients, α_n, $n=1, 2, \cdots, N$, for N traffic types, with the higher priority corresponding to the larger α_n.

On the other hand, because mobile users are more sensitive to terminating an ongoing real-time service than blocking a new one, handover real-time SFs are usually given higher priority over the new SFs. Thus, apply β_k to weight $P^{ho}_{m}(t)$ according to the handover state of MS. From the viewpoint of BS, we consider three handover states. β_k is defined on the set $\{\beta_{in}, \beta_{stay}, \beta_{out}\}$ with $\beta_{in}>\beta_{stay}>\beta_{out}$ and each β_k corresponds to one handover state.

- β_{in} is used for the MSs that have active real-time SFs and are likely to immigrate into the BS's coverage area from the neighbor cells.
- β_{stay} is applied to the MSs that hardly move, stay in the BS's coverage area and send real-time traffics prospectively. In this case, $P^{ho}_{m}(t)$ is always small, even approaching zero. In order to reserve bandwidth for the real-time SFs on these local MSs, let $P^{ho}_{m}(t)=1$.
- β_{out} is for the MSs that are likely to move out of the serving BS's coverage area. In this case, $P^{ho}_{m}(t)$ is replaced by its complement, $1-P^{ho}_{m}(t)$.

Accordingly, (6) is transformed to

$$P^{res}_{m}(t) = \beta_k P^{ho}_{m}(t) \times \sum_{n=1}^{N} \frac{s_{m,n}}{\sum_{n=1}^{N} s_{m,n}} \alpha_n P^{arr}_{m,n}(t). \tag{7}$$

As we can see from (7), the larger α_n and β_k are, the larger $P^{res}_{m}(t)$ is, which means BS reserving bandwidth for MS m with greater probability. Thus, traffic obtains its desired bandwidth with greater possibility during the admission control process. If $P^{res}_{m}(t)=1$, the bandwidth will be fully reserved for MS m, which is the same as conventional bandwidth reservation. Full-bandwidth reservation induces low bandwidth utilization. Therefore, taking the tradeoff between the efficiency of bandwidth reservation and the bandwidth utilization into account, α_n and β_k should be designed.

The proposed scheme allows a certain bandwidth range to be quasi-reserved for the traffics belonging to different MSs simultaneously [8]. Thus, (8) should be satisfied in the certain bandwidth range during time interval t; otherwise, the quasi-reservation will be performed in the other available bandwidth ranges.

$$\sum_{m=1}^{Mr} P^{res}_{m}(t) \le 1, \qquad Mr \le M \tag{8}$$

where Mr is the number of MSs with quasi-reserved bandwidth in the same bandwidth range during time interval t.

With regard to the reserved bandwidth required by MS m, B_m, we have

$$B_m = \sum_{n=1}^{N} B_{m,n} = \sum_{n=1}^{N} b_{m,n} \times s_{m,n}, \tag{9}$$

where $b_{m,n}$ is the required bandwidth per n-type SF on MS m. Thus, the mean reserved bandwidth for MS m is estimated as

$$\overline{B}_m = B_m \times P_m^{res}(t). \tag{10}$$

In the real system, the serving BS monitors the position of MS, the velocity and direction of MS movement. Based on the information, the serving BS estimates $P_m^{ho}(t)$ for MS m. Meanwhile, the serving BS calculates $P_{m,n}^{arr}(t)$ and B_m according to traffic models. As for the handover MS, the serving BS transmits the MS's information to the target BS over backbone periodically. It is noted that bandwidth is quasi-reserved for the handover MS at both target BS and serving BS using different handover probabilities, $P_m^{ho}(t)$ and $1-P_m^{ho}(t)$, respectively. The BS performs dynamic bandwidth quasi-reservation for MSs according to $P_m^{res}(t)$ and $\overline{B}_m$. Fig. 2 sketches the bandwidth quasi-reservation situation.

When a handover MS immigrates into the BS's coverage area, the MS can gain the required bandwidth for its ongoing SFs immediately. At the same time, the BS quasi-reserves bandwidth for local MS, so that once a new real-time SF belonging to the MS requests bandwidth, it can obtain desired bandwidth more easily. Thereby, the fairness of getting bandwidth between handover and local real-time SFs is improved.

We simplify the calculation of these probabilities from following three aspects.

1) Generally speaking, it is difficult to solve instantaneous state probability. But, after a period of time of MS's initialization, all sorts of traffics reach a steady state, i.e., the normal operating situation. We can make use of the steady state probabilities, instead of instantaneous state probabilities, to estimate the probabilities of these traffics occurring, $P_{m,n}^{arr}(t)$.

2) Since each update of traffic model parameters may incur some communication and computation overheads, the BS may update these parameters when having received a certain number of SFs, instead of receiving a new or handover SF. The number of SFs could be chosen to provide the tradeoff between system performance and overheads [9].

3) In order to reduce the overhead of calculation, we pre-calculate and pre-store N tables with regard to those traffic model parameters and steady state probabilities for N traffic types. When the traffic model parameters change, those steady state probabilities can be obtained by searching these tables.

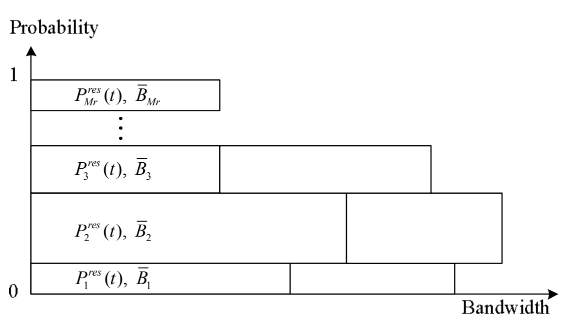

Figure 2. Schematic representation of bandwidth quasi-reservation scheme.

C. Admission Control Policy

Admission control is implemented whenever a handover MS with active SFs enters the BS's coverage or a local MS issues new SFs. The proposed admission control policy is given in Fig. 3, where B_{free} denotes the free bandwidth in the cell.

When a real-time SF x of MS m requests bandwidth, BS releases the previous quasi-reserved bandwidth for MS m and recalculates B_{free}. Here, MS m may be a handover or local one. If B_{free} meets the requirement of SF x, SF x is admitted; otherwise it is rejected.

As for non-real-time SF, based on the quasi-reservation concept, it can occupy the quasi-reserved bandwidth temporarily when the free bandwidth is insufficient and real-

```
if (SF x of MS m is a real-time SF)
{
   if (the quasi-reserved bandwidth for MS m is occupied
                                        by non-real-time SFs)
   {
      deactivate the non-real-time SFs through DSC exchanges;
   }
   release the previous quasi-reserved bandwidth for MS m;
   B_free = B_free + B_quasi-reserved ;
   // B_quasi-reserved is the quasi-reserved bandwidth for MS m
   if (B_x <= B_free)     // SF x requests the bandwidth B_x
   {
      accept SF x;
      B_free = B_free  -  B_x ;
   }
   else   reject SF x;
}
else     // SF x of MS m is a non-real-time SF
{
   if (B_x <= B_free)
   {
      accept SF x;
      B_free = B_free  -  B_x ;
   }
   else if (the quasi-reserved bandwidth for MS m is idle)
   {
      B_free = B_free + B_quasi-reserved ;
      if (B_x <= B_free)
      {
         accept SF x;
         B_free = B_free  -  B_x ;
         mark SF x occupying the quasi-reserved bandwidth;
      }
      else   reject SF x;
   }
   else   reject SF x;
}
```

Figure 3. Admission control policy.

time SFs are not using the reserved bandwidth. Once real-time SFs arrive, non-real-time SFs must release the reserved bandwidth occupied by them for real-time SFs. These operations can be realized by BS initiating DSC message to change the state of non-real-time SFs to be inactive. Then, after a certain backoff time, non-real-time SFs re-request bandwidth or piggyback bandwidth request with data.

IV. Performance Simulation

To evaluate the performance of the proposed DBQRS, we design a simulation model with OPNET Modeler and bring two-phase activation scheme (TPAS) [1][2], adaptive bandwidth reservation scheme (ABRS) [10] and DBQRS into comparisons. Our simulation environment is composed of 7 hexagonal cells with 70 local MSs and 30 handover MSs per cell. Our evaluation is based on the central cell. As defined in IEEE 802.16e standard, five types of data delivery services, UGS, RT-VR, ERT-VR, non-real-time variable rate (NRT-VR) service and best effort (BE) service, are considered. The traffic models of corresponding applications applied to the simulation are shown in Table II. The weighting coefficients are set as follows: α_1=1 for UGS, α_2=0.8 for RT-VR/ERT-VR, β_{in}=1 for the incoming handover MSs, β_{stay}=0.5 for the local MSs and β_{out}=0.2 for the outgoing handover MSs.

Figs. 4 and 5 illustrate the effects of diverse schemes on the new real-time SFs in terms of new SF blocking rate (NSBR) and access delay, respectively. Here, access delay is defined as the time between the MS sending bandwidth request message for the SF and the SF obtaining its desired bandwidth. Due to reserving bandwidth for new real-time SFs in the DBQRS, these SFs can obtain required bandwidth as soon as possible; thereby the NSBR and the access delay are reduced. The bandwidth reservation only for admitted SFs in the TPAS causes that the most real-time SFs cannot obtain desired bandwidth, especially when more SFs arrive. The ABRS doesn't reserve bandwidth for new real-time SFs, so that both NSBR and access delay are higher than those of the DBQRS.

In Fig. 6, the handover SF dropping rate (HSDR) of DBQRS is lower than that of TPAS and ABRS, especially

TABLE II. Traffic Models Used in the Simulation.

Traffic Type	Real-time traffic		
	UGS	RT-VR	ERT-VR
Application	Voice	Video	VoIP with silence suppression
Inter-packet Time	Constant mean: 100 ms	Gamma mean: 35-90 ms std dev: 10 ms	Exponential mean: 50-100 ms
Packet Size	Constant mean: 64 bytes	Gamma mean: 64 bytes std dev: 3 bytes	Exponential mean: 32 bytes
Traffic Type	Non-real-time traffic		
	NRT-VR		BE
Application	File transfer		E-mail
Inter-packet Time	Geometric mean: 200 ms		Exponential mean: 3600 ms
Packet Size	Pareto mean: 1024 bytes shape parameter: 2		Exponential mean: 500 bytes

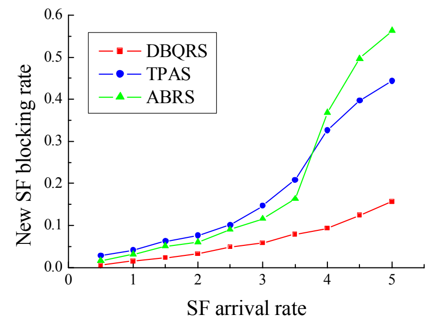

Figure 4. New SF blocking rate.

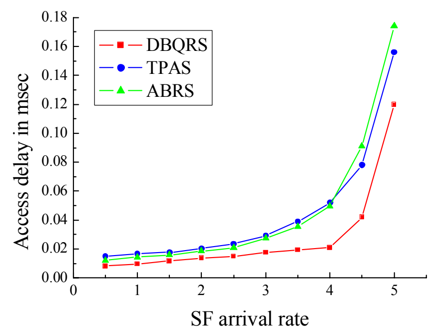

Figure 5. Access delay.

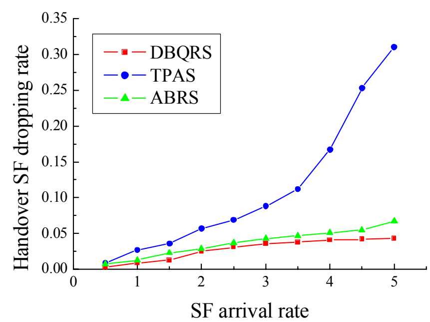

Figure 6. Handover SF dropping rate.

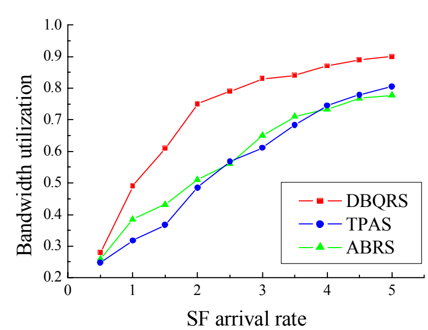

Figure 7. Bandwidth utilization.

compared with that of TPAS. In the TPAS, bandwidth isn't reserved for handover SF dedicatedly. When the overall traffic load is heavy, the bandwidth requirement of handover SF is satisfied difficultly, which results in higher HSDR.

In the DBQRS, though bandwidth is reserved for each MS with real-time SFs like in ABRS, the reserved bandwidth can be assigned to non-real-time SFs. When real-time SFs arrive, BS can control these non-real-time SFs to release the reserved bandwidth. As shown in Fig. 7, the bandwidth utilization is maximized by the DBQRS.

V. CONCLUSIONS

In this paper, considering that no appropriate bandwidth reservation scheme was specified for real-time services in IEEE 802.16e standard, we design the DBQRS and the corresponding admission control policy. According to the handover probability, the traffic arrival probability and the desired bandwidth of traffics, bandwidth is quasi-reserved for mobile and fixed wireless real-time multimedia services in 802.16e networks. Moreover, the reserved bandwidth can be adjusted dynamically. In addition, when the reserved bandwidth is idle, it can be occupied by non-real-time service; when real-time service arrives, the reserved bandwidth can be released. The proposed scheme not only provides QoS guarantee for real-time services, but also ensures the fairness of admitting handover and new real-time services. The simulation results demonstrate that the proposed scheme achieves low NSBR and HSDR, low access delay for new real-time service as well as high system bandwidth utilization.

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