Dynamic Bandwidth Reservation Admission Control Scheme for the IEEE 802.16e Broadband Wireless Access Systems

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***Abstract*—The IEEE 802.16e Broadband Wireless Access (BWA) system is developed to cater for the rapidly growing requirement for multimedia wireless services. Since the heterogeneous services provided by the system are connection-oriented, admission control and associated resource reservation (RR) mechanisms are needed to achieve desired quality of service (QoS). In this paper, we develop a dynamic bandwidth reservation admission control scheme for the IEEE 802.16e system. In the proposed scheme, we set some overall reserved resource as admission guard bandwidth, which is dynamically adjusted according to the bandwidth request of on-going real-time variable-bit rate (VBR) services in addition to guaranteeing the resource requirement of potential handoff services. We also propose an analytical traffic model to evaluate the scheme. The results prove that our scheme can satisfy the bandwidth request of real-time VBR services and improve the system bandwidth utilization efficiently while guaranteeing the QoS requirements of all services at the same time.**

I. INTRODUCTION

The IEEE 802.16e [1] Broadband Wireless Access (BWA) system is promising to provide always-on high-speed Internet access. That Internet access will spur a rapid growth in the use of multimedia services, especially the real-time variable-bit rate (VBR) services. The real-time VBR services, which provide the opportunity as well as challenge to the resource utilization of the IEEE 802.16e system, require the allocation of sufficient resource to guarantee their desired quality of service (QoS). As the key steps in QoS guarantees of heterogeneous services, effective admission control and associated resource reservation (RR) policies are needed by the IEEE 802.16e system. Unfortunately, the standard [1] does not indicate a complete solution. In this paper we develop a *Dynamic Bandwidth Reserving Admission Control* (DBRAC) scheme for the IEEE 802.16e system to solve this problem.

Although admission control for wireless networks has been intensively studied, the strategy in [2, 3] is the only scheme exclusively for the IEEE 802.16 system. The scheme accepts each service based on its Minimum Reserved Traffic Rate (*MinTR*) and thus can not satisfy the bandwidth request of real-time VBR services. In addition, due to no consideration of handoff traffics, the scheme does not adapt to the IEEE 802.16e system which supports mobility.

The broadly used handoff priority-based admission control is guard bandwidth scheme, in which a portion of bandwidth is reserved extensively for handoff purpose. Epstein and Schwartz [4] compare different reservation strategies for heterogeneous types of traffics with identical guard bandwidth size for each traffic flow. The scheme proposed in [5] sets different guard sizes for different service classes. In above schemes, however, the guard bandwidth for a certain service class does not change along with the traffic state and thus results in low bandwidth utilization. Dynamic guard bandwidth schemes are introduced to improve system performance. Naghshineh and Schwartz [6] develop a theoretical model to compute the resource requirements of handoff calls. Yu and Leung [7] propose a dynamic strategy based on periodical queries of neighboring base stations (BS) about the information of potential handoff traffics. The scheme in [8] is shown to be general enough to include previously known guard bandwidth schemes as special cases. However, all the schemes above only aim to satisfy the QoS in terms of call blocking probability.

In our DBRAC scheme, we set an overall reserved guard bandwidth to satisfy the bandwidth request of both real-time VBR services and handoff traffics. The unique characteristic of our scheme is that the overall reserved resource is adjusted flexibly according to the bandwidth request of on-going real-time VBR services besides the resource requirements of potential handoff traffics. Performance evaluation proves that the DBRAC scheme can satisfy the QoS requirements of all services while improving the bandwidth utilization of the system. The DBRAC scheme is adapt to any multiple-class services wireless networks, which employ real-time VBR traffics.

The remainder of this paper is organized as follows. We propose the detailed rational of the DBRAC scheme in section II. In section III, we develop a traffic model for the IEEE 802.16e system to analyze the performance of the admission control schemes. Section IV provides simulation results and discussions. Section V concludes the paper.

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II. Bandwidth Reservation Admission Control Scheme

A. *Overview of the IEEE 802.16e service classes*

The IEEE 802.16e standard defines five types of service classes which are characterized by their distinct levels of QoS requirements, as listed in Table I.

Since all the communication in the IEEE 802.16e system is connection-oriented, a logical connection must be set up and sufficient bandwidth resource ($B_{reserved}$) should be reserved to guarantee the desired QoS before any service flow can be admitted. The reserved resource $B_{reserved}$ is determined by the characteristics of the service classes.

The UGS is provided for real-time constant-bit rate (CBR) traffics that generate fixed-sized data packets periodically. Therefore, the bandwidth allocated to UGS is fixed and characterized by its Maximum Sustained Traffic Rate (*MaxTR*).

The rtPS is designed to support real-time VBR services which produce constant-quality video by keeping the output traffic rate to change from frame to frame. Therefore, the bandwidth reservation for rtPS is the challenge for admission control schemes. The *MaxTR* and *MinTR* are the upper and lower bounds of its bandwidth requirements, respectively. The resource utilization is low if bandwidth is allocated according to the *MaxTR* value. On the other side, the services will always be in poor quality if the bandwidth is assigned with *MinTR*. Hence, the resource reserved to rtPS should be in the range of [*MinTR, MaxTR*]. The ErtPS supports similar applications as the rtPS does and they have almost the same QoS requirements.

Since the applications belonging to the nrtPS are non-time-sensitive and can tolerate longer delay, it is fine to satisfy the *MinTR* only.

The BE has no bandwidth or delay requirements and its $B_{reserved}$ can be set to zero.

TABLE I. IEEE 802.16E QOS REQUIREMENTS AND APPLICATIONS

Service Class	Key QoS parameters	Applications
Unsolicited Grant Service (**UGS**)	• Maximum Sustained Traffic Rate • Maximum Latency • Jitter Tolerance	VoIP
real-time Polling Service (**rtPS**)	• Minimum Reserved Traffic Rate • Maximum Sustained Traffic Rate • Maximum Latency	Streaming Audio or Video
Extended Real-Time Polling Service (**ErtPS**)	• Minimum Reserved Traffic Rate • Maximum Sustained Traffic Rate • Maximum Latency • Jitter Tolerance	VoIP with Activity Detection
non-real-time Polling Service (**nrtPS**)	• Minimum Reserved Traffic Rate • Maximum Sustained Traffic Rate	FTP
Best Effort (**BE**)	• Maximum Sustained Rate	Data Transfer, Web Browsing,

Furthermore, the IEEE 802.16e protocol defines the feature of mobility support and thus each service class includes two traffic types: new connections generated in the current cell and handoff connections from other cells.

B. *Dynamic Bandwidth Reservation Admission Control Scheme*

According to the analysis above, there are two difficulties in designing admission control and resource reservation strategies for the IEEE 802.16e network. One is to set the reserved resource for real-time VBR traffics while utilizing the bandwidth efficiently. The other is to set aside a certain number of resources for handoff purpose to provide higher probability in admission for handoff traffics.

In our DBRAC scheme, those two problems are solved as follows. In order to avoid data loss of rtPS traffics, we reserve a portion of bandwidth in the range of [0, *MaxTR- MinTR*] for each of the traffics besides its *MinTR*. The sum of all these excess resource is referred to as R_{rt_vbr}. We provide handoff traffics with higher priority by reserving some certain of bandwidth resource (R_{hf}) exclusively for them. Since superfluously reserved resources lower the utilization of bandwidth, we introduce an overall reserved bandwidth called R as the function of R_{rt_vbr} and R_{hf} (i.e. $R=F(R_{rt\_vbr}, R_{hf})$). In our scheme, we set R to be the maximal one between R_{rt_vbr} and R_{hf} as shown in (1). The scheme performances for different $F(\cdot)$ will be studied in our future research.

$$R = \max\left(R_{rt\_vbr}, R_{hf}\right) \qquad (1)$$

Whenever a new (handoff) service flow is generated, the mobile subscriber station (MSS) sends a request message carrying the QoS parameters to the BS of the reference cell in the IEEE 802.16e system. Then our DBRAC algorithm makes the admission decision like this: if the available bandwidth (C-BW_{used}) for a new traffic exceeds the sum of its minimal required resource $B_{reserved}$ and the overall reserved bandwidth R, the traffic will be admitted, otherwise it will be rejected; the handoff traffic is rejected only when the available bandwidth can not satisfy its $B_{reserved}$. Let C donate the total bandwidth of the reference cell and BW_{used} donate the sum of $B_{reserved}$ of all on-going traffic flows. Thereby, the currently available bandwidth is represented by C-BW_{used}. And the $B_{reserved}$ for each service class is described in (2) according to the analysis above.

$$B_{reserved} = \begin{cases} MaxTR & , for \ \ UGS \\ MinTR & , for \ \ rtPS, ErtPS, nrtPS \\ 0 & , for \ \ BE \end{cases} \qquad (2)$$

In the DBRAC scheme, the overall reserved resource R is dynamically adjusted according to the current real-time VBR traffics load and handoff connections state. Therefore the bandwidth requirements for all types of services can be guaranteed while the resource utilization of the system is improved. In the following of this section, we present the details about the determination of the two important portions of R: R_{rt_vbr} and R_{hf}, respectively.

C. Resource reserved for real-time VBR services

In our DBRAC strategy, according to the definition in the previous subsection, R_{rt_vbr} can be expressed as the following equation:

$$R_{rt\_vbr} = \sum_{all\ real-time\ VBR\ connections} \beta * (MaxTR - MinTR) \quad , \beta \in [0,1] \qquad (3)$$

where β is a nonnegative number less than one and its value determines the system performance. If β is set to be identical for all real-time VBR connections, those connections whose bandwidth requests change in a wide range get more reserved resources. Without loss of fairness, β should be defined according to the variety of bandwidth request of each service flow as follows.

In order to determine β, in our scheme, we define a bandwidth variety factor δ for real-time VBR services to stand for their variety degree of bandwidth request as:

$$\delta = \frac{MaxTR - MinTR}{MinTR} \qquad (4)$$

It can be found that the big value of δ indicates that the bandwidth request changes in a wide range and vice versa. Then β is calculated as:

$$\beta = \begin{cases} \beta_{reference} & , if \quad \delta \le \delta_{TH} \\ \beta_{reference} * \dfrac{\delta_{TH}}{\delta} & , if \quad \delta > \delta_{TH} \end{cases} \qquad (5)$$

where δ_{TH} is threshold for δ and it can be set to the average value of δ of all real-time VBR service flows in the IEEE 802.16e system; the reserved bandwidth ratio factor $\beta_{reference}$ is determined according to the QoS requirements and call blocking probability.

D. Resource reserved for handoff purpose

The calculation of R_{hf} is based on the historic traffic information. The reason why we do not query neighboring cells for information of potential handoff traffics is to decrease the signaling traffic and complicacy of the scheme. R_{hf} is calculated based on the following assumptions:

- New (handoff) traffics of each service class are generated independently according to Poisson distribution with different arrival rate values.
- The channel holding times for new (handoff) traffics of each service classes are independent exponential distribution with different expectations.

Based on the above assumptions, the handoff traffics of a single service class i can be modeled as a one-dimensional Markov chain in which the state variable is the handoff connection number n. If we let $B_{i,min}$ donate the average Minimum Reserved Traffic Rate of service class i, the state space $S_{i,h}$ of the Markov chain is:

$$S_{i,h} = \{ n \mid 0 \le n * B_{i,\min} \le C \} \qquad (6)$$

We future assume that the statistical value of arrival rate is $\lambda_{i,h}$ and the average channel holding time is $1/\mu_{i,h}$, respectively. According to queuing theory, we can have the stationary probability $P_{i,h}(n)$ for state n in the Markov chain as:

$$P_{i,h}(n) = \left(\rho_{i,h}{}^{n} / n!\right) \Big/ \sum_{j=0}^{J} \left(\rho_{i,h}{}^{j} / j!\right) \qquad (7)$$

where

$$J = \lfloor C / B_{i,\min} \rfloor, \ \rho_{i,h} = \lambda_{i,h} / \mu_{i,h}$$

Let $E_{i,h}$ donate the expectation of handoff connection number n, then $E_{i,h}$ is given by:

$$E_{i,h} = \sum_{n=0}^{J} n * P_{i,h}(n) \qquad (8)$$

In our scheme, the system is supposed to admit at most $E_{i,h}$ handoff traffics of class i. Given there are $A_{i,h}$ handoff connections in current system already, the system can accommodate ($E_{i,h}$ - $A_{i,h}$) more connections. Then, the R_{hf} is expressed as:

$$R_{hf} = \sum_{all\ service\ class\ i} (E_{i,h} - A_{i,h}) * B_{i,\min} \qquad (9)$$

With the results in (3) and (9), the overall reserved bandwidth R in our DBRAC can be obtained from (1). Then a new (handoff) admission request can be accepted or rejected according to the DBRAC scheme described in section II.B.

III. ANALYTICAL MODEL

In this section, we develop an analytical traffic model for the IEEE 802.16e system. With this model, we can derive the relationship between overall reserved bandwidth R and the QoS metrics: new calls blocking probability ($P_{i,nb}$) and handoff calls blocking probability ($P_{i,hb}$). And the theoretical results are verified by intensive simulations in the following section.

A. Traffic model assumptions

As we mention before, the QoS requirements of rtPS and ErtPS are similar and BE services have no bandwidth requirements. Hence, we only take three service classes (i.e. UGS, rtPS and nrtPS) into consideration in our model and call them service class 1, 2 and 3, respectively. Each class has two traffic types: new and handoff (referred to as n for new and h for handoff).

The traffic model is based on the assumptions described in section II.D. The parameters of the traffic model are defined as:

C	The total system bandwidth of the reference cell
R	Overall reserved bandwidth
$B_{i,max}$	Average Maximum Sustained Traffic Rate for service i
$B_{i,min}$	Average Minimum Sustained Traffic Rate for service i (hereinto, $B_{1,min}$=$B_{1,max}$)
$\lambda_{i,n}$	Arrival rate of new calls for service i
$\lambda_{i,h}$	Arrival rate of handoff calls for service i
$1/\mu_{i,n}$	Channel holding time of new calls for service i
$1/\mu_{i,h}$	Channel holding time of handoff calls for service i

$N_{i,n}$ Number of on-going new calls in the cell for service i

$N_{i,h}$ Number of on-going handoff calls in the cell for service i

B. *Traffic model analysis*

According to the assumptions in section II.D, the IEEE 802.16e traffic model can be characterized by a six-dimensional Markov chain, in which the state variable is the connection numbers of call (handoff) traffics of each service class. Then we can get the state space S as:

$$S = \{ \left(N_{1,n}, N_{2,n}, N_{3,n}, N_{1,h}, N_{2,h}, N_{3,h}\right) | \; 0 \le B_n \le C - R \, , B_{all} \le C \} \quad (10)$$

where

$$B_n = \sum_{i=1}^{3} N_{i,n} * B_{i,\min} \, , \; B_{all} = \sum_{i=1}^{3} \left(N_{i,n} + N_{i,h}\right) * B_{i,\min}$$

According to different approaches to calculating R, this model adapts to any guard bandwidth schemes for the IEEE 802.16e system. For example, in our DBRAC scheme R is calculated from (1) and in a fixed guard bandwidth scheme R is set to be a fixed value.

In order to simplify the equations below, we define a new notation: $\overline{g(N_{i,j})}, i \in \{1,2,3\}, j \in \{n,h\}$ to describe the states in space S. Here only the expression of $\overline{g(N_{1,n})}$ is shown and others are defined in the same way.

$$\overline{g(N_{1,n})} = g(N_{1,n}), N_{2,n}, N_{3,n}, N_{1,h}, N_{2,h}, N_{3,h} \quad (11)$$

where

$$g(N_{1,n}) = N_{1,n} \quad or \quad N_{1,n} + 1 \quad or \quad N_{1,n} - 1$$

Let $T(\overline{N_{i,j}}; \overline{N_{i,j} - 1})$ donate the probability transition rate from state ($\overline{N_{i,j}}$) to state ($\overline{N_{i,j} - 1}$) and so on. We obtain the state transition equations of the model as:

$$\begin{cases} T(\overline{N_{i,j}} \; ; \; \overline{N_{i,j} - 1}) = N_{i,j} * \mu_{i,j} & ,\left(0 < B_n \le C - R \, , \; B_{all} \le C \right) \\ T(\overline{N_{i,j}} \; ; \; \overline{N_{i,j} + 1}) = \lambda_{i,j} & ,\left(0 \le B_n < C - R \, , \; B_{all} \le C \right) \end{cases}$$
$$, i \in \{1,2,3\}, j \in \{n,h\} \quad (12)$$

Then the Kolmogorov-Chapman balance equation of the model is expressed as (13). Hereinto, $P(\overline{N_{i,j}})$ donates the steady-state probability of feasible state ($\overline{N_{i,j}}$) in state space S.

$$\sum_{i,j} \left(T(\overline{N_{i,j}} \; ; \; \overline{N_{i,j} - 1}) + T(\overline{N_{i,j}} \; ; \; \overline{N_{i,j} + 1}) \right) * P(\overline{N_{i,j}})$$
$$= \sum_{i,j} T(\overline{N_{i,j} - 1} \; ; \; \overline{N_{i,j}}) * P(\overline{N_{i,j} - 1})$$
$$+ \sum_{i,j} T(\overline{N_{i,j} + 1} \; ; \; \overline{N_{i,j}}) * P(\overline{N_{i,j} + 1}) \quad , i \in \{1,2,3\}, j \in \{n,h\} \quad (13)$$

To compute $P(\overline{N_{i,j}})$, we use iterative approach. Then we obtain the formulas of new call blocking probability ($P_{i,nb}$) and handoff call blocking probability ($P_{i,hb}$) of service i. Here only the probabilities for service class one (i.e. $P_{1,nb}$ and $P_{1,hb}$) are given and the probabilities for other classes are similar.

$$P_{1,nb} = \sum_{B_n + B_{1,\min} > C - R \, , \; i \in \{1,2,3\}, \; j \in \{n,h\}} P(\overline{N_{i,j}})$$
$$P_{1,hb} = \sum_{B_n + B_{1,\min} > C \, , \; i \in \{1,2,3\}, \; j \in \{n,h\}} P(\overline{N_{i,j}}) \quad (14)$$

In (14), we can see that in our scheme, the new call blocking and handoff call blocking probabilities are closely related to the overall reserved bandwidth.

IV. Simulation Results

To verify our analysis, the simulation results are shown and compared with the theoretical ones in this section. We implement the operations of the proposed *Dynamic Bandwidth Reserving Admission Control* (DBRAC) scheme with NS2. To evaluate the effectiveness of the DBRAC scheme, a reference fixed guard bandwidth scheme is employed. They are compared with the same configurations except that the guard bandwidth size of the reference scheme is set to be the average overall reserved bandwidth size of our DBRAC scheme.

We compare the performance of both schemes in terms of new call blocking probability, handoff call blocking probability and system bandwidth utilization ratio. In addition, we define a metric to quantify in what degree the resource request of VBR services can be satisfied.

A. *Simulation configurations*

The traffic flows of UGS, rtPS (ErtPS), nrtPS (which are referred to as service 1, 2 and 3) are generated according to the assumptions described in section II.D. Since BE services have the lowest priority and are always admitted without QoS guarantee, they do not affect the performances of other classes of services. Thereby, BE services are not generated in our simulation. The bandwidth allocation scheme consists of two phases: the minimum reserved resource assurance and excess bandwidth distribution. First, we guarantee the Maximum Sustained Traffic Rate for UGS and the Minimum Reserved Traffic Rate for service classes in the order of rtPS (ErtPS) and nrtPS; then the unused bandwidths are allocated to satisfy the excess bandwidth requests of the current rtPS (ErtPS) and nrtPS services.

The input parameters are C, $B_{i,min}$, $B_{i,max}$, $\lambda_{i,n}$, $\mu_{i,n}$, $\lambda_{i,h}$, $\mu_{i,h}$, $\beta_{reference}$ (for DBRAC scheme), and R(for fixed guard bandwidth scheme). They are set as follows: C=150, $B_{1,min}$=8, $B_{1,max}$=8, $B_{2,min}$,=10, $B_{2,max}$=20, $B_{3,min}$,=5, $B_{3,max}$=10 (the total system bandwidth and traffic rates are in terms of bandwidth units); $\mu_{i,n}$ =1/120s, $\mu_{i,h}$ =1/80s; $\lambda_{i,h}$=70%* $\lambda_{i,n}$. The actual min (max) traffic rate of each connection belonging to service 2 and 3 is uniform distributed in the range of $B_{i,min}(B_{i,max})\pm 5$. We define the system traffic rate ρ as:

$$\rho = \sum_{i=1}^{3}\left(\frac{\lambda_{in}}{\mu_{in}} + \frac{\lambda_{ih}}{\mu_{ih}}\right) \qquad (15)$$

B. Simulation results

Figure 1 and 2 show the new (handoff) call blocking probabilities of UGS and rtPS services as function of ρ for different $\beta_{reference}$ (0.2, 0.4) and arrival rate ratios of new calls i.e. $\lambda_{1,n}$: $\lambda_{2,n}$: $\lambda_{3,n}$ (1:1:1 and 2:1:1), respectively. When the value of $\beta_{reference}$ decreases, the traffic load of all service classes will increase. And the traffic load of each class also increases along with the ratio of its arrival rate to the sum of all arrival rates. The solid lines represent the theoretical values of DBRAC scheme achieved according to the analytical model proposed in section III; the dashed lines are the theoretical values of fixed guard bandwidth scheme. The points in the left parts of the two figures show the simulation values of UGS. In order to keep the figures easy to identify, the simulation values of the rtPS are not given. From the figures, it is clear that the theoretical and simulation results match very well.

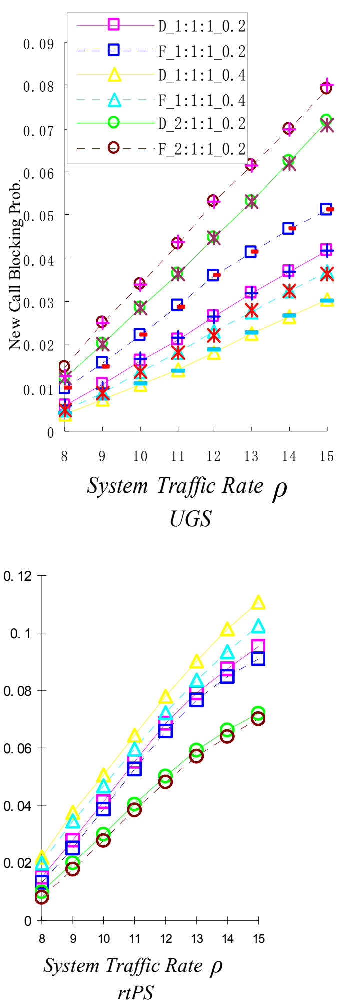

Figure 1. New call blocking probability of UGS and rtPS

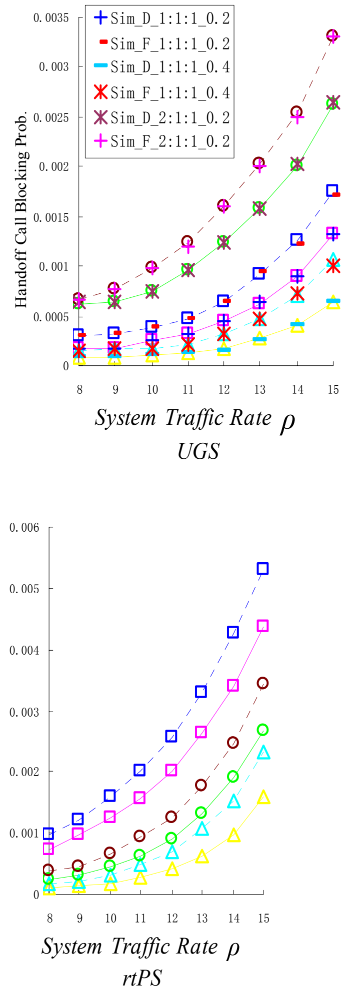

Figure 2. Handoff call blocking probability of UGS and rtPS

In figure 2, it can be seen that the DBRAC can provide better handoff call blocking probability performance in different configurations, while the average amounts of overall reserved resources of the two schemes are same. From another point of view, the DBRAC scheme needs less average reserved resource to obtain target handoff call blocking probability and thus improves the system bandwidth utilization compared with fixed scheme.

In figure 1, for UGS services, the new call blocking probabilities of DBRAC scheme are lower than that of the fixed scheme and the performance gain improves with the increase of rtPS traffic load. That makes sense because the overall reserved bandwidth in our scheme is stricter to rtPS services which have higher average bandwidth requests compared with UGS services. Thereby, a small amount of new call blocking probability performance loss of rtPS services will reduce the new call blocking probability of UGS greatly. Since UGS has fixed-sized bandwidth request, more admission of UGS services results in higher bandwidth utilization. And the dynamically adjusted overall reserved guard bandwidth can give more admission opportunity to services in light system traffic load condition. As shown in figure 3 which represents the bandwidth utilization ratio of the system, the DBRAC scheme can utilize the system resources more efficiently compared with fixed scheme. In addition, the bandwidth utilization ratio upgrades with the increase of UGS traffic load.

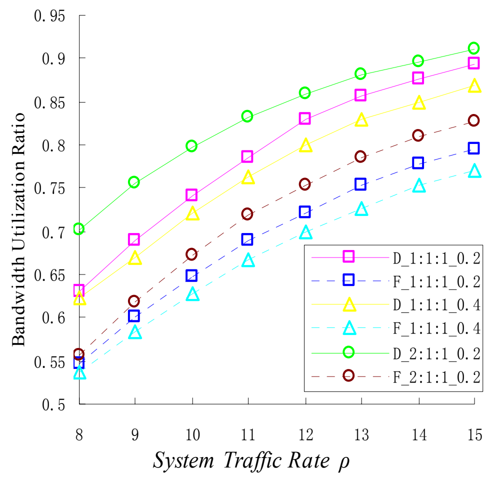

Figure 3. Bandwidth Utilization Ratio

In order to quantify the data loss performance, we define a metric called *BandWidth Assignment Non-Satisfaction Ratio* (BWANSR) to figure out in what degree the bandwidth requirement of real-time VBR is not met:

$$BWANSR = \frac{\sum_{all\ real-time\ VBR\ connections} \max\left(B_{req} - B_{grt}, 0\right)}{\sum_{all\ real-time\ VBR\ connections} B_{req}} \quad (16)$$

where B_{req} describes the bandwidth requested by a connection during each bandwidth allocation and B_{grt} represents actual bandwidth granted to it. According to the definition, the lower value of BWANSR shows the better performance.

Figure 4 proposes comparison results of two schemes on BWANSR as function of system traffic rate. It is clear that our DBRAC scheme reduces the BWANSR compared with the fixed guard bandwidth scheme. The reason is that, in our scheme, we set a stricter overall reserved bandwidth to rtPS services. In addition, the performance gain increases with the rtPS traffic load.

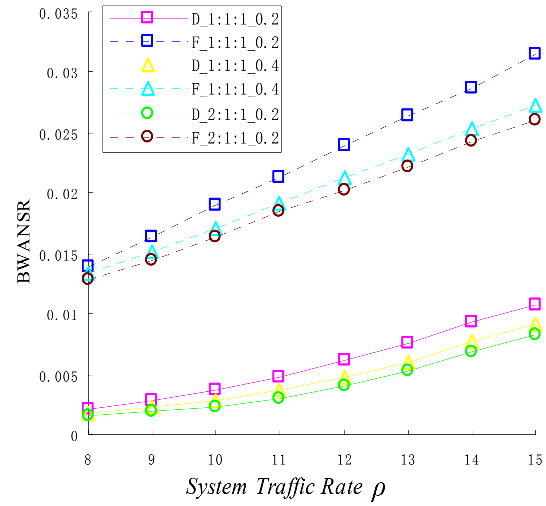

Figure 4. BWANSR of rtPS

V. CONCLUSION

This paper has proposed a new admission control and resource reservation scheme for the IEEE 802.16e system – the DBRAC scheme. In our scheme, the overall reserved guard bandwidth is dynamically adjusted based on not only the bandwidth requirement of potential handoff calls but also the bandwidth request of on-going real-time VBR services. In this paper we also provide an analytical traffic model to compute the performance in terms of call blocking probabilities. Our simulation and analysis shows that the CBRAC policy outperforms the fixed guard bandwidth scheme on guaranteeing the bandwidth request of real-time VBR services and improving the system bandwidth utilization while satisfying the QoS of all types of services.

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