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Efficiency-driven selection of bandwidth request mechanism in broadband wireless access networks

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ABSTRACT

To avoid collisions in WiMAX networks, the connections in Subscriber Stations (SSs) use a request–grant process to acquire transmission resources from the Base Station (BS). In accordance with the IEEE 802.16 standard, the request–grant process is accomplished using either a unicast polling method or a contention request method. In WiMAX systems, the number of bandwidth-request (BR) slots per frame is limited. Thus, to enhance the network performance, the BR slots must be used in the most efficient manner possible. In practical WiMAX systems, the offered network load varies over time, and thus the strict use of either the unicast polling method or the contention request method results in a poor utilization efficiency of the BR slots. Accordingly, the present study proposes a scheme designated as Efficiency-Driven Selection of Bandwidth Request (EDSBR), in which the request–grant mechanism is adjusted dynamically on a frame-by-frame basis in accordance with the network conditions. The performance of the proposed scheme is evaluated by simulations. The results show that EDSBR achieves a more efficient utilization of the BR slots than the unicast polling scheme or the contention request scheme, and therefore yields an improved network performance.

1. Introduction

Wireless local area networks, generally referred to as WiFi networks [1,2], provide a convenient means of accessing the Internet via stationary or mobile devices. However, such networks have insufficient bandwidth to adequately support multimedia services with large bandwidth requirements such as Youtube [3] or Netflix [4]. In addition, WiFi is impractical for outdoor use due to its narrow transmission range. As a result, various Broadband Wireless Access (BWA) technologies have been proposed to support higher data rates and a wider transmission range [5–7]. The IEEE 802.16 set of standards [8,9], referred to conventionally as Worldwide Interoperability for Microwave Access (WiMAX), define the MAC and PHY specifications of the air interface and provide various mechanisms for guaranteeing the Quality of Service (QoS) [10] in terms of the required bandwidth [11] or delay [12]. WiMAX is one of the most widely used BWA technologies around the world and is regarded as a promising solution for the realization of next-generation networks.

In WiMAX, the MAC layer is connection-oriented, i.e. every traffic flow is associated with a particular connection. Furthermore, each connection is associated with a particular service flow, where this flow is characterized by a particular set of QoS parameters. The IEEE 802.16 standards define five different service types, namely Unsolicited Grant Service (UGS), real-time Polling Service (rtPS),

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extended real-time Polling Service (ertPS), non-real-time Polling Service (nrtPS), and Best Effort (BE) service. To meet the QoS requirements of these different service types, and to avoid collisions during transmission, WiMAX employs a request–grant process [13] to request transmission resources. Specifically, when a connection of Subscriber Station (SS) has data to transmit, it first sends a bandwidth-request (BR) to the Base Station (BS). If sufficient transmission resources are available, the BS grants the requested resource to the connection of SS, which then uses this resource to transmit its data. In WiMAX, the request–grant process is performed using one of two different mechanisms, namely unicast polling [14] or contention request [15]. In unicast polling mechanism, the BS would poll each connection and each connection is assigned a specific time slot within which to transmit its BR to the BS; thereby avoiding contention. By contrast, in the contention request mechanism, the connections transmit their BRs using a random access scheme, and thus the BRs contend for the BR slots. In WiMAX networks, the number of BR slots per frame is strictly limited. Thus, the slots must be used in the most efficient manner possible if the system performance is to be enhanced.

Oh and Kim [16] proposed a mechanism for improving the performance of WiMAX systems by determining the optimal number of BR slots required to support the contention request mechanism. However, the proposed scheme did not consider the efficiency with which the BR slots were actually used, and thus the performance improvement was inevitably constrained. Lu et al. [17] presented a method for determining the optimal size of the backoff window used in the contention request mechanism based on the number of active SSs (i.e. the number of SSs intending to transmit a BR). In theory, the optimal backoff value reduces the risk of collision, and therefore increases the likelihood of the BR being successfully received. However, the method proposed in [17] does not consider the optimal number of BR slots per frame and takes no account of their utilization efficiency. As a result, an overflow problem may occur and the utilization efficiency of the BR slots is reduced.

In practice, the contention-request mechanism results in a more efficient use of the BR slots in networks with fewer active connections (i.e., connections intending to transmit a BR), whereas the unicast polling mechanism achieves a higher utilization efficiency of the BR slots in networks with a greater number of active connections. However, in real-world WiMAX systems, the network conditions would vary over time. As a result, the strict use of either the contention-request method or the unicast polling method fails to make the most efficient use of the BR slots. Thus, the ability of the BS to allocate the bandwidth in an optimal manner is constrained. To resolve this problem, the present study proposes a scheme designated as Efficiency-Driven Selection of Bandwidth Request (EDSBR), in which the request–grant mechanism is adjusted adaptively in accordance with the current network conditions. Specifically, the contention request mechanism is employed when the active rate of the connections is less than a certain threshold value (E_{peak_m}), and the unicast polling mechanism is applied otherwise. The performance of the proposed scheme is evaluated both analytically and numerically. It is shown that EDSBR achieves a higher utilization efficiency of the BR slots than the contention request scheme or the unicast polling scheme, and yields an improved system performance as a result.

The remainder of this paper is organized as follows: Section 2 describes the basic principles of WiMAX networks and discusses the unicast polling and contention request mechanisms. Section 3 reviews the related literature in the field. Section 4 introduces the EDSBR scheme proposed in this study. Section 5 presents and discusses the analytical and numerical results. Finally, Section 6 provides some brief concluding remarks.

2. Background

The IEEE 802.16 standards define two operation modes for WiMAX networks, namely the point-to-multipoint (PMP) mode and the mesh mode. In the PMP mode, the SSs transmit their data to the BS and the BS then forwards the data to the destination (see Fig. 1). In other words, all of the data transmissions are processed by the BS and the SSs do not communicate directly with one another. By contrast, in the mesh mode, the SSs are able to transmit their data to the destination directly.

In WiMAX systems, transmissions occur in two different directions, namely from the BS to the SSs (i.e. the downlink direction) and from the SSs to the BS (i.e. the uplink direction) [18,19]. In the downlink direction, the BS is the sole transmitter and the data are transmitted via broadcasting. By contrast, in the uplink direction, all of the SSs are potential transmitters. If multiple SSs transmit their data simultaneously, traffic collisions would occur at the uplink and the system performance would be reduced. Therefore, the WiMAX prescribes the use of a request–grant process to reserve resources in such a way as to avoid collisions. Specifically, when a connection of SS wishes to transmit its data, it first sends a BR message to the BS. If sufficient bandwidth is available, the BS grants the requested resource to the connection of SS and the connection then uses this resource to transmit its data. As described in the previous section, the request–grant process is implemented using one of two different mechanisms, namely unicast polling or contention request.

2.1. Unicast polling

The BS would poll each connection. Thus each connection is assigned a particular time slot in which to transmit its BR to the BS. In other words, unicast polling is contention-free.

2.2. Contention request

The connections use a random access scheme to transmit their BRs to the BS within a specific interval of the uplink subframe, called contention period. Since a random access scheme is used to access the uplink bandwidth, collisions may occur, and thus some form of resolution procedure is required [20–22].

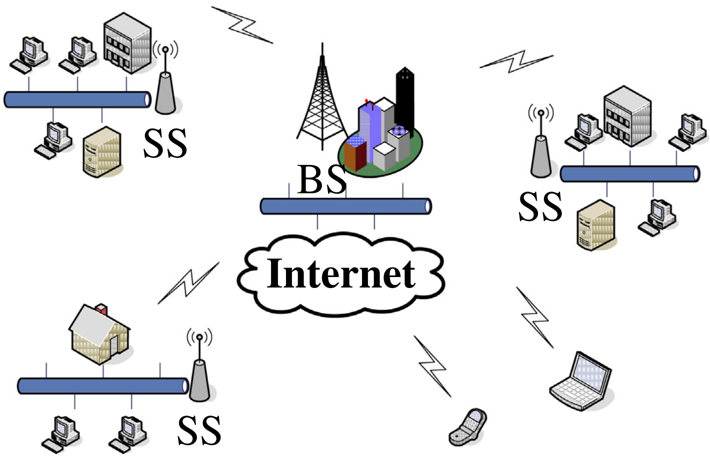

Fig. 1. PMP network topology.

Although unicast polling is contention-free, some connections may not have data to transmit. Thus, the BR slots allocated to them are wasted and the utilization efficiency of the BR slots would be reduced. Similarly, while the probability of collisions in the contention request mechanism can be reduced by means of an appropriate resolution scheme, a certain number of collisions are nevertheless inevitable. Thus some of the BR slots are again wasted and the utilization efficiency of the BR slots would also be reduced. Therefore, both unicast polling and contention request mechanisms would reduce the system performance because BR slots are wasted.

To satisfy the differentiated QoS requirements of WiMAX networks, the IEEE 802.16 standard defines five different service types, namely UGS, rtPS, ertPS, nrtPS and BE.

1. UGS: Used to support real-time applications such as VoIP without silence suppression or T1/E1, in which fixed-size packets are generated on a periodic basis. In supporting UGS services, the BS simply allocates a fixed amount of resources periodically. In other words, the UGS services cannot request additional resources.
2. rtPS: Used to support real-time applications such as MPEG video streaming or IPTV, in which variable-size packets are generated periodically. Generally speaking, rtPS services utilize the unicast polling mechanism to request resources.
3. ertPS: Used to support real-time applications such as VoIP with silence suppression, in which variable-size packets are generated on a periodic basis. ertPS services use either the unicast polling mechanism or the contention request mechanism to request resources from the BS.
4. nrtPS: Used to support delay-tolerant applications such as FTP, which generate variable-size packets on a regular basis. As with ertPS services, nrtPS services use either the unicast polling mechanism or the contention request mechanism to request resources.
5. BE: Used to support applications with no specific QoS requirements, e.g. TELNET. For such applications, resources are requested using either the unicast polling mechanism or the contention request mechanism.

Table 1 summarizes the mechanisms used by the five service types to request resources from the BS.

Table 1
Service types and request–grant mechanism rules.

Service type	Unicast polling	Contention request
UGS	Not allowed	Not allowed
rtPS	Allowed	Not allowed
ertPS	Allowed	Allowed
nrtPS	Allowed	Allowed
BE	Allowed	Allowed

3. Related works

When the connections in a WiMAX system use the contention request mechanism to request resources and more than one connection transmits a BR at the same time, collisions would occur at the uplink. In practice, the collision probability is dependent on the number of the BR slots per frame and the size of the backoff window. The literature contains various proposals for minimizing the probability of BR collisions. For example, the authors in [16] examined the tradeoff between the throughput and the delay of the BR messages, and showed that the optimal number of the BR slots is equal to $2m - 1$, where m is the number of active SSs. However, the utilization efficiency of the BR slots was not considered and thus the system performance may be reduced. For example, in the case where all of the SSs in the WiMAX network are active and transmit BR messages successfully in one frame, the utilization efficiency of the BR slots is always under 50% (i.e. $m/(2m - 1)$). By contrast, if unicast polling is employed, the BS is required to allocate just m BR slots to poll all of the SSs and the utilization efficiency of the BR slots is equal to 100%. In other words, the unicast polling method makes more efficient use of the BR slots; particularly in networks with a greater number of active SSs.

In [17], the authors proposed a method for minimizing the probability of BR collisions by means of a coordinated backoff algorithm, in which the global backoff window size was set equal to the number of the active SSs. However, the optimal number of the BR slots was not considered. Thus, the overflow problem may occur and the utilization efficiency of the BR slots is reduced.

The schemes proposed in [16,17] both result in a poor utilization efficiency of the BR slots, and therefore constrain the system performance. Accordingly, the present study proposes a scheme designated as Efficiency-Driven Selection of Bandwidth Request (EDSBR), in which the utilization efficiency of the BR slots is improved by adaptively adjusting the request–grant mechanism on a frame-by-frame basis in accordance with the network conditions. The details of the proposed scheme are described in the following section.

4. Efficiency-Driven Selection of Bandwidth Request (EDSBR)

In developing the EDSBR scheme, the utilization efficiency of the BR slots is defined as the ratio of the number of the BR slots used to transmit the BRs successfully to the total number of the BR slots allocated by the BS. In the following, the considered service types associated with connections are restricted to ertPS, nrtPS and BE since only these service types support both unicast polling and contention request mechanisms (see Table 1). If unicast polling is selected as the request–grant mechanism, the BS polls all of the connections in the frame. Conversely, if the contention request mechanism is selected, the active connections randomly choose a time slot within the assigned contention period to transmit their BR messages. In addition, every SS could have more than one connection in this study.

Table 2 summarizes the notations used in the following mathematical analysis.

The discussions commence by analyzing the utilization efficiency of the BR slots when the contention request mechanism is employed. Assume that f BR slots are allocated to transmit the BR messages in the frame and m connections are active. Furthermore, to avoid the overflow problem, assume that the backoff window size is equal to the number of the BR slots. Given these assumptions, the probability that one of the f BR slots is successfully used by one of the m connections to transmit its BR message is given by

$$m \times (1/f) \times (1 - 1/f)^{m-1} \tag{1}$$

Since there are a total of f BR slots in one frame, the expected number of slots used to successfully transmit the BRs of all the active connections within the frame is equal to

$$m \times (1/f) \times (1 - 1/f)^{m-1} \times f = m \times (1 - 1/f)^{m-1} \tag{2}$$

From Eq. (2), the utilization efficiency of the BR slots can be obtained as

$$E = m \times (1 - 1/f)^{m-1}/f. \tag{3}$$

The maximum utilization efficiency of the BR slots can be determined by differentiating Eq.(3), i.e.

$$\begin{aligned}
&\frac{dE}{df} = \frac{-m}{f^2} \times \left(\frac{f-1}{f}\right)^{m-1} + \frac{m \times (m-1)}{f^3} \times \left(\frac{f-1}{f}\right)^{m-2} = 0\\
&\frac{-m \times (f-1)^{m-1}}{f^{m+1}} + \frac{(m^2 - m) \times (f-1)^{m-2}}{f^{m+1}} = 0\\
&\frac{(f-1)^{m-2} \times (-mf + m + m^2 - m)}{f^{m+1}} = 0\\
&\frac{(f-1)^{m-2} \times (-mf + m^2)}{f^{m+1}} = 0\\
&-mf + m^2 = 0, i.e., f = m
\end{aligned} \tag{4}$$

From Eq. (4), it is seen that the maximum utilization efficiency of the BR slots is obtained in contention request mechanism when f is equal to m. In other words, the maximum utilization efficiency of the BR slots under the contention request mechanism given m active connections, i.e. E_{peak_m}, is derived from Eqs. (3) and (4) as

$$E_{peak\_m} = (1 - 1/m)^{m-1} \tag{5}$$

As shown in Eq. (5), the maximum utilization efficiency of the BR slots reduces as the number of active connections increases. Furthermore, as shown in Fig. 2, the peak utilization efficiency of the BR slots saturates at a value of approximately 37% given 10 or more active connections in the network. Therefore, we can treat 37% as the maximum bound on the utilization efficiency of the BR slots in WiMAX networks in which the contention request mechanism is used.

In order to allocate the suitable number of the BR slots in a frame, the number of active connections must be acquired. We assume that there are M registered SSs in WiMAX network and every SS has $N_1, N_2, \ldots, N_M$ connections. Therefore, the total number of connections is

$$N = N_1 + N_2 + \ldots + N_M \tag{6}$$

We assume that every connection would send BR message based on ON–OFF model as Fig. 3. Based on ON–OFF model, the probability that connections would send their BR messages is

$$P_{active} = \frac{C_1}{C_1 + C_2} \tag{7}$$

From Eqs. (6) and (7), the expected number of connections which would send BR messages is acquired as follows.

$$N_{active} = N * P_{active} \tag{8}$$

Because BR may collide with others when contention request is employed, the connection would retransmit the BR. Thus, to acquire m, the number of connection which would retransmit BRs must be obtained. From Eqs. (2) and (4), the number of connections which fail to transmit BRs successfully in the frame is derived as follows,

$$\begin{aligned}
N_{fail} &= m - m * (1 - 1/m)^{m-1}\\
&= m * (1 - (1 - 1/m)^{m-1})
\end{aligned} \tag{9}$$

Table 2
Notations used in mathematical analysis.

Notation	Meaning
M	Number of registered SSs
N	Total number of connections
N_{fail}	Number of connections which fails to transmit BRs successfully in one frame
$N_{collision}$	Number of connections which retransmit BRs
m	Number of active connections
f	Total number of BR slots per frame for contention request mechanism
E	Utilization efficiency of the BR slots
E_{peak_m}	Peak utilization efficiency of the BR slots in contention request mechanism given m active connections
P_{active}	The probability that one connection is active
R_{active}	Active rate of the connections in previous frame

Because the connections which fail to transmit BRs successfully are able to become active based on ON–OFF model in next frame, the number of connections which retransmit BRs due to collision would be as follows.

$$N_{collision} = (1 - N_{active}/N) * N_{fail} \quad (10)$$

From Eqs. (8) and (10), m would be derived as follows.

$$m = N_{active} + N_{collision} \quad (11)$$

Therefore, the BS would allocate the BR slots in every frame based on Eq. (11) when the contention request mechanism is employed in EDSBR scheme and the utilization efficiency of the BR slots would be close to E_{peak_m}.

In unicast polling, the BS polls each connection in every frame. Thus, the utilization efficiency of the BR slots is equal to m/N (i.e. the active rate of the connections). In a frame containing few active connections, most of the BR slots are wasted if the unicast polling mechanism is used, and thus the utilization efficiency of the BR slots is very low. Conversely, in a frame containing many active connections, many of the BR slots are wasted as a result of collisions if the contention request mechanism is used. To resolve this problem, the EDSBR scheme is proposed in this study. As described above, when contention request is employed, the maximum utilization efficiency of the BR slots would be E_{peak_m}. Thus, the EDSBR scheme adopts E_{peak_m} as a bound (i.e. a threshold value) in determining which request–grant mechanism should be applied. Specifically, if the active rate of the connections in the previous frame (R_{active}) is greater than or equal to E_{peak_m}, EDSBR instructs the use of the unicast polling mechanism in the current frame and the BS allocates N BR slots for all connections. Hence, the utilization efficiency of the BR slots is equal to

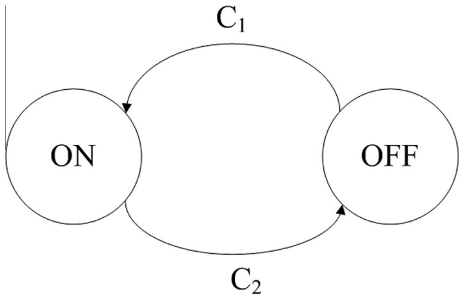

Fig. 3. ON–OFF model.

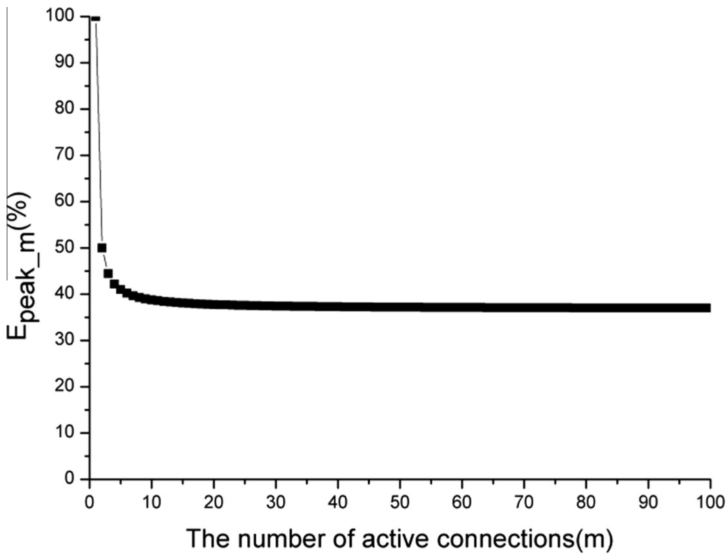

Fig. 2. Peak utilization efficiency of the BR slots in contention request mechanism given different number of active connections.

```
Input: number of active connections in previous frame and number
of registered connections in current frame
Output: request-grant mechanism
Repeat in every frame
    R_active = m/N
    If R_active < E_peak_m then
        Mechanism←contention request
          f = m
    else
          Mechanism←unicast polling
          f = N
    end If
until all SSs leave network system
```

Fig. 4. Pseudocode of EDSBR algorithm.

Table 3
Simulation parameters.

PHY 802.16 transmission power	31.0 dB
Simulation time	100 s
Frame duration	20 ms
TDD-DL duration	10 ms
DCD/UCD broadcast interval	5 s
Service flow timeout interval	15 s

m/N. Conversely, when R_{active} is less than E_{peak_m}, EDSBR instructs the use of the contention request mechanism and sets the number of the BR slots equal to the number of active connections. As a result, the utilization efficiency of the BR slots is close to E_{peak_m}. The pseudocode of the EDSBR algorithm is presented in Fig. 4.

In accordance with the discussions above, the utilization efficiency of the BR slots in EDSBR is obtained as follows.

$$E = \begin{cases} E_{peak\_m}, & R_{active} < E_{peak\_m} \\ R_{active}, & R_{active} \geqslant E_{peak\_m} \end{cases}. \tag{12}$$

Therefore, the EDSBR scheme would achieve a higher utilization efficiency of the BR slots than the strict use of either the unicast polling method or the contention request method.

5. Experimental results and discussion

In this study, the validity of the mathematical analysis presented in Section 4 and the performance of the EDSBR scheme are evaluated by performing Qualnet simulations [23]. In performing the simulations, the PMP topology shown in Fig. 1 was assumed. The major simulation parameters are summarized in Table 3.

Here, two scenarios are used to verify the validity of the mathematical analysis presented in Section 4. In each scenario, WiMAX network has 100 SSs and every SS has at

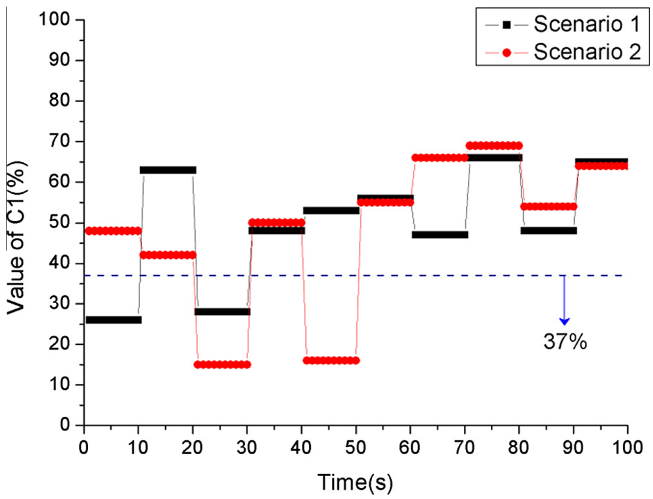

Fig. 5. Value of C_1 for ON–OFF model versus time in scenarios 1 and 2.

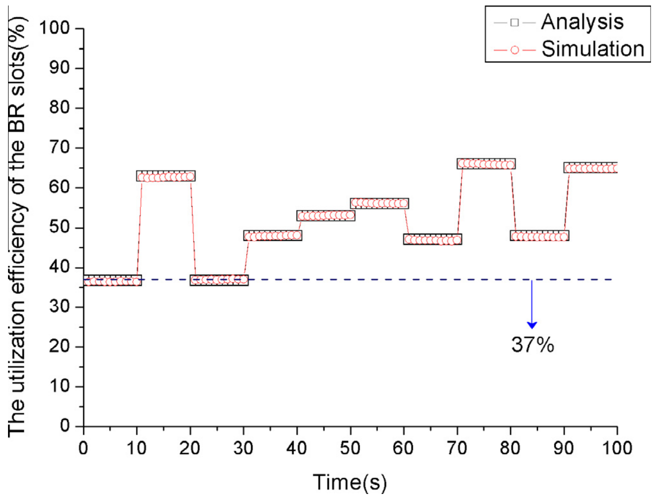

Fig. 6. Comparison of analytical and simulation results for the utilization efficiency of the BR slots in scenario 1.

most 6 connections. To verify the validity of the mathematical analysis, C_1 in ON–OFF model would be changed every 10 s. The value of C_1 is presented with time in Fig. 5 for these two scenarios. In this paper, the sum of C_1 and C_2 would be equal to 1. Therefore, C_1 is able to be regarded as the active rate of the connections. In addition, 37% is regarded as a bound and one dash line whose value of y-axis is equal to 37% is drawn to observe easily in the following figures. Because C_1 is able to be regarded as the active rate of the connections, unicast polling would be employed when C_1 is larger than E_{peak_m} and the utilization efficiency of the BR slots would be larger than E_{peak_m}. When C_1 is less than E_{peak_m}, contention request method would be employed and the utilization efficiency of the BR slots would be close to E_{peak_m}. We are able to see such situation in the following figures.

Fig. 6 compares the analytical and simulation results for the variation of the utilization efficiency of the BR slots. (Note that the analytical results are obtained using Eq. (12).) Simulations are performed for 100 times and the average utilization efficiency of the BR slots is calculated. (Figs. 7–12 are the same.) It is seen that a good agreement exists between the two sets of results for all the time. Thus, the basic validity of the mathematical analysis is presented in Section 4 is confirmed.

Fig. 7 compares the analytical and simulation results for the variation of the utilization efficiency of the BR slots in scenario 2. It is observed that a good agreement still exists between the two sets of results for all the time. Thus, the basic validity of the mathematical analysis presented in Section 4 is once again confirmed. The mathematical analysis presented in Section 4 is verified by Figs. 6 and 7.

To evaluate the performance of the EDSBR scheme, we compare the utilization efficiency of the BR slots under the EDSBR scheme with that under unicast polling and contention request schemes. When unicast polling scheme is employed, the BS would poll all connections in one frame and allocate N BR slots in one frame. When contention request scheme is employed, the BS would allocate $(2m-1)$ BR slots in one frame based on [16] and active connections would choose one BR slot randomly to transmit their BRs. When contention request mechanism is

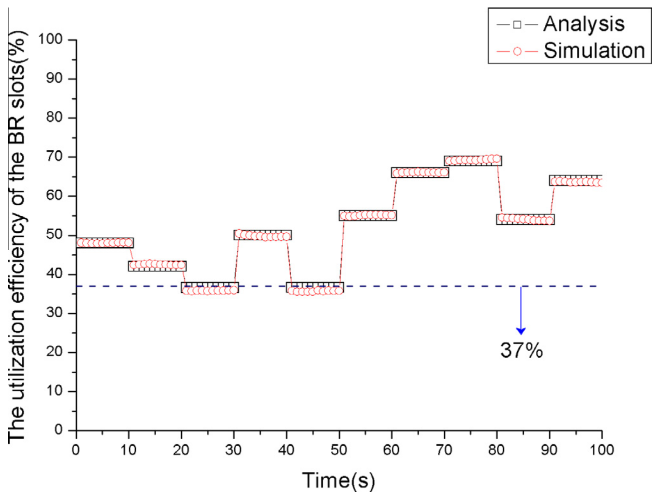

Fig. 7. Comparison of analytical and simulation results for the utilization efficiency of the BR slots in scenario 2.

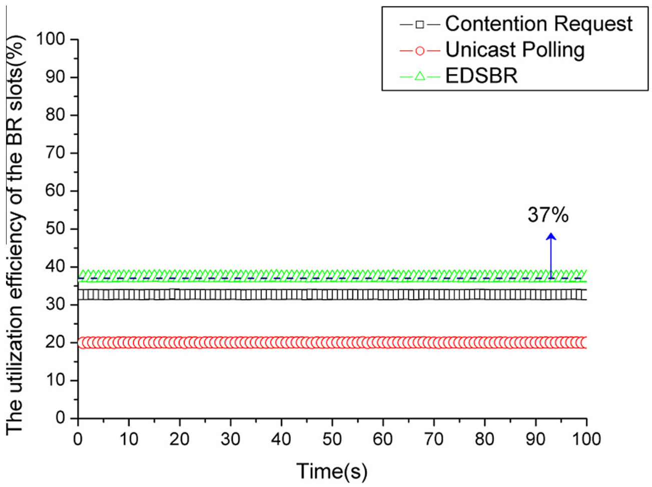

Fig. 8. Utilization efficiencies of the BR slots under EDSBR, contention request and unicast polling schemes given $C_1 = 0.2$.

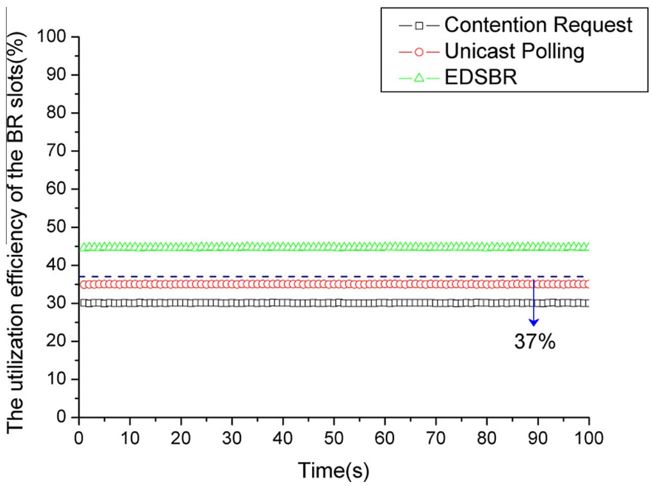

Fig. 9. Utilization efficiencies of the BR slots under EDSBR, contention request and unicast polling schemes given $C_1 = 0.35$.

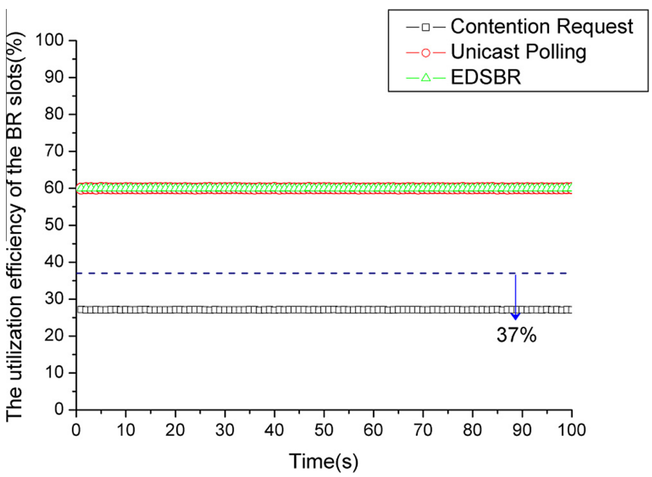

Fig. 10. Utilization efficiencies of the BR slots under EDSBR, contention request and unicast polling schemes given $C_1 = 0.6$.

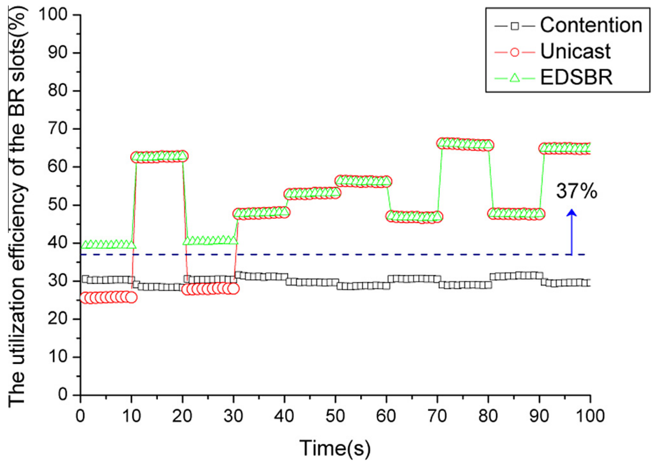

Fig. 11. Utilization efficiencies of the BR slots under EDSBR, contention request and unicast polling schemes in scenario 1.

employed in EDSBR, the BS would allocate *m* BR slots in one frame. Here, the simulation results under these schemes are firstly presented when C_1 is equal to 0.2, 0.35 and 0.6 separately in simulation time.

Fig. 8 compares the utilization efficiencies of the BR slots under the unicast polling, contention request and EDSBR schemes given $C_1 = 0.2$. In Fig. 8, because C_1 is equal to 0.2, that means the active rate of the connections would be close to 20%. Therefore, the utilization efficiency of the BR slots under unicast polling scheme would be close to 20%. As described in Section 4, the EDSBR scheme applies the contention request mechanism when the active rate of the connections is less than E_{peak_m}, and the unicast polling mechanism otherwise. In Fig. 8, the active rate of the connections is less than E_{peak_m}. Thus, EDSBR guarantees that the utilization efficiency of the BR slots is close to E_{peak_m} (Here, i.e. 37%) and the utilization efficiency of the BR slots under EDSBR scheme is larger than that under contention request scheme. The results presented in Fig. 8 show that the proposed EDSBR scheme consistently achieves a higher utilization efficiency of the BR slots than the unicast polling scheme and contention request scheme. In other words, the EDSBR scheme achieves a better utilization efficiency of the BR slots under low active rate of the connections.

Fig. 9 presents the utilization efficiencies of the BR slots under the unicast polling, contention request and EDSBR schemes given $C_1 = 0.35$. As described above, that means the active rate of the connections is close to 35% and thus the utilization efficiency under unicast polling is also close to 35%. Because C_1 is close to E_{peak_m}, the EDSBR scheme would employ either unicast polling or contention request mechanism based on the active rate of the connections. (Note that the active rate of the connections would be higher than E_{peak_m} because some connections would retransmit their BRs due to collision in the EDSBR scheme.) Therefore, the utilization efficiency of the BR slots under the EDSBR scheme would be higher than E_{peak_m} and still larger than that under contention request scheme. The results presented in Fig. 9 show that the proposed EDSBR scheme consistently achieves a higher utilization efficiency of the BR slots than the unicast polling scheme and

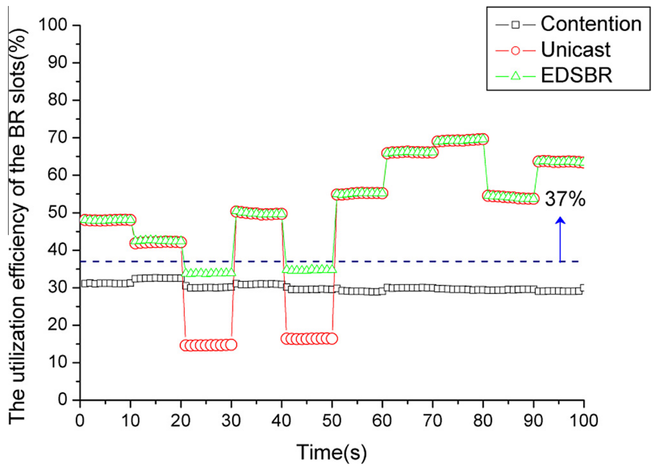

Fig. 12. Utilization efficiencies of the BR slots under EDSBR, contention request and unicast polling schemes in scenario 2.

contention request scheme. In other words, the EDSBR scheme achieves a better utilization efficiency of the BR slots under moderate active rate of the connections.

Fig. 10 presents the utilization efficiencies of the BR slots under the unicast polling, contention request and EDSBR schemes given $C_1 = 0.6$. As described above, that means the active rate of the connections is close to 60% and thus the utilization efficiency of the BR slots under unicast polling would be close to 60%. Because the active rate of the connections is higher than E_{peak_m}, the EDSBR would always employ unicast polling to transmit BRs. Therefore, the utilization efficiency of the BR slots under the EDSBR scheme would be almost the same as that under unicast polling scheme. The results presented in Fig. 10 show that the proposed EDSBR scheme almost achieves the same utilization efficiency of the BR slots as unicast polling scheme and a higher utilization efficiency of the BR slots than the contention request scheme. In other words, the EDSBR scheme achieves a better utilization efficiency of the BR slots under high active rate of the connections.

Actually, the network conditions in WiMAX would vary over time. Thus, the active rate of the connections would vary over time and the performance of EDSBR is also evaluated in scenarios 1 and 2 as described above. Figs. 11 and 12 present the utilization efficiencies of the BR slots under the contention request, unicast polling and EDSBR schemes in scenarios 1 and 2 separately. In scenarios 1 and 2, when the active rate of the connections is larger than E_{peak_m}, the utilization efficiency of the BR slots under the EDSBR scheme is almost the same as that under unicast polling scheme. However, when the active rate of the connections falls below E_{peak_m}, the EDSBR scheme maintains a utilization efficiency of the BR slots close to E_{peak_m} (Here, i.e. 37%), whereas that under unicast polling scheme reduces in accordance with the reduction in the active rate of the connections. In addition, contention request scheme would always have worse utilization efficiency of the BR slots than the EDSBR scheme. Thus, the results presented in Figs. 11 and 12 demonstrate that the EDSBR scheme consistently outperforms the unicast polling and contention request scheme in WiMAX networks.

6. Conclusion

In WiMAX networks, the connections request resources from the BS using either a unicast polling mechanism or a contention request mechanism. In the unicast polling mechanism, the BS polls each connection and each connection is assigned a specific time slot within which to transmit its BR to the BS. However, since not all of the connections have data to transmit (particularly under low active rate of the connections), many of the BR slots are wasted and the utilization efficiency of the BR slots would be reduced. In the contention request mechanism, the active SSs transmit BR messages to the BS during a predetermined interval, called contention period, in each frame. However, the SSs access the uplink bandwidth using a random access scheme, and thus collisions may occur (particularly under high active rate of the connections). As a consequence, some of the BR slots are again wasted and the utilization efficiency of the BR slots would be reduced. Accordingly, this study has proposed a scheme designated as Efficiency-Driven Selection of Bandwidth Request (EDSBR), in which the request–grant mechanism is adjusted adaptively on a frame-by-frame basis in accordance with the current network conditions. Specifically, the contention request mechanism is employed when the active rate of the connections is less than a critical bound value (E_{peak_m}), and the unicast polling mechanism is applied otherwise. The simulation results have shown that the EDSBR scheme consistently outperforms the unicast polling scheme and contention request scheme in terms of achieving a higher utilization efficiency of the BR slots. Importantly, by improving the efficiency with which the BR slots are used, the BS is able to allocate the network resources in a more effective manner, and thus the overall system performance is improved.

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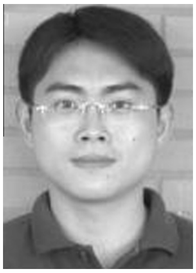

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