A Novel Bandwidth Request Mechanism for IEEE 802.16j Networks

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Abstract

IEEE 802.16e has been deployed widely in the world. However, using IEEE 802.16e in a metropolis may suffer the shadow-of-building problem that prevents a Mobile Station (MS) from receiving signals of a Base Station (BS). Accordingly, IEEE 802.16j is proposed to resolve the shadow-of-building problem with a Relay Station (RS) to both overcome the coverage-hole problem and extend the signal coverage range of a BS. Since MSs use IEEE 802.16j to contend for bandwidth before transmitting data, they incur the collision when sending the bandwidth requests simultaneously. The collisions will delay data transmission time and make a negative impact on the performance. In this paper, we propose the Consecutive Bandwidth Request Scheme (CBRS) to avoid the collisions in IEEE 802.16j. The CBRS allows the MS to transmit multiple Ranging Codes in order to increase the probability of gaining bandwidth in the bandwidth contention when making the bandwidth request. The simulation results show that the CBRS can greatly increase throughput, decrease bandwidth contention times, and shorten data transmission time.

Key Words: IEEE802.16j, Bandwidth Request Scheme, Multi-Hop Relaying, WiMAX

1. Introduction

IEEE 802.16 is a protocol standardized by Institute of Electrical and Electronics Engineers (IEEE) to allow for communication over Wireless Metropolitan Area Network (WMAN). IEEE 802.16 [1,2] not only has a coverage range larger than IEEE 802.11, but also supports Quality of Service (QoS). In the ideal case, IEEE 802.16 can transmit data over 50 kilometers and have throughput up to 75 Mbps. To speed up the development of IEEE 802.16 technology and the popularization of the related products in the market, many industries setup the World Interoperability for Microwave Access (WiMAX) Forum [3] in 2001. Since IEEE 802.16 [2] only supports fixed stations, IEEE regulates IEEE 802.16e [4] in 2005 for mobile stations.

Based on IEEE 802.16e, IEEE 802.16j [5] is proposed in 2005 because the distance between a Mobile Station (MS) and a Base Station (BS) will degrade signal quality between them. IEEE 802.16j uses the Relay Station (RS) to extend the signal coverage range of a BS. Many BSs have to be deployed in order to extend the signal coverage range in the original design of IEEE 802.16e. However, the high price of BS makes the deployment of many BSs a costly operation. Considering the cost, RS is used to replace BS because a RS is cheaper than a BS.

The BS is referred to as the Multihop Relay-BS (MR-BS) in IEEE 802.16j. A RS has the hardware architecture simpler than a MR-BS. A RS works merely in the PHY layer and the MAC layer. In Figure 1, the RS can relay the MR-BS control message and transmit data to the area beyond the signal coverage range of a MR-BS. Besides, deploying the RS inside the signal coverage range of a MR-BS as shown in Figure 2 can improve the signal quality, increase throughput of MSs, and enhance the system capacity without changing the design of MSs.

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It always is a tough issue to increase throughput in wireless networks. Currently, the main reason behind throughput degradation in wireless networks is the collisions resulting from different users intend to transmit data at the same time. The collisions not only degrade throughput but also delay data transmission time. Although widely deploying RSs can support more users than a MR-BS, multitudinous users will increase the probability of collisions in IEEE 802.16j. However, the IEEE 802.16j specification does not suggest a practicable solution against the collision. In this paper, we propose the Consecutive Bandwidth Request Scheme (CBRS) to increase the bandwidth request transmission success rate in IEEE 802.16j. Through the simulation, we verify that the proposed CBRS can increase throughput, decrease bandwidth contention times, and shorten data transmission time.

This paper is organized as follows. In section 2, we briefly introduce IEEE 802.16j as the background. In section 3, we explain the proposed CBRS. In section 4, we conduct the simulation with the CBRS to verify its benefits in comparison with the original IEEE 802.16j. Finally, we conclude this paper.

2. Background

2.1 IEEE 802.16j Overview [6–8]

In IEEE 802.16j, RS can be divided into the transparent RS and the non-transparent RS. The transparent RS can relay the MR-BS control message to a MS and make the MS believe that it was receiving the message from the MR-BS directly. Accordingly, the MS is not aware of the transparent RS. Usually, the transparent RS is deployed inside the signal coverage range of the MR-BS to improve signal quality and increase the user’s data transmission rate.

Conversely, the non-transparent RS not only relays the MR-BS control message from the MR-BS to the MS, but also transmits the MR-BS control message generated by itself. Accordingly, the MS will think that the non-transparent RS is another MR-BS. The non-transparent RS is usually deployed at the border district of the signal coverage range in order to extend the signal coverage range of the BS.

2.2 Principle of IEEE 802.16j Data Transmission

In IEEE 802.16j, data transmission is achieved by encapsulating data in a frame of the MAC layer. A frame can be further divided into the Downlink (DL) and the Uplink (UL). The DL is used by the MR-BS or the RS to transmit data to the RS or the MS, while the UL is used by the MS or the RS to transmit data to the RS or the MR-BS. In the UL, a certain slot is assigned the Ranging Slot. The Ranging Slot can be used by the MR-BS to carry the Bandwidth Request (BR) to the RS.

In IEEE 802.16, the MS has to transmit the BR to the MR-BS before the data transmission operation can be executed. After the MR-BS receives the BR from the MS, the MR-BS has to schedule the BR to reserve bandwidth for the MS. In IEEE 802.16j, the Code Division Multiple Access (CDMA) modulation method is used to transmit the BR. When the MS transmits the BR, it chooses a CDMA Code and encodes the BR with the chosen CDMA Code before transmitting the BR to the MR-BS. With the CDMA method, multiple MSs can successfully transmit data at the same time if they choose
different CDMA Codes. In IEEE 802.16j, the CDMA Code is called the Ranging Code.

In Figure 3, the MS waits for the Uplink Map (UL_MAP) message from the MR-BS and the UL_MAP message can tell the MS the bandwidth allocation result of the next frame in the UL. Next, the MS selects a Ranging Code from the Bandwidth Request Ranging Code set and puts the selected Ranging Code into the Ranging Slot according to the instructions in the UL_MAP message. When the MR-BS successfully receives the Ranging Code from the MS, the MR-BS will send the anonymous BW allocation (CDMA_Allocation_IE) in the UL_MAP message to the MS in order to acknowledge the BR from the MS. Finally, the MS uses the BR MAC PDU to tell the MR-BS about the required bandwidth quantity. The MR-BS will schedule and reserve bandwidth in the next frame for the MS according to the requirement of the MS.

If different MSs put their BRs in different Ranging Slots as shown in Figure 4, they can deliver the BRs to the MR-BS successfully without the collision. In Figure 5, if the MSs simultaneously put their BRs in the same Ranging Slots, however, there are two different consequences. If the MSs choose different Ranging Codes, they can avoid the collision because the BRs are encoded differently. Conversely, the collision happens if more than one MS select the identical Ranging Code.

When a collision happens, the Truncated Binary Exponential Back-off (TBEB) algorithm [9–11] is used to resolve the collision according to the IEEE 802.16j specification. However, the TBEB algorithm has been proved [9–11] to have the poor performance. Once many colli-

**Figure 3.** Bandwidth request procedure.

**Figure 4.** IEEE 802.16j frame format with Ranging Codes in different Ranging Slots (collision-free).

**Figure 5.** IEEE 802.16j frame format with Ranging Codes in identical Ranging Slot (collision).
sions exist in wireless networks, the overall system performance will degrade suddenly. In order to resolve the collision problem, we propose the CBRS in this paper. We use the CBRS to increase the probability of successful data transmission in the first transmission attempt, and alleviate the negative impact on the performance due to the retransmission committed by the TBEB algorithm in IEEE 802.16j.

3. Consecutive Bandwidth Request Scheme (CBRS)

We propose the CBRS to increase the probability of BR transmission in the MS. We allow the MS to transmit Ranging Codes up to $n$ trials for a BR. In the $n$ tails, we select different Ranging Codes and put them into different Ranging Slots before transmitting them to the MR-BS. We consider that the BR is successful if any of the $n$ trials is successful. Only if all of the $n$ trials meet the collisions, we consider that the BR is unsuccessful and retransmit the BR.

Figure 6 shows the Data Flow Diagram of the CBRS. When the MS wants to transmit the BR, the TBEB algorithm will be used to randomly select a back-off time $T_b$ that indicates how many Ranging Slots should be waited before transmitting the BR. Next, the MS selects $n$ Ranging Codes from the Bandwidth Request Ranging Code set and begins to count down the value of the back-off time $T_b$. When the value of the back-off time is counted down to zero, the MS begins to transmit the $n$ selected Ranging Codes in the $n$ Ranging Slots. We can use Equation (1) to get the Ranging Slot of a frame used by the MS to transmit the Ranging Code.

$$S_{rs} = \frac{T_b}{N_{rs}}, \quad N_{rs} \geq 1$$

where $N_{rs}$ indicates the available number of Ranging Slots in a frame and at least has to be 1. And, $S_{rs}$ denotes which frame will be used by the MS to transmit the Ranging Code. For example, current frame number is $i$, and $S_{rs} = j$ indicates that the MS will transmit the Ranging Code in frame $(i+j)$. Next, we can use Equation (2) to calculate $S_{rs}$ that indicates the Ranging Slot in the frame used by the MS to carry the Ranging Code. For example, $S_{rs} = 0$ can denotes that the MS will use the first Ranging Slot to transmit the Ranging Code.

$$S_{rs} = T_b \mod N_{rs}, \quad N_{rs} \geq 1$$

If the Ranging Code in any of the $n$ trials is received by the MR-BS, the BR procedure is considered successful. When the MR-BS receives multiple Ranging Codes from a MS, the MR-BS will use the UL_MAP message to ask the MS to transmit the corresponding BR MAC PDU. However, the CBRS only allows the MR to transmit a single BR MAC PDU to avoid flooding multiple BRs over wireless networks.

When the MS begins to transmit the Ranging Codes in the Ranging Slots, the Ranging Slots may be the final ones in the frame which is not enough to carry all
of the \( n \) Ranging Codes. Instead of transmitting the remaining Ranging Codes in the Ranging Slots in the next frame, which delays the time of judging whether the BR is successful or not, the CBRS disallows the MS to transmit the \( n \) Ranging Codes across two frames. For example, a MS is supposed to transmit the Ranging Codes 5 times. However, the MS is only allowed to transmit the Ranging Codes one time just because the first used Ranging Slot is the final available Ranging Slot in the frame.

We explain the principle of the CBRS with an example. We assume that a frame has 10 available Ranging Slots and one data unit can occupy 2 Ranging Codes (i.e. \( n = 2 \)) for each transmission trial. There are 42 Ranging Codes in the Bandwidth Request Ranging Code set which have number 0, 1, 2... and 41 respectively. Two MSs namely the MS\(_1\) and the MS\(_2\) want to transmit the BRs and select 6 as the back-off time \( T_b \). While the MS\(_1\) uses 10 and 15 as the two Ranging Codes, the MS\(_2\) uses 10 and 20 as the two Ranging Codes. The two MSs simultaneously transmit the two Ranging Codes in the 7\(^{th}\) and 8\(^{th}\) Ranging Slots in the first frame. Because the collision happens to the 7\(^{th}\) Ranging Slot but the 8\(^{th}\) Ranging Slot carries different Ranging Codes of the two MSs, the two MSs can deliver their Ranging Codes successfully to the MR-BS for their BRs. According to the example, the difference between the CBRS and the original IEEE 802.16j is that the collision will happen to the original IEEE 802.16j in the first transmission trial and make the original IEEE 802.16j initiate the retransmission operation, but will not happen to the CBRS. The retransmission operation will waste bandwidth and time to back off the transmission attempt. Using the CBRS not only decreases the probability of the retransmission operation but also makes the MS efficiently transmit data in the bandwidth contention.

4. Simulation and Discussion

4.1 Simulation Configuration

In this section, we use simulations to observe throughput and data delay time of the CBRS and take the original IEEE 802.16j for comparisons. We configure the simulation environment to have a MR-BS, a RS, and 1600 MSs connected by a 4,700,000 bps wireless network. We simulate 5M slots and make the MS drop data when the data is retransmitted more than 15 times due to collisions. We follow Table 1 to configure the remaining parameters.

We conduct two experiments as follows:
- Experiment 1: It is very important to choose the suitable number of Ranging Codes for a BR in the CBRS. If the MS transmits few Ranging Codes for a BR, the probability of successful BR delivery is limited. If a MS transmits many Ranging Codes for a BR, the network can be overloaded to decrease the probability of successful BR delivery as well. In the experiment, we try to find the suitable number of Ranging Codes for a BR in the CBRS. In the experiment, we prepare two patterns, i.e. CBRS(2) expressing 2 Ranging Codes for a BR and CBRS(3) expressing 3 Ranging Codes for a BR.
- Experiment 2: We compare the original IEEE 802.16j with the pattern having the better performance in Experiment 1.

In the simulations, we observe the average collision times, the average delay time, and the average throughput. The average collision times denote the result of dividing the total collision times by the quantity of successfully transmitted data. While the delay time denotes the time of successfully transmitting data minus the time of data arriving in the MS, the average delay time denotes the result of dividing the total delay time by the quantity of successfully transmitted data. The average throughput denotes the result of dividing the quantity of successfully transmitted data by the quantity of transmitted data.

<table>
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<th>Parameter</th>
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<td>RS</td>
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4.2 Simulation Results

4.2.1 Experiment 1: Comparison between CBRS(2) and CBRS(3)

Figure 7 shows the average collision times of the CBRS(2) and the CBRS(3) in different loads. When the load is greater than 0.4, the average collision times of CBRS(3) increase obviously because the CBRS(3) overloads the wireless network with a huge amount of data. When the load reaches 0.6, the average collision times of CBRS(3) rise smoothly because a certain amount of data is dropped after the maximum retransmission trial is reached. Meanwhile, the collision times of the dropped data is not taken into the calculation of the average collision times. Although the average collision times of the CBRS(2) increase according to the loads, the slope of the CBRS(2) is not as steep as that of the CBRS(3).

Figure 8 shows the average delay time of the CBRS(2) and the CBRS(3) in different loads. When the load is smaller than 0.5, the CBRS(3) has the slight average delay time because data can be easily delivered to the MR-BS. When the load is greater than 0.5, however, the average delay time of the CBRS(3) increases suddenly due to the increase of the collision times. Conversely, the CBRS(2) has the slight average delay time until the load is greater than 0.7. When the load is greater than 0.7, the collision times increase the average delay time of the CBRS(2), but the slope is much smooth. When the load is 1, for example, we can see that the CBRS(2) merely has one fifth of the average delay time in the CBRS(3).

Figure 9 shows the average throughput of the CBRS(2) and the CBRS(3) in different loads. The CBRS(3) can maintain average throughput equal to 1 until the load is 0.5. Conversely, the CBRS(2) can maintain average throughput equal to 1, even though the load reaches 1. The experiment shows that the CBRS(2) can has a higher probability of successful data transmission than the CBRS(3). In other words, using 2 Ranging Codes for a BR can outperform using 3 Ranging Codes for a BR.

According to the results of the experiments, we observe that the CBRS(2) can outperform the CBRS(3). Although the CBRS(3) can transmit more Ranging Codes than the CBRS(2) to have more transmission chances, the MS may overload the wireless network with the Ranging Codes and suffer more collisions in the overloaded wireless network. In the following experiments, therefore, we test the CBRS(2), i.e. using 2 Ranging Codes for a BR, and compare it with the original IEEE 802.16j.

4.2.2 Experiment 2: Comparison between CBRS(2) and Original IEEE 802.16j

In the experiment, we compare the CBRS(2) and the original IEEE 802.16j. Figure 10 shows the average...
collision times of CBRS(2) and the original IEEE 802.16j. According to the load, the original IEEE 802.16j has the curve raising greatly until the load is 0.5. When the load is greater than 0.5, the IEEE 802.16j has the stable average collision times because a certain amount of data is dropped after the maximum retransmission trial is reached. The collision times of the dropped data is not taken into the calculation of the average collision times, so we can see the stable curve when the load is greater than 0.5. When the load is greater than 0.5, moreover, we observe that the original IEEE 802.16j needs to retransmit averagely 7 times to make the BR delivered to the MR-BS, which is harmful to real time communication. Conversely, the CBRS(2) works exactly as the observations in Experiment 1 and outperforms the original IEEE 802.16j in the average collision times no matter the load is high or low.

The average delay time of the CBRS(2) and the original IEEE 802.16j in different loads is respectively shown in Figure 11. We observe that the average delay time of the IEEE 802.16j suddenly increases when the load is greater than 0.5. It is because the average collision times great increase at that time according to Figure 10. Although the average collision times do not change in Figure 10 after the load reaches 0.6, the average delay time still is affected by the data that is dropped after the maximum retransmission trial is reached. The delay due to the data that is dropped after the maximum retransmission trial is reached postpones the subsequent data transmission operations. Accordingly, we observe that the average delay time still rises continuously even when the load is greater than 0.6. Comparing the curves of the CBRS(2) and the original IEEE 802.16j, we can see that the average delay time of the CBRS(2) is obviously smaller than that of the original IEEE 802.16j.

Figure 12 shows the average throughput of the CBRS(2) and the original IEEE 802.16j. The original IEEE 802.16j has the average throughput continuously degrading when the load reaches 0.4, because a certain amount of data is dropped to affect the average throughput. When the load is 1, the average throughput difference between the CBRS(2) and the original IEEE 802.16j reaches 0.15.

According to the experiment, we observe that the CBRS can make the MS finish the bandwidth request much faster than the original IEEE 802.16j.

5. Conclusion

IEEE 802.16j improves IEEE 802.16e that has the signal quality degradation problem due to the shadow of buildings when transmitting data over wireless networks in a metropolis. It can be expected that IEEE 802.16j will become popular with the wide development of the IEEE 802.16e infrastructures in the world. However, the TBEB
algorithm that IEEE 802.16j uses to resolve the collision problem has been proved to work poorly. To resolve the collision problem, we propose the Consecutive Bandwidth Request Scheme (CBRS) in this paper for IEEE 802.16j. The CBRS allows the MS to transmit multiple Ranging Codes in order to increase the probability of gaining bandwidth in the bandwidth contention when making the bandwidth request. In the experiments, we observe that sending 2 Ranging Codes for a bandwidth request in a MS can get better performance. After comparing the CBRS and the original IEEE 802.16j in the experiments, we show that the CBRS outperforms the original IEEE 802.16j in the average collision times, the average delay time, and the average throughput. We prove that the CBRS indeed can obviously improve network performance by making the MS easily finish the bandwidth request.

References