A Channel Allocation based WiMax Topology

S.C. Wang, K.Q. Yan and C.H. Wang

***Abstract*—Along with information technology of flourishing, the popularization rate of the wireless communication equipment is higher and higher. However, WiMax is the one of new broadband wireless technologies. It can provide high data rate, large network coverage, and different application services. When large amount of users use these applications, the network may occur transmission collision and broadcast storm. The most important factor to cause this problem is the competition of communication bandwidth by different service requests. However, due to the limitation of communication channel, the OFDMA is used in this research to divide the channel into several sub-channels and those sub-channels can be provided for different users. In this research, a channel allocation mechanism is proposed. The channel is divided into reservation and dynamic by the allocation mechanism to enhance the utilization of channel and shorten the length of minislot.**

***Index Terms*—WiMax, Mesh, Centralized scheduling, Distributed scheduling.**

I. Introduction

In recent year, the rapid growth of wireless communication technology improves the transmission data rate and communication distance. Although the transmission rate of wireless network still cannot catch up with the cable one, there are still increasingly applications on wireless network due to its features of mobility and low setup cost.

WiMax, based on the IEEE 802.16, is one of the new emerging technologies of broadband wireless system. Its transmission rate and distance can reach up to 75 Mbps and 50 km. Compared with other wireless networks, WiMax has the virtues of higher transmission speed and larger transmission coverage. In contrast with the traditional wire network, WiMax has the advantages of rapid and cost-effective deployment and high scalability. It can solve the last mile problem of the metropolitan network because of the features of high bandwidth and long distance [7,12].

Owing to the features of WiMax, it can be extensively applied to various related fields, including mobile service, mobile entertainment, mobile commerce, mobile learning and mobile healthcare. However, if a large number of users use these applications in a region with high population density simultaneously, it may cause the transmission collision and broadcast storm because of a great deal of message broadcasting at the same time. The most important factor to cause this problem is the competition of communication bandwidth by different service requests. Hence, the channel allocation mechanism is proposed to improve the high power consumption problem and reduce the collision of the packet, so as to make the network transmission more stable.

The WiMax network, which consists of Base Station (BS) and Subscriber Station (SS), has two transmission modes of network topology, one is Point to MutiPoint (PMP) and the other one is mesh that show as Figure 1 and 2 respectively [4,10]. Under the PMP topology, all the SSs are in the transmission range of the BS and the traffic only occurs directly between BS and SSs. Under the mesh topology, the SS can communicate with each other through BS or not and the traffic can be delivered by using hop-by-hop. Compared with PMP mode, the mesh mode has several advantages:

1) Traffic can occur directly between each node.
2) Traffic can be relayed by other nodes.
3) Topology can provide more flexibility and scalability.
4) Transmission rage and throughput can be improved.

In this study, the Orthogonal Frequency Division Multiple Access (OFDMA) is employed to divide the channel into several subchannels [1]. It allocates the subchannels to users based on their demands including time and capacity so that the channel can be utilized more effectively and flexibly.

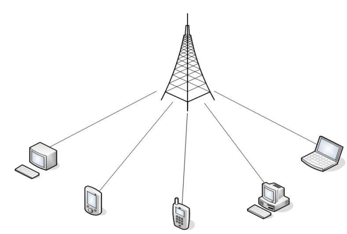

Figure 1. The PMP network topology

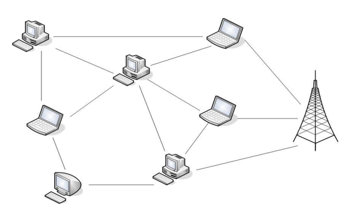

Figure 2. The mesh network topology

In the channel allocation mechanism, the channel is divided into reservation and dynamic channel. In the circumstance of low requirement, the reservation channel cannot utilize the resource allocated fully. However, the dynamic channel can be adjusted according to requirement of transmission to enhance the channel utilization. For this reason, a part of the channel is reserved to offer the users who raise the requirement in the first time. Then the dynamic channel allocation is used to share the remnant of channel and to utilize the resource effectively.

The remainder of this paper is organized as follows. Section 2 gives a brief overview of the IEEE 802.16 standard.

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The proposed channel allocation mechanism is introduced in Section 3. The simulation result is presented in section 4. Finally, Section 5 concludes the paper.

II. Previous Work

In this section, WiMax network system is introduced which includes modulation techniques, frame structure and scheduling mechanism.

A. *Modulation Techniques*

IEEE 802.16 defines three modulation techniques for channel dividing; they are Time Division Multiple Access (TDMA), Orthogonal Frequency Division Multiple (OFDM) and Orthogonal Frequency Division Multiple Access (OFDMA) individually. The TDMA is using the time sharing aspect to segment the channel. It segments the time into fixed size and provides bandwidth for users. Only one user can use within each time interval.

However, what each time interval provided may excess one user's demand and this may cause waste on bandwidth. Compare the OFDM/OFDMA with the TDMA, the OFDM/OFDMA divides the channel into a number of subcarriers which are orthogonal and independence. The subchannels are constructed from several continued or non-continued subcarriers, and they are not mutually interference. In other words, the subchannels which can be combined with any suitable subcarriers provide appropriate service for user based on their demands. Moreover, the modulation techniques of the WiMax are shown in Figure 3.

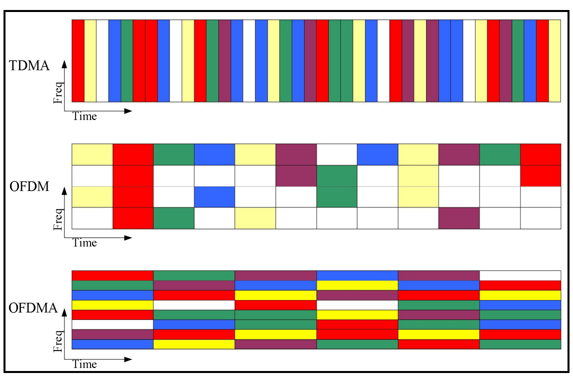

Figure 3. The modulation techniques of the WiMax

The main difference between the OFDM and OFDMA is that the OFDM only provides the resources for one user at the same time; however, the balance unused subchannels become a waste. The OFDMA provides each subchannel an appropriate numbers of users at the same time. Therefore, in this study, the OFDMA is used to allocate the subchannels to users in the consideration of their demands, time and capacity, so that the channel can be utilized in a more effective and flexible way.

B. *Frame Structure*

The WiMax system supports two modes to divide the frame; they are Frequency Division Duplex (FDD) and Time Division Duplex (TDD) modes [2]. In the FDD mode, the uplink and downlink data traffic are delivered on different channels respectively in the meanwhile. In the TDD mode, the uplink and downlink data traffic are delivered on different time interval which can be modulated the proportion based on user's requirements. To sum up, the TDD mode can share the resource more flexibly than FDD.

The IEEE802.16 mesh mode only supports TDD mode to divide the frame. A frame is divided into two parts, including control and data subframe [8]. The data subframe is further divided into a number of minislots. Each minislot depends on message of control subframe to decide if the link can process the data transmission. Figure 4 shows the frame structure of the WiMax network.

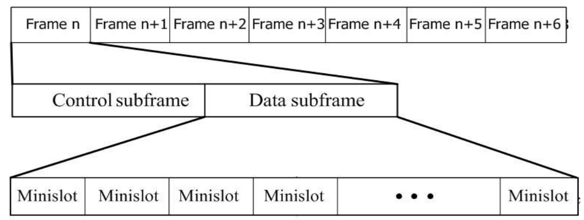

Figure 4. The frame structure of WiMax network

C. *Scheduling Method*

The IEEE802.16 defines two scheduling methods to allocate the minislot for users. There are centralized and distributed scheduling, and we discuss these as follows [5].

1) *Centralized scheduling*

In the centralized scheduling, the resource is managed by BS. Firstly, the BS collects and calculates the requests made by SSs, and then sends the grant message to all nodes. If the message received does not allow SS to process the transmission, then SS needs to make request for transmission in next time. All communications, which are established by centralized scheduling, transmit data to destination through the BS. Because all the internet traffic need to be connected by BS, the centralized scheduling is appropriate to be applied to internet traffic transmission.

2) *Distributed scheduling*

In the distributed scheduling, the resource is allocated by each node which competes and coordinates with other nodes to get resource. Providing that node A want to transmit data to node B, the node A sends request message to node B. In addition, node B collects all requests of neighbor nodes and calculates the priority, then sends the grant massage to each neighbor node. If node A is granted to transmit data, it should send confirm massage and then the communication link will be established. Once SS receives the request message, the communication of distributed scheduling can be established immediately and occur directly between each node. Therefore, the distributed scheduling is appropriate to transmit intranet traffic

The advantages and disadvantages of the centralized and distributed scheduling are shown in Table 1. When all communications are established by centralized scheduling, it will cause heavy load on BS. On the contrary, if all communications are established by distributed scheduling, it may make entire network over loading. As a rule, the traffic in the mesh network includes both internet and intranet traffic, thus a hybrid mechanism is designed in this study, including both centralized and distributed scheduling to share the resource more effectively.

Table 1. Comparison of centralized and distributed scheduling

	Operation	**Advantage**	**Disadvantage**
Centralized scheduling	The resource is managed by BS which includes collecting and calculating the request.	1. It is appropriate for internet traffic. 2. It has better performance on resource allocation and calculation.	1. It may cause over loading on BS. 2. It requires all the transmission paths to pass through BS.
Distributed scheduling	The resource is allocated by each node which competes and coordinates with other nodes to get resource.	1. It is appropriate for intranet traffic. 2. It has less delay on data transmission. 3. It occurs between each node at random. 4. It has better real time transmission.	1. It needs additional messages to set up the link. 2. It may cause over loading on entire network.

In this research, OFDMA and TDD techniques are used to divide the frame which is shown in Figure 5. First, the OFDMA is used to divide the channel into several subchannels, and then the TDD is used to divide the subchannel into a number of minislots. Last, the channel allocation mechanism is used to allocate the resource effectively and the performance of WiMax is improved.

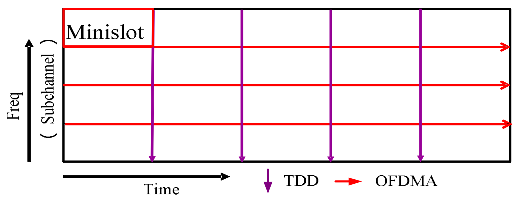

Figure 5. The illustration of frame division

III. THE COMPONENTS OF OUR STUDY

According to the previous section, this research focuses on the design of channel allocation mechanism. It uses the channel allocation mechanism to divide the channel for centralized and distributed scheduling beforehand. Afterward each parent node modulates the number of subchannels dynamically and the channel can be fully utilized by users. The goal of the research is to combine the centralized scheduling with distributed scheduling and to enhance the performance of WiMax.

A. The Assumptions of the Research

In this section, the assumptions of the research and the steps of the topology transformation method are introduced. In this research, the network topology is constructed on the mesh network; hence, the network topology can be expressed by the hierarchical frame which is shown in Figure 6. The upper node is called BS. Under BS, there are several nodes, called SS. These nodes can transmit mutually as long as within the transmission range.

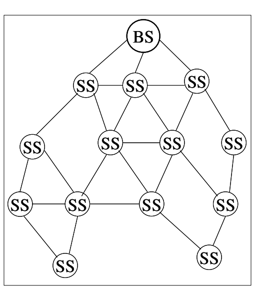

Figure 6. The mesh network topology

In this research, the assumptions for the mesh network topology are listed as follows:

1) The nodes are fixed under the mesh network.
2) The execution and remnant waiting time of the request is predicable.
3) Every node has two queues to store the centralized and distributed scheduling request.
4) The BS dispatches the agent to collect and record the information of each node in the network.
5) The SS knows if the request which is made by it, is normal or non-normal.

Transforming network topology into routing tree topology must depend on adaptive routing protocol [1]. However, the shortest path routing protocol is not the best routing protocol which is introduced in [3]. Using interference aware routing protocol is better than shortest path routing protocol which is demonstrated in [6,13], and it corresponds with our research. In this research, OFDMA is used to divide the channel into several subchannels, and each subchannel only provides the resource for one user in the same time. Hence, using the interference aware routing protocol to establish the routing tree topology can provide more users to transmit data within the channel. Figure 7 is a routing tree topology which is transformed from Figure 6.

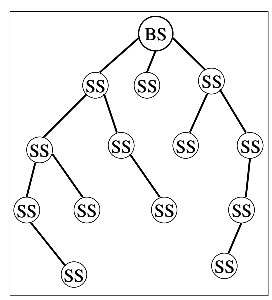

Figure 7. The routing tree topology

The steps of establishing routing tree topology are shown as below：

1) Firstly, each SS detects and calculates the number of neighbor nodes by broadcasting the massage and the amount of neighbor nodes is equal to the interference value.
2) Secondly, it calculates the interference value of entire possible routing path from the SS toward the BS, and selects the least interference value of the route. Every upper layer is the parent node for the lower layer.
3) Finally, it repeats the actions mentioned above until the rout of each node established.

B. Agent Mechanism

Due to the traffic in the mesh network including internet and intranet traffic, this research uses the agent mechanism to collect information from each node. When system initiates, the BS dispatches the agent to collect all requests of internet and intranet traffic that includes traffic size, execution time, remnant waiting time, category of requests and scheduling in the network. The BS receives and manages the information by using channel allocation mechanism, then records the result into the history request database and broadcasts the result to each node.

C. Channel Allocation Mechanism

In the past, the passive allocation method is adapted [5,10] which allocates the resource by centralized and distributed scheduling when receiving the request. However, in this research, the channel allocation mechanism is applied to allocate proactively the channel for normal requests, called reservation channel. In addition, the remnant channel, called dynamic channel, is shared by non-normal requests which compete with each other for getting the resource.

Under the OFDMA, the channel is divided into several subchannels for users. In our study, the channel allocation mechanism is adapted to allocate the subchannels. However, these subchannels are divided into reservation and dynamic channel. The formula (1) is shown as below. *SCr* stands for the number of subchannels in the reservation channel; *SCd* stands for the number of subchannels in the dynamic channel; *TSC* stands for the total amount of subchannels.

$$TSC = SCr + SCd \qquad (1)$$

For the reservation channel, the bandwidth is proactively allocated to each node. Therefore, the BS calculates the bandwidth of each node based on the recorded history requests, and then broadcasts the result to each node. The main purpose is to reserve the bandwidth for normal requests proactively.

The reservation channel can be divided into two parts which are centralized and distributed reservation channel. In addition, they are allocated according to the percentage of the history requests. The BS calculates the average of the priority of the centralized and distributed scheduling queue, and then calculates the number of priority value greater than average one. The formula (2) is shown as follow.

$$SCrc = SCr * \left(\frac{CS}{CS + DS} * 100\%\right) \qquad (2)$$
$$SCrd = SCr - SCrc$$

The *CS* and *DS* represent the priority value which is greater than the average in the centralized and distributed scheduling queue individually. The *SCr* denotes the number of subchannels in the reservation channel. The *SCrc* and *SCrd* represent the number of subchannels in the centralized and distributed reservation channel individually.

In the aspect of dynamic channel, the centralized and distributed scheduling share a common bandwidth which provides the service passively. When a node has request, it would transmit the request massage to parent node. Then the parent node calculates the priority of each request and sends the result to the upper level. This action will be repeated until the parent node is the BS. The BS compares all the priority of requests and then broadcasts the grant massage to each node. Finally, each node transmits the data according to the grant massage.

For the allocated channel number in the reservation and dynamic channel, this research provides the number of subchannels based on certain percentage. According to the allocation principle of communication demand, the 80% of the channels are controlled by the 20% of the normal requests [9]. Therefore, the proportion of the reservation and dynamic channel is 8:2, and the number of subchannels is the threshold. The flow chart of channel allocation mechanism is shown in Figure 8, and the steps of channel allocation mechanism are shown as below:

1) Firstly, the BS uses the formula (1) and (2) to divide the channel, and then allocates the resource to users according to the history requests in advance. The normal requests are chosen firstly. When the request of centralized or distributed exceeds the threshold, the SS will check if another reservation channel has resource to support the request. If the answer is yes, then the SS will allocate the resource from the reservation channel; otherwise, the SS will get the resource from the dynamic channel. Then the BS broadcasts the message to each node.
2) When the SS receives the message from the BS, it will send the message to the nodes of the lower layer. This action will be repeated until all SSs receive the message. After that, each node makes its request and the normal request gets the resource from the reservation channel directly. Afterward, the node transmits the message, including arranged normal request and non-arranged non-normal request to its parent node.
3) When the node receives the message from its child nodes, it calculates priority of all requests, and then sends the result message to its parent node. This action will be repeated until the BS receives the message. Integrating and calculating the scheduling and requests by each parent node can reduce the load of BS.
4) When the BS receives the message, it will calculate and schedule the final scheduling. If the resource of the dynamic channel is exhausted, the SS will check if reservation channel has resource to support the request. Then the BS broadcasts final scheduling to each node.
5) When all nodes receive the final scheduling, they will transmit the data according to the final scheduling at next time.

D. Priority Mechanism

In order to let each request has a corresponding priority, this research proposes the priority mechanism to calculate priority of each request. In this research, three factors of the priority mechanism for priority calculation are used which are demand size, urgency and category of request individually. Each factor has a weight and the sum of the weight is equal to 1. The formula for priority is shown in below.

$$V = \sum_{i=1}^{3} w_i f_i(x_i)$$
$$\sum_{i=1}^{3} w_i f_i(x_i) = w_1 f_1(x_1) + w_2 f_2(x_2) + w_3 f_3(x_3) \qquad (3)$$
$$\sum_{i=1}^{3} w_i = 1$$

The value of *V* means the priority. Once the value of *V* is greater, the priority is higher. The $f_1(x_1)$ is denoted as below.

$$f_1(x_1) = 1 - \frac{REQ}{MREQ} \qquad (4)$$

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$f_1(x_1)$ means proportion of demand size. *REQ* represents the demand size which is made by the node. *MREQ* represents the max of demand size. The value of $f_1(x_1)$ is between 0 and 1. Once the demand size is less, then the value of $f_1(x_1)$ will be bigger.

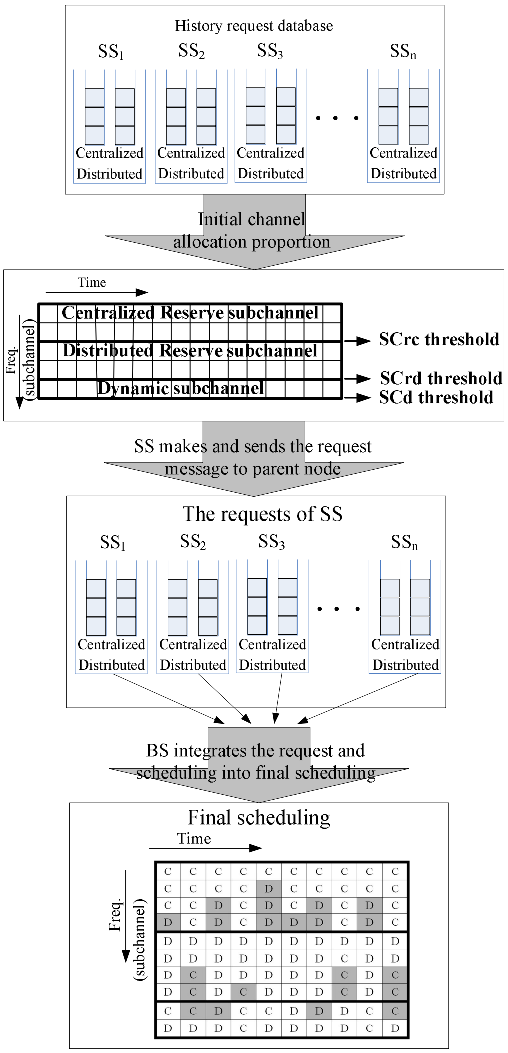

Figure 8. The flow chart of channel allocation mechanism

$f_2(x_2)$ means degree of urgency and its formula is shown as follow. *RT* denotes the remnant waiting time of request. *EXT* denotes the execution time of request. The value of $f_2(x_2)$ is between 0 and 1.

$$f_2(x_2) = \frac{1}{1+e^{RT-EXT}} \tag{5}$$

Finally, $f_3(x_3)$ means service degree of request which formula is shown as below.

$$f_3(x_3) = SL \tag{6}$$

The IEEE 802.16 defines four service types which are Unsolicited Grant Service (UGS), Real-Time Polling Service (rtPS), Non-Real-Time Polling Service (nrtPS) and Best Effort service (BE) individually [11]. In this research, the four service types are defined as 1, 0.75, 0.5 and 0.25 four different values in order.

IV. SIMULATION RESULT

In this section, the simulation is set up based on the parameters shown in Table 2. The OFDMA is applied to divide the channel into 128 subchannels; and the subchannels will be divided into 256 minislots further by using TDD. Hence, there are 32,768 minislots can be used by each frame.

Table 2. The simulation parameters

Modulation technique	OFDMA
Duplexing scheme	TDD
Bandwidth	40Mb/s
Frame size	20ms
The number of subchannels	128
The number of minislots	256

In the experiment, the performance of transmission between before and after is compared using the channel allocation mechanism, and the result shows that the utilization of bandwidth can be enhanced by the channel allocation mechanism. Without using the channel allocation mechanism, the subchannels are allocated to the centralized and distributed scheduling equally. For using the channel allocation mechanism, the subchannels are allocated to the reservation and dynamic channel according to the 8:2 principles [9].

In this simulation, the range of transmission request, demand size, and time of request are defined as below.

1) For transmission request: the number of transmission requests is 10 and 20 respectively.
2) For demand size: the demand size is form 1 to 3mb (1-3mb) and from 1 to 5mb (1-5mb).
3) For time of request: the time of request is between 0 to 10 seconds.

In the experiment, it runs every setting 10 times and compares the difference of the average length of scheduling and the number of request-drops.

A. Average Length of Scheduling

In the average length of scheduling, the simulated result of 10 requests is shown in Figure 9. However, the channel allocation can be shorten 20~25% of the length of scheduling when the channel allocation mechanism is used. It is because using the channel allocation mechanism makes the centralized and distributed scheduling to share the resource under the same subchannel. In the contrast, without using the channel allocation mechanism, only one scheduling can exist and use the resource on the subchannel.

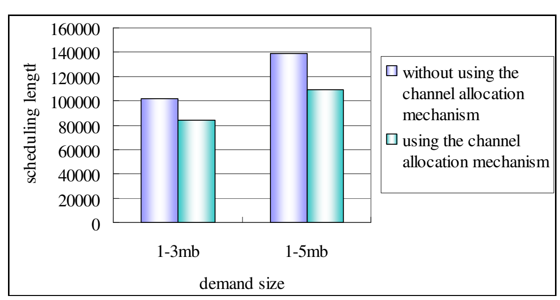

Figure 9. The scheduling length of 10 requests

Figure 10 reports the result of the average length of scheduling under 20 requests. The result shows when the

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demand size is getting smaller, the gap of length of scheduling will be smaller. Once the demand size become smaller, there are more requests can be scheduled at the same time; hence the gap become smaller.

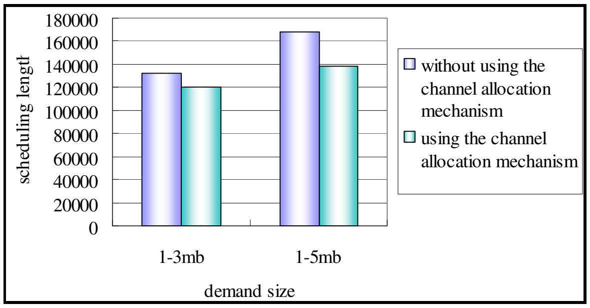

Figure 10. The scheduling length of 20 requests

B. *Average Request-drop*

Table 3 depicts the number of average request-drops of the demand size from 1 to 5 under different number of requests. The result shows that the number of request-drops can be reduced by the channel allocation mechanism effectively. Once the number of requests increases, the number of request-drops will also increase. It is because there is no sufficient resource to support the requests in the remnant waiting time. The number of dropped requests in the channel allocation mechanism is almost equal to the number of non-normal request; therefore, it does not influence the normal requests of transmission directly.

Table 3. The average request-drop of demand size 1~5mb

	Without using channel allocation mechanism	Using channel allocation mechanism
10 requests	0.2	0
20 requests	2.1	1

Table 4 reports the number of average request-drops in different range of demand size under 20 requests. When the range of demand size increases, the number of average request-drops will also increase. It is because the increase of demand size make other requests cannot get resource in the remnant waiting time.

Table 4. The average request-drop of 20 requests

	Without using channel allocation mechanism	Using channel allocation mechanism
1~3mb	0.7	0.2
1~5mb	2.1	1

From the above experiments, the length of scheduling can be shorten and the number of request-drops can be reduced by using the channel allocation mechanism are proven. In addition, when additionally executing other requests, the length of scheduling does not increase. This interprets that the utilization of channel can be increased and the throughput can be enhanced effectively by the channel allocation mechanism.

V. CONCLUSION

The higher throughput and further transmission range of WiMax make it become one of the popular wireless network technologies. However, how to allocate bandwidth effectively to users is an important issue to be studied. It can be concluded from the experiments of the average length of scheduling and the average request-drops in this study that: 1) the normal requests have higher priority; 2) the channel allocation can shorten the length of scheduling and increase the utilization of bandwidth; 3) the concept of hierarchical management can reduce the loading of BS.

In the future research, the interference between nodes will be discussed. Currently, only one user is allowed to transmit data within one minislot. After the problem of interference is solved, more than one user can transmit data within one minislot. Then, the spatial reuse rate can be increased and the performance of entire network transmission can be improved.

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REFERENCES

[1] http://www.intel.com/netcomms/technologies/wimax
[2] *IEEE standard for local and metropolitan area networks part 16: Air interface for fixed broadband wireless access systems*. IEEE STD 802.16TM-2004, Tech. Rep, 2004.
[3] D.S.J.D. Couto, D.B. Aguayo, A. Chambers and R. Morris, “Performance of multi-hop wireless networks: Shortest path is not enough,” *Proceedings of First Workshop on Hot Topics in Networks*, 2002.
[4] J. Chen, C. Chi and Q. Guo, “An odd-even alternation mechanism for centralized scheduling in Wimax mesh network,” *Proceedings of the Global Telecommunications Conference*, 2006, pp. 1-6.
[5] S.M. Cheng, P. Lin, D.W, Huang, and S.R. Yang, “A study on distributed/centralized scheduling for wireless mesh network,” *Proceedings of the 2006 International Conference on Wireless Communications and Mobile Computing*, 2006, pp. 599-604.
[6] L. Fu, Z. Cao and P. Fan, “Spatial reuse in IEEE 802.16 based wireless mesh network,” *Proceedings of the IEEE International Symposium on Communications and Information Technology*, 2, 2005, pp. 1358-1361.
[7] B. Han, W. Jia and L. Lin, “Performance evaluation of scheduling in IEEE 802.16 based wireless mesh networks,” *Computer Communications*, 30(4), 2007, pp. 782-792.
[8] D. Kim and A. Ganz, “Fair and efficient multihop scheduling algorithm for IEEE 802.16 BWA systems,” *Proceedings of the 2nd International Conference on Broadband Networks*, 2, 2005, pp. 895-901.
[9] R. Koch, “*The 80/20 principle: The secret to success by achieving more with less*,” Bantam Dell Pub Group, 1999.
[10] B. Makarevitch, “Distributed scheduling for WIMAX mesh network,” *Proceedings of the IEEE 17th International Symposium on Personal, Indoor and Mobile Radio Communications*, 2006, pp. 1-5.
[11] J. Sun, Y. Yao and H. Zhu, “Quality of service scheduling for 802.16 broadband wireless access systems,” *Proceedings of the Vehicular Technology Conference*, VTC 2006-Spring, IEEE 63rd, 3, 2006, pp. 1221-1228.
[12] K. Vinay, N. Sreenivasulu, D. Jayaram and D. Das, “Performance evaluation of end-to-end delay by hybrid scheduling algorithm for QoS in IEEE 802.16 network,” *Proceedings of the IFIP International Conference on Wireless and Optical Communications Networks*, 2006, pp. 1-5.