A Centralized Scheduling Algorithm based on Multi-path Routing in WiMAX Mesh Network

Yang Cao, Zhimin Liu, Yi Yang,
School of Electronics Engineering and Computer Science
Peking University
Beijing, 100871, China
{caoyang,liuzm,yiyang}@pku.edu.cn

Abstract

Enhancing the capability of WiMAX Mesh network is one of the focal problems nowadays. In this paper, we propose a centralized scheduling algorithm based on multi-path routing (MR-CS) in WiMAX mesh network, which introduces the cross-layer concept between the MAC and network layers. The network load balance, spatial reuse and QoS guarantee are synthetically considered. The result of analysis shows this algorithm greatly improves the network throughput and the efficiency of the centralized scheduling.

Keywords: Centralized Scheduling, Multi-path Routing, WiMAX Mesh Network, Cross-layer, Spatial Reuse, Load Balance, QoS

1. Introduction

Due to the high bandwidth, flexible mobility and QoS demand in wireless access system, The BWA (Broadband Wireless Access) has gained an increased interest these years. The WiMAX (World interoperability for Microwave Access) based on IEEE 802.16 standard [1] is one of the most promising technologies in the future. As the last-mile solution, WiMAX can offer greater wireless coverage of 5 miles, with LOS (Line of Sight) transmission with bandwidth up to 70 Mbps.

The optional mesh network connection defined in IEEE 802.16-2004 is the supplement of the single hop PMP (Point to Multipoint) mode. In the Mesh mode, several Mesh SS (Subscriber Station) can constitute a small multipoint to multipoint wireless connection, without specific uplink and downlink sub-frames. It may commendably support the NLOS (Non-Line of Sight) transmission, adopting the multi-hop technology based on packet switch to keep away from obstruction, interference and congestion.

Enhancing the capability of WiMAX Mesh network is one of the focal problem nowadays. Basically, the appropriate routing and scheduling algorithm could effectively enhance the throughput of WMN (wireless mesh network). And some research has been done in this field. The spatial reuse concept was brought forward to make the non-interference links concurrent transmission in [2-3]. A routes construction scheme was proposed to reduce the interference during transmission in [4]. And in [5], a mathematics model was advanced for centralized scheduling. More, a node sort idea based on certain weight was put forward in [6]。But in these researches, nobody considered the route metrics and scheduling schemes together, as well as the network load balance and QoS.

In this paper, we introduce the cross-layer concept. An effective centralized scheduling algorithm based on multi-path routing (MR-CS) in WiMAX mesh network was proposed. And the network load balance, spatial reuse and QoS guarantee are synthetically considered.

The rest of the paper is organized as follows. Section 2 introduces the scheduling in WiMAX Mesh network briefly. In section 3, we describe the details of the algorithm. And a simulative sample is analyzed to prove the performance in section 4. Section 5 draws a conclusion for the paper.

2. Scheduling in WiMAX Mesh Network

In the WiMAX Mesh mode, the MAC supports both centralized and distributed scheduling. Here, for the easy operation and high reliability, we focus on the centralized scheduling.

In the centralized scheme, every Mesh SS estimates its resource request, and sends it to the Mesh BS (Base Station) with the message MSH-CSCH:Request (Mesh Centralized Scheduling). Then, the Mesh BS collects the bandwidth requests, determines the resource allocation for each link and responds with the message MSH-CSCH:Grant. To disseminate the Mesh SS topology, routing and scheduling tree configuration information to all participant Mesh SS within the mesh network, the MSH-CSCF (Mesh Centralized Scheduling Configuration) message is broadcasted by the Mesh BS and then re-broadcasted by all the intermediate nodes.

3. Centralized Scheduling based on Multi-path Routing

1-4244-0517-3/06/$20.00

3.1. Basic Ideas

In the centralized scheduling, Mesh BS determines the optimized network routing tree and resource scheduling scheme. The Mesh SS receive the corresponding scheduling message and behave based on it strictly. Following this, the whole network could work effectively. Thus, designing the routing and scheduling scheme of the Mesh BS is the core problem of the algorithm.

In order to design according to the IEEE 802.16 and the actual instance, we make the following assumption. 1) Nodes can not send and receive data at the same time. 2) Nodes can not send or receive data in the signal range of communicating nodes because of interference. 3) The signal of a node can only cover the range of a single-hop neighborhood. 4) Non-interference links can communicate concurrently. 5) The topology doesn't make any change during the scheduling period. 6) The control and scheduling sub-frame are long enough. 7) The traffic is always between the Mesh SS and Mesh BS, and routes in this paper just represent the route between the Mesh SS and the Mesh BS.

In this paper, the basic idea of MR-CS is the cross-layer design between the network (routing) and MAC (scheduling) layers. The framework is as the following Figure 1.

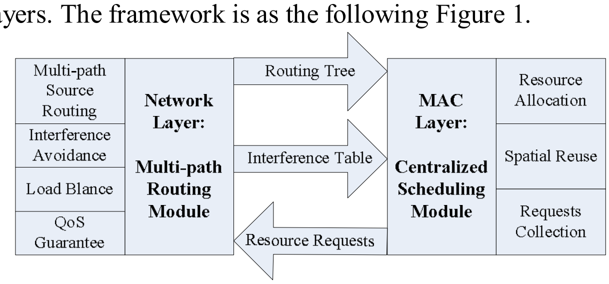

Figure1: Framework of Cross-layer Design

It can be divided into two parts: the Multi-path Routing Module in the network layer and the Centralized Scheduling in the MAC layer. These two modules exchange the Routing Tree (the Mesh BS to each Mesh SS), the Interference Table (the interference links muster of each link while communicating) and the Mesh SS resource request information.

Launching the routes searching process, we could obtain multiple available routes for each Mesh SS and the Interference Table for each link (based on the neighborhood of each node). And then in every scheduling period, the Mesh SS resource demands are collected by the Centralized Scheduling Module in the MAC layer and sent to the Multi-path Routing Module in the network layer. Associating with the topology information, Mesh BS can choose an optimized route for each node according to the following three metrics.

1) Least Interference: The total interference links of all the links along the route should be the least. This ensures the largest concurrent transmission number and spatial reuse in the mesh network.
2) Load Balance: Nodes in the network apportion the load fairly, in order to avoid the network load concentrated on a few links.
3) Low QoS Class: Nodes with high QoS demand should not act as intermediate forwarding nodes in the route.

Then the Optimized Route Tree and Interference Table are fed back to the Centralized Scheduling Module for the Resource Scheduling Table calculating. The spatial reused should be well considered to make the non-interference links communicate concurrently, the QoS and fairness should be considered as well. In the end, we can get the Resource Scheduling Table and distribute it to all the Mesh SS. The Mesh SS must behave strictly based on this table. What need to be noticed is that the optimized route tree may be adjusted in every scheduling period according to the different resource demand.

3.2. Multi-path Routing

The Multi-path Routing Module includes two steps: the Available Routes Search and the Optimized Route Selection.

3.2.1. Available Routes Search. Since the structure of the Mesh network is similar to the Ad hoc network, the Multi-path Source Routing (MSR) [7] could be adopted by the routes search process to find the available Multi-path Routes for each Mesh SS. For a Mesh SSx, its Multi-path Routes note as $R_x=\{R_x(1), R_x(2), \ldots, R_x(N)\}$, and N is the number of available Multi-path Routes.

Then, we can obtain the Interference Table of any link connecting Mesh SSx and Mesh SSy, noting as Ix-y. Let Lx-y denotes the link between Mesh SSx and SSy, and N(x) denotes the neighbor muster of Mesh SSx. For any link Li-j, if one of the following qualifications is satisfied, we get Li-j $\in$Ix-y. 1) i=x or i=y or j=x or j=y; 2) j $\in$N(x); 3) I $\in$N(y).

3.2.2. Optimized Route Selection. The i-th Multi-path Routes of Mesh SS_x, $R_x(i)$, let $R_x(i) = \{L_{x\text{-}j1}, L_{j1\text{-}j2}, \ldots, L_{jk\text{-}B}\}$ (B denotes the Mesh BS), and the elements in the muster are all the links composing this route. Define some parameters of $R_x(i)$ as follow.

1) Interference Factor $I_x(i)$, which is the interference link amount muster of every link $L_{x\text{-}y}$ along the route $R_x(i)$, i.e. $I_x(i) = \{C(I_{x\text{-}j1}), C(I_{j1\text{-}j2}), \ldots, C(I_{jk\text{-}B})\}$, and $C(I_{x\text{-}y})$ denotes the number of elements in $I_{x\text{-}y}$.
2) Load Factor $P_x(i)$, which is the resource demand ($P_{x\text{-}y}$, counting in minislots including source and forward traffic) muster of every link $L_{x\text{-}y}$ along the route $R_x(i)$, i.e. $P_x(i) = \{P_{x\text{-}j1}, P_{j1\text{-}j2}, \ldots, P_{jk\text{-}B}\}$.
3) QoS Factor $Q_x(i)$, which is the QoS index(Q_x) muster of every node along the route $R_x(i)$. Q_x, give the QoS class of the node, is define as follow: $Q_x = (P_{x1} \cdot 3+ P_{x2} \cdot 2+ P_{x3} \cdot 1) / (P_{x1} + P_{x2} + P_{x3})$. The traffic type are divided into 3 classes, and P_{x1}, P_{x2} and P_{x3} are the respectively traffic for these classes.

Taking the above all parameters into account, we can define the Routing Factor $S_x(i)$ as the following formula.

$$S_x(i) = \mathrm{sum}(\ I_x(i) \cdot P_x(i) \cdot Q_x(i)\ )$$
$$= C(I_{x\text{-}j1})*P_{x\text{-}j1}*Q_x + C(I_{j1\text{-}j2})*P_{j1\text{-}j2}*Q_{j1} + \cdots + C(I_{jk\text{-}B})*P_{jk\text{-}B}*Q_{jk}$$

The $R_x(i)$ with the least $S_x(i)$ in Multi-path Routes R_x will be chosen as the Optimized Route.

Then evaluate every available Multi-path Routes for every Mesh SS in turn to generate the Routing Tree (only one route for each node is reserved). What should be paid special attention to is that the Load Factor $P_x(i)$ will be updated when every Optimized Route for a Mesh SS is decided.

3.2.3. Centralized Scheduling. In Centralized Scheduling, we assign the minislots for every Mesh SS according to the Routing Tree and Interference Table obtained in the Multi-path Routing Module. First, define two musters used in the following scheduling process. 1) Pending Links, PL_t. It denotes the link muster with data transmission demand in minislot t. 2) Scheduling Links, SL_t. It denotes the link muster having been scheduled to transmit in minislot t. And the detailed rules are as follows.

1) Always choose the highest QoS class as preference;
2) In the 1^{st} minislot, the Pending Links can be denote as $PL_1 = \{L_{x1\text{-}y1}(c_1), L_{x2\text{-}y2}(c_2), \cdots, L_{xn\text{-}yn}(c_n)\}$, and $L_{xi\text{-}yi}(c_i)$ denotes that the link $L_{xi\text{-}yi}$ demands c_i minislots to transmit the traffic. Choose the link with the largest c_k, as the Preferential Link, i.e. $PrL_1 = L_{xk\text{-}yk}(c_k)$, and put it into PL;
3) Then find the links that can communicate concurrently with all the links in PL according to the Interference Table. And arrange them into the Scheduling Links, $SL_1=\{L_{xi\text{-}yi} \mid L_{xi\text{-}yi} \mathbin{!\in} I_{PrL1}\ 且\ L_{xi\text{-}yi} \in PL_t, i=1, 2, \cdots\}$;
4) Updating the Pending Links PL_t, delete the links that has been transmitted and add the new ones because of packet forwarding, i.e. $PL_2 = PL_1 - SL_1 + p(SL_1)$. And $p(SL_1)$ denotes the parent links of SL_1.

Repeat the above steps in the next minislot till all the scheduling has been accomplished, i.e. $PL_t = \Phi$.

4. Performance Analysis

4.1. Case Study

Here, we give an example to illuminate the validity of the MR-CS algorithm. The network structure is as that in Figure 2. The Mesh SS3, SS4, SS5, SS11, SS13 need to send data to Mesh BS, occupying 1(1, 0, 0), 2(1, 1, 0), 1(1, 0, 0), 2(1, 1, 0), 3(1, 1, 1) minislots respectively, the three numbers in the parentheses are the resource demand according to the QoS classes.

Following the above Multi-path Routing scheme, Mesh SS13 chooses the route 13-10-6-2-B, SS11 chooses 11-7-3-B, SS5 chooses 5-1-B, SS4 chooses 4-1-B, SS3 choose 3-B. The scheduling result is shown in the Figure 3, and 13 minislots are needed for the whole traffic.

If we only adopt the spatial reuse scheme in [2-3], the route selection will be as follow. Mesh SS_{13} chooses 13-11-7-3-B, SS_{11} chooses 11-7-3-B, SS_5 chooses 5-1-B, S_4 chooses 4-1-B, and S_3 chooses 3-B. 18 minislots are needed. The result is shown in Figure 4.

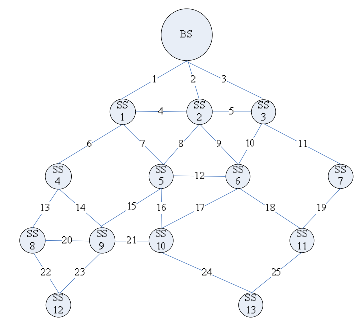

Figure2: WiMAX Mesh Network Structure

link	1	2	3	4	5	6	7	8	9	10	11	12	13
13-10	13.1				13.2		13.3						
11-7		11.1		11.2									
10-6			13.1			13.2				13.3			
7-3			11.1			11.2							
6-2				13.1				13.2				13.3	
5-1		5.1											
4-1	4.1			4.2									
3-B	3.1				11.1				11.2				
2-B							13.1				13.2		13.3
1-B			4.1			5.1				4.2			
slot	1	2	3	4	5	6	7	8	9	10	11	12	13

Figure 3: Scheduling Result of MR-CS

link	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
13-11	13.1	13.2	13.3															
11-7				13.1	13.2	13.3							11.1	11.2				
7-3							13.1	13.2	13.3						11.1	11.2		
5-1	5.1																	
4-1		4.1	4.2															
3-B	3.1									13.1	13.2	13.3					11.1	11.2
1-B				5.1	4.1	4.2												
slot	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18

Figure 4: Scheduling Result of without MR-CS

The analysis result shows that the MR-CS proposed in this paper improves the network throughput and the scheduling efficiency.

4.2. Simulation

In this section, we evaluate the performance of the MR-CS scheme, using Matlab tool. The scenarios are as follow. Random topology is generated in a round area with radius $R = d \cdot \sqrt{N/8}$, where N is the number of Mesh SSs, d is the maximal transmission between two nodes. We assume the single channel in the network without any bit errors, and the nodes fixed. The transmission data rate is set to 51.2Mbps. There are 3 types of traffic, real-time CBR, real-time VBR and data flows. The packet length of CBR is

440bytes, with constant interval of 10ms. The VBR is generated by the ON/OFF model, setting 1s to the average ON time and 1.35s to the average OFF time. The VBR packet length is 160ms, coming every 20ms in the ON time. The data flow is a Poisson stream with rate λ according to the bandwidth. Suppose every node in the network has the equal traffic load.

In figure 5, we compare the result of MR-CS and the scheme only using spatial reuse when the network load is 46 Mbps. It shows us the MR-CS could improve the throughput in centralized scheduling and the throughput goes down when the node number increases.

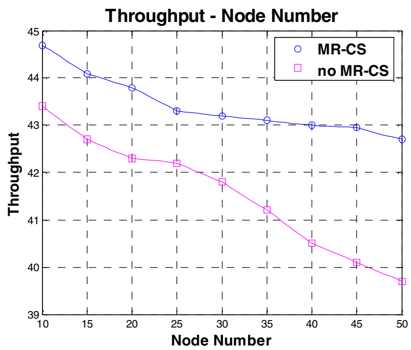

Figure 5: Throughput (Mbps) vs. Node Number

In figure 6, we give the average delay for the 3 traffic types when the load is 46 Mbps. It shows that, the higher class traffic will get shorter delay in MR-CS. And the QoS guaranteed in the MR-CS scheme. The average delay grows as the node number increase because of the hop number increasing.

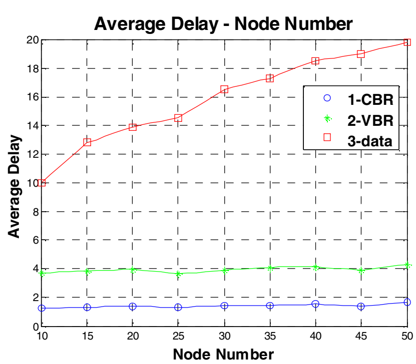

Figure 6: Average Delay (ms) vs. Node Number

Figure 7 shows the result of the throughput with different network load and node number in MR-CS. The throughput is increasing along with the load increasing. But when the load is greater than about 46Mbps, the Throughput gets to the up bound. The 5 lines give the result with different node numbers, from 10 to 50. As the node number increase, the throughput drops. It is because the hops for every packet getting to the BS increase along with the node number. It will take more time for packets arriving at BS.

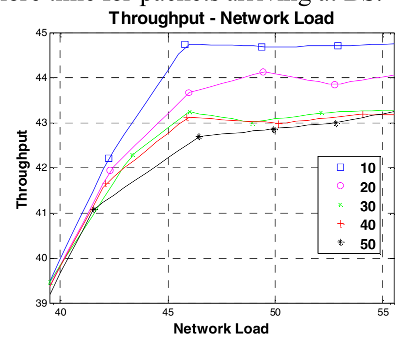

Figure 7: Throughput (Mbps) vs. Network Load (Mbps) in MR-CS

5. Conclusions

In this paper, we propose a centralized scheduling algorithm based on multi-path routing (MR-CS) in WiMAX mesh network, which introduces the cross-layer concept between the MAC and network layers. The network load balance, spatial reuse and QoS guarantee are synthetically considered. Analyzing MR-CS with a random network structure and traffic flow, we have compared the algorithm with the one in [2-3]. The analysis result shows this algorithm has greatly improved the network throughput and the efficiency of the centralized scheduling.

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