Signaling Cost Evaluation of Centralized Scheduling in IEEE 802.16 Mesh Networks

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***Abstract*—To achieve long distance network access, the wired technologies, such as digital subscriber line (xDSL), cable, and T1, are applying higher cost and lower elasticity than wireless network. IEEE 802.16 network provides broadband wireless access to connect the Legacy LAN to Internet. Furthermore, the Mesh mode of IEEE 802.16 can support to construct a large area via BS and SSs. As in legacy LANs, signaling control is necessary in IEEE 802.16 for regulation of data transmission. A framing structure of time consisting of the control subframe and the data subframe is defined in IEEE 802.16 for TDD supporting. Configuration of the control subframe and the data subframe in a TDD time frame has an significant impact on access delay and link utilization. Understanding of the signaling cost can help to better determine the configuration of the TDD time frame. In this paper, we try to evaluate the signaling cost of centralized scheduling in IEEE 802.16 mesh mode. A simple analytical model for signaling cost is proposed. Simulation results has demonstrated the correctness of the model.**

Keywords-802.16; WiMax; Mesh; signal;

I. Introduction

Broadband Wireless Access (BWA) technology is aiming to provide an easy, time-saving, and low-cost method for deployment of next generation (beyond 3G) network infrastructure. Since 1998, IEEE 802.16 working group has launched a standardization process called *Wireless Metropolitan Area Network (Wireless MAN^{TM})* for BWA. The newly released specification of 802.16 (*IEEE Std 802.16-2004*) [1] focuses on fixed location wireless access and can support up to 134 Mbps bit rate. Moreover, the standardization of a new 802.16 interface, *802.16e* [2], to support wireless access with high mobility has also been completed recently. The *WiMax Forum (Worldwide Interoperability for Microwave Access)*, a wireless industry consortium with about 100 members including major vendors such as *AT&T*, *Fujitsu*, *Intel*, and *Siemens Mobile*, is supporting 802.16 technology and promoting its commercial use, which means 802.16 is becoming the most important technology in BWA.

There are two deployment configurations in IEEE 802.16: *Point to Multipoint (PMP)* and *Mesh*. The PMP configuration of IEEE 802.16 consists of a *base station (BS)* and a couple of *subscriber stations (SSs)* that connect to the BS via high-speed wireless link, in Figure 1-(a). The BS acts as a gateway to the Internet. Legacy LANs or even more complex subnet systems can connect to the 802.16 network via SS. As an extension of 802.16 PMP configuration, the 802.16 Mesh mode provides that there is no need to have direct link from subscriber stations to the base station and a node can choose the links and path with best quality to transmit data and avoid the congested area. For example, in Figure 1-(b) a traffic flow originated from subscriber station SS_D can be transmitted along either the path [SS_D, SS_C, SS_A, BS] or the path [SS_D, SS_C, SS_B, BS] for Internet access. Moreover, the mesh mode can provide a more flexible and faster approach for network deployment.

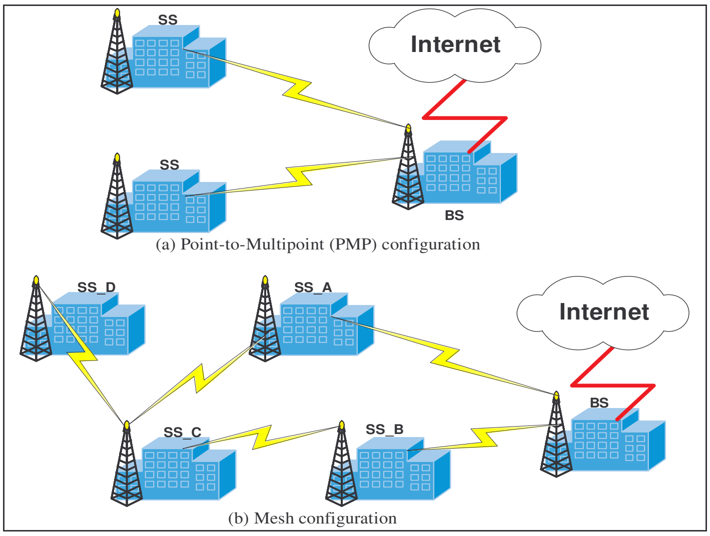

Figure 1. IEEE 802.16 networks

There are two mechanisms to schedule data transmission in the IEEE 802.16 mesh networks [1]: centralized and distributed scheduling. In the centralized scheduling scheme, the BS works like the cluster head and determines time slot allocation of each SS. In order to transmit data packets, the SS is required to submit the request packet (a Layer 2 frame namely *BW_REQ*) to the BS via the control channel. The BS grants the access request to all SS nodes about slots information. In this paper, we propose a simple analytical model and simulation study to investigate the signaling cost (i.e. rate of *BW_REQ*) of the centralized scheduling in IEEE 802.16 mesh networks.

The remainder of the paper is organized as follows. First of all, we present the IEEE 802.16 Mesh network with centralized scheduling in section 2. Numerical analysis of signal is

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presented in section 3. Simulation study for performance evaluation is presented in section 4. Finally, section 5 concludes this paper.

II. IEEE 802.16 MESH NETWORK

The IEEE 802.16 mesh networks defined the frame structure with two divided parts as shown in Figure 2, one is the data subframe, and the other is control subframe; however, there are no clearly separate downlink and uplink subframes in the 802.16 mesh mode. The frame can be divided into many units, these are called as *Transmission opportunities* in control subframe, and named as *Minislots* in data subframe. The scheduling information and how many allocation time slots in the data subframe are specified in the control subframe by requesting SSs.

Although the SSs could connect to each other and BS, they also need a centralized leader in 802.16 Mesh mode. Therefore, the major basic mechanism to schedule data transmission in the IEEE 802.16 Mesh networks [1]: centralized scheduling is a similar concept of PMP mode. In the centralized scheduling scheme, the BS works like the cluster head and determines time slot allocation of each SS. In centralized scheduling the BS *provide schedule configuration (MSH-CSCF)* and *assignments (MSH-CSCH)* to all SSs. In order to transmit data packets, the SS is required to submit the request packet (a L2 frame namely BW_REQ including in the MSH-CSCH) to the BS via the control channel. The BS grants the access request by sending the slot allocation schedule called UL_MAP (uplink map for slot access) to all SS nodes. Since all the control and data packets need to go through the BS (following the uplink path and then the downlink path), operations of scheduling as well as routing at each SS are simple. However, a longer path in the Mesh network is inevitable.

Some research works discussed the IEEE 802.16 Mesh networks. For centralized scheduling in 802.16 Mesh networks, to increase the total capacity, [3]-[6], they proposed the flexible transmission structure as tree topology and tried to find the maximum non-interference links to increase the performance of bandwidth in the centralized mesh mode. Instead of fixed centralized transmission tree, Hincapie et al [7] proposed the dynamic topology to find the most of links in the same single time frame. In their approach, they constructed transmission topology tree with different kinds of physical modulation and power based on load of traffic flows during run time. So the total capacity could be increased. Considering the control and data subframes divided, Schwingenschlogl et al [8] brought up an adjustable mechanism of allocation of control and data subframes to support the different traffic specific and increase the system utilization. In the above articles, they did not consider the signal impact in the IEEE 802.16 Mesh networks with centralized mode, however, the control message triggered by traffic flows and deal out the data slot allocation to schedule all of SSs can access share link without collision. In this paper, we focus on the correlation between traffic discipline and signal cost in centralized mesh network. So we propose a basic signal cost analysis model to identify signaling character.

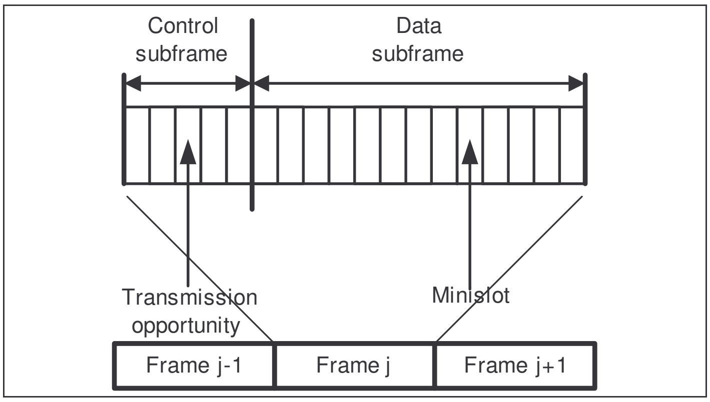


Figure 2. Frame structure

III. ANALYSIS OF THE SIGNALING COST

In order to model the signaling cost of a given SS_i in a mesh networks, the following assumptions are made: (1) Each flow entering the mesh networks is a *Poisson* process with the same rate λ (data slots per second), (2) The size of the buffers in the SS is large enough to prevent data loss, (3) The total input load is under the capacity of the network, (4) the number of flows passing through SS_i is denoted by N_i, and (5) The size of the time frame for slot allocation is denoted by T. Since the aggregation of the N_i independent flows is a *Poisson* process with rate $\lambda * N_i$, the probability of SS_i sending a *BW_REQ* control frame is the probability that more than one data slot arrived within a time frame. Therefore, *BW_REQ* rate at SS_i (denoted by $BwReqRate_i$ in the paper) can be calculated as follows:

$$BwReqRate_i = 1 - Prob\ [\text{no data slots arrived within a time frame}] = 1 - e^{-\lambda N_i T} \quad (1)$$

The total signaling cost in the mesh networks is therefore the summation of the signaling cost of all SS (assume the number of SSs in the network is n, $i=1, 2, \ldots, n$), i.e.

$$TotalBwReqRate = \sum_{i=1}^{n} (1 - e^{-\lambda N_i T})$$

IV. PERFORMANCE EVALUATION

The simulation study was conducted to verify the correctness of the analytical results. Our simulation topology is a 2-dimensions mesh network as shown in Figure 3. In Table I, the frame time used in the simulation is 64ms, and there are 10 flows in the mesh networks. Figure 4 shows the simulation results as well as the analytical values of the signaling cost at the SS with different number of flows. The figure demonstrates the correctness of the analytical results. Moreover, Figures 5-6 display the signaling cost at each active SS for two different cases of flow distribution in the mesh networks. Although the total input load (the number of flow, the flow rate, and the average hop count of the flow path) is the same, the distribution of the source-destination pair of the flows is different in the two cases. The figures show that the total signaling cost (i.e. the size of the shaded area in the figures) varies even though the total input load is the same. On the other hand, Figures 7-8 show two different flow rates, we can also calculate the request rate based on Figure 4. More specifically, the total signaling cost of the centralized scheduling depends on the number of active SS and the load at each active SS, which are affected by the flow rate and the hop count of the flow path.

V. CONCLUSIONS

In this paper, we propose a simple theoretical model to evaluate the signaling cost of the centralized scheduling in IEEE 802.16 mesh networks. Simulation study is used to verify the correctness of the analysis and the factors affecting the signaling cost are identified. According to our signaling model, we can try to allocate the two parts of control and data subframes to enhance the network utilization. On the other hand, in the distributed scheduling scheme, every Mesh node competes for channel access using an election algorithm based on the scheduling information of the two-hop neighbors. Distributed scheduling implies more signal message to achieve their MAC protocol. The future work of the research is to investigate the signaling cost of the more complex distributed scheduling.

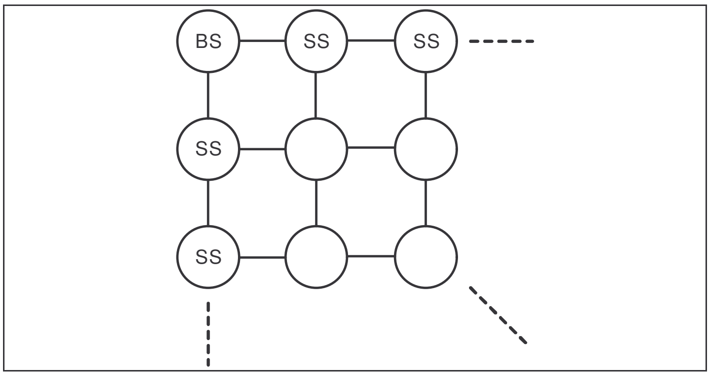


Figure 3. Simulation topology

TABLE I. SIMLATION PARAMETERS

Description	Value
Network size	5×5 mesh
Link capacity	5 Mbps
Time frame duration	10 ms
# of slots per time frame	10
# of flows per service type	10
Average date rate of all flows (λ)	4, 24, 40 Kbps
Average hop count	6

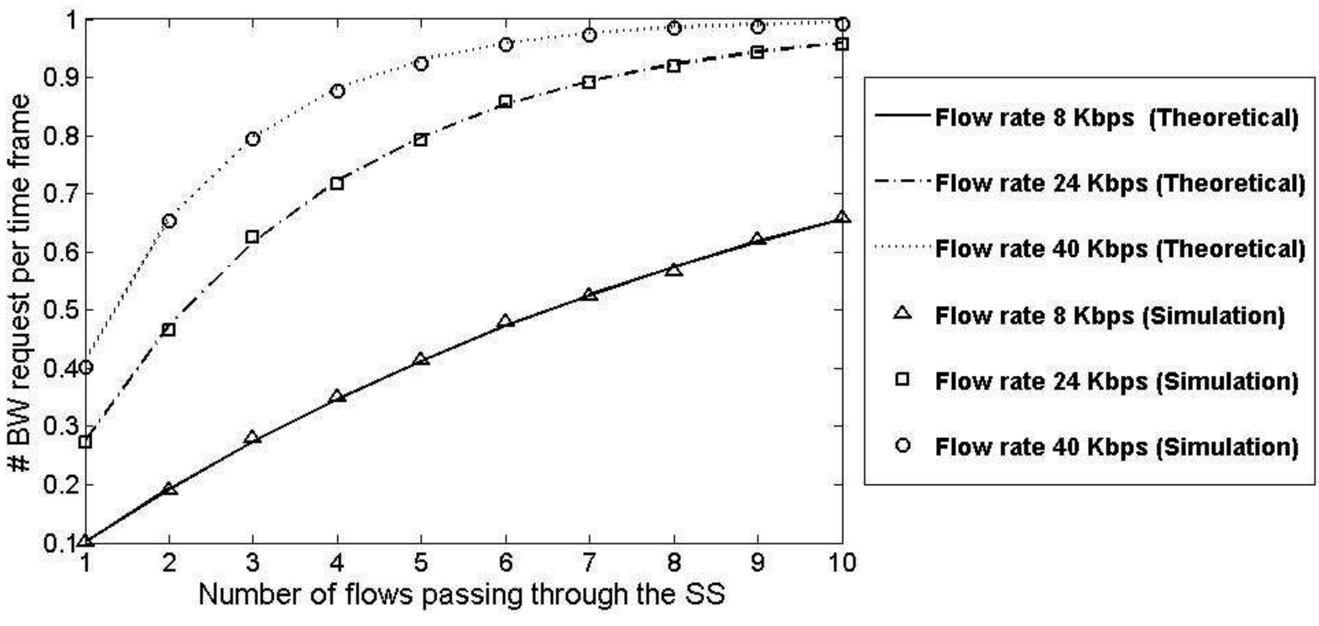
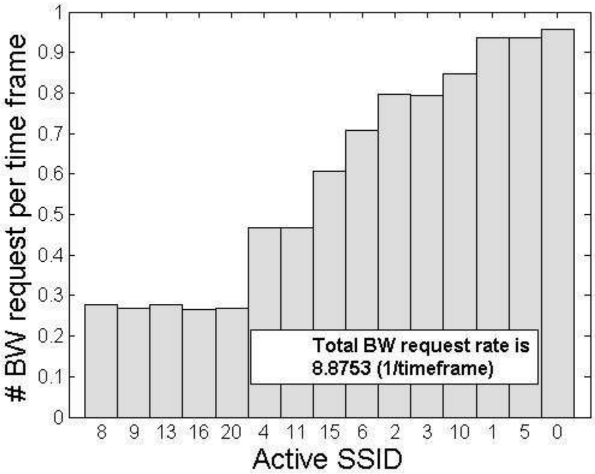


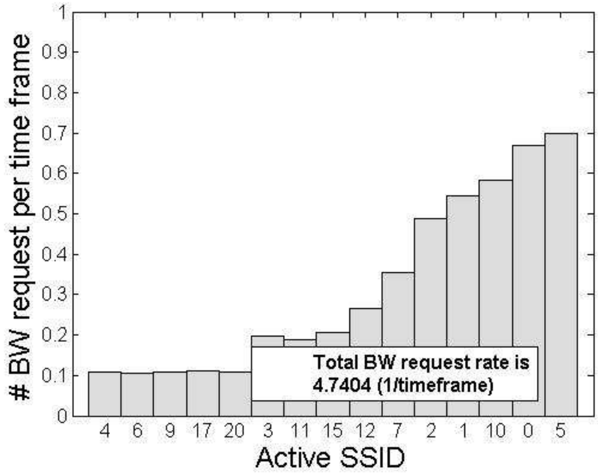
Figure 4. BW_req rate per SS in different flow rate



# of flows via SS	1	2	3	4	5	6	9	10

Total number of flows=10, avg. hop-counts=6, flow rate=24kbps

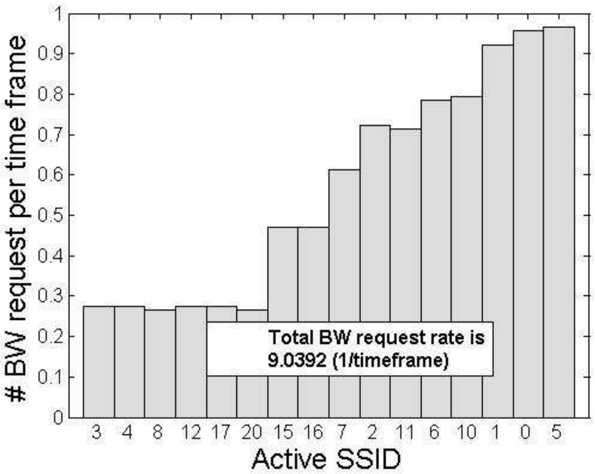
Figure 5. Flow rate=24kbps, BW_REQ rate at each active SS, in case 1



# of flows via SS	1	2	3	4	5	6	9	10	11

Total number of flows=10, avg. hop-counts=6, flow rate=8kbps

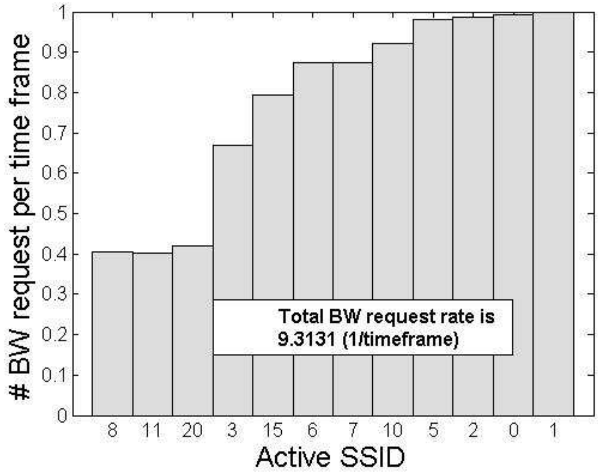
Figure 7. Flow rate=8kbps, BW_REQ rate at each active SS



# of flows via SS	1	2	3	4	5	8	10	11

Total number of flows=10, avg. hop-counts=6, flow rate=24kbps

Figure 6. Flow rate=24kbps, BW_REQ rate at each active SS, in case 2



# of flows via SS	1	2	3	4	5	8	9	10	12

Total number of flows=10, avg. hop-counts=6, flow rate=40kbps

Figure 8. Flow rate=40kbps, BW_REQ rate at each active SS

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