Performance Evaluation of Scheduling in IEEE 802.16 Based Wireless Mesh Networks

Bo Han, Fung Po Tso, Lidong Lin and Weijia Jia
Department of Computer Science, City University of Hong Kong
83 Tat Chee Avenue, Kowloon, Hong Kong
Email: {Bo.Han, Lin.Lidong}@student.cityu.edu.hk, wjia@cs.cityu.edu.hk

***Abstract*-We propose an efficient centralized scheduling algorithm in IEEE 802.16 based Wireless Mesh Networks (WMN) to provide high qualified wireless multimedia services. Our algorithm takes special attention on the relay function of the mesh nodes in a transmission tree which is seldom studied in previous research. Some important design metrics, such as fairness, channel utilization and transmission delay are considered in this scheduling algorithm. IEEE 802.16 employs TDMA and the selection policy for scheduled links in a time slot will definitely impact the system performance. We evaluated the proposed algorithm with four selection criteria through extensive simulations and the results are instrumental for improving the performance of IEEE 802.16 based WMNs in terms of link scheduling.**

I. INTRODUCTION

The rapid growth of high-speed multimedia services for residential and small business customers has created an increasing demand for last mile broadband access. Traditional broadband access is offered through digital subscriber line (xDSL), cable or T1 networks. Each of these techniques has different cost, performance, and deployment trade-offs. While cable and DSL are already being deployed on a large scale, Fix Broadband Wireless Access (FBWA) systems [1, 2] are gaining extensive acceptance for wireless multimedia services with several advantages. These include rapid deployment, lower maintenance and upgrade costs, and granular investment to match market growth [2]. Recently, study group 802.16 was formed under IEEE Project 802 to recommend an air interface for FBWA systems that can support multimedia services [3]. In 802.16 protocol stack, the medium access control layer (MAC) supports both point-to-multipoint (P2MP) mode and mesh (multipoint-to-multipoint) mode.

All these mesh nodes naturally form a WMN [4, 5]. Compared with the traditional wireless ad hoc networks, WMN has the following distinct features. First, WMNs are not isolated self-configured networks and emerge as a flexible and low-cost extension of the existing wired infrastructure networks. Generally, WMNs serve as the *access networks* that employ multi-hop wireless forwarding to relay traffic. In such an environment, power consumption is not a primary concern as mesh nodes are fixed and wire-powered. Traffic patterns may be asymmetric which mostly involve communication to and from wired gateway (Base Station), rather than involving pairs of end-nodes. Moreover, nodes in a mesh network are either stationary or minimally mobile. Thus, contrary to routing in ad hoc networks, the links in WMNs have much longer duration times. At last, most applications of WMNs are broadband services with various QoS requirements [4].

In IEEE 802.16 mesh mode, scheduling is one of the most important problems that will impact the system performance. A scheduling is a sequence of fixed-length time slots, where each possible transmission is assigned a time slot in such a way that the transmissions assigned to the same time slot do not collide. Generally, there are two kinds of scheduling – *broadcast* and *link*. In a broadcast scheduling, the entities scheduled are the nodes themselves. The transmission of a node is intended for, and must be received collision-free by all of its neighbors. While in a link scheduling, the links between the nodes are scheduled. The transmission of a node is intended for a particular neighbor, and it is required that there be no collision at this receiver.

We propose an efficient centralized scheduling algorithm for IEEE 802.16 mesh mode. Compared with the existing scheduling algorithms, the proposed scheme considers some distinct features of WMNs, such as the function of access networks and the inherent relay model. Moreover, this scheduling scheme also considers some important performance metrics, such as, fairness, channel utilization and transmission delay. To the best of our knowledge, this is the first centralized scheduling algorithm in IEEE 802.16 based WMNs which considers the relay model. In what follows, Section II introduces some related work. The scheduling mechanism in the IEEE 802.16 mesh mode is described in Section III. In Section IV an efficient centralized scheduling scheme for IEEE 802.16 based WMNs is proposed. Section V presents performance evaluation and Section VI contains some conclusion remarks.

II. RELATED WORK

Several IEEE special task groups have been established to define the requirements for mesh networking in wireless personal area networks (WPANs), wireless local area networks (WLANs) and wireless metropolitan area networks (WMANs). Although at different degrees of maturity, the following emerging standards have been identified: IEEE 802.11s, IEEE 802.15.5, IEEE 802.16a, and IEEE 802.20. A brief introduction of these open standards can be found in [5].

Most of the existing researches about WMNs are based on IEEE 802.11 standard [6–10, 27]. Kyasanur and Vaidya studied the problem of improving the capacity of multi-channel wireless networks by using multiple interfaces [6]. Aguayo et al analyzed the causes of packet loss in a 38-node urban multi-hop 802.11b mesh network [7]. Raniwala and Chiueh proposed a multi-channel WMN architecture that equips each mesh network node with multiple 802.11 network interface cards [8]. Draves et al presented a new metric, which is a function of the loss rate and the bandwidth of the link, for routing in multi-radio multi-hop wireless mesh networks [9]. Gambiroza et al studied fairness and end-to-end performance in multi-hop wireless backhaul networks through a formal reference model and an extensive set of simulation experiments [10]. Tang et al studied interference-aware topology control and QoS routing in IEEE 802.11-based multi-channel wireless mesh networks with dynamic traffic [27]. Little work has been done about IEEE 802.16 based

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wireless mesh networks. Wei et al adopted an interference-aware cross-layer design to increase the throughput of 802.16 WMN [11]. Cao et al developed a stochastic model for the distributed scheduler of the IEEE 802.16 mesh mode [28]. Recently, two centralized scheduling algorithm were proposed for WMN [32, 33]. However, none of them consider the relay model which is very important in WMN.

The general scheduling problem has been extensively studied in Packet Radio Network (PRNET) [12–21]. The work in [12] is mainly about the capacity region of a PRNET which is defined as the set of all origin-to-destination (o-d) message rates that are achievable via any arbitrary protocol. The author showed that the problem of determining whether a given point belongs to the capacity region of a PRNET is NP hard. Nelson and Kleinrock defined a channel access protocol for a PRNET in which the locations of the nodes of the network were assumed to be fixed and known [13]. An approximation to the mean system delay of packets in the network was developed and compared to simulations. Two polynomial time algorithms were proposed for link scheduling in a spread spectrum radio network [14]. Cidon and Sidi introduced new distributed dynamic channel assignment algorithms for a multihop PRNET [15]. The basic idea of the algorithms is to split the shared channel into a control segment and a transmission segment.

Ephremides and Truong provided a comprehensive study of scheduling broadcast transmissions in a multi-hop, mobile PRNET [17]. Chou and Li derived an upper bound of the minimum TDMA frame length of any collision-free node assignment protocol in a PRNET in which a node had multiple reception capacity [18]. Ramanathan and Lloyd considered both link and broadcast scheduling in multi-hop PRNETs [19]. In each instance, scheduling algorithms were given that improved upon existing algorithms both theoretically and experimentally. Gronkvist compared broadcast and link scheduling and determined which one was preferable [20]. They showed that only the connectivity of the network and the input traffic load of the network were needed in order to determine whether broadcast or link scheduling was preferable. Bjorklund et al developed mathematical programming formulations for resource optimization for both broadcast and link scheduling [21]. They further presented a column generation approach which constantly yielded optimal or near-optimal solutions in numerical experiments. Unfortunately, no extensive experimental study or only very simple experiment was given in these existing literatures.

Scheduling algorithm is also an important research topic in the traditional ad hoc networks and Bluetooth scatternets. Rácz et al proposed a pseudo-random coordinated scatternet scheduling algorithm to perform the scheduling of both intra and inter-piconet communication in Bluetooth networks [22]. Kim et al presented two versions of QoS-aware scheduling algorithms: a perfect assignment algorithm for bipartite scatternet and a distributed localized algorithm [23]. Recently, Salonidis and Tassiulas presented a framework for the provision of deterministic end-to-end bandwidth guarantees in wireless ad hoc networks [24]. This framework did not require any apriori knowledge on the number of nodes in the network nor even network-wide slot synchronization.

Several research works also have been done to make ad hoc networks take the role of wireless access networks. Hsiao et al described a new distributed routing algorithm that performed dynamic load-balancing for wireless access networks [25]. Bejerano considered the problem of designing an efficient and low-cost infrastructure for connecting static multi-hop wireless networks with wired backbone, while ensuring QoS requirements such as bandwidth and delay [26].

III. BACKGROUND ON IEEE 802.16 MESH MODE

In P2MP operation, the wireless link operates among a central Base Station (BS) and a set of Subscriber Stations (SSs). The BS is the only transmitter operating in the downlink (from BS to SS), so it transmits without having to coordinate with other stations. Subscriber stations share the uplink to the BS on a demand basis. In the mesh mode, all nodes are organized in an ad hoc fashion, each node can relay traffic for other nodes and QoS is provisioned on a packet-by-packet basis. Within a mesh network, a system that has a direct connection to backhaul services outside the mesh network is termed the *Mesh BS*. All the other systems of a mesh network are termed *Mesh SSs*. Uplink and downlink are defined as traffic in the direction to the Mesh BS and that away from the Mesh BS, respectively. Mesh differs from P2MP mode in that in the mesh mode, traffic can be routed through other SSs and can occur directly between the SSs. Whereas in the P2MP mode, traffic only occurs between the BS and SSs. Moreover, unlike the P2MP mode, the mesh mode only supports Time Division Duplex (TDD) for uplink and downlink traffic [3]. For the transmission, several SSs share the channel in a TDMA (Time Division Multiple Access) fashion. In what follows, unless specified otherwise, we will refer to BS and SS as Mesh BS and Mesh SS. And we will use the terms SS and node interchangeably.

A new SS, say u, entering IEEE 802.16 based WMN obeys the following procedures. At first u scans for MSH-NCFG (Mesh Network Configuration) messages to establish coarse synchronization with the network (the cost of synchronization phase is beyond the scope of this paper). Then u shall build a physical neighbor list from the acquired information. From this list, u selects a Sponsoring Node (SN) according to some policy. A sponsoring node is defined as a neighboring node that relays MAC messages to and from the BS for u. That is, it is an upstream node that is closer the BS. Registration is the process where u is assigned its node ID. After entering the network, a node can also establish the links with other nodes. Fig. 1 gives an example of network topology which is composed of one BS and 11 SSs. There is a link between two SSs if they are within the transmission range of each other. Fig. 2 shows the corresponding scheduling tree that only contains the transmission links between a node and its SN. We refer the omitted links in Fig. 2 (compared with Fig. 1) as the interference links. BS will periodically broadcast MSH-CSCF (Mesh Centralized Scheduling Configuration) messages that include the complete topology of scheduling tree to the nodes. Due to the centralized nature of the scheduling algorithm, there are no hidden terminal problems here.

In IEEE 802.16 based WMNs, communication in all the links shall be controlled by a scheduling algorithm. There are three kinds of scheduling in IEEE 802.16 mesh mode: centralized, coordinated distributed and uncoordinated distributed scheduling. We will brief the general idea of centralized scheduling below. For distributed scheduling, we refer the interested readers to [3]. In centralized scheduling, the BS shall gather resource requests through MSH-CSCH (Mesh Centralized Scheduling) messages from all the SSs within a certain hop range. The BS determines the flow assignments from these resource requests and communicates

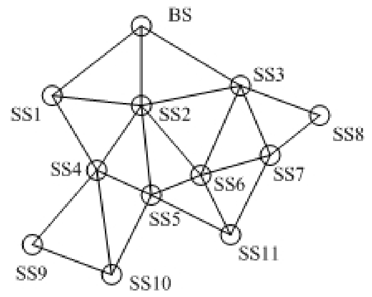


Figure 1. Network Topology

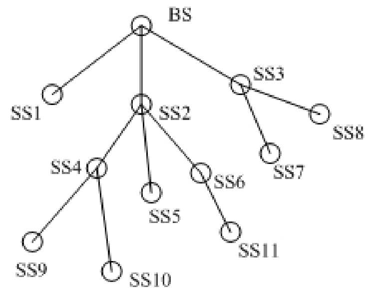


Figure 2. Scheduling Tree

these assignments to all the SSs. Subsequently, the SSs determine their own transmission opportunities in a distributed fashion, using a common predetermined algorithm with the same input information. The SSs will let the BS know their changes of resource request through MSH-CSCH messages. Then the BS will rebroadcast the adjusted flow assignment and the SSs can recalculate their transmission opportunities. To quote the IEEE 802.16 standard [3], the advantage of centralized scheduling is that "it is typically used in a more optimal manner than distributed scheduling for traffic streams, which persist over a duration that is greater than the cycle time to relay the new resource requests and distribute the updated schedule".

IV. QOS-AWARE SCHEDULING SCHEME

A. *Problem Definitions and Modeling*

As mentioned above, the considered traffic in IEEE 802.16 based WMNs is mainly to and from the BS, thus we focus on link scheduling in this paper. In 802.16 mesh mode, the underlying TDMA communication is structured into frames, each composes of several equal duration time slots. A TDMA scheme makes a considerable effort at maximizing the spatial reuse of the available bandwidth while at the same time eliminating the possibility of collision [16].

We define the closed one-hop neighbor set of node u as $Nei[u]$ and the set of node v's sponsored nodes is represented as $Sons(v)$. The cycle of a link scheduling is the time needed to transmit all the traffic to/from the BS in the WMN, under certain traffic model. The length of a link scheduling is the number of time slots in the cycle. The cycle keeps repeating until the next scheduling update. The channel utilization ratio (CUR) is defined as the ratio between the number of occupied time slots and the number of available time slots (the length of scheduling multiplied by the number of nodes). Note that, the resulted CUR is, in fact, the average CUR for all SSs. The average transmission delay is the number of time slots between the time slot when a packet is transmitted by the source SS and the time slot when the same packet arrives at the destination. Suppose a packet is sent out in time slot 2 and arrives to the destination in time slot 7, the transmission delay is then calculated as 5 time slots. Here, we consider the following special *scheduling problem*: how to assign time slots to transmission links in IEEE 802.16 based WMNs so as 1) to reduce the length of scheduling; 2) to improve the channel utilization ratio and 3) to decrease the transmission delay, subjected to some constraints that are presented below.

In particular, depending on the signaling mechanism, transmissions may collide in two ways in wireless networks: *primary* and *secondary* interference [19]. *Primary interference* occurs when a node has to do more than one thing in a single time slot. The reason for this constraint is that the nodes cannot transmit and receive simultaneously and cannot transmit/ receive more than one packet at the same time. Thus, this constraint is also referred to as the transmission/reception constraint. *Secondary interference* occurs when a receiver R tuned to a particular transmitter T is within the range of another transmitter whose transmissions, though not intended for R, interfere with the transmissions of T. This constraint is also referred to as the interference-free constraint.

We can use the partial topology in Fig. 3 to illustrate the interference more clearly. In this figure, two nodes that are within the transmission range of each other are connected by a link. The solid lines represent the transmission links in the scheduling tree and the dashed lines represent the interference links. We stress that although there is no traffic transmitted over interference links and these links do not have to be scheduled, they may induce conflicts between links that must be scheduled. Suppose the node in the higher part of the figure is closer to the BS and the link from node A to B (uplink) is scheduled in the current time slot. Due to these two kinds of interference, nodes B, C, E, F, N and P cannot transmit through their uplinks in the same time slot. In fact, these interfered nodes can be divided into two types: 1) $Nei[B]-\{A\}$, such as nodes B, C and P and 2) $Sons(Nei[A]-\{B\})$, such as nodes E, F and N. For example, if node P is scheduled to transmit to Q, B will receive packets from both A and P. If node N is scheduled to transmit to M, M will receive packets from both A and N. Thus, these transmissions will collide. Note that, there is no difference in the mechanisms for the scheduling of downlink and uplink. In IEEE 802.16 mesh mode, uplink and downlink are scheduled separately. Thus, for the limited space, we only describe the scheduling algorithm for uplink and it can be easily extended to the case of downlink.

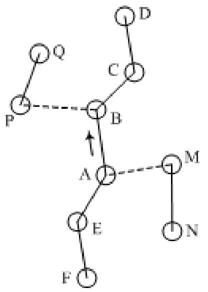


Figure 3. Interference Model

B. Transmission-Tree Scheduling (TSS) Algorithm

In the proposed algorithm, the SS is assigned *service token* based on its traffic demand. We use service token to allocate time slots to each link proportionally according to the required bandwidth of the link's transmitter, thus, the fairness is guaranteed (no nodes will be starved). Suppose there are totally n SSs and the traffic demand of SS_i is tr_i. Then the service token assigned to SS_i will be $token_i = tr_i/g$, where g is the greatest common divisor (GCD) of tr_1, tr_2, $\ldots tr_n$. We divide the traffic demands by their GCD to reduce the length of scheduling. For example, if the traffic demands of the SSs are 2Mbps, 8Mbps, 6Mbps and 4Mbps. The service tokens assigned to the SSs will be 1, 4, 3 and 2. Compared with the service token assignment 2, 8, 6 and 4, the length of resulted scheduling is reduced to half. Here, we name the set $\{token_i\}$ as ST. Each time after a link is assigned a time slot, the service token of its transmitter is decreased by one and that of the receiver is increased by one. Therefore, using the change of service token, we can easily integrate the hop-by-hop relay model of WMN into our algorithm.

Fig. 4 gives the details of the algorithm. Suppose the length of the resulted scheduling is k. The inputs of this algorithm are the scheduling tree T and the service token set ST, and the output is an $n \times k$ scheduling matrix S. If node i is scheduled in time slot j, $S_{ij} = 1$, otherwise, $S_{ij} = 0$. Initially, all the elements in S are 0. In each round (for the *while* loop), initially, if the service token of the transmitter of a link is non zero, this link is marked as *available*, otherwise, it is marked as *idle*. An available link satisfied with some selection criterion (to be discussed later) is scheduled in the current time slot. The selected link is marked as *scheduled* and all the conflicting neighboring links of this selected link are marked as *interfered*. The service tokens of the transmitter and receiver of this scheduled link are also adjusted. Then, the next scheduled link is selected based on the same rule. The selection is repeated until none of the links are marked as *available*. The same procedure is repeated until the service tokens of all these SSs are decreased to 0.

The implementation of function `select_one_link()` is determined by different selection criteria. In this paper, we consider four kinds of criteria: *random*, *min interference*, *nearest to BS* (hop count) and *farthest to BS*. In *random* selection, each time the scheduled link is selected randomly. In the *min interference* selection, the link whose transmitter interferes the minimal number of other SSs is chosen for scheduling. While in the *nearest to BS* and *farthest to BS* selections, the link whose transmitter has the minimal or maximal hop count to the BS is scheduled. If two SSs have the same number of interfered neighbors or the same hop count to the BS, we use the node ID to break the tie and choose the SS with the smaller node ID. Note that, when the service token of nodes with smaller ID is decreased to 0, nodes with higher ID will get the chance to be scheduled, thus will not be starved forever. Moreover, the transmission slots assigned to a node is determined by the number of its server tokens. Then nodes with smaller ID can not always transmit more frequently than nodes with higher ID.

```
Algorithm TSS
Input: Scheduling tree $T = (V, E)$ and service token set $ST$
Output: A time slot assignment $S$
  $k = 1$;
  assign service token to each SS
  while $\exists\ token_i \neq 0$ do
     initialize the status of all transmission links in $E$
     while $\exists\ e \in E$ and status ($e$) = available do
        $m$ = select_one_link();
        status ($m$) = scheduled;
        adjust_service_token ($m$);
        $S_{mk} = 1$;
        mark_interference ($m$);
     end while
     $k$++;
end while
```

Figure 4. Pseudo code for the proposed scheduling algorithm

C. Performance Analysis

This section analyzes the time complexity of the proposed scheduling algorithm and gives some bounds on the length of scheduling.

Proposition 1*. Using hop_i to represent the hop count of SS_i to BS, the length of scheduling k is at most $O(n)$.*

Proof: The total number of occupied time slots is $\sum_{i=1}^{n} token_i \times hop_i$. Thus, we can get $k \le \sum_{i=1}^{n} token_i \times hop_i$. The worst case occurs when there is only one link can be scheduled in each time slot. As mentioned above, the BS shall gather resource requests from all the SSs within a certain hop range $HR_{threshold}$, therefore $hop_i \le HR_{threhold}$. In a real IEEE 802.16 based WMN, the traffic demand of each SS will also have the maximal value which should be a constant. Thus, $k \le O(n)$. ■

Proposition 2*. The time complexity of the proposed scheduling algorithm is of $O(n^2)$.*

Proof: From the pseudo code in Fig. 4, we can see that the proposed algorithm TSS consists of two loops with executions of at most k times and n times respectively. Therefore, the time complexity is $O(nk)$. Based on Theorem 1, we have that $k \le O(n)$, thus, this theorem is proved. ■

Proposition 3*. The channel utilization ratio CUR $= \sum_{i=1}^{n} token_i \times hop_i\ /nk$.*

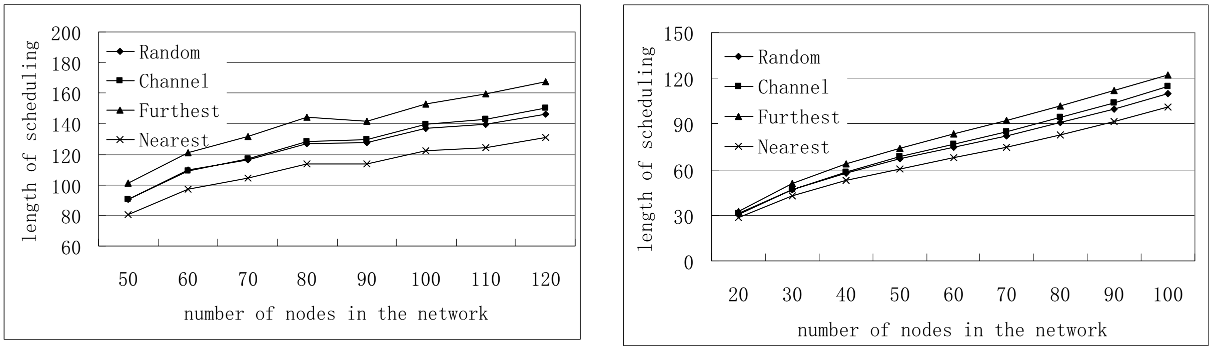
The proof of Theorem 3 is straightforward by the definition of CUR.

V. SIMULATION

A. Performance Metrics

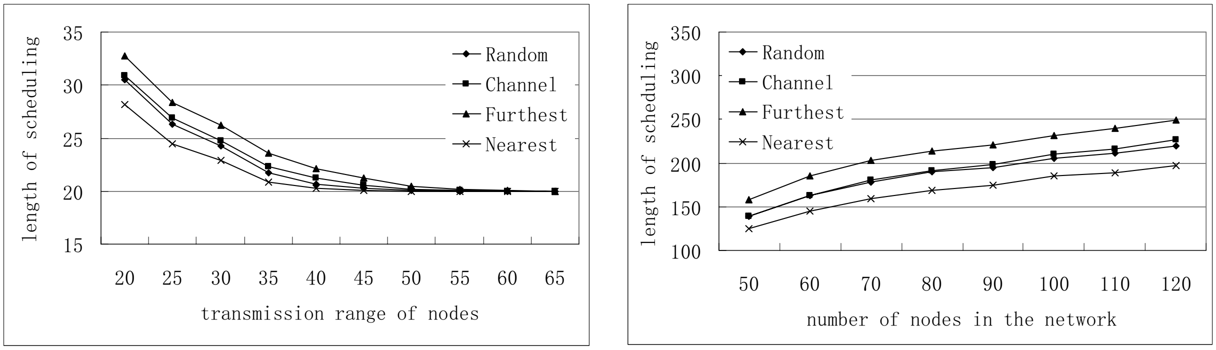
As mentioned above, three metrics are set up for the performance evaluation. They are the *length* of scheduling k, *CUR*, and the *average transmission delay*. The length of scheduling is the most important measure of the performance of a scheduling algorithm, and it is considered in most of the previous literatures. In many applications, the transmission schedule is constructed only when the network is initialized and the data communication is done according to this schedule for as long as the network remains up.

Due to the shared nature of wireless channel, CUR is another significant performance metric that we must consider. Higher CUR will improve the effect transport capacity of WMNs. Since CUR = $\sum_{i=1}^{n} token_i \times hop_i\ /nk$, we can see that given the scheduling tree and service token set, CUR is



(a) r = 15 units, $token_i = 1$ and n is from 50 to 120

(b) r = 20 units, $token_i = 1$ and n is from 20 to 100



(c) n = 20, $token_i = 1$ and r is from 20 units to 65 units

(d) r = 15 units, $token_i \in [0, 3]$ and n is from 50 to 120

Figure 5. Length of the scheduling

inverse proportional to the length of scheduling k. That is, smaller k will lead to a better CUR. Moreover, since IEEE 802.16 based WMN is used to provide broadband wireless multimedia services, we also aim to reduce the transmission delay using the proposed scheduling algorithm. Because each SS can transmit only one packet in a time slot, packets will be buffered in the intermediate SS. The buffer management policy will definitely impact the transmission delay. In the simulation, we give priority to packets from nodes that are further away from the BS.

B. Simulation Setup

As mentioned above, to the best of the author's knowledge, this is the first scheduling algorithm in IEEE 802.16 mesh mode that considers the relay model. Therefore, no comparison can be made with existing schemes. A *C*-coded custom simulator is used for the performance evaluation of the proposed scheduling algorithm. We aim to investigate the impact of different selection criteria on above mentioned performance metrics. For simplicity, in the following we call the scheduling algorithms using the above four selection criteria as *Random*, *Channel*, *Furthest* and *Nearest*, respectively. In the simulation, a given number of SSs were randomly and uniformly distributed in a square simulation area of size 100 by 100 units. The BS is placed atthe center of the simulation area. Each SS has a fixed transmission range r. The SS's movement is not considered. Thus, two SSs are neighbors when their distance is smaller than their transmission range. All the simulation results presented in this section were obtained by running these algorithms on 300 connected graphs. We obtain the simulation results for both homogeneous (the service token number of nodes is 1) and heterogeneous (the service token number of nodes is randomly selected from 0 to 3) traffic demands.

C. Simulation Result

For the limited space, we only present the results about the length of scheduling in Fig. 5. We show the results for average transmission delay and channel utilization ratio in [31]. The configurations of simulation for Fig. 5 (a), (b), (c) and (d) are as following: (a) the node's transmission range is 15 units, the number of nodes in the network ranges from 50 to 120 with increment step of 10 and the service token of nodes is 1; (b) the node's transmission range is 20 units, the number of nodes in the network ranges from 20 to 100 with increment step of 10 and the service token of nodes is 1; (c) the number of nodes in the network is 20, the node's transmission range ranges from 20 to 65 units with increment step of 5 and the service token of nodes is 1 and (d) the node's transmission range is 15 units, the number of nodes in the network ranges from 50 to 120 with increment step of 10 and the service token of nodes is randomly selected from 0 to 3. As mentioned above, we use the number of time slots to measure the length of scheduling and average transmission delay. Therefore, the unit of the y-axis in Fig. 5 is the number of time slots. From Fig. 5 (a), (b) and (d), we notice that when the node's transmission range is fixed, the increase of the number of nodes in the network will increase the length of scheduling. When the number of nodes is fixed, the increase of node's transmission range will decrease the length of scheduling as shown in Fig. 5 (c).

Comparing Fig. 5 (a) with Fig. 5 (d), we find that the increase of average service token will lead to longer scheduling length. From Fig. 5 (c), we can see that when the node's transmission range increases to be larger than 55 units, the scheduling length decreases to 20 which is the same as the number of the nodes. The reason is that under this network topology, almost all the SSs are one hop away from the BS and the mesh network degrades to P2MP network, so every SS needs only one time slot to transmit its own data to the BS.

Among these four algorithms, *Nearest* performs best, followed by *Random* and *Channel* (these two algorithms perform very closely) and the performance of *Furthest* is the worst. The reason is that when the mesh network is used as access network, the nodes which locate nearer to the BS will become the bottleneck in the scheduling tree and thus giving higher priority to these nodes will reduce the number of needed time slots.

VI. CONCLUSION

We proposed an efficient centralized scheduling algorithm for IEEE 802.16 based WMNs. In this algorithm, we consider some particular features of WMNs, such as the function of access networks. The relay model is also integrated into this scheduling algorithm. The scheduling scheme takes fairness, channel utilization and delay requirements for all traffic into consideration. In the proposed algorithm, the selection policy for scheduled nodes will impact the algorithm's performance. We use the length of scheduling, transmission delay and channel utilization ratio to evaluate the performance of the proposed scheduling algorithm. Our comprehensive simulation studies show that giving higher priority to the nodes nearer to the BS will reduce the length of scheduling and transmission delay and improve the channel utilization ratio. Our current work includes investigating the impact of different buffer management policy on the transmission delay and further research on the computation complexity of the proposed scheduling problem.

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