Collision-free Routing Centralized Scheduling Using EbMR-CS Algorithm for IEEE 802.16 Mesh Networks

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Abstract. Being an emerging wireless broadband technology with numerous prospects, Worldwide Interoperability for Microwave Access (WiMAX) not only provides high data rate but also the last mile solution for broadband wireless access (BWA). WiMAX enables both point to multi-point (PMP) and mesh topologies solution. In centrally controlled WiMAX mesh mode, all data packets are routed to the subscriber stations (SSs) via base station (BS). Thus, the BS link may be constantly congested with data traffic which impacts the performance of the system. The goal of this paper is to create an efficient multi-hops routing with suitable scheduling algorithm in WiMAX mesh networks (WMN). This algorithm is called energy/bit minimization routing and centralized scheduling (EbMR-CS) algorithm. Here, a routing tree is constructed based on the energy/bit minimization (EbM). This algorithm looks for a short path from the current node to BS, while the optimal path is achieved when the whole path has the lowest EbM. After the route is fixed, and the traffic demanded at each node is known, the total traffic arriving at a node is centrally scheduled such that the transmission interferences can be avoided. The proposed algorithm has considered some important design metrics such as fairness, reuse timeslot, balanced load, concurrent transmissions and hop count. The result shows that the proposed EbMR-CS algorithm has reduced the length of scheduling up to 43%. The system throughput and channel utilization ratio (CUR) have been enhanced up to 68% and 45%, respectively.

Keywords: WiMAX mesh networks, fairness, CUR, EbM routing, centralized scheduling.

1 Introduction

Advances in broadband wireless access (BWA) technologies over the years intensively stimulate the interest of customers [1]. The IEEE 802.16 family of technologies which is popularly known as Worldwide Interoperability for Microwave Access (WiMAX) is one such standard that renders various service types in last mile BWA solutions. Currently, this standard enables both point to multi-point (PMP) and mesh topologies solutions [2].

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In the mesh mode operations, data packets are not necessarily routed through the base station. They may alternatively be routed to the destination through other intermediary nodes as mesh routers. This reduces the base station (BS) link from becoming a network bottle neck in that mesh networks. They have self-organizational capabilities in the case of link failure as shown in Figure 1. Hence, this WiMAX specification ushers the implementation of WiMAX mesh networks (WMN) [3], [4].

It could be recalled that routing and link scheduling continue to pose problems to the improvement of the mesh networks technology, which provokes the interest of researchers. The authors in [5] have proposed a heuristic greedy scheduling model for mesh networks. They further gave an estimate of the achievable throughput in this scenario. Narlikar *et. al.* in [6] has discussed the various routing models proposed by researchers for mesh mode applications. However, these models can only afford an interference-free routing with scheduling algorithm to eliminate the interference in the network by utilizing a two-frame period where half the links are activated in each frame.

A mathematical model has been presented for centralized scheduling, which the authors refer to as routing, channel and link scheduling (RCL) algorithm [7]. A cross-layer design for tree type routing, level-based centralized scheduling and distributed power control to improve the network throughput has been presented in [8]. Similarly, various bandwidth allocation strategies have been proposed for WiMAX mesh mode operation. One such research is from [9], where the authors employed matrix algebra to construct collision avoidance schedule of links to enhance system throughput. On the other hand, the authors in [10] differed in their approach. They argued that upon constructing a routing tree, the path with the least number of hops will optimize system throughput.

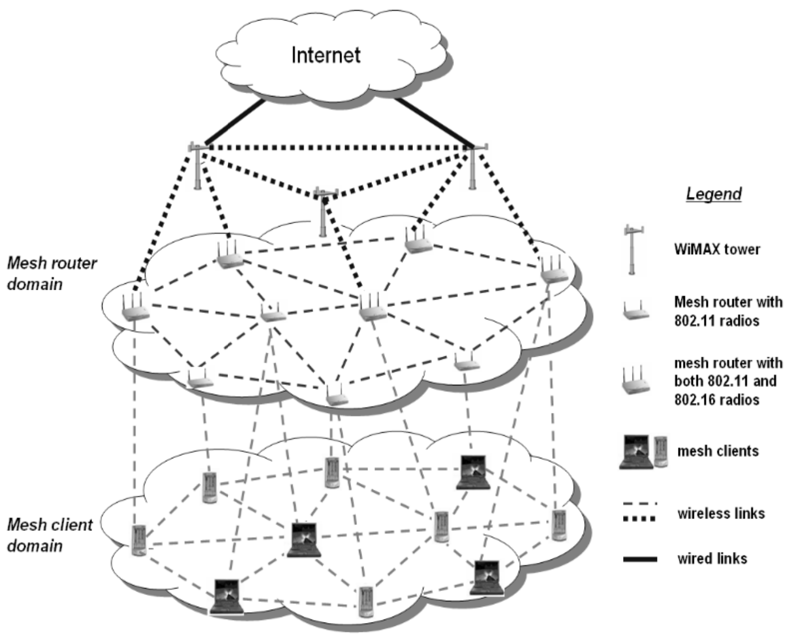


Fig. 1. IEEE 802.16 based WMNs

The authors in [11] suggested that the path with the least number of blocking nodes improve system throughput. In recognition to the transmission requirements of real-time services, and attempting to improve efficiency, the authors in [12] achieved this goal by inducing adjustments to the key parameter of interest. Constructing a routing path in a short path algorithm was done by Han *et. al.* in [13, 14] and Peng *et. al.* in [15]; they select the neighbouring subscriber station (SS) with the least node ID (Identifier) number as parent node (PN). Similarly, Wang in [16] used the Breadth First Search (BFS) algorithm to construct the routing tree by firstly choosing the BS in the first level as the new routing tree's root node and then selecting the neighbouring node by choosing the node with a small ID number. All the nodes in this routing may choose the same node with the least ID number from their neighbouring nodes, and this may cause series of interferences in the network. Moreover, in [16], the assignment of the transmission slots to the nodes is determined by the number of service tokens. It is crucial to note that a node is allocated a service token based on its packets. In the nearest-to-the BS model, which gives a better result than the farthest model in [16], the author did not consider other important parameters into the selection process such as the traffic load and the interferences. Kyasanur and Vaidya in [17] introduced a multi-radio network for the IEEE 802.11 network interface card. While one radio is kept fixed to one channel, the other radio keeps switching between the remaining channels for communication with the fixed channel of its neighbor nodes. Kodialam and Nandagopal in [18] proposed a WMN with the assumption that fast channel switching can be attained. With that in mind, the authors modeled a dynamic Channel Allocation algorithm; however, the algorithm resembles a fixed channel allocation algorithm.

In this paper, an efficient multi-hops routing for WMN through suitable scheduling algorithm called energy/bit minimization routing and centralized scheduling (EbMR-CS) is proposed. We focus on eliminating the collision packets and enhancing the performance of WMN system. Some important design metrics such as fairness, reuse timeslot, balanced load, concurrent transmission, relay model and hop-count are considered. The results show that the proposed EbMR-CS algorithm has reduced the length of scheduling up to 43% besides enhanced the system throughput and channel utilization ratio (CUR) up to 68% and 45% respectively.

The rest of this paper is arranged as follows. Scheduling in IEEE 802.16 WMN is presented in Section 2. In Section 3, the interference in WMN is described. The proposed EbMR-CS algorithm is explained in Section 4. The system performances of the proposed EbMR-CS algorithm in terms of length of scheduling, CUR and system throughput are discussed in Section 5. This paper is concluded in Section 6.

2 Scheduling in IEEE 802.16 WMN

To be precise, scheduling in WiMAX can be defined as an array of fixed length timeslots as shown in Figure 2. Each potential transmission is allocated some timeslots in a manner that higher priority is given to the SS with higher traffic demand. Thus, the SS with higher traffic demand needs a longer scheduling period and causes a transmission delay to the SS with lower traffic demand. For a mesh networks operating in the centralized mode, the BS is charged with the responsibility of determining the scheduling for the whole network. However, it is usually employed in the communication between BS and SS. An example of centralized scheduling in the WiMAX based mesh networks is illustrated in Figure 3.

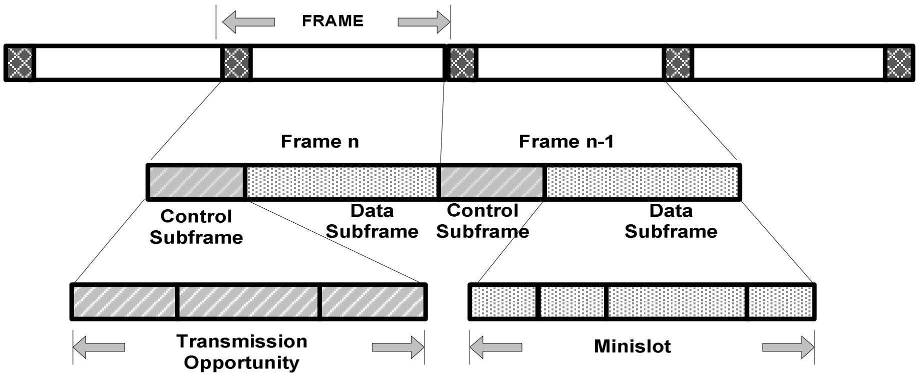
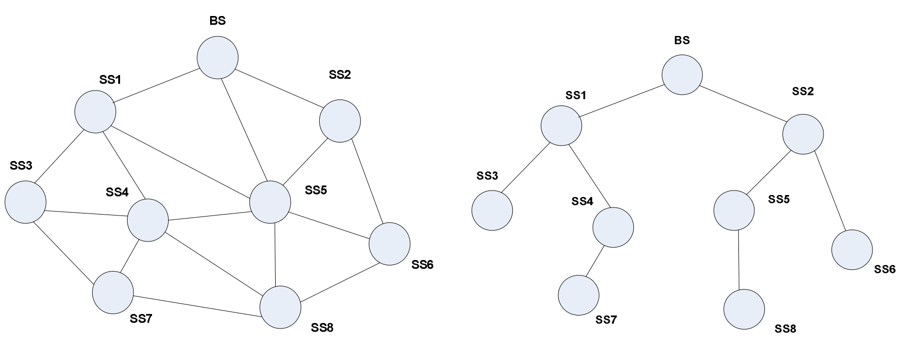


Fig. 2. The IEEE 802.16 frame structure

The WiMAX based mesh networks supports both mesh centralised scheduling (MSH-CSH) and mesh distributed scheduling (MSH-DSCH) schemes. To allocate data (time) mini slots to the various SSs in either of these scheduling schemes, control packets are exchanged in the scheduling control sub frame [19]. However, the total number of possible transmissions per sub frame is a reconfigurable parameter as shown in Figure 2. While centrally controlled scheduling is most favoured for communication between BS and SSs which corresponds to internet traffic, distributed scheduling tends to favour SS to SS communication which corresponds to intranet traffic. When operating in centralized mode, all scheduling decisions are made at the BS to allocate the mini slots to all the SSs.



(a) Network topology (b) Scheduling tree

Fig. 3. The network architecture; (a) network topology and (b) scheduling tree

3 Interferences in WMN

As IEEE 802.16 networks operate synchronously in a timeslot mode. It is also essential to allocate timeslots such that collision is avoided over the network to achieve the required bandwidth and high system throughput in each connection. A challenging issue in the IEEE 802.16-2004 WiMAX networks is that the routing and scheduling schemes are strongly coupled. This is particularly different from that in Wi-Fi based mesh networks, in which the medium access control (MAC) layer is contention-based. Their routing algorithms and MAC layer protocols can be separately designed and operated.

To schedule two links at the same timeslot, the scheduling should be done in such a way that interference is avoided [20]. This particularly depends on the transmission and signalling mechanism between the nodes. Packet collision in the IEEE 802.16d WiMAX networks basically occurs in two distinct forms, namely primary and secondary interferences [21]. Primary interference is due to the half duplex nature of the transceiver. A node cannot transmit and receive simultaneously as shown in Figure 4(A) [13]. Besides that, a node also cannot transmit to or receive from multiple neighbour nodes at the same time as shown in Figure 4(B) [14].

Secondary interference occurs where the transmission of one link can be corrupted by the interference from a neighbouring link as shown in Figure 5 [22]. Figure 5 explains this case, when a receiver of node D tuned to a transmitter of node C is within the range of transmitter of node B which is transmitting to node A, D’s reception interferes with B’s transmission, though not intended for receiver D. Peculiar to multi-hops communication is the problem of contention for channel access by both the arriving and departing data packets. This is solved by equipping the nodes with a multiple transceivers system, with each tuned to a different channel, thus enabling simultaneous transmission and reception per node.

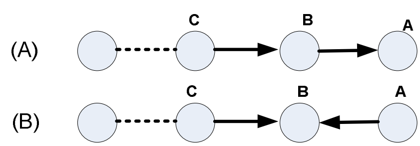


Fig. 4. Primary interference in WMN

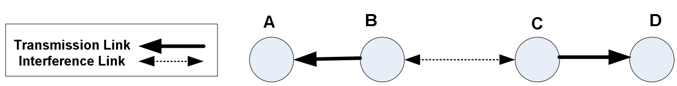


Fig. 5. Secondary interference in WMN

4 Proposed EbMR-CS Algorithm

The proposed EbMR-CS algorithm is presented in this section. Here, a routing tree is constructed based on EbM. This algorithm looks for a short path from the current node to BS, while the optimal path is achieved when the whole path has the lowest EbM. After the routing is fixed and the traffic demanded at each node is known, the total traffic arriving at a node must be determined for further transmission. This system design algorithm consists of four parts: namely network model, EbM routing algorithm, channel allocation and multi-transceivers scheduling algorithm as shown in Figure 6.

In order to avoid interference and system bottleneck, a network model is constructed where both path loss (PL) and signal to noise ratio (SNR) are taken into consideration to maintain the communication link between the transmitter and receiver. Hence, the EbM routing algorithm is designed to find the optimal path from source to destination to create a balanced network. The multi-channel allocation is then implemented by using first order algorithm to increase the reuse timeslot and concurrent transmission. Finally, a multi-transceiver scheduling algorithm is added to enhance the performance of the system and avoid the collision in the network.

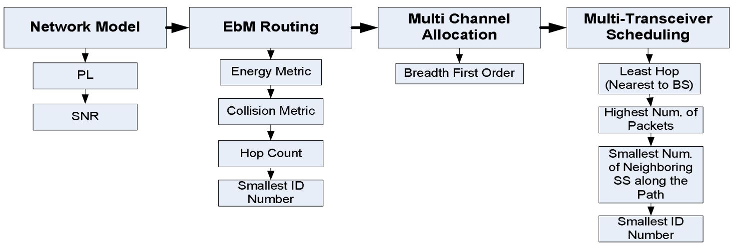


Fig. 6. The EbMR-CS algorithm methodology stages

4.1 Network Model

The network topology is modelled as a directed graph $G(V,E)$. An example of this topology is shown in Figure 3a, where V represents the set of nodes in the mesh cell $\{SS_1, SS_2, ..., SS_n\}$, n is the number of nodes in the network, and E represents the set of edges between every SS and its PN that carry data. In wireless communication, the signal from transmitter suffers from PL attenuation as it traverses the network to the receiver. This PL is a function of the distance of separation, d of the nodes. Thus, we can calculate the PL using the NLOS equation [23] as follows

$$PL = 122.5 + 26.5 * \log_{10}(d) \tag{1}$$

If node p, for example, sends packets to node q, it is regarded successful if and only if the following condition holds [24].

$$PTx - 10\log_{10}(BW) + GTx + GRx - PL - 10\log_{10}(KTo) + NF > SNR_{threshold} \tag{2}$$

Where, PTx is the mean power at the antenna port, BW is the occupied bandwidth, GTx, GRx are the antenna gain for Tx and Rx respectively, NF is the receiver noise figure and KTo = -144 dBW/MHz = Equipartition Law.

The *SNR thresh* is the minimum threshold below which the signal will not be received at node q. Table 1 shows the value of SNR threshold [2], which can be applied to calculate the $SNRp,q$ at the receiver of every link. The *SNR* must always be kept above the QPSK ½ threshold for correct reception of data packets at receiver. Whenever the *SNR* falls below this threshold, the link disconnects immediately and link capacity nullified. In this way, a connectivity graph $G(V,E)$ is derived using the links marked with its capacity, which is then used as the basis for routing-tree construction.

Table 1. Receiver SNR threshold assumptions [2]

Modulation	Coding Rate	Receiver SNR (dB)
BPSK	½	6.4
QPSK	½	9.4
	¾	11.2
16-QAM	½	16.4
	¾	18.2
64-QAM	2/3	22.7
	¾	24.4

In the proposed algorithm, the nodes are randomly distributed. The link between any two nodes is selected. The PL and SNR of this link are measured. If the SNR is found to be larger than the SNR threshold, the link is connected. Otherwise the link fails. This procedure is repeated until all the nodes select their neighbours. In this way, the PL and SNR are used to reduce the number of link connectivity, which helps the routing algorithm to make optimal decisions for selecting their parents.

4.2 EbM Routing Algorithm

The routing strategy is employed to transfer traffic from a node to the BS to determine which path is feasible. As such, only static routes are considered in this paper. Beginning with the BS, the SS nodes are added into the tree one by one. The routing tree is constructed after the connectivity graph is obtained. Since EbM model minimizes energy used per bit transmitted to the mesh BS, the overall energy consumption is kept to a minimum without any regard to the number of hops. In Wireless MAN/HIPERMAN systems, this function is handled by the Mesh Networks Configuration (MSH-NCFG) messages.

The energy value *eb(n) = eb(n,PN(n))* is the dissipated energy per unit data byte received by the parent node PN(n) from node *n* [24]. To compute the energy metric *Eb(i)* dissipated along the routing path from node *i* to Mesh BS, the following formula is used [24]

$$Eb(i) = \sum_{v \in path(i)} e_b(v) \tag{3}$$

The BS is chosen as the new routing tree's root node. For each of the candidate subscriber node (CSN), *n* is the node with neighbours in the routing tree but as at now not in the tree themselves. Hence, the route to mesh BS is found by choosing the path with the smallest energy (E) and its parent node PN(n) is selected as follows

$$PN(n) = \arg\min\{E_b(i) + e_b(n,i)\} \tag{4}$$

This strategy typically produces a fairly high hop count to reach the BS. This results in using shorter hops with higher modulation complexities.

After the topology is fixed, the algorithm can select only one PN to obtain the routing tree. Four metrics are of paramount significance to this algorithm instead of one used in [24]; these are minimum energy per bit (EpB), minimum collision metric, minimum hop-count and smallest *ID* number. However, the collision metric and hop-count metrics play important roles to maintain a balanced network.

- In the algorithm, for each CSN, the parent node is selected from the upper level which has the minimum hop count to the BS. At initialization, there is only one sponsor node (SN), and hence this SN is selected to be the PN.

(If the number of SN=1, then PN1=SN, where PN1 is the parent node with only one SN).

- If there is more than one SN for each CSN, the PN with the minimum EpB is selected as the PN.

(If the number of SN1 >1, then $PNe = \arg\min\{E_b(i) + e_b(n,i)\}$*, where SN1 is the number of SNs, and PNe is the parent node with minimum EpB).*

- If there are more than one SN having the same minimum EpB, the PN with the smallest collision metric (the number of neighbouring nodes) is selected as the PN.

(If the number of SNe>1, then $PNc = \arg\min\{Neigh(SNe)\}$*, where SNe is the number of the SNs that have equal minimum EpB, PNc is the PN having the minimum collision metric and Neigh(SNe) is the number of neighbouring nodes for each SNe).*

- If there are more than one SN that has the same minimum collision metric, the PN having the minimum hop-count to the BS is selected as the PN.

(If the number of SNc>1, then $PNh = \arg\min\{hop(SNc)\}$*, where SNc is the number of SNs having equal minimum collision metric, PNh is the PN with the minimum hop-count and hop(SNc) is the number of hop-count from the SNc to BS).*

- If there are more than one SN having equal minimum hop-count to BS, the SN with the smallest ID number is selected as the PN.

(If the number of SNh>1, then $PNid = \arg\min\{ID(SNh)\}$*, where SNh is the number of SNs with equal minimum hop-count to BS, the PNid is the PN which has the smallest ID number, and ID (SNh) is the ID number of each SNh).*

4.3 Channel Allocation

The idea behind the graph $G(V,E)$ is to join the mesh nodes. On a given set of SSs and BS, communication trees with the BS as roots need to be built. An important prerequisite to this channel allocation strategy is the important assumption that nodes are fitted with one or two radios. The goal is to model a channel assignment set for the set of radios such that interference is kept at a minimum and capacity fairly distributed.

Figure 7 shows the nodes fitted with two radio interfaces, with each having a distinct function. While one maintains connectivity with other colleague nodes, the other ensures connectivity with subscriber stations. Hence, a reliable allocation mechanism should put into consideration, the service demands of each and every node in the network. Channel distribution for interference minimization is one good way to achieve this.

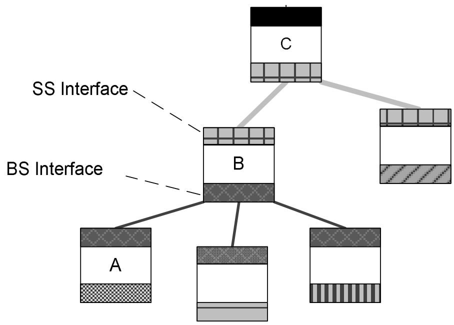


Fig. 7. An example of network with multiple interfaces

The following aptly describes the channel assignment mechanism of this network.

- As depicted in Figure 7, all the other nodes are subscribers to node B. As such, they must use a common channel to access B. The channel used for this purpose is dependent on B's base station interface. Similarly, each station tunes its SS interface to match B's BS interface.
- To establish subscription to some other node, i.e. C in our scenario, a different channel is used by B. as shown in Figure 7.
- Nodes transmitting on different channels do not cause any interference to one another.

In this paper, the breadth first order is used. As depicted in Figure 8, a channel is first allocated to the BS, followed by assigning it to the SSs nearest to the BS, and then to all the SSs with more than one hop away from BS, and so on. However, taking into consideration the cost implication of equipping all the nodes with multi transceivers, the nodes in the edges {SS3, SS5, SS6, SS7, SS8} of the network are fitted with only one transmitter. This is because of the fact that while a multi transceiver for these edge nodes will raise their cost, there is no child node for these nodes and hence need not be fitted with multi transceivers as shown in Figure 8. Furthermore, since the BS is also fitted with two receivers operating at different channels, the proposed model uses both for transmitting because there is no PN for BS as shown in Figure 8.

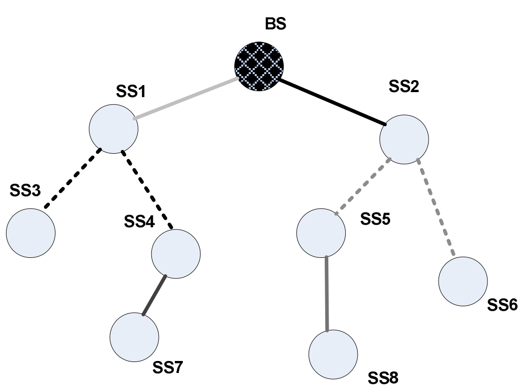


Fig. 8. Breadth first algorithm

4.4 Multi-transceiver Scheduling Algorithm

This is an infrastructure based multi-hop WMN comprising of a BS and a number of SSs, where the BS also acts as the internet gateway. In such a scenario, the SSs not only transmit packets to and from BS, but also act as routers. The multiple transceivers on the SSs enable multi channel operations to reduce interferences. In the centralized scheduling algorithm, the following assumptions were made according to the WiMAX standard:

- We assume that the transceiver cannot switch to other channels after the transceiver is fixed at one channel.
- Any pair of nodes separated by two-hops and using different channels is considered to be none interfering.
- Multi-transceiver nodes may communicate simultaneously with as many neighbours as there are transceivers without interference.
- Each node's communication radius is only enough to cover its one-hop neighbours.
- Concurrent interference-free communication is possible along different channels.
- The network is assumed to be constant throughout the course of any particular scheduling. Control and scheduling sub-frames are considered to be of considerable length.

The aim of the centralized scheduling is to employ reuse timeslot and concurrent transmission to reduce the length of schedule and to attain optimum performance of the system. To achieve this, we must maximize concurrent transmissions while simultaneously minimizing interferences in the network. Therefore, we must take into account the traffic needs of the various SSs in the network.

In 802.16-2004, two scenarios of centralized scheduling algorithm are therefore proposed. First scenario: multi-transceiver systems as shown in Figure 9, which enable transmission and reception simultaneously at all nodes. Second scenario: the nearest multi-transceiver system (only the nearest nodes to the BS have two transceivers) as shown in Figure 10. In this system, only the nodes closest to the BS can transmit and receive simultaneously.

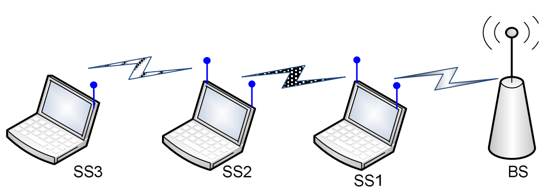


Fig. 9. Multi-transceiver system

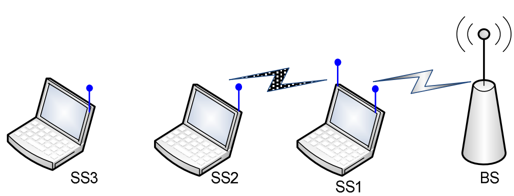


Fig. 10. The nearest multi-transceiver system

In both types of centralized scheduling algorithm scenarios (i.e. the multi-transceiver system and the nearest multi-transceiver system), the hop-count, rely model, node ID number, reuse timeslot, concurrent transmission and fairness (for this, the fairness constraints need to be taken into account to prevent starvation to nodes further away from the BS) are considered.

The idea behind the centralized scheduling algorithm is to take note of all interfering nodes in the forward link and to allow non-interfering nodes to transmit simultaneously for optimal bandwidth use. The algorithm considers four important metrics instead of only the two used in [14]; these metrics are nearest nodes (minimum hop-count to BS) to reduce the system bottleneck, number of traffic (number of packet) to achieve the fairness among the nodes, number of interfering node to maximize the reuse timeslot and concurrent transmissions. The node ID number is finally used to break the tie between the nodes.

The allocation of service tokens to the subscriber stations is a function of their traffic demand. The procedure ensures that timeslot allocation is directly proportionate to the traffic requirement of the various links, thereby ensuring fairness. For scheduling of a link to occur, its associated service token must not be zero. In short concerned SS must at least have a free non-interfering channel and its PN having buffer capacity for the incoming packets. Once these conditions are fulfilled, the link is considered available; else it is considered unavailable.

In addition to fulfilling the above conditions, for a link to be available, it must satisfy the nearest to BS condition (meaning it exhibits the minimum hops to the base station BS) and is scheduled in the current timeslot. In the case of a tie in the nearest to base station condition, the first priority is accorded to the node having the maximum packets for achieving QoS and fairness. In the case of a tie in the number of packets, priority is given to the node with the minimum interfering neighbours for want of maximum reuse timeslot and concurrent transmissions.

As a final step, if a tie occurs in the number of interfering nodes, priority is given to the node with the smallest ID number. When the link is finally selected, it is denoted as scheduled while its interfering neighbours are denoted as interfered. Now that the link is allocated a timeslot, the transmitter's service token is decremented by one while the receiver's is incremented by one at every timeslot. Then, the algorithm keeps repeating itself in this manner until the service tokens of all the SSs are decreased to 0. Hence, using the change of service token, the 802.16-2004 can be integrated into the proposed algorithm.

Multi-channel multi-transceivers lead to shorter lengths of scheduling, increase system throughput, improve the CUR and provide collision free channel access. Hence, it can provide a better performance as compared to the single transceiver system. The proposed scheme has shown good performance and can be implemented in the IEEE 802.16 WiMAX based mesh networks. In addition, it has also achieved better system throughput in WMNs.

5 System Performances of Proposed EbMR-CS Algorithm

In this paper, an efficient algorithm of EbMR-CS is developed with the aim of finding the optimal path of routing and scheduling, which is evaluated through simulation. In the simulation, the performance of the EbMR-CS scheme was assessed using

MATLAB platform [25]. After a series of 300 Monte Carlo simulation runs, the data is collected and averaged. The simulation configurations are set as follows: the simulated model consists of 100 SSs positioned around a BS operating in mesh mode for uplink traffic. The SS to BS communication was ensured through single or multiple hops. Nevertheless, SS mobility is not considered. Using a step wise increment of 5 nodes, the network is loaded from 5 to 100. For each SS, the number of packets was selected for one packet and between one to three randomly generated packets.

The results from the multi-transceiver consist of multi-transceiver system and nearest multi-transceiver system which are intended to eliminate the primary interference and reduce the scheduling length. These two schemes are dependent on the EbM routing tree algorithm, multi-channel scheduling and the number of transceivers in the network. The first multi-transceiver system is denoted as EbMR-CS1 and a construct of the EbM routing, multi-channel scheduling; the whole network is equipped with two transceivers except the nodes in the edges. In the nearest multi-transceiver system, which is denoted by EbMR-CS2, the EbM routing and multi-channel scheduling equipped only the nearest nodes to BS with multi-transceivers. Moreover, reuse timeslot, the hop-count, relay model, node ID number, concurrent transmission and fairness are also considered in both systems. Both the EbMR-CS1 and EbMR-CS2 are compared with the routing and scheduling schemes proposed by Wang in [16] in terms of length of scheduling, CUR and system throughput.

The results from the simulation on the scheduling length are presented in Figures 11 and 12. They are based on packet generation for one packet and between 1 to 3 randomly generated packets, as shown in Figures 11 and 12 respectively, to represent the heterogeneous traffic demands for all the nodes. Based on the assumption that one transceiver can transmit at most one token (packet) at a timeslot, it is clearly seen that the duration of the scheduling cycle gradually increases with network size for all scenarios as shown in Figure 11. The increasing traffic demand also led to longer length of scheduling as shown in Figure 12. The results from the simulation indicate that the EbMR-CS1 achieved a higher system performance in terms of the scheduling length compared to the other schemes. In other words, the EbMR-CS1 maintains shorter length of scheduling as compared to EbMR-CS2 and Wang [16]. The EbMR-CS1 at 80, for example, where the node has one packet to send is equivalent to 42 timeslot, whereas the EbNR-CS2 is equivalent to 47 timeslots.

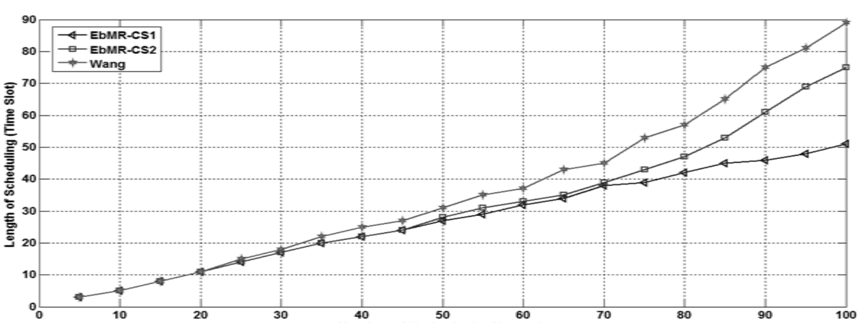


Fig. 11. Length of scheduling with one packet for each node

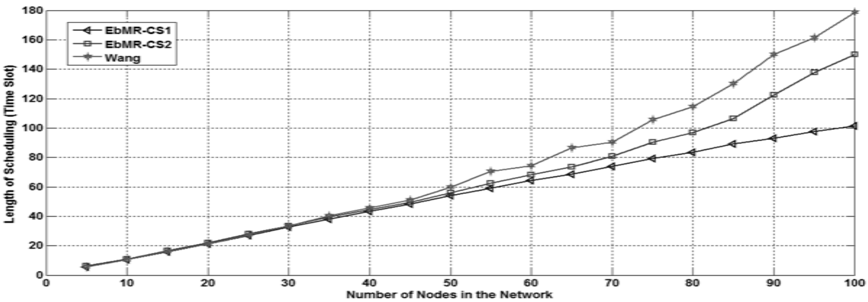


Fig. 12. Length of scheduling with random packets from 1 to 3 in each node

Using Wang [16], this is found to be 57 timeslot. Besides, both schemes proposed in this study achieved better system performance than the scheme presented in Wang [16].

The simulation results for the CUR are presented in Figures 13 and 14, with number of packet generation for one packet and between 1 to 3 randomly generated packets respectively. After obtaining the length of scheduling, the number of timeslots required to send all the packets to BS has to be determined, so as to identify the total CUR using the following equation:

$$CUR\ (\%) = \frac{(No.Packets * No.Hops)}{(No.Nodes * Length.of.scheduling)} \tag{6}$$

Based on this equation, it is observed that the increase in the number of nodes in the network can reduce the CUR, as the additional nodes in the network increases the number of interfering SS nodes when one node is transmitting as shown in Figure 13. This may be due to the fact that the additional nodes worsen the interference level in the case where only one node is sending data, thereby downgrading the possible number of concurrent transmissions. In addition, it is also observed that when the number of packet is increased, the CUR is stabilized. It is determined by the ratio of the reuse timeslot and the concurrent transmissions as illustrated in Figure 14.

However, the results from the simulation indicate that the EbMR-CS1 achieved higher CUR. For example, the EbMR-CS1 at 60 when the node has one packet to send is equivalent to 7%, whereas the EbNR-CS2 is equal to 6%.

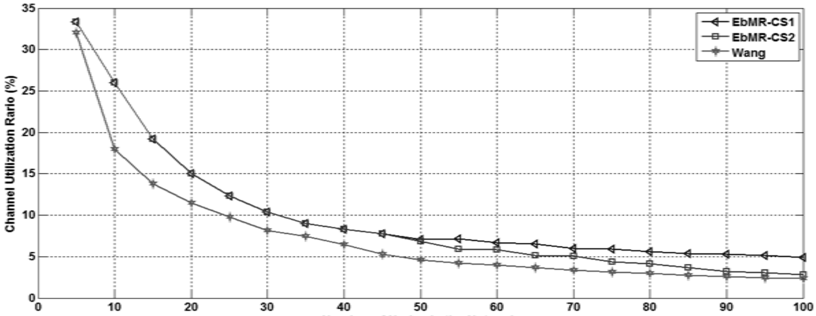


Fig. 13. CUR with each node has one packet

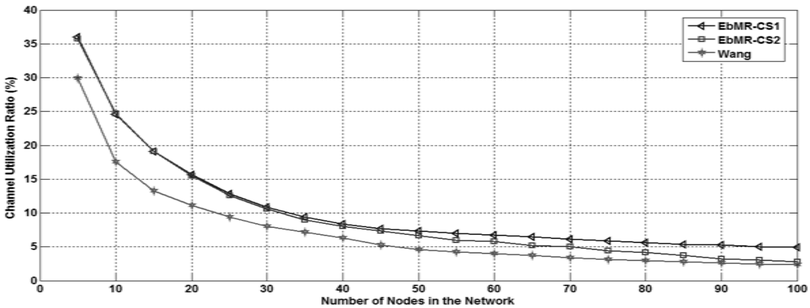


Fig. 14. CUR with each node having random packets from 1 to 3

In Wang [16], this corresponds to 4% at 60 nodes. At 10 nodes, however, both the EbMR-CS1 and EbMR-CS2 are equal to 26%, as compared to 18% in Wang's scheme. Hence, both EbNR-CS1 and EbNR-CS2 schemes outperform Wang's scheme.

Figure 15 shows the results from the simulation on the throughput of the BS in which each node has one service token to send. As shown in Figures 15 and 16, the throughput of the EbM-CS1 algorithm is much larger than the other algorithms when all the nodes are equipped with two transceivers. This result indicates that the algorithm in the present study can support more users as compared to the others.

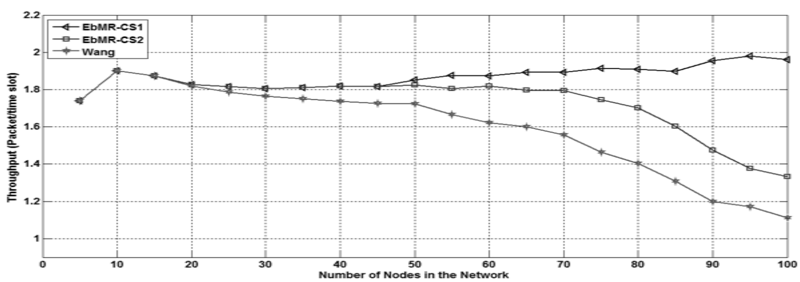


Fig. 15. System throughput in which each node has one packet

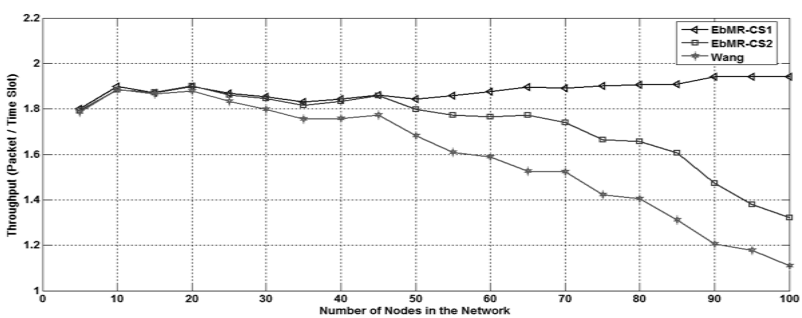


Fig. 16. System throughput when each node has random packets from 1 to 3

Both Figures 15 and 16 show that the throughput is reduce as the number of the service tokens and nodes increase. For example, the system throughput at 80 nodes, for the EbMR-CS1 is equal to 1.9 packets/timeslot, while in the EbMR-CS2 it is equal to 1.7 packets/timeslot when each node has one packet to send. In Wang's scheme, the system throughput is very small as compared to the other schemes which are equivalent to 1.4 packets/timeslot. Based on this example, the analyzed results show that the algorithms in the present study not only optimizes system throughput, but also enhances the overall efficiency of centrally controlled scheduling scheme.

6 Conclusions

Routing and scheduling in WiMAX are active areas of research, in which many algorithms have been proposed in an attempt to enhance system throughput, reduce the length of scheduling, increase CUR and provide more robustness over the wireless channel. The related problems of routing and scheduling for IEEE 802.16-2004 are still open research challenges left unsolved. The impact of interference on IEEE 802.16-2004 based mesh networks is very strong. In this paper, the EbMR-CS1 and EbMR-CS2 have been proposed for centralized scheduling in WiMAX to improve system throughput. In particular, the EbMR-CS1 and EbMR-CS2 use the multi-transceiver and multi-channel systems. Therefore, the interferences could be virtually eliminated. The results from simulation indicate that the proposed schemes achieved shorter lengths of scheduling, higher CUR and higher system throughput, as compared to Wang [16]. At the same time, it ensures fairness and better load balanced in the IEEE 802.16-2004 based mesh networks, particularly when the number of nodes is large. Moreover, the algorithms increase the reuse timeslot and concurrent transmission which allows the non-interfering links to transmit simultaneously. In addition, the proposed EbMR-CS can avoid packet loss and afford collision-free operations. The work in this paper can be extended in several directions. First, it can be further extended to distribute traffic when multiple paths are available to the destination. Second, the SS mobility can be introduced so as to compare its performance on IEEE 802.16d and IEEE 802.16e.

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