Centralized Routing and Scheduling Using Multi-Channel System Single Transceiver in 802.16d

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Abstract. This paper proposes a cross-layer optimized strategy that reduces the effect of interferences from neighboring nodes within a mesh networks. This cross-layer design relies on the routing information in network layer and the scheduling table in medium access control (MAC) layer. A proposed routing algorithm in network layer is exploited to find the best route for all subscriber stations (SS). Also, a proposed centralized scheduling algorithm in MAC layer is exploited to assign a time slot for each possible node transmission. The cross-layer optimized strategy is using multi-channel single transceiver and single channel single transceiver systems for WiMAX mesh networks (WMNs). Each node in WMN has a transceiver that can be tuned to any available channel for eliminating the secondary interference. Among the considered parameters in the performance analysis are interference from the neighboring nodes, hop count to the base station (BS), number of children per node, slot reuse, load balancing, quality of services (QoS), and node identifier (ID). Results show that the proposed algorithms significantly improve the system performance in terms of length of scheduling, channel utilization ratio (CUR), system throughput, and average end to end transmission delay.

Keywords: WMN, Routing, Scheduling, Multi-Channel Single Transceiver.

1 Introduction

Worldwide Interoperability for Microwave Access (WiMAX) is an emerging broadband fixed wireless access (BFWA) system with optimized delivering of fixed and portable wireless connections in a metropolitan area networks (MANs). It is an alternative and complementary solution for extension of fiber-optic backbone. The core of WiMAX technology is specified by the IEEE 802.16 standard that provides specifications for the medium access control (MAC) and physical (PHY) layers. WiMAX is also called wireless last mile broadband because it is the final transmission distance of delivering connectivity from a service provider main network to a customer place [1]. The 802.16 standard is large and complicated, which offers many options and extensions. One of the extensions for the fixed WiMAX technology is known as 802.16a or its later version 802.16d (popularly known as IEEE

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802.16-2004) which become the focus of industry attention because it is the easiest and most useful to implement. In addition to the point to multi-point (PMP) mode, it support mesh mode. The term “mesh” can also be described as “multi-hopping”, where the connection from a particular subscriber station (SS) to the base station (BS) is via one or more successive wireless links. Hence nodes are not required to be within line of sight (LOS) of the BS transmission and are organized in an ad-hoc fashion in the mesh mode. WMN provides a more robust broadband access topology, enables direct communication between the nodes. Nodes can relay their transmissions through other subscribers in mesh networks if they cannot directly reach a BS. This condition helps to extend the range of the BS and allow the network to grow in an organic fashion [2]. There are two types of mesh mode, full mesh and partial mesh. In the full mesh network, every node has a connection to every other node in the network but this type is difficult to implement while in the partial type, nodes can only connect to one or more nodes but not all in the network.

Many researchers have tried to come out with suitable solutions to one of the major problems in the WMN that is dealing with interferences coming from the transmission of the neighbouring mesh nodes. The transmissions from any node can block all the neighboring nodes from transmitting or receiving signals. Previous researches mitigate the effect of the interference by constructing a routing tree and/or scheduling algorithms by focusing on each layer without considering the parameters on other layers [3] - [9]. In this paper, we introduce cross-layer design approach to overcome the interferences in WMN. The scope of cross-layer design strategy here is between MAC and network (NET) layers. The MAC layer uses centralized scheduling by considering the relay model to assign a time slot for each possible node transmission in WMN, while the NET layer uses routing tree algorithm to find the best route for all SS to the BS by taking into account the load balancing in WMN. In additions, the nodes that are far enough in space can make transmission simultaneously in the same time slot without collisions through the slot reuse and concurrent transmission concepts. The fairness transmission between the nodes is necessary to ensure that well-behaved nodes seeking to send data are not penalized or left unattended for so long time. A lot of design parameters are considered in the system design such as the hop counts to the BS, the interference from the transmission of the neighboring nodes, traffic load per node in terms of number of packets, and the node ID number. A new design metric, namely number of children per node, is introduced in the proposed algorithms. The cross-layer optimized strategy is considered for multi-channel single transceiver and also single channel single transceiver systems for WMNs. To the best of authors’ knowledge it is the first cross layer design using multi-channel single transceiver system in WMNs.

2 System Design Algorithms

The system design consists of three algorithms; constructing routing path for each node, channel assignment strategy in case of multi-channel system, and collision free centralized scheduling algorithm. In order to design in accordance to IEEE 802.16 standard, the following assumptions were made:

- The signal of a node can only cover the range of a single-hop neighborhood.
- Node can transmit one packet in each time slot.

- All the links have the same capacity and the capacity does not change when a link switches from one channel to another.

  There are five definitions in WMN as follows:
- A sponsor node is defined as the neighboring node that relays data transmission to and from the interest node, which is closer to the BS than the node itself.
- Children nodes are defined as the number of nodes that connect directly to other node in the routing path.
- A neighboring node is defined as a node that is exactly one hop-count away from the node of interest.
- Block node: A node is defined to be blocked if its transmission or reception will interfere with the currently receiving or transmitting nodes (Active node).

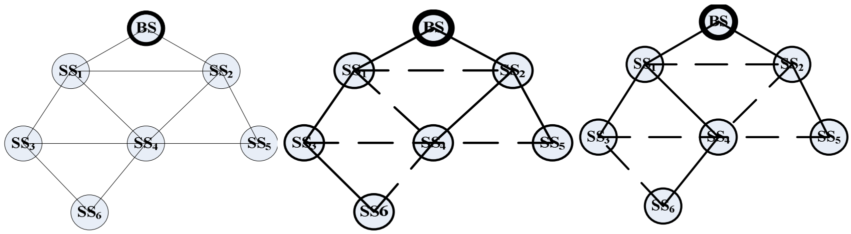
2.1 Routing Path Construction Algorithm

The primary focus of the routing algorithm is to provide a scalable routing in the presence of static node. The WMN topology is paths rooted to the BS and the criteria are to select the best root for the all SSs (source) to the BS (destination). Two routing algorithms are developed; in the first one, we need to take into account five design parameters, i.e. number of children per each node, node ID number, hop-count to the BS, the interference from the neighboring nodes (number of neighboring nodes), and number of packets for each node along the root to the BS. The best route is selected with the least number of children, the least number of interfering neighboring nodes, minimum hops to BS and load balancing network. In the second procedure, the last four parameters are taken into account in selecting the best route with the least number of interfering neighbor nodes, minimum hop to BS and load balancing network.

To develop the first procedure we will follow the steps:

1. Always select sponsor nodes from the upper level (with minimum hop-count to the BS).
2. If there is only one sponsor node, select it, else calculate the number of children for each sponsor node and select the sponsor nodes with the least number of children.
3. If there is one sponsor node, select it, else, calculate:
   a. Number of blocked nodes for each node.
   b. Number of packets for each node.
   c. Blocking metric for each node: number of blocked node multiply by number of packets. Then calculate the blocking metric for each path by summing the blocking metric for all the nodes along the path to the BS. Select the path (sponsor node) with minimum blocking metric.
4. If there is one sponsor node, select it. Otherwise the sponsor node with smallest ID number will be chosen.

To develop the second procedure, the same step in procedure 1 is followed except step 2. The routing path construction algorithm is illustrated in Fig. 1 with WiMAX mesh topology in Fig. 1a. Assume that a random number of packet generation per node for example, $SS_1 = 1$, $SS_2 = 2$, $SS_3 = 3$, $SS_4 = 1$, $SS_5 = 2$, and $SS_6 = 3$. In Fig. 1b the number of interfering neighbor nodes, hop-count, node ID number, number of packets, and number of children per node are have been considered in finding the path for the nodes using Procedure 1. However, we will only consider the number of interfering neighbor nodes, hop-count, node ID number and number of packets per node to construct the routing path for each node using Procedure 2 as shown in Fig. 1c. In Figs. 1b and 1c the solid line represents the routing path while the dashed line represents the mesh topology. The number of interfering neighbor nodes and the blocking metric for each node is shown in Table 1.



(a) WiMAX mesh topology (b) First routing algorithm (c) Second routing algorithm

Fig. 1. Routing path construction

Table 1. Number of interferers and the blocking metric for each node

Node	Interferences nodes number	Blocking metric
SS_1	4	4
SS_2	4	8
SS_3	3	9
SS_4	5	5
SS_5	2	4
SS_6	2	6

2.2 Channel Assignment Algorithm for Multi-Channel System

In a multi-channel system single-transceiver, each node can support one channel in each time slot, but can tune to another channel in another time slot. By using this algorithm the secondary interference can be eliminated. The different SSs can work on different channels then many nodes can be active at the same time slot using different channels. However, the primary interference cannot be eliminated because we are using single transceiver with half-duplex system for cost effective system.

The switching delay occurred when a transceiver tuned between the channels, but the delay is rather negligible. We first assign the channels on the edge set of the routing paths. Starting with the SS nearest to the BS following the node ID number, we can start the channel assignment algorithm with the ID number equal the one the nearest to the BS, before choosing the next ID number. The nodes that interfere with their neighbors used different channel except the nodes that have direct link to the BS.

To demonstrate the benefit of multi-channel system, assignment algorithm is presented in Fig. 2. We will use Fig. 1b to show the routing path and mesh topology. The solid line represents the routing path and dashed line represents the mesh topology. The two nodes SS_1 and SS_2 are linked to BS using the same channel denoted as L_1 because they linked directly to the BS. Then, the link SS_3 to SS_1 use different channel because it has interference with link SS_1 to BS and SS_2 to BS denoted as L_2. This is similar for the links SS_4 to SS_1 that use different channel because it has interference with link SS_1 to BS, SS_2 to BS and SS_3 to SS_1 denoted as L_3. The links SS_5 to SS_2 used another channel compare to link SS_1 to BS, SS_2 to BS and SS_4 to SS_1 because it has interference with them but it use the same channel that is used at link SS_3 to SS_1 because there is no interferences between them so it is also denoted as L_2 .The last link SS_6 to SS_4 will assign other channel because it has interferences with all the links in topology denoted as L_4.

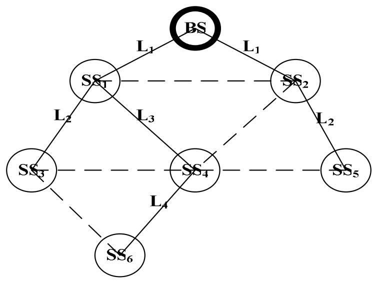


Fig. 2. Multi-channel assignments algorithm

2.3 Collision Free Centralized Scheduling Algorithm

In the 802.16d, time slot allocation for each SS is controlled by centralized scheduling algorithm in BS. We propose two types of centralized scheduling algorithm for multi-channel system and single channel system. In multi-channel and single channel we are considering the number of interfering neighbor nodes, hop-count, slot reuse, concurrent transmission, node ID number, fairness (no nodes will be ignored) and the relay model (each node responsible to transmit its packets and its children node packets). QoS is determined by assigning high priority to the nodes that have more packets than the others. The centralized scheduling algorithm is divided into two parts, node selection algorithms and collision avoidance scheduling algorithm.

Node Selection Algorithm. There are a lot of selection criteria in selecting nodes to send data: random, minimum interference, nearest to BS (hop count), and farthest to BS. We propose two selection algorithms. This selection depends on:

- i Minimum hop-count to the BS. All the SSs send data to the BS (relayed by the nodes that near the BS), hence there will be a lot of traffic (bottleneck) near the BS, Priority is given to the nodes nearest to the BS to send the data, hence decreasing the bottleneck of the system.
- ii Maximum number of packets to achieve the QoS.
- iii Minimum number of interfering neighbors to increase the slot reuse and concurrent transmission.
- iv Node with the smallest ID number.

First select the node with minimum hop-count to the BS depend on the link using criteria (i). If there is more than one node that has the same hop-count to the BS, go to criteria (ii). Second, select the node in the same level depending on link chosen based on criteria to achieve the QoS (ii). If all the nodes have the same number of packets then shifts to link in criteria (iii), if all the nodes have same the number of interfering neighbors then shift to link in criteria (iv). Then finally we select the nodes with smallest ID number to send the data before the other in same level.

Note that the second link selection algorithm is similar to the first one except link criteria (iii). Here we select the nodes with maximum number of interfering neighbors to achieve the fairness between the nodes because the nodes that have a lot of neighbors will be blocked due to their multiple transmissions compared to the nodes that have less number of interfering neighbors.

Collision Avoidance Scheduling Algorithm. The following is the collision avoidance scheduling algorithm that was used to transmit the data.

- i An SS is assigned a service token based on its traffic demand. We use service token to allocate time slots to each link proportionally according to the traffic demand of the link's transmitter, hence fairness is guaranteed.
- ii A link can be scheduled only if the service token number of its transmitter is nonzero. This link is marked as available, and otherwise, it is marked idle.
- iii An available link satisfying the link selection algorithm is scheduled in the current time slot.
- iv The selected link is marked as scheduled and all the conflicting neighboring links of it are marked as interference depending on the interference model.
- v Each time after a link is assigned a time slot, the service token of the transmitter is decreased by one and that of the receiver is increased by one.
- vi The same procedure is repeated until the service tokens of all these SSs reduced to zero.

The relay model can easily be integrated and provide fair sharing among all SS nodes by using the exchange of service token because when the service token of SSs with smaller ID number is reduced to 0, SSs with higher ID number get the chance to be scheduled, thus it will not be starved forever. To illustrate this scheduling algorithm clearly, the first node selection algorithm for multi-channel system is explained here. We use the mesh network shown in Fig. 2 as an example. Suppose all nodes have one packet to transmit to the BS. Initially the counter allocated to each node is equal to one.

- During the first time slot (Time slot 1), all transmission links are available. In the first link selection algorithm, since Nodes SS_1, and SS_2 are all one hop away from the BS, and have the same of number of packets and interfering neighbors, the node with the smallest ID number, which is Node SS_1, is scheduled first. Nodes SS_2, SS_3, and SS_4 are thus marked as interfered block nodes.
- The rest of the nodes, say Node SS_5 is then chosen in the same time slot and Node SS_2 is also interfered block node because of this selection.
- At last Node SS_6 is also chosen in time slot one and Nodes SS_4 are marked as interfered block node. Finally, Node SS_1, SS_5 and SS_6 are scheduled to transmit in time slot 1.

- Decrease the counter of SS_1, SS_5, and SS_6 by one and increase the counter of SS_2, and SS_4 by one. Move to Time Slot 2.
- In Time Slot 2 we select nodes SS_2, and SS_4 as active.
- This process repeats until the all the nodes counter equal zero.

The scheduling result is presented in Table 2. In Table 2 only the active nodes are recorded. For example, first column of the table contains SS_1, SS_5, and SS_6, which means in the Time Slot 1, these nodes are active.

Table 2. Scheduling Results

Time slot 1	Time slot 2	Time slot 3	Time slot 4	Time slot 5	Time slot 6	Time slot 7
SS_1	SS_2	SS_1	SS_2	SS_1	SS_4	SS_1
SS_5	SS_4	-	SS_3	-	-	-
SS_6	-	-	-	-	-	-

3 Cross-Layer Design

The concept of cross layer design is based on an architecture where different layers can exchange information in order to improve the overall network performance or can be defined as some kind of interaction between the different layers of the OSI layer stack. This kind of interaction is not presented in the layer stack of wire line networks. Cross layer design breaks away from traditional network design where each layer in the OSI layers operates independently. Basically, a cross-layer design involved feedbacks received from other layer to optimize the information in the current layer so that the performance is enhanced [10], [11].

The research on cross-layer design in wireless networks has been stimulated by the fact that the condition of wireless channel varies over time and its scarce resources are shared by multiple users. Thus, the traditional layered architecture seems to be inefficient and not suitable for this kind of networks. Most of the cross-layer design proposals for wireless networks involve exchanging information between multiple layers or between just two layers from MAC, PHY and network layers [12]. In this paper, the cross layer design between MAC and network layers is divided into two parts; the routing algorithm in the network layer, and the channel assignment and centralized scheduling in the MAC layer for the multi-channel system as shown in Fig. 3. These two parts exchange information of the routing paths, the interference table (the number of interferences neighboring nodes), and the number of packets for each SS for optimal selection. In the routing algorithm, we obtain route for each node and interference table for each SS. Figure 1b will be used to find the interference table and is presented in Table 3. Then in every scheduling period, the SS resource demands are collected by the centralized scheduling algorithm in the MAC layer and sent to the routing algorithm in the network layer.

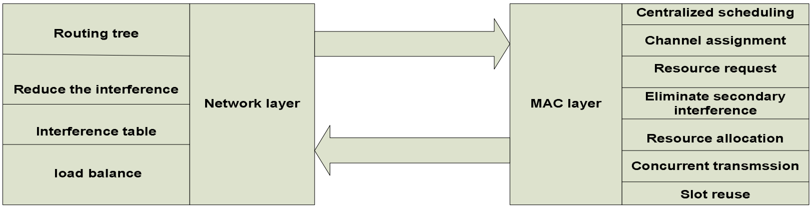


Fig. 3. Cross-layer design for multi-channel system

Table 3. Interference table

SS_1	SS_2	SS_3	SS_4	SS_5	SS_6
SS_2, SS_3, SS_4	SS_1, SS_4, SS_5	SS_1, SS_4, SS_6	SS_1, SS_2, SS_3 ,SS_5, SS_6	SS_2, SS_4	SS_3, SS_6

After choosing the route for each node, the routing paths and interference table are fed back to the centralized scheduling algorithm in order to eliminate the interference through the channel assignments algorithm and the resource scheduling table calculation in case of multi-channel system. The slot reuse and concurrent transmission algorithm is considered to make the non-interference links communicate concurrently. Load balancing in the network is also considered. In the end, we can get the paths for each node and the scheduling table and distribute it to all the nodes. The nodes must behave based on this table and we consider only one scheduling period. Note that in the single channel system, there is no channel assignment algorithm and we consider the existence of all the interference types but in the multi-channel system only the primary interferences are considered.

4 Simulations

4.1 Performance Metrics

The performance of the proposed design is based on the following parameters:

Length of scheduling. The most important measure of the performance of the proposed design is the length of scheduling, which is defined as the number of time slots used to complete all the data transmissions or the total transmission time to finish all traffic demands for all the nodes. The length of scheduling might be reduced if node selected to be active concurrently do not collide. Note that, the scheduling length is measured in time slots.

Channel utilization ratio (CUR). The CUR is defined as the ratio between the numbers of occupied time slots (which is the number of packet multiplied by number of hop-count to the BS for each node) to the total 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.

Throughput of the system. The throughput is the amount of data the BS receives in a time slot, since all packets should be routed through the BS. The throughput of BS equals the throughput of the system. Thus throughput is equal to the total data transferred divided by the total time it took for the transfer, and it is measured in packets/time slots. Note that, the upper limit for the throughput of the BS is one for single radio system because it depends on the number of radios BS carries.

Average end-to-end transmission delay. The average transmission delay is defined as the average number of time slots it takes between the time slot when a packet starts to be transmitted by the source SS and the time slot when the same packet arrives at the destination. The average transmission delay parameter measures the delay of all the packets per node measured in number of time slot.

4.2 Simulation Setup

In the multi-channel system, there are two schemes depending on the routing algorithm and the node selection mechanism in the scheduling algorithm. The first scheme denoted as Proposed MC1 for the multi-channel system, which construct the routing path using the first routing algorithm. A new metric, namely the number of children per sponsor node is considered, and in the centralized scheduling, the first selection algorithm is used. The second scheme is also for the multi-channel system denoted as Proposed MC2 used the second routing algorithm of Fig. 1 which finds the routing path by considering the node ID number, hop-count, number of interfering neighbor nodes and number of packets per node. The second selection algorithm will be used in the centralized scheduling. Note that in Proposed MC1 and MC2, the channel assignment algorithm in section 2.2 will be used after finding the routing path for each node in the network for channel distribution. Results of the multi-channel system in [4] denoted as MC [4] is used as a comparison to the Proposed MC1 and Proposed MC2 in terms of four performance metrics; the length of scheduling, the throughput of the system, CUR and average end-to-end transmission delay.

In the single channel system, there are two proposed scenarios like the multi-channel system but using one channel only. The first scenario is denoted as Proposed SC1 for the single channel system. It is the same as Proposed MC1 in the multi-channel system but without the use of channel assignment algorithm due to the single channel system. The last scenario is also for the single channel system denoted as Propose SC2, which is the same as Proposed MC2. However no channel assignment algorithm will be used. We compare our results obtained from Proposed SC3 and SC4 with the single channel system which are based on [3] and denoted as SC [3] in terms of length of scheduling, throughput of the system, CUR, and end to end average transmission delay.

The proposed designs had been implemented and simulated using MATLAB. The system performance is simulated using three scenarios as follows: The traffic for each SS selected randomly from 1 to 3 packets; 1 to 5 packets; 1 to 10 packets. The number of nodes is increased from 5 to 120 with step of 5 and the nodes movement is not considered. The buffer in each node works following first in first out (FIFO) in sending data from the node queue.

5 Results and Discussions

In this section, we present the results obtained for the multi-channel and single channel systems by implementing the three stages described in previous section. The results can be classified into four proposed mechanism according to the implementation namely Proposed MC1, Proposed MC2, Proposed SC1, and Proposed SC2 includes a new factor called number of children per sponsor nodes in Proposed MC1 and SC1. The first two scenarios are for the multi-channel system while the last two are for the single channel system. The results of multi-channel single transceiver system are compared with the multi-channel scenarios found in [4] and the results of single channel single transceiver system are compared with the single channel scenarios of [3] in terms of length of scheduling, CUR, throughput of the system, and end to end average transmission delay.

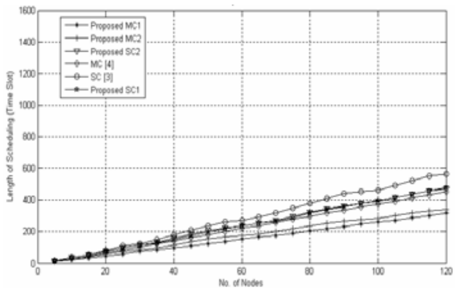
Figure 4 shows the results of the length of scheduling based on traffic demand for all the nodes: The random number of packets selected for (a) 1 to 3, (b) 1 to 5, and (c) 1 to 10 respectively to represent heterogeneous traffic demands for all the nodes. The number of time slots is used to measure the length of scheduling. In these figures, we compared the results of MC [3] and SC [4] with the result of proposed schemes MC1, MC2, SC1, and SC2. It is observed that proposed schemes reduce the length of scheduling dramatically in all the scenarios. It shows that the length of scheduling increases with the increased number of nodes in the network. It is clear that the increasing traffic demand leads to longer length of scheduling. Figure 4 also shows that the proposed system MC1 gives the shorter length of scheduling compared to others. Here, the proposed SC1 and SC2 exhibit the same performance due to the interferences in the single channel system. However, SC1 is more scalable than SC2 when the number of packets is increased. This happens due to use of number of children per sponsoring node in the first routing algorithm.

Figure 5 shows results with nodes having random number of packets from 1 to 10. It is observed that the increase of the number of nodes in the network reduces the CUR because the additional new nodes in the network increase the number of interfering neighbor nodes when one node is transmitting. Consequently, this reduces the number of nodes that can transmit in the same time slot, hence reducing the average CUR. It is also observed that when the number of packets is increased, the CUR is stable because it depends on the ratio of the slot reuse and the concurrent transmission. In most of the situations, this ratio is below 15% after the number of nodes increased to more than 20 in the multi-channel system while in single channel system, the average CUR is below 8% when the node is increased to more than 20 nodes. The reasons behind this are based on two condition, the first one is the slot reuse and the concurrent transmission are heavily affected by the interference therefore the scheduling cycle is very low when all the nodes use the same channel at the same time slots in the single channel system. The second one is the bottleneck of the routing path (the links that is near to the BS), so the links far from the BS are idle most of the time and response to send her packets only compared to node that near to the BS that is responsible to send her packets, children nodes packets and grandchildren nodes packets. Again, it is observed that CUR is increases in all schemes (MC1, MC2, SC1, and SC2) with MC1 outperform the other schemes.

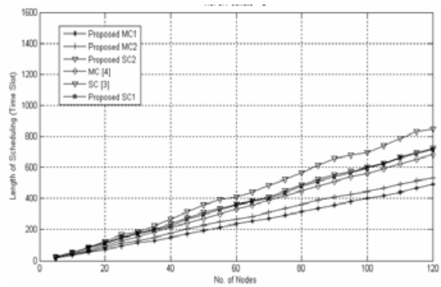
The overall performances in Fig. 6 show that the throughput has improved in all our proposed schemes. However, throughput will decrease when the number of nodes is increased because hops count also increases along the path getting to the BS. So the traffic needs to be forwarded many times by intermediate nodes until it reach the destination. The more nodes in the system results more interferences and reduction in the slot reuse. It also shows that proposed MC1 gets the higher network throughputs in the system and Proposed SC1 performs slightly better that proposed SC2 due to the congestion between the nodes in the single channel system. However, the system throughputs are below one packet. The single transceiver system can transmit or receive one packet at the same time due to half duplex system. The upper bound of the throughputs in the system can be deduced by the number of transceiver the nodes carries so that the upper limit is one packet per one time slot for single transceiver system. The fluctuations in the results are expected because the throughputs depend on the nodes number and the total transmission time needed to complete sending of the data. The increasing of the nodes in the system increased in interval by five nodes but their location is different and their traffic is increased randomly.

Figures 7, 8, and 9 plot the simulation results about the multi-channel system average end-to-end transmission delay for the nodes from levels 5 to 7 with three different random generation packets from 1 to 3, 1 to 5 and 1 to 10 respectively. We use the same number of time slots to measure the average transmission delay. Depending on the WiMAX mesh topology, the number of nodes in Fig. 7 of level 5 is from 32 to 62 nodes, level 6 of Fig. 8 are from 64 to 99 nodes and Fig. 9 with the last level from 100 to 120 nodes. In our solution, the nodes that have the minimum depth to the BS have a high priority compare to the others. We do not mix all nodes together because the nodes that are farther from the BS may suffer longer transmission delay than the nodes that are nearer to the BS. We found that when the traffic demands are increased the average end-to-end transmission delay will increase because the congestions will increase as the traffic increased. It is also increase as the node number increased due to the fact that the packets transmission time affected by the increasing in the hop count to the BS which is increase as the node number increased.

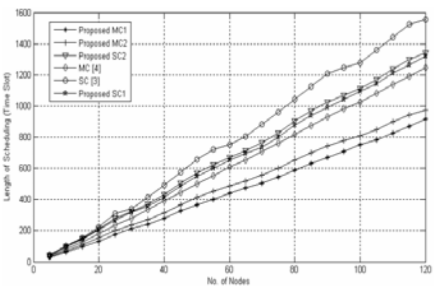
However the farthest nodes to the BS generate the largest delay. The graph shows that the average transmission delay is improved and more scalable in Proposed MC1 and Proposed MC2 than the MC when the number of nodes increased. The MC result is better than the proposed work when there are few nodes in the network because in their node selection algorithm the selected nodes are depending on their hop count and their ID number. The nodes that are nearest to the BS and have the smallest ID number will be served first. However, we notice that there is unfair selection of node between the nodes in the system as compared to our proposed work. We provide the fair selection node among the nodes based on provided QoS in terms of the number of packets and other issues as explained in the section 2.3. Note that the figures show the Proposed MC2 outperforms and more stable than Proposed MC1 whenever we increase the number of the nodes. The second routing algorithm in Propose MC2 has considered the number of packets per node as a second option to select the sponsor node. This is unlike the first routing algorithm in Proposed MC1 that considered the number of packets per node as a third option (less priority).



(a) Number of packets from 1 to 3



(b) Number of packets from 1 to 5



(c) Number of packets from 1 to 10

Fig. 4. Length of scheduling

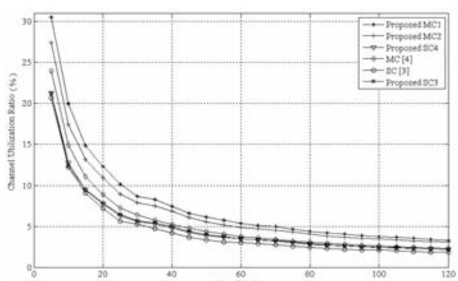
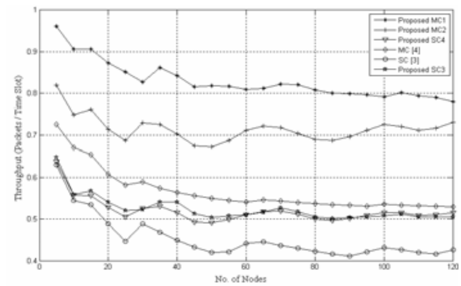
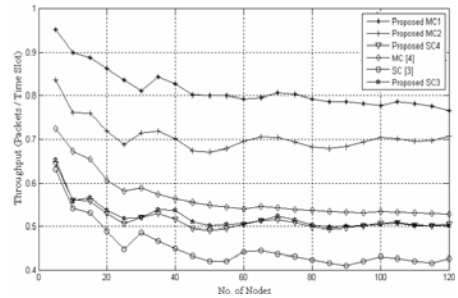


Fig. 5. Channel utilization ratio (CUR) for number of packets from 1 to 10

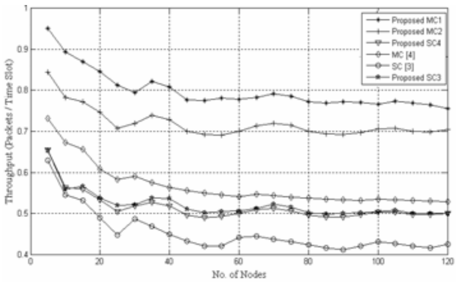
Figures 10, 11, and 12 show the results of the single channel system average end-to-end transmission delay in terms of time slot for levels 5, 6, and 7 respectively. The graph shows that the proposed mechanism improves the average transmission delay better than the SC. We found that the number of node with increase the traffic demands will increase the average transmission delay. The delay is reduced when the nodes are located at the edge of the network due to the least of interferences from the neighboring nodes compared to the nodes. The nodes at higher level produce a longer average transmission delay than those at the lower level as shown in the multi-channel system. The average end-to-end transmission delay is calculated independently for different levels because the nodes with farthest hop to the BS will produce larger



(a) Number of Packets from 1 to 3

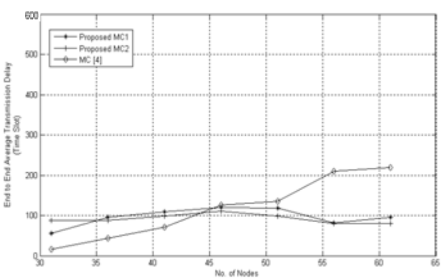


(b) Number of Packets from 1 to 5

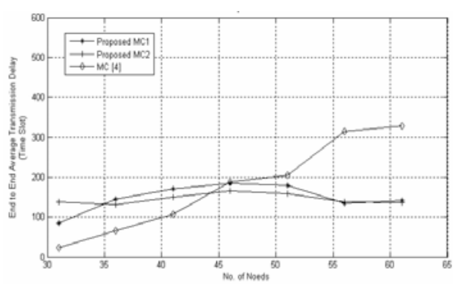


(c) Number of packets from 1 to 10

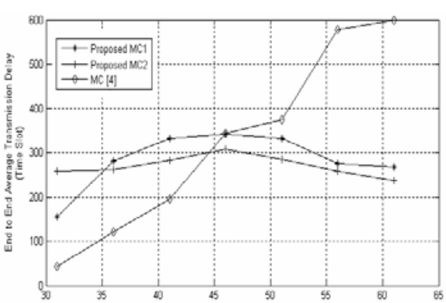
Fig. 6. System throughput



(a) Number of packets from 1 to 3



(b) Number of packets from 1 to 5



(c) Number of packets from 1 to 10

Fig. 7. Average end-to-end transmission delay (Level 5)

delay than the nodes with nearest hop to the BS. The figures also verify that Proposed SC2 exhibits a better delay performance than Proposed SC1 as the data traffic and the interferences conditions in the route construction are more in Proposed SC1.

We also observed that the delay of SC is increase when the node number increased and dropped suddenly near the last nodes in the graphs. This is due to the nature of routing algorithm and scheduling algorithm that contribute to the interferences

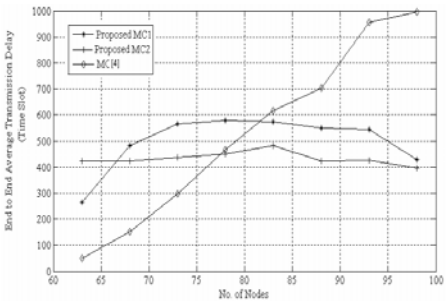


Fig. 8. Average end-to-end transmission delay (Level 6)

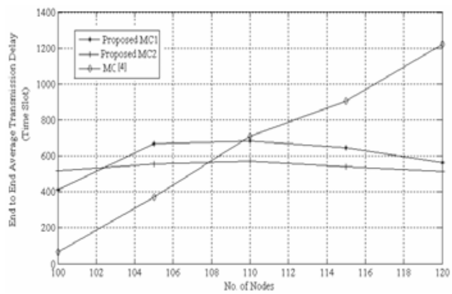
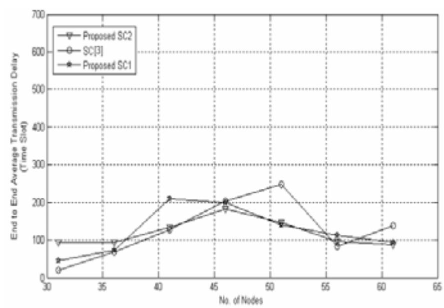
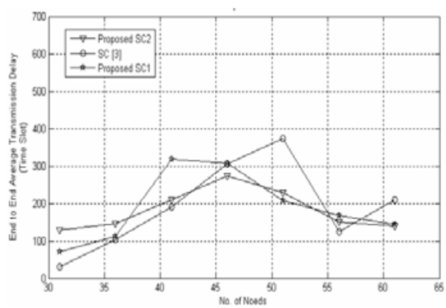


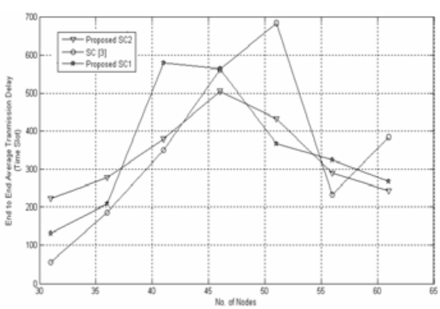
Fig. 9. Average end-to-end transmission delay (Level 7)



(a) Number of packets from 1 to 3



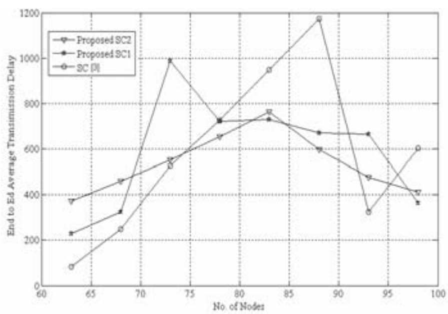
(b) Number of packets from 1 to 5



(c) Number of Packets from 1 to 10

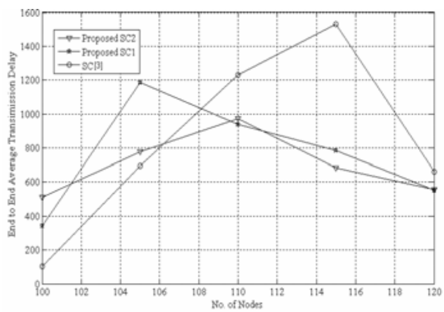
Fig. 10. Average end-to-end transmission delay (Level 5)

between the nodes. In [3], the nodes select the sponsor node from their neighbors nodes with the least ID number and the nearest to the BS only. Therefore a lot of nodes, especially the node in middle of the network, may select the same path and will be suffered from interferences except the node that is at the edge of the network which has the least number of neighboring nodes. In scheduling algorithm, the selected node will begin with the least ID number and nearest to the BS. Hence the node at the edge will be served first and at the same time will block most of the node in the core network. The performances are not stable due to the fact that one channel is used at a time, which producing a lot of inferences in the system compared to the multi-channel system. On the node selection algorithm, we select the nodes based on many criteria that are explained in sub-section 2.3. Once the node_is selected from the network core, all the others will be blocked to provide the fairness between the nodes.



Number of packets from 1 to 10

Fig. 11. Average end-to-end transmission delay (Level 6)



Number of packets from 1 to 10

Fig. 12. Average end-to-end transmission delay (Level 7)

6 Conclusions

This paper presents a new mechanism for WMN that deals with the problem of the interferences from the nodes transmission in the network. This paper also discusses the issues related to the problem of providing the communication between the SSs and the BS such the load balancing and fairness, slot reuse, concurrent transmission, and the relay model in the network. It presents a cross-layer design between the NET layer and the MAC layer to improve the performance of the WMN by reducing length of scheduling, enhancing the throughput of the system, improving CUR, and reducing end to end average transmission delay. We have proposed two routing algorithms to find the scalable path to the BS for each node in the network and two centralized scheduling for multi-channel and single channel single transceiver system. The results show the proposed schemes to be superior the multi-channel system of [4] and the single channel system of [3] in terms of length of scheduling, CUR, and system throughputs. We have discussed the improvements obtained when single channel and multi-channel system are employed. Moreover the improvement that is achieved is better when number of children per nodes is used to in the design. To the best of author knowledge this metric is the first who is being considered in IEEE 802.16 mesh mode. Finally, the results show that the improvement is more significant in the multi-channels system than the single channel system. Table 4 shows the summary of performance improvement of multi-channel system when the number of node is 60.

Table 4. Summary of improvement at node = 60

(a) Number of packets: 1 to 3

No. of Packets: 1 to 3	MC	Proposed MC1	Proposed MC2	Proposed MC1 Improvement	Proposed MC2 Improvement
Length of Scheduling	221.794	153.250	174.2820	30.904%	21.423%
CUR	3.7201	5.5844	4.9014	50.114%	31.755%
System Throughput	0.5407	0.8095	0.7113	49.713%	31.552%
End to End Average Transmission Delay	218.884	94.8733	80.1093	56.656%	63.401%

(b) Number of packets: 1 to 5

No. of Packets: 1 to 5	MC	Proposed MC1	Proposed MC2	Proposed MC1 Improvement	Proposed MC2 Improvement
Length of Scheduling	332.904	237.110	267.784	28.775%	19.562%
CUR	3.7239	5.4943	4.7694	47.542%	28.075%
System Throughput	0.5407	0.7934	0.6953	46.197%	28.593%
End to End Average Transmission Delay	327.6035	142.1624	135.7964	56.605%	58.549%

(c) Number of packets: 1 to 10

No. of Packets: 1 to 10	MC	Proposed MC1	Proposed MC2	Proposed MC1 Improvement	Proposed MC2 Improvement
Length of Scheduling	608.000	442.254	487.292	27.261%	19.853%
CUR	3.7373	5.3473	4.8594	43.079%	30.024%
System Throughput	0.5409	0.7784	0.6995	43.908	29.322
End to End Average Transmission Delay	599.9069	267.8345	236.53	55.354%	60.572%

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