Cross Layer Design in 802.16d

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Abstract: WiMAX based wireless mesh network aims to provide broadband wireless for the last-mile access. It has high-speed data rate for large spanning area and is the key topology for the next generation wireless networking. The WiMAX mesh network (WMN) is developed with the use of base station (BS) as the main controller. However, the effects of the interferences from the transmission of the neighboring nodes within the mesh networks are inevitable and critical because all the nodes are using the same medium to communicate. This paper presents a cross-layer design that rely on the routing information in network (NET) layer and the scheduling slots in the medium access control (MAC) layer. The construction of the routing path with multi-channel single transceiver system and single channel single transceiver is proposed together with centralized scheduling (CS) algorithms that reduce the existing interferences in WMN. The analysis results show that the proposed algorithms have significantly improved the system performance in term of length of scheduling, channel utilization ratio (CUR), and throughput of the system.

Key words: WiMAX, Cross-Layer, Routing, Scheduling, Multi-Channel, Single Channel.

INTRODUCTION

The worldwide interoperability for microwave access (WiMAX) is an emerging broadband wireless access system with optimized delivering of fixed, portable and mobile wireless connections on a metropolitan area networks (MANs). It is an alternative and complementary solution for the extension of fiber-optic backbone. The core of WiMAX technology is specified by the IEEE 802.16 Standard (2004). In addition to the point to multi-point (PMP) connection mode, WiMAX also supports mesh mode. The term WMN 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 nodes. The nodes are organized in an ad-hoc fashion in mesh mode. SSs can relay their transmissions through other SS nodes in the network if they cannot directly reach to BS. This helps to extend the range of the BS and allow the network to grow in an organic fashion (Pareek, 2006).

Many researchers have tried to come out with suitable solutions to the one of the major problems in the WMN that is dealing with interferences from the transmission of the neighbouring nodes. The transmissions from any node can block all the other neighboring nodes from transmitting or receiving data. Previous researches avoid the effects of the interference by constructing routing tree and / or scheduling algorithms by focusing on a particular layer without considering parameters of other layers. Han et al., (2007) designed a scheduling algorithm for IEEE 802.16d by considering the relay model using single channel. However, Du in et al., (2007) constructed a multi-channel system in the scheduling algorithm but did not focus on routing algorithm. Jiao in et al., (2007) designed a CS by constructing routing path under multi-channel system but did not consider bandwidth request for each node. Fu in et al., (2005) presented a spatial reuse concept to establish non-interference concurrent links transmission. Lu in et al., (2007) took into account both interference and bandwidth request for each node during the construction of routing path but considered only the interference at the receiver.

This paper focuses on fixed IEEE 802.16 in the scope of cross layer design between routing algorithm in the NET layer and CS algorithm in the MAC layer in BS. The routing algorithm in the NET layer aims to find the best route to the BS by considering the network load balancing. The CS algorithm in MAC layer aims to make transmission simultaneously using the same time slot without collision, and create fairness between nodes such that nodes are not penalized or starved in sending data.

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A lot of parameters in designing the system are considered such as the hop counts to the BS, number of children per node, the interference from the transmission of the neighboring nodes and traffic load per each node in terms of number of packets, and the node ID number. It is acknowledged that a new design metric namely the number of children per node is being considered in WMN. The proposed algorithms are the first cross layer design in WMN that use multi-channel single transceiver system. The results of the proposed algorithms show that the system performances in term of length of scheduling, CUR, and the system throughput are improved.

**Interferences in WMN:**

WMN uses a shared medium to communicate to each other and have a common channel assigned to their radios for direct communication between them. Wireless links using the same channel within the communication range may interfere with each other even when they are not communicating directly. Hence, they should not make transmission at the same time. However, the wireless links that are using different channels can be active simultaneously with no interference. Therefore WMN uses time division multiple access (TDMA) communication to access data. Each data is structured into frames that composed of several equal duration time slots (Tao et al., 2005). A TDMA scheme is employed at maximizing the time slot reuse while eliminating the possibility of collision in the WMN. All the interference information in existing WMN is traced in the interference table of each SS node for scheduling and routing purposes.

Wireless transmissions may collide in two ways. These are typically referred to as primary and secondary interferences. Primary interference occurs when the node is performing more than one task in a single time slot. For instance, receiving data from two different transmitters. Secondary interference occurs when a transmission/reception of receivers or transmitters is within the range of a transmitter interferes with its transmissions/reception. (Ramanathan and Lloyd, 1993). There are five types of transmission interferences as shown in Fig. 1 and are described as follows:

1. The transmitter-transmitter (t-t) interferences due the parallel transmissions garble each other at the common receiver.
2. The receiver-receiver (r-r) interferences, happen when a single transmitter cannot separate packets intended for two different receivers.
3. The transmitter-receiver (t-r) interferences, the nodes in a situation cannot transmit and receive at the same time due to the half-duplex system.
4. The transmitter-receiver-transmitter (t-r-t) interference is a situation where the nodes cannot transmit at the same time because the receiver within the communication range of both the transmitters and hears both transmissions.
5. The receiver-transmitter-receiver (r-t-r) interference. In the r-t-r conflict, the two conflicting nodes cannot transmit at the same time because the two transmitters are within the communication range of each other and can overhear each other.

The first three types of interferences are between the nodes that share a primary interference that cannot be eliminated by both multi and single channel systems. The last two types are the interferences between the nodes that share a secondary interference that cannot be eliminated by the single channel system [10].

![Fig. 1: Types of interference in WMN.](image)

**Cross Layer Design:**

Traditionally, a layered architecture like the seven layer open systems interconnect (OSI) model, defines a hierarchy of services to be provided by the individual layers (Bertsekas and Gallager, 1992). The services
at the layers are realized by designing protocols for the individual layers. However, this method does not necessarily lead to an optimum solution for wireless networks. 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 which has served well for wired networks seems to be inefficient and not suitable for the wireless networks. Most of the cross-layer design proposals for wireless networks involve exchanging information between multiple layers or between just two layers (Akyildiz and Wangd, 2005). 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 (Raisinghani and lyer, 2004).

The cross layer design in this paper is between MAC and NET layers. It is divided into two parts as shown in Fig. 2; the routing paths in the NET layer, and the CS in the MAC layer. The channel assignment is added in the MAC layer for the multi-channel system. These two layers exchange information interactively. In the NET layer, route information and interference table for all nodes are obtained from BS. In the MAC layer, all nodes scheduling information from the CS algorithm is sent to the routing algorithm in the NET layer. After the route for each node has been made, the routing paths and interference table are fed to the CS algorithm in MAC layer in order to eliminate the interference through the channel assignments algorithm in case of multi-channel system.

The fairness, time slot reused and concurrent transmission algorithm in the MAC layer can be proposed to make the non-interference links communicate concurrently. The routing paths also can be improved by the network load balancing which is obtained in NET layer. Finally, in cross layer design, the routing and scheduling tables are optimized by exchanging information between NET and MAC layers.

Fig. 2: Cross Layer Design.

**System Design Algorithms:**

In order to design the system according to IEEE 802.16 standards, the following assumptions are made:

- The transmission signal of a node can only cover the range of a single-hop neighborhood node and all the nodes have the same transmission range.
- Node with non-interference links can communicate concurrently.
- The traffic is always between the SS and BS for every node.
- The buffer in each node works as first in first out (FIFO) concept for data transmission from the node queue.
- Every node can only transmit one packet in each time slot.
- The network topology does not change during the scheduling period.
- All the links have the same capacity and the capacity does not change when a link switches from one channel to another in case of multi-channel system.
- There are two terms 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.

The system design here consists of three algorithms: Routing algorithm for both single and multi-channel systems, channel assignment algorithm for multi-channel system, and collision free centralized scheduling algorithm for both single and multi-channel systems.

**Routing Algorithm:**

The purpose of the routing algorithm is to provide the best routing paths for the all SSs to the BS in the presence of static node. Two proposed routing algorithms are developed. In the first algorithm, five design
parameters are considered; number of children per node, node ID number, number of hop-count to the BS, number of interfering nodes, and number of packets per node. The best route is selected based on the least number of children, least number of interfering nodes, minimum hop to BS, and network load balancing. The first proposed routing algorithm is developed based on the following steps:

1. Select the sponsoring nodes from the upper level (the least hop-count).
2. If there is one sponsor node, select it, else go to 3.
3. Calculate the number of children for each sponsor node and select the sponsor nodes with the least number of children.
4. If there is one sponsor node, select it, else go to 5.
5. If there are more than one sponsor nodes that have the same number of children calculate:
   a. Number of blocked node for each node (number of neighboring nodes which will be blocked because of the interference from the selected nodes).
   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.
6. If there is one sponsor node, select it. Otherwise go to 7.
7. If there are more than one sponsor nodes that have the same number of blocking metric, the sponsor node with the smallest ID number will be chosen.

In the second proposed routing algorithm, only the last four parameters are considered in selecting the best route for the SSs. To develop the second routing algorithm, the following steps are taken:

1. Select the sponsoring nodes from the upper level (the least hop-count).
2. If there is one sponsor node, select it, else go to 3.
3. If there are more than one sponsor node that have the same hop-count calculate:
   a. Number of blocked node for each node (number of neighboring nodes which will be blocked because of the interference with selected nodes)
   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 go to 7.
5. If there are more than one sponsor nodes that have the same number of blocking metric, the sponsor node with the smallest ID number will be chosen.

The routing path construction algorithm can be illustrated in Fig. 3. The WMN topology is shown in Fig. 3a. Random generation of number of packets per node is assumed, for instance, SS_1 = 1, SS_2 = 2, SS_3 = 3, SS_4 = 1, SS_5 = 2 and SS_6 = 3. The first routing algorithm is shown in Fig. 3b. And the second routing algorithm is shown in Fig. 3c. In both Figs. 3b and 3c, the solid line represents the routing path while the dashed line represents the interference topology. Note that the number of interfering SS notes, a and the blocking metric, b for each node can be illustrated as SS# = (a, b). Thus, SS_1 = (4, 4), SS_2 = (4, 8), SS_3 = (3, 9), SS_4 = (5, 5), SS_5 = (2, 4), and SS_6 = (2, 6) respectively.

Fig. 3: Routing algorithms: (a), (b), and (c).
**Proposed Channel Assignment Algorithm for Multi-Channel System:**

In the multi-channel system, single transceiver each node can support one channel in each time slot, and also can tune to another channel in another time slot. Hence, by using this algorithm, the secondary interference can be eliminated to enhance the system performance. This is because different nodes can work on different channels, so a lot of nodes can be activated at the same time slot using different channels. But obviously, the primary interference cannot be eliminated because single transceiver with half duplex system is used for cost effective system. The switching delay occurred when a transceiver tune for channels is ignored because it is negligible.

The channels assignment algorithm starts at the edge set of the routing paths. Starting with the SS nearest to the BS with the node ID number 1. The nodes that have interferences with their neighboring nodes used different channel. Fig. 4 shows the channels assignment base on the routing path and interference topology of Fig. 3c. The two nodes SS, and SS, are linked to BS using the same channel which denoted as L, because they are linked directly to the BS. Then, the link SS, - SS, use different channel because it has interference with links SS, - BS and SS, - BS, and it is denoted as L, This is similar for the link SS, - SS, that use different channel because it has interference with links SS, - BS, SS, - BS and SS, - SS, and it is denoted as L, The link SS, - SS, used another channel compared to links SS, - BS, SS, - BS and SS, - SS, because it has interference with them. It, however, uses the same channel as link SS, - SS, hence L, because there is interference free between them. The last link SS, - SS, is assigned another channel, L, because it has interferences with all the links in topology.

![Multi-channel assignment algorithm](image)

**Proposed Centralized Scheduling Algorithm:**

In the fixed WiMAX IEEE 802.16d standard, time slot allocation for each SS is controlled by CS algorithm in BS. Two types of CS algorithm for both multi-channel and single channel systems are proposed. The CS algorithm is divided into two parts: node selection algorithm and collision avoidance algorithm.

**Node Selection Algorithm:**

Two types of node selection algorithm are proposed. In the first algorithm, the SS node with minimum hop-count to the BS is selected. If there is more than one node that has the same hop-count to the BS, then the node with high number of packets is selected to achieve the QoS. If the SS nodes have same number of packets then the node with small number of interfering SS nodes is selected to increase slot reuse and concurrent transmission. Finally, the node with smallest ID number is selected to send the data in the same level if the SS nodes have same number of interfering SS nodes.

The second algorithm of node selection is similar to the first algorithm except link criteria of the number of interfering SS nodes. Here the node with high number of interfering SS nodes is selected to achieve the fairness transmission among the nodes otherwise they will be left idle for a long time.

**Collision Avoidance Scheduling Algorithm:**

In this scheduling algorithm, each node is assigned service token. The service token is used to allocate time slots to each node proportionally according to the traffic demand, hence fairness is guaranteed. A node can only be scheduled if the number of service token is nonzero. This node is marked as available; otherwise it is marked as idle. The available node that satisfies the node selection algorithm is scheduled in the current
time slot. The selected node is marked as scheduled and all the conflicting neighbor nodes are marked as interference. Each time a transmitter node is assigned a time slot, the service token is decreased by one and the receiver node’s service token is increased by one. The same procedure is repeated until the service token of all nodes is decreased 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 decreased to 0, SSs with higher ID number get the chance to be scheduled, thus will not be starved forever.

To illustrate this scheduling algorithm clearly, the first node selection algorithm for multi-channel system is explained here. In the mesh network shown in Fig. 4, let consider that all nodes have one packet to transmit to the BS. Initially the allocated counter to each node is equal to one. In the first time slot, all transmission links are available. Since the nodes SS_{1} and SS_{5} are one hop away from BS, the node with the smallest ID number, which is node SS_{1}, is scheduled first. The remainder nodes, node SS_{5} and SS_{6} are scheduled in the same time slot as SS_{1}. That means nodes SS_{5}, SS_{1}, and SS_{6} are scheduled to transmit in time slot one. The counter of SS_{1}, SS_{5}, and SS_{6} is then decreased by one. Thus, the counter of nodes SS_{5}, and SS_{6} in time slot one, is increase by one. In the second time slot nodes SS_{6} and SS_{2} will be selected. This process is repeated until the all the nodes counter is equal to zero. It can be easily extended to the second node selection algorithm for the multi-channel system, and also both node selection algorithms for the single channel system. The scheduling result is presented in Table 1. In this table only the active SSs are recorded.

**Wmn Performance Metrics:**

The main advantage of the proposed design mechanism is that it provides the completion of the whole services in the networks in a shortest time and reduces the use of network resources to give other senders the chance to use the link efficiently. The performance of the proposed design is investigated 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. Note that, the scheduling length measured in time slot.

**Channel Utilization Ratio (CUR):**

The CUR is defined as the ratio between the numbers of occupied time slots to the total number of available time slots. Note that, the resulted CUR, in fact, is 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 are routed through the BS. The throughput of BS is equaled to the throughput of the system. Thus, it is the total data transferred divided by the total time it took for the transfer, and it is measured in packets/time slot. Note that, the upper limit for the throughput is one for single radio system because it depends on the number of BS radio carriers.

**Simulation Setup and Results:**

In this section, the obtained results for the multi-channel and single channel systems by implementing the algorithms that described in previous section are presented. The results can be classified into four proposed mechanism according to the implementation namely Proposed MC1, Proposed MC2, Proposed SC1 and Proposed SC2. The first two scenarios are for the multi-channel system while the last two are for the single channel system. The results of Proposed MC1 and Proposed SC1 are including a term of the number of children per node. The results of multi-channel single transceiver system are compared with the multi-channel scenarios found in (DU et al., 2007) and the results of single channel single transceiver system are compared with the single channel scenarios of (Han et al., 2007). Three performance metrics are considered in the simulation such that length of scheduling, CUR, and throughput of the system. The system performances are simulated using two scenarios as follows; the traffic for each SS is selected randomly from 1 to 3 packets, and 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.
In the multi-channel system, two schemes are considered 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 is constructed from the first routing algorithm. In the CS scheme, the first node selection algorithm is used. The second scheme is also for the multi-channel system denoted as Proposed MC2. This scheme uses the second routing algorithm. The second node selection algorithm will be used in the CS. Note that in Proposed MC1 and MC2, the channel assignment algorithm in section 4.2 will be used. The multi-channel system in (Du et al., 2007) denoted as MC (Du et al., 2007) is compared with Proposed MC1 and Proposed MC2.

In the single channel system, there are two proposed schemes similar to the multi-channel system but using one channel only. Both schemes are denoted as Proposed SC1 and Proposed SC2 that similar to Proposed MC1 and Proposed MC2 respectively in the multi-channel system but without the using of channel assignment algorithm. The results obtained from Proposed SC1 and Proposed SC2 are compared with the single channel system which base on (Han et al., 2007), and denoted as SC (Han et al., 2007).

The simulation results on the length of scheduling are presented in Fig. 5. It shows that the length of scheduling increases with the increase number nodes in the network. The increasing traffic demand will also lead to longer length of scheduling. It is observed that the length of scheduling of the results is reduced dramatically in both schemes (a) and (b). Note that the results show that the system in Proposed MC1 gets the shorter length of scheduling compared to other results. The performances of Proposed SC1 and Proposed SC2 are the same because the interferences in the single channel system are same. However, Proposed SC1 is more scalable than Proposed SC2 when the number of packets is increased for example from 1 to 10 as shown in Fig. 5 (b). This is due to the use of the number of children per sponsoring node in the first routing algorithm.

Fig. 5: Length of Scheduling

Fig. 6 presents the results of the CUR. From these figures, it is observed that the increase of the number of nodes in the network reduce the CUR because the additional new nodes in the network increase the number of interfering SS nodes when one node is transmitting. It is also observed that when the number of packet is
increased, the CUR is stabled 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 reason is due to the scheduling cycle which is very low, when all the nodes use the same channel at the same time slots in the single channel system, therefore the interference will increased which are heavily affected the slot reuse in the network and the concurrent transmission; and the other reason is the bottleneck of the routing path (the nodes that are near to the BS), so the nodes far from the BS idles most of the time and response to send their packets only compared to nodes that near to the BS that are responsible to send their packets, children nodes packets and grandchildren nodes packets. Again, it is observed that we have increased the CUR in all our schemes and the system in Proposed MC1 is outperforms the other schemes.

(a) Number of Packets from 1 to 3.

(b) Number of Packets from 1 to 10.

Fig. 6: Channel Utilization Ratio

The result of the throughput is shown in Fig. 7. The overall performances show that throughput have improved in all the proposed schemes. However, throughput will decrease when the number of nodes is increased because hops count also increases along the path to the BS so the traffic needs to be forwarded many times by intermediate nodes and it will take more time until the packets from the farther nodes reach the destination. The more nodes in the system more interference exist, hence reduce the slot reuse. Fig. 7 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. Note that in all the results shown, the system throughputs is below one packets at the time slot because of using the single transceiver system and it can transmit or receive only one packets at the same time due to the half duplex system. Note that the fluctuations in the results are expected because the throughputs depend on the number nodes and the total transmission time needed to complete sending of the data. The increasing of node in the system increase in interval by five nodes but their location is different and their traffic is increased randomly.
Fig. 7: Throughput of the System

**Conclusion:**

Since WiMAX IEEE 802.16 standards do not specify the exact routing and scheduling algorithms, this paper presents a new cross layer design mechanism to reduce the interferences in WMN. The cross layer design discussed here is dealing with the exchangeable information between MAC and NET layers to optimize the system performances. Two routing algorithms to find the scalable path to the BS for each node, and two CS algorithms for single and multi-channels single transceiver system have been proposed. Some related issues pertaining to the system improvement such that load balancing and fairness, slot reuse, concurrent transmission, and the relay model in the network also have been discussed. The results show that the proposed schemes outperform the multi-channel system based on (DU et al., 2007) and the single channel system based on (Han et al., 2007). In term of the length of scheduling, CUR, and the system throughputs. The system performances are further improved when a new design metric such as number of children per nodes is introduced. In general, our results also show that the multi-channel system performs better compared to single-channel system.

**REFERENCES**


