Directivity with Efficient Routing and Centralized Scheduling Algorithms for WiMAX Based Mesh Networks

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Abstract

Multiple access interference is a major limiting factor for the WiMAX based Mesh Network (WMN) performance. A backbone model equipped with directional antenna for WMN with two routing tree construction algorithms, Paralleled (Para-RTC) and Balanced-Paralleled (Bala-Para-RTC) are proposed here in conjunction with fair centralized scheduling algorithm and efficient link selection criteria in certain time slot, this is an important task to minimize the effect of secondary interferences for a WMN. The use of directivity with these routing algorithms increases concurrent transmissions by making use of spatial reuse, this will result in higher system performance in terms of schedule length and Channel Utilization Ratio CUR. The results also show, that using the Para and Bala-Para RTC algorithms, without directivity, will give CURs of 15.4% and 14.3% respectively, (i.e an improvement of 3.6% & 2.5% over the 11.8% CUR). When the standard Breadth First tree routing BFT is used), and with directivity it will give the same CUR of 18.2%, (i.e an improvement of 2.8% relative to the 15.4% CUR when the BFT is used).

Keywords: WiMAX, WMN, Para-RTC, Bala-Para-RTC, CUR, Schedule Length

التوجيه مع خوارزميات تحديد المسار وجدولة إرسال كفوءة مركزية لشبكات WiMAX نوع Mesh

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الخلاصة

تعتبر التداخلات الناتجة من تعدد الوصول (Multiple Access) العامل الرئيسي الذي يحد من أداء شبكات الـ (WiMAX) نوع (Mesh). تم اقتراح نموذج أساسي مجهز بهوائيات توجيه ونوعين من خوارزميات تحديد المسار (Para-RTC) و (Bala-Para-RTC) وخوارزمية جدولة مركزية تتصف بالعدالة وذلك لتقليل التداخلات الثانوية في هذه الشبكات. إن استعمال التوجيه (Directivity) مع خوارزميات تحديد المسار المقترحة سوف يسمح لخوارزمية جدولة الإرسال من تخصيص أكثر من إرسال في نفس الشقب (slot) وهذا سيؤدي إلى تحسين أداء النظام بدلالة الـ CUR و الـ Length of Schedule. إن نتائج محاكاة الـ CUR للخوارزميات المقترحه (Para-RTC) و(Bala-Para-RTC) وبدون توجيه كانت 15.4% و 14.3% على التوالي (أي بنسب تحسن 3.6% و 2.5% نسبة إلى 11.8% عند تطبيق خوارزمية تحديد المسار التقليدية BFT) ومع التوجيه كان لها نفس القيمة 18.2% (أي بنسبة تحسن 2.8% نسبة إلى 15.4% عند تطبيق خوارزمية BFT).

1. Introduction

WiMAX networks operate synchronously in a time slotted mode and can be configured to work in different modes, point-to-multipoint (PMP) or Mesh mode[1][2] see Fig.(1).
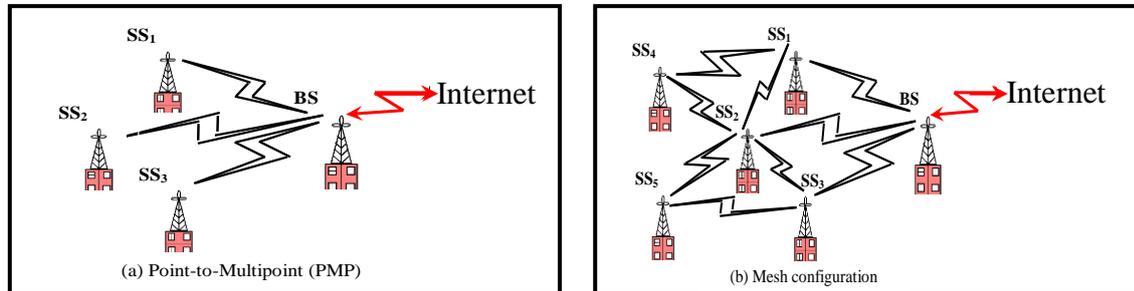
Fig.(1): WiMAX PMP network and mesh network

It is also necessary to allocate time slots without collision over the network to achieve the assigned bandwidth for each connection.

The routing and scheduling problem for WiMAX networks is different from 802.11 based mesh networks. IEEE 802.16 mesh mode has defined the messages and signalling mechanisms for transmission scheduling, but the minislots which are assigned to the different stations are left unspecified, therefore an efficient channel (minislots) allocation algorithm which allows more concurrent transmission among links over the same timeslot is needed. Accordingly and in order to allow more concurrent transmission, the interferences among the transmission links should be reduced.

2. Related work

The problem of route construction is investigated and different strategies are used to reduce the interference in the routing tree .For example in [3] an interference-aware routing tree is introduced by connecting each Subscriber Station (SS) to the Base Station (BS) via a route path that has the minimum degree of interference. In [4], two tree construction algorithms: min max degree and maximum parallelism are proposed. The former one aims to minimize the maximal node degree in a routing tree, the latter one aims to maximize the number of link pairs in a routing tree that can work simultaneously without interference. The authors in [5] proposed a collision-free centralized scheduling where a SS is assigned service tokens based on its traffic demand. In [6][7], a series of scheduling algorithms are discussed, but all of them suffer from an *ordering delay* problem [8] in which an SS is scheduled to forward packets before receiving them.

Current research on WiMAX mesh centralized scheduling mainly focuses on minislot and spectrum reuse, which are constrained by the routing tree structure algorithm.

In this paper, directivity, which makes use of the space diversity, is proposed with two efficient Routing Tree constructions (Para & Bala-Para) algorithms to reduce the interferences among the links of the multihop mesh network. The aim of this paper is to effectively exploit the directional antenna benefit ,by introducing the proposed routing tree construction algorithms which increase the chance of applying the minislot reuse. Both interferences and relay models are taken into consideration when investigating the scheduling problem in directional antenna-based WiMAX mesh network. An efficient way to make use

of space diversity is provided when scheduling the transmission in each time slot and the total scheduling length time is thus minimized.

3. Background Theory

3.1 WiMAX Mesh Mode & Mesh Frame Structure

Time Division Multiple Access (TDMA) is the protocol being used for channel access. Transmission through the channel is divided into frames. Each frame consists of 256 minislots for data and control messages. Fig.(2) shows the mesh frame structure which consists of control and data subframes. In the control subframe, *transmission* slots, are used to carry control messages for network configuration and scheduling of data subframe minislot allocation [9]. There are two types of control subframes: network and scheduling control subframes.
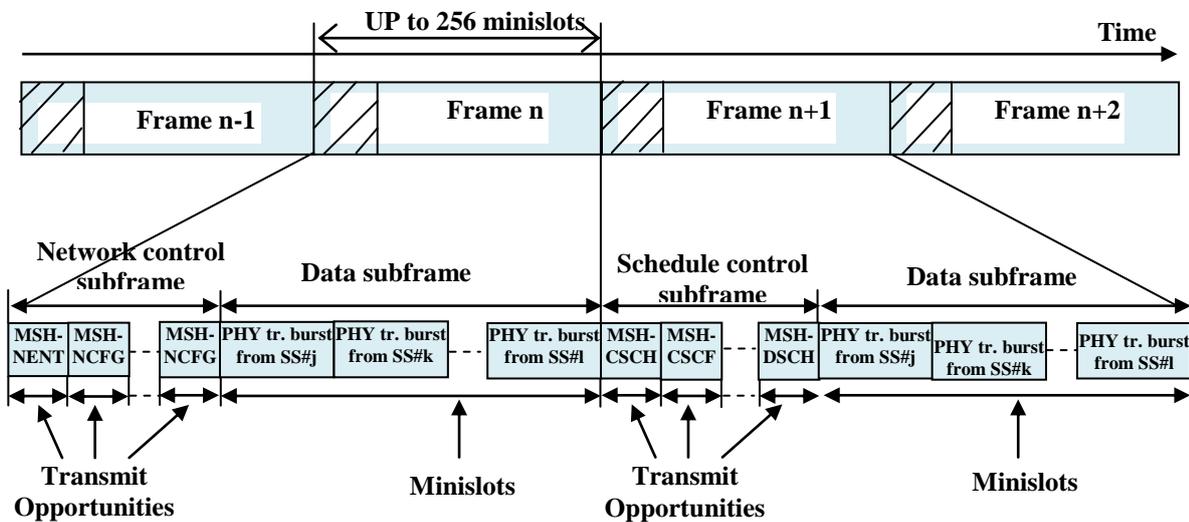
Fig.(2): frame structure in the mesh mode

In the network control subframes, Mesh Network Configuration (MSH-NCFG) and Mesh Network Entry (MSH-NENT) messages are transmitted for the creation and maintenance of the network configuration. For the routing path between each SS and the MBS, a scheduling tree at the mesh BS is constructed.

A new node will listen to MSH-NCFG to establish synchronization with the frame and to select one of the active nodes as its sponsor node. Upon receiving the new node's registration (MSH-NENT) message, through the sponsor node, the MBS adds the new node as the child of the SN node in the scheduling tree, and broadcasts the updated network configuration to all SSs.

In WiMAX mesh mode, both centralized and distributed schedulings are supported. Centralized scheduling is mainly used to transfer data between the mesh BS and the SSs, which corresponds to external traffic from the Internet. The centralized scheduling handles both the uplink and downlink traffics. In the mesh mode, to share the channel between uplink and downlink, Time Division Duplex (TDD) is used. The distributed scheduling targets data delivery between two SSs in the same WMN, which corresponds to intranet traffic [12]. In centralized scheduling, the mesh BS acts as the centralized scheduler and determines the

allocation of the minislots among all the SSs. The time period for centralized scheduling is called scheduling period. Each scheduling period has two steps:

1) The SSs send bandwidth requests using the MSH-CSCH Request message to their sponsor nodes, which are routed to the MBS along the scheduling tree. Each SS not only sends its own bandwidth request but also relays that of its children in the scheduling tree. The SSs transmit MSH-CSCH Request messages in such an order that the sponsor nodes always transmit after all their children. In this way, the mesh BS collects bandwidth requests from all the SSs.

2) The mesh BS calculates and distributes the schedule by broadcasting the MSH-CSCH Grant message, which is propagated to all the SSs along the scheduling tree. Since the dominant traffic in a WiMAX mesh network is Internet traffic, in this paper focusing will be on centralized scheduling.

3.2 System Interference Model

The WiMax mesh network with centralized scheduling is an on demand assignment TDMA based multi-hop network, the data transmission may collide in two ways (see Fig. (3): due to primary and secondary interferences [5][10][11].
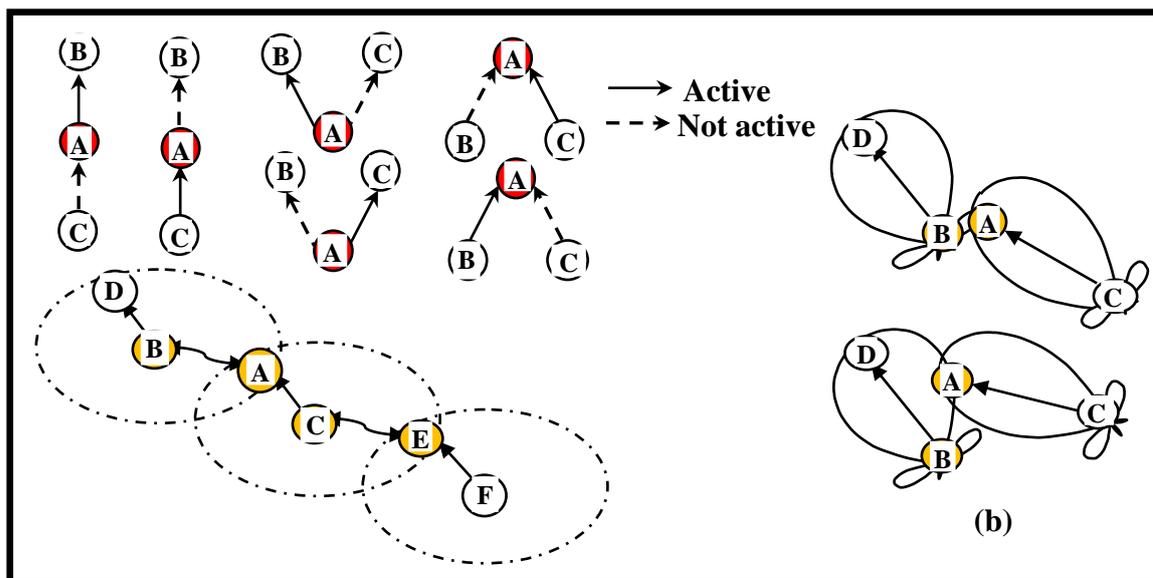
Fig.(3): shows interferences **(a)** primary and secondary interferences without directivity
(b) places where secondary interferences could happen when directivity introduced.

1. Primary interference (transmission/reception constraint), it occurs when a SS has to do more than one job in a single time slot as follows:
a) The SS cannot transmit and receive simultaneously.
b) The SS cannot transmit/receive more than one packet at the same time.
2. Secondary interference (interference-free constraint), it occurs when a receiver R tuned to a particular transmitter T is within the range of another transmitter whose transmission interferes with the transmission of T.

Fig.(4) illustrates this interference more clearly. The solid lines represent edges in the routing tree and the dashed lines represent interference links. For example, suppose SS_4 transmits to SS_2 in certain time slot. Then links (SS_2,BS), (SS_9,SS_4) and (SS_{10},SS_4) are blocked because of

primary interference (a) and links (SS$_5$,SS$_2$) and (SS$_6$,SS$_2$) are blocked because of primary interference (b).links(SS$_1$,BS) and (SS$_3$,BS) are blocked due to secondary interference.

4. Design of Routing and Scheduling algorithms

4.1 Routing Tree Construction Algorithm

Fundamentally, the routing algorithm is aiming to provide a scalable routing in the presence of static node. On the other hand, it is possible to make use of directional antenna efficiently to reduce the secondary interferences among the mesh network links. Two routing
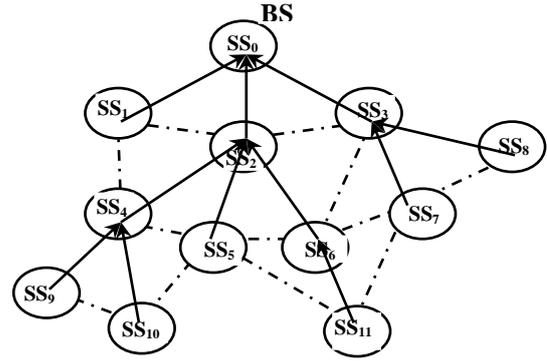
Fig.(4) Shows clarifications of interferences among nodes of the mesh topology

algorithms are proposed to reduce or convert the primary interferences (b) into secondary. The main features of these two algorithms are:

1) Parallelism, which is used to minimize the maximal node degree of the routing tree and this, can be achieved by examining down node group (degree) values.

2) Balance the traffic from child nodes to parent, by examining child bandwidth (BW) requests. It is worth to mention that the second Bala-Para RTCA has the feature, which gives priority for nodes (with highest BW request as primary key and identification ID as secondary key). To choose their routes first and these nodes are members of the down node groups with values greater than two (values greater than two are chosen because maximal node degree and primary interferences type (b) increase as the down node group values increase). This feature increases the chance of minimizing the maximal node degree, support quality of service, then increasing the chance of making the system parallel (and as a consequence the directivity or spatial reuse will reduce the secondary interferences).

To keep the shortest route paths to the tree root (BS), the topology $G=(V,E)$ of the mesh network is translated into a layer graph $G_L=(V,E)$.Each node (SS_i) in G_L is associated with a layer number $l(SS_i)$ which is equal to the minimal hop count of this node to SS_0 (tree root or BS). Nodes with the same layer number are placed on the same level.

The nodes (SS_s) relationship in G_L are explained by the following:

1) up nodes (SS_i) = {SS_u | $SS_u \in V$, $l(SS_u) = l(SS_i)-1$ and SS_u is connected with SS_i in G_L}

2) down nodes (SS_i) = {SS_d | $SS_d \in V$, $l(SS_d) = l(SS_i)+1$ and SS_d is connected with SS_i in G_L}

3) Parent (SS_i): parent node of SS_i.

4) Children (SS_i): set of child nodes of SS_i.

5) subtree_nodes (SS_i): set of all nodes including SS_i in the subtree rooted at SS_i.

6) level_nodes (i) = { SS_j | $SS_j \in V$, $l(SS_j) = i$}

7) down node group (SS_i) = set of nodes which are down SS_i and routed at SS_i

8) child BW reqs (SS_i) = $\sum_{\forall children(ss_i)} N_{PDU}(g_{ui}).L_{PDU}(g_{ui}) for up-link$ or $\sum_{\forall children(ss_i)} N_{PDU}(g_{di}).L_{PDU}(g_{di}) for down-link$

9) NBM=node blocking metric (SS_i) = number of blocked node multiply by number of packets transmitted by SS_i.

10)   PBM=path blocking metric(SS_i) = summation of node blocking metrics along the chosen path for SS_i towards the BS (SS_0)

The tree construction flow chart is shown in Fig.(5) .

The nodes, which are within the Transmission Range (TR), of the BS join the network in the first layer, the minimum identity, will be given to the first node join the network. while the last node which joins the network will be given the maximum ID in the last layer (maximum Hop Range (HR) parameter typically five) defined by network descriptor.

In Fig.(4), the mesh network in dashed lines with its routing tree in solid lines is constructed by using the breadth-first traversal (BFT) according to the IEEE802.16 standard. When a new node join the network, it must select the shortest path to the base station with the condition that if there are more than one node in the same level then priority will be given to node with minimum ID to choose its path first. This algorithm is suggested by [5] and adopted in this paper for comparison purposes

According to the first Parallel routing tree construction algorithm, Fig.(6)shows the final uplink traffic constructed tree links

Fig. (5) Flow chart routing tree construction algorithm

in solid lines. For simplicity the granted BW for each node is given in the Packet Data Unit (PDU). All nodes are assumed to have same number & size of PDU . In this algorithm, routs between the nodes and the base station are chosen by given precedence to nodes joining the net first. So the node sequence to be examined is 1,2,3,4,5,6,7,8,9,10 and 11. For each node in the up-node set, the child Bandwidth Requests (BW reqs) , down node degree values and blocking metric values are computed. Then for each node, a parent node is selected from its up-node set and if more than one node exists in its up-node set then the following rules are used to select the proper one between them:

1) Select node with the minimal child BW reqs value.
2) Select node with the minimal down node group degree value.
3) Select node which leads to the minimum path blocking metric.
4) Select node with minimum ID.

Fig.(7) shows the final routing tree which is constructed according to the proposed second Balanced-Parallel routing tree algorithm. In this algorithm, precedence is given to nodes (which are members of down node groups having values greater than two) with highest BW requirements and ID (long distance away from the BS) to make the network more balanced and parallel. This can be achieved by reducing the maximum degree of the nodes through which these members are routed. In choosing parent nodes, the selection criterion between more than one node in the up-node set is the same as that used in the first routing algorithm with the condition that the precedence will be given here to the following node sequence priority 8,6,3,1,2,4,5,7,9,10 and 11.
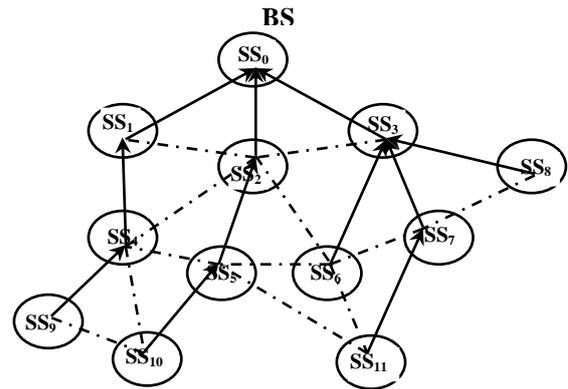
Fig.(6) Shows Routing Tree Construction According to Para RTC Algorithm
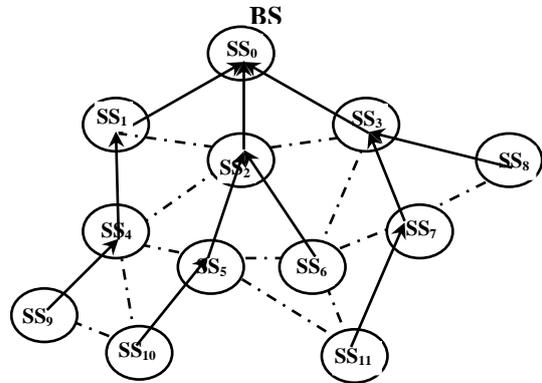
Fig.(7) Routing Tree Constructed According to Bala-Para RTC Algorithm

4.2 Centralized TDMA Scheduling Algorithm

The principal of scheduling is to find a valid minisolt allocation with minimum $\sum_{\forall SS_i \in V} S_i$ value which can be achieved by maximizing the degree of minislot reuse.

In order to design a centralized scheduling algorithm according to the IEEE 802.16 the following assumptions were made:

1. The topology is fixed during the scheduling period.
2. No node can transmit and receive data simultaneously.
3. Nodes can not send or receive data in the range of communication between nodes.
4. The signal of a node can only cover the range of a single-hope neighborhood.
5. The control and scheduling sub-frame are long enough.
6. Node can transmit one packet in each time slot.
7. The buffer in each node is of the type first in first out (FIFO).
8. Each node generates random numder of packets (one packets for Constant Bit Rate (CBR) and random number from 0 to 3 for Variable Bit Rate (VBR)).
9. Node can select suitable transmission power to reach its immediate "receiving" next hope.

It is worth to mention that the BS collects the active SS's bandwidth request through MSH-CSCH request messages,then it updates the network configuration tree according to the RTC algorithims and propagates the routing tree to active SS through MSH-CSCF message. BS centrally performs time slot allocation for SSs (according to their BW demands) taking into account the interferences of each SS on its neighboring SSs, as well as avoiding the collsions that may arise from hidden terminals.The assigned time slots to the granted connection will be propagated by the BS to all SSs through MSH-CSCH grant message.

According to the centrelized TDMA scheduling algorithm and in order to achieve high system throughput and provide fairness, the Relay Model CS adapted in this paper gives praiority to the nearer nodes to the BS to transmit first. The algorithm also considers interferences, slot reuse, and QoS.

In this algorithm, link scheduling is used and a SS is assigned Service Token (ST) which is based on its traffic demand, this can be performed by intially setting a counter /timer equal to the number of packets or slots for each SS link proportional to the traffic demand (1 for 1Mbps, 2 for 2Mbps …etc),thus, the fairness is guaranteed and no nodes will be starved. A link can be scheduled only if the service token number of its transmitter is nonzero. Also more than one link can be scheduled at the same time slot if they are not interfered with each other according to the interference module described before. Each time after a link is assigned a time slot, the service token of the transmiter is decreased by one and that of the receiver is increased by one. Flow chart of the proposed centrelized scheduling algorithm is shown in Fig.(8).

To clarify the scheduling algorithm, Fig.(9) shows the scheduling (slot assignment) matrics using nearest to BS (NS) selection criteria for the three (BFT, Para & Bala-Para RTC) routing algorithms with & without directivity for unified traffic.

From the slot assignment matrix, the length of schedule (L) and the channel utilization ratio (CUR) (which is given by the occupied over available slots) can be determined.

5. Analytical performance
The analysis of IEEE 802.16 mesh network is based on the assumption that
      1) There is a number of Mesh SS nodes which are randomly scattered
      2) A link connectivity graph is based on the assumption that there is a link between two nodes if they are in the range of each other
      3) Three routing trees are built using the three construction algorithms summarized in (4.1)
The efficiency of the simultaneous transmission with spatial reuse of different scheduling schemes can be related to the concept of concurrence rate a follows :
  a) The total number of transmission opportunity (in slot) required to complete the overall transmission is assumed to be L
  b) Let $AL(K_F)$ is the number of links that are active for uplink and or downlink traffic,
  c) $|E|$ is the number of branches (edges) of the routing tree,

Input Routing Tree T=(V,E) & service tokens (ST)

Assign service token to each SS

Set service token according to the requested BW for each SS

Output S when A=0

Set time slot assignment S = 0

Mark status of every transmission link (TL) either Available if the ST of the link's transmitter is non zero or Idle if the ST of the link's transmitter is zero

Set number of Available nodes = A

Output L when A=0

Set Length of schedule L =1

While A > 0, select the available node with minimum hop count (nearest) to BS to transmit first by scheduling its available link in the current time slot

If there is one nearest available node — Yes/select

No

Check the BW of each nearest available node

If there is only one available node with highest BW — Yes/select

No

Select the available node with minimum ID — Yes/select

Schedule The Selected node

Update A = A-1

Update S = S + required number of time slot

Adjust Service Token to the required number of time slot

Check available nodes for scheduling in the same time slot

Mark the interferences (primary & secondary) with scheduled link

Update L = L + 1

If there is any other available node can be scheduled in the same time slot

No

Yes

Fig.(8): Flow chart of the proposed scheduling algorithm

CUR=22/11X17=11.8%

n ↑, L →

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1 (17)																
2	1															
3		1				1			1		1		1		1	1
4			1	1			1									
5					1			1		1						
6												1				
7													1	1		
8	1															
9				1												
10			1													
11				1												
				1												

CUR=22/11X13=15.4%

n ↑, L →

	1	2	3	4	5	6	7	8	9	10	11	12	13
1	1												
2		1	1		1		1		1		1		1
3				1		1		1					
4	1			1		1							
5								1					
6										1		1	
7	1												
8		1											
9		1											
10			1										
11	1												

CUR=22/11X13=15.4%

n ↑, L →

	1	2	3	4	5	6	7	8	9	10	11	12	13
1	1			1			1						
2		1								1			1
3			1		1	1		1			1		
4			1			1							
5									1		1		
6	1												
7			1			1							
8								1					
9				1									
10			1										
11		1											

CUR=22/11X11=18.2%

n ↑, L →

	1	2	3	4	5	6	7	8	9	10	11
1	1		1		1						
2		1		1		1					
3							1	1	1	1	1
4		1		1							
5	1		1								
6	1										
7		1	1								
8			1								
9	1										
10		1									
11	1										

CUR=22/11X14=14.3%

n ↑, L →

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	1			1			1							
2		1								1		1		1
3			1		1	1		1						
4			1			1								
5									1		1			
6													1	
7	1			1										
8							1							
9				1										
10	1													
11		1												

CUR=22/11X11=18.2%

n ↑, L →

	1	2	3	4	5	6	7	8	9	10	11
1	1		1		1						
2		1		1		1	1				
3								1	1	1	1
4		1		1							
5	1		1								
6				1							
7	1		1								
8		1									
9	1										
10		1									
11		1									

Fig.(9): slot assignment using Relay Model Scheduling with NS criteria (a), (b), (c) without and (d), (e), (f) with directivity for BFT-RTC, Para-RTC and Bala-Para-RTC algorithms respectively

The channel utilization ratio CUR for a scheduling scheme is given by:

$$\text{CUR} = \left\{ \sum_{i=1}^{K_F} \text{AL}(i)/(L|E|) \right\} \tag{1}$$

Where:

K_F = total number of frame slots & $K_F \in [1 , L]$

Assume that the number of SSs in the network is "n", and the uplink and downlink traffic requests are $D_u(i)$ and $D_d(i)$ respectively, which have been normalized by $C_{BPSK,1/2}$, (link capacity with modulation matrix of BPSK 1/2, where 1/2 represents the coding rate, i.e. one coding bit for every two data bits).

If $D(i) = D_u(i) + D_d(i)$

Then the total network demand is D which is given by

$$D = \sum_{i=1}^{n} D(i) \tag{2}$$

To take into account the case, where the traffic from a given SS_i needs to be relayed h(i) times to reach the destination. let *C(l)* be the average link capacity in the branch *l* of the routing tree, α is the weighted factor which varies simultaneously by the active link number and link capacity, then L can be expressed as

$$L = \sum_{i=1}^{n} (D(i) \bullet h(i))/\alpha , \tag{3}$$

Where

$$\alpha = \text{CR} \bullet \sum_{l=1}^{|E|} C(l)/C_{BPSK,1/2} \cdot \tag{4}$$

6. <u>Simulation results</u>

Qualnet simulator version 5.0.2 is used to evaluate the performance of the proposed (Para and Bala-Para) routing algorithms. The results are compared with the results of the standard BFT-RTCA.

The simulation results are based on the following assumptions :

1. The simulation area being used is a 100×100 units.

2. The BS is placed at the middle of the cell.

3.   In the long term, all nodes have the same average therefore, for unified traffic, it is assumed that all the stations generate the same amount of uplink traffic (1 packet each) and hence request the same amount of recourses (1 slot each).

4. One packet is transmitted in each slot and two nodes are neighbors only if they are in the transmission range of each other.

5. Power control is applied when directivity is used.

6. All nodes have the same transmission range TR = 22.5 units.

7. The SSs (ranges from 10 to 100 with increment step of 10) has been scattered randomly and uniformly in the topology of the cell.

8. The number of active links was varying randomly depending on the involved interferences among links.

9. To account for the randomness behavior of active links, readings were averaged over 10 connected random mesh topologies for each set (10,20,30,…..100) of nodes involved in the topology.

10. Maximum hop range is five.

11. For directivity, every SS is equipped with six directional antennas, each one cover 60 degree, one of them is switched on (depending on direction of transmission or reception) when SS is scheduled at certain slot.

Figure (10) shows the relationship between the length of schedule and the number of nodes. It is found that there is an increment in the length of scheduling time as the number of nodes increase.

It is important to mention that, as the number of nodes increases, the effect of directivity starts to appear for the three routing algorithms, the length of scheduling has max reduction around the ranges 30-40, 40-50 and 50-60 nodes for the BFT, Para and Bala-Para-RTCAs respectively. The effect of directivity starts decreasing as the number of nodes increases beyond the range 50-60 nodes.

Also, the Figures show that at higher number of nodes (from around 20 up to around 50 nodes) there is a better improvement in the directivity with maximum reductions (around 5, 8 &10) in the length of the scheduling time for the standard and proposed (BFT, Para & Bala-Para) RTC algorithms respectively.

For BFT, Figure (10a) shows that as the number of nodes decreases (below 30), the reduction of the length of scheduling will be more sensitive to the directivity in comparison with the proposed routing algorithms. The reason for that is related to the fact that the secondary interferences are dominated and can be significantly treated by the directivity.

Figure (11a) shows the relationship between the length of the schedule and the number of nodes for the three routing algorithms with the lower and upper bounds. It is found that the performance of the proposed (Para & Bala-Para) routing algorithm is better than that of the BFT routing algorithm as far as the reduction of the length of the scheduling time is concerned (max reduction 15 slots at 100 nodes), the reason is related to the parallel way of routing the data.

Figure (12a) shows the relationship between the length of the schedule and the number of nodes with directivity for the three routing algorithms with the lower and upper bounds. It is clear that a maximum reduction of 16 and 18 slots at 100 nodes for Para and Bala-Para respectively are obtained. This can be related to the proposed algorithms which are efficiently exploiting the routing of data in a Parallel way.

Figure (10) shows the relationship between the channel utilization ratio and the number of nodes. It is found that for a certain transmission range, the increment of the number of nodes in the network will reduce the CUR. The reason for that is related to the fact that as the
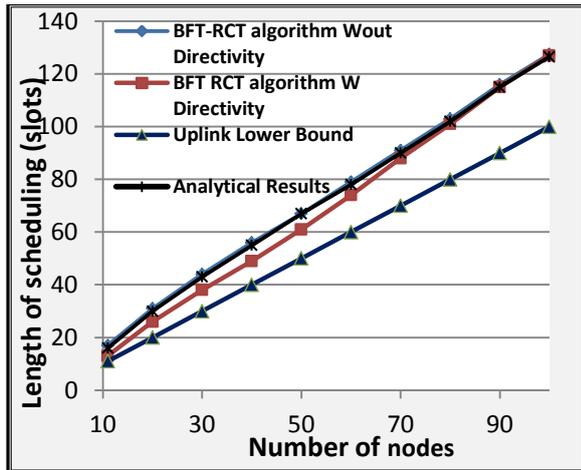
(a)
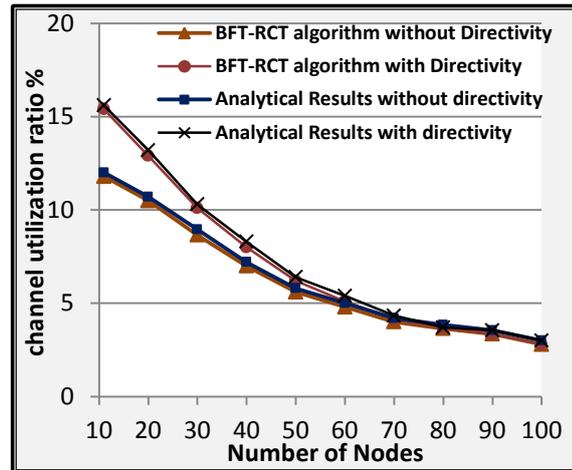
(a′)
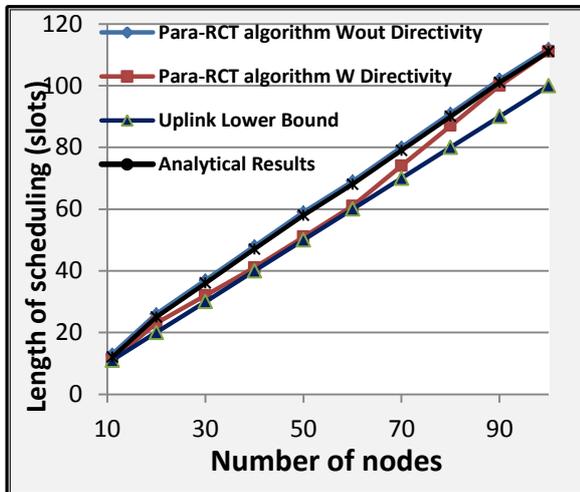
(b)
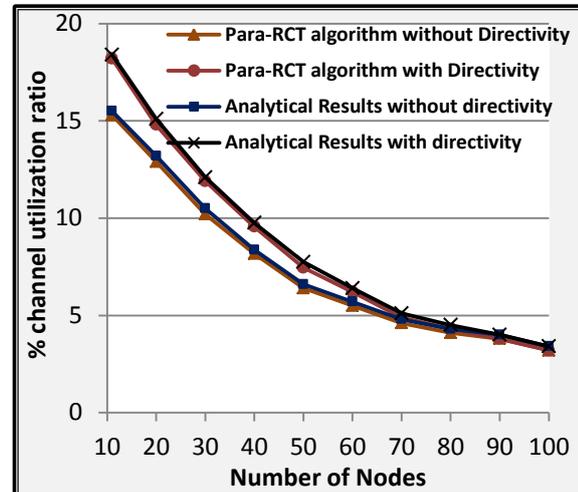
(b′)
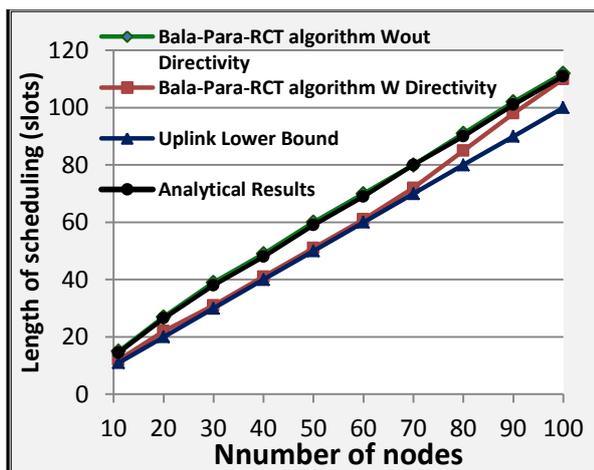
(c)
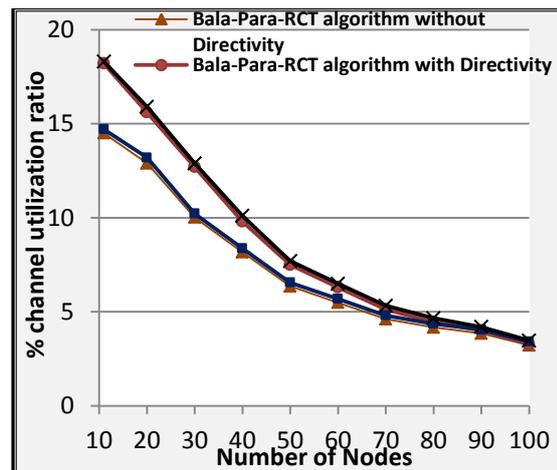
(c′)

Fig. (10): shows the relationship between the length of schedule (a,b.c) and the channel utilization ratio (a',b',c') against the number of nodes for BFT, Para and Bala-Para RTCAs with and without directivity when the traffic demand is unified

number of nodes increases, the number of interfered nodes will be increased too leading to the reduction of the number of transmitting nodes.

Also the Figure shows that the effect of directivity is obvious for the three routing algorithms and its effect is decreasing as the number of nodes increases. The effect of directivity is noticeable up to 50, 60 and 70 nodes for BFT, Para and Bala-Para RTCAs respectively. With directivity, the BFT-RTC algorithm in comparison with Para-RTC algorithm has better improvement of the CUR for low (< 20 nodes) number of nodes as compared with the no directivity case. The reason is coming from the fact that most of the secondary interferences affecting the proposed routing algorithms will be eliminated by the parallel property of routing algorithms in conjunction with scheduling algorithm.

Figures (11b,12b) show the relationship between the channel utilization ratio and the number of nodes. It is clear that CURs using the Para-RTC and Bala-Para-RTC algorithms without directivity has an improvement of 3.6% & 2.5% respectively higher than the standard Breadth which has 11.8% CUR. While with directivity they produce the same CUR of 18.2%. Their performance is better than the BFT performance which can be related to the parallelism and balance properties.
The Figure also shows that the performance of the Bala-Para-RTCA is slightly outperform the Para-RTCA and that is due to the feature which gives priority for down-node group if the values are greater than two.

(a)   (b)
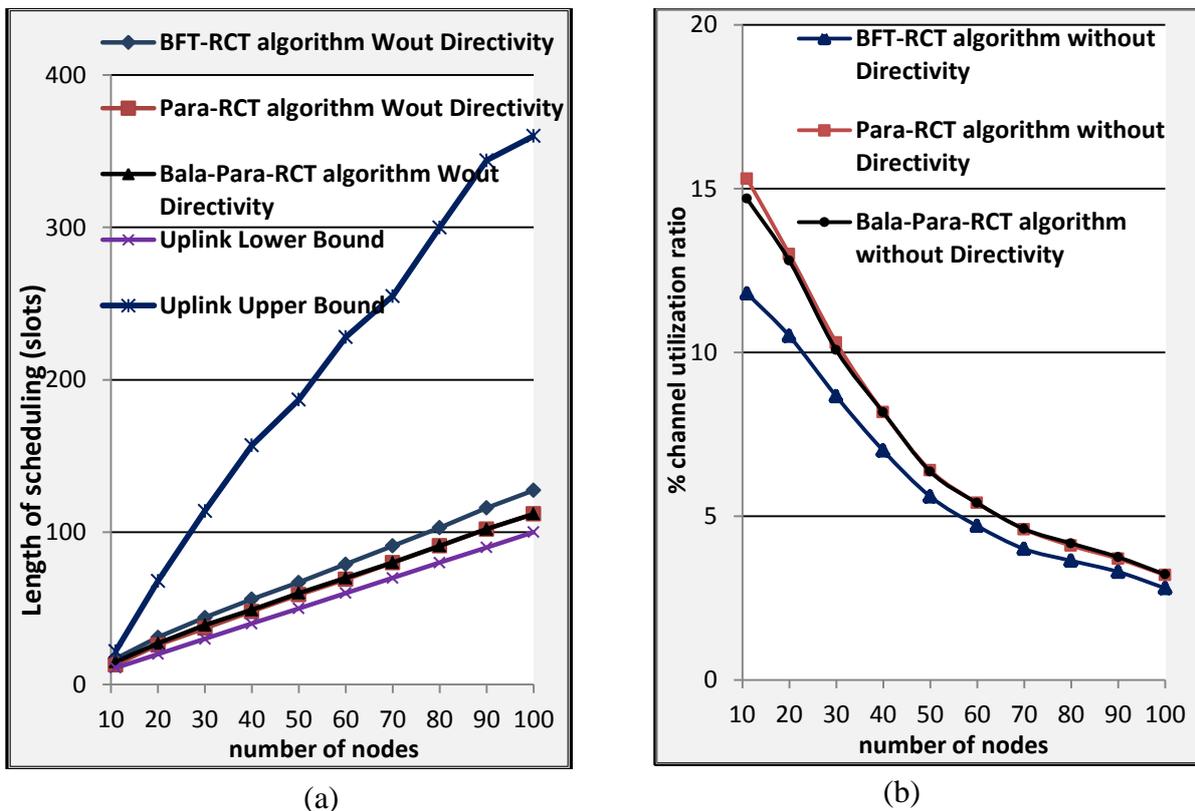
Fig. (11): shows the relationship between (a) the length of schedule and (b) channel utilization ratio against the number of nodes for BFT, Para and Bala-Para-RTCAs without directivity when the traffic demand is unified and TR= 22.5 with uplink lower and upper bounds

(a)   (b)
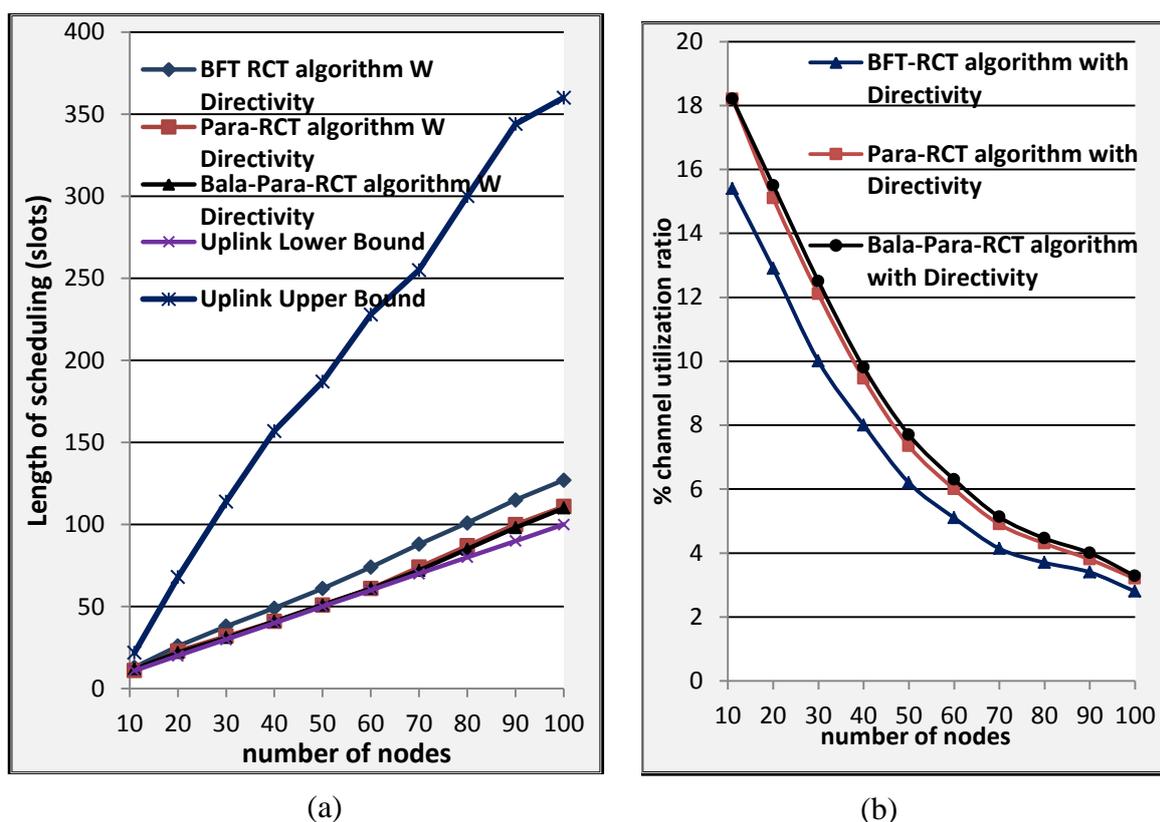
Fig. (12): shows the relationship between (a) the length of schedule and (b) channel utilization ratio against the number of nodes for BFT, Para and Bala-Para-RTCAs with directivity when the traffic demand is unified and TR= 22.5 with uplink lower and upper bounds

7. Conclusion

The trend of the relay scheduling models is to impose fairness on WiMAX mesh network. In this paper, two routing algorithms with proposed parallelism & balancing features are used to enhance the system performance. The proposed routing algorithms without directivity provide a maximum reduction in the length of schedule of around 14 slots at a number of nodes =100. Also they show significant improvement in CUR of about 3.6 % & 2.5 % relative to the conventional algorithm which has 11.8 %. The proposed routing algorithms with directivity provide a maximum reduction in the length of scheduling of around 15&16 at 100 nodes for Para and Bala-Para RTCAs respectively. Also they have a better improvement of 18.2 % relative to the 15.4 % of BFT algorithm.

Since directivity shows an improvement over large number of nodes, therefore the proposed routing algorithms are suitable for large scale networks.

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