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Adaptive Resource Allocation for WiMAX Mesh Network

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Abstract Worldwide Interoperability for Microwave Access (WiMAX) is a technology used to enable fast and cost-effective network deployment as well as facilitating multimedia based services and applications available to the users. However, Interference constitutes a major constraint in the widespread use of shared resources for interaction among devices. In this paper, a greedy resource allocation mechanism, which consists of Learning Automata based Greedy Channel Assignment (LAGCA) and Learning Automata based Greedy Centralized Scheduling (LAGCS) algorithms, is presented to cope with interference as well as to improve spatial reuse in the resource allocation mechanism. Finally, the simulation results demonstrate that our proposed algorithms outperform existing approaches.

Keywords WiMAX mesh network · resource allocation · channel assignment · centralized scheduling

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1 Introduction

WiMAX mesh network (IEEE 802.16) is recognized [1] as the corresponding wireless communication standard which can be used for large distances with a very wide bandwidth (i.e., 266 GHz) with data rate up to 70 Mbps. Due to broadband nature of WiMAX mesh network, it is used for multimedia applications in long distance transportations. WiMAX mesh network is a connection-oriented technology in which each subscriber station transmits data only when a channel is allocated to subscriber station.

WiMAX mesh technology is used as one of the main cost-effective network deployment [2–5]. However, failures [6] and limited shared resources are the main constraints in the use of WiMAX mesh technology. Limitations on shared resources come from the interference happening between the subscribers. Indeed, the transmission and reception of a signal on a wireless link is affected by interference from other ongoing transmissions.

Depending on the signaling mechanism, there are two types of interferences for transmissions which are referred to as primary and secondary interference [7–9]. Primary interference occurs when a node performs more than one task (transmission/reception) in a single time slot. In fact, activating the nodes with one hop away from each other together means that they have to send and receive data at the same time, which is referred as primary constraint. Secondary interference happens as the result of receiving signals from more than one sender in a single time slot due to the broadcast nature of wireless networks. Actually, the attempt is to receive only one signal from the specific sender while the other signals are involved accidentally at the receiver.

In fact, interference affects the utilization of shared resources resulting in spatial reuse decrease. Thus, in order to improve spatial reuse and data rate for WiMAX mesh network, resource allocation should be applied to different layers including MAC and physical layers for scheduling and channel assignment.

A critical part of MAC layer specification of WiMAX mesh network is packet scheduling, which resolves contention for bandwidth and determines the transmission order of users [1, 10, 11]. IEEE 802.16 specifies a centralized scheduling mode for base stations (BSs) to manage network and to enhance spatial reuse [1]. In this mode, BS collects the unicast connections from all its subscriber stations (SSs) through mesh centralized scheduling (MSH-CSCH) request messages, and then performs appropriate nodes' activation at each time slot to grant bandwidth requests. Scheduling decisions are propagated by BS to all SSs through MSH-CSCH grant messages. Note that in centralized scheduling, BS and SSs form a routing tree, where BS is the root node and SSs are the leaves and the relay nodes.

Furthermore, PHY layer of WiMAX supports OFDM to subdivide whole bandwidth channel into multi frequency channels which are not overlapped. Multiple frequency channels are supported to enhance bandwidth access to end users by using simultaneous transmissions. Therefore, nodes should operate on different channels in a multi channel system for simultaneous transmissions to mitigate the impact of secondary interference.

Indeed, our aim is to find the maximum number of SS nodes assigned with the same channel without any secondary interference. Furthermore, to increase the number of concurrent transmissions and data rate, it is necessary to find maximum number of SS nodes which can be scheduled in the same time slot for transmissions. Therefore, we have defined a concept called Interference-free Set of Nodes (ISN), by means of which spatial reuse can be enhanced when maximal ISN is obtained either in channel assignment or resource scheduling. Indeed, Maximal ISN refers to the maximum number of SS nodes that can operate on the same channel or transmit in the same time slot for scheduling.

The rest of paper is organized as follows: In Section 2, we overview related work on scheduling and channel assignment multi channel WiMAX mesh network. Moreover, network communication model and assumptions are presented in Section 2. In Section 3, we describe the new greedy resource allocation including greedy channel assignment and centralized scheduling. Section 4 presents the simulation results and finally, Section 5 concludes the paper and provides our future work.

2 Related Work

Once data is gathered through sensing technologies from each device(node), it should be transmitted across the network. However, resource scarcity is a limiting factor which impedes data rate increase. The limitation of shared resources consists of scheduling in MAC layer and channel assignment in Physical layer.

There are several approaches to address centralized scheduling in WiMAX mesh network to minimize scheduling length in MAC layer [7, 8, 12–24].

In [12, 8], a collision-free centralized scheduling algorithm was proposed for SSs based on transmission routing tree in Wireless Mesh Network (WMN). The objective of this algorithm is to provide high-quality wireless multimedia services by considering channel utilization and transmission delay with different selection criteria including minimum interference and nearest/furthest nodes to BS. Their results show that giving higher priority to nodes nearest to BS would result in higher performance in terms of scheduling length, channel utilization ratio(CUR) and delay. In [16, 25], similar selection criteria were deployed for centralized scheduling with similar results. Indeed, a fundamental drawback of scheduling algorithm in these studies ([18, 26, 27, 21, 19, 20]) is that giving higher priority to nodes located further from BS leads to a reduction in spatial reuse.

Furthermore, The authors in [28] proposed a scheduling scheduling algorithm based on genetic algorithm with SS grouping resource allocation (GGRA) scheme for IEEE 802.16 uplink systems. GGRA scheme uses a rate assignment strategy to formulate the resource allocation problem as an optimization function subject to the system constraints. The authors in [29] present a dynamic programming algorithm to find the conflict-free set of nodes that can be activated and to solve the optimization problem of scheduling. However, these studies [28, 29] suffer from high computational overhead causing performance degradation.

In addition to the specifications of MAC layer for scheduling, the specification of PHY layer is used to divide available frequency band into multiple non-overlapping frequency channels [1]. Multiple frequency channels are deployed to provide simultaneous transmissions which result in more available bandwidth aggregation. However, it is worth noting that multiple simultaneous transmissions should be performed on different channels to remove the effect of possible secondary interference [7,8]. Thus, to mitigate secondary interference, efficient channel assignment schemes are required.

Several studies used multi channel single transceiver WiMAX to maximize the number of concurrent transmissions in the network [7,30–34,25]. The basic idea behind these studies is to map channel assignment problem into graph coloring problem. The aim is to color the links of the graph with minimum possible colors which represents minimum interference in wireless networks. Although, this objective minimizes interference, solving graph coloring problem does not generate an optimal channel assignment and utilizes more channels than the minimum number of required channels. Authors in [31] extended the scheme, presented in[7], by equipping each node with two transceivers operating at different frequencies in order to ignore the primary interference. Although empowering nodes with multiple transceivers results in short scheduling length and high throughput, it significantly increases the cost of deployment and hardware complexity.

The contribution in [9] mapped channel assignment problem into a maximum clique problem which is also investigated in [35–37]; the objective is to find the maximum number of concurrent interference-free transmissions. Maximum clique problem is a NP-hard problem and, thus, an exact solution can not be obtained in general.

Table 1 shows a comparison between existing channel assignment schemes and scheduling algorithms.

In this paper, we propose a greedy learning automata based channel assignment and centralized scheduling algorithms to find the maximal interference-free set of nodes (ISN) for channel and time slot allocation. We are aiming at (a) minimizing the number of channels required for transmission; and (b) achieving maximum spatial reuse in terms of shorter scheduling length, higher channel utilization ratio as well as shorter delay in comparison with previous studies.

2.1 Network Model

In this section, the network model with assumptions used in this paper is identified. WiMAX mesh network can be represented by means of an undirected graph $G = (V,E)$ consisting of vertex-set $V = \{v_1, v_2, ..., v_N\}$, the set of nodes in the network, where $N =$ number of nodes, and undirected edge set $E = \{e_1, e_2, ..., e_N\} \subseteq V \times V$ in which e_k denotes the edge between nodes i,j depicted by $< i, j > \in E$. Every edge e_k belonging to E indicates that nodes v_i and v_j are one hop away from each other meaning that they are neighboring nodes [9].

The adjacency matrix A is defined by an $n \times n$ matrix, where n is the combination of BS and SSs nodes in the net-

Table 1 Comparison among all previous proposed scheduling and channel assignment algorithms.

Reference	Spectral reuse quantification	Criteria	Slot assignment	Channel assignment	Improved metrics
[15]	Yes	Unallocated traffic demands	Yes	No(Single Channel)	scheduling length
[26]	Yes	Furthest	Yes	No(Single channel)	Throughput
[12,8]	Yes	Nearest, Random,Furthest	Yes	No	scheduling length, average transmission delay, CUR
[16]	Yes	Nearest, Random,Furthest	Yes	No (Multi radio is used)	scheduling length, average transmission delay, CUR
[19,20]	Yes	Furthest based on traffic demand	Yes	No	Throughput
[7]	Yes	Insufficient: linear programming, Sufficient: Nearest	Yes	Graph coloring(Multiple channel)	Scheduling length, average transmission delay
[30]	Yes	Random	Yes	Graph coloring(Multiple channel)	Scheduling length, Throughput
[31]	Yes	Nearest	Yes	(Multiple channel) multi radio	Scheduling length, average transmission delay, CUR
[9]	Yes	Nearest	Yes	(Multiple channel)	Scheduling length, CUR
[38] [39]	Yes	Nearest, Maximum load Minimum Interference	Yes	(Multiple channel)	scheduling length, CUR, delay
[40] [28]	Yes	Genetic algorithm	Yes	Single channel	Throughput
[29]	Yes	Genetic algorithm	Yes	Single channel	Scheduling length
[41]	No	Neuro-fuzzy	No	Single channel	CUR
[42]	Yes	Neuro-fuzzy	No	Single channel	
[24]	Yes	smallest hop count first and hop by hop, largest hop count first and hop by hop	Yes	Single channel	Scheduling length, CUR
[43]	Yes	Heuristic algorithm	Yes	Multiple channel	Number of packets/frames are received
[44]	Yes	Lagranian algorithm	Yes	Multiple channel	Average data rate, Throughput
[45]	Yes	Linear programming	Yes	Single channel	Average packet are received

work. The entry $A_{i,j}$ should be 1 if nodes i and j are in the transmission range of each other, Otherwise $A_{i,j} = 0$ [9].

$$A = \begin{cases} 1 & \text{if } < e_{ij} > \in E \\ 0 & \text{Otherwise} \end{cases} \tag{1}$$

The primary interference matrix P is defined by an $n \times n$ matrix, where n is the total number of nodes in the routing tree of the network. The entry $P_{i,j}$ should be 1 if nodes i and j heve the primary interference, Otherwise $P_{i,j} = 0$ [9].

$$P_{i,j} = \begin{cases} 1 \text{ if link between } < v_i, v_j > \text{ has primary interference} \\ 0 \text{ Otherwise} \end{cases} \tag{2}$$

The secondary interference matrix S is defined by an $n \times n$ matrix, where n is the total number of nodes in the routing tree of the network. The entry $S_{i,j}$ should be 1 if nodes i and j heve the secondary interference, Otherwise $S_{i,j} = 0$ [9].

$$S_{i,j} = \begin{cases} 1 \text{ if link between } < v_i, v_j > \text{has secondary interference} \\ 0 \text{ Otherwise} \end{cases} \tag{3}$$

3 Learning Automata based Greedy Resource Allocation Mechanism

In this section, we propose a Learning Automata based Greedy Resource Allocation (LAGRA) mechanism for multi-channel IEEE 802.16 mesh network to reduce interference and to improve spatial reuse in resource allocation mechanism. LAGRA consists of two algorithms: Learning Automata based Greedy Channel Assignment (LAGCA) and Learning Automata based Greedy Centralized Scheduling (LAGCS) algorithms. LAGCA addresses the problem of multiple non-overlapping channels in WiMAX mesh network, while LAGCS improves scheduling in terms of scheduling length as the number of consumed time slots for SS nodes' bandwidth request.

3.1 LAGCA: Learning Automata based Greedy Channel Assignment Algorithm

In this section, an efficient channel assignment algorithm is proposed based on cellular learning automata(CLA) approximation to mitigate the impact of secondary interference. The basic idea behind LAGCA is to map WiMAX mesh topology into a network of learning automata. To do so, a CLA isomorphic to the secondary interference graph should be provided. In fact, actions and rules of learning automata should be identified to form a CLA corresponding to the secondary interference graph.

CLA is formed by building a network of learning automata based on the secondary interference graph. Indeed, it consists of a set of $\{\underline{A_i} \;\; | \;\; 1 \le i \le m\}$ learning automata corresponding to the interference-free set of nodes (ISN). The same channel number Ch_i can be assigned to all the selected nodes of ISN by all learning automata. m is initialized to $\frac{N+1}{2}$,meaning the cardinality of the maximal ISN having the same channel, were N is the number of SS nodes. In our approach, each learning automaton consists of n actions corresponding to the number of SSs in the secondary interference graph. Thus, SS_i and action $\underline{\alpha_i}$ represent the same concept; they can be used interchangeably throughout this paper.

The resulting network of learning automata can be described by two-tuple $\langle \underline{A}, \underline{\alpha} \rangle$, where $\underline{A} = \{\underline{A_1}, \underline{A_2}, ..., \underline{A_m}\}$ denotes the set of learning automata matched to the maximal ISN, and $\underline{\alpha} = \{\underline{\alpha_1}, \underline{\alpha_2}, ..., \underline{\alpha_n}\}$ denotes the set of actions for each learning automaton A_i. Moreover, to initialize, the probability vector of actions for each automaton is set to the same value of $\frac{1}{n}$ where n is the number of nodes with no assigned channel.

Here, the goal is to find the minimum number of channels, as shown in Algorithm 1. In the first step, the algorithm looks through the probability vector of the actions and selects the action with maximum probability for each learning automata. Note that the selection of one action is performed randomly in the first round due to the same initial probability value assigned to the actions of each learning automaton. Selecting action α_i (aka node i) from the whole set of actions of each learning automaton A_i generates a new ISN which implies that the same channel can be assigned to the selected actions(nodes).

In the second step, based on the selected actions from each learning automata, the response of each learning automaton should be evaluated to identify whether the selected actions should be rewarded or penalized. In fact, the evaluation of the selected actions identifies whether the same channel can be assigned to all selected nodes or not. This eval-

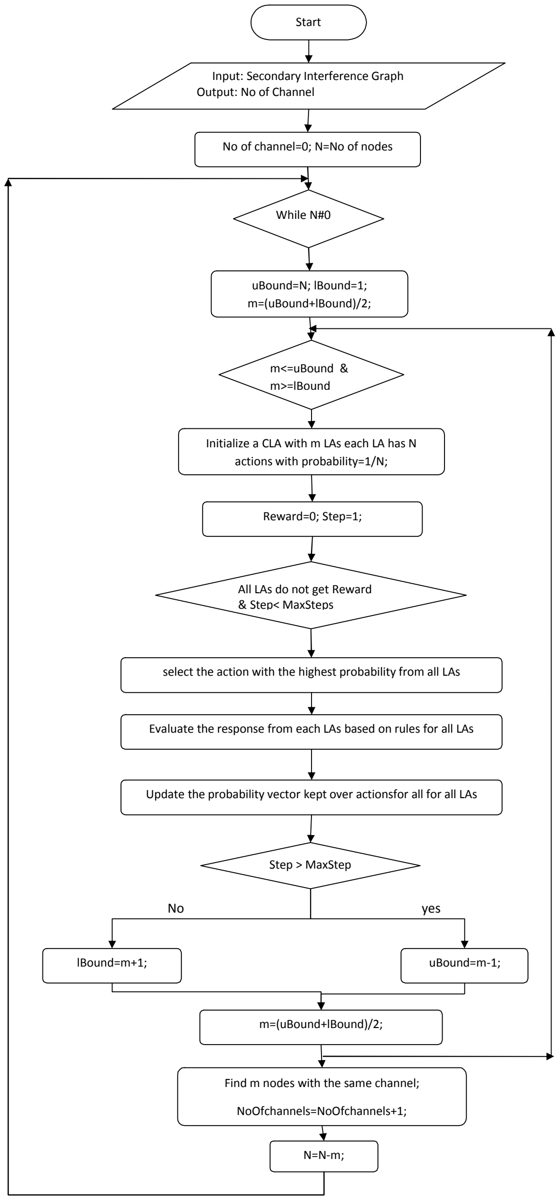

Fig. 1 LAGCA Flowchart.

uation is performed in the second step based on the three following rules:

(a) Two learning automata are penalized if they select the same actions due to the maximal ISN violation.

(b) Two learning automata are penalized if their two selected actions are connected through the secondary interference graph owing to the conflict resulting from secondary interference.

(c) Otherwise, two learning automata are rewarded due to the possibility of allocating the same channel to the respective selected nodes.

In the third step, based on the response, reward or penalty, the probability vector of each learning automata is updated. Updating the probability vector is performed according to learning algorithm $(L_{R-\varepsilon P})$ of learning automata.

The three-step process continues until two conditions are met. The first condition is satisfied when all m learning automata are rewarded. As a result, the maximal ISN with size m will be formed meaning that the same channel is assigned to m nodes. The second condition occurs when the maximum numbers of loop iterations (MAXstep) exceed meaning that the algorithm could not find m ISN to allocate to the same channel.

Depending on which condition is met, either finding m ISN or exceeding the MAXstep, m should be updated. In the case of finding m ISN, m will be updated to $\frac{n+n/2}{2}$. Otherwise, it will be updated to $\frac{1+n/2}{2}$. In fact, the whole process of updating m and three steps are performed based on binary search algorithm to find the maximal ISN with a complexity of $O(\lg n)$.

After the first iteration of the algorithm, maximal ISN indicates the interference free set of nodes for transmission within the same channel. For the next iteration, nodes and their corresponding links, which were identified in the first iteration, should be removed from the secondary interference graph. This algorithm continues until all the channel assignment requests are processed and no more request are remained.

Algorithm 1 LAGCA Algorithm to Find the Minimum Number of Channel Set.

Inputs: Secondary interference graph;
Outputs:NoOfchannels, ChannelMatrix;
Initialization:
NoOfchannels=0;
N=NoOfNodes which have request for channel assignment;
while $N \neq 0$ **do** /means that node exists for channel assignment request;
  uBound=N; lBound=1;
  m=(uBound+lBound)/2;
  while m<=uBound and m>=lBound **do**
    Initialize a CLA with m LAs;
    Each LA has N actions corresponded with the number of nodes with unassigned channel;
    Initialize probability vector of all LA_i including n actions:
    for j = 1 To n **do**
      $P_{i,j} = 1/N$;
    end for
    Reward=0; Step=1;
    while All LAs do not get Reward and Step $\leq$ MaxSteps **do**
      /Phase 1: select the action from all learning automata:
      for each LA_i in CLA Do In Parallel **do**
        select the action with the highest probability, $P_{i,j}$, for all learning automata;
      end for
      /Phase 2: Evaluation of actions:
      Evaluate the response from each LAs based on rules;
      /Phase 3: Update the probability vector kept over actions:
      for each LA_i in CLA Do In Parallel **do**
        Update Action Probability Vector according to Rules and $(L_{R-\varepsilon P})$;
      end for
    end while
    if Step $>$ MaxStep **then**
      uBound=m-1;
    else
      lBound=m+1;
    end if
    m=(uBound+lBound)/2;
  end while
  NoOfchannels=NoOfchannels+1;
  /all nodes chosen by all m LAS which should be allocated to the same channel:
  ChannelMatrix[NoOfchannels]=$\{\forall \alpha_i \mid \alpha_i \in \textit{current action of } LA_i\}$;
  N=N-m; n=N;
end while
return NoOfchannels, ChannelMatrix;

3.2 LAGCS: Learning Automata based Greedy Centralized Scheduling Algorithm

Our network topology consists of one BS node and a number of SS nodes. The topology is represented by a routing tree where the BS node is placed at the root and SS nodes are placed as the intermediate and leaf vertices. Dijkstra algorithm is used to find the shortest path between BS and every SS node. Note that, in the centralized scheduling algorithm, there is a concept named service token which is defined as the number of traffic demands for each SS node [8].

In this section, an efficient greedy centralized scheduling algorithm is proposed based on Dijkstra algorithm and CLA approximation. Similar to LAGCA, LAGCS uses the same concept of cellular learning automata to encode the scheduling of WiMAX network into a cellular learning automata based on primary interference graph. Mapping scheduling problem into CLA is formed by assigning a network of learning automata to maximal ISN which determines the nodes that can transmit concurrently in one time slot.

Algorithm 2 shows the pseudo code of centralized scheduling algorithm. Although Algorithm 2 is similar to Algorithm 1, they have key differences:

(a) the evaluation process of time slot allocation for bandwidth demands is done according to the following three rules:
   (1) Instead of considering the same channel, the same time slot is allocated to maximal ISN.
   (2) However Algorithm 1 is based on secondary interference graph, Algorithm 2 is based on primary interference graph.
   (3) After executing the first iteration of Algorithm 2, service token of the nodes, which are chosen as maximal ISN, is decremented by 1 while service token of their parents is incremented by 1.

(b) Algorithm 2 stops whenever no service token exists in the network. In other words, the algorithm terminates when no bandwidth demands are requested by the nodes.

Algorithm 2 LAGCS Algorithm to Find the Minimum Number of Time Slots.

```
Inputs: G = (V ,E) as the interference graph, N: Number of nodes, Routing Tree,
bandwidth request of nodes;
Outputs: NoOfTimeSlot, TimeSlotMatrix;
initialization:
NoOfTimeSlot=1;
while There is bandwidth request from nodes do
    uBound=N;
    lBound=1;
    m=(uBound+lBound)/2;
    while m<=uBound and m>=lBound do
        Initialize a CLA with m LAs each has N actions;
        Initialize probability vector of all LA_i including N actions;
        for j = 1 To N do
            P_{i,j} = 1/N;
        end for
        Reward=0; Step=1;
        while All LAs do not get Reward and Step ≤ MaxSteps do
            /Phase 1: select the action from all learning automata:
            for each LA_i in CLA Do In Parallel do
                select the action with the highest probability, P_{i,j},
                for all LAs;
            end for
            /Phase 2: Evaluation of actions:
            Evaluate the response from each LAs based on rules;
            /Phase 3: Update the probability vector kept over actions:
            for each LA_i in CLA Do In Parallel do
                Update Action Probability Vector according to
                Rules and (L_{R-εP});
            end for
        end while
        if Step > MaxStep then
            uBound=m-1;
        else
            lBound=m+1;
        end if
        m=(uBound+lBound)/2;
    end while
    /means m nodes scheduled in each time slot:
    TimeSlotMatrix(NoOfTimeslot)={∀α_i | α_i ∈ current action of LA_i};
    NoOfTimeSlot=NoOfTimeSlot+1;
    Decrease the bandwidth demand of m nodes scheduled in
    the same time slot;
    Increase the bandwidth demand of m node's parents
    scheduled in the same time slot;
end while
return NoOfTimeSlot, TimeSlotMatrix
```

4 Simulation Results

In this section, simulation-based performance evaluation is conducted using Matlab-Coded simulator to compare the performance of the proposed LAGCA with random selection algorithm and also, to compare LAGCS with the existing algorithms named Nearest, Minimum, Furtest.

In all simulation scenarios, a given number of static SS nodes are randomly and uniformly distributed in a square

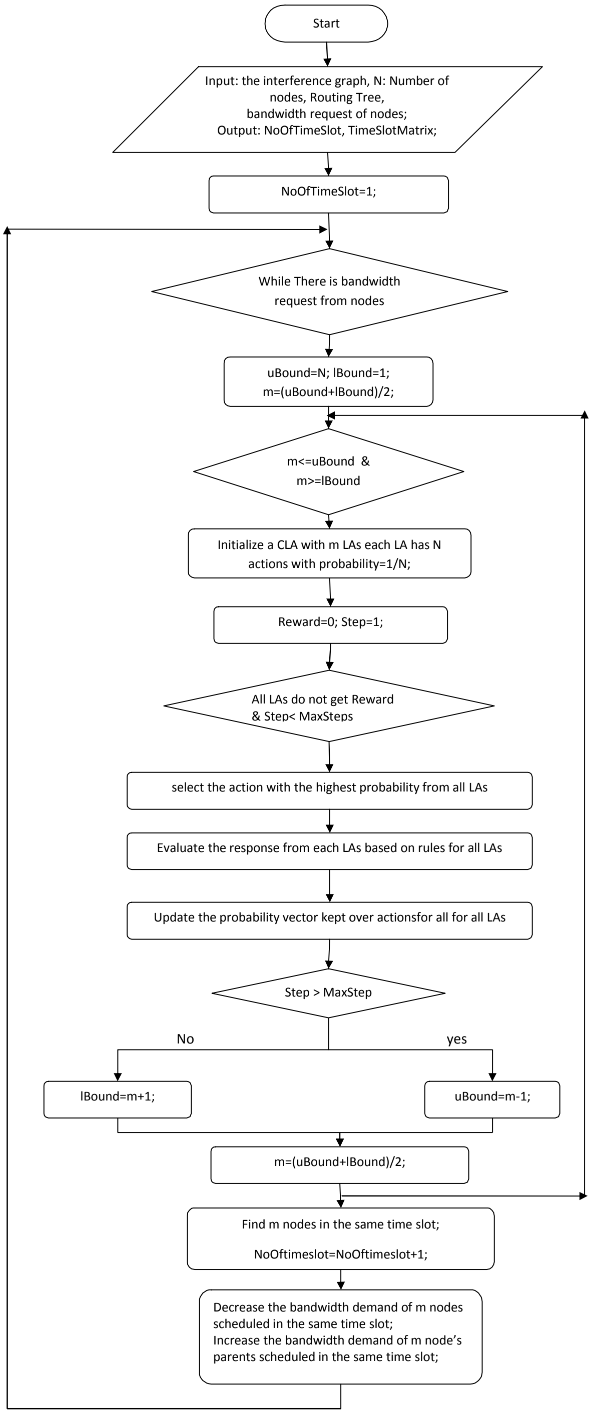

Fig. 2 LAGCS Flowchart.

area of 100 by 100 meters. BS is located at the center of the simulation area; and the transmission range of each SS node is assumed to be r . Two SS nodes are called neighbors if they are located in the transmission range of each other. For the sake of accuracy, the average of 20 runs on different random topologies are considered for the evaluation purpose. Moreover, in the simulation scenarios, the transmission range is assumed to be the same as the interference range. Besides, SS's Traffic demand is identified as the assigned service token to SS_i which is expressed as follows:

$$token_i = \frac{tr_i}{g} \tag{4}$$

where tr_n and g are the traffic demands and the greatest common divisor (GCD) of $tr_1, tr_2, ..., tr_n$, respectively. The division of traffic demands by their GCD reduces the length of scheduling. For instance, in the case of considering 2Mbps, 8Mbps, 6Mbps and 4Mbps for traffic demands of SS nodes, 1, 4, 3, and 2 values are assigned to service tokens of SS nodes [8]. In the following two sections, simulation results are presented in Section 6.1 and and 6.2.

4.1 LAGCA: Evaluation

Basically, number of channels is considered as one of the most important evaluation parameters. In many applications, channel assignment is performed when network is initialized, and then after, packet transmission goes on in the network using the same assigned channels as long as the network remains unchanged. Here, LAGCA is compared with random channel assignment algorithm.

The simulation results of the number of required channels with respect to the number of SS nodes are shown in Figure 3. We observe that the number of channels increases

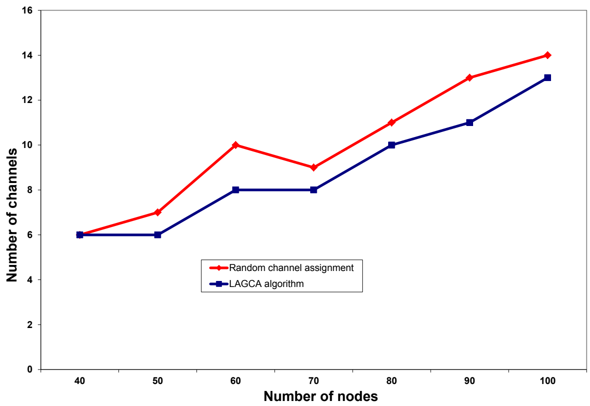

Fig. 3 The number of required channels versus different number of SS nodes when $r = 20$.

with the number of nodes. We also observe that LAGCA uses a smaller number of channels compared to random selection algorithm. For instance, when the number of nodes is 100, LAGCA outperforms random channel assignment by 8% with respect to the number of interference-free channel set. This can be explained by the fact that LAGCA defines the value of maximal ISN which indicates the maximum number of nodes using the same channel.

4.2 LAGCS: Evaluation

The simulation results of scheduling length versus different number of SS nodes and scheduling length versus transmission range of each SS node have been demonstrated in Figure 4 in two different cases: single channel and multi channels.

Scheduling length is defined as total numbers of consumed time-slots for granting bandwidth requests from SSs to destination BS. Figure 4 shows the variation of scheduling length versus different number of SS nodes and transmission range of each SS node in two different cases: single channel and multi channels.

We observe that scheduling length, for all scheduling algorithms, increases with the number of nodes. This is due to the fact that an increase in the number of nodes causes more interference among transmitting nodes and more collisions will occur during packet transmission. Figure 4(a) and Figure 4(c) show that scheduling length increases with the average service token. We observe that LAGCS outperforms all other algorithms. This can be explained by the fact that LAGCS chooses maximal ISN transmitting in the same time slot. For instance, in Figure 4(a) and Figure 4(c), when the number of nodes is 100, scheduling length will be reduced by 16% using LAGCS compared Nearest algorithm [8, 9].

Moreover, Figure 4(b) and Figure 4(c) show that multi channels outperforms single channel. When the number of nodes is 100 and $token_i \in (1, 2, 3)$, scheduling length will be significantly reduced by 55% using multi channels. This can be explained by the fact that the secondary interference is removed when multi channel technique is applied.

Figure 4(d) shows scheduling length versus transmission range of SS node. When the number of nodes is fixed, scheduling length will be decreased by increasing node's transmission range. It is due to the fact that by increasing the transmission range of the nodes, topology will be changed

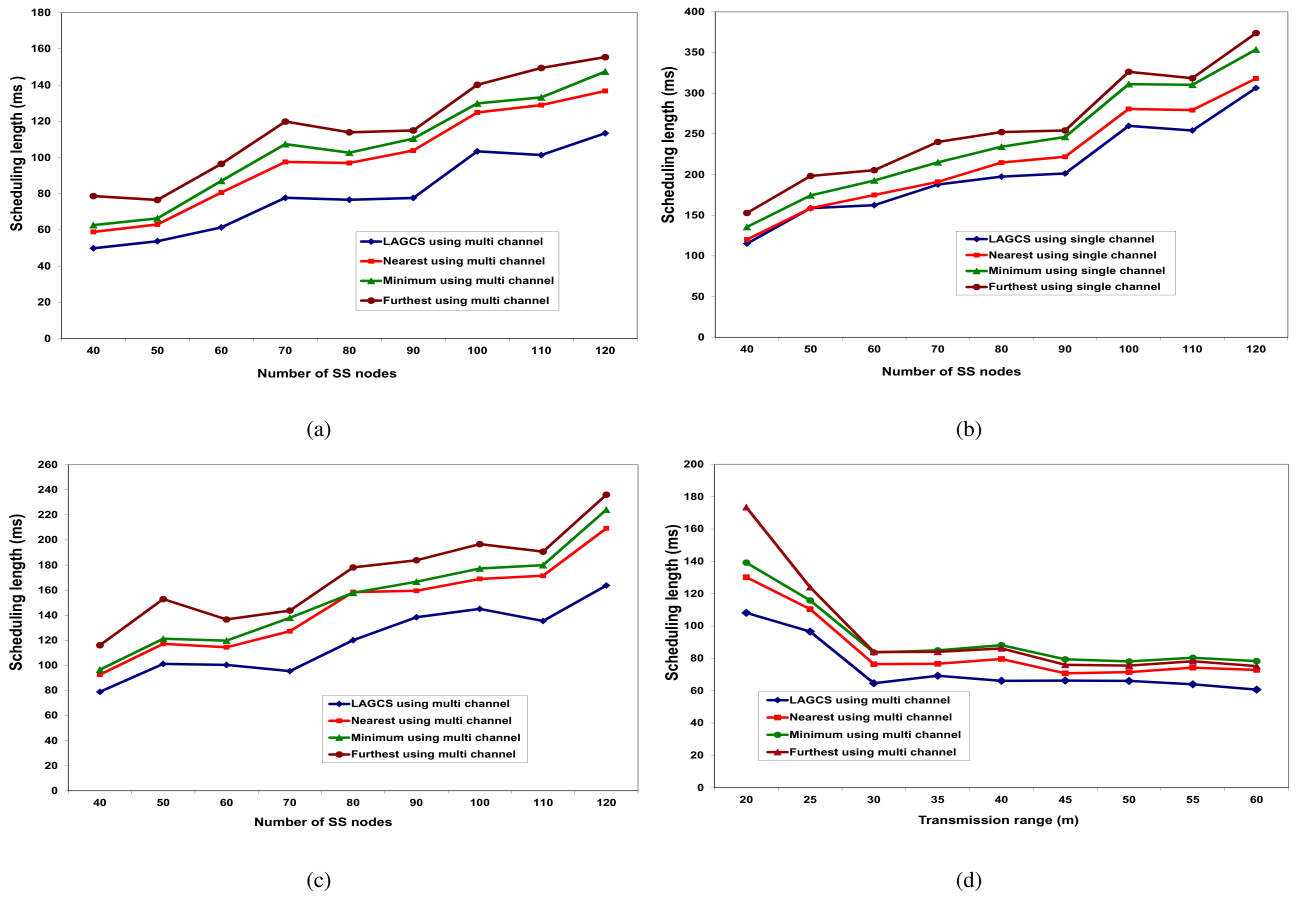

Fig. 4 Scheduling length a. multi channel and $token_i = 1$, $r = 20$, $n \in [40-120]$ b. single channel and $token_i \in [1-3]$, $r = 20$, $n \in [40-120]$ c. multi channel and $token_i \in [1-3]$, $r = 20$, $n \in [40-120]$ d. multi channel and $token_i \in [1-3]$, $n = 60$, $r \in [20-60]$.

to Point-to-Multi-Point and nodes will be placed mostly one hop away from BS and, thus, only one time slot is required for transmission of nodes. Also, when the node's transmission range rises up to 55 and more, the number of consumed time slots falls down by 15% using LAGCS compared with Nearest algorithm in high traffic demands.

In order to evaluate LAGCS, Channel Utilization Ration (CUR) is identified to show the utilization of shared bandwidth. To do so, CUR is computed based on Equation (5) as the ratio between the number of consumed time slots and the total number of available time slots which means scheduling length multiplied by the number of nodes. Higher CUR improves the capacity of wireless mesh network. However, the value of CUR is below 10 percent [8].

$$CUR = \frac{token_i \times hop_i}{N \times K} \tag{5}$$

Let hop_i, N and K represent the hop count of SS_i to BS, the number of nodes and scheduling length, respectively [8]. Figure 5 depicts CUR with respect to the number of SS nodes and transmission range of each SS node for all algorithms.

A prompt result of this performance evaluation is that an increase in number of SS nodes leads to a lower CUR for all scheduling algorithms in the case of fixed transmission range (Figure 5(a)). This means that increasing the number of nodes has direct effect on interference. As a result, the number of nodes which can transmit at the same time slot will be decreased.

According to Figure 5(a), LAGCS shows better performance compared with other scheduling algorithms. Since LAGCS selects the maximal ISN in each time slot, spatial reuse in terms of channel utilization ratio is enhanced. For example, comparing LAGCS with Nearest algorithm in Figure 5, CUR is improved by 16% considering multi channels in high traffic load demands.

Finally, the last evaluation parameter is average transmission delay versus number of SS nodes. In this scenario, the focus is on average transmission delay for all nodes located anywhere in the network topology whether nearer or further to BS node.

By decreasing the scheduling length in LAGCS, the average time granted to the bandwidth requests of each SS node will be more reduced as compared with others. Furthermore, LAGCS shows significant decrease in average transmission delay in high traffic demands.

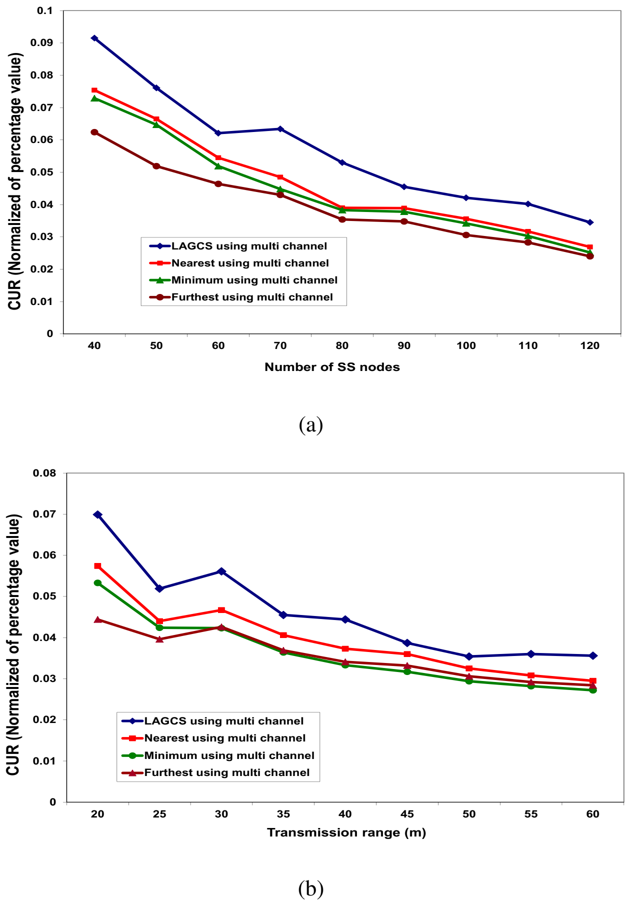

Fig. 5 Channel Utilization Ratio(CUR) in case of $token_i = [1-3]$ a. $r = 20$, $n \in [40-120]$, b. $n = 60$, $r \in [20-60]$.

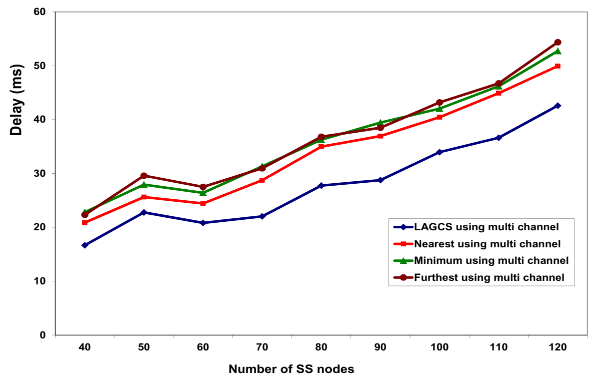

Fig. 6 Average transmission delay and $token_i \in [1-3]$, $r = 20$, $n \in [40-120]$.

5 Conclusion

In this paper, we investigated the problem of assigning resources to wireless interfaces in WiMAX mesh networks.

We proposed a greedy resource allocation mechanism that supports channel assignment and centralized scheduling; it is based on CLA to select the maximal ISN for the SS nodes which are assigned to the same channel and are scheduled in the same time slot. LGCA was evaluated, via simulations, and compared with random channel assignment algorithm. Also, LAGCS was evaluated, via simulations, and compared with Nearest, Minimum interference and Furthest algorithms in terms of scheduling time, channel utilization ratio and average transmission delay. The results have shown that the proposed approach outperforms traditional ones. In our future work, we plan to include resource allocation for IPTV distribution over WIMAX[46,47] as well as to provide analytical model for channel access delay in channel assignment and to obtain packet transmission delay through scheduling in Wimax mesh network.

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