

# Exploiting Spatial Reuse in Resource Allocation for WiMAX Mesh Networks

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**Abstract**—Due to the scarceness of communication resource, therefore, resource allocation in wireless networks is an important issue. In this paper, we introduce a time slot allocation problem for multi-user wireless networks to achieve fairness at the node level and high network throughput in WiMAX mesh networks. We first propose a multi-objective programming formulation to model the subscriber stations' requirements and network throughput. Then, a dynamic programming based resource allocation and scheduling algorithm is presented to provide an optimal resource allocation in WiMAX mesh networks. Simulation results show that our proposed algorithm significantly provides both fairness of channel access and optimal network throughput.

**Index items**—resource allocation, dynamic programming, spatial reuse, World Interoperability for Microwave Access (WiMAX)

## I. INTRODUCTION

IEEE 802.16 standard [1], also known as WiMAX supports a mesh mode in which all nodes organized in an ad hoc fashion, each node can relay traffic for others. This technology has the advantages such as high speed, low cost and easy deployment. In WiMAX mesh networks, a node that has a direct connection to backhaul services outside the Mesh network is termed a Mesh Base Station (MBS). All other nodes of Mesh network are termed Mesh Subscriber Stations (MSS). In WiMAX mesh networks, time division multiple access (TDMA) is employed as the channel access method and only time division duplex (TDD) is supported [1]. The standard specifies a centralized scheduling mechanism for mesh networks. Under this scheme, stations will form a routing tree rooted at the Mesh Base Station for communication purpose. Then, Mesh Subscriber Stations send requests messages containing their traffic demands and link quality to the MBS for resources. At last, the MBS uses the topology information and MSSs' requirements to determine the routing and scheduling. Resources in WiMAX mesh network are presented by time slots, which are grouped into frames of equal length. A frame contains control sub-frame and data sub-frame. The control sub-frame and data sub-frame is future divided into multiple time slots. Time slot is the basic unit for resource allocation. Although the standards [1] define the multiple access signaling mechanisms, however, the standard does not specify algorithms for scheduling of the time slots to MSSs and remain as open-issue.

There are some researches focused on resource allocation and scheduling. D.Kim and A.Ganz present a

transmission scheduling algorithm for IEEE 802.16 mesh networks, which maximize the network throughput and provide equal bandwidth to each node in the network [2]. T.Y.Chung et al. propose a dynamic clique-based link scheduling algorithm with minimal bandwidth guarantee [3]. C.Y.Ng and Tat M.Lok propose a goal programming formulation to model the client requirements [4]. J.Tao et al. propose a routing tree reconstruction and concurrent transmission scheme to achieve spatial reuse [5]. N.H.Lee et al. introduce a time slot allocation problem for multi-users wireless networks to achieve minimum rate guarantee under the condition of fixed total power [6]. D.Ghosh, et al. present a few representative research proposals and the research issues and challenges for multi-hop WiMAX networks to realize their full potential [7].

Different from previous works on resource allocation and scheduling in WiMAX networks, we present a multi-objective programming based optimal schemes for resource allocation in WiMAX mesh networks in this paper. Each node's requirements are first defined by two functions, namely, unsatisfactory index and throughput function. Then, we propose a multi-objective dynamic programming model, which optimizes unsatisfactory index and throughput function over a fixed number of time slots. Depending upon the objective function, a resource allocation and scheduling algorithm is proposed for meeting the node's requirement and maximizing the channel utilization.

This remainder of this paper is organized as follows. In Section II describes network model. Multi-objective programming optimization scheme and fairness resource allocation and scheduling algorithm are proposed in Section III. Section IV presents simulation results. Section V concludes this paper.

## II. SYSTEM MODEL

In this paper, we only conducted for upstream traffic from MSSs to MBS, therefore, network is model as a directed graph  $G = G(V, E)$ .  $V$  is the set of MSSs in WiMAX mesh networks and  $n = |V|$  is the number of MSSs.  $E$  is the link set. There is a directed link  $(u, v) \in E$  from SS  $u$  to SS  $v$  iff a single-hop transmission from  $u$  to  $v$  is possible. When node  $u$  transmits on link  $(u, v)$ , we say link  $(u, v)$  transmits. In addition, we assume that there are  $K$  time slots in a

data sub-frame, and label these time slots as  $(1, 2, \dots, K)$  respectively.

The spatial reuse in TDMA means multiple links can transmit concurrently only if they do not interfere with each other. We then present the methods to compute current transmission sets. Usually, the well-known contention graph is used to assist computation. In contention graph  $G_C(V_C, E_C)$  of the network graph  $G = G(V, E)$ , every vertex corresponds to a wireless link in  $G$ . There is an undirected edge connecting two vertices in  $G_C$  if their corresponding links in  $G$  interfere with each other. A clique ([3]) actually corresponds to an current transmission set (CTS) in the contention graph  $G_C$ . In this work, we use existing polynomial time heuristic algorithms [8] to generate close to optimal CTS offline.

### III. RESOURCE ALLOCATION SCHEME

In this section, we introduce a transmission scheduling that determines the transmission order and the number time slots of nodes within a frame. The goal of the algorithm is to achieve fairness among different nodes as well as optimal network throughput.

#### A. Multi-objective programming optimization model

To model each SS's requirement, there are two metrics, unsatisfactory index (UnSI) and throughput. Briefly speaking, the unsatisfactory index is the ratio of the average difference between node's requirement and time slots allocated in a given number of frames to node's requirement. The average is taken over a pre-configured interval of time, called the unsatisfactory window  $T$ , in this work, we set  $T=10$  frames. At the start point of the frame  $x$ , that is, also the end of the frame  $x-1$ , the unsatisfactory index of the SS  $i$ ,  $UnSI_i(x_0)$  is defined as

$$UnSI_i(x_0) = \frac{\sum_{i=x-T}^{x-1} (\omega_i - n_i)}{\sum_{i=x-T}^{x-1} \omega_i} \quad (1)$$

Where  $\omega_i$  and  $n_i$  is the number of SS  $i$ 's time slot requirements and allocated respectively in the  $i$ -th frame. The more difference between  $\omega_i$  and  $n_i$ , the more unsatisfactory index is.

The unsatisfactory index will change, when more time slots are to be allocated for the SS  $i$ . For example, at the end of the  $k$ -th ( $1 \leq k \leq K$ ) in the frame  $x$ , if the node  $i$  has been allocated  $n_i$  time slots, then, at the end of the  $k$ -th time slot in the frame  $x$ , we can compactly represent the unsatisfactory index of the node  $i$  as

$$UnSI_i(x_k) = UnSI_i(x_0) - \frac{n_i}{\sum_{i=x-T+1}^x \omega_i} \quad (2)$$

Where  $n_i$  should be effective, that is, the node's queue length should be greater or equal to  $n_i * \gamma$ , otherwise,  $n_i$  is wasted, in this work, it is not permitted.  $\gamma$  is the bits per time slot.

For brief, we define the node  $i$ 's throughput at the end of the  $k$ -th in the frame  $x$  as

$$\Gamma_i(x_k) = \gamma * n_i \quad (3)$$

Where  $n_i$  is the number of time slots allocated to SS  $i$  at the end of the  $k$ -th in the frame  $x$ .

As mentioned above, spatial reuse allows multiple links within a current transmission set can transmit at the same time. Thus we derive the CTSj's unsatisfactory index and throughput at the end of the  $k$ -th ( $1 \leq k \leq K$ ) in the frame  $x$  as

$$CUnSI_j(x_k) = \sum_{i \in CTS(j)} UnSI_i(x_k). \quad (4)$$

$$CT_j(x_k) = \sum_{i \in CTS(j)} \Gamma_i(x_k). \quad (5)$$

For achieving fairness among different nodes as well as high network throughput, therefore, we define stage gain function  $g(k)$  as

$$g(k) = (CUnSI_j(x_k), -CT_j(x_k)). \quad (6)$$

Obviously, the more time slots to be allocated for the CTSj, the smaller  $CUnSI_j(x_k)$  and  $-CT_j(x_k)$  are. However, the other CTSs' unsatisfactory index and throughput are likely to become large. Thus, we should adopt appropriate allocation scheme so that the total network unsatisfactory index and the total throughput is minimum. Thus, our optimization objective is derived as

$$\min F = \left( \sum_{j=1}^L CUnSI_j(x_K), -\sum_{j=1}^L \sum_{k=1}^K CT_j(x_k) \right) \quad (7)$$

Where,  $L$  is the total number of all CTSs generated by algorithm [8] for a given WIMAX mesh network topology

$$G. \sum_{l=1}^L CUnSI_j(x_K) \text{ and } -\sum_{l=1}^L \sum_{k=1}^K CT_j(x_k) \text{ are}$$

described as the total unsatisfactory index and the total network throughput at the end of the frame  $x$ .

According to the nodes' allocation of the time slots in each of the CTSs, the above formula (7) is easily transformed into as following expression:

$$\min F = \left( \sum_{i=1}^N UnSI_i(x_K), -\sum_{i=1}^N \Gamma_i(x_{total}) \right) \quad (8)$$

Where,  $x_{total}$  is number of the total time slots allocated in the frame  $x$ .

### B. Optimization resource allocation algorithm

To solve the multi-objectives programming problem above, we propose the following dynamic programming algorithm.

**Algorithm:** Let  $f(0,0)$  be the optimization value at the start point of the frame  $x$ . Thus,  $f(0,0)$  is defined as

$$f(0,0) = \left( \sum_{j=1}^L CUnSI_j(x_0), -\sum_{j=1}^L CT_j(x_0) \right). \quad (9)$$

Let  $f(l,k)$  is optimization function at the point of the  $k$ -th ( $1 \leq k \leq K$ ) in a frame. Thus,  $f(l,k)$  is defined as

$$f(l,k) = \begin{cases} 0 & k \geq 0, l = 0 \\ -\infty & k < 0, l = 0 \\ \min\{f(l-1,k), (f(l-1,k-1) \\ + g(k))\} & 1 \leq l \leq L \end{cases} \quad (10)$$

This recursive (10) yields optimization in the current frame. When the available time slots of the current frame is  $k$ , the decision to include  $CTS_l$  can be lead to one two situation: (i) the  $CTS_l$  is not included, available time slots of the current frame remains  $k$ , the unsatisfactory index and the total network throughput is unchanged; (ii) the  $CTS_l$  is included, available time slots become  $k-1$ , and network throughput increased by  $g(k)$ . The dynamic programming algorithm decides whether or not to include  $CTS_l$  based on which choice leads to lexicographically optimal.

By using this recursive relation (10), the resource allocation and scheduling is obtained by means of evaluating  $f(L,K)$ .

If we first calculate from  $f(0,0)$ , by the following of the recursive relation of the formula (10), then, we can obtain  $f(L,1)$ , the rest may be deduced by analogy, at last, we obtain  $f(L,K)$ . Also, from the meaning of this function (10), the proposed algorithm must give the optimal solution.

The way to obtain the optimal  $f(L,K)$  and the corresponding time slot allocation is outlined as follows. We can use a  $L \times (k+1)$  table [9] to store each instance of  $f(l,k)$ . The value of  $f(l,k)$  is stored in the  $l$ -th row and  $k$ -th column of the table. Firstly, we put the corresponding  $f(0,0)$  to the column 0 for all  $l$ . Then, we evaluate the entries in column 1 by using the recursive relation and the column 0's information. Next, we

compute the entries in column 2 in a similar way based on column 1's information. Then, we continue this process column by column until we reach the entry of  $f(L,K)$ .

In the calculation of each entry  $(l,k)$ , we have to make use of the entries information of the column  $k-1$ . There are totally  $(k+1)L$  entries to be evaluated. Therefore, the time complexity for this algorithm is  $\Theta(L^2K)$ .

## IV. PERFORMANCE EVALUATION

In this section, we present some experimental results conducted by MATLAB simulator to evaluate the performance of the proposed algorithm. We would like to compare how network performances of the proposed algorithm with others approach and a fairness and network throughput optimization scheme vary with the number of network nodes. For comparison, we also implement the algorithm proposed by D.Kim[2], referring to D.Kim algorithm, and the algorithm proposed by J.Tao[5], referring to J.Tao algorithm.

### A. Simulation Metrics

There are two performance metrics used to evaluate the network performance:

- Network throughput: which is defined as

$$\Gamma_{total} = \left( \sum_{i=1}^N n_i * \gamma \right) / F_d, \text{ where } F_d \text{ is a frame}$$

duration,  $\gamma$  is the data rate per time slot, and  $n_i$  is the total number of already arranged time slots for node  $i$  in a frame duration.  $\Gamma_{total}$  is the sum of throughput over all nodes.

- Fairness index: which is the average ratio between time slots allocated and time slots required for node

$$i \text{ in simulation period, that is, } \alpha_f = \frac{n_i}{\omega_i}.$$

### B. Simulation setup and results

We apply the shortest path routing algorithm to obtain a tree network. In the simulation, a given number of MSSs were randomly distributed in a square simulation area of size 100 by 100 units, the MBS is placed at the center of the simulation area. Both MBS and MSSs are stationary and work in half duplex. The node's transmission range is 20 units. The interference neighbourhood of an MSS includes all its neighbours within the two-hop range. Packets were generated by each MSS and transmitted towards the MBS in upstream direction. The parameters used are given as follows. Time slots per frame (K) is 100, bits per time slot  $\gamma$  is 512 bits, each of the packet size is 512 bits, node's requirement is uniformly distributed in [2,10] packets, frame duration  $F_d$  is 10ms, unsatisfaction window is 10 frames. In this paper, we only

conducted for upstream traffic for the proposed algorithm, but the results for downstream traffic can be inferred from analysis of the upstream traffic.

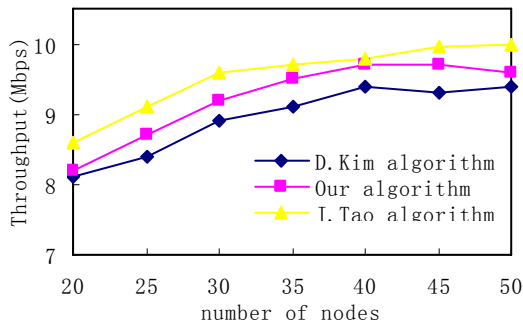


Figure 1. Network throughput.

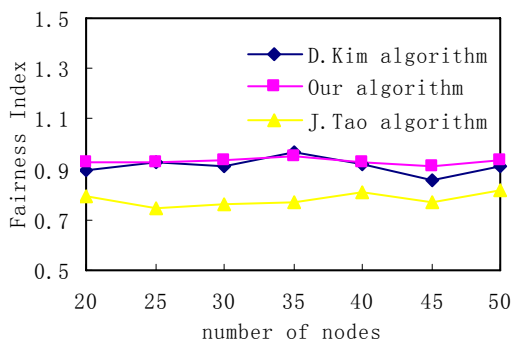


Figure 2. Fairness index.

First, we compare the network throughput between three scheduling algorithms presented above. Fig.1 illustrates the performance of various schemes with various nodes. The result shows that J.Tao algorithm always achieves the highest throughput of the scheduling schemes, because it always tries to maximize parallel transmission without considering node's fairness. Although our propose algorithm's throughput is lower than J.Tao algorithm's, yet our propose scheme performs well than D.Kim algorithm's. To demonstrate the proposed algorithm's fairness, Fig.2 shows the individual node's fairness index of various scheduling schemes. The results illustrate that our proposed algorithm performs the best in fairness no matter what number of network nodes variance is. The result also show that J.Tao algorithm have low fairness although they can achieve high network throughput.

## V. CONCLUSION

In this paper, we have developed multi-objective programming based link scheduling model as formed by WIMAX standard. Based on our proposed model, a dynamic programming based resource allocation and scheduling algorithm for WIMAX Mesh network is presented, which exploits the spatial reuse and meets each node's requirements. We have compared our proposed algorithm with other algorithms and found that our proposed scheme provides very good performance. Compared with previous works, our model is complete in exploiting the spatial reuse for WIMAX mesh networks.

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