Throughput Enhancement in WiMax Mesh Networks Using Concurrent Transmission

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Abstract—**The WiMax Mesh networks based on IEEE 802.16 standard [1] was developed with the goal of providing for easy, fast and cost-effective network set-up, deployment and extension. The standard defines scheduling scheme in mesh mode, but don't specify spatial resource management in the protocol. In this paper, we design a general algorithm for SSs to achieve concurrent transmission in both uplink and downlink streams. Constructing and adjustment of routing tree is also given in the paper. Simulation results show that overall end-to-end throughput is greatly improved when using our proposed algorithm for concurrency, and that the algorithm performs best when the routing tree is adjusted.**

Keywords- WiMax; IEEE 802.16; Mesh; throughput; concurrent transmission

I. INTRODUCTION

Broadband Wireless Access (BWA) system has gained an increased interest during the last years. The WiMax (World Interoperability for Microwave Access) technology based on IEEE 802.16 standards addresses the last-mile BWA problem in metropolitan areas and underserved rural areas. For the advantages of fast and cost-effective deployment, WiMax is considered one of the most promising technologies in the future.

As various wireless networks evolve into the next generation to provide better services, a key technology, wireless mesh networks (WMNs), has emerged recently [2]. There are many advantages about wireless mesh network such as rapid building, robustness and easy deployment, which makes it one of the indispensable technologies in next generation networks.

IEEE 802.16 MAC protocol is mainly designed for point-to-multipoint (PMP) access in wireless broadband application. To accommodate the more demanding physical environment and different service requirements of the frequencies between 2 and 11 GHz, the 802.16a project upgrades the MAC to provide automatic repeat request (ARQ) and support for mesh [3]. The Mesh mode is the extension to the PMP mode, with the advantage of less coverage path loss, coverage and robustness improved exponentially as subscribers are added, the larger user throughput over multiple-hop paths than PMP's [4,5].

Capacity enhancement in mesh networks is quite desirable. One way to increase the capacity of the multi-hop systems is to allow concurrency among the multi-hop transmissions. For example, Wei et al. [6] proposed an interference-aware route construction algorithm and centralized scheduling scheme, which achieves high utilization of the WiMax Mesh network. However, their algorithm may result non-minimized interference along the path because of the entry order. And it is constrained by the format of centralized scheduling messages that the information of concurrent transmission generated by scheduling algorithm in [6] deliver to every SS. So a lot working on improving WiMax Mesh capacity remains for further exploration. In light of Wei et al's work, in this paper we propose a general algorithm for SSs to achieve concurrent transmission in both uplink and downlink streams based on IEEE 802.16 centralized scheduling. We compare the performances of the algorithm with different routing trees, which shows overall end-to-end throughput is significantly improved using our algorithm.

The remainder of this paper is organized as follows. In Section II, we introduce centralized scheduling in mesh mode of IEEE 802.16. In Section III we firstly discuss a construction algorithm of routing tree based on interference, then propose a concurrent algorithm for WiMax Mesh network. Simulation and analysis is given in Section IV. Section V wraps up the paper.

II. SCHEDULING IN IEEE 802.16 MESH MODE

There are two scheduling methods: distributed scheduling and centralized scheduling, or a hybrid of both can be adopted in mesh mode. When using distributed scheduling, there is no clearly defined BS in the network. Scheduling is determined in a distributed manner like an ad-hoc network. In centralized scheduling, a BS determines slot allocation for all the SSs in a centralized manner like PMP mode, and traffics from or to the BS can be relayed by other SSs through a multi-hop route which is different from PMP mode.

There are two control messages, MSH-CSCF (Mesh centralized scheduling Configuration) and MSH-CSCH (Mesh centralized scheduling), in centralized scheduling. MSH-CSCF message delivers the information of channel configuration and routing tree, while MSH-CSCH message delivers the

0-7803-9335-X/05/$20.00

information of bandwidth request and grant and updating of routing tree.

The BS generates MSH-CSCF and broadcasts it to all its neighbors, and all the BS neighbors shall forward (rebroadcast) this message according to its index number specified in the message. This process repeats until all SS nodes have broadcasted the MSH-CSCF message.

According to the routing tree in MSH-CSCF message, all the SSs maintain a routing tree whose root is BS and children are SSs. All SSs are eligible to transmit MSH-CSCH:Request message. The transmission order is determined with regard to the hop-count - the one with the largest hop-count is transmitted first, but retains the transmission order as listed in the routing tree for nodes with the same hop-count. Before transmitting a MSH-CSCH:Request message, an SS puts the requests from its children into its own MSH-CSCH:Request, and transmits it to father node. Thus, the BS can gather bandwidth requests from all the SSs, and assign spatial resource for SSs. These assignments (grants) are put in MSH-CSCH:Grant message, and broadcasted by BS. Then the BS's children node which has no less than one child, ordered by their appearance in the routing tree, rebroadcast the MSH-CSCH:Grant message. This process repeat until all the SSs receive MSH-CSCH:Grant.

After receiving a MSH-CSCH:Grant message, the SSs determine its actual uplink and downlink transmission time from MSH-CSCH:Grant by a common algorithm which divides the frame proportionally. In the next section, we will discuss a concurrent transmission algorithm in detail to enhance the overall throughput for centralized scheduling.

III. ACHIEVING CONCURRENT TRANSMISSION

A. *Link Interference*

The wireless network inherently uses a shared medium to communicate with neighboring nodes. In a single-channel Time Division Duplex (TDD) network, any unicast transmission follows the principle that there must be only one receiver among the neighborhood of a transmitter and there must be only one transmitter among the neighborhood of a receiver. As we can see in Fig. 1, the solid lines with arrow denote directional links in the routing tree. The dashed lines connect the neighboring nodes in one-hop. And the curves with arrow denote the interference by an active link. Let L(x,y) represent the link from x to y, then the interfered links by L(4,6) are L(6,4), L(2,4), L(5,2), L(4,2), L(BS,2), L(BS,1), L(3,1), i.e. when node 4 is transmitting data to node 6, the 7 links above can't be active to avoid collision. The number of interfered links by L(x,y) is given by I(x,y), so I(4,6)=7 for example.

B. *Constructing Routing Tree*

As said in Section II, the performance of centralized scheduling benefits from well-structured routing tree. To reduce the interference between links, balance traffic load, shorten the period of request and grant, the structure of routing tree plays a key role. In this section, we propose a construction algorithm based on interference to achieve the following concurrent algorithm, and to improve network performance.

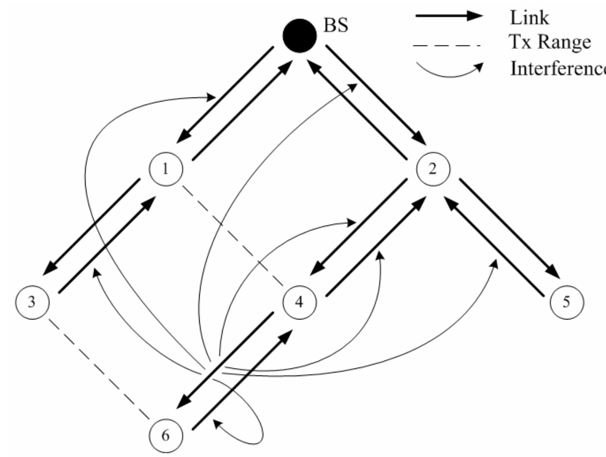

Figure 1. Link interference in routing tree

Assume BS-z-y-x is a path in the routing tree, and $P_y(x)$ is the sum of uplink and downlink interference through the path from node x whose father node is y to BS. So $P_y(x)$ is calculated by

$$P_y(x) = I(x,y) + I(y,x) + P_z(y). \tag{1}$$

In Fig. 1, for example, $P_4(6) = I(4,6) + I(6,4) + P_2(4)$.

We suppose network begins with only one BS, and all the SSs enter the network one by one. When an SS is entering, all its neighbor nodes are eligible to be the father node of the entering SS. In order to minimize interference, the entering SS should select a father node with minimal interference. So father node is

$$F_x = \arg \min_{i \in Neighbor(x)} P_i(x), \tag{2}$$

where Neighbor(x) is a set of x's neighbor nodes.

So far we consider the minimal interference along the path, but after an SS entering the network, the interference value on the path of other SSs in the network may be changed. Therefore, the entry order impacts the construction of routing tree. Improved method to construct routing tree is to make the impacted SSs select father node once more. Fig. 2 represents the process of entering and adjustment, where SS5 is the entry node. After SS5 entered the network, $P_2(4)=46$,$P_5(4)=30$, so the father node of SS4 is adjusted from SS2 to SS5.

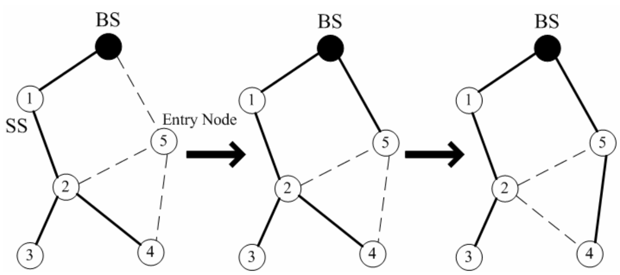

Figure 2. Construction and adjustment of routing tree

C. *Concurrent Transmission Algorithm*

Achieving spatial reuse with concurrency is an effectual method to improve the throughput in multi-hop systems. After analyzing the scheduling and construction of routing tree in WiMax Mesh networks, we propose a concurrent transmission algorithm with no collision to improve the overall end-to-end throughput.

The idea of the algorithm in uplink is described as follows. The order of transmission time determination in uplink is the same as transmission order of MSH-CSCH:Request, i.e., nodes with the biggest hop-count first, and remain the order in the routing tree for nodes with the same hop-count. The transmission time should be as early as possible on condition that no collision would happen. Considering the delay of relaying data, the transmission time of an SS should not be earlier than any of its children's. The algorithm is described as following.

```
A ← φ                          //nodes assigned Tx time
B ← {1,2,....,n}               //nodes to be assigned
while B ≠ φ
  x = arg max_{i∈B} hopcount ( i ) //node to be assigned
  C ← φ                        //interference time
  for all i ∈ neighbor(x)
     C ← C + {(Rx(i), Rx(i) + t_i)}
  end for
  for all i ∈ neighbor(father_x)
     C ← C + {(Tx(i), Tx(i) + t_i)}
  end for
  Tx(x) ← assign(x, C)         //assign x's Tx time
  Rx(father_x) ← Tx(x)         //record Rx time of
                                  x's father
  A ← A + {x}                  //add x to A
  B ← B − {x}                  //remove x from B
end while
```

Note that the algorithm in downlink is similar to that in uplink, and will not be discussed in this paper.

IV. Simulation and Analysis

A. *Simulation Scenario*

Random topology is generated in an L*L square. And $L = d\sqrt{n/2}$, where n is the number of SSs, d is the maximal transmission range between two nodes. We also insure that any SS can communicate with BS through one or multiple hops.

We assume a single channel network with no bit errors, and all the SSs are immobile and working in half duplex. Since we only care the performance of our algorithm, it is nearly optimal to transmit at the highest available rate (set to 50Mbps here) regardless of the channel state. Every SS request 0.5Mbps bandwidth for both uplink and downlink.

B. *Results and Analysis*

Fig. 3 and Fig. 4 show the overall end-to-end throughput with different routing trees. The number of SSs increases from 20 to 120 with a step of 10. The throughput values are the average of simulations in 500 times.

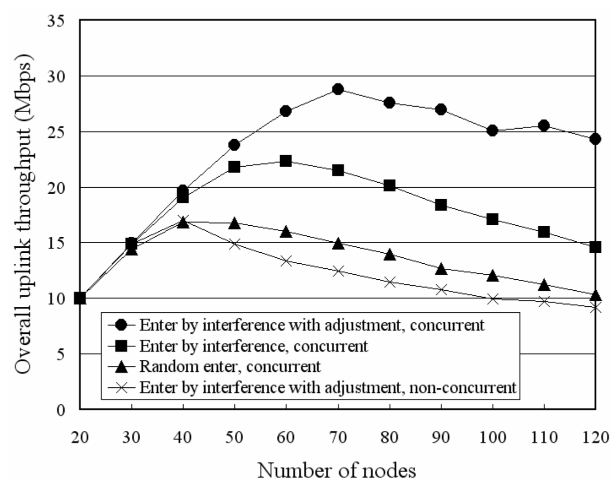

Figure 3. Throughput vs. number of nodes in uplinks

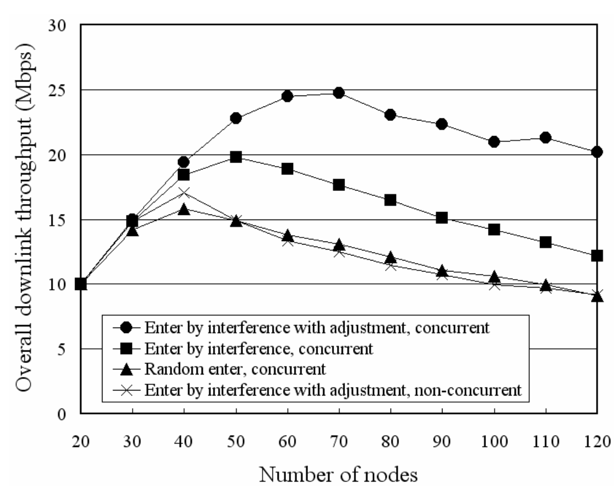

Figure 4. Throughput vs. number of nodes in downlinks

As we can see in the two figures, the overall end-to-end throughput is increased greatly using concurrency, and the routing trees generated by different means impact the throughput. When concurrency is adopted, the throughput with interference-based routing tree is greater than that with random routing tree, and the throughput with adjusted interference-based routing tree is higher than that with non-adjusted interference-based routing tree. Therefore, our concurrency algorithm performs best when using an adjusted and interference-base routing tree.

V. Conclusions

WiMax Mesh networking is a promising technology for wireless broadband access. Much research remains to be done before the maturity of this technology. This paper proposes a concurrent transmission algorithm to promote spatial resource reuse, which increases the overall end-to-end throughput. Simulation results indicate that different constructions of routing tree impact the performance of the concurrent algorithm. However, our research has been carried out under some assumptions such as fixed nodes and no bit errors. With rapid demands of mobility wireless access we need to consider the scenario that SSs are mobile to improve our algorithm.

Acknowledgment

This research was supported in part by National 973 Program (No.2004CB719802). Authors thank all individuals who have contributed to this research either directly or indirectly.

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