A New Approach to Improve the Efficiency of Distributed Scheduling in IEEE 802.16 Mesh Networks

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Abstract— The recent standard for broadband wireless access networks, IEEE 802.16, which resulted in the development of metropolitan area wireless networks, includes two network organization modes: Point to Multi Point and Mesh. The mesh mode provides distributed channel access operations of peering nodes and uses TDMA technique for channel access modulation. According to IEEE 802.16 MAC protocol, there are two scheduling algorithms for assigning TDMA slots to each network node: centralized and distributed. In distributed scheduling algorithm, network nodes have to transmit scheduling message in order to inform other nodes about their transfer schedule. In this paper a new approach is proposed to improve distributed scheduling efficiency in IEEE 802.16 mesh mode, with respect to network condition in every transferring opportunity. For evaluating the proposed algorithm efficiency, several extensive simulations are performed in various network configurations and the most important system parameters which affect the network performance are analyzed.

Index Terms— IEEE 802.16, WiMAX, Wireless Mesh Networks, MAC protocol, Time Division Multiple Access, Distributed scheduling procedure.

I. INTRODUCTION

The IEEE 802.16 standard [1], also known as Worldwide Interoperability for Microwave Access (WiMAX), is a recently developed standard for Broadband Wireless Access (BWA) in fixed and mobile networks. The IEEE 802.16 specifies two different modes of sharing the wireless medium: Point-to-Multipoint (PMP) and mesh. In PMP mode, the network organization operations are performed by a node namely Base Station (BS) that has to coordinate Subscriber Stations (SSs). On the other hand, in mesh mode the SSs can communicate with each other directly. This mode has been designed to be employed as a technology for Wireless Mesh Networks (WMNs) and can accommodate longer distance coverage than the PMP mode by exploiting cooperative packet relaying. The interest in WMN is rapidly increasing due to the growing potential of its recently envisaged applications[1]. In IEEE 802.16 mesh, two different coordination modes are defined: centralized and distributed. In the centralized mode the BS is responsible for defining the schedule of transmissions in the entire network [2]. In the distributed mode transmissions are scheduled in a fully distributed fashion without requiring any interaction with the BS. In this paper the focus is on the distributed mode, which is much more flexible and responsive than the centralized mode, since decisions are taken locally by SSs according to their current traffic load and physical channel status. The bandwidth modulation in IEEE 802.16 mesh mode is based on TDMA in which bandwidth is divided into frames of fixed duration and each frame is partitioned into two subframes: control subframe and data subframe and each subframe is divided into equal size time slots. The number of control slots is ranging from 2 to 16 and data slots’ number is up to 256 depending on the physical layer profile and employed system parameters. Every node who is ready for data transfer, initially, broadcasts bandwidth allocation messages into the control slots. Therefore two types of bandwidth allocation messages are used in this process: Mesh Network Configuration and Mesh Distributed Scheduling message. The latter is used to identify the nodes which are waiting to access control slots. Therewith, the procedure used by nodes to access the control slots and transmit control messages is named the mesh distributed scheduling procedure. The mesh distributed scheduling procedure is a distributed algorithm which provides a collision-free access to control slots.

In Ref. [3] the authors analyzed the performance of the mesh distributed scheduling procedure through a stochastic model. This allowed the estimation of the time interval between two consecutive accesses to the control sub-frame, i.e. the access interval. Then the model is validated through simulation, and can be used to gain insights into the properties of the mesh distributed scheduling procedure, in terms of the mean access interval. However, the model is unable to capture all the details of the mesh scheduling procedure due to its simplifying assumptions, which are nonetheless indispensable to reduce the complexity of the problem so that it can be solved. Afzali et al. [4] have improved scalability problems of stochastic model which were introduced in [3]. Bayer et al. carried out a preliminary investigation of the mesh distributed scheduling procedure through simulation[6]. Wei et al. [7] suggested a load-aware and interference aware scheduling algorithm for IEEE 802.16 mesh mode. Their simulation results
show that the provided schemes effectively improve the network throughput performance in IEEE 802.16 mesh networks and achieve high spectral utilization. Tao et al. [8] proposed 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. Fu et al. [9] used the concept of collision metric to model the interference level and prepared a novel routing algorithm to increase the degree of spatial reuse in wireless mesh networks. Both the scheduling and routing schemes are based on IEEE 802.16 mesh mode. In Ref. [10] a linear programming model for optimum routing and scheduling of flows in a wireless mesh network that include the effect of interference and allow for variable-rate transmissions was propounded. Cicconetti et al. [11] investigated network scalability and tried to minimize the end to end delay problems by means of performance analysis. Due to the importance of an efficient distributed scheduling algorithm in IEEE 802.16 network performance, in this paper a heuristic scheduling algorithm is proposed that can reduce transmission delay. The performance of the mesh distributed scheduling procedure is evaluated, using extensive simulations in a wide variety of scenarios. Our analysis covers some aspects of the mesh distributed scheduling procedure that have not been yet thoroughly addressed in the literature.

The remainder of the paper is organized as follows. In Section II we describe the IEEE 802.16 mesh distributed scheduling procedure in details. The novel approach is discussed in section III. The performance of the new approach of mesh distributed scheduling procedure is analyzed in Section IV, with respect to relevant factors, such as the network topology and system configuration parameters. We conclude the paper in Section V.

II. MESH DISTRIBUTED SCHEDULING PROCEDURE

Hereafter in the mesh distributed scheduling procedure node $x$ is assumed as a generic node of the network which is referred to both BS and SSs. Additionally the common name for mesh BS and SSs in the literature of WMNs is node.

In IEEE 802.16, a logical link is set up between each couple of nodes, so the directly linked nodes are called one-hop neighbors also they called simply neighbors. On the other hand, nodes which have at least one common one-hop neighbor but are not linked directly, are called two-hop or extended neighbors.

As already introduced, the distributed scheduling procedure is applied to coordinate the access to the control slots in a distributed collision-free manner. For this reason a node cannot transmit into a control slot that is reserved by one- or two-hop neighbors which are referred to as competitors of that node. Specifically, each node performs a virtual contention by propagating the control information of its neighbors which is sent during previous control slots. This contention based procedure enforces a strict precedence among competitors. While every node contends until it wins; only one competitor can win and access a specific control slot. The procedure of performing this contention is described in [1] and isn’t the matter of interest in this paper. The major concern in this article is the delay time after which a node contends again since last access to a control slot.

Every node must defer its transmission by a holdoff time, namely $H_x$ (referring to node $x$) in units of time slots. Waiting for a period of $H_x$ guarantees a collision free access to time slots.

As specified by the IEEE 802.16 standard, the holdoff time $H_x$ is calculated as (1):

$$H_x = 2^{4+E_x}. \tag{1}$$

Where $E_x \in [0, 7]$ is a system parameter called $XmtHoldoff Exponent$ which can be configured on a per node basis. Thus, two consecutive slot accesses by the same node are separated by at least 16 slots according to formula (1), when $E_x=0$. The challenge is whether the delay of 16 slots is efficient or not?

III. THE HEURISTIC APPROACH

As mentioned in previous section, when $E_x=0$, a node has to wait for at least 16 slots to access next slot for its transmission. But waiting for 16 slot isn’t efficient, particularly when there is not even one competitor node for using these 16 empty slots. For example consider a typical WiMAX mesh network (Fig.1 section IV.B) that each node has two one-hop neighbors. Therefore, at max, every node can have up to four neighbors and extended neighbors. If we divided sixteen into four, in average we obtain 4 slots per each neighbor for transmission. What happens if some of those nodes do not want to use their opportunity to send any data?

Therefore the standard scheduling mechanism does not perform well and causes a significant delay on data packets. On this point of view, we focus on the constant value 4 and make this value adaptive with the number of competitor nodes i.e. nodes competing to access the same slot.

The basic method of IEEE 802.16 standard for calculating hold off time is obtained from (1). The new approach is computing the logarithm of number of competitor nodes and using the result instead of constant 4 in (1). So the new formula is introduced as follows:

$$H_x = 2^{\log_2(cm+E_x)}. \tag{2}$$

where $cm$ is the number of competing nodes.

By computing the number of competing nodes, it is evaluated that how many nodes want to transmit message(s) in the current competitive slot. So every node that wins the competition, after sending data in regarded slot, has to wait as long as hold off time ($H_x$). This mechanism guarantees the efficient use of channel by reducing idle slots in control subframe. Simulations in the following section show that the adoption of this mechanism reduces the transmission interval. Furthermore the delay on data packets caused by the MAC layer is reduced significantly.
IV. PERFORMANCE EVALUATION

In this section, the settings under which the simulation analysis is carried out and the used performance metrics are defined. Then the performance of the mesh distributed scheduling procedure is evaluated in several scenarios with varied network configurations. The analysis is aimed at identifying the effect of applying this solution in IEEE 802.16 based WMN. The preliminary information on network configuration for evaluation setting is provided in Part A. Specifically, the simulation are run, with the following network topologies: a sparse and narrow network topology i.e. chain in Part B, a complicated and dense network topology i.e. grid-full in Part C.

A. Evaluation Setting

The parameters used in the simulations are compliant with the IEEE 802.16 standard [1]. Specifically, the frame duration is 10 ms and the channel bandwidth is 10 MHz. According to the standard, only one channel is used to transmit control information, thus the use of multiple channels is not considered. Furthermore, the traffic considered is of Voice over IP (VoIP) and Video on Demand (VOD) type; however, they did not have any impact on the transmission in control slots.

We now define the performance indices that have been considered in order to assess the distributed scheduling procedure performance in new approach. First metric is average interval (in slot units) between two consecutive mesh distributed scheduling messages sent by a node. Second one is the average end-to-end one-way delay (in seconds). Third metric is the average number of competitors per slot during virtual contention and the last one is average of end-to-end throughput per flow (in bytes/seconds).

The patch program [12] of coordinated distributed mode of IEEE 802.16 mesh is used in NS2 simulator [13]. The simulation output analysis is carried out using the method of independent replications. Specifically, for each scenario a variable number of independent replications are run. The duration of each simulation run varied depending on how the specific system was configured.

B. Chain

In order to decrease the number of idle slots and improve the network performance, in this scenario a sparse and narrow topology i.e. chain is considered. Fig.1 shows the connections between nodes in chain topology.

![Figure 1. Schematic representation of nodes connection in chain topology](image)

To obtain the network performance parameters, six simulations are run with respectively 4, 9, 16, 25, 36, 49 number of network nodes. To be compatible with grid-full, in chain topology, numbers are selected complete squared. Fig.2 shows the average frame intervals between two consecutive mesh distributed scheduling messages, in basic standard IEEE 802.16 and heuristic method. There is an obvious drop in access interval that is originated by decrement of idle slots with applying proposed method. Additionally, in the heuristic method, the average access interval rises with the number of nodes increasing, while in basic method this metric is almost constant. This implies that the average number of nodes competing to access a certain slot increases while network being more populated.

![Figure 2. Average frame intervals between two consecutive mesh distributed scheduling messages for chain](image)

The comparison of end-to-end one-way delay between the standard and heuristic method is shown in Fig.3. The chart implies that delay increases with the network extension. It can be observed that the proposed algorithm has smaller end-to-end one-way delay as a result of reducing Hold off time and unused control slots.

![Figure 3. Average end-to-end one-way delay for chain](image)

![Figure 4. Average end-to-end throughput for chain](image)
Fig. 4 indicates the average of end-to-end throughput. As expected, the network throughput in proposed algorithm is better than basic standard scheduler. This improved result is due to the fact that nodes can quickly return to the competition state, thus the usage of network free opportunities become more efficient.

C. Grid-Full

Another simulation scenario is using a dense network topology i.e. grid-full as Fig. 5 shows the nodes connection in a schematic way.

In such networks, every node has more than two neighbors that affect the performance of network transmission scheduling. The simulations with grid-full topology are run with respectively 4, 9, 16, 25, 36, 49 number of network nodes. Fig. 6 shows the distinction between average frame intervals in basic IEEE 802.16 standard and heuristic method. It can be seen that the frame intervals become smaller in heuristic method because the nodes can sooner return to competition situation. Additionally, the average access interval growth in grid-full topology is more than in chain. The reason is that the average number of competitors of every node at each slot increases because in grid-full there are more neighbors than chain.

The comparison of end-to-end one-way delay is shown in Fig. 7. As expected, the heuristic algorithm has smaller end-to-end one-way delay, caused by reduction of Hold off time due to decreasing the empty control slots. In other hand in grid-full topology, the value of delay is less than chain topology as number of nodes in the network becomes greater. Because of dense nature of grid-full topology, with the number of nodes increasing the hop distance between nodes do not increase significantly.

The average of end-to-end throughput is indicated in Fig. 8. It can be seen that the network throughput in proposed algorithm has an improvement comparing to the basic standard scheduler. The reason is the same as explained for the chain in part B and This can be explained by a decreased network contention and thus a decreased MSH-DSCH transmission interval.

The remarkable point in two recent charts is optimum values in grid-full topology with 9 nodes. As it can be seen, the lowest delay as well as the highest throughput is obtained in network with 9 nodes. That can be the result of the most efficient use of network resources in this specific situation. Therefore we can say this is the optimum network configuration among studied networks in which the highest value of about 140000 bytes per second of throughput and the least delay of about 0.063 seconds are computed.

V. CONCLUSIONS

For solving the scheduling problems of wireless metropolitan area networks, a new approach in IEEE 802.16 distributed scheduling algorithm in mesh mode is proposed and the method of calculating hold off time between two consecutive channel accesses is improved. Simulations with various network configuration and scenarios show that, applying this solution, inefficient use of channel is effectively decreased. It is observed that the proposed method provides efficient use of network resources and decreases end-to-end delay. Thus, the proposed distributed scheduling method improves the
performance of IEEE 802.16 networks, comparing to the basic standard scheduling. The utilization of IEEE 802.16 scheduler with respect to accumulated network load is considered as future work.

REFERENCES


