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Full Length Research Paper

Link establishment and performance evaluation in IEEE 802.16 wireless mesh networks

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Wireless mesh networks (WMNs) are one of the emerging technologies. Their capability for self-organization significantly reduces the complexity of network deployment and maintenance, and thus, requires minimal upfront investment. These networks consist of simple mesh routers and mesh clients, where mesh routers have minimal mobility and form the backbone of WMNs. They provide network access for both mesh and conventional clients. IEEE 802.16 standard (www.ieee 802.org/16) is a recent standard for broadband wireless access networks, which includes a mesh mode operation for distributed channel access of peering nodes. In accordance with the IEEE 802.16 MAC protocol, time is partitioned into frames of fixed duration, each one divided into two sub-frames, for control and data transmission, respectively. Slots in the control sub-frame are used by nodes to negotiate the schedule of transmissions in data sub-frames, and are accessed by means of a collision-free distributed procedure, namely the mesh election procedure. In this paper, we have analyzed the performance of the mesh election procedure by means of simulations, and identify the system configuration parameters that have the most impact on the performance of control message transmission using distributed scheduling algorithm.

Key words: Mesh, 802.16, distributed scheduling, performance.

INTRODUCTION

The IEEE 802.16 standard (http://WirelessMan.org/) defines the physical and MAC layers for a fixed and mobile Broadband wireless network. IEEE 802.16 operates at 10-66 GHz for Line-Of-Sight (LOS) and 2-11 GHz for non-LOS. Typically, channel bandwidth is 25 MHz or 28 MHz, the data transmission rate is up to 134.4 Mbits/s. An IEEE 802.16 network consists of two types of nodes which are base station (BS) and subscriber station (SS). The BS serves between the IEEE 802.16 network and the external network. The SS acts like a client side terminal through which mobile users can access the network through air interface. The air interface in the license band is WirelessMAN-OFDM. Figure 1 shows the architecture of WMN.

IEEE 802.16 has two transmission nodes, point to multipoint (PMP) mode and mesh node. The main difference between the PMP mode and the mesh mode is the ability of multihop communication in the mesh mode. As shown in Figure 2, while in the mesh mode SSs can directly communicate with each other through multihop communications, the PMP mode requires each SS to be connected to a central BS through single hop communication. Consequently, the mesh mode enables SSs to relay each other's traffic towards the mesh BS, which also connects the SSs to the backhaul network. Furthermore, in the mesh mode there are two types of TDMA-based packet scheduling mechanisms: centralized scheduling and distributed scheduling. In the centralized scheduling, the BS assigns the radio resources for all SSs within a certain hop range. In other words in centralized scheduling, the BS acts like a cluster head and determines how the SS's should be shared in different time slots. As all the packets are not required to go through the BS, the centralized scheduling is relatively simple but setting up is quite complex. This is the reason why centralized scheduling is not used for occasional traffic needs (http://wirelessman.org) On the other hand, in the distributed scheduling, all nodes, including the BS,

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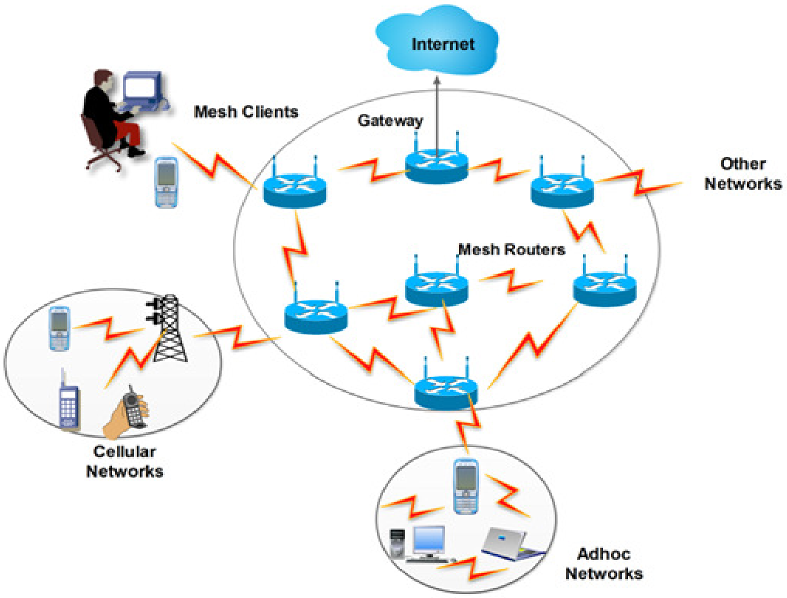
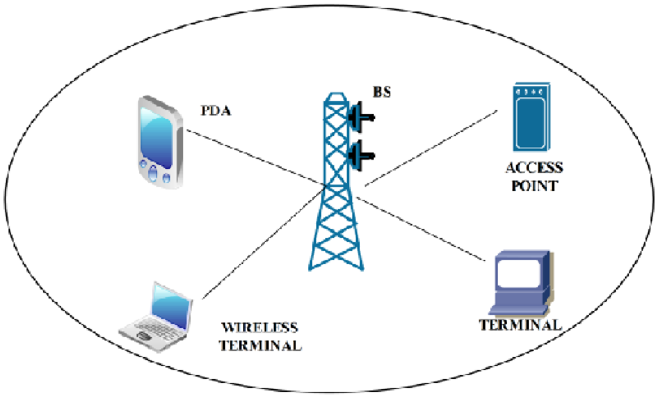
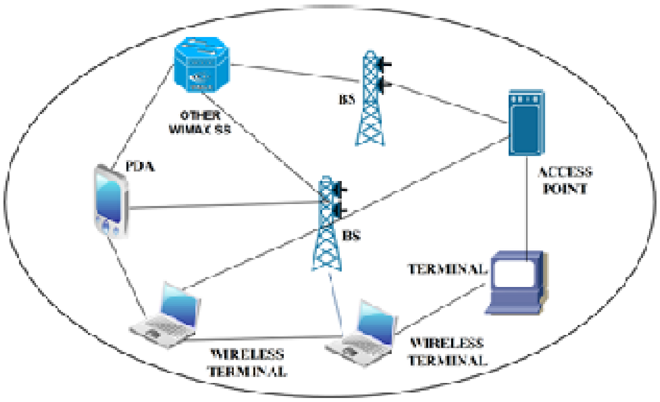


Figure 1. Wireless mesh network architecture.



PMP MODE



MESH MODE

Figure 2. Networking architecture of IEEE 802.16: PMP mode versus mesh mode.

coordinate with each other for accessing the channel. During this coordination, all the nodes broadcast their schedules, that is, available resources, requests, and grants, to all their neighbors within their two-hop neighborhood.

Data sub-frames are allocated on the basis of request grant and confirm three-way handshaking among the nodes. Mesh systems typically use omnidirectional or 360° steerable antennas, but can also be co-located using sector antennas. At the edge of the coverage area of the Mesh network, where only a connection to a single point is needed, even highly directional antennas can be used.

In this paper, we have created a simulation model in opnet for link establishment. We have also done the performance evaluation of the distributed scheduling mechanism in IEEE 801.16 WMNs.

PROBLEM DISCUSSION

In IEEE 802.16 wireless mesh networks, no communication is allowed if it is not previously scheduled. The scheduling mechanisms have been extensively studied by researchers for both wired and wireless networks. They found that the application of these mechanisms for wireless environments is much more challenging than the wired ones due to the intrinsic characteristics of the medium. A good scheduling mechanism should address the channel utilization, end-to-end delay, throughput, QoS support and fairness. The scheduling mechanism is better, the more it utilizes the channel.

The end-to-end delay performance metrics is the protocol capabilities of avoiding collision and exploiting spatial reuse. It defines the protocol efficiency of channel access and achieved fairness. End-to-end delay should be as low as possible for the traffic. Throughput is one of the most widely used performance metrics. If the scheduling algorithms can increase the throughput they are considered better. The scheduling schemes are considered as part of the MAC layer protocols. They should be able to understand the QoS preferences of the upper layers flows, ensuring their specific requirements, such as throughput, packet loss ratio, packet delay and jitter requirements.

Fairness is a good quality of any scheduling mechanism. Fairness property grants access to every user in accordance to previously established rules. Traffic flows, with the same QoS level, should have an equal chance to use the wireless medium, but due to highly loaded situations, internal scheduling polices may lead to unfairness. This is not undesirable and should be avoided as much as possible. Cao et al. (2006) showed that hard fairness approach undermines the possible network capacity. Hard fairness approach is the scheduling of the node even if it is not transmitting.

RELATED WORK

Scheduling is defined as the allocation of limited resources to tasks over time (Attanasio et al., 2006). Scheduling is one of the most important components of an 802.16 mesh network, severely affecting the overall performance of the system. Scheduling problem for 802.16 is defined as a sequence of time slots, where each possible transmission is assigned a time slot such that the transmissions on the same slot are collision free while the QoS requirements are fulfilled efficiently and the total time to calculate the schedule is minimized. In this paper, we have focused on distributed scheduling.

Research in distributed scheduling can be broadly classified into two groups. They are (a) election algorithm based policies (b) Reservation based distributed scheduling (RBDS) policies.

The performance of the election algorithm has been evaluated theoretically as well as by simulation (Cao et al., 2007; Cicconetti et al., 2007). The performance enhancement was tried by dynamically adjusting algorithm parameters (Bayer et al., 2007; Kim et al., 2008; Wang et al., 2008; Zhu et al., 2008). (Hu et al., 2008; Zhang et al., 2006, 2007) have proposed QoS differentiation scheme based on the adjusted election algorithm parameters. An OPNET based simulation model WiMAX-RBDS-Sim for IEEE 802.16 was proposed by Vejarno and Mcnair (2010). They then evaluated it in terms of speed and performance with an increase in number of nodes. (Cicconetti et al., 2007) developed an open source simulation tool in NS2 for IEEE 802.16 PMP support to simulate multi-channel WMN's. A detailed survey on proposed scheduling methods and performance evaluation methods was done by Kas et al. (2010). Lee and Chen (2009) proposed an enhanced election-based transmission timing mechanism to prevent the unexpected collisions of MSH-DSCH messages to gain better performance on time-sensitive traffic.

RBDS policies are based on the future data frames so that no two interfering links are assigned the same data frames. For reduction of scheduling overhead reservations for each link are calculated based on the statistical characteristics of data traffic (Kuran et al., 2008). Other RBDS schemes have been proposed by (Cheng et al., 2006; Kong et al., 2009; Lin et al., 2008).

DISTRIBUTED SCHEDULING MECHANISM

Here, we give a general introduction about IEEE 802.16 distributed scheduling. The IEEE 802.16 mesh frame structure is shown in Figure 3. Every channel is divided into series of frames. A mesh frame can be divided into control and data sub-frames. The control sub-frame is responsible for making control messages for network configuration. It also takes cares of process like bandwidth allocation and management. The data frames are

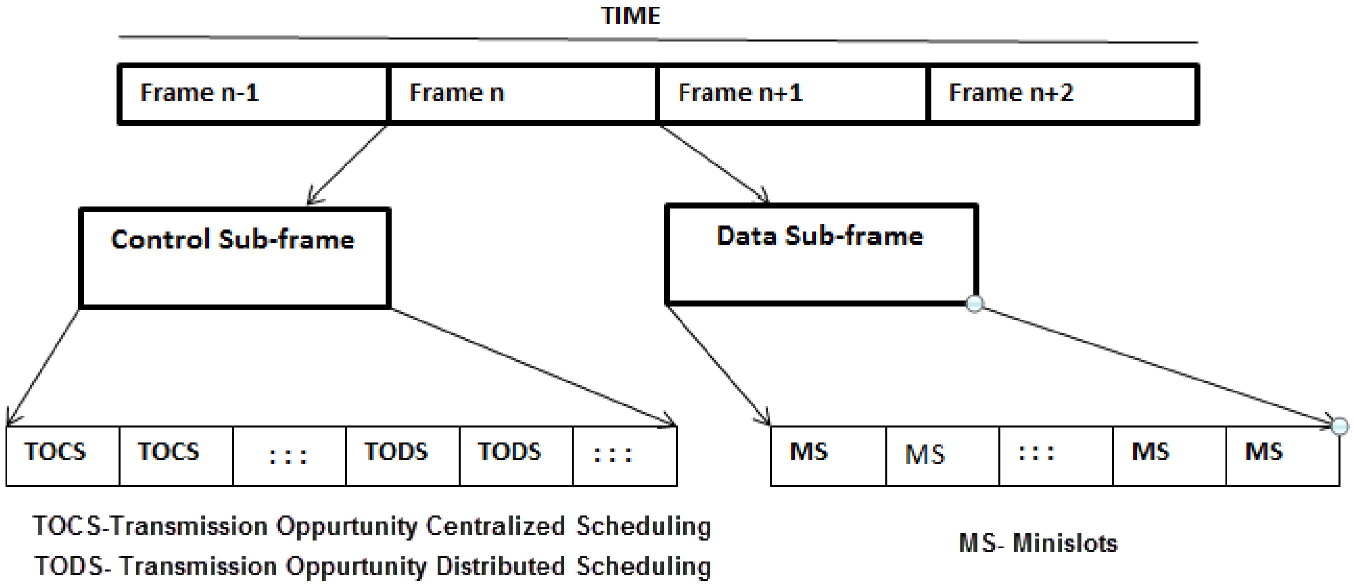


Figure 3. The IEEE 802.16 mesh frame structure.

used for data transmission. The data sub-frame is divided into minislots. In distributed scheduling, each node periodically broadcasts available minislots. The minislots are the basic units of resource allocation.

Distributed scheduling can be classified as coordinated and uncoordinated scheduling mechanisms. In co-ordinated distributed scheduling, all nodes arrange their transmissions through a pseudo-random algorithm so that their messages do not collide with messages from other nodes within their two-hop neighborhood. In uncoordinated scheduling, MSH-DSCH (Mesh distributed schedule) messages may collide and it is less reliable than the coordinated scheduling. There are mainly two phases of distributed scheduling: (1) Election based transmission timing phase (2) Connection setup with neighbors (three-way handshaking)

Election based transmission timing (EBTT) phase

This is a distributed algorithm which is used to manage the control slots' allocation or we can say it is transmission timing of broadcast messages to competing nodes in a collision-free manner in two-hop neighborhood (optionally, 3-hop neighborhood). EBTT is used for the transmission time calculation in coordinated distributed scheduling for the MSH-NCFG (Mesh Network Configuration) and MSH-DSCH messages. MSH-NCFG messages are scheduled in the network control sub frame and MSH-DSCH messages in the schedule control sub frame. In coordinated distributed scheduling the MSH-DSCH messages are scheduled in a free manner, there are no collisions. Every node calculates its Next Xmt_Time (eligibility interval for transmission) during the current transmission time according the distributed election algorithm. In this algorithm one node sets the first transmission slot just after the Xmt_Holdoff_Time (holdoff time of the node) as the temporary next transmission opportunity. In this instant this node shall compete with all the competing nodes in the two-hop neighborhood (this node is called Node A).

There are different types of competing nodes:

(1) Next Xmt_Time includes the temporary transmission slot (Node B).
(2) Earliest subsequence Xmt_Time (equal to Next_Xmt_Time + Xmt_Holdoff_Time) is ≤ the temporary transmission slot (Node C).
(3) The Next Time is not known (Node D).

Xmt_Holdoff_Time is the number of MSHNCFG/MSH-DSCH transmits opportunities after Next Xmt_Time (there are MSH-CTRL-LEN – 1 opportunity per network/schedule control sub frame), that this station is not eligible to transmit MSH-NCFG/MSH-DSCH packets.

$$\text{Xmt\_Holdoff\_Time} = 2^{(\text{Xmt\_HoldoffExponent}+4)} \qquad (1)$$

An election is held among this set of nodes for example, A, B, C and D as shown in Figure 4. The seed for the pseudo-random algorithm selecting one of the eligible nodes as the winner of the slot consists of the combination of the competed slot ID along with the IDs of all competing nodes. Since the seed value is known by all nodes, each node will produce the same result, so that they can all know who the winner is and predict others'

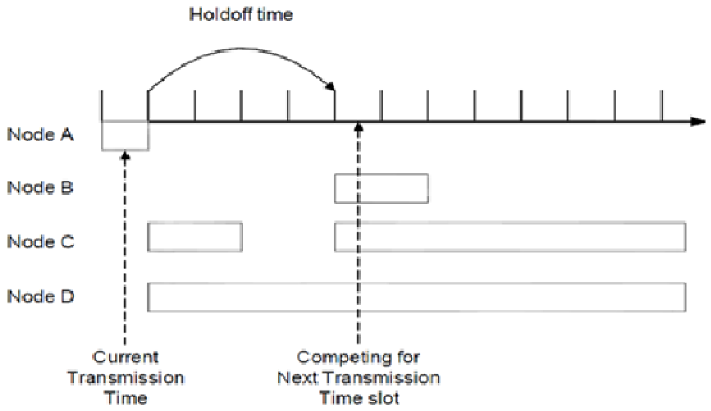


Figure 4. Competing for next transmission slot.

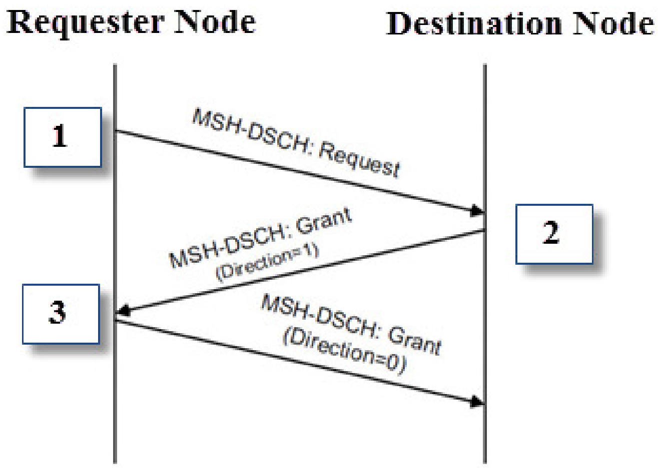


Figure 5. Three-way handshaking procedure.

behavior without explicit message exchange.

When any node wins, it sets the temporary transmission opportunity as its next transmission time and logically it shall communicate this information to all the neighbors by sending the corresponding packet. For example, if node A wins the election, it informs its neighbors to prevent collisions, and then the three-way handshake procedure gets started.

In the case where the node has not won, it chooses the next transmission opportunity and repeat the algorithm as many times as it need to win.

Connection setup with neighbors (three-way handshaking)

Connection setup is a three-way handshake messaging procedure which two nodes perform in order to negotiate upon the data slots prior to exchange data as shown in Figure 5.

Connection setup in distributed scheduling is done in three steps:

Step 1: Request

Before initiating the message exchange procedure, the requester node checks, if the data transmission rate it needs is available using all the free slots it has or not. If it has enough number of slots itself, it sends a request message in the MSH-DSCH packet along with the data sub-frame availability to the destination node that it wants to send data to or receive data from (destination) node. The information in the request message is the link ID, number of requested data slots per data frame and number of data frames requested. If numbers of slots are

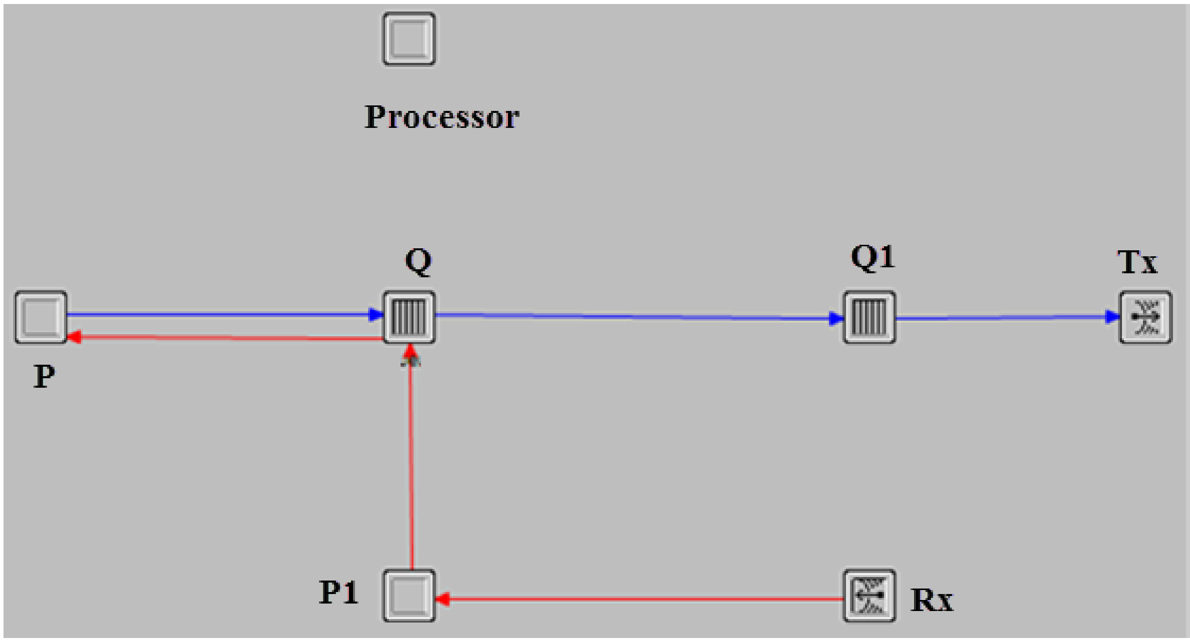


Figure 6. Node model.

not available the requester node quits the connection procedure.

Step 2: Grant

Upon receiving the request message, the receiver node checks the availability of free slots to provide the data transmission rate the requester node requires. The destination node responds with a grant message indicating whether a full or partial request of the requester node can be fulfilled. The grant message contains the IDs of the available minislots which have been selected for transmission. It also contains the listing of the channels of the available slots. If the number of matching slots matches the data transmission rate needed, then the destination node sets the states of these slots as receiving otherwise it quits the connection procedure.

Step 3: Confirmation

When the requester node receives the grant message, it means the framework for distributed scheduling is ready. The requester node sends out a confirmation message to the receiver node in the form of MSH-DSCH message which contains the information of all the slots granted and sets the states of the slots as transmitting.

LINK ESTABLISHMENT

During initialization, every node is assigned an ID randomly. To communicate among nodes, communication links have to be established. This is achieved by the three-way handshaking procedure as shown in Figure 4 with the transmission of MSH-DSCH messages in link establishment packets. Handshaking is initiated by the node with lowest ID. The exponent value determines a node eligible interval and the channel contention. In our simulations, the set of possible exponent values is {0, 1, 2, 3 and 4}.

SIMULATION MODEL AND PERFORMANCE ANALYSIS

We evaluate the performance of our algorithm through simulation study. In the simulated wireless mesh network, 10 mesh nodes are randomly deployed 800 x 800 m^2. OPNET Modeler 16 PL6 was used to build the simulation model. All the operations are done by using OPNET kernel procedures. Figure 6 shows the node model used.

The process P acts as a source and sink which generates data packets randomly and sends to the input queue process (physical neighbor list process). The queue Q calculates the set of 1 hop neighbors and establishes incoming and outgoing links with all the 1 hop neighbors as per the three- way handshaking mechanism discussed previously that is, on arrival of MSH-NCFG. It updates the physical neighbors and BS lists. It puts data packets forwarded by the upper layer in their respective queues.

Once this is done the packets are sent to the transmitter module (Tx). The processor calculates the minislots starting time of the network according to the

Table 1. Simulation parameters.

Parameter	Value
Network scenario	Campus network
Network grid	800 x 800
Number of nodes	5-10
Xmt_Holdoff_Exponent (E)	0-4
Next_Xmt_Mx	2
Max no. of scheduled minislots per frame	16
Data packet generation	Exponential
Xmt_Power	25 mW
Radius interference	0.5
Radius_tx	0.5

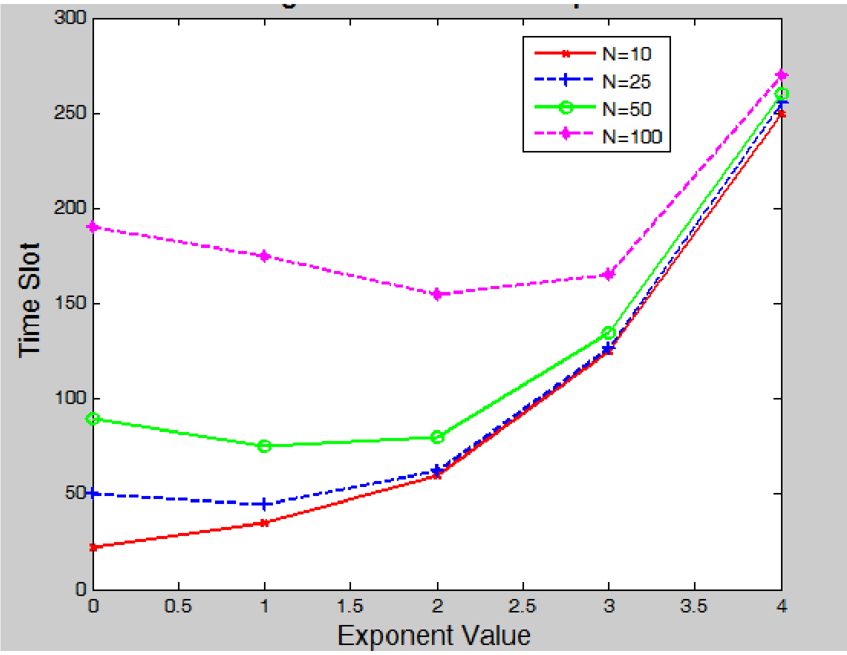


Figure 7. Handshaking time for different exponent value.

simulation parameters and interrupts the physical neighbors list and output queue processes at the start of every minislot. It communicates (minislot number, frame number, minislot type) to the interrupted process. The queue Q1 does the scheduling and configuration of the data packets which were not destroyed in the network. The radio receiver (Rx) receives all the successfully transmitted packets and passes to process P1.

Table 1 defines the simulation parameters. To find an optimum value of exponent E for the three-way handshaking time the number of nodes taken were 10, 25, 50 and 100. The nodes were randomly placed. Simulation was done for different value of exponent {0, 1, 2, 3, and 4}. Figure 7 shows that, with an increase in number of nodes and a larger exponent there is an increase in Holdoff time resulting in larger connection time. From Figure 6, we come to the conclusion that the optimum value of exponent is 3. This is the reason we have taken the value 3 in our simulation.

In Figures 8 and 9 we see that for the first 60 s there was no throughput. This delay is the time required for link establishment between the one hop neighbor's nodes with the three-way handshaking mechanism.

CONCLUSION AND FUTURE WORK

In accordance with recent literature, "the solution to the scheduling problem may enable the provisioning of quality of service at the MAC layer by focusing on certain

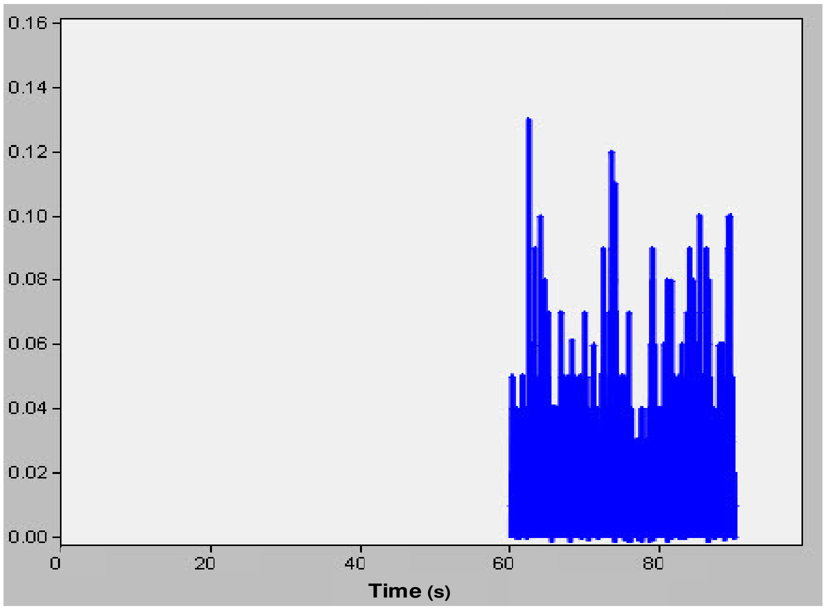


Figure 8. Handshaking delay.

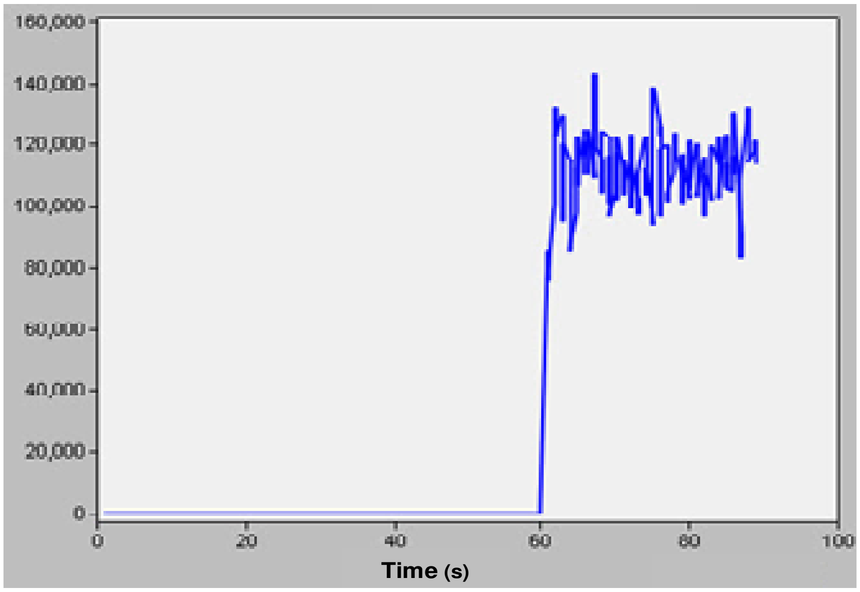


Figure 9. Throughput bits/second.

performance characteristics". In this paper, the performance of IEEE 802.16 with end to end delay and throughput has been evaluated. Here every node competes to get channel access and tries to broadcast its information periodically. The channel bandwidth is dependent on the network topology, number of modes and the Xmt_Holdoff_Exponent (E) value. An effort to show the effect on handshaking time with different Xmt_Holdoff_Exponent value has been done. Going by the simulation results, in our opinion an optimum value of E is 3. Since the standard is still open for different implementations, there are not many results of practical measurements. All the results are obtained from simulations which are not completely reliable. Therefore, it would be interesting to test a real 802.16 mesh network. Thus, the practical data rate and the real coordination among the nodes would be known.

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REFERENCES

Attanasio A, Ghiani G, Grandinetti L, Guerriero F (2006). Auction Algorithms for Decentralized Parallel Machine Scheduling," Parallel Computing, 32(9): 701–709.

Bayer B, Xu B, Rakocevic V, Habermann J (2007). Improving the performance of the distributed scheduler in IEEE 802.16 Mesh Networks. In VTC2007-Spring, pp. 1193-1197.

Cao M, Ma W, Zhang Q, Wang X (2007). Analysis of IEEE802.16 Mesh Mode Scheduler Performance. IEEE Trans. Wireless Communication, 6(4): 1455-1464.

Cao M, Raghunathan V, Kumar PR (2006). A Tractable Algorithm for Fair and Efficient Uplink Scheduling of Multi-hop WiMax Mesh Networks, Proceedings Second IEEE Workshop on Wireless Mesh Networks, pp. 101-108, Sep. 25, 2006, Reston, VA.

Cheng SM, Lin PDW, Yang SR (2006). A study on Distributed/Centralized Scheduling for Wireless Mesh Network. In IWCMC'06, pp. 599-604.

Cicconetti C, Erta A, Lenzini L (2007). Performance Evaluation of the Mesh election Procedure of IEEE 802.16/WiMAX. MSWiM 2007.

Hu H, Zhang Y, Chen HH (2008). An effective QoS Differentiation Scheme for Wireless Mesh Networks, IEEE Network, 22(1): 66-73.

I.W.G. on Broadband Wireless Access Standards, "IEEE working group 802.16 on Broadband Wireless Access Standards web page," http://www.ieee802.org/16/. "IEEE Standard for Local and Metropolitan Area Networks Part 16: Air Interface for Fixed Broadband Wireless Access Systems," IEEE Std. 802.16-2004, pp. 1–895, 2004 http://WirelessMan.org/tga/contrib/C802.16a-02 30r1.pdf

Kas M, Yargicoglu B, Korpeoglu I, Karasan EA (2010). Survey on Scheduling in IEE 802.16 Mesh Mode. IEEE Communications surveys and tutorials, Vol.12 No.2 Second Quarter 2010.

Kim BC, Kwak DG, Lee HS, Ma JS (2008). An Adaptive Hold off Algorithm based on Node State for IEEE 802.16 Mesh Mode with Coordinated Distributed Scheduling in PIMRC'08, pp. 1-5.

Kong PY, Wang H, Ge Y, Ang CW, Pathmasuntharam J, Su W, Zhou MT, Harada H (2009). Distributed, Adaptive Time Slot Allocation for WiMAX Based Maritime Wireless Mesh Networks in WCNC'09.

Kuran MS, Gur G, Tugcu T, Alagoz F (2008). Cross-Layer Routing-scheduling in IEEE 802.16 Mesh Networks. In Mobilware'08, pp. 1-6.

Lee BH, Chen CM (2009). An Enhanced Election-Based Transmission Timing Mechanism in IEEE 802.16 Mesh Networks. ISAP 2009 October 20-23, 2009, Bangkok, Thailand.

Lin HM, Chen WE, Chao HC (2008). A Dynamic Minislot Allocation Scheme Based on IEEE 802.16 Mesh Mode in FGCN'08, pp. 288-293.

Vejarno G, Mcnair J (2010). WiMAX-RBDS-Sim: An OPNET simulation Framework for IEEE 802.16 Mesh Networks, SIMUTools 2010, Torremolinos, Malaga, Spain.

Wang SY, Lin CC, Chu HW, Hsu TW, Fang KH (2008). Improving the Performances of Distributed Coordinated Scheduling in IEEE 802.16 Mesh Networks. IEEE Trans. Vehicular Technol., 57(4): 2531-2547.

Zhang Y, Zheng J, Li W (2007). A simple and effective QoS Differentiation Scheme in IEEE 802.16 WiMAX Mesh Networking. In WCNC'07, pp. 3216-3220.

Zhang Y, Zhou M, Xiao S, Fujise M (2006). An Effective QoS Scheme in WiMAX Mesh Networking for Maritime ITS in Proceedings of the 6th Int. Conf. Telecommunications, pp. 612-616.

Zhu H, Tang Y, Chlamtac I (2008). Unified Collision Free Coordinated Distributed Scheduling (cf-cds) in IEEE 802.16 Mesh Networks. IEEE Trans. Wireless Communication, 7(10): 3889-3903.