Scheduling Algorithms in Wireless Mesh Networks: A Review

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***Abstract* - Wireless Mesh Network (WMN) is considered to be an effective solution to support multimedia services in last miles due to their automatic configuration and low cost deployment. The main feature of WMNs is multi-hope communications which may result in increased region coverage, better robustness and more capacity. Implemented on limited radio range wireless media, WMNs bring about many challenges such as fading alleviation, effective media access control, efficient routing, quality of service provisioning, call admission control and scheduling. In this paper main concepts of scheduling in mesh networks are introduced and its basic techniques in WMNs are reviewed.**

Index Terms – Scheduling, Wireless Mesh Networks, MAC.

I. INTRODUCTION

Scheduling in general means managing access of users to media in such a way that assigned transmissions to similar timeslots would not cause destructive interference [1]. Media access protocols (MAC) in WMNs have substantial differences from their counterparts in classic wireless networks. In WMNs, protocols of MAC layer should be well suited to the special features of WMNs such as multi-hop communications [2]. As in mesh topology there may be no accessible central controller, MAC layer should be able to operate in a distributed fashion so that each network node communicates with all neighbouring nodes. Due to problems like competition and collision, the distributed MAC is much more challenging than centralized one. In WMNs, MAC protocols may be affected by mobility which changes network configuration dynamically. In order to adapt to mobility or even to utilize it, it is necessary for network nodes to exchange network topological data which is crucial for designing a scalable MAC architecture. In WMN, communication channel may include a single-frequency channel or several channels, but most WMNs use multi radio channels for improving network capacity and efficiency. Due to limited bandwidth, it is essential to use complex and sometimes intellectual protocols in MAC for coordination of transmissions from/to routers and clients. At present two basic concepts of MAC protocol for WMNs is under study [4]: *random access protocols* such as CSMA/CA that is present in 802.11 and is not capable to meet needs of carrier classification due to increased delay and packet loss resulted from heavy traffic load in the network. Another one is *coordinated access protocols* such as TDMA that is used in 802.16.

CSMA/CA protocol is beneficial in light traffic load where the stations are allowed to do transmission with insignificant delay. Designed for single-hop WLAN, CSMA/CA based MAC in 802.11 i.e. has not been suited for a multi-hop network. As mesh network draft in 802.11 (802.11s) is under preparation, we will review the literature related to scheduling of mesh networks with a focus on 802.16. In the following section scheduling problem in mesh networks will be defined. In section 3 different kinds of schedulers are introduced and finally, section 4 presents conclusion and future works.

II. SCHEDULING IN WMNS

As mentioned before, scheduling is one of the main issues in maintaining network performance. As the efficiency objectives in MAC layer are throughput and delay, scheduling criteria for wireless networks include: Efficiency, Applicability, QoS support, and Fairness [5]. Although in order to support QoS, differentiate services are preferred in general, however, this is not feasible in mesh network architectures. Therefore, it seems that necessary design for a QoS centric architecture to support appropriate scheduling services within this framework still requires more investigations.

802.16 Standard defines two centralized and distributed scheduling schemes to coordinate using simultaneous mini slots (MSs)in data sub-frames. The centralized scheme in mesh mode is managed by Base Stations (BSs) to form a scheduling tree whose root is BS itself. Centralized scheme applies a 2-way handshaking for source transmission requests to be granted in data sub-frames. Centralized scheduler cannot be used for bandwidth allocation to links that are not present in scheduling tree; therefore, in such cases horizontal links will be overlooked [6 and 7]. In this model, each node

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competes with communicational nodes within its two hop distance to acquire bandwidth.
The distributed scheduling itself is classified to coordinated and non-coordinated categories. The coordinated distributed scheduling schedulers allow mesh nodes to transmit distributed scheduling signaling messages that contain bandwidth requests in control sub-frames, without any collision. In coordinated distributed scheduling, nodes schedule their transmissions with their two adjacent hopes using a three-way handshaking (request, grant and grant confirmation) for reservation of bandwidth in a link. To perform a non-collision scheduling, each node memorises (locally) the positions of MSs based on information obtained from its neighbours. 802.16 standard employs an election distributed algorithm to access to transmission opportunities in control sub-frames so that when a node is in transmission, no other node at least within its two hope neighbourhood attempts to transmit simultaneously. This ensures that neighbors of a node are more likely to be able to receive the transmitted control messages properly.

In non-coordinated distributed scheduling, similar mechanism to that of coordinated distributed scheduler is used with only difference in mesh election algorithm. This difference lies in the fact that handshaking messages transmitted in data sub-frames and in MSs, are reserved for specified links instead of being transmitted in control sub-frames. The framework for request process and allocation of bandwidth by 802.16 standard is defined but exact scheduling rules and the mechanisms as well as resource coordinating methods have not been yet defined [2,6 and 7].

III. Related Works

This section presents a review on the research performed in the area of wireless mesh networks scheduling.

A. Centralized Scheduling Algorithms

In [8] Authors have analysed using centralized scheduling of MAC layer in 802.16 mesh networks. The result of this analysis has led to trade-off between scalability and efficiency. Effect of network configuration parameters on scheduling delay is also studied. In [9] delay in WMNs has been examined and a topology aware scheduler is proposed to reduce delay in delivered packets. But parameters like jitter and packet error rate which are crucial to delay and loss sensitive applications have not been examined. In [10] a QoS aware centralized model has been presented to allocate resources using a tree structure in time frames to reduce processing requirements at the beginning of each frame. [11] has proposed a cross-layer algorithm over network and MAC layers in order to improve efficiency. The proposed centralized scheduling algorithm reduces interference by creating a routing tree in a multi-channel single-transceiver system in WIMAX mesh networks. The selection of the best route for each node is made by creation of routing tree with respect to quantity of offspring of each node, interference from other nodes, the number of packets, node index, traffic load of each node, and the number of hops to result in improved efficiency in terms of decreased scheduling length and operational power.

B. Distributed Scheduling Algorithms

Most of the scheduling models in literature use distributed algorithms. In [12] distributed scheduling for channel access in wireless mesh networks has been treated as a problem of assigning time slots to nodes to guarantee that all nodes are able to communicate with their neighbors within a distance of one hop in allocated time slots. The purpose is to minimize cycle length, i.e. the total number of different temporal slots in a scheduling cycle. Moreover, a greedy algorithm with a different criterion is proposed. The basic idea of this algorithm is organizing collided nodes via a certain criterion like node recognition, node degree, or the number of coincidental neighbours to prevent the adjacent nodes to a high priority node to interfere with its transmissions. In [13] a scheduling and routing algorithm has been proposed with the purpose of providing the minimal end to end delay for traffic flows. Simulation results show that the proposed model reduces traffic flow delays considerably and provides load balancing to some extent. Authors [14] have proposed a call admission protocol to ensure required bandwidth and QoS delay in multi-hop wireless mesh networks using multi-channel multi-radio features along with a distributed link scheduling algorithm for bandwidth allocation with at least one hop delay, as well as a routing criterion for setup of the routes. This model, first schedules temporal slots for allocation of bandwidth of required flows with minimal scheduling delay and then allocates channels to minimize switching overhead. Evaluation results indicate that in order to avoid switching overhead, time slot should be rather large. In [15] to improve operational power, partitioning of mesh network to several sub-networks with high capacity as well as applying simple distributed algorithms is employed. [16] proposes DRAND algorithm which is a distributed, scalable, and resistant implementation of RAND algorithm which is in turn an ad-hoc centralized scheduling algorithm for allocation of time slots based on TDMA. This algorithm is suitable for networks with moderate mobility like mesh and sensor networks. In [17] a fair algorithm for mesh networks has been proposed using OFDMA to maximize NBS fairness criterion. This research instead of solving an overall control problem has separated the problem of power allocation and sub carrier into two sub-problems that can be solved hierarchically by a distributed model. In this model, mesh routers utilize a fairly distributed scheduling algorithm to solve the problem of subcarrier allocation based on limited available information. In [18] Lang et.al have developed a distributed algorithm integrated with rate control and resources allocation (power and subcarrier) in an OFDMA mesh network. This algorithm allows for spatial reuse when two simultaneous transmissions using a single sub carrier impose weak interference to adjacent nodes. Their subcarrier allocation algorithm is based on routing data and contains incorporation of rate and power control as a utility maximizing problem that considers interference of simultaneous transmissions on similar subcarriers. In [19] first, channel aware distributed scheduling has been studied for utilization of MAC/PHY multiplicity in one-hop ad hoc networks, then it has been shown that optimal distributed scheduling algorithms that are channel aware, have threshold based structures and hence can be implemented easily. This has extended for multi-hop networks as well. In [20] the improvement of resource utilization using STDMA has been considered to increase performance of TDMA. STDMA benefits from advantages of nodes spatial distribution and allows nodes that are scattered from each other widely enough, to do simultaneous transmissions. It is also stated that still a lot of unsolved problems related to resource allocation in WMNs have remained including combination of routing with link scheduling based on STDMA, investigation of above mentioned algorithms, and proposition of new algorithms based on multiple-channel or multiple-radio environments. [21] has proposed an algorithm to activate a link that affects route length to increase network capacity. This algorithm has reduced the simultaneous transmissions based on STDMA and has increased network capacity but has overlooked traffic requirements. [22] also has proposed a greedy framework for distributed scheduling that uses an End-to-end QoS aware bandwidth Reservation Protocol (EQRP) to provide QoS in mesh internal flows. The proposed framework offers a comprehensive solution for routing and contact reception control in WIMAX mesh that does not use a singular node for resource management to result in scalability and more robustness against link outages. EQRP preserves a regular list of traversing hops for each destination through learning bandwidth reservation errors, and employs greedy algorithm for bandwidth reservation using information from routers within a distance of two hops. Efficiency of EQRP algorithm has been evaluated to show that for static WIMAX mesh networks, greedy algorithm used by EQRP improves VOIP contacts by 10%. Moreover, this algorithm shows a slight improvement with respect to time delay in contact regulations. However, only CBR traffic generated in static stations has been considered and VBR traffic and mobile stations have not been treated. Wang et.al in [23] have proposed a model that incorporates scheduling and routing, achieving a considerable efficiency. In [24] a model has been proposed in which nodes compete with each other using a semi-random fashion for transmission opportunities based on their neighbours with two hop distances. In this article analytical examination of scheduling efficiency in mesh 802.16 has been performed and scheduler efficiency under different situations has been analyzed quantitatively. Cao et.al, asserted that controlling distributed channel access is very complicated and channel competition depends on total number of nodes, exponent value and network topology. Hence, they studied behavior of distributed schedulers in order to optimize network operational power and delay performance. [1] considers MAC protocols in 802.16 where the focus lies on CDS coordinated distributed scheduling schemes. Also a distributed scheduling scheme (DSS) algorithm is presented and compared with coordinated distributed scheduling (CDS). Their experiments show that values of parameters should be set up with any change in network density and its topological features when CDS model is used. Therefore, a DSS algorithm is proposed which is not dependent on network topology. It is claimed that in DSS there is no need to setup and this model acts 10% better than CDS regarding delivery of packets in different densities. This algorithm reduces the amount of allocated ranges and delay. [4] has studied the problem of resource provisioning for VOIP traffic that needs exact and precise efficiency in terms of delay, jitter and loss. Several algorithms and scheduling models for access control based on TDMA have been analyzed mathematically. Also it has been stated that scheduling based on demand is not able to provide required VOIP quality in a WIMAX mesh network in real environment. Instead, continuous scheduling fits better with VOIP traffic servicing. Thus, an application aware resource coordination method is presented and shown by simulation that it is scalable and provides a good quality for VOIP services. This model is also more resistant against quantity of hops, increased number of simultaneous VOIP sessions, and background traffic load and tends to increase the number of calls. They have found that some parameters like over provisioning (OP) that needs re-transmission due to packet error or high jitter values have been defined as static while they would better be obtained dynamically with respect to channel conditions. This paper only considers continuous resource allocation in each frame while 3-way handshaking messages have been overlooked. Moreover, their investigations have focused on determination and regulation of coordination distributed scheduling parameters like hold-off exponent parameter and period of messages. However, more research is required regarding these parameters and valuable innovations can be presented in this area. For example, hold-off exponent strongly influences IEEE 802.16 performance which has not been investigated yet. [25] emphasized that in distributed non-coordinated operational mode, control messages can be transmitted only within remaining opportunities of coordinated distributed scheduling or unallocated mini slots. So coordinated distributed scheduling better supports QoS compared to non-coordinated distributed scheduling. Authors in [25] have shown with simulations that dynamic hold-off time setup in two phases can guarantee successful primary quantification of network and improve efficiency in MAC layer scheduling. [26] has proposed a new MAC module which works according to queue length, to setup hold-off parameter in CDS dynamically. In another model this dynamic adaptation mechanism is able to improve network efficiency in terms of throughput and end to end average data packet delay. [27] has shown that in real conditions, ratio of control message collisions for distance of 2 and 3 hop neighborhood is 20%

and 7% respectively. To solve the collision problem, the study has show that through proper configuration for hold-off exponent the collision ratio can be decreased and efficiency of scheduling algorithm may be improved. [28] has introduced a model for dynamic setup of hold-off parameter and shown that throughput has improved compared to determination of constant value for this parameter.

Some algorithms have dealt with combination of centralized and distributed algorithms and have tried to propose solutions for scheduling in mesh networks. In [29] two scheduling schemes, one of which is a combination of distributed and centralized called CDC and another one is a combination of distributed and centralized with queue capacity called CDCQ, have been presented in order to allocate the mini slots flexibly and to increase utilization. Results of their simulations show that CDC algorithm increases reception rate of external packets, and decreases probability of loss for external packet requests slightly. But regarding efficiency of internal packets, it has been shown that probability of downfall for internal packets has been bounded with the ratio of number of users around BS to the total number of users in mesh network.

IV. Conclusion and Future Works

WMNs had been viewed as networks that fail to meet multimedia QoS requirements due to using multi hop wireless communications. However a number of investigations have led to solve some WMN drawbacks but still a lot of unsolved problems persist. Mesh network scheduling has also been one of the centres of attention. Some proposed centralized scheduling for inter-mesh flows have been able to provide end to end QoS. But distributed scheduling provides facilities for intra-mesh traffic between client stations. Such a scheduling model does not provide end to end QoS for flows but makes mesh network suitable for situations in which a resistant and scalable ad hoc network is needed. Future research has focused on new techniques for cooperative mesh network using artificial intelligence techniques to improve scheduling models in order to satisfy requirements of future services.

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