Mesh Networks

Communication backbones in PSNs are normally organized as a mesh network. However, Wireless Mesh Networks (WMN) generally require self-organization and topology control algorithms to enable its broad use [6]. Studying this problem, of self organization in Mesh networks, has lead us to the main contribution of this part of the thesis, a topology control algorithm to maintain, in an efficient way, the topology of PSNs. Note that this technique can also be applied in ad hoc networks.

Because the next part of the thesis rely on WMN concepts, before moving on to the proposed topology management algorithm, this Chapter provides an introduction to WMN. We use the IEEE 802.16 standard [2] as an example, which could also be used to organize nodes in PSN. This chapter focuses on the main characteristics of WMN, how the nodes can communicate, using the IEEE 802.16 scheduling, to avoid inter-node interference and the possible types of services that can be provided over a WMN. These aspects are relevant to PSNs since these networks must be stable, predictable and provide QoS.

5.1 Introduction

Wireless Mesh Networks have been attracting a huge amount of attention from both academia and industry in the last few years. Indeed, WMN is now emerging as a promising technology for broadband wireless access [6]

[17]. One of the main reasons for this sudden popularity of WMN is their inclusion in many of the IEEE wireless standards, e.g. IEEE 802.11 [21] and IEEE 802.16 [2]. Specifically for the IEEE 802.16 or WiMAX networks standard, the addition of the mesh mode brought a series of advantages., such as non-Line-of-Sight (NLOS) capability, higher network reliability, scaling, throughput and availability [25].

However, to become really useful and valuable for the applications running on top of them, the WMN must i) provide some level of Quality of Service (QoS), ii) be easy to use and iii) provide network self-organization and topology control [6]. To fulfill this requirement, Radio Resource Management (RRM) techniques play a major role [5]. RRM is the term used to identify a series of strategies and algorithms employed to optimize the use of the radio spectrum and the limited resources of wireless networks. RRM techniques include frequency and/or time channel allocation, transmission power adaptation, access to base stations, handover criteria, modulation schemes, error coding schemes [114]. According to [5] RRM policies, along with the network planning and air interface design, truly determine the QoS network performance at both individual user and network level. Figure 5.1 presents the RRM process. The call admission control procedure is responsible for granting/denying access to the network. The decision of which connections are accepted and which are not, is based on predefined criteria, taking into account the network status and the requirements of new calls. The admitted calls are then controlled by other mechanisms of the RRM, such as the scheduler. The scheduler is the RRM process that decides when to grant bandwidth for the admitted calls.

5.2 Main characteristics

WMNs are normally defined as consisting of two types of nodes: mesh routers and mesh clients [6]. Mesh routers are the nodes in charge of routing messages while mesh clients are the nodes that use the mesh routers' capability to connect to other mesh routers/clients or even other networks through backhauls. Backhauls are special nodes capable of interconnecting the WMN to other networks, such as the Internet. A WMN is dynamically self-organized and self-configured, and the nodes should automatically create and maintain the links among them. In opposition to ad hoc networks, where normally no organization is imposed, WMNs consist of a wireless backbone with mesh routers providing connectivity capabilities to mesh clients. The wireless backbone provides large coverage, connectivity, and robustness in the wire-

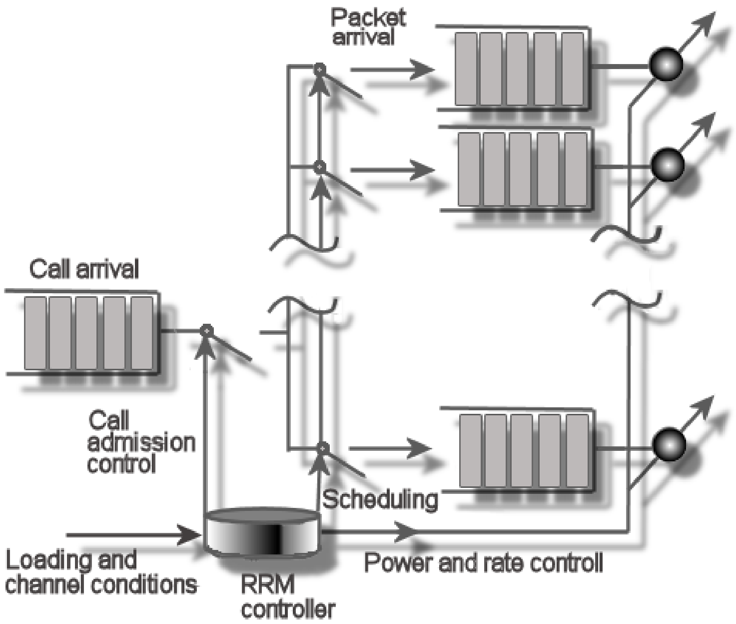

Figure 5.1: The radio resource management model [5]

less domain [6]. Mesh routers usually have minimal mobility, while mesh clients can be stationary or mobile nodes. Another important characteristic of WMNs is their capacity of integrating various existing networks such as Wi-Fi, the Internet, cellular and sensor networks through gateway/bridge functionalities in the mesh routers [6].

In contrast to ad hoc networks, where the connectivity depend on the individual contributions of end-users which may not be reliable, WMNs rely their connectivity on trustable mesh routers with, typically, low mobility and higher capacity. For both, WMNs and ad hoc networks the capacity of the network decreases as the density of the network increases. To minimize this effect a node should only communicate with nearby nodes, and nodes can be organized into clusters interconnected by relay nodes [6].

We need to remember that, in principle, the wireless medium is a broadcast one where, at any time, a number of different stations are accessing the channel concurrently. The main problem with this is that, if concurrent transmissions occur on the same carrier frequency at the same time, this may result in mutual destruction of the transmitted signals. Unfortunately the interference range is greater than the transmission one. The receiver can only decode or sense the message if the Signal-to-Interference-and-Noise-Ratio (SINR) is above some level. For example, in Figure 5.2, node D can have its signal jammed by the signal sent from B to C and may not be able to actually decode the signal. The interference range means that any transmission made from A, which is in the interference range, can damage the signal between B and C. These different ranges can lead to a number of different scenarios, among them the hidden and exposed node problems, common in IEEE 802.11 networks. For WiMAX networks, scheduling and CAC are the techniques used to avoid the interference problems. However, regardless of the claims that WiMAX networks are free from such problems, Zhu and Lu [116] show they can also occur in WiMAX environments.

5.3 WiMAX Mesh Mode Overview

The WiMAX mesh mode, introduced in the standard by the IEEE 802.16a amendment [3], supports two different physical layers: $WirelessMAN-OFDM^{TM}$, operating in a licensed band, and $WirelessHUMAN^{TM}$, operating in an unlicensed band. Both of them use 256 point FFT OFDM TDMA/TDM for channel access and operate in a frequency band below 11GHz.

Even though the standard permits both Time Division Duplex (TDD)

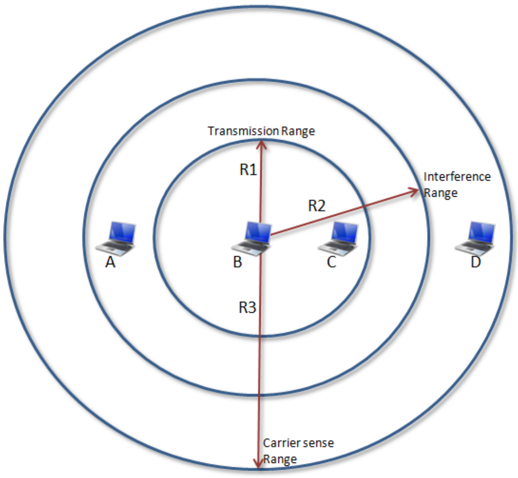

Figure 5.2: Different ranges in the nodes communication

Message Type	Name	Description	Connection Mode
39	MSH-NCFG	Mesh Network Configuration	Broadcast
40	MSH-NENT	Mesh Network Entry	Basic
41	MSH-DSCH	Mesh Network Distributed Schedule	Broadcast
42	MSH-CSCH	Mesh Network Centralized Schedule	Broadcast
43	MSH-CSCF	Mesh Network Centralized Schedule Configuration	Broadcast

Table 5.2: Mesh MAC Management Messages.

and Frequency Division Duplex (FDD) as access schemes, for the mesh mode only the TDD is allowed [2]. This means that the uplink and downlink transmissions share the same frequencies and, doing so, they must occur at different times. However, for IEEE 802.16j, the upcoming part of the standard related to relay networks some people proposed the use of FDD [101].

The Mesh frame is divided into control and data sub-frames. There are two types of control sub-frames: schedule control and network control sub-frame. The network control sub-frame provides basic functionality for network entry and topology management. The schedule control sub-frame controls the transmissions. The scheduling is done by negotiating minislot ranges for the traffic demands of each link. All the communications are done in terms of the links established between nodes. All data transmissions between two nodes are done through one link and the QoS is provisioned over links on a message by message basis. Upper layer protocols are in charge of the traffic classification and flow regulation.

5.3.1 Scheduling policies

In Mesh mode *all* transmissions have to be scheduled: not even the Mesh BS can transmit without having its transmission coordinated with other nodes [2]. To organize the medium access, the standard defines three different scheduling mechanisms: coordinated centralized scheduling, coordinated distributed scheduling and uncoordinated distributed scheduling. These three scheduling policies can be either used alone or together in the same network.

According to some authors the centralized schedule should be used for external traffic and the distributed schedule for intra network traffic [25] [30]. This is due to the fact that the centralized scheduler relies on a mesh BS, which is a backhaul responsible for acting as a gateway between the internal and external network traffic. Table 5.2 presents the messages used by the CAC and scheduling mechanisms in the WiMAX mesh mode.

Centralized scheduling

For Centralized Scheduling, the mesh BS schedules all network transmissions, even the mesh BS ones. The resource request and the mesh BS assignments are both transmitted during the control portion of the frame. The centralized scheduling coordinates the transmissions and ensures that they are all collision-free. Once the BS has the knowledge of the entire network, it is typically more efficient at using the spectrum than the distributed forms.

The MSH-CSCH message has two variants, MSH-CSCH Request and MSH-CSCH grant. With the MSH-CSCH Request each node estimates and reports the level of its own upstream and downstream traffic demand to its parent. This demand comprises also the demands reported by the node's children. With the MSH-CSCH Grant the mesh BS propagates down, through the routing tree, the levels of flows and grants to each node in the network. Fig. 3 shows an example of message flow for the centralized schedule.

All MSH-CSCH Grant messages contain information about all network grants, since all nodes need the complete information for the schedule computation. Upon receiving any message in the current scheduling sequence and assuming that nodes have up-to-date scheduling configuration information, any node is able to compute locally the schedule for all transmissions, including its own. Besides the mesh BS, a node should not transmit any downstream centralized scheduling packet without receiving a MSH-CSCH message from a parent. Also, a node should not send any centralized scheduling packets, if its MSH-CSCF information is outdated. Figure 5.3 presents an schematic example of the message flow in the centralized scheduling scheme.

In terms of eligibility to send and receive MSH-CSCH messages, all nodes are eligible to retransmit the grant schedule, except those with no children. For transmitting MSH-CSCH grant messages, all nodes with children are eligible. For transmitting MSH-CSCH request messages, all nodes, except the mesh BS are eligible.

Distributed scheduling

In both coordinated and uncoordinated distributed scheduling mechanisms, all the stations in the two-hop neighborhood must have their transmissions coordinated to avoid collision. The coordinated distributed scheduling uses the control part of the frame to transmit its own traffic schedule. Both scheduling schemes, centralized and distributed, may coexist at the same time in the same network.

The uncoordinated distributed scheduling is a simpler version of the dis-

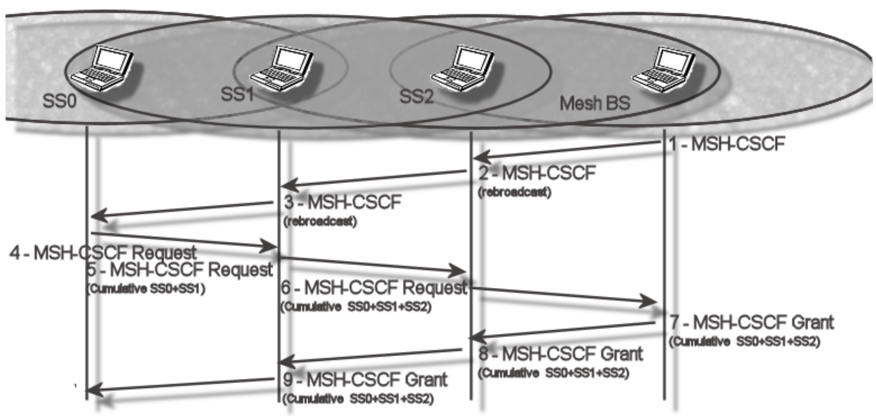

Figure 5.3: A message flow example for the centralized scheduling scheme

tributed scheduler and may be used for fast ad-hoc setup of schedules in a hop-by-hop basis. The uncoordinated schedule is basically an agreement between two nodes and should not cause collision with the data and control traffic scheduled by the coordinated schedules. Both coordinated and uncoordinated distributed scheduling employ a three-way handshake to setup the connection.

The first message in the three-way handshake is a MSH-DSCH request. The transmission is scheduled using a random-access algorithm among the "idle" slots of the current schedule. If the attempt was unsuccessful a random backoff is used to avoid new collisions. Figure 5.4 shows schematically the messages in the distributed schedule three way handshake.

The MSH-DSCH Grant can be issued by any neighbor that hears the MSH-DSCH Request. The grant message contains the list with the subset of the resources awarded. The first granter node may start its grant transmission in the immediately following base-channel idle minislot. More than one granter may also respond to the request.

The requester node sends the same received MSH-DSCH Grant message in confirmation. This ensures the requester's neighbors become aware of the grant awarded. The grant confirmation is then sent in the first available minislots following the minislots reserved for the grant opportunity of the last potential granter.

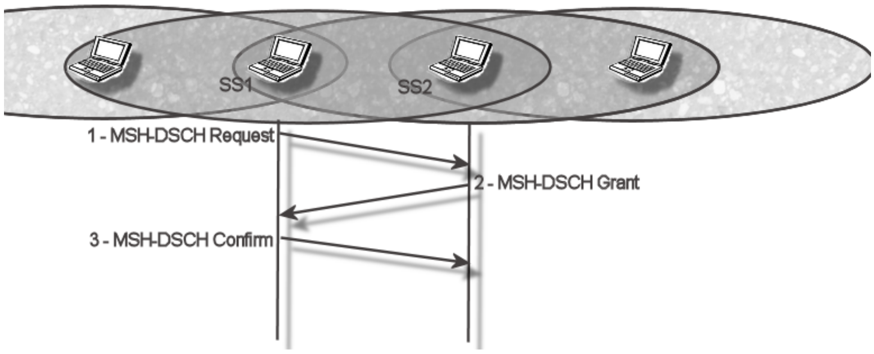

Figure 5.4: Distributed scheduling three way Hand Shake

5.3.2 Network configuration

Two more messages, responsible for creating and maintaining the network configuration, may be transmitted in the network control sub frame: Mesh Network Configuration (MSH-NCFG) and Mesh Network Entry (MSH-NENT).

A new node that wishes to join the mesh network needs to wait until it hears a MSH-NCFG message. When the new node receives this message it is able to synchronize with the mesh network. In reality it should decide which node will be the best sponsor for its communication, so the new node may wait for more than one MSH-NCFG message to arrive. When the sponsor node is chosen, the new node sends through the sponsor a MSH-NENT message to the mesh BS with its registration information. The sponsor node then establishes a quick scheduling, through the uncoordinated scheduler process, and communicates it to the new node. The new node confirms the schedule and sends the required security information. Finally, in the last step, the sponsor node grants the new node access to the network.

5.4 Quality of Service over IEEE 802.16

The IEEE 802.16 standard defines five different scheduling types of services: Unsolicited Grant Service (UGS), Real-time Polling Service (rtPS), Extended Real-time Polling Service (ertPS), Non-real-time Polling Service (nrtPS), and Best Effort (BE). Table 5.4 summarizes the main characteristics of these five types of services.

- Unsolicited Grant Service - UGS: Designed to support real-time data streams where packets are generated at a fixed data rate, for example, VoIP connections without silence suppression. The mandatory QoS parameters for this service are Maximum Sustained Traffic Rate, Maximum Latency, Tolerated Jitter, Uplink Grant Scheduling Type and Request / Transmission Policy. Once the data rate is constant, if present, the Minimum Reserved Traffic Rate parameter should have the same value as the Maximum Sustained Traffic Rate parameter, since the data rate is constant. The grants for this service are issued periodically and without any explicit request. The main advantage of this is that it eliminates the overhead and the latency of the subscriber station, (SS) issuing for new grants for this specific traffic.

- Real-time Polling Service - rtPS: The Real-time Polling Service is designed to support the same kind of traffic that UGS does, but with variable data rate, e.g. MPEG video. The mandatory QoS parameters are Minimum Reserved Traffic Rate, Maximum Sustained Traffic Rate, Maximum Latency, Uplink Grant Scheduling Type and Request/Transmission Policy. Differently of the UGS flow, this service offers periodic unicast request opportunities for the SS to adjust the size of its grants.

- Extended Real-time Polling Service - ertPS: The extended rtPS service, introduced at a later stage into the standard [1], is a service based on both UGS and rtPS. For ertPS the flow has some amount of resources reserved in an unsolicited grant way, but the allocation may change if the SS requests it. In other words, the allocation is dynamic and depends on the needs of the SS, but once set, it works in a similar way as the UGS type. The key service information elements are the Maximum Sustained Traffic Rate, Minimum Reserved Traffic Rate, Maximum Latency and Request/Transmission Policy. The extended rtPS is designed to support real-time service flows that generate variable size data packets on a periodic basis, such as Voice over IP services with silence suppression.

- Non-real-time Polling Service - nrtPS: The nrtPS is designed to support delay-tolerant data streams consisting of variable-sized data packets that require variable data grant on regular basis. FTP (File Transfer Protocol) is an example of application that could use this kind of service. The mandatory QoS parameters for this scheduling service are Minimum Reserved Traffic Rate, Maximum Sustained Traffic Rate, Traffic Priority, Uplink Grant Scheduling Type and Request/Transmission Policy. The advantage of this kind of service is that it can support data streams even in very saturated network conditions. The mesh BS provides SS the opportunity to request bandwidth using unicast and contention period. In addition, piggyback request opportunities are also available.

- Best Effort Service - BE: Best Effort service is intended to be used for any other kind of traffic that does not have any significant QoS requirements and that can be handled on a space-available basis, e.g. http and e-mail traffic. The mandatory QoS service flow parameters for this scheduling service are Maximum Sustained Traffic Rate, Traffic Priority and Request/Transmission Policy.

Characteristic ———— Scheduling type	Max Sustained Traffic Rate	Min Reserved Traffic Rate	Max Latency	Tolered Jitter	Traffic Priority	Req./ Transm. Policy	Piggy Back Request	Bandw. Stealing
UGS	M	O	M	M	X	M	NA	NA
rtPS	M	M	M	O	M	M	A	A
ertPS	M	M	M	M	M	M	A	NA
nrtPS	M	M	X	X	M	M	A	A
BE	M	X	X	X	M	M	A	A

M - Mandatory, O - Optional, X - Not Available, A - Allowed, NA - Not Allowed

Table 5.4: WiMAX services and their main parameters and characteristics.

5.5 Further reading

For future reading, among many other related works, we may highlight the survey presented by Kuran and Tugcu [69] in general dealing with emerging broadband wireless technologies. For a general survey of mesh networks the Alkydiz et al. work [6] presents a good overview of many aspects of the mesh networks, discussing how these aspects affect the entire network stack. The problem of CAC mechanisms in general is discussed in [5]. A broad view of the problem of distributed medium access control for mesh networks can be found in [31]. Zhao presents a consistent view of the problem of distributed coordination in mesh networks in [115]. For a deeper discussion, more specifically for 802.16 mesh networks centralized scheduling algorithms, see [39]. In [89] Redana and Lott present an analysis of the overhead caused by the control messages on the IEEE 802.16 mesh mode and show that, for multihop networks, the centralized approach have a better performance than the distributed one. For an analysis of the times involving the phases of the distributed scheduler mode see [23] and [24].