Chapter 3

A Mobile WiMAX Mesh Network with Routing Techniques and Quality of Service Mechanisms

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Additional information is available at the end of the chapter

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1. Introduction

The constant evolution of technologies for future wireless networks, along with the demand for new multimedia applications (voice, video,...) have led to the creation of new technologies for wireless communications. This is becoming one of the main challenges for this second decade of the third millennium, where new communications technologies must be sensitive to the need for bandwidth with high speed access, broadband in large coverage areas and the provision of services to an increasing number of users to ensure the next generation networks support for the content of new multimedia applications. Moreover, new technologies are an effective way of reducing physical barriers to the transmission of knowledge and transaction costs over fixed networks [1] [2]. Along with the creation of these wireless technologies, one of the current operating modes that is emerging is the mesh mode.

WMNs (Wireless Mesh Networks) are a special kind of MANET (Mobile Ad Hoc Network) and this research started out from the study and development of the MANETs. Compared with traditional networks, WMNs have many useful characteristics and peculiarities, such as dynamic self-organization, self-configuring, self-healing, high scalability and reliable services and are able to balance traffic and provide support to drop connections to fixed or mobile clients. In this way, it can prevent the decline of its services and avoid problems with flows where there is a need for bandwidth and high rates that are constantly required. This is achieved through a reconfiguration that always seeks the best alternative path to a better distribution of network traffic. Currently, many standard groups are improving the specifications of mesh networks from IEEE 802.11s to Wi-Fi (Wireless Fidelity), IEEE 802.15.4 to

Bluetooth and IEEE 802.16j to WiMAX (Worldwide Interoperability for Microwave Access) to multi-hop relay that will be the subject under study in this chapter.

The mobile WiMAX (Figure 1) is a technology based on IEEE 802.16 standard [3] developed as a feasible and attractive solution to these problems. It provides access to wireless broadband, especially an enabling context-sensitive network for the FI (Future Internet) with new multi-media applications, connectivity services for handover scenarios, long distances reaching the last mile, mobility management and mechanisms that improve communications with support for bandwidth and throughput metrics. These influence the network QoS (Quality of Service) with a certain level of end-to-end quality for multimedia applications through the management of layer 2 (Link Layer / MAC) and layer 3 (Network Layer / IP) for the provision of better services that give support to multimedia applications such as video stream and VoIP (Voice over Internet Protocol) that require real-time data delivery [4] [5].

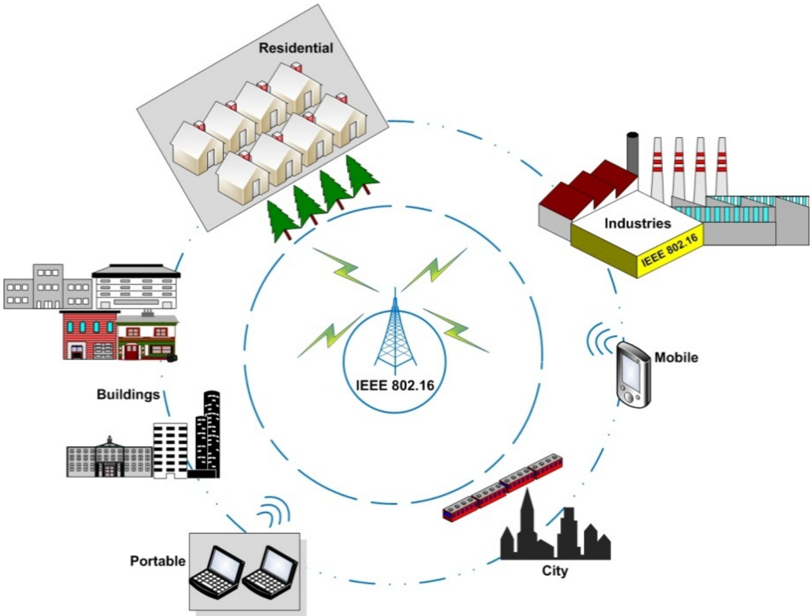

Figure 1. IEEE 802.16 / WiMAX network architecture

However, it is not clear enough how far the behavior of the WiMAX mesh network can support real-time services such as video streaming and VoIP, especially in mesh operation mode. Thus, this study provides an analysis of this question by analyzing network performance measurements through the properties of an IEEE 802.16 mesh network in several real-time applications. The chapter helps investigate the influence of routing protocols and the benefits of QoS to the network, as well as measurements for clients in a WiMAX wireless mesh environment, by showing their impact on flows and the final quality of multimedia applications.

QoS metrics, known as the rate of packet loss, delay and throughput, are generally used to measure the impact of multimedia streams on the level of quality of service, viewed from the perspective of the network, but do not reflect the user experience or the quality. As a result, these QoS parameters do not reflect subjective factors associated with human perception. In order to overcome the limitations of the existing schemes to guarantee QoS in networks with multimedia streaming that take account objective and subjective factors, the tests also address the impact of QoS and routing protocols on final quality through the QoE (Quality of Experience) concepts. This is carried out by addressing the user's perspective as the end-to-end quality of the video stream, by studying, evaluating and validating the results of QoS and QoE incidents on the routing metrics [6].

This chapter will provide an overview of the main challenges of the WiMAX mesh mode with a focus on routing protocols and the effect of quality of service mechanisms on scenarios with mobile clients. The chapter will describe the importance of mesh networks and how they can provide quality service and quality of experience for customers. It will also explain the impact of multimedia applications on this network and the importance of choosing the best route to ensure the network provides higher quality communications.

This section has provided a brief introduction to the main aims of this chapter. The second section will describe the mesh networks and explain their topology and operations. The third section will examine the QoS in WiMAX mesh networks. The fourth section will focus on routing protocols and draw attention to their main advantages and disadvantages. The fifth section will show the results of simulation tests obtained from analyzing the routing protocols with QoS and QoE. The sixth section explains the significance of the findings and conclusions, and this is followed by the seventh section with the main references.

2. WiMAX mesh network architecture

Wireless mesh operation mode is one of the most effective network branches among the emerging technologies. This network can connect multiple wireless access points (known as nodes) and form a mesh network, which is a network of connections that provides broad coverage and enables multiple paths and routes of communication. It is able to balance the traffic load and provide support for fault tolerance, so that if a node goes down, the network can self-configure and self-heal to find alternative routes of access [7].

WMNs can be seen as one type of MANETs [8]. An ad-hoc network (possibly mobile) is a set of network devices that want to communicate, but have no fixed infrastructure available and no pre-determined pattern of available communication links. The individual nodes of the network are responsible for a dynamic discovery of the other nodes that can communicate directly with them, i.e. what are their neighbors (forming a multi-hop network). Ad-hoc networks are chosen so that they can be used in situations where the infrastructure is not available or unreliable, or even in emergency situations. A mesh network is composed of multiple nodes / routers, which starts to behave like a single large network, enabling the client to connect to any of them. In this way it is possible to transmit messages from one node to another in different ways. Mesh type networks have the advantage of being low cost, easy to deploy and reasonably fault tolerant.

In another analogy, a wireless mesh network can be regarded as a set of antennas, which are spaced a certain distance from each other so that each covers a portion or area of a goal or region. A first antenna covers an area, the second antenna covers a continuous area after the first and so on, as if it were a tissue cell, or a spider web that interconnects various points and wireless clients. What is inside these cells and covers the span of the antennas, can take advantage of the network services, provided that the client has a wireless card with the interface technology.

Mesh networks are networks with a dynamic topology that show a variable and constant change with growth or decline, and consist of nodes whose communication at the physical level occurs through variants of the IEEE 802.11 and IEEE 802.16 standard, and whose routing is dynamic. The image below (Figure 2) shows an example of a mesh network. In mesh networks, the access point / base stations area is usually fixed.

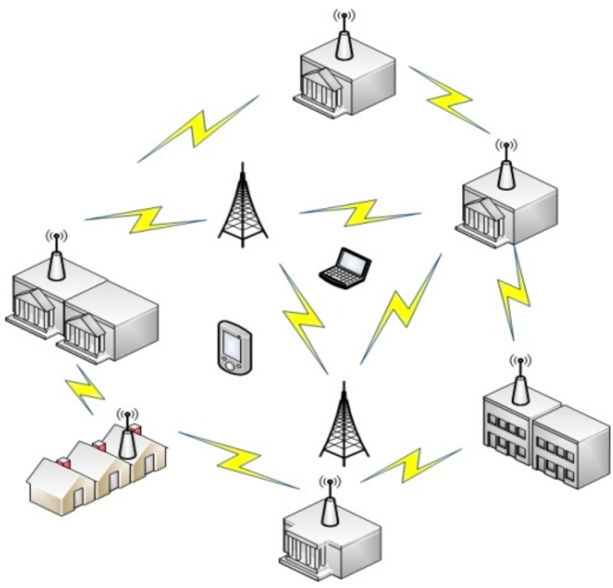

Figure 2. Mesh network

To achieve these goals, WiMAX networks can be structured into two operating modes: PMP (Point-to-Multipoint) and mesh networks, and the second is the focus of this chapter. Mesh mode is a type of operation that can interconnect multiple mobile clients together with many WiMAX base stations (nodes) and form a network of connections so as to provide a wide coverage area for mobile clients. All the clients can communicate with each other and there is no need for an intermediate node to act as the mediator of the network. In this mode, the IEEE

802.16 can provide broadband access with wireless support both single-hop and multi-hop settings [2].

The basic topology of an IEEE 802.16 mesh network consists of two participating entities, called Base Station (BS) and Subscriber Station (SS), displayed below (Figure 3). The BS is the central node, responsible for coordinating all the communication and providing connectivity to the client stations (fixed or mobile).

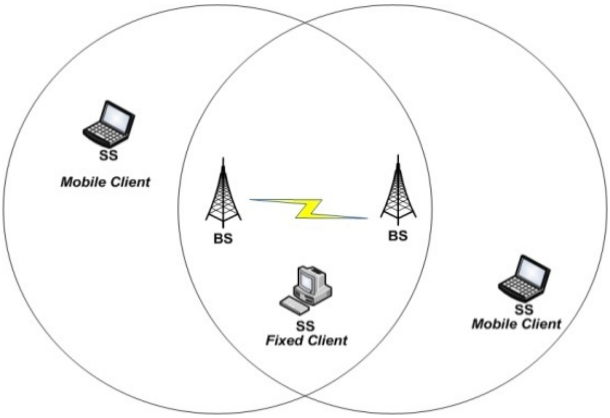

Figure 3. Basic topology of a WiMAX network network

Mesh networks reverse the idea of using a wired network to the backbone network and wireless access in the last mile. The backbone of a wireless mesh network comprises the router nodes that interconnect with the customers. As the nodes in the backbone network of this type have a fixed location and only the clients can be mobile, they may readily be fed, since they have no limiting power, and thus can rid themselves of many of the constraints of ad-hoc networks.

2.1. Operation

The most effective way to discover the operation of the mesh network is the routing protocol, which scans the different possible routes / paths of data flow, on the basis of a pivot table where devices such as BS select the most efficient route to follow to reach a goal, while taking into account that the greater the speed, the packet loss, or the faster the access to the Internet (and others). This scan is carried out several times per second and is transparent to the user, even when it occurs at re-routing access gateways, which are the nodes that have direct access to the internet.

An important feature of mesh networks is the concept of roaming, also known as a transparent handoff mobility scheme offering fast handoff in wireless networks. This makes it feasible for users to become mobile clients who can move around between network nodes without losing the connection at the time of exchange. The practical consequence is that the system allows geographical mobility. The system will always know which jumps are required for the request of a customer at any point in the network so that it can reach the Internet in the most efficient manner possible.

2.2. Challenges and problems

The growing interest in multimedia applications in mesh networks is accompanied by challenges that make the provision of QoS and group communication (multicasting) a more complex task. This complexity is the result, among other factors such as high mobility of the stations, which implies that there is a need to manage their locations and the environment and cope with the limitations of the devices involved, such as transmission quality in a wireless environment, bandwidth scarcity, etc.

Mesh networks have good prospects of being the solution to a series of problems in the provision of access services, since they are flexible, dynamic and potentially low cost [9]. However, for this to become effective there is much that needs to be improved and developed.

Besides routing, the major problems in mesh networks are scalability and security. The first can be defined as the level of acceptable service packages in the presence of a large number of nodes in the network. An important factor is the potential reduction in performance when there are an increased number of nodes. Hence, any protocol layers involved should be scalable. The security schemes proposed for ad hoc networks can be adopted for mesh networks, although most of these solutions have not been studied in depth and there are still problems that prevent them from providing authentication and reliability to clients.

Today the provision of QoS to any network is mandatory. When the mesh networks follow these steps, with the growth of multimedia applications, the services often seek a guaranteed bandwidth and QoS requirements, as a result of the growth of multimedia applications [2] [10]. In addition, they know that choosing the best path routing is an important decision for the WMNs to enable them to provide a wide range of services to different client types, each with their own peculiar characteristics. Provisioning QoS in mesh networks is not devoted to a single task layer. It requires the joint effort of all the layers, and specific strategies for signaling quality of service using resource reservation and QoS for the data link layer.

Owing to this and a number of other problems, when compared with other wireless network models, the mesh networks pose a special challenge, because the wireless environment is shared by adjacent nodes and the topology may change dynamically in the same way as the mobility of the nodes and input / output in the same network. As a result, QoS has become a key area of research of comparable importance to algorithms.

3. Quality of service in WiMAX networks

WiMAX has been developed with QoS in mind. Five different service classes have been introduced for different applications and packets from different service classes and are being handled on the basis of their QoS constraints. However, this mechanism can only be used in the PMP (Point-to-Multipoint) mode. In the Mesh mode, QoS is maintained on a message-by-message basis.

In PMP mode, the WiMAX MAC layer uses a scheduling service to deliver and handle SDUs (Service Data Units) and MAC PDUs (Protocol Data Units) with different QoS requirements. A scheduling service uniquely determines the mechanism the network uses to allocate UL (UpLink) and DL (DownLink) transmission opportunities for the PDUs. WiMAX defines five scheduling services:

1. Unsolicited grant service (UGS): This is designed for the real-time constant bit rate (CBR) applications such as T1/E1 and VoIP. Unsolicited data grants are allocated to eliminate the overhead and latency of the request/grant process. During the connection establishment phase, maximum sustained traffic rate is declared and BS assigns fixed bandwidth grants in each frame accordingly.

2. Real-time polling service (rtPS): This is designed to support real-time services that generate variable-size data packets on a periodic basis, such as MPEG (Motion Pictures Experts Group) video. In this scheduling service, the BS provides unicast polling opportunities for the MS to request bandwidth. The unicast polling opportunities are frequent enough to ensure that latency requirements of real-time services are met.

3. Extended real-time polling service (ertPS): This scheduling service combines features from UGS and rtPS service classes. An initial ensured bandwidth allocation is carried out as in UGS and then this allocated bandwidth can be decreased or increased as in the case of rtPS.

4. Non-real-time polling service (nrtPS): This scheduling service is the most appropriate for the delay tolerant applications. As in rtPS, dedicated periodic slots are used for the bandwidth request opportunity, but with much longer periods. In nrtPS, it is allowable to have unicast polling opportunities, but the average duration between two such opportunities is in the order of a few seconds, which is large compared to rtPS. All the MSs belonging to the group can also request resources during the contention-based polling opportunity, which can often result in collisions and additional attempts.

5. Best effort (BE): This provides very little QoS support and is applicable only for services that do not have strict QoS requirements. It is for the traffic with no minimum level of service requirements. Like in nrtPS, contention slots are used for bandwidth request opportunities as long as there is space available [1] [2].

Classifiers are also present in the MAC layer of both the Base Station and Subscriber Station, whose goal is classify and map service flow into a particular connection for transmission between the MAC peers. The mapping process associates a data packet with a connection, which also creates a link with the service flow characteristics of this connection [11].

In this architecture there are schedulers in both the Base Station (BS) and Subscriber Station (SS), whose goal is to determine the burst profile and the transmission periods for each connection, while taking into account the QoS parameters associated with the service flow, the bandwidth requirements of the subscriber stations and the parameters for coding and modulation. Figure 4 illustrates the WiMAX QoS Architecture in PMP mode.

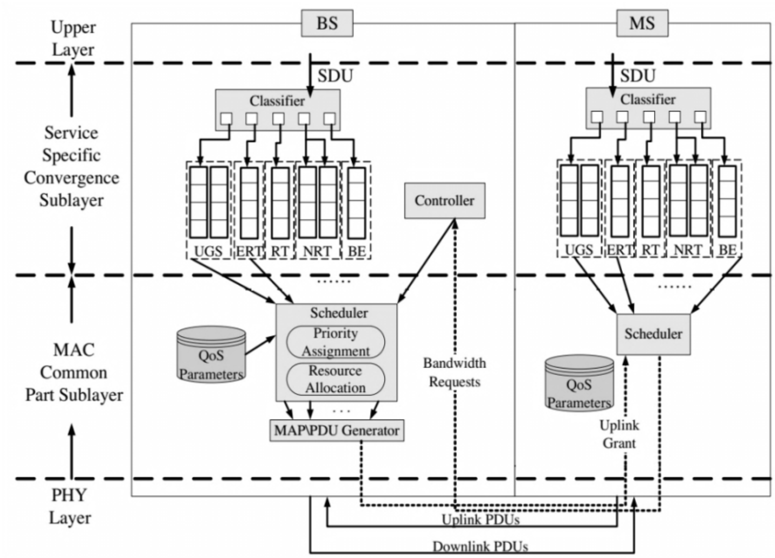

Figure 4. Architecture for IEEE 802.16 QoS

3.1. QoS in WiMAX networks in mesh mode

In a WiMAX mesh network, a "Mesh BS" (MBS – mesh base station) provides the external backhaul link. The backhaul links connect the WiMAX network to other communication networks. There may be multiple Mesh BSs in a network; other nodes are known as ''Mesh SSs" (MSS – mesh subscriber stations). In point-to-multipoint mode, the SSs are under the direct control of the BS. In Mesh mode, the uplink and downlink is not clearly separated and SSs can communicate with each other without communicating with the BS.

3.1.1. IEEE 802.16 mesh frame

In the mesh mode, bidirectional links can be established between any of the WiMAX nodes, and the information is transmitted on a hop-by-hop basis. The system access follows a frame-based approach where each channel is divided in time into a series of frames. The number of frames in a series is defined during process of creating the network..

A frame is divided into two subframes: a control subframe and data subframe (Figure 5). The control subframes are used for carrying the information necessary for access control systems, bandwidth allocations, connection establishment and connection maintenance. The data subframes are used for carrying the packets of upper layers. The control subframe is divided into a number of transmission opportunities. The data subframe is similarly divided into a number of minislots.

There are two types of control subframes depending on their function. The first type of control subframe is the scheduling subframe in which nodes transmit scheduling messages. The second is the network configuration subframe in which nodes broadcast network configuration packets containing topology information, network provisioning information, and network management messages.

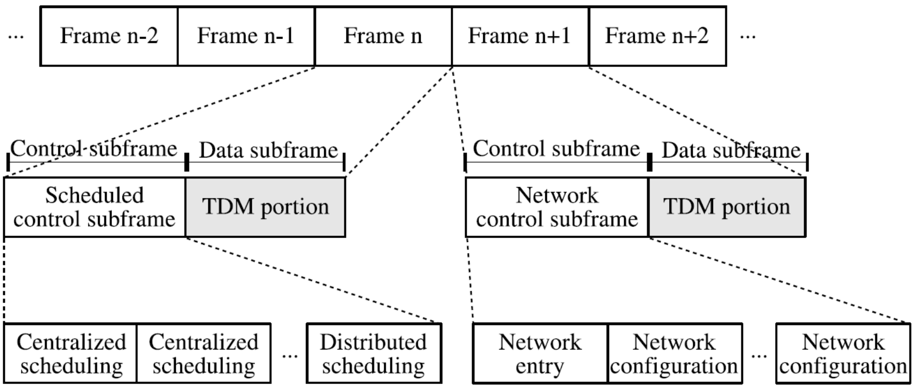

Figure 5. Mesh frame structure

The IEEE 802.16 mesh standard uses a combination of a 16-bit mesh node identifier (node ID) and a 16-bit connection identifier (CID) to identify the source and destination of every transmission. The CID in mesh mode is a combination of an 8-bit link ID and an 8-bit QoS description for the connection. All the communications occur in the context of a link, which is established between two nodes. One link will be used for all the data transmissions between two nodes. QoS is provisioned over links on a message-by-message basis. No services or QoS parameter are associated with a link, but each unicast message has service parameters in the header. Figure 6 shows the Mesh connection identifier (CID) construction which contains these service parameter fields.

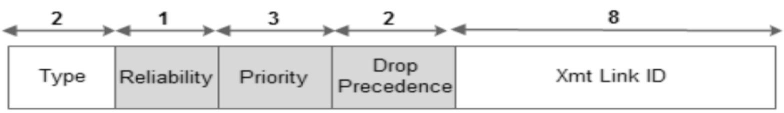

Figure 6. QoS bits in the mesh CID

The 8-bit QoS in the CID contains three definable fields: Reliability, Priority/Class, and Drop Precedence. Reliability refers to retransmit or not (0 indicates no retransmit while 1 indicates retransmit). Priority/Class refers to the priority of the packet. Drop Precedence refers to the probability of dropping the packet when congestion occurs [12] [13].

3.1.2. Default mesh QoS mechanism

In the mesh mode, a special MAC is defined in the IEEE 802.16, which provides two different types of scheduling mechanisms – centralized and distributed scheduling.

Centralized Scheduling (Mesh CS): the Mesh-BS is responsible for supplying resources for each link in response to resource requests. Mesh centralized scheduling messages transmitted in a scheduled control subframe are used for this purpose.

In centralized scheduling, when a node has packets to send to either other MSS or the MBS, it sends a request packet in the control subframe, using the Mesh Centralized Scheduling Message (MSH-CSCH message) to the MBS. The node sends one bandwidth request for each link it has and all requests belonging to that node are sent in one MSH-CSCH message. After receiving requests from all the MSSs in the network, the MBS applies its traffic scheduler to these requests, including its own traffic requests.

Based on the scheduler used in the MBS, these requests are granted, either wholly or partially. Then the MBS broadcasts these grants in a MSH-CSCH message. A grant packet describes the data subframe usage of a frame. This data subframe description belongs to a frame after the frame from which the grant is sent. Each MSS forwards this grant message to its children. However, these requests and grants only include the amount of data that a node can transmit [14]. Figure 7 illustrates how it works in mesh mode.

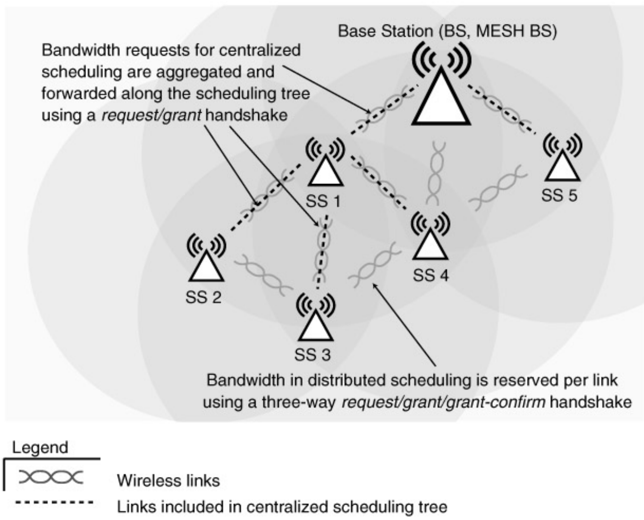

Figure 7. Overview of scheduling in the mesh mode

Distributed Scheduling (Mesh DS): The neighboring Mesh SS responds to a request with a corresponding grant for a link between two Mesh SSs. Mesh distributed scheduling messages are exchanged to perform this operation.

The scheduling policy for accessing data slots in coordinated distributed fashion, is not specified in the IEEE 802.16 standard. The standard only defines the Mesh Distributed Scheduling Message (MSH-DSCH message), and specifies the scheduling to avoid collisions between messages of different nodes. The MSH-DSCH message contains the scheduling information organized in Information Elements (IE): Request IE, Availability IE, Grant IE and Scheduling IE.

The scheduling procedure follows a three-way handshake to reserve the minislots. First, a node sends an MSH-DSCH message to one of its 1-hop neighbors, requesting a set of data slots. In the message, the node also includes the set of data slots that it has available for reservation. The 1-hop neighbor grants the request by replying with another MSH-DSCH message that specifies a set of data slots that confirms the availability of data slots at both nodes. Finally, the first node confirms the reservation of this set of data slots by repeating the grant in another MSH-DSCH message.

In contrast with point-to-multipoint WiMAX networks, the standard does not define scheduling services for Mesh WiMAX networks [13].

4. Routing protocols in wireless mesh networks

Currently, one of the main areas of mesh networks that is being studied, is the routing protocol used to find the best path to the base stations (or access points). This allows customers who use this type of technology to take advantage of their services in a more effective way and with efficient communication, as well as transferring their data stream through the wireless communication environment [15]. Routing is a service in which the router evaluates the possible paths to transmit packets to their destination, and determines the best route this packet should follow [16].

The concept of network performance optimization is carried out through the construction of the routing tree selection which is characterized by the topological properties that are independent when the network is being formed. The construction of the tree and arrangement of the nodes allows a distribution of the nodes that leads to a better chance of routing and optimization. The correlations between the topological parameters of the tree and the efficiency of the network must be estimated, and those that show the strongest correlations should allow the creation of the best trees and thus provide some routing and topology optimization [17].

Currently there are a number of routing protocols with several differences and similarities between them, that show the particular advantages and disadvantages when applied to mesh networks. Among these various routing protocols, there is no exists single protocol that can be claimed as the best. The reason for this is that they have several peculiarities and there not exists a protocol that is considered to be optimal for all scenarios. Each protocol has a unique characteristic, which makes it either suitable for a particular application.

By studying the scientific and academic papers in mesh networks, it is clear there has been a notable growth in the number of research studies in this area [18] [19]. There are currently several projects spread across the networks, some on a large scale. This is because of the benefits that can be derived from this mode operation, including the cost-effective deployment of broadband, and ease of access. Another potential element of fundamental importance is digital inclusion and the Future Internet which can provide services and comprehensive long-range topology wireless, suitable for specific topologies, with the implementation of QoS to meet the requirements of situations such as the next generation networks and the ever-increasing demand for multimedia applications and real-time.

As discussed earlier, mesh networks are a promising technology. However, to develop their full potential as a product, mesh networks require research in fields related to all the layers of the TCP / IP stack. Specifically in the routing area, there is a need for new protocols and critical metrics. However, the adoption of routing protocols of ad hoc networks in mesh networks, although possible, causes a number of problems and has drawbacks, such as the large number of control packets used for these protocols. The dynamics of an ad hoc network requires the constant assessment of the network topology, which is different from a mesh network with a static topology. Thus, a mesh routing protocol should be a more stable and less costly network.

However, before understanding routing protocol operations, it is necessary to understand the operation of routing algorithms that are of two kinds: non-adaptive algorithms (static) that calculate the route when the network is initialized and not based on a network topology and adaptive algorithms (dynamic) that take into account the topology and where to search for information.

Adaptive routing algorithms can in turn be classified in two ways:

a. Distance Vector (DV): Due to its applicability to packet routing on the Internet, this became known as Routing Information Protocol (RIP) or Distributed Bellman-Ford (DBF). This algorithm operates by enabling each router to maintain a table (i.e. a vector) which provides the smallest distance to each known destination and determines which line should be followed to get there. In a distance vector. routing is defined as a metric unit that will be the cost value of a path between nodes of a network. This metric unit could be the physical distance between nodes, the amount of hops (hops), the delay in transmission, the node congestion and other factors.

b. Link State (LS): This dynamic algorithm was devised with the purpose of solving the problem of distance vector routing, since it used the number of hops to the destination, although a packet could reach a destination by going a short way, ie with few hops. However, the link bandwidth could be small and the delay be greater. As a result,, the link state has arisen to find efficient routes, and is not concerned about the number of hops or the conditions under which the network is located.

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4.1. Routing protocols

Among the ad-hoc networks, there are three basic types of routing protocols: proactive, reactive and hybrid [20] [21]. The proactive type requires us to maintain the route network for all possible destinations when there is a need to send a data packet. In reactive protocols, the nodes discover the destinations on demand. The hybrid protocols are those where there is only one set of nodes that provides periodically updated information on possible destinations.

4.1.1. Pro-active routing protocol (Table- driven)

This protocol requires all the network nodes to maintain routes to all possible destinations so that, when the need arises to send a data packet, the route that must be taken is known immediately. These protocols operate through their routing tables by exchanging messages continuously. Examples of proactive protocols are: : OLSR (Optimized Link State Routing Protocol), DSDV (Destination-Sequenced Distance-Vector) and WRP (Wireless Routing Protocol), the first, the OLSR is the representative of the protocols used for the following tests of this chapter.

The OLSR is a routing protocol developed for MANETs, and is an optimized link state protocol. The OLSR reduces the control packet size and the number of these packets that are sent to the network. This reduction in the number of control packets is achieved through the use of Multipoint Relays (MPR), which characterizes the OLSR. MPR is a node chosen from among the neighbors to send control packets, and the choice is made by the neighbors when there are only a hop of the node [22].

4.1.2. Reactive routing protocol (On-demand)

In the reactive protocols, the nodes discover the on-demand destinations, i.e. they do not require a route to the destinations where they have to send data, and seek the efficient use of resources like energy and bandwidth. Examples of reactive protocols are : AODV (Ad-Hoc On-Demand Distance Vector), DSR (Dynamic Source Routing) and TORA (Temporally Ordered Routing Algorithm). An examination of he AODV protocol, which is the representative of the reactive protocols used for testing, follows in this chapter.

The AODV routing protocol is a reactive protocol, i.e. the route to a destination node is discovered only when it wants to send a packet (data) to this node., This protocol enables dynamic routing, where the route of the packet can be changed in accordance with the route that the data is following, if the route used is unavailable. This discovery quickly results in new destinations [20] [23].

The AODV protocol is a protocol based on the Destination-Sequenced DistanceVector (DSDV) [19], and is created primarily to eliminate errors in DSDV, on account of the constant changes of topology and the large number of control messages between the network components. During the route discovery, the AODV protocol uses a traditional routing table as a storage mechanism. This only stores one entry, i.e. it only stores the next hop to the destination, unlike the DSR that stores multiple routes to the same destination and also stores the entire route from the source to a destination. The AODV is designed to be used in ad-hoc networks which have provided small numbers of nodes (up to thousands). The main purpose of the protocol is to adapt quickly and dynamically to the changing conditions of the network links, and find routes which can allow it to provide a desirable QoS. In this way it, avoids wasting bandwidth, minimizing memory usage and processing the nodes that act as routers.

4.1.3. Hybrid routing protocol

The hybrid is a protocol where a certain set of nodes, (only a limited number of nodes) periodically updates the information nodes / routes of possible destinations, and attempts to make a suitable use of the two previous approaches. Examples of hybrid protocols are : HWMP (Hybrid Wireless Mesh Protocol), ZRP (Zone Routing Protocol) and FSR (Fisheye State Routing); the HWMP protocol is the representative of the hybrid protocols used for the following tests of this chapter. HWMP is based on AODV [22] and also has an optional routing protocol, called RAOLSR (Radio Aware OLSR) based on OLSR [23] [24].

HWMP is a hybrid routing protocol. It has both re-active and proactive components. The creation of HWMP is an adaptation of AODV to radio-aware link metrics and MAC addresses. It is the basic, reactive component of HWMP. The on-demand path setup is achieved through the path discovery mechanism that is very similar to that of AODV. If a mesh point needs a path to the destination, it broadcasts a path request message (PREQ) into the mesh network. The hybrid routing protocols combine the best features.

4.2. Correlation between QoS and routing

QoS routing is an important parameter for the provision of guaranteed QoS in mesh networks. This issue has been exhaustively studied in wireless mesh networks. The aim of QoS routing for these networks is twofold: to find a best feasible path for each incoming connection in the presence of the underlying link interference and to optimize the usage of the network by balancing the load.

This chapter evaluates the routing problem in the IEEE 802.16 mesh networks. Unlike other routing strategies, this chapter is concerned with providing paths, mainly at certain QoS levels that guarantee traffic flows. The simulations will evaluate multimedia applications such as VOIP, video conference and other multimedia streams that have grown over the Internet, and verify the best qualifications between QoS and routing protocols by evaluating the major impacts on these two important factors in the WMNs.

The number of hops is the most common criterion that is adopted by traditional routing protocols. However, it is clear that these protocols are inadequate for multimedia applications, such as VoIP and video conferencing, which require QoS guarantees. Routing protocols with QoS, not only need to find the route with the shortest path, but the best route that meets the requirements of end-to-end QoS, regardless of the number of hops or how the routing protocols need to find the best routes through multiple hops. It, is necessary and important that the new protocols and routing algorithms also take into account the parameters and other measurements such as power consumption, the closeness of the backbone network output and especially the quality over quantity link for users and the quality of wireless communications, while taking into account attenuation, signal quality and interference.

5. Evaluation and results

The Simulations experiments were carried out with the aid of Network Simulator version 2 [25] to show the performance of some routing protocols with QoS as network measure in WiMAX Mesh Network. For the WiMAX Mesh simulations it was used a module developed by the Network and Distributed System Laboratory [26] with extensions to use on PMP and mesh mode. The results compare four routing protocols: AODV, OLSR, HWMP Proactive and HWMP Reactive. Figure tal show the topology used for the tests, a random topology.

The simulation scenario chosen for the experiments were formed in a randomly generated with sixteen nodes, but that could easily represent a pre-existing base stations in a city, a rural area or a group of cities in proximity.The base stations act as routers through which network traffic will be routed through them choosing the best path according to its algorithms so that traffic is routed between source and destination.

The scenario (Figure 8) aims to test the choices of the best routes according to the algorithms / routing protocols and verify the flow and the delay due to these choices. The results are found in the simulations are evaluated along with the following analysis of these.

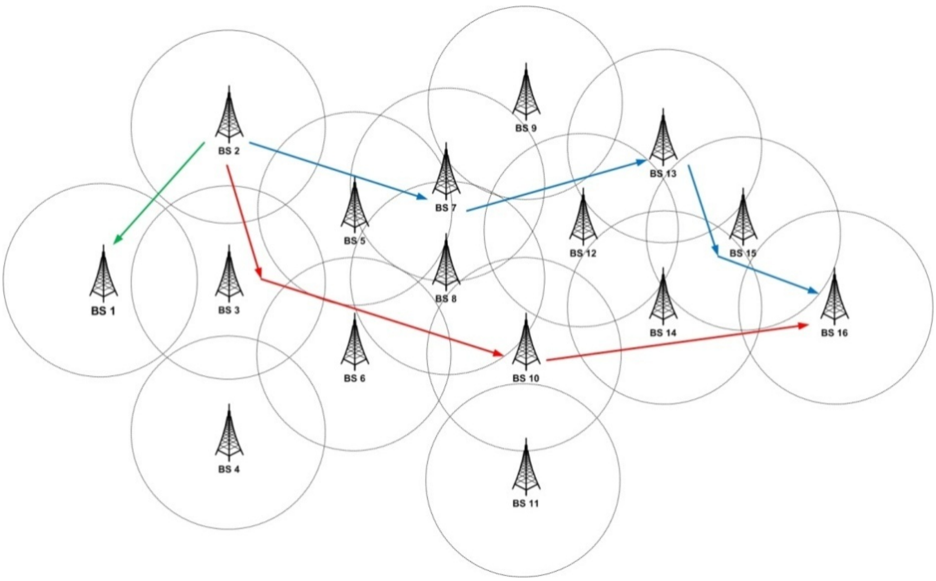

Figure 8. Simulated Topology

Faced with this scenario, routing protocols, based on their algorithms must choose the best route for that traffic out of the source node (node 2/BS 2) and reaches the destination node (node 16/BS16) and there is the question. What's the best route? The red route or blue route? Will would other routes? Perhaps green route. Certainly there are several routes and choosing each one behind certain characteristics and particular outcomes to the performance of this network and its communication. Simulated parameters presented below (Table 1).

Cover Area	1km
Frequency	3,5GHz
Standard	IEEE 802.16 (MESH)
Modulation	OFDM
Router WiMAX Mesh Number	16
Simulation Time	60s
Traffic	Video and CBR

Table 1. Simulated parameters

5.1. CBR traffic

In the first situation, the simulations were conducted with CBR traffic (1 MB), the transmission consists hop-by-hop by four routing protocols: AODV, OLSR, HWMP Proactive and HWMP Reactive. By the analyze of the throughput, achieved better performance result by HWMP Reactive (Figure 9). This result is because of the protocol in this scenario constantly keep checking the best route and always find a solution when faced with a new, always managing to optimize the flow through the best link at any given time.

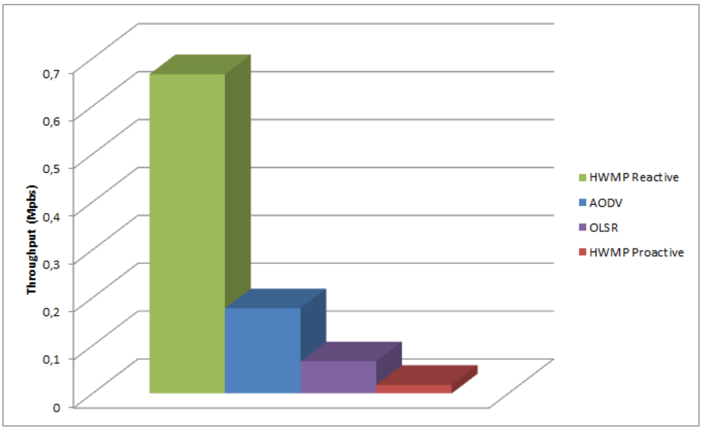

Figure 9. Comparison of CBR traffic throughput for the four routing protocols

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The result of the hybrid routing protocol show the better results in comparison with other protocols presented here. In other protocols, it takes a long time to find a best route for data flow and sometimes, take congested routes, which reduces the throughput of the network.

5.2. Video on CBR traffic

In the second situation, the simulations were conducted with Video and CBR traffic (as background traffic). The transmission consists hop-by-hop by four routing protocol: AODV, HWMP Proactive, HWMP Reactive, OLSR. When we analyze the throughput, we observed a better performance by AODV. This case was carried out by using the Evalvid tool [27] that allows control of real video quality called "Grandma". The video simulations parameters presented below (Table 2).

In this particular case the transmitted traffic behind will focus on some decrease in the quality of connections that take the main traffic to the destination and make the hybrid routing algorithms are flawed when compared to non-hybrid and in this case, can best AODV results in selecting the best route and consequently better results regarding the flow, providing a certain QoS to the end customer and the quality of multimedia applications used. The AODV establishes the route more faster than other protocols, for this reason it had better throughput and better video performance.

Parameters	Value
Resolution	352 x 288
Frame Rate	30 Frame/sec
Color Scale	Y, U, V
Packet Length	1052
Packet Fragmentation	1024

Table 2. Video simulation parameters

Traditionally, the performance of network archictetures have been evaluated through Quality of Service (QoS) metrics. QoS is defined as the ability of the network to provide a service at an assured service level. QoS is also a commonly used metric set (e.g., throughput, packet loss, delay, jitter, handoff dropping and blocking probability) to represent the capability of a network to provide guarantees to selected network traffic. QoS considers parameters of a network that can be easily measured, but do not tell how the service is perceived by users. To satisfy the user-centric approaches, QoE is used to quantify the perception of the user about the quality of a particular service or network. The QoEmetrics confirm the previous statement.

The PSNR (Peak Signal to Noise Ratio) [6] [28] is the most traditional QoE/video metric, which estimates the video quality in decibels, comparing the original video with the video received by the user considering the aspects of luminosity. Figure 10 shows the better video quality using the PSNR statistics (Table 3).

For each PSNR range values, there is a qualification for the received video by the user. The Table II shows the PSNR range quality:

PSNR (dB)	Quality
> 37	Excellent
31 – 37	Good
25 – 31	Fair
20 – 25	Poor
< 20	Bad

Table 3. PSNR range

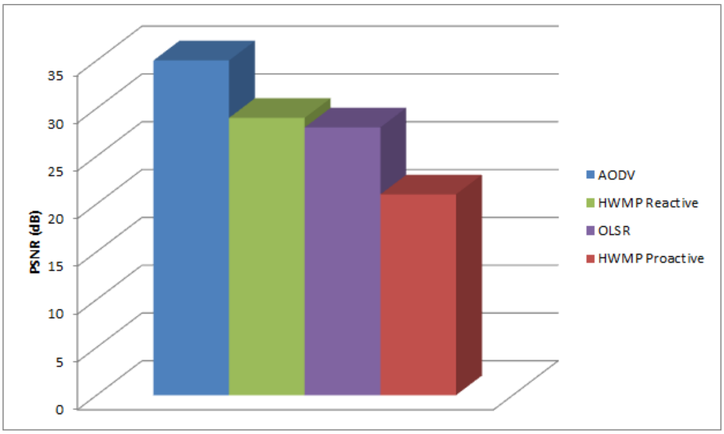

Figure 10. PSNR

The Structural Similarity (SSIM) [6] [28] metric evaluates the received video by the user taking into account the characteristics of the HVS (Human Visual System). The SSIM examines the color, light and structure similarity. The SSIM value is expressed by a number between 0 and 1, where 0 means zero correlation with the original image and 1 means the exact same video. As can be noted (Figure 11) by analyzing the QoS metrics, AODV has the best closeness in quality compared to the original video and HWMP Proactive worse.

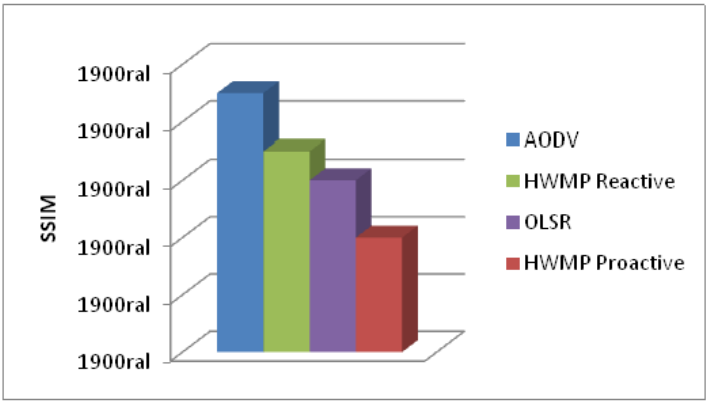

Figure 11. SSIM

The Video Quality Metrics (VQM) [6] [28] as MSU VQM metric also compares the original video with the video received by the user. They are considered the most complete metrics because compare the following aspects: noise, distortion and color. Again, AODV (Figure 12) has the best values because the smaller the value of this metric, better the video quality.

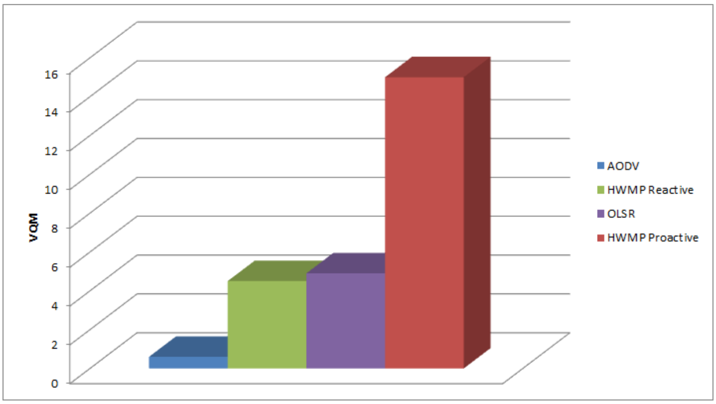

Figure 12. VQM

The evaluation of routing protocols are clear when we look at the frames in Figures. The frame number 100 was selected to compare the quality. As we can see, the AODV presents the best results, followed by hybrid reactive, OLSR and hybrid proactive protocols respectively (Figure 13).

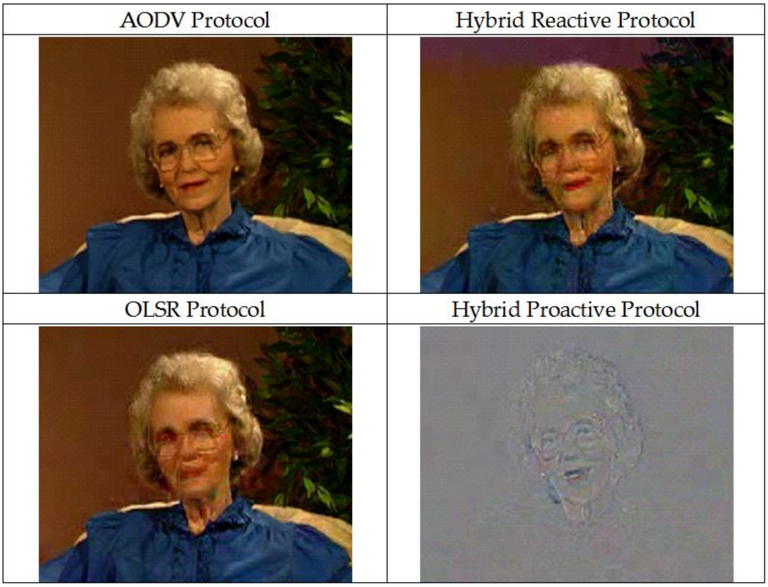

Figure 13. Result of frame 100 for the four routing protocols

The Figure 14 shows the delay average over time for the four routing protocols, showing their results in this network metric. AODV and HWMP reactive had the lowest delay.

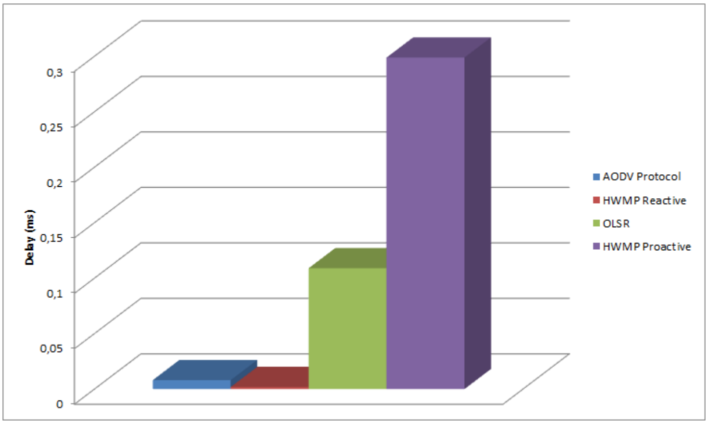

Figure 14. Delay average over time

If a routing protocol takes longer time to find the best route and took and thus decide to use your communication path, in normal situations, present a lower performance as measures of network for those with a behavior in choosing the fastest route.

6. Conclusions

This chapter showed an initial study on wireless mesh networks, pointing out the main goals of interest, challenges and issues encountered, highlighting the advantages and disadvantages of this mode of operation. During the work, focused on the IEEE 802.16 popularly known as WiMAX, a technology standardized by the WiMAX Forum as an alternative wireless communication with wide area coverage and bandwidth, providing high speed and mobility, important peculiarities in the context of next-generation networks in Future Internet.

The chapter provides a more detailed study of the WiMAX mesh mode, pointing to two very important points for this type of network the next generation of wireless communications: algorithms / routing protocols and QoS, mainly to meet the demands for new multimedia applications as VoIP, telemedicine, videoconferencing and other real-time applications that require a large bandwidth with constant to meet the constant flow needs, providing quality network metrics such as throughput and delay and qualitative results regarding the perception of the end user when evaluated on the QoE metrics, with valid results on human perception of quality in real end user.

The studies and validated through simulation showing what the main advantages of routing protocols when incidents of random scenario presented here, however, it is noteworthy that these results are specific to this scenario, not ensuring that the protocols achieve similar results in any type of scenario. It is important to mention that the protocols have different results as there is a variability of scenarios or data flow, increasing them or decreased them and so, some protocols may have better results in some scenarios and worse in others, there is certain variability.

Conclusively, routing protocols have advantages and disadvantages and present very particular results, and there is a protocol that presents the best results ever, nor how to choose the best route, nor as to the best results of QoS and QoE.

Simulation results shown that the AODV protocol provides the best results when analyzed on the scenario shown to video traffic, however, the hybrid routing protocol that operates in a reactive mode, gives good results and operates in hybrid form, could be better than AODV depending on some parameter variations. This makes us believe that the hybrid reactive would be a protocol that can be relatively good in all cases, although not an optimal model, can be efficiently and effectively providing a good alternative routes and relative quality to the end user about the prospect of QoS and QoE. The hybrid reactive and AODV protocol gave good results as the data flow rate and video quality, but could have different results in other settings and with other simulation parameters.

In some future work, the authors intend to make optimizations in routing protocols and mechanisms include your choice between a more complete analysis taking into account other important points beyond the amount of jumps as energy consumption and output communications to the Internet outside the backbone of the mesh network with algorithms that also take into consideration the proximity.

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