# MAC layer Mechanism for Wireless WiMAX Networks with Mesh Topology

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***Abstract:*** *The application of wireless local area networks has significantly increased in the last decade, and the 802.11x standards have directed this exponential growth. However, the need to cover greater areas at higher transmission speeds gave rise to the 802. 16x standards. These new standards provide the necessary guidelines that establish coverage, transmission capacities, types and quality of services. The technologies required to implement the 802. 16x standards, however, are much more costly than traditional WLANs. This work proposes a MAC layer mechanism that increases the coverage area of wireless broadband networks that does not require increased physical infrastructure.*

## 1. Introduction

Wireless technologies have become increasingly important because of the mobility it offers. The convenience offered by wireless mobile LANs is contributing to an evolution from traditional cable networks to wireless infrastructureless networks in an increasing number of public and private spaces. Wireless ad hoc networks differ, however, from traditional wireless technologies in that they do not require centralized Access Points (APs).

Coverage and transmission capacity are important concerns, whether evaluating wireless personal area networks (WPAN), wireless local area networks (WLAN), and wireless metropolitan area networks (WMAN). However, in WPANs and WLANs, resolving difficulties related to coverage and transmission capacity is much more prevalent [1] and requires considerable investment in physical infrastructure. Additionally, expanding coverage of traditional wireless networks often becomes difficult because of the additional deployment of APs at the borders of the coverage area.

Wireless mesh networks (WMN) provide a possible solution to the connectivity problem of traditional wireless networks and their development has become a priority of the ZigBee, WiFi and WiMAX alliances [2]. The primary goal of these alliances is to expand the coverage of wireless networks by exploiting the multi-point and multi-hop capacities of nodes, thus improving the capacity and robustness of the network at decreased cost.

Some research results for these areas of opportunity are reported in [3] where using a mesh topology and installing large towers can reduce costs. This proposal, however, employs technology that supports the IEEE 802.11 standard, which requires a large number of access points in order to afford adequate service. Equipment is described in [4] that support the IEEE 802.16a standard for application in the South American countryside where the topography is irregular. This research, however, is limited to tests and implementation of the Medium Access Control Sub-layer (MAC). Coverage continues to be of primary concern when high transmission speeds are obtained. In [5], the authors primarily focus on analyzing wireless networks with a mesh topology as a possible low-cost solution to this problem. Difficulties related to coverage and high costs are considered in [6], which also provides possible solutions for networks using Wi-Fi technology.

Because the routing protocol is one of the main elements in a Wireless Mesh Network (WMN), the primary objective of this work is to develop a MAC mechanism that permits node connectivity beyond the actual network coverage at a minimal cost and without modification of the network infrastructure.

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The remainder of this paper is organized as follows: Section 2 reviews the wireless ad hoc network concepts. Section 3 describes the wireless mesh networks. Section 4 analyzes the WiMAX technology. Section 5 shows the development process and Finally, Section 6 summarizes our work and proposes future research.

## 2. Wireless Ad hoc Networks

Wireless ad hoc networks have special characteristics related to node mobility, node self-configuration and the lack of centralized access points (APs). However, wireless ad hoc technologies have several disadvantages when compared to traditional wireless networks, including their limited resources, such as: lower processing capacity, limited memory and their battery dependency. Because operations are not centralized in a single access point, information is openly distributed among the network nodes. As a result, wireless ad hoc networks are not as secure as typical wireless networks. Authors in [7] discuss how the distributed communication strategy of wireless ad hoc networks permits connectivity in less favorable circumstances for some specific applications.

Wireless ad hoc networks are usually associated with wireless mesh networks; however, these two concepts can be dealt separately. The work reported in [8] suggests, WMNs offer flexibility in terms of mobility; their nodes can be stationary or mobile, forming a mesh topology among them. In addition, WMNs can incorporate multiple radios in different channels, permitting them to increase their capacity and reduce interference. The essential idea of wireless ad hoc networks is that they are mobile and dynamic. This concept is not at all new. In fact, Mobile Ad hoc Networks (MANETs) represent an important research area of the wireless networks.

In wireless ad hoc networks, a node can seamlessly communicate with neighbor nodes within a specific coverage area. The nodes within a specific coverage area can also communicate with nodes outside their range by using intermediate nodes to forward messages to any destination node outside the coverage area [8]. MANET nodes can do this by means of routing protocols that can cover their operational requirements.

## 3. Wireless Mesh Networks

Wireless mesh networks do not have a centralized mechanism to regulate traffic flow. Every node in the mesh network shares the same communication protocol. This permits them to auto configure and determine the most efficient route between transmitter/receiver nodes. These networks, known as multiple point networks (Figure 1), offer great redundancy because of their node interconnectivity mechanism, which allows nodes to freely move within a coverage area without losing their connection.

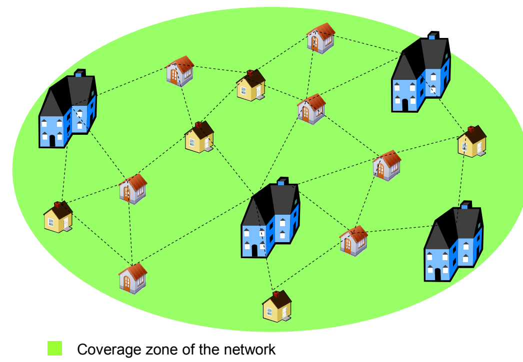


***Figure 1: Wireless mesh network***

One of the main advantages of WMNs is that they do not require line of sight (LOS) between the transmitter/receiver pair [2].
The flexibility of WMNs and their ability to adapt to change makes them a viable alternative in emergency situations, especially when nodes are constantly entering and exiting the network. This special characteristic of WMNs is possible precisely because they do not depend on any one specific node to guide the conduct of the rest.

## 4. WiMAX Technology

Worldwide Interoperability for Microwave Access (WiMAX) is widely used for personal broadband communications for both fixed and mobile stations because of its transmission capacity, flexibility, and coverage [9]. Because of these advantages, WiMAX is currently the most widely accepted technology used by wireless broadband users, expanded services, QoS, and IP data transmission, among others, that cellular technologies cannot support.

The authors in [10] discuss how WiMAX's flexibility provides broadband Internet access, allows multicast communications, and offers distributed services in metropolitan areas with QoS guarantees. WiMAX technology can efficiently perform these different functions because its physical layer employs orthogonal frequencies division multiple access

(OFDMA), a new technology that provides increased capacity for fourth generation mobile networks.

There are currently two systems that use WiMAX technology according to subscriber station characteristics. The first is known as "fixed WiMAX," based on the IEEE 802.16-2004 standard and the second is known as "mobile WiMAX, which uses the IEEE 802.16e standard.

The physical layers (PHY) of the IEEE 802.16x standards support several specifications in licensed and free bands. For example, one is based on a single carrier (SCa), others use orthogonal frequency division multiplexing (OFDM), and still others OFDMA. The great majority physical layer specifications do not consider line of sight (NLOS) primarily because communication systems using OFDM perform suitably without line of sight while offering acceptable reception despite multiple trajectories. Furthermore, the IEEE 802.16x standards can use Time Division Duplexing (TDD) or Frequency Division Duplexing (FDD) to better handle multiple subscribers [10].

Besides considering PHY layer, the standard includes two operations modes at the MAC layer: point to multi-point (PMP) and mesh. In PMP, the network requires a base station (BS) and at least a subscriber station (SS). In this case, the communication between these two elements is realized through an uplink channel between each SS to the BS and the BS downlink channel to the SS. Point to multi-point communication, however, requires all SS have specific transmission periods, as well as LOS with the BS. Mesh architectures can send and receive information without a BS.

## 4.1. IEEE 802.16-2004 Standard

In IEEE 802.16-2004 standard, antennas are installed on ceilings or masts at the SS location. This broadband wireless alternative (Figure 2) provides functionality that is similar to cable modems, including xDSL technologies that can be considered "last mile" broadband solutions. When using OFDM, this standard is considered optimized for the wireless data transmission due to its 256 carriers, which this technology allows to have immunity to the problem known as multi-trajectory caused by the interference of different obstacles [1].

## 4.2. IEEE 802.16e-2005 Standard

The IEEE 802.16e-2005 standard focuses principally on client mobility; however, unlike the IEEE 802.16-2004, it employs OFDMA, which allows subcarrier and subchannel transmission. Consequently, a station can transmit using all the carrier subchannels, or split the subchannels to handle different clients simultaneously.

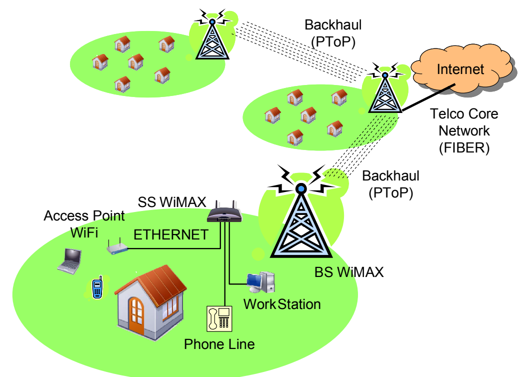


*Figure 2: Topology for WiMAX networks*

The IEEE 802.16e-2005 standard employs TDD to improve asymmetric traffic flow and its advanced antenna system more efficiently uses available power resources and can support both broadcast and multicast services of mobile applications.

## 4.3. IEEE 802.16 mesh architecture

Presently, the 802.16-2004 provides improved mesh and multi hop communication between SSs. When a SS becomes a transmitter, it can send the information using different routes to reach the BS. New nodes wishing to join the network must have a self configuration capacity and notify all mesh neighbor nodes periodically so that they can update their tables. This synchronization process requires specific configuration parameters so that nodes entering and leaving the network can communicate their status to their neighbors, who then forward the information to the base station. Once a candidate node has been authorized by the sponsoring nodes, it is assigned a unique identifier within the network, allowing it to acquire and offer seamless and synchronous service to all neighbor nodes. The principal weakness of the 802.16-2004 is that it does not consider node mobility. However, future specifications included in the 802.16e standard are expected to correct this limitation [2].

Table I describes some challenges for wireless mesh networks.

| Requirement | Technical Challenge | Potential Solution |
|---|---|---|
| Coverage without LOS | Reducing interferences | Antenna diversity<br>Channel Coding |
| QoS | Supporting voice, video and data in a single link. | Extended MAC layer |
| | Managing wireless resources | Efficient scheduling of algorithms |
| | Providing end-to-end QoS | DiffServ, IntServ and MPLS |
| Mobility | Localization | Expanded databases that include roaming and localization, |
| | Connectivity | Mobile IP |
| Security | Providing privacy and integrity. | Cryptography |
| | Denial of service | Improved authentication and access control |
| Low cost | IP architecture | Adaptation of IP protocols for wireless communication. |

***Table I: Challenges for wireless mesh networks***

## 5. Development Process

This work offers an economically viable solution for remote nodes outside the base station coverage area to access services (Figure 3). Our proposed solution permits remote nodes to directly communicate with their neighbor nodes, thus improving the capacity of the WiMAX network. We selected the 802.16-2004 standard for the present work because it considers both PMP and mesh architectures.

The easiest way to expand the coverage area of a wireless network using WiMAX technology is to add more BSs. Importantly, coverage areas must overlap to allow roaming from an area to another. The disadvantage of this "easiest" strategy is the considerably elevated implementation costs.

Traditional PMP architecture has a very centralized communication structure whose nucleus is the BS. In this architecture, the BS controls the access to the network and the transmission between the SSs and the BS. Network access for a mesh topology is different from a PMP. In mesh topology, each node has the privilege of initiates or authorizes the access to the network. The network entry and synchronization mechanism for both mesh and PMP topologies is described in the IEEE 802.16-2004 standard [12]. Four phases are considered necessary for the operability of remotes nodes (Figure 4).

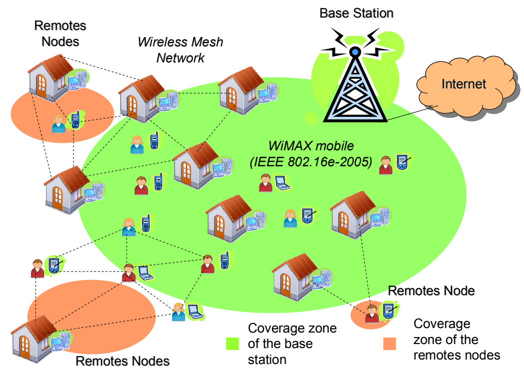


***Figure 3: Connection of the remote nodes to the base station with mesh topology.***

Mesh networks permit flexible and robust interconnection of "remote nodes" by means of SSs located near the outer limits of the coverage area of the BS. Remote nodes are considered network entry points and all SSs are possible candidates to the destination node.

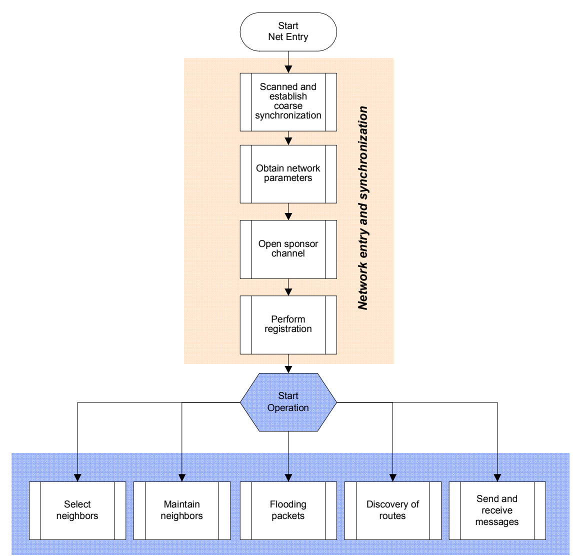


***Figure 4: Network entry and synchronization***

The primary goal of this work is to achieve the maximum capacity possible from the existing network infrastructure with the objective of decreasing network cost. Our work presents a MAC mechanism that allows the seamless, transparent interaction with neighbor nodes.

Our proposed mechanism does not use centralized equipment to regulate and control traffic flow because we have considered a mesh topology and mobile nodes.

The mechanism we are developing requires little processing power by nodes functioning within the operational area of the mesh network. The proposed mechanism will be simple to avoid routing difficulties.

The entry procedure for remote nodes (Figure 5) scans and selects the channel to ease node synchronization with the network by receiving a (MSH-NCFG) configuration message. Upon receiving the configuration message, a timer counts down waiting for the next MSH-NCFG message. If a MSH-NCFG message is not received within a specific time, the entry node seeks a new synchronization channel. This phase is particularly important because, at this time, the node acquires relevant information about sponsoring nodes and receives its network ID.

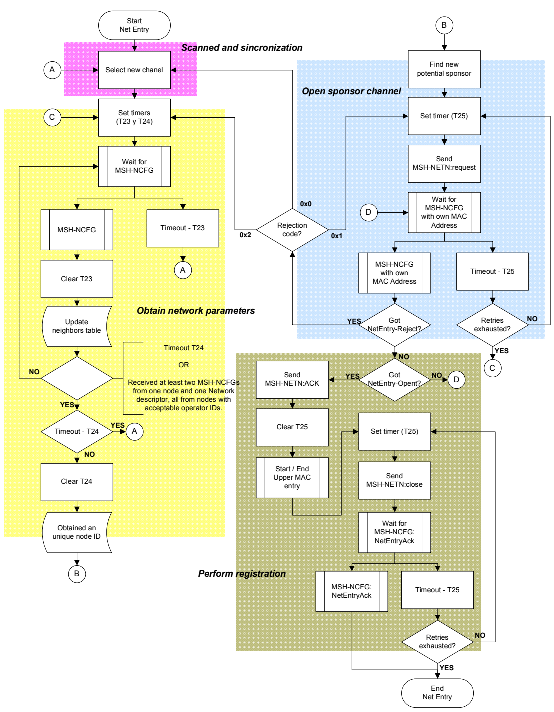


***Figure 5: Network entry and synchronization of the remote node.***

Once the remote nodes chooses a sponsor from its neighbor list, it transmits a MSH-NENT:request message which is then either accepted or rejected by the sponsor. When the sponsor nodes accepts the remote node's entry request, the entering node initiates the registration phase by sending a MSH-NENT:ACK message. The communication cycle is repeated until the remote node successfully enters the mesh network.

When this communication cycle is completed, the remote node closes communication by sending a final MSH-NENT:close message (Figure 6).

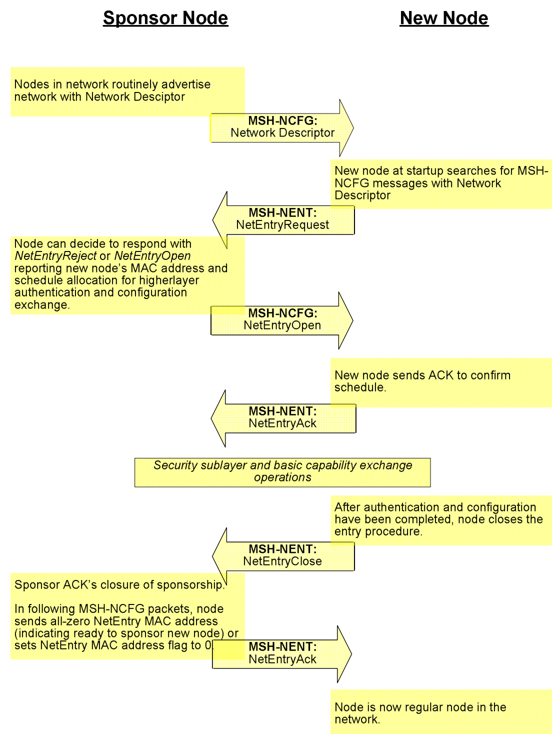


***Figure 6: Successful network entry message exchange.***

# 6. Conclusions

This proposal aims to support wireless Internet services in urban areas as it allows networks to rapidly expand their coverage area without greatly increasing costs.

Before developing a wireless mesh network routing algorithm, this work proposes a MAC mechanism that will permit node connectivity beyond the actual network coverage at a minimal cost without modification of the physical network architecture.

The benefits provided later by our algorithm will offer more rapid and efficient communication, making it a viable option for "last mile" connectivity. Future work will include simulation of the initialization mechanism of wireless mesh networks.

# 7. Referencias

[1] Intel Corp. (2004), White Paper: Understanding Wi-Fi and WiMAX as Metro-Access Solutions, [Online]. Disponible: http://www.intel.com.

[2] M. J. Lee, J. Zheng, Y. Ko, and D. M. Shrestha, Emerging standards for wireless mesh technology, *IEEE Wireless Communications*, 1536-1284, pp. 56-63, Apr. 2006.

[3] P. Dutta, S. Jaiswal, and R. Rastogi, VillageNet: A low-cost, IEEE 802.11-based mesh network for connecting rural areas, *Bell Labs Technical Journal*, vol. 12, pp. 119-131, Aug. 2007.

[4] R. Hincapie, J. Sierra, and R. Bustamante, Remote Locations Coverage Analysis with Wireless Mesh Networks based on IEEE 802.16 Standard, *IEEE Communications Magazine*, 0163-6804, pp. 120-127, Jan. 2007.

[5] G. R. Hiertz, et al, Mesh technology enabling ubiquitous wireless networks, presented at 2nd Annual International Workshop on Wireless Internet, Boston, Massachusetts, 2006.

[6] S. Sen, B. Raman, Long Distance Wireless Mesh Network Planning: Problem Formulation and Solution, presented at 16th International Conference on World Wide Web, Banff, Alberta, Canada, 2007.

[7] J. V. Merwe, D. Dawoud, and S. McDonald, A survey on peer-to-peer key management for mobile ad hoc networks, *ACM Computing Surveys*, Vol. 39, No. 1, Article 1, Apr. 2007.

[8] S. A. Mahmud, K. Shahbaz, K. Shoaib, and H. Al-Raweshidy, A Comparison of MANETs and WMNs: Commercial Feasibility of Community Wireless Networks and MANETs, presented at *1st International Conference on Access Network*, Athens, Greece, 2006.

[9] WiMAX Forum (2006), Mobile WiMAX PersonalBroadband, [Online]. Disponible: http://www.wimaxforum.org.

[10] K. Lu, Y. Qian, and H. H. Chen, A Secure and Service-Oriented Network Control Framework for WiMAX Networks, *IEEE Communications Magazine*, 0163-6804, pp. 124-130, May. 2007.

[11] J. G. Andrews, A. Ghosh, R. Muhamed, Introduction to Broadband Wireless, in *Fundamentals of WiMAX: understanding broadband wireless networking*, ISBN 0-13-222552-2, T. S. Rappaport, Ed. Massachusetts: Prentice Hall, 2007, pp. 3-32.

[12] IEEE Standard for Local and Metropolitan Area Networks Part 16: Air Interface for Fixed Broadband Wireless Access Systems. IEEE Computer Society, pp. 1-857, 2004.