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# Mobile Multi- Hop Relay WiMAX

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**Abstract:** The goal of this paper IEEE 802.16j (mobile multi-hop relay, mmr) is to add multi hop capabilities to IEEE 802.16e so that the throughput and coverage area of mobile WiMAX networks is increased while ensuring compatibility with the PMP mode. The network topology of a Mobile Multihop Relay (MMR) network is a tree with the BS at the root of the tree. New network entities called Relay Stations (RSs) are introduced. RSs relay information between a subscriber station (SS)/mobile station (MS) and a BS or between other RSs or between an RS and a BS. A RS does not provide backhaul functionality and hence it is much simpler than a BS. The range of the network can be significantly extended. This could be achieved without need of other costly BSs. The maximum allowed number of hops must be carefully considered (higher number of hops increases a transmission time). Multi-hop based network may also improve system performance by sending information simultaneously via multiple different paths and combining the received information at the side of receiver [62].

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This standard will be backward compatible with IEEE 802.16-2004 and IEEE 802.16e and so conventional 802.16 SSs terminals will function normally in mmr enhanced infrastructure. On the other hand, some modifications to BS must be made to allow communication with RSs and supporting of aggregation of traffic from multiple RSs. To obtain best possible performance of the network, character of RSs and their placement must be carefully chosen. There are defined three kinds of RS: fixed, nomadic and mobile. Fixed RS is permanently installed at a fixed location. Nomadic RS is intended to function from a location that is fixed for period of time comparable to a user session. Finally mobile RS is fully mobile and may be for example installed at moving vehicle (bus, train…). In some cases, SSs may also act as relay station. Link air interface is based on OFDMA PHY which had been chosen for its many advantages [55]. MAC (Medium Access Control) layer must be further enhanced to support multi-hop communication (BS to RS and RS to RS).

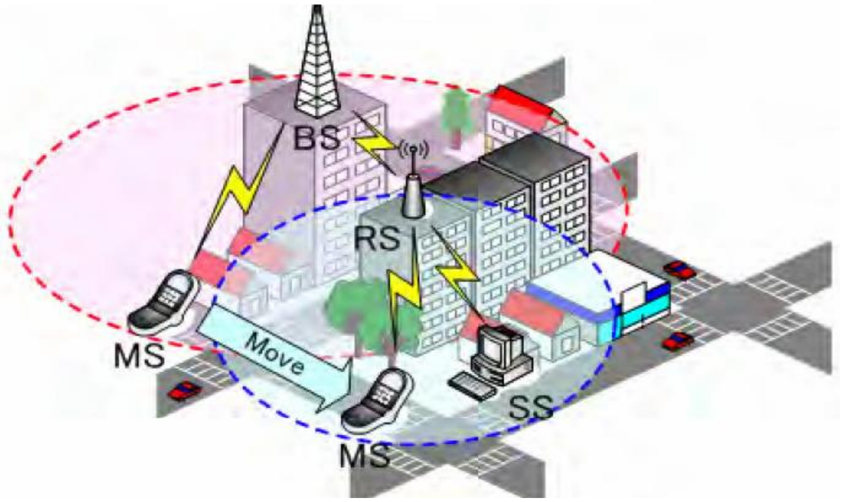

Fig 1.1 : MMR WiMAX

In MMR network, the whole cell is divided into two regions: BS region and RS region. The users near the base station who belong to BS region are connected directly to BS while users in the relay region, out of BS region are connected to RS. Here, RS pretends to be a MS for BS and to be a BS for MS as shown in fig 1.1. A SS that is in the coverage hole or in the shadow of buildings (a geographic area where SS does not have total functionality due path loss) may have full operability with RS. Relay technology may also be used to extend range at the cell edge or to isolated areas and better in-door coverage can be offered.

WiMAX provides two types of wireless service–line-of-sight (LOS) and non-line-of-sight (NLOS). In LOS, the receiver antenna (at SS) and the WiMAX BS are in line of sight; hence, the connection is more stable owing to less interference and better signal strength. LOS transmissions operate at a higher frequency band of 11–66 GHz covering a range of 50 Km. The NLOS service operates at 2–11 GHz because lower frequency transmissions are able to diffract or bend and hence are not disrupted easily by any physical obstacle. The operating range for a NLOS service is around 6–8Km. WiMAX uses large chunks of spectrum, and delivers high bandwidth up to 75 Mbps. Despite the high bandwidth promised by WiMAX, there are several issues that network operators face during actual deployment of these networks. The first problem is that of dead spots or coverage holes. Such spots of poor connectivity are formed due to high path-loss, and shadowing due to obstacles such as large buildings, trees, tunnels, etc. and this leads to degradation in overall system throughput. The other key design challenge is that of range extension. At times, it is required to provide wireless connectivity to an isolated area outside the reach of the nearest base station (BS). The above problems of throughput enhancement by filling coverage holes and range extension can be easily tackled by deploying additional base stations. However, such a solution could be an overkill, and too expensive in several scenarios. In such contexts, relay stations are a cost-effective alternative.

The primary goals of MMR are:

- extend coverage area,
- enhance throughput and system capacity
- saving battery life of SSs and
- Minimizing of RS complexity.

### 1.2.1 Frame Structure

A typical WiMAX network consists of a base station (BS) that serves fixed and mobile users, called subscriber stations (SS) and mobile stations (MS), respectively. Communication occurs in two directions: from BS to SS / MS is called Downlink and from SS / MS to BS is called Uplink. During Downlink BS broadcasts data to all subscribers and subscribers selects packets destined for it. While Uplink channel is shared by multiple SSs and to ensure this sharing this channel is slotted and these slots are allocated by BS to various SSs in one uplink frame by using Time Division Duplexing (TDD) or Frequency Division Duplexing (FDD). This slot allocation information is broadcasted by the BS through the Uplink Map Message (UL-MAP) at the beginning of each frame. UL-MAP contains Information Element (IE) which includes the transmission opportunities, i.e., and the time slots in which the SS can transmit during the uplink subframe. After receiving the UL-MAP, each SS will transmit data in the predefined time slots as indicated in IE.

The base station divides the timeline into contiguous *frames*, each of which further consists of a downlink (*DL*) and an uplink (*UL*) *subframe*. For the case where MR-BS supports more than two-hop relay, the DL and UL sub-frames shall include at least one access zone and may include one or more relay zone to enable RS operating in either transmit or receive mode. The DL/UL access zones are dedicated for transmission between MSs and their access stations (MR-BS or RS), and they are fully compatible with the 802.16e frame structure. The DL/UL relay zones are dedicated for transmission between MR-BS and the RS or between two RS. In each relay zone, BS and RS can stay in the mode of transmission, reception or being idle. However, it is not expected to have BS or RS switch from one mode to the other within the same zone. In order to give wireless device sufficient time to switch from one mode to another, the corresponding time gap (e.g., TTG and RTG) is inserted between two consecutive sub-frames. The IEEE Std. 802.16j specifies the following gaps:

- R-TTG: RS transmit/receive transition gap between uplink access zone and uplink relay zone in RS frame between DL access zone and DL relay zone in RS frame

- R-RTG: RS receive/transmit transition gap between uplink access zone and uplink relay zone in RS frame. The case where each DL and UL sub-frame comprises of more than one relay zones is shown in Fig. 1.2

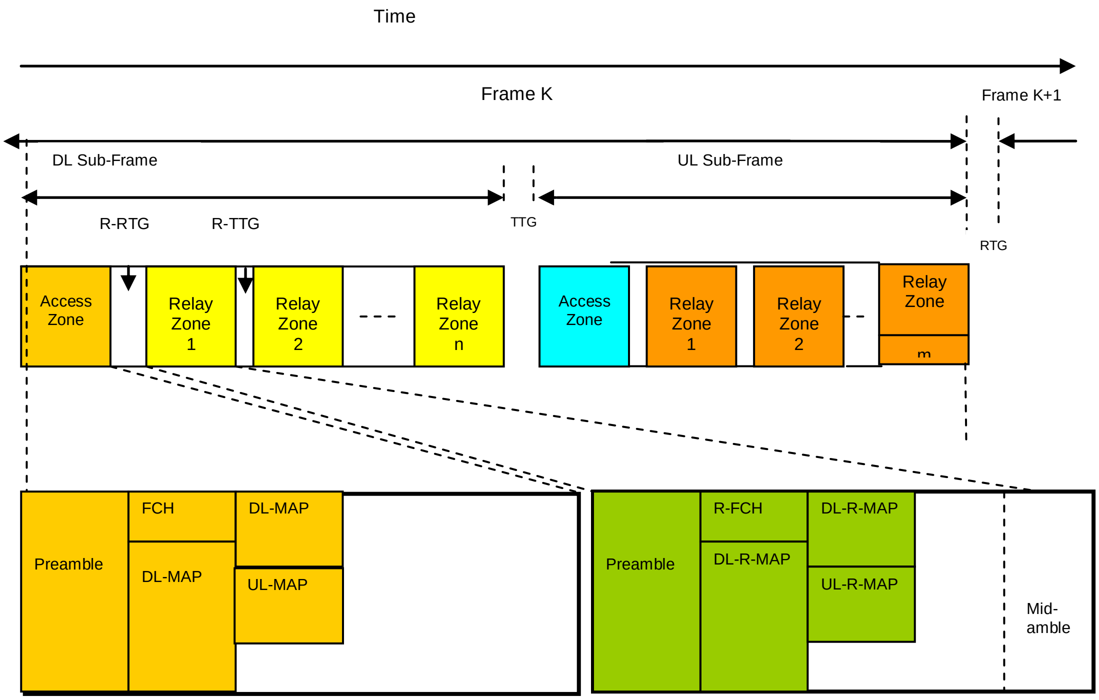

Fig.1.2 Frame Structure for MMR

The new frame structure for MMR network is also composed of a downlink and a uplink portion. However, in order to enable Multihop communication, the downlink and uplink subframe is further divided into multiple *zones* in the time domain. The first zone in both the downlink and uplink subframe is dedicated for communication that directly engages MSs, and thus is naturally called *access zone*. More specifically, MSs receive from or transmit to the BS or RS with which they are associated in the access zone of the downlink and uplink subframe, respectively. The access zone in both downlink and uplink may be followed by one or multiple relay zones. In each relay zone, BS and RS can stay in the mode of transmission, reception or being idle. However, it is not expected to have BS or RS switch from one mode to the other within the same zone.

Certainly, proper signalling function has to be installed to support the frequent switch of the zones, without confusing the legacy MSs. Similar to the legacy frame structure, both BS and RS transmit in the first data OFDMA symbol in the downlink access zone an FCH, which is immediately followed by a DL- MAP and an UL-MAP. However, the DL-MAP and UL-MAP in MMR frame structure have to convey the new information pertaining to the succeeding relay zone(s) in the same frame. The notion of relay zone remains transparent to legacy MSs, as they will only become aware of the existence of some new zones following the access zone based upon the UL-MAP and DL-MAP, and thus simply stay idle during these relay zones. Meanwhile, when a RS initially enters the MMR network, it would lock onto the preamble transmitted by BS or existent RSs in the access zone, and establish proper synchronization with the network. The RS can then extract complete information related to succeeding relay zones from the DL-MAP and UL-MAP, and thus become prepared to receive further signaling instruction in the first downlink relay zone.

In the first downlink relay zone, BS and access RS will transmit its own *preamble*, *relay FCH* (R-FCH), *relay DL- MAP* (R-DL-MAP) and *relay UL-MAP* (R-UL-MAP) consecutively. Since this preamble is placed in an intermediate zone within a downlink subframe, it is also known as *midamble*. Midamble can help further synchronize subordinate RSs with the BS or access RS, while R-FCH specifies the length of the R-DL-MAP. Since the channel on a relay link is expected to enjoy better quality, R-DL-MAP may can be transmitted using a higher modulation scheme and less repetition coding, thereby reducing the signaling overhead. All the detailed burst allocations within each downlink and uplink relay zone of the current frame then will be provided by R-DL-MAP and R-UL-MAP, respectively. Moreover, R-DL-MAP and R-UL- MAP can also indicate the partition of the access zone and relay zone(s) within the frame that immediately follows, there by enabling a flexible and adaptive frame structure configuration on a per-frame basis. To improve the overall network performance, multiple wireless transmissions at the same frequency band can occur simultaneously, if there is no destructive interference to a transmission made by others.

The frame structure design is more challenging in the new mobile Multihop relay based (MMR) network architecture, as numerous dimensions of design constraints and challenges have been introduced. In [80] a generic frame structure to support mobile Multihop relay (MMR) operation of IEEE 802.16j, while maintaining the backward compatibility with the legacy 802.16e mobile stations was proposed and analyzed.

## 1.3 Protocol Layers

The primary task of the WiMAX MAC layer is to share efficiently the wireless channel and to provide an interface between the network layer and the PHY layer. It can be seen that the 802.16 standard defines only the two lowest layers, the Physical Layer and the MAC Layer, which is the main part of the Data Link Layer, with the LLC layer very often applying the IEEE 802.2 standard. The MAC layer is itself made of three sub layers as shown in Figure 1.3. The IEEE 802.16 MAC [87] was designed for point-to-multi-point BWA applications to support QoS for up-link (SS to BS) and down-link traffic (BS to SSs), power management, mobility management and security.

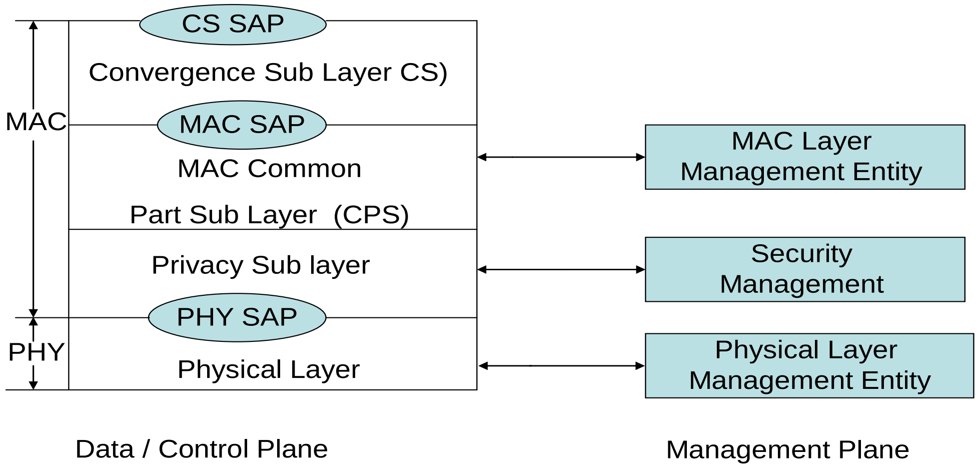

Fig. 1.3: Protocol layers of 802.16 Standard

The dialogue between corresponding protocol layers or entities is made as follows. A Layer X addresses an XPDU (Layer X Protocol Data Unit) to a corresponding Layer X (Layer X of the peer entity). This XPDU is received as an (X-1) SDU (Layer X-1 Service Data Unit) by Layer X-1 of the considered equipment. For example, when the MAC Layer of equipment the CS (Convergence Sublayer), the CPS (Common Part Sublayer) and the Security Sublayer sends an MPDU (MAC PDU) to corresponding equipment, this MPDU is received as a PSDU (Physical SDU) by the Physical Layer.

## Convergence Sub Layer (CS)

The service-specific Convergence Sublayer (CS), often simply known as the CS, is just above the MAC CPS sublayer. The CS uses the services provided by the MAC CPS, via the MAC Service Access Point (SAP).

The CS performs the following functions:

1. Accepting higher-layer PDUs from the higher layers. In the present version of the standard, CS specifications for two types of higher layers are provided: the asynchronous transfer mode (ATM) CS and the packet CS.
2. Classifying and mapping the MSDUs into appropriate CIDs (Connection Identifier). This is a basic function of the Quality of Service (QoS) management mechanism of 802.16 BWA.
3. Processing (if required) the higher-layer PDUs based on the classification.

4. An optional function of the CS is PHS (Payload Header Suppression), the process of suppressing repetitive parts of payload headers at the sender and restoring these headers at the receiver.
5. Delivering CS PDUs to the appropriate MAC SAP and receiving CS PDUs from the peer entity.

**Medium Access Control Common Part Sub Layer (MAC CPS)**

The Common Part Sub layer (CPS) resides in the middle of the MAC layer. The CPS represents the core of the MAC protocol and is responsible for:

1) bandwidth allocation
2) connection establishment
3) maintenance of the connection between the two sides

The 802.16 standard defines a set of management and transfer messages. The management messages are exchanged between the SS and the BS before and during the establishment of the connection. When the connection is realised, the transfer messages can be exchanged to allow the data transmission. The CPS receives data from the various CSs, through the MAC SAP, classified to particular MAC connections. The QoS is taken into account for the transmission and scheduling of data over the PHY Layer. The CPS includes many procedures of different types: frame construction, multiple access, bandwidth demands and allocation, scheduling, radio resource management, QoS management, etc.

## Security Sub Layer

The MAC Sublayer also contains a separate Security Sublayer providing authentication, secure key exchange, encryption and integrity control across the BWA system. The two main topics of a data network security are data encryption and authentication. Algorithms realising these objectives should prevent all known security attacks whose objectives may be denial of service, theft of service, etc. In the 802.16 standard, encrypting connections between the SS and the BS is made with a data encryption protocol applied for both ways. This protocol defines a set of supported cryptographic suites, i.e. pairings of data encryption and authentication algorithms. An encapsulation protocol is used for encrypting data packets across the BWA. This protocol defines a set of supported cryptographic suites, i.e. pairings of data encryption and authentication algorithms. The rules for applying those algorithms to an MAC PDU payload are also given.

An authentication protocol, the Privacy Key Management (PKM) protocol is used to provide the secure distribution of keying data from the BS to the SS. Through this secure key exchange, due to the key management protocol the SS and the BS synchronize keying data. The basic privacy mechanisms are strengthened by adding digital-certificate-based SS authentication to the key management protocol. In addition, the BS uses the PKM protocol to guarantee conditional access to network services. The 802.16e amendment defined PKMv2 which has the same framework as PKM, re-entitled PKMv1, with some additions such as new encryption algorithms, mutual authentication between the SS and the BS, support for a handover and a new integrity control algorithm.

## Physical Layer

WiMAX is a BWA system. Hence, data are transmitted at high speed on the air interface through (radio) electromagnetic waves using a given frequency (operating frequency). The Physical Layer establishes the physical connection between both sides, often in the two directions (uplink and downlink). As 802.16 is evidently a digital technology, the Physical Layer is responsible for transmission of the bit sequences. It defines the type of signal used, the kind of modulation and demodulation, the transmission power and also other physical characteristics. The 802.16 standard considers the frequency band 2–66 GHz. This band is divided into two parts:

1. The first range is between 2 and 11 GHz and is destined for NLOS transmissions. This was previously the 802.16a standard. This is the only range presently included in WiMAX.
2. The second range is between 11 and 66 GHz and is destined for LOS transmissions. It is not used for WiMAX.

The physical layer of IEEE 802.16 consists of a number of air interfaces such as Wireless MAN- OFDM and Wireless MAN-OFDMA. Both frequency- division duplex (FDD) and Time-Division Duplex (TDD) are supported for communication between BS and SS. A frame consists of a downlink subframe and an uplink subframe. IEEE 802.16 also supports adaptive burst profile that enables the transmission parameters to be modified on a frame-by-frame basis for each SS.

The MAC is connection-oriented, which means that all services are mapped to a connection identified by a 16-bit connection identifier (CID). Scheduling of data transfer is done by the Base Station in the PMP mode. The downlink subframe sent by the BS contains the DL-MAP and UL-MAP. The DL-MAP specifies the downlink channel access and the associated burst pro- file. The UL-MAP defines the uplink channel access, that is, the time slot in which the SS can transmit in the uplink subframe and the uplink data burst profiles.

## OFDM and OFDMA

IEEE 802.16d (fixed WiMAX) uses Orthogonal Frequency Division Multiplexing (OFDM), IEEE 802.16e (mobile WiMAX) uses Orthogonal Frequency Division Multiplexing Access (OFDMA) and IEEE 802.16j only focuses on the OFDMA PHY mode of IEEE 802.16e-2005 as explained in [65].
Instead of a single carrier, OFDM uses multi-carrier modulation that increases the data throughput and eliminates problems with multi-path signal and spectral interference. OFDM allows only one user on the channel at a time. Time Division Multiple Access (TDMA) is used to accommodate multiple users where interfering users are assigned different timeslots.

OFDMA is a multi-user OFDM that allows multiple users to access the channel at the same time. Interfering users are assigned different sub channels on the same timeslot. Thus OFDMA can be viewed as a combination of FDMA and TDMA. A slot refers to a timeslot in OFDM-based fixed WiMAX (WiMAX mesh) networks and a slot refers to a slot in the time-frequency grid in OFDMA-based mobile WiMAX (MMR) networks as depicted in Figure 1.4.

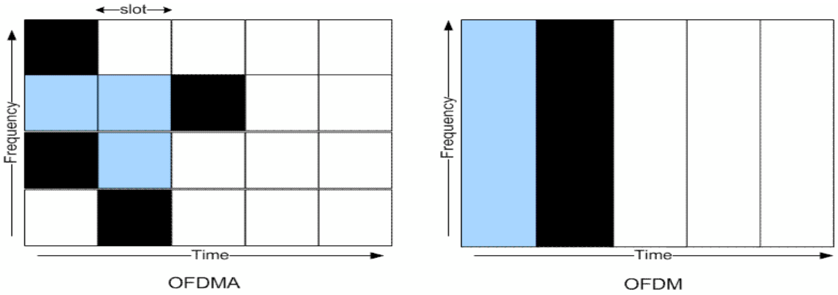

Fig 1.4: OFDMA and OFDM

## 1.4 Traffic Classes

Scheduling services represent the data handling mechanisms supported by the MAC scheduler for data transport on a connection. Each connection is associated with a single data service. Each data service is associated with a set of QoS parameters which quantify aspects of its behavior. IEEE 802.16 defines five QoS service classes [72]: Unsolicited Grant Scheme (UGS), Extended Real Time Polling Service (ertPS), Real Time Polling Service (rtPS), Non Real Time Polling Service (nrtPS) and Best Effort Service (BE). Each of these has its own QoS parameters such as minimum throughput requirement and delay/jitter constraints.

## Unsolicited Grant Service (UGS)

Unsolicited grant service is a service flow in which the transmission system automatically and periodically provides a defined number of timeslots and fixed packet size that is used by a particular receiver. UGS is commonly used to provide services that require a constant bit rate (CBR) such as audio streaming or leased line (e.g. T1 or E1) circuit emulation. UGS provides a constant bit rate for a single connection. A subscriber device may need additional bandwidth for an additional service that is added to a connection or to temporarily provide more bandwidth on the UGS connection. To request more bandwidth on a UGS connection, a poll me bit or slip indicator bit may be used.

## Error real time Polling service (ertPS)

ertPS is a scheduling mechanism that builds on the efficiency of both UGS and rtPS. The ertPS is designed for realtime traffic with variable data rate (such as VOIP service with silence suppression) over the WiMAX network. This service is designed to support VoIP with silence suppression. No traffic is sent during silent periods. ertPS service is similar to UGS in that the BS allocates the maximum sustained rate in active mode, but no bandwidth is allocated during the silent period. There is a need to have the BS poll the MS during the silent period to determine if the silent period has ended. The QoS parameters are the same as those in UGS.

## Real time polling service (rtPS)

The Real-Time Polling Service (rtPS) is designed to support real-time service flows that generate variable size data packets on a periodic basis, such as MPEG video. The service offers real-time, periodic, unicast request opportunities, which meet the flow's real-time needs and allow the SS to specify the size of the desired grant. This service requires more request overhead than UGS, but supports variable grant sizes for optimum data transport efficiency.

## Non real time polling service (nrtPS)

The Non-Real-Time Polling Service (nrtPS) is designed to support non real-time service flows that require variable size Data Grant Burst Types on a regular basis, such as high bandwidth FTP. The service offers unicast polls on a regular basis, which assures that the flow receives request opportunities even during network congestion.

## Best effort (BE)

Most of data traffic falls into this category. This service class guarantees neither delay nor throughput. The bandwidth will be granted to the MS if and only if there is a left-over bandwidth from other classes. In practice most implementations allow specifying minimum reserved traffic rate and maximum sustained traffic rate even for this class. The BS and the SS use a service flow with an appropriate QoS class (plus other parameters, such as bandwidth and delay) to ensure that application data receives QoS treatment appropriate to the application.

## 1.5 Quality of Service

Quality of service (QoS) parameters is the parameters that control the priority, reliability, speed and amount of traffic sending over a network. Typical QoS parameters include [72]: throughput, delay, jitter, loss ratio, and error rate.

**Throughput:** It is the average rate of successful message delivery over a communication channel. This data may be delivered over a physical or logical link, or pass through a certain network node. The throughput is usually measured in bits per second (bit/s or bps), and sometimes in data packets per second or data packets per time slot.

**Latency or delay**: Latency is a measure of time delay experienced in a system, the precise definition of which depends on the system and the time being measured. Latency in a packet-switched network is measured either *one-way* (the time from the source sending a packet to the destination receiving it), or *round-trip* (the one-way latency from source to destination plus the one-way latency from the destination back to the source).

**Fairness**: Aside from assuring the QoS requirements, the left-over resources should be allocated fairly. The time to converge to fairness is important since the fairness can be defined as short term or long term.

**Packets lost:** it is the number of packets lost in the network during transmission.

In Wireless transmissions the packet loss will be more than that of wire transmission. So packets lost is also a QoS parameter which should be minimized.

## 1.6 Motivation

As the technology is being enhanced, so are the demands of end users and their applications. A wide variety of new applications are coming up daily. These applications have different demands from the underlying network protocol suite. High bandwidth internet connectivity has become a basic necessity for almost all these applications. For example, real time applications such as video streaming and voice conferencing are very common and have stringent QoS requirements. Therefore, it is crucial to understand, analyze, evaluate and eventually propose a flexible architecture and scalable protocols to address these requirements. The motivation behind our work is to tackle critical issues for successful deployment of Multihop relay based wireless networks.

Though the concept of WMANs is both exciting and thrilling, considerable work is still required at all layers of the network protocol suite before their wide scale deployment could commence. This suffers from a multitude of problems. Some of the key challenges are improving the capacity, guaranteeing minimum bandwidth and end-to-end fairness. Moreover with the real time applications, flexible Quality of Service provisions are more in demand. Existing protocols are not sufficient to completely satisfy these requirements.

As found from literature, most of the available techniques doesn’t provide fair access to all nodes in Multihop WiMAX. In fact, the flows that have to travel fewer hops tend to enjoy higher performance while longer hop length flows suffer from extremely low throughputs. Moreover, end-to-end delay and throughput bounds cannot be guaranteed with the current MAC/Routing protocols.

In this context the present work focused on the design of some scheduling schemes so that enhancements in performance could be achieved.