A Comprehensive Review on WiMAX Networks

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Abstract- In the new era of communication, WiMAX (IEEE 802.16) is the most emerging technology that enables ubiquitous delivery of broadband wireless access for fixed and mobile users. It is a more innovative and commercially viable alternative to cable modems and DSL technologies as it is cost effective, easy to implement, high performance and high resource utilization technology. This economic environment has led to the development of the IEEE 802.16 standards [1] to support broadband wireless multi-service access in metropolitan area. In addition, the Worldwide Interoperability for Microwave Access (WiMAX) Forum [2] has been formed which promotes the technology and provides compatibility and interoperability for 802.16-based products. Accordingly, the term WiMAX is often used interchangeably with IEEE 802.16 technologies. WiMAX a wireless standard which uses orthogonal frequency division multiple access (OFDMA) and promises to offer mobile broadband services even at a vehicular speed of up to 120 km/h. WiMAX complements the third generation (3G) wireless standards and the wireless local area networks (WLANs) on coverage and data rate. IEEE 802.16e-based WiMAX is the standard that is likely to dominate the fourth generation (4G) wireless world. WiMAX needs no line of sight for a connection and covers a larger coverage area than WLAN and is comparatively less costly compared to the current 3G cellular standards. Although the WiMAX standard supports both fixed and mobile broadband data services, the latter have larger demand. In WiMAX, quality of service (QoS) is provided through scheduling of the different types of traffic classes defined by the standard. Each class has its own bandwidth requirements as well as its QoS, which has to be maintained. This paper reviews and compares different types of connections defined in the WiMAX standard and provides an overview of the state-of-the-art mobile WiMAX technology and its development, the Mobile WiMAX standard, the development of the standards to support mobile multihop relays in a WiMAX network and applications of WiMAX are provided.

Keywords- IEEE 802.16, WiMAX, QoS, OFDMA, Scheduling.

I.INTRODUCTION

Before the development of IEEE 802.16 standard, the effective ways to obtain access to broadband internet services were mainly through T1, Digital Subscriber Line (DSL), or cable modem based connections. However, these wired infrastructures are costlier, especially for deployment in rural areas and developing countries. This limitation propelled the industry to devise an alternative means of obtaining broadband internet access and the wireless medium was selected as the viable approach. In the hierarchical architecture, base stations (BSs) are connected to the core network by one or many centralized network elements, such as the radio network controller (RNC) and the general packet radio service (GPRS) serving node (GSN) in Universal Mobile Telecommunications System (UMTS) networks [3], or the access service network gateway (ASN-GW) in mobile WiMAX networks [4]. Such centralized controllers manage all the control contexts of mobile nodes (MNs) that are attached to the BSs under their supervision. They also handle data traffic flow between the core network and the BSs, so all user traffic always goes through these centralized controllers. The name WiMAX was proposed by the WiMAX Forum, a consortium of about 420 members including major corporations like AT&T, Fujitsu, Intel and Siemens, was set up in June 2001 to promote conformance and interoperability of the technology and promote its commercial use in the market. The WiMAX Forum and IEEE 802.16 subcommittee are both involved in the development of open standards based broadband wireless networks. The IEEE 802.16 subcommittee is purely a technical body that defines the 802.16 family of broadband wireless radio interface standards. IEEE 802.16 defines the layer 1 (physical, also referred as

PHY) and layer 2 (data link or Media Access Control - MAC) of the (Open Systems Interconnection) OSI seven layer network model. The IEEE 802.16 standard provides specification for the MAC and PHY layers for the air interface. The standard includes details about the various flavors of PHY layers supported and characteristics of the MAC layer such as bandwidth request mechanisms and the scheduling services supported. It does not define standardized network architecture beyond the base station. The WiMAX Forum fills this gap and creates an end-to-end broadband wireless network, so it prepares profiles for systems that comply with the IEEE 802.16 standard and create interoperability tests to ensure different vendors' implementation can work together. WiMAX supports high data rate applications with a variety of Quality of Service (QoS) requirements. Companies like Motorola and Samsung are already developing WiMAX phones and PDAs and they are already in use in Korea with WiMAX cousin technology, WiBRO (Wireless Broadband) [5].

The paper is broadly divided into eleven sessions. The first session opens with a brief introduction to networks and its types. A description of WiMAX (IEEE 802.16) networks is given in the first session and second session deals with literature review. The related research work published in this field WiMAX networks is properly reviewed and given in chronological order. Also, Standards, Certification profile, structure of the standard, comparison with other standards, QoS, QoS mechanism and services classes as prescribed by WiMAX are presented, this is followed by the applications of WiMAX. In last conclusions drawn and also an insight into the future work is presented.

II.WiMAX

In the new era of communication, WiMAX (IEEE 802.16) is the most emerging technology that enables ubiquitous delivery of broadband wireless access for fixed and mobile users. The IEEE 802.16 standard widely known as WiMAX (Worldwide Interoperability for Microwave Access), has been developed to accelerate the introduction of broadband wireless access into the marketplace. Prior to the introduction of the IEEE 802.16 standard, the most effective ways to obtain access to broadband internet service were mainly through T1, Digital Subscriber Line (DSL), or cable modem. However, these wired infrastructures are considerably more expensive, especially for deployment in rural areas and developing countries. This limitation propelled the industry to devise an alternative means of obtaining broadband internet access and the approach taken was via the wireless medium. The traditional wireless cellular networks have a hierarchical architecture in which centralized controllers facilitate resource management and mobility support in a highly efficient manner, typically for voice call services. Although they are designed primarily for wireless internet access, currently deployed mobile WiMAX networks also adopt this cellular-style hierarchical architecture, but they use less hierarchy. It is one of the most emerging technologies and provides an exciting range of additional features to the existing techniques for the broadband. It can also be treated as an alternative to the existing cable and DSL technologies as it has low cost and can be easily implemented. It also provides high data rate applications with a variety of Quality of Service (QoS) requirements. The famous companies like Motorola and Samsung are already developing WiMAX phones and PDAs and they are already in use in Korea with WiMAX cousin technology, WiBRO (Wireless Broadband) [5]. Nowadays WiMAX is considered as one of the main technologies for next generation high speed wireless access networks. It gives a larger coverage compared to Wi-Fi while supporting string QoS and security mechanism because of its optimizable physical layer and too many adaptable capabilities. This latest innovative WiMAX technology is considered as one of the main standards for future wireless networks. Several technologies used by WiMAX, such as Orthogonal Frequency-Division Multiple Access (OFDMA) and resource allocation methods with differentiated QoS are parts of Next Generation Networks (NGN) standards [7]. Mobile WiMAX standard offers scalability in both radio access technology and network architecture; thus, it provides flexibility in network deployment and service offerings [8]. WiMAX can be convenient for Hybrid Networks, Local Area Networks or long range transmission thanks to MAC relays defined in 802.16j [9].

Key Features of WiMAX Networks [10]

The eight key features of WiMAX networks that differentiate it from other metropolitan area wireless access technologies are: use of Orthogonal Frequency Division Multiple Access (OFDMA), Scalable use of any spectrum width (varying from 1.25 MHz to 28 MHz), Time and Frequency Division Duplexing (TDD and FDD), Advanced antenna techniques such as beam forming, multiple input multiple output (MIMO), Per subscriber adaptive modulation, Advanced coding techniques such as space-time coding and turbo coding, Strong security and Multiple QoS classes suitable not only for voice but designed specifically for a combination of data, voice and video services.

III.LITERATURE REVIEW

In recent years, there has been a rapid growth in various wireless networks. Along with it, there is a multifold increase in demand for wireless data services and multimedia applications. To meet the growing demand and provide better services, there has been a lot of research in this field. In this session, a brief summary of current work in this field is presented.

Guerin and Peris [11] studied basic mechanisms and directions for providing Quality of Service in packet networks. They have investigated control path mechanisms that are needed to allow the users as well as network to agree on service definition and data path mechanisms which will enable to provision of differentiated services. These concepts have been adapted into IEEE 802.16 standard in providing the QoS support.

Chu *et al.* [12] proposed QoS architecture for the MAC protocol of IEEE 802.16 BWA system. It includes the traffic classifier, the SS's upstream scheduler and the BS's upstream and downstream schedulers. The architecture that provides QoS guarantees for 802.16 systems is based on priority scheduling and dynamic bandwidth allocation. It also proposes efficient scheduling strategy for the schedulers.

Wongthavarawat and Ganz [13] present an integrated scheduling algorithm and an admission control policy by which the bandwidth is allocated among different service classes according to the fixed priority of each traffic class strictly. They propose a centralized system, where the QoS architecture is based in the BS and the scheduling or the admission control algorithms are also managed by the BS.

Nair *et al.* [14] present the MAC protocols used in the WiMAX networks and discuss the types of provisioning and Quality of Service (QoS) that can be achieved using the features of this MAC protocol to facilitate the WiMAX deployments. They cover implementation challenges of the WiMAX MAC to achieve QoS goals.

A general framework of a cross-layer network-centric solution is presented by Zhang *et al.* [15]. They have described the recent advances in network modeling, QoS mapping and QoS adaptation in term of providing end-to-end QoS for video delivery over wireless internet.

Alavi *et al.* [16] present an inclusive QoS architecture for IEEE802.16 standards. The architecture supports QoS mechanisms in IEEE 802.16 standards. They contend that although the IEEE 802.16 standard defines different mechanisms to provide QoS requirements, the challenge lies in developing efficient design to meet those requirements. This makes providing QoS, a challenging issue. To overcome this issue, they put forward a design approach to implement the proposed architecture for all kinds of traffic classes defined in the standard.

QoS support in IEEE 802.16 networks has been covered by Cicconetti *et al*. [17]. They have evaluated performance of the networks using a prototypical simulation for IEEE 802.16 protocol.

An analysis and discussion of the performance of the five scheduling algorithms, namely UGS, ertPS, rtPS, nrtPS and BE, is discussed by Lee *et al*. [18]. Through the analysis of resource utilization efficiency and VoIP capacity, they have identified some of the bottlenecks in Unsolicited Grant Service (UGS) and real-time Polling Service (rtPS). The performance of UGS suffers due to waste of uplink resources. In rtPS there is an additional access delay and MAC overhead due to bandwidth process in rtPS algorithm for delivery of VoIP services.

Sayenko *et al*. [19] put forward a paper for ensuring the QoS requirements in 802.16 scheduling. They describe a scheduling solution for the WiMAX base station. The scheduling policy i.e. the algorithm to allocate slots in not defined in WiMAX specifications. It is open for alternative implementation. Their simulation results reveal that the proposed scheduling algorithm ensures QoS requirements for all WiMAX service classes.

Mai *et al.* [20] put forward a cross-layer QoS framework in the IEEE 802.16 network. They discussed support mechanisms and opportunistic scheduling designs tailored for WiMAX. Two novel mechanisms are proposed in the framework for performance improvement. A TCP-MAC layer cross-layer design has been proposed which maps network layer and data-link layer functionalities to provide QoS support in the IEEE 802.16d networks.

Roca [21] defined QoS as an indicator of level of performance of the wireless technology or system which can be measured by throughput, jitter, delay and packet loss. The author built a simulator relying on Network Simulator NS-2 to test the QoS parameters using 5 types of services. NS-2 doesn't implement a definitive WiMAX module. Thus, modules should be added to NS2 in order to run simulations to test WiMAX networks. Some of these modules were implemented by National Institute of Standards and Technology (NIST) and Distributed Systems Laboratory (NDSL). The NIST module implements Orthogonal Frequency Division Multiplexing (OFDM) while the NDSL module implements Orthogonal Frequency Division Multiple Access (OFDMA) [22].

Performance analysis of three types of connections defined in the WiMAX standard (UGS, rtPS, nrtPS) have been given by Ghazal *et al.* [23]. Different levels of priority and blocking probability are assigned to each class of service. This performance analysis has been done using an analytical model for evaluating admission control (AC) for the previous mentioned classes in WiMAX network. The probability of blocking of a connection is higher for lower priority service classes, while delay of the UGS service class is much affected by the increase of the size of a contention window.

Neves *et al.* [24] addressed the lack of QoS support for WiMAX in NS2-NISTsoftware. A QoS framework, composed by a packet classification mechanism and a scheduler, has been specified and implemented on the simulator, providing service differentiation over WiMAX networks. Furthermore, in order to validate the developed solutions, a set of QoS oriented scenarios have been simulated and the obtained results show that the implemented model is able to differentiate efficiently between the different traffic classes defined in the WiMAX model.

Islam *et al*. [25] conducted a statistical analysis of QoS parameters of mobile WiMAX. Two important QoS parameters of VoIP service in Mobile WiMAX network were end-to-end delay and jitter. The paper presented the statistical analysis for these two parameters. The sampled data is analyzed with Chi-Square Goodness-of-Fit Test, Kolmogorov-Smirnov and Anderson-Darling test, to verify the distribution of parent population and then confidence level with minimum number of samples. The authors considered about 400 samples for end-to-end one way delay and jitter for the analysis. The maximum delay was 63.57 ms and the minimum delay was 31.77 ms. The maximum and minimum values of jitter were 9.8 ms and 0.23ms. Though the values were very less but they can be further reduced.

Dai and Zhao [26] proposed schemes for the enhancement of the bandwidth request messages. They put forward resource allocation and scheduling schemes for use under real-time traffic conditions. The scheme proposed by them can be viewed as an extension of the existing WiMAX rtPS and ertPS bandwidth request schemes. The bandwidth requests, in their solution, are made to carry latency related information about the buffered real-time packets. Three different schemes have been proposed. Different levels of delay-budget information in the bandwidth request messages are carried by each of these schemes to the BS. They put forward that the bandwidth request scheme with partial delay information achieves good real-time performance.

Talwalkar and Ilyas [27] present the general concepts of Quality of service (QoS) in wireless networks. The IEEE 802.16/WiMAX network architecture was presented and the MAC layer features that enable end-to-end QoS mechanism in the network were discussed. Various service flows that are supported in WiMAX were discussed in details. VOIP traffic and video streaming traffic was analyzed using a simulation based on network simulator, ns-2. The effect of different service flows on QoS parameters like throughput, packet loss, average jitter and average delay were studied. In general, it was observed that the UGS service flow has the least overhead in terms of bandwidth request and it is the highest in rtPS service flow. It can be concluded from the results that the VOIP traffic can be best served with UGS service flow. The rtPS service flow is designed for applications such as streaming audio and streaming video. During the analysis of the video traffic, as the number of nodes increases, rtPS service flow comes out to be better than BE service flow for average jitter. UGS still has lower packet loss. However, UGS service flow does not utilize the network resources effectively when the traffic is not constant bit rate traffic. The simulation was done for less number of mobile nodes (< 50).

In a study by Mach [28], simulation was performed with the aim to compare the different scheduling services UGS, rtPS and ertPS. The performance metrics used in the simulation were system throughput, delay and signaling overhead as a function of traffic load in the system. The simulation was done in Matlab and consisted of movement algorithms for the SS's to never move beyond the coverage area of the BS's. The results showed that UGS is not a good alternative because overall system capacity tended to decrease a lot in its use. When ertPS was in use the best results were obtained; system throughput was considerably higher, whereas signaling overhead and packet delay were smaller in comparison to the other test cases.

Park [29] put forward an efficient uplink bandwidth allocation scheme for real-time services. In order to minimize the wastage of bandwidth and provide proper QoS, the author proposed a dual architecture and introduced the notion of target delay. In the scheme presented, based on the amount of bandwidth request, the delay and its variation with time (i.e., jitter) are regulated as per the desired level for real-time services. The paper proposes a dual feedback scheme, which can help in updating the bandwidth request for the backlogged data packets in the queue, which could have occurred due to the differences in the rates attributed to packet arrival and packet servicing. The performance results appear to be consistent even for different traffic patterns.

Sedoyeka *et al.* [30] evaluated Quality of Service of WiMAX in a developing country's environment also the critical QoS parameters delay and throughput (packets/seconds) were analysed. The values of the QoS parameters were not optimized and lesser number of nodes were taken into consideration.

Delannoy *et al.* [31] presents QoS estimation methods, measurements over WiMAX networks and highlights the complexity of this process. The paper presents performance measurements in term of achievable rate of an operational WiMAX network to evaluate its capability to support different types of media transmission. It narrates the importance of accurate time synchronization in the measurement process which is difficult to achieve and therefore proposes a time synchronization method to derive end-to end delay measurements with appropriate accuracy.

An analysis of a location based performance scenario was carried out by Jha *et al*. [32]. They studied location based performance of WiMAX network for QoS with optimal Base Stations (BS) and critical QoS parameters delay and throughput (packets/seconds) were analysed. The values of the QoS parameters were not optimized and lesser number of nodes were taken into consideration.

Rengaraja *et al*. [33] presented an integrated view of E2E QoS support in WiMAX and LTE networks, and how the QoS and QoE can be monitored by the ISPs. The E2E QoS support includes the existing QoS and service assurance supports in WiMAX and LTE networks, and the cross-layer works to assure the E2E QoS before establishing the applications. This approach is useful for the service provider to take a preventive action and to ensure service assurance.

Lin *et al.* [34] study presents a two-stage game-theoretic framework for modeling market interactions between Ethernet and WSPs for how best to share upstream bandwidth at each ONU in an integrated EPON/WiMAX network. The results also show that the proposed schemes namely, a Stackelberg game (noncooperative market) and a coalition game (cooperative market) provides better QoS support than the VOB DBA scheme [35].

IV.STANDARDS BEHIND WiMAX

Most researchers are familiar with the technical features of WiMAX technology but the evolution that WiMAX went through, in terms of standardization and certification, is missing and unknown to most people. *Pareit et al.* [36] presents a survey on all relevant activities that took place within three important organizations: the 802.16 Working Group of the IEEE (Institute of Electrical and Electronics Engineers) for technology development and standardization, the WiMAX Forum for product certification and the ITU (International Telecommunication Union) for international recognition. It is shown that most interest went to the 2.5 GHz and 3.5 GHz frequencies, that most deployments are in geographic regions with a lot of developing countries and that the highest people coverage is achieved in Asia Pacific.

V.CERTIFICATION PROFILE

A Certification Profile is defined as a particular instantiation of a system profile where the operating frequency, channel bandwidth and duplexing mode are specified. WiMAX equipments are certified for interoperability against a particular certification profile [36]. For practical reasons of interoperability, the scope of the standard needs to be reduced and a smaller set of design choices for implementation need to be defined. The WiMAX Forum does this by defining a limited number of system profiles and certification profiles. Currently, the WiMAX Forum has two different system profiles [37]. One based on IEEE 802.16-2004, OFDM PHY, called the fixed system profile and the other one based on IEEE 802.16e-2005 scalable OFDMA PHY, called the mobile system profile. The WiMAX Forum defined five fixed certification profiles and fourteen mobility certification profiles.

VI.STRUCTURE OF THE STANDARD

The Mobile WiMAX specifications basically consist of the document for the fixed system (IEEE 802.16-2004 Air Interface standard), the document for the mobile system (IEEE 802.16e amendment), and the document for the higher-layer networking from the WiMAX Forum. The first two documents define specifications for the PHY layer (such as the frame structure, OFDMA, modulation, and coding) and the MAC layer (such as data and control plane and the sleep mode for the terminals). The higher-layer networking document specifies how wide-area roaming and handoff protocol are being addressed. A licensed spectrum is a spectrum leased by an operator(s) for a given locality, whereas the licensed-exempt spectrum is the so called “free” spectrum in which anybody can use the spectrum provided certain rules are followed [38].

VII.COMPARISON WITH OTHER STANDARDS

WLAN standards such as IEEE 802.11a and IEEE 802.11g provide user throughput of 1 Mb/s or more, and allow broadband access to the Internet within a cell radius of a couple of hundred meters. On the other hand, current 3G cellular networks, which are optimized for voice, provide paging and low-data-rate services within a very large area. As stated earlier, Mobile WiMAX is a metropolitan access technique that was developed to provide not only broadband wireless access but also larger area coverage. Both WLAN and Mobile WiMAX provide high-data rate services but with quite different area of coverage; therefore, they complement each other. However, in the long run, the existing 3G networks may be threatened by the emergence of a successful Mobile WiMAX. To respond to this threat, another competing standard - 3GPP long-term evolution (LTE) is currently being developed to include advanced antenna technology, OFDMA, and flexible transmission bandwidth. Both 3GPP LTE and Mobile WiMAX share many common technologies and architectures, but also exhibit differences [39].The main common technology is orthogonal frequency-division multiple access (OFDMA [40]. In WiMAX, OFDMA is used on both the downlink and the uplink, whereas in LTE it is used only on the downlink. However, the technology used in the uplink of LTE, single-carrier frequency division multiple access (SCFDMA), is nothing but a simple modification of OFDMA [41]. Therefore, many of the OFDMA related points are valid for SCFDMA as well, and we shall point out the minor differences as we go. There are many good reasons for choosing OFDMA such as multipath handling capability, scalability of operation in different bandwidths, the ability to handle different data rates, and the ability to easily combine with multiple antenna techniques [42]. Mainly, OFDMA enables relatively simple channel compensation techniques in frequency selective fading channels, which makes it popular [42]. In addition, frequency diversity and channel feedback can be used effectively to improve robustness and throughput. One of the main differences is in the uplink, where the single-carrier FDMA (SC-FDMA) is being adopted. The SC-FDMA signal carries a lower peak-to-average power ratio and hence has better power efficiency for the subscriber units compared to OFDMA (as used in the Mobile WiMAX standard).

VIII.QUALITY OF SERVICE

There is no formal definition of Quality of Service. QoS, in the field of telephony, was defined in 1994 in the International Telecommunication Union (ITU) Recommendation E.800. This definition is very broad, listing 6 primary components: Support, Operability, Accessibility, Retainability, Integrity and Security. In 1998, the ITU published a document discussing QoS in the field of data networking. The term Quality of Service refers to the different parameters in the network that determine the type of traffic that can be supported and the type of experience a user will have. Quality of Service (QoS) is what determines if a wireless technology can successfully deliver high value services such as voice and video. It is the probability of the telecommunication network meeting a given traffic contract. In the field of packet-switched networks and computer networking it is used informally to refer to the probability of a packet succeeding in passing between two points in the network [27].

IX.QoS MECHANISM

It is important to administer efficient QoS support to various networks and to do so we have two ways. The first one is to provide plenty of resources to meet the expected peak demand with substantial safety margin. In this approach all packets get a quality of service sufficient to support applications sensitive to QoS. This approach is relatively simple but expensive, results in wastage of resources and cannot cope if the peak demand increases faster than the predicted rate. The second approach is of Admission Control. This technique consists of admitting a new connection only if the available bandwidth in the network is enough to satisfy its QoS requirement and without degrading the QoS for current connections. To administer QoS support in IP layer (layer 3) two important methods are:

i. Integrated Services (IntServ) [43]: It is a model used for providing traffic forwarding service levels in networks. It allows for microflows to be created with reserved resources (such as bandwidth) and other traffic handling characteristics (maximum packet size, maximum burst size, etc.). Traffic is pushed into these microflows in the direction of the required destination. IntServ is implemented by four components: the signaling protocol (e.g. Resource reSerVation Protocol RSVP), the admission control, the classifier and the packet scheduler. Applications requiring guaranteed service or controlled-load service must set up the paths and reserve resources before transmitting their data. The admission control routines will decide whether a request for resources can be granted. After classification of packets in a specific queue, the packet scheduler will then schedule the packet to meet its QoS requirement.

ii. Differentiated Services (DiffServ) [44]: DiffServ is architecture for providing different types or levels of service for network traffic. One key characteristic is that flows are aggregated in the network, so that core routers only need to distinguish a comparably small number of aggregated flows, even if those flows contain thousands or millions of individual flows.

The IEEE 802.16 standard includes the QoS mechanism in the MAC layer (layer 2) architecture. It defines service flows which can map to DiffServ code points. This enables end-to-end IP based QoS. Among other things, the MAC layer is responsible for scheduling of bandwidth for different users. The MAC layer performs bandwidth allocation based on user requirements as well as their QoS profiles. The standard is designed to support a wide range of applications. These applications may require different levels of QoS [27].

X.SERVICE CLASSES SUPPORTED IN WiMAX

To meet all the different QoS requirements such as packet loss, jitter, data rate, delay, system availability and other performance parameters, WiMAX utilizes different scheduling mechanisms to allocate downlink and uplink transmission opportunities for the different PDUs. The service classes supported by WiMAX are summarized in Table 1 [45]:

Table1: Summary of QoS Classes [45]

Sr.No.	Quality of Service Class	Application	QoS Specification
1.	**Unsolicited Grant Service (UGS)**	**Voice over IP (VoIP) without silence suppression, T1/E1**	**Maximum sustained rate, Maximum latency tolerance, Jitter tolerance**
2.	**Real-time Polling Services (rtPS)**	**MPEG video**	**Minimum reserved rate, Maximum sustained rate, Maximum latency tolerance, Traffic priority**
3.	**Non Real-time Polling Services (nrtPS)**	**File Transfer Protocol (FTP)**	**Minimum reserved rate, Maximum sustained rate, Traffic priority**
4.	**Best Effort (BE)**	**Web browsing, data transfer**	**Maximum sustained rate, Traffic priority**
5.	**Extended Real-time Polling Service (ertPS)**	**Voice with activity detection (VOIP)**	**Minimum reserved rate , Maximum sustained rate , Maximum latency tolerance**

XI.APPLICATIONS OF WiMAX

WiMAX due to its varied applications can be used as an alternative to existing telecommunications infrastructures. This technology basically provides Internet Protocol (IP) connectivity employing mobile broadband data access to the subscriber. The potential applications used in IP networks have tremendously increased in the recent years globally. In a fixed WiMAX variant it can substitute the telephone company's copper wire networks, the cable TV's coaxial cable infrastructure while offering Internet Service Provider (ISP) services. In mobile wireless configuration, it can substitute cellular networks and also can be used for emerging applications like Mobile TV, streaming audio/video when user is mobile [46*]*. WiMAX has the potential to impact all forms of telecommunications as shown in Figure 1.

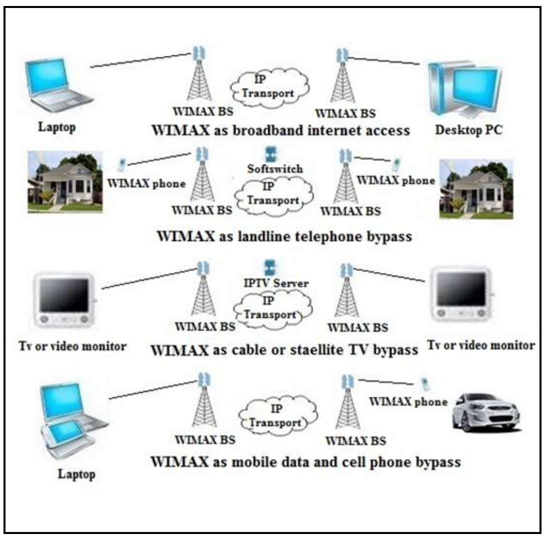

Figure 1: WiMAX Applications

The major applications can be categorized as follows:

Internet Access: Internet access is a major demand in WiMAX networks. In developing countries like India with low broadband connectivity, WiMAX is a straightforward method to provide a unicast connection between SSs and the BS, which has the link toward the Internet. Due to its wireless nature, it is faster to deploy, easier to scale and more flexible, so it is competent to serve users not satisfied by wired broadband alternative.

Group Communications: WiMAX networks cover comparatively large area and serve many group communications, such as videoconferences. To support such communication scenarios, multicast is the key technology. Since all nodes in a WiMAX network are located inside, providing such group communication becomes possible.

Metropolitan Area Distributed Service: WiMAX is an emerging wireless communication system that is expected to provide high data rate communication in metropolitan area networks. WiMAX network has enabled more value-added services in a metropolitan area. To efficiently support a large number of customers, distributed services can be enabled. In other words, a customer can access the service from any of the servers in the network in which these servers are distributed to serve the entire metropolitan area. Carter [47] proposed a novel routing framework in the network layer, manycast routing to enable distributed service. In this scheme the customer does not need to specify the exact address of a server in the network. Instead, it only needs to indicate the service it wants to access. Moreover, in such a communication scenario, the user can communicate with a subset of all the servers in order to achieve better reliability and security.

Content-Based Distribution: The content-based routing scheme is a service-oriented communication model as proposed by Carzaniga *et al*. [48]. In this scheme the sender of a message does not need to explicitly specify its destination(s). The network layer will automatically deliver the message to receivers that are interested in the content of the message.

Quality Guaranteed Applications: For a variety of applications, it is essentially desired that the network layer should provide a sufficient quality of service (QoS) guarantee, mainly in terms of bandwidth, data rate, delay and delay jitter. It is difficult to provide such a guarantee in a wireless networks as they are generally error prone. In order to address this issue, multipath routing has been studied by many researchers. Multipath routing can provide excellent quality of Service (QoS) than single-path as put forward by Zhang and Mouftah [49].

Multihoming Applications: Multihoming [50] is a technology that can provide services similar to those of multipath routing with a difference that in multi-homing, one station has two or more IP addresses and generally has the same number of interfaces. In this manner, the station can have multiple paths to access the same resources. In short, the application layer requirements routing must be addressed in the network layer design.

XII. CONCLUSION

Confucius already quoted 'Study the past if you would define the future'. Therefore, an in-depth investigation, historical review of WiMAX standard and an overview of the state-of-the-art mobile WiMAX technology and its development is provided in this paper. The results of some recent work on WiMAX networks are reported and an extensive survey of recent and relevant literature published in this field WiMAX networks is properly reviewed and given in chronological order.

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