INTEGRATION OF 4G WIRELESS TECHNOLOGIES IN A TEST-BED ENVIRONMENT

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ABSTRACT

Amongst other mandates of the 4th Generation of Wireless Networks (4G), integration and unification of various technologies is a critical subject. In this paper an end-to-end wireless network deployment in a test-bed environment is established to demonstrate a practical model for integration of various wireless technologies used by ISPs to provide services to large and small enterprise customers. The focus of this research is on the Quality of Service (QoS) considerations in a WiFi-WiMAX integrated network. The results show that integrated deployment does not deteriorate throughput as compared to a standalone WiMAX system. The throughput of approximately 967.5 kbps was observed throughout the path and shows a steady performance across various parts of the network regardless of the technology involved. Numerical results also confirm that outcomes for effectiveness of the QoS routines defined in the proposed architecture are not severely affected by the integration.

KEYWORDS

WiMAX, WiFi, Wireless technology integration, IPerf

1. INTRODUCTION

In recent years, wireless and mobile applications have rapidly become an integral part of our everyday life, demanded by a large portion of the global population. These applications and their user demands have led to the development of innovative wireless research technologies at a fast pace. Researchers in this area work on sophisticated solutions that involve network integration, Quality of Service (QoS), security as well as all-IP networks with anywhere and anytime network availability.

Workplace mobility is essential for companies to perform their day-to-day activities. Mobile devices are equipped with business-like applications to meet employees' needs such as use of emails, make voice and video calls and utilize many other web based client applications. Several competing broadband wireless technologies exist to provide enterprises with wireless coverage on local and/or global scale. These wireless technologies include 3G/4G cellular networks such as Wideband CDMA, High Speed Packet Access (HSPA), Worldwide Interoperability for Microwave Access (WiMAX), Long Term Evolution (LTE) and Wireless Fidelity (WiFi) 802.11n. Majority of enterprises have adopted Wireless Local Area Network (WLAN) deployments for their infrastructure which are based on WiFi. WLANs are fixed networks, have relatively small coverage area but have very high throughput. Extending WLAN coverage to the Internet usually requires enterprises to connect their wireless Access Points

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(APs) to the wired networks. Enterprises located in remote areas far from Internet Service Provider's (ISP) core have a choice of several technologies to use to backhaul their traffic. WiMAX is one of the contending 4G technologies that can extend long range coverage to WLANs [1].

Due to widespread adoption of WLAN, and level of consumer comfort resulting by its low cost and ease of maintenance, WiMAX is not introduced as a replacement, but rather a complement to the technology. WiMAX has been proposed as an ideal backhaul to WiFi networks, which could provide an end-to-end wireless network if deployed in an integrated WiFi-WiMAX infrastructure.

Wireless technologies are consistently improving many different aspects of their functionalities such as transmission speed, coverage, and QoS support. The prevalence of WLANs in the consumer and enterprise market made IEEE 802.11 the de-facto standard that has been deployed around the globe; give that there are limitations inherit to WiFi standard. Conventionally WiFi setups still would require a wired connection as their backend to be able to connect to Internet. This is not the desirable prerequisite in many instances such as rural or less developed areas which lack the required infrastructure. This need justifies a new wireless schema that would provide the required backhaul between the WiFi spots and the internet backbone in a reasonable and cost effective manner. One such solution is the IEEE 802.16 family of Wireless Metropolitan Area Network (WMAN) technologies that showcase an encouraging resolution to provide WLAN hotspots with required backend support. This hybrid approach would provide an ideal answer to our requirements for having a cost effective and broadband wireless network solution.

The purpose of this research is to design and implement an integrated WiFi-WIMAX network. Our design resembles an enterprise with two separate remote offices each with a local WLAN of its own that are connected to each other through a WiMAX backhaul network. We have established connection from one of these locations to the other through our WIMAX network. Our next goal is to define and study implementing a QoS system on our network. We created multiple scenarios with dissimilar usage patterns and analyzed the result of applying different classes of service on their access time and throughput.

The rest of this paper is organized in the subsequent arrangement. Section 2 is 4G technologies with emphasis on the background and comparison of how each wireless technology defines and implements QoS support. In Section 3 we discuss the design and define the requirements for the simulated network topology. In Section 4, we establish a test-bed environment to investigate the end-to-end connectivity and data rate flow. Section 5 covers the results and also provides analysis for the gathered data. Section 6 is conclusion to the study.

2. BACKGROUND

The transition to wireless network usage is increasing at an incredible rate. 3G/4G high-speed wireless technologies such as WiMAX and LTE, and WLANs' WiFi, will coexist, working in tandem to meet service provider and customer needs for truly mobile computing. No single technology can be ubiquitous since they all meet unique user requirements in a wirelessly connected world. The most robust wireless solutions will use a combination of technologies to enable increased mobility and eventually seamless roaming [1, 2].

2.1. New developments in 4G

New developments in 4G account for the success of recent wireless technologies such as LTE and WiMAX [2]. Those include new techniques in medium access, Orthogonal Frequency Division Multiple Access (OFDMA), and Multiple Input Multiple Output (MIMO) to name a few [3]. 4G networks go beyond the traditional wireless technology capabilities and explore many features that have not yet been explored comprehensively.

Important areas to this end include complete IP layer support using wireless technologies, end-to-end wireless connectivity, wireless network integration, security and QoS support at packet level. In this research we examine one of these areas namely wireless integration between WiFi and WiMAX technologies as well as the QoS considerations for such integrated networks [4].

2.2. Technologies involved in the wireless integration

Wireless technology integration is an important area in the race towards 4G. Different wireless technologies support wide variety of applications, features, and capabilities. By integrating these technologies, designers could implement solutions that utilize the capability of one technology to compensate the shortcoming of the other. In-order to accomplish the above, different types of cellular-WLAN combinations such as WiFi-LTE and WiFi-WiMAX have been proposed. [5].

As shown in Table 1, complementary features of WiFi and WiMAX make it a suitable choice for integrating these two technologies. WiFi is plug and play network while WiMAX is like a carrier transport network. WiFi is built into laptops and handsets, whereas WiMAX requires larger standalone receivers mounted on customer rooftops for optimum utility. An important benefit of WiMAX is its spectral efficiency, at least 50% more than 3G cellular networks, so it has much higher data-carrying capabilities in limited spectrum [6]. WiFi provides service over a range of 250m; whereas WiMAX can carry 100Mbps over a range of 50km between base-stations. WiFi provides a proven case for enterprise networks, while WiMAX is capable of carrier-class networks.

Table 1: Complementary capabilities of WiFi and WiMAX

Parameter	**WiFi**	**WiMAX**
Difficulty in deploying	Easy and cheap	Difficult and expansive
Mobility	Walking speeds	120 km/h
Range	250 m	50 km
Active Users	13	150
Data Rate	288.90 Mbps	100 Mbps
Typical Usage	WLANs	ISP Carrier-class networks

WiFi-backhaul has been proposed as one of the most popular derivers for WiMAX applications WiFi could benefit from WiMAX features such as long range coverage, security, QoS, and VPN capabilities. An integrated WiFi-WiMAX network is an ideal technology for service providers, to provide end-to-end wireless networks to customers in rural areas (Figure 1).

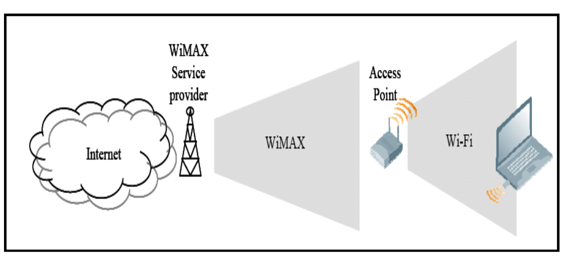

Figure 1: WiFi client with WiMAX Backhaul

2.3. QoS in Wireless Systems

Quality of Service is interpreted differently based on application and usage. Consequently one could define a set of parameters used to measure variety of radio resource levels related to the end user requirements [7]. WiMAX provides the ISPs with an excellent opportunity in allowing them to offer variety of different plans to customers depending on cost and usage model. They could potentially use different flow types offered in WiMAX to provide different levels of guaranteed service for voice, data, and video [8, 9]. This is highly desirable for both the enterprise and consumer as well. For example using a voice over IP (VoIP) program should promptly be recognized by the system and prioritized in a way that guarantees an unbroken and high quality conversation to be happening. Therefore we require a flexible QOS implementation that provides acceptable levels of latency and jitter which are the requirements of providing time sensitive services such as VoIP and Video Conferencing. The IEEE802.16d WiMAX standard provides five classes of prioritization of traffic which as follows: Unsolicited Grant Service (UGS), Real-Time Polling Service (rtPS), Extended Real-Time Polling Service (ertPS), Non-Real-Time Polling Service (nrtPS), and Best Effort (BE) [10].

WiMAX has two scheduling agents that work in tandem to make the system work; one in the Base Station (BS) and the other in the Subscriber Station (SS). Main scheduling unit would be the BS, which controls all system parameters and the burst profile and transmission periods for every connection. It is also responsible for selection of coding and modulation techniques based on the link quality, the demand, and the load on the network. On the SS side the main job of the scheduling agent is to categorize all the outgoing packets in to different classes.

3. INTEGRATED NETWORK DESIGN AND IMPLEMENTATION

The complete network architecture is comprised of an ISP core and several sites connecting to the core using a combination of WiMAX and WiFi and based deployments.In the current study we have designed a complete WiFi-WiMAX network, and demonstrated how service providers could capitalize on benefits of both technologies to provide an end-to-end wireless network, without use of infrastructure networks or cellular systems. We employed Cisco Unified Wireless Network [11] and AlvarionBreezeMAX Extreme [12] platform solutions respectively to implement the end-to-end wireless network, and measured network performance and traffic using software application Paessler Router Traffic Grapher (PRTG) network monitoring solution [13]. In this section, we illustrate the overall topology of our design and how we used integration techniques to create end-to-end WiFi-WiMAX-WiFi connectivity.

3.1. Design Overview

WiFi WLAN deployment including Access Points (AP) and Wireless LAN Controller (WLC); a WiFi-WiMAX network integration including base station, subscriber stations and ASN-gateway; and a Network Operation Center (NOC) side with the required equipment: routers, switches, severs, etc.

The design and implementation is divided into three distinct sections – a large enterprise, a small business, and an ISP core. The large enterprise network is scattered over multiple sites located in rural places, whereas the NOC, sales sites, and head office are located in urban areas. WiMAX is an apt choice to connect the enterprise’s sites. This enterprise has its server site provisioned in the NOC directly connected to the ISP’s core network.

The second enterprise is an example of a small business. It resides in an urban area and has connectivity to the service provider’s network through wired networks. The small enterprise site does not require WiMAX. Instead it utilizes a wireless LAN controller and light weight

APs with in-house DHCP and authentication servers to provide a high quality wireless experience to its customers and employees.

The ISP is the core part of the network environment. It will provide wireless connectivity using WiMAX for the rural enterprise sites thus connecting them to the Internet and other enterprise sites. The ISP consists of core routers connected to the Base Transceiver Station (BTS) as illustrated in Figure 2.

The main objective of this study is to measure an end-to-end QoS support in a WiFi – WiMAX network model. To create this topology we have built a core wireless network, based on WiMAX technology which consists of a Base Station and two Subscribers. We have also used an internal DHCP and local authentication for assigning IP addresses and authenticating the subscribers.

The WiMAX segment is considered to be the ISP section of our design. We used AlvarionBreezeMAX Extreme (BTS 5Ghz RADIO and Embedded ASN Gateway, Version 1.5.1.72) as our base station and AlvarionBreezeMAX PRO 5000 CPE as our customer side WiMAX receiver.

On the WiFi side, we have simulated an enterprise which consists of two different locations. Both locations are based on wireless environments with Cisco's Wireless LAN Controllers (WLC) and Light weight Access Points (LWAP). More specifically the WLCs are Cisco 4402 IOS Version 7.01 and LWAPs are Cisco Aironet 3500 IOS Version 7.01. WLC on each site are using layer 2 authentications to validate the APs and Layer 3 authentication to verify clients. They are also using an internal DHCP server for assigning IP addresses to the clients and to the APs[14].

Our service provider network provides three different levels of service: Best Effort (BE), none Real Time (nRT), and extended Real Time (eRT) services. We will employ these levels of service for three types of traffic: management, data and VOIP in BS and will compare their differences.

We used PRTG Network Monitoring Solution software Version 8 [13] for monitoring the network based on predefined levels of service we have in the WiMAX BS. We monitored five different types of packets that go through the system, and compared their performance in different levels of service: Ping, HTTP, FTP, RDP and VOIP.

3.2. Enterprise WiFi-WiMAX Network Architecture

The large enterprise has two main sites, located miles away from each other. In order to provide connectivity to its sites, the company utilizes WiMAX service from the ISP. The ISP's access router is plugged into a LAN switch. The WiMAX BTS, RADIUS server and a management station are also connected to the same LAN network. The Customer Premise Equipment (CPE) is located directly at one of the sites and communicates with the BTS wirelessly.

The management station equipped with the Alvaricraft software is utilized to configure the BTS. The free RADIUS server is used by the BTS to authenticate a CPE connecting to it, thus preventing any rogue CPE's from unauthorized access. The BTS comprises of an inbuilt DHCP server which is used to assign IP addresses both to the CPE as well as the network behind the CPE.

The CPE is directly connected to an AP which provides wireless connectivity to all clients. The AP and all the clients receive IP addresses from the BTS. Client machines that possess a WiMAX card can directly connect to the BTS; however WiMAX NIC cards are not yet popular, hence we extend WiMAX connectivity by using WiFi wireless LANs. This provides more flexibility in terms of wireless SSID's and user security options, since the CPE can be managed locally from client side machines by authorized users as well as over the air from the management station connected to the BTS.

The hypothetical enterprise has two different locations (branch offices). Both locations are using Unified Wireless LAN Controller. To provide end-to-end connectivity and Internet connection for the two sites they both have a WiMAX network connection in their network.

In each location the service provider has installed a CPE to establish wireless connectivity from the customer site to the service provider's network. Since the company's systems are only equipped with WiFi adaptors, we used a switch to build a connection between WiFi and WiMAX network. In order to do this we plugged our CPE to the same switch which we have our Wireless LAN Controller and LWAP on it. The CPE is used as a Gateway to Service Provider.

The second site for the enterprise network is co-located with the NOC which houses the corporate servers. The NOC consists of an oracle database server which stores the entire inventory and the company's intellectual properties. This server needs to be accessible from the other sites, so that employees at the site can update information as and when required. It also includes a web server, which hosts the enterprise corporate site.

We have also implemented a simplified representation of a service provider's core network, which plays the role of connecting inter and intra company sites. The core is utilized to demonstrate end-to-end connectivity, and consists of three routers using RIP-v2 for routing. The main site, the off-shore site and the NOC are connected to different routers in the ISP's core network.

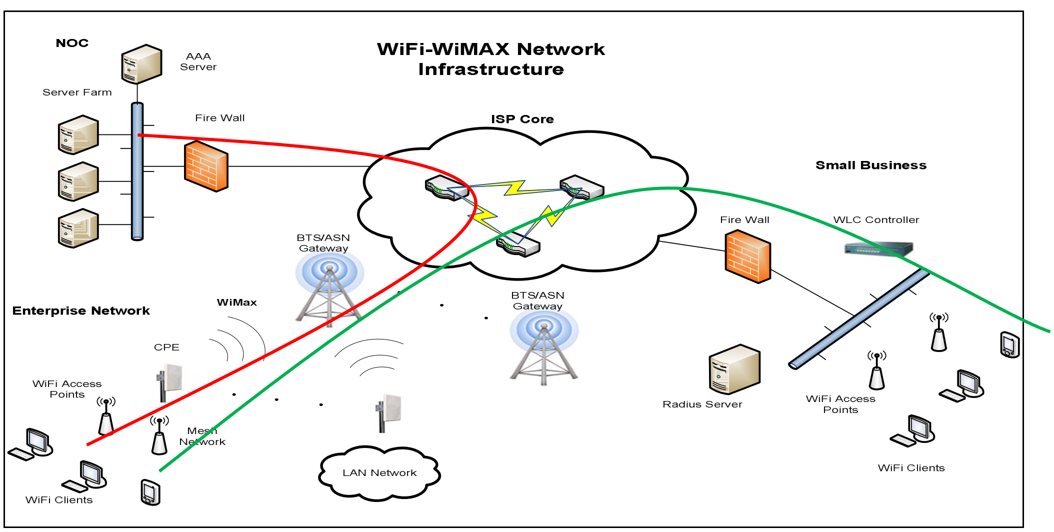

Figure 2 Network Topology
(a) Traffic flow from Enterprise Network to NOC
(b) Traffic flow from Enterprise Network to Small Business

3.3. WiFi Wireless LAN Solution

The small company resembles a coffee shop located in the city. The ISP's access router is connected to a switch in the shop. The small business is spread over two floors in a building connected through multiple APs for better wireless network coverage to all. For effective management of all APs we used Cisco's 2100 series wireless LAN controller (WLC) for AP management. The WLC and the APs are all connected to the same switch as the ISP.

The controller broadcasts two SSIDs called 'EE_Guest' and 'EE_Employees', which provide internet access to customers and the employees respectively. Since employees may need to access sensitive information, all users connecting to this SSID are authenticated by a radius server. The inbuilt DHCP server provides IP addresses to clients connecting to both SSID's. The access router from the ISP plays a router on stick role to provide inter-connectivity between the two SSID's.

3.4. WiMAX Solution Implementation

WiMAX technology is the solution for many applications transported across long distances with QoS support, longer reach, and high data rate. Typical applications for enterprise class networks are high speed Internet, VoIP telephony, Video conferencing and surveillance, and secured VPN.

WiMAX solution is provided to integrate various sites for the enterprise. In the proposed network scenario, we have two sites connected via the ISP's core network; the server farm site connected via an access router to the ISP's core network; and the client handling site, which utilizes WiMAX technology as a fixed broadband connection. The BTS and CPE are both provided and configured by the ISP to provide fixed WiMAX service. The CPE on the enterprise customer site can be plugged into a switch through which all employees can easily access the internet.

When a WiMAX service is used, clients need to be provisioned and a billing relationship established, in the same way as mobile phone or cellular data service. Rather than a SIM card, as in GSM networks, or a hardcoded equipment identifier as in CDMA, the WiMAX subscriber is identified by an X.509 certificate embedded in the client's device. The provisioning steps for the scenarios are required to identify the WiMAX client cards, and to activate them with the WiMAX network operator. All WiMAX trials and services thus far use operator-supplied client cards.

WiFi client cards are inexpensive as compared to WiMAX cards. The new WiFi -3G dual-mode phones are comparable in price to their cellular-only counterparts, while the simplest PCs today incorporate WiFi cards. Since WiFi entails no service subscription, it is a more economical connectivity option for all manner of consumer and business devices. Hence our enterprise extends wireless connectivity by converting the WiMAX connection to WiFi. This is achieved by plugging an AP to the Ethernet port of the CPE as shown in Figures 3.

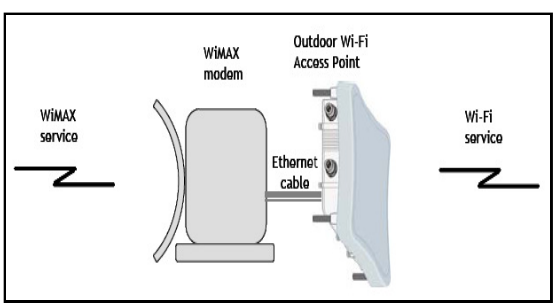

Figure 3 WiMAX - WiFi Integration

In the small business site we deploy WLANs to increase employee productivity, enhance collaboration, and improve responsiveness to customers. The company uses Cisco Unified Wireless Network Solution (CUWNS) which is a wired and wireless network solution that cost-effectively addresses the wireless network security, deployment, management, and control issues an enterprise faces with a low total cost of ownership. The modular architecture supports 802.11a/g/n, and enterprise wireless mesh for indoor and outdoor locations [15]. The small business network resembles a cafe, which offers WiFi connectivity to all its customers via Cisco's WLC. It also offers a secure wireless access for all employee wireless connections by utilizing a Cisco ACS RADIUS server.

4. TEST-BED ANALYSIS OF END-TO-END TRAFFIC FLOW

In this study, we designed and built a real-world WiFi-WiMAX integrated scenario depicting interoperability in a testbed environment. In this section we present the overall, end-to-end connectivity including both WiMAX and WiFi conversion signalling mechanism (inter- and intra-site conversions), as well as the bandwidth test results achieved using the IPerf tool. IPerf [16] is a tool to measure the bandwidth and the quality of a network link. The network link is limited to two hosts running IPerf. The quality of a link can be tested for latency, jitter and datagram loss. The bandwidth is measured through TCP tests. One host is set as a client and the other one as server using the commands "iperf –c <server ip address>" and "iperf –s <client ip address>" respectively. The Iperf client connects to the Iperf server on the TCP port 5001 and the bandwidth displayed by Iperf is the bandwidth from the client to the server.

4.1. Connectivity between the enterprise, small business and the NOC site

We used laptops as end user wireless devices to connect to the WiFi network for both client sites. The traffic flows are shown in Figure 2. Traffic flow 2 (a), indicated in red, shows the packet originating from a client device in the Enterprise Network passing through the WiFi-WiMAX link then through the ISP core routers and finally reaching the NOC site. The traffic flow 2 (b), indicated in green, shows the same flow path of the packet to the ISP core after which it enters the Small Business' WiFi network and the destination client on the other side.

4.2. Bandwidth Test

We investigated the results for the performance of WiFi-WiMAX system as compared to a standalone WiMAX system. Our results indicate that system throughput of WiFi-WiMAX integration did not deteriorate. We performed the test using IPerf tool on all three sites and investigated the effect of network integration on the performance of the network. The traffic flowed seamlessly throughout the network between WiFi and WiMAX networks, and we did not observe any performance degradation or packet loss due to integration. We carried out several sets of tests between the clients in Enterprise and Small Business networks. We also tested intra-site connectivity within the Enterprise. The results are displayed in Figure 4.

Figure 4(A) depicts a bandwidth of 971 kbps over a WiFi-WiMAX-WiFi link for traffic flowing from the WiFi client at the small business network traversing over the ISP core and WiMAX link to reach the WiFi client at the large Enterprise. The traffic in the reverse direction over the same link is highlighted by Figure 4(B). The achieved data rate of the above mentioned link averages to approximately 967.5 kbps. For the WiMAX link we are using QPSK modulation with a code rate of ½ and channel bandwidth of 10 MHz. The WiMAX base station and the client machine are tested in Non Line of Sight (NLOS) conditions.

A study was carried out by A. Durantini et al. [17] which showed the performance of an end-to-end WiMAX system using CPE's that were placed at varying locations from the BS. They performed tests for different modulation schemes. Their results also show data rate values for

QPSK-1/2 modulation ranging from 950 kbps to 1000 kbps for the various CPE's, which is in coherence with our results. This indicates that a WiFi-WiMAX system still retains all the advantages of a basic WiMAX system while allowing enterprises to keep their WiFi architectures intact. It reinforces that integrating WiFi with WiMAX doesn't deteriorate WiMAX capabilities.

Lastly, Figure 4(C) represents a bandwidth over a WiFi–WiMAX link to the NOC. The observed bandwidth is 957 kbps which is slightly less as compared to a WiFi-WiMAX-WiFi link. The overall bandwidth can be significantly improved by using higher modulation schemes on the PHY WiMAX link [17].

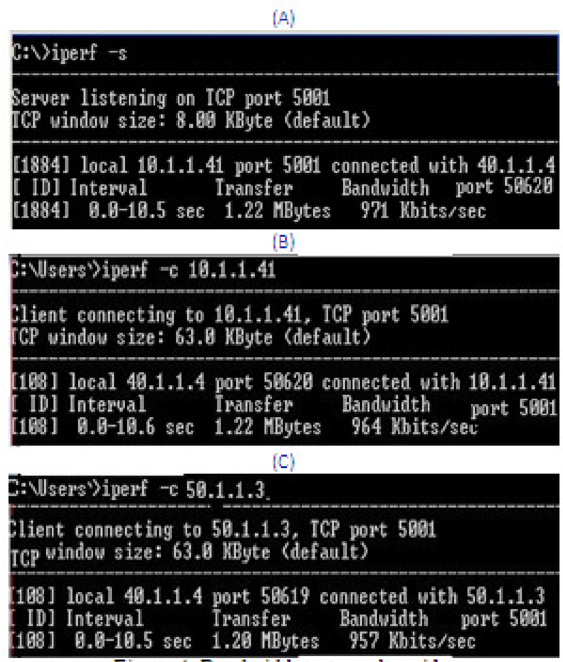

Figure 4: Bandwidth test results with:
(A) WiFi -WiMAX-WiFi link with small business site as server and large enterprise client
(B) Reverse of flow path from A
(C) Large Enterprise site to the NOC

In the next set of experiments, we setup the WiFi–WiMAX integration network, generated traffic for the network, and installed PRTG to further monitor the network performance, with the QoS parameters under surveillance. In the following section we explain different scenarios to monitor our network and further review all the results from these scenarios in the Result and Discussions section. The following scenarios are designed to monitor our wireless network using five installed sensors: Ping, FTP, HTTP, RDP and VOIP. The WiMAX BS supports three different predefined categories for shaping the traffic: nRT, eRT and BE. We will use these classes of service with our traffic and capture the results.

In the first Scenario we have a single type of traffic with each class of Service, including the traffic flow for Ping traffic with BE class of service. In the second scenario we generated traffic for all five types of packet which we have in our network with different class of service designated to all packets.

5. RESULTS AND DISCUSSION

In this section we present the result of each scenario in the entire experiment and compare the result with the influence of each class of service in WiFi–WiMAX integrated network. Due to the limitation of the equipment we cannot take advantage of all WiMAXQoS capabilities and are limited to only three classes of service instead of the five classes identified by the standard.

5.1. Scenario one

In the first scenario we have a single type of traffic with each class of service. Due to similarity of topology diagram we are going to only illustrate PING traffic given different Class of Service. For other type of packet the diagram would stay the same and only the traffic type is going to change.

The graphs presented in Figures 5 through 9 are derived from our results in RTPG and showcase the responsiveness of the system given different types of flows (PING, FTP, HTTP, RDP, VOIP) matched with three types of QoS profiles (i.e. nRt, eRT, BE) in the BreezeMaxWiMAX setup [18]. Each packet flow is running individually in order to create a base line for the next scenarios.

Ping results in Figure 5 show that the average ping time stayed the same in three different types of QoS scenarios. The results show the evident exception that having only one type of traffic on the line would make the QoS prioritization mute, and the result will not change.

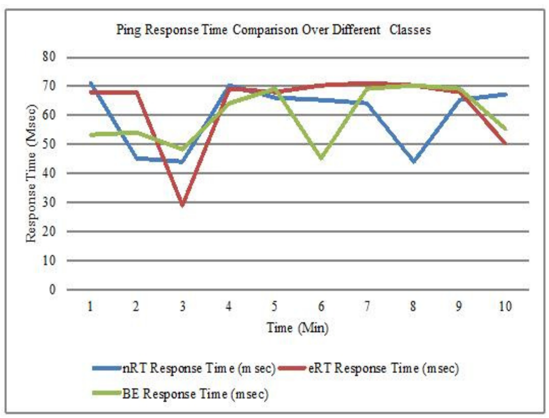

Figure 5: Response Time Comparison for Ping Traffic

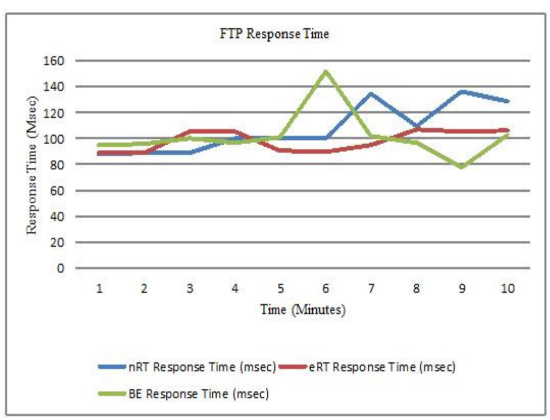

Figure 6: Response Time Comparison for FTP Traffic

Again we notice that in FTP, HTTP, and RDP traffic (Figures 6, 7 and 8) response time and page loading time stays the same and do not change by the type of QoS profile, whether we use nRT, eRT or BE.

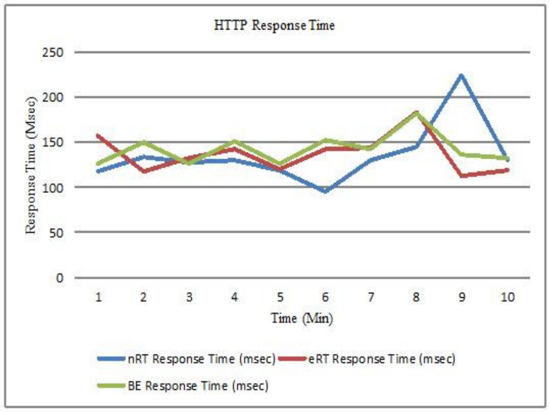

Figure 7 Response Time Comparison for HTTP Traffic

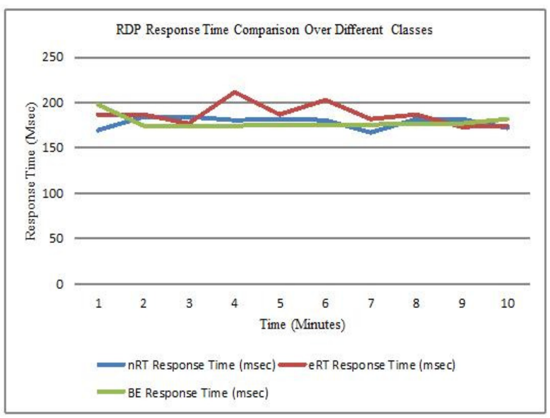

Figure 8 Response Time Comparison for RDP Traffic

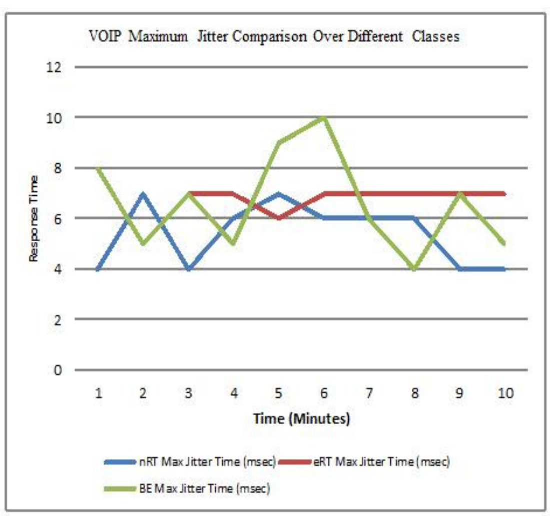

Figure 9 Response Time Comparisons for VOIP Traffic

In Figure 9, a comparison of VOIP traffic in different classes of service based on response time has been shown. We were expecting to see higher response time for the Best Effort class and this was evident in the result. In terms of response time however, nRT flows unexpectedly showed lower values than their RT counterparts.

5.2. Scenario two

Having captured a baseline of how different types of traffic response time are affected based on each class of QoS assigned in the WiMAX environment we further investigated the results by executing all of the flows at the same time and measure how this will be reflected on the overall system response time.

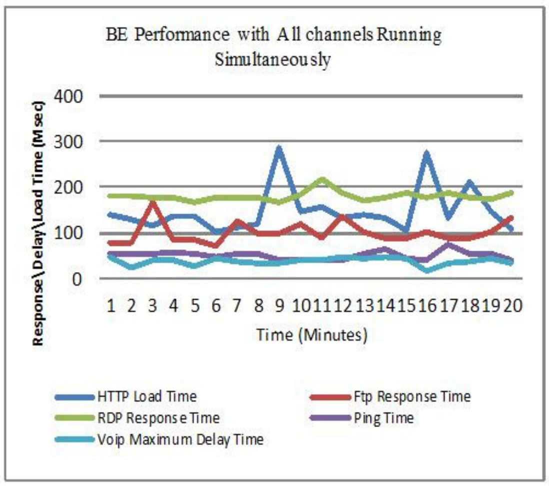

Figure 10: BE Performance With all Traffic Flows

Figures 10 and 11 are derived from the results in RTPG and showcase the responsiveness of the system given all type of traffic (PING, FTP, HTTP, RDP, VOIP) running simultaneously and matched with each types of QoS profile (nRt, eRT, BE) in the BreezeMaxWiMAX [19] setup on three separate instances.

Figure 10 QoS profile is set to Best Effort, which shows competition between packets trying to pass the media, consequently all the flows' response time are fluctuating. The winners are VOIP and Ping with response times around 50 ms. HTTP has the highest response time at almost 300 ms.

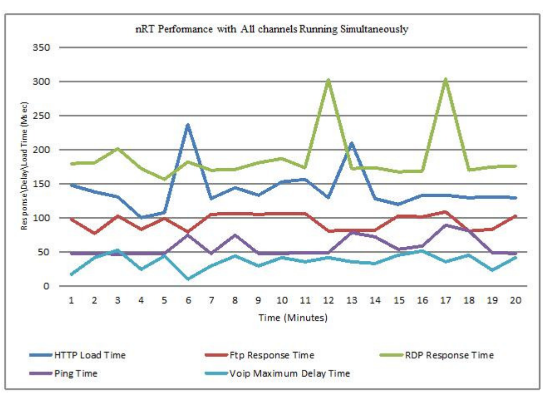

Figure 11: nRT Performance With all Traffic Flows

By changing the class of service from BE to nRT, we had a better response time as an overall trend. All five types of traffic flow had an improvement in their response time ranging from 50 to just under 200 Msec (Figure 11).

6. CONCLUSIONS

WiMAX has emerged as a prevailing technology for wireless metropolitan area services in licensed and unlicensed spectrums. It utilizes RF technology comparable to WiFi, while providing superior performance to current cellular standards in terms of data rates and wide coverage area. In this paper, we explored the WiFi-WiMAX integrated architecture. WiMAX equipment is now available for the 5.4-5.9 GHz unlicensed band. It is a profitable solution for enterprise networks to integrate their multiple sites. It also enables ISP's to integrate existing WiFi networks operating in similar bands with WiMAX as backhaul.

An ISP could use WiMAX to backhaul multiple WiFi hotspot sites. An enterprise could receive services from a WiMAX service provider and then combine the WiMAX terminal equipment with WiFi WLANs to achieve a complete mobile experience. We successfully demonstrated this solution by providing end-to-end WiFi-WiMAX connectivity with providing similar data rates to those of pure WiMAX network solution. Generally, WiMAX will be useful for providing intermediate-distance backhaul for WiFi access points, which could be a preferable arrangement to WiFi mesh technology.

In this study, we integrated the CPE with a basic access point; however advanced options using the CPE in conjunction with a Wireless LAN controller is an open area to be investigated further. True 802.16e mobility and handover testing using WiMAX cards and BS operation with an external ASN gateway are also areas that need to be investigated. Lastly, the bandwidth of integrated WiFi-WiMAX link can be explored by using different modulation schemes on PHY WiMAX link.

We further investigated the effect of integration of the technologies on one of the important aspects of WiMAX networks; namely the quality of service (QoS) support, and carefyully measured the QoS parameters like throughput, and delay values for the entire network, and compared it to those of the stand-alone networks.

We built the integrated network for a complete ISP/Enterprise deployment, and created multiple scenarios and configured different types of QoS settings in the laboratory environment. The results showed that in congested circumstances implementing any of QoS policies has a positive effect on the overall responsiveness of the integrated network just as in the stand-alone scenarios.

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