Performance Evaluation of IEEE 802.16 WiMAX Link With Respect to Higher Layer Protocols

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***Abstract*—The WiMAX technology based on the IEEE802.16-d standard is a Broadband Wireless Access (BWA) technology and considered to be an important ingredient of the composition of the Next Generation Networks (NGN). Till date, due to lack of deployment not enough data is available in terms of its operational capabilities and efficiencies.**

The main objective of this paper is to evaluate, analyze and compare the performance of a WiMAX link under different load and traffic conditions. For this purpose an experimental WiMAX test-bed has been deployed at the Communication Network Institute (CNI), University Dortmund and several experiments and stress tests are carried out over this CNI WiMAX test-bed in the uplink and downlink directions for various service and traffic types and at various distances from the Base station. The results of these experiments are presented in this paper.

***Index Terms*—WiMAX, IEEE 802.16-2004, experiments, field tests, measurements**

I. Introduction

WiMAX was formally introduced in 2004, with the publishing of the IEEE 802.16-2004 standard [1], which specifies the air interface, including the medium access control (MAC) layer and multiple physical (PHY) layer specifications for Fixed Broadband Wireless Access (FBWA) systems supporting not only higher data rates over larger geographical areas but also claiming QoS support capability matching its wired counterparts. WiMAX is a wireless alternative to wired Cable and DSL technology for last-mile solutions and a Wireless Metropolitan Area (WMAN) solution for providing backhaul services by aggregating traffic emanating from various other wireless hotspots, thereby filling in the gap between the high data rates but small area of coverage provided by wireless LAN (WLAN) and high-mobility and large area of coverage but lower data rate support provided by cellular technologies.

II. Motivation and Objectives

Due to lack of deployment not enough information is available that would provide quantitative and qualitative data in terms of the performance and operational capabilities of the WiMAX link, that could be used as a benchmark by telecommunication engineers and researchers to develop accurate mathematical and simulation models that could compare more realistically to the actual performance behavior of the WiMAX link, and thereby develop and recommend better and efficient algorithms and solutions in terms of Next Generation Wireless Access Networks. This lack of real empirical data was the main motivation behind conducting field experiments over an actual 3.5 GHz WiMAX test-bed established at Communication Networks Institute (CNI), University of Dortmund to better understand the performance of the WiMAX link in terms of data throughput and link stability versus distance.

Although some performance data is available but that is mostly based on analytical and/or simulation models [2]. Also some experimental results are provided in [3], but the experiments were conducted by emulating the WiMAX link using different channel models. The experiments performed in [3] were conducted with multirate support enabled in which the Subscriber Station (SS) is allowed to choose a specific modulation scheme according to its SNR and the experiments were conducted for a limited range of modulation schemes. There is no mention of the transmit power of the base station or the type of the antennas used, a factor crucial to the correct understanding of the system's scope, and the maximum distance over which the tests were conducted was around 3000 meters (around 2 miles).

In our experiments, the multi-rate support was disabled to correctly ascertain the throughput and link quality of each of the eight available modulation schemes (please see table 1) over distances ranging from 220 meters to 9400 meters (9.4 km) with minimum transmit power of 13dBm from the base station (BS). The link was tested for both the TCP and UDP data in both uplink and downlink direction, thereby providing data relating to a case of real customer deployment.

In terms of testing the QoS support in WiMAX, experimental measurements have been made in [4] targeting the residential broadband access scenario, in which multiple subscriber stations (SS), each having the same QoS configuration, communicate with a single base station in a point to multipoint (PMP) configuration. In our tests we have targeted a SOHO/SME broadband access scenario in which a single SS will be providing services to hundreds of users and/or multiple departments, each with a possibly unique QoS requirements, in a Virtual LAN (VLAN) configuration environment, where subscribers sharing the same QoS class are mapped onto the same service pipe, a virtual connection between a subscriber's application and the network resources, over the WiMAX link.

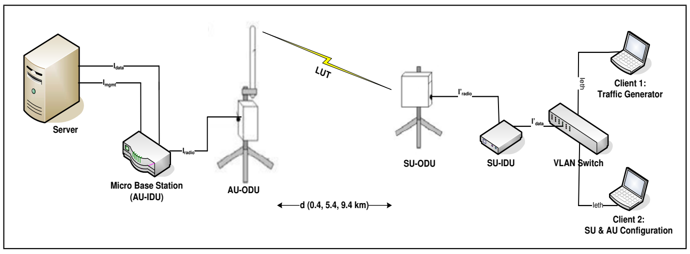

Fig. 1. Measurement Setup

III. Test Bed Arrangement and Setup

For the field experiments an IEEE 802.16d [1] compliant Alvarion's BreezeMax equipment operating in a 3.5 GHz licensed band was selected. As the WiMAX link is tested in terms of its capacity and its ability to provide QoS to multiple simultaneous applications services, two different test beds were composed and configured. Both the test beds had the same generic setup as shown in figure 1 but differed in terms of the equipment configuration.

On the subscriber side, the Client1 laptop is used for generating user traffic in the uplink direction and captures and analyses data in the downlink direction whereas client2 laptop is running scripts for remote access and configuration of the WiMAX base station (AU-IDU) and the Customer Premises Equipment (CPE) (SU-IDU). The two client laptops and the Subscriber Unit Indoor Unit (SU-IDU) are connected via an Ethernet Interface (Ieth) to the VLAN switch, where the VLAN feature is disabled except for the QoS testing, described later. The SU-IDU in turn is connected to the Subscriber Unit Outdoor Unit (SU-ODU), which is a vertically polarized directional antenna with an 18dBi gain.

On the base station side, the Server is used for generating traffic in the downlink, over the LUT (Link Under Test), and capturing and analyzing data in the uplink. The Access Unit Indoor Unit (AU-IDU) is connected via an IF cable (Iradio) to the Access Unit Outdoor Unit (AU-ODU), which consists of a 10.5 dBi gain omni-directional antenna and a high-power, full-duplex multi-carrier radio unit. The AU-IDU consists of two RJ45 ports namely; management port and data port, for micro base station remote configuration and the latter for data communication. These two ports are connected to the Server via Ethernet. The detailed radio specifications of the IDU and the ODU is given in table I.

IV. Measurement Methodolgy

The tests were divided into two categories: ***Link Capacity/Throughput Testing***, in which the ability, reliability and the robustness of the WiMAX link was tested in both the uplink and downlink direction for all eight modulation schemes by transmitting TCP and UDP traffic and real time video streams at different distances from the BS, and ***QoS Testing***, in which the inherent QoS support feature of the WiMAX was tested.

To attain reliable results with an appreciable level of confidence, each test run was conducted ten times and the duration of each test run was 60 seconds, accounting to a total approximate test duration of 260 minutes excluding the time for initializing the test scripts and making necessary configurations on the equipment. The throuput of the uplink and the downlink were measured seperately in order to exclude interference effects.

Frequency		Uplink (MHz)	Downlink (MHz)
	AU-ODU	3399,5 - 3453,5	3499,5 - 3553,5
	SU-ODU	3399,5 - 3500	3499,5 - 3600
Ch. Bandwidth	3,5 MHz		
Operation Mode	AU-ODU	FDD, Full Duplex	
	SU-ODU	FDD, Half Duplex	
Modulation	OFDM Modulation, 256 FFT points; BPSK, QPSK, QAM16, QAM64		
TX Power	AU	13 dBm (20 mW) - 28 dBm (631 mW)	
	SU	20 dBm (100 mW)	
Bit Rate	Modulation and Coding	Net Physical Bit Rate (Mbps)	
	BPSK 1/2	1,41	
	BPSK 3/4	2,12	
	QPSK 1/2	2,82	
	QPSK 3/4	4,23	
	QAM16 1/2	5,64	
	QAM16 3/4	8,47	
	QAM64 2/3	11,29	
	QAM64 3/4	12,71	

TABLE I
Test Bed Equipment Radio Specifications

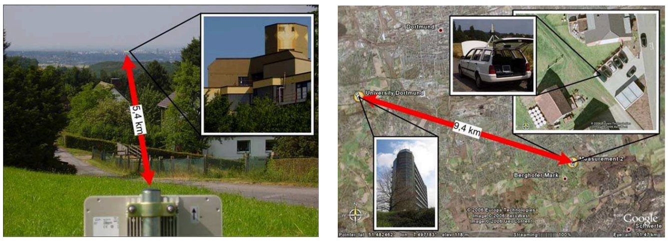

Fig. 2. Test Locations

The amount of traffic generated was always equal to the net physical data rate for each respective modulation scheme (see table 1) and corresponding packet losses were obviously measured. The link capacity was tested for both Line Of Sight (LOS) and Near-LOS scenarios, but Non-LOS (NLOS) was not possible. The CPE were stationed away from the BS at the following distances and locations:

- d = 220 meters; North Campus, University Dortmund
- d = 5400 meters (5.4 km); Auf dem Schnee, Dortmund. LOS (Figure 2(a))
- d = 9400 meters (9.4 km); Radiotower Schwerte, Dortmund. Near-LOS (Figure 2(b))

Table 2 summarizes the relevant test configuration of the AU.

To stress-test the link the transmit power of the AU was set to the minimum of 13 dB and the Automatic Transmit Power Control (ATPC) feature was enabled for the SU and AU. Although the maximum transmit power of the BS is 28dBm (6.918 Watts EIRP *incl. 10.5dBi antenna gain*), but the limit

Multi Rate Support (BS)	Disable
ATPC Support (BS)	Enable
TX Power (at BS antenna port)	Minimum = 13 dBm (20mW) Maximum = 20 dBm (100mW)
TX Frequency (BS)	Downlink: 3501.25 MHz Uplink: 3401.25 MHz
VLAN support	Yes
QoS Profile	Real Time (RT), Non Real Time (NRT), Best Effort (BE)

TABLE II
ACCESS UNIT CONFIGURATION

of 20dBm (1.096 Watts EIRP *incl. 10.5dBi antenna gain*) was imposed by the terms and conditions of the 3.5GHz research license.

As a QoS-Profile a non real-time setting with a Committed Information Rate (CIR) of 12Mbps is chosen.

The *Multirate* support in the AU was disabled, as mentioned earlier, in order to set the modulation scheme manually for each measurement to validate the link behavior for each specific modulation scheme.

The outdoor tests were carried out by mounting the antenna on the roof of a car and powering the whole SU by a portable DC to AC power supply, which also powers the switch and the client PC.

A. Uplink and Downlink Test Configurations

For both the uplink and downlink tests, TCP and UDP traffic was generated using IPerf [5], which reported bandwidth, delay jitter and datagram loss, and captured on the receiver end by Ethereal [6] to capture and analyze the received data. In case of uplink capacity tests, the Client1 runs the IPerf server instance whereas the Server runs the IPerf client instance and Ethereal application and this arrangement is reversed for the downlink capacity tests. The Client2 machine is used primarily to manage and configure the AU remotely by establishing an SSH session and is also used to monitor the configuration and connection statistics of the SU (for example, RSSI, SNR, Modulation scheme, transmit and receive power level of the SU). This automatic management, configuration and monitoring of the AU and the SU is controlled by a custom Perl Test Processing scripts.

The captured data is then fed to the custom Perl Test Processing scripts where it is analysed for various parameters and mean values are calculated. The results are then graphically depicted using the GNU-Plot application.

B. QoS Test Configurations:

In order to test the inherent ability of the WiMAX protocol to support QoS over the broadband wireless links the general set up is the same as in figure 1 with the exception that the VLAN feature in the switch is now enabled and the two client machines (client 1 and client 2) are placed in two separate VLANs. Client1 is generating UDP traffic with transmission parameters emulating a real time VoIP service, whereas Client2 is generating TCP traffic streams emulating a non-real time service application such as HTTP etc. The two VLANs are mapped onto two different service pipes, where the service pipe designated to carry the real time applicaiton data is configured with a Real Time Polling Services (rtPS) service class and the second service pipe carrying the non-real time application data is configured with a Best Effort (BE) service class. The two clients generate simultaneous traffic using the QAM64 3/4 modulation scheme over the maximum bandwidth of the link so that the effect of these two interfering traffic streams over the QoS enabled WiMAX link can be duly analysed.

V. ANALYSIS AND EVALUATION

This section will provide the measurement results for the test configurations discussed above and also discuss the effect of transmit power on the overall link quality.

A. Throughput Tests

Table III shows the TCP and UDP average throughput measured, which can be compared to the net physical bit rates for the corresponding modulation scheme given in table I, for the eight modulation schemes at reference distances of 220 meters, 5400 meters and 9400 meters and the transmit power was set at a constant minimum of $13dBm$. In the *downlink direction*

Modulation Schemes	**Downlink Throughput in Mbps**					
	220 meters		**5400 meters**		**9400 meters**	
	TCP	**UDP**	**TCP**	**UDP**	**TCP**	**UDP**
BPSK 1/2	1.08	1.13	1.08	1.12	1.08	1.12
BPSK 3/4	1.65	1.74	1.64	1.73	1.65	1.73
QPSK 1/2	2.21	2.32	2.20	2.32	2.20	2.32
QPSK 3/4	3.37	3.53	3.35	3.53	3.35	3.53
QAM16 1/2	4.50	4.74	4.48	4.73	4.48	4.74
QAM16 3/4	6.80	7.11	6.41	7.11	6.41	7.10
QAM64 2/3	8.88	9.40	8.31	9.51	8.31	9.51
QAM64 3/4	9.58	10.55	8.34	10.71	8.34	10.69
Modulation Schemes	**Uplink Throughput in Mbps**					
	220 meters		**5400 meters**		**9400 meters**	
	TCP	**UDP**	**TCP**	**UDP**	**TCP**	**UDP**
BPSK 1/2	0.98	0.98	0.97	1.03	0.97	1.03
BPSK 3/4	1.51	1.54	1.46	1.57	1.50	1.58
QPSK 1/2	2.03	2.14	2.03	2.13	2.03	2.14
QPSK 3/4	3.09	3.24	3.08	3.23	3.08	3.23
QAM16 1/2	4.16	4.33	4.14	4.33	4.14	4.33
QAM16 3/4	6.24	6.52	6.22	6.52	6.22	6.52
QAM64 2/3	8.28	8.67	8.22	8.64	8.25	8.65
QAM64 3/4	9.25	9.67	9.22	9.69	9.22	9.67

TABLE III
TCP/UDP AVERAGE THROUGHPUTS

(see figure 3) TCP throughput remains almost stable but shows greater inconsistency especially at higher modulation schemes (QAM64). It has been experimentally verified and observed that the TCP throughput stability is dependent on distance and transmit power. In terms of distance, the higher modulation schemes shows greater consistency at 220 meters (figure 3 (a)) than at 5400m (figure 3 (b))or 9400m (figure 3 (c)). The effect of transmit power on the TCP downlink throughput is subsequently discussed. The TCP throughput in the *uplink* direction is more stable at all the three reference distances and

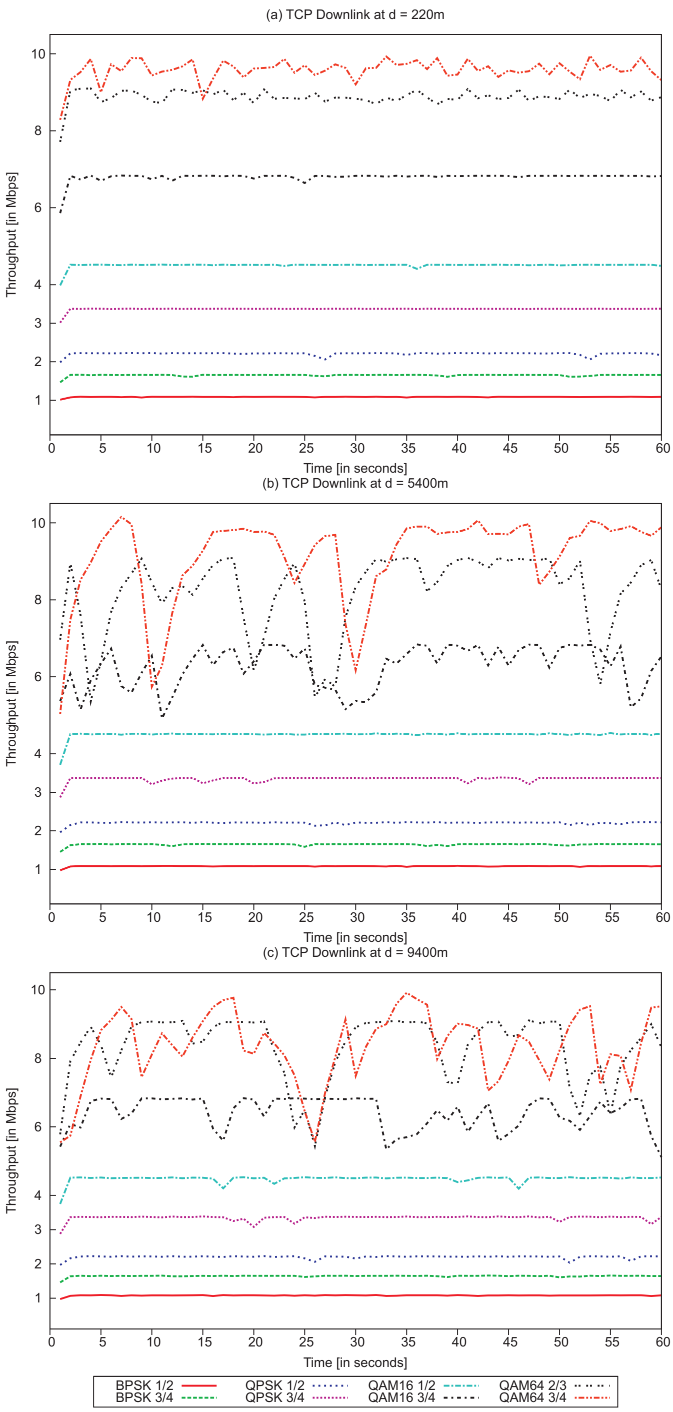

Fig. 3. TCP Downlink Throughput at d = (a)220m, (b)5.4km, (c) 9.4km

for all the modulation schemes and is similar, in performance, to figure 3 (a).

In contrast to TCP downlink traffic, UDP has shown more throughput stability for all the modulation schemes in both the uplink and downlink direction at all three reference distances and the stability in throughput is similar to figure 3 (a)). The average UDP throughputs is given in table III.

B. QoS Tests

To test the QoS support, every test was conducted by sending TCP background traffic through a non real-time connection at full capacity of the bandwidth throughout the duration of the test. A 12 Mbps UDP traffic is sent in periodic durations of 10 seconds through a real-time connection with a committed bit rate of 5 Mbps and 10 Mbps the result of which is shown in figure 4.

It is evident that the TCP background traffic will occupy only that portion of the bandwidth which is not utilized by the UDP traffic and upon greater demand for bandwidth by the real-time traffic, the system ensures the guaranteed provisioning of the demanded bandwidth by claiming it from non-real time traffic, which in turn will experience bandwidth reduction, and this behavior is consistent with the overall QoS philosophy.

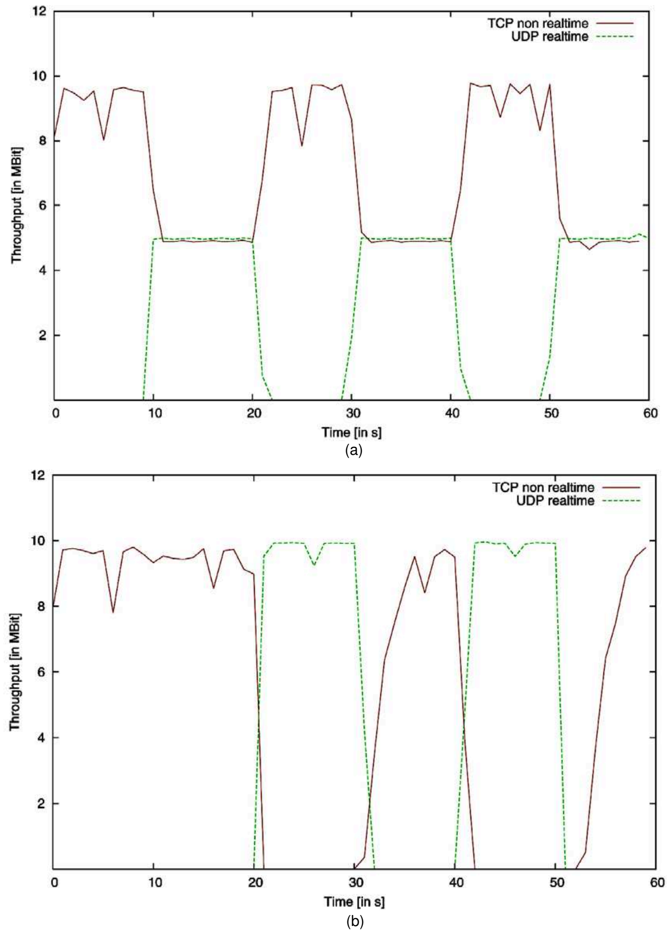

Fig. 4. QoS Measurement with (a) 5Mbps and (b) 10Mbps UDP traffic and TCP Background Traffic

C. Effects of the Distance and Power Control Level on the Performance

As the link was stress tested by keeping the transmit power of the base station to the minimum value of 13dBm at all distances and for all tests, in order to evaluate the effect of

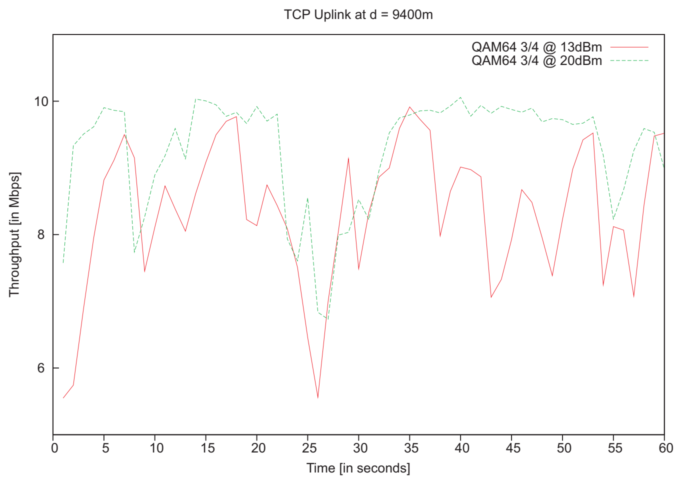

Fig. 5. Effect of Transmit Power

transmit power on the overall link quality, a second set of tests at 20dBm transmit power was carried at d=9400m by transmitting TCP traffic in the downlink direction using QAM64 3/4, as that was more critical in terms of throughput stability (see figure 3(c)) . As seen in figure 5, there is marked improvement in terms of link and throughput stability, especially for TCP traffic, which earlier had shown considerable instability.

VI. Conclusions and Future Work

With the results gained from this pilot project, and within the given limits, resources and distance limitations the WiMAX test arrangement, the field tests conducted at the CNI's WiMAX test bed can be regarded as meeting the functional specification and requirements of a wireless broadband access network as per the IEEE 802.16-d standard. The measurements and results gathered through stress testing the WiMAX link demonstrates satisfactory throughput and level of services at different distances for both LOS and Near-LOS, even at the lowest transmission power (13dBm) at distances as far as 9.4km. One important observation is that Non Line of Sight (NLOS) operation is not possible and the correct operation depends on the accurate adjustment of the CPE in order to get the best possible receive signal. It has been observed that even one centimeter change of the vertical or horizontal orientation could have a strong influence on the RSSI and the SNR and with this the quality of the link, adversely affecting the throughput.

Considerable degradation of service was observed during adverse weather conditions, such as during rain fall, resulting in delay, jitter and inconsistent service due to packet losses. Such weather conditions will prohibit the use of bandwidth intensive streaming multimedia services over the WiMAX link.

As part of the future work, more field tests are being planned at distances beyond 9.4 km and by introducing a second SS. More tests with the TCP traffic in the downlink direction will be conducted so as to be able to make precise recommendations for TCP settings when operating over a WiMAX link.

Further investigation into the effect of transmit power on the link throughput and extensive testing of the QoS feature is also planned, particularly in terms of interference of different traffic types through traffic flow using all available service classes simultaneously.

Acknowledgment

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