Practical Performance Measurements and Analysis of IEEE 802.16 Networks

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Abstract— **IEEE 802.16 standard defines the wireless broadband technology called WiMAX. When compared to other wireless technologies, it introduces many interesting advantages at physical (PHY) and media access control (MAC) layers. The WiMAX technology based on air interface standard 802.16 wireless metropolitan area network (MAN) is configured in the same way as a traditional cellular network with base stations using point to multipoint architecture to drive a service over a radius up to several kilometres. The range and the non line of sight (NLOS) ability of WiMAX make the system very attractive for users, but there will be slightly higher bit error ratio (BER) at low signal to noise ratio (SNR). WiMAX networks incorporate quality of service (QoS) mechanisms at the MAC layer. The problem of assuring QoS is basically that of how to allocate available resources among users in order to meet the QoS criteria such as delay, jitter and throughput requirements and how to achieve the optimal usage of resources to maximize throughput and to minimize power consumption while ensuring system scalability. In this paper, we make practical measurements of the WiMAX- system's QoS performance behaviour of the unsolicited grant service (UGS) and real time polling (RTP) classes.**

Keywords- ***IEEE802.16; WiMAX; Performance; Analysis***

I. INTRODUCTION

IEEE 802.16, called also WiMAX, is a basic standard for the wireless broadband access network that can support a fast speed wireless access to different subscribers [1, 2].

The main benefit of WiMAX when compared to other wireless access network technologies like IEEE 802.11 are the longer range and more intelligent QoS support at the Medium Access Control (MAC) level [3]. There are several different types of applications and services, which can be used in the 802.16 networks and the MAC layer is designed to support this collaboration. An important feature of WiMAX is also that it is connection oriented and this means that an SS has to register to the base station before it can start to communicate with it. During the registration process, an SS asks the initial QoS requirements with the BS. These demands can be changed later if needed, and new connections can also be set up when needed. For providing the QoS guarantees in the WiMAX network the BS uses scheduling for both the uplink and the downlink channels. For that purpose there is an algorithm in the BS, which translates the QoS requirements of SSs into the appropriate number of slots [6-9].

According to the latest WiMAX Forum statistics, IEEE 802.16-based networks were deployed in 149 countries and regions, including 117 in Africa, 117 in Latin America, 109 in Asia-Pacific region, 86 in Eastern Europe, 76 in Western Europe, 53 in North America and 29 in the Middle East [13]. Global coverage using WiMAX service back in early 2009 had reached 430 million, to the end of 2010 more than 621 million WiMAX service coverage of population, according to forum latest estimates, 2011 will be expected to cover more than one billion users access to next-generation WiMAX networks.

The aim of this research is to compare the results received in WiMAX laboratory environments and in conjunction with laboratory exercise tests as well as the theoretical results from the mathematical modeling with the results received in authentic urban environments.

II. IEEE 802.16

A. General

The idea behind providing QoS in WiMAX lies on connection-oriented MAC architecture, service flow management and scheduling. Every time a SS and a BS need to communicate with each other, a unidirectional logical link is established. Each connection is mapped to a WiMAX service flow which works as a transport service for packets i UL or DL direction. The service flow defines QoS traffic parameters to be used for a connection. This include, for instance, traffic priority, maximum latency, tolerated jitter and maximum sustained traffic rate ensuring a specific level of service. Each service flow is identified by a 32-bit service flow identifier (SFID) [2].

Moreover, using adaptive modulation helps to utilize the bandwidth efficiently [4, 5]. WiMAX contains five QoS classes for the needs of various types of traffic: UGS , RTP, NRTP (non-real-time polling), ENRTP (enhanced non-real-time polling) and BE (best effort).

B. Different Traffic Types and Applications

The following scheduling types are applied to service flows, affecting the usage of UL bandwidth request opportunities. UGS - the Unsolicited Grant Service grants fixed-size UL allocations for an application minimizing the need for bandwidth requests, thus eliminating overhead and latency. This allows usage of real-time applications like VoIP. rtPS - the real-time Polling Service offers support for real-time UL transport with variable-size data packets. This makes it useful for video transmission. The rtPS optimizes data transport efficiency with a cost of slight overhead. ertPS - similarly to the UGS, in the extended real-time Polling Service the BS provides unsolicited unicast grants for the SS. Unlike the UGS, the ertPS allows dynamic-size UL allocations which makes it good for real-time voice and video applications. nrtPS - using the non-real-time Polling Service offers user unicast BW request opportunities on a regular basis, making it applicable even when the network resources are limited due to congestion. BE - the Best Effort service type allows SSs to use contention request opportunities. It is designed to be used when there is no minimum requirements for the connection. This service type suits for Web browsing. For each subscriber in the WiMAX network a QoS profile is defined and stored in the AAA server. This forms a basis for connection-oriented service, that is, associations between connections and service flows. The QoS profile stores allowable number of service flows, their scheduling types and values for other QoS parameters. [1][2].

Depending on the QoS profile and network properties the subscriber may use service flows provisioned via the network management system or dynamically created service flows. The provisioned service flows, including the initial service flow (ISF), can be created during the registration phase of the network entry after a successful authentication of the user. At this stage ASN-GW obtains SS´s QoS profile from AAA server which it uses to initialize service flow creation. Provisioned service flows can be activated or deactivated at any time when the SS is connected to the network (applicable to both static and dynamic service models). The dynamic service flow creation may be requested/initiated by the SS or by the network whenever a new connection is needed. DSA, DSC or DSD message exchange is used for service flow creation, modification or deletion, respectively [2].

III. PHYSICAL AND MAC LAYER QOS PROVISIONING

A. Physical layer basic concepts for QoS provisioning

Before transmission to the wireless link at the sender side, or right after reception at the receiver side, packets go through the IEEE 802.16 PHY layer. It performs operations, such as channel coding and interleaving, before passing on the packet. An adaptive physical layer is required to optimize the usage of resources, to accommodate user requirements and services and to maximize the spectral efficiency.

An adaptive modulation enables dynamic bandwidth allocation to match the current channel conditions. Modulation and coding scheme can be changed for each burst separately. Different modulation and coding schemes offer either robust or efficient network access, thus offering stable QoS in varying conditions. Three modulation schemes are are 64-QAM (quadrature amplitude modulation), 16-QAM, and QPSK (quadrature phase shift keying). The 64QAM offers highest bandwidth whereas the QPSK modulation is the most robust, therefore offering highest distance from the serving station. Also BPSK modulation can be used but it is not mandatory for UL or DL connections. In addition to different modulations there are a few coding rates used also to provide flexible networking. Depending on the Carrier-to-Noise Ratio (CNR) a coding rate of 1/2, 3/4 or 5/6 can be used.

The most commonly used technique for error correction is called forward error correction (FEC), which is capable of detecting and correcting some errors upon reception. This technique can reduce latency by cutting down the retransmissions, but the FEC requires more bits. The addition of FEC to every transmitted block reduces the efficiency of the channel and could increase the delay of good protocol data units (PDUs), on the other MAC-level ARQ can increase the delays in channel with high error rate. Many systems support hybrid techniques where a combination of FEC and ARQ parameters can be adjusted to allow the service requirements to be met under a variety of conditions [9].

WiMAX supports time division duplexing (TDD), full-duplex frequency division duplexing (F-FDD) and half-duplex frequency division duplexing (H-FDD). The usage of different duplexing modes affect the data transmission convention. In WiMAX user data is transmitted inside frames that consist of uplink and downlink subframes separated from each other by a TTG guard interval in TDD or different frequencies in FDD. Both DL and UL frames store user information into bursts which applies for both TDD and FDD frame. Depending on the duplexing mode being OFDMA/OFDM TDD, F-FDD or H-FDD, the frame structure changes. In addition to these, 802.16j defines a new frame format for communication between a multihop relay base station (MR-BS) and a RS [3].

In TDD the DL subframe and the UL subframe are transmitted in the same channel consecutively which is useful when working with limited bandwidth resources. In addition, TDD´s dynamically adjustable DL/UL ratio allows it to be used with both symmetric and asymmetric traffic. In FDD the DL and UL subframes are transmitted in separate concurrent channels using different frequencies. The difference between F-FDD and H-FDD is that in F-FDD a user is able to transmit and receive at the same time while in H-FDD user can either transmit or receive at given time but not do both simultaneously [8].

TDD is mostly used where WiMAX network is deployed. Main reasons for the popularity of TDD are flexibility, cost efficiency and high spectral efficiency [5].

Taking a closer look into a TDD frame reveals how user information is divided within a frame. The smallest time-frequency divided element in WiMAX is called a slot, which constitutes one subchannel and one, two or three OFDM/OFDMA symbols. All the data regions in a frame are composed from sequential slots.

The uplink subframe is the TDMA portion which may be used by one or more SSs to transmit information to the BS. Unlike the downlink, the UL-MAP grants bandwidth to specific SSs. The SSs transmit in their assigned allocation using the burst profile specified by the uplink interval usage code (UIUC) in the UL-MAP entry granting them bandwidth. The uplink subframe may also contain contention-based allocations. The number of contention slots per UL subframe is determined by the BS [7]. The BS assigns burst profiles for a specific connection or subscriber based on variety of constraints, including the QoS and channel conditions.

B. MAC layer concepts for QoS provisioning

Since the QoS requirements vary a lot in different network situations, WiMAX has many handling and transporting mechanisms to handle this. The IEEE 802.16e MAC uses a variable length PDU and multiple PDUs can be put into a single burst to save physical overhead. The MAC has a self-correcting bandwidth request/grant method that minimizes the overhead and delay of acknowledgements.

The MAC layer has three sublayers, which defines the access mechanisms and packet formats. These sublayers are service specific convergence sublayer (CS), MAC common part sublayer (MAC CPS) and MAC privacy sublayer (MAC PS). The CPS layer mainly interfaces with higher layer protocols, such as IPv4, IPv6 or ATM. The PS handles authentication and data encryption issues.

The IEEE 802.16 has two service-specific convergence sublayers that are used to map services to MAC connections. The first one is the ATM Convergence sublayer and the second is a Packet Convergence sublayer. It is used for IP, Ethernet, and virtual local area network environments. The goal of Packet Convergence sublayer is to classify SDUs and put them at the proper MAC connection. This ensures that QoS requirements are met and the bandwidth allocation takes place. The QoS requirements have the following features [6]:

a) A configuration and registration function for preconfiguring SS-based QoS service flows and traffic parameters.

b) A signaling function for dynamically establishing QoS-enabled service flows and traffic parameters.

c) Utilization of MAC scheduling and QoS traffic parameters for uplink service flows.

d) Utilization of QoS traffic parameters for downlink service flows.

e) Grouping of service flow properties into named Service Classes, so upper-layer entities and external applications (at both the MS and BS) may request service flows with desired QoS parameters in a globally consistent way. To meet all these requirements, the standard has three main methods: service flow QoS scheduling, dynamic service establishment and two-phase activation model.

IV. MEASUREMENTS IN URBAN ENVIRONMENTS

The measurement compared the behavior of the UGS and RTP classes upon overloading the link with 40 Mbps upstream BE traffic. The best effort traffic was generated with a Fluke Optiview analyzer over a WiMAX link. Simultaneously, a JDSU MTS-6000A analyzer was used to generate 70 VoIP telephone calls (G.729 codec) within the measured QoS class to a SmartClass Ethernet remote end. This number of phone calls with the above-mentioned codec amounts to a traffic flow of approx. 2 Mbps, and it was confirmed for both of the measured QoS classes (See Figure 1).

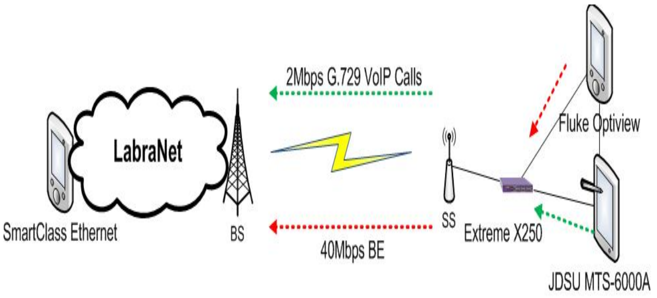

Figure 1. Measurement environment.

The MTS-6000A analyzer was used to read the delays, delay variations and throughput of the QoS class under observation. The measurement was conducted with adaptive and forced 16QAM3/4 modulation.

Measurement 1

The goal of the measurement was to receive results concerning the effect of modulation and channel width on data transfer speed in an urban environment. The aim was to compare the results with the theoretical results of mathematical modeling presented in [10].

The measurements were carried out with the base station installed on the roof of building 1 in Figure 3 and the subscriber station installed on the surrounding environments of Jyväskylä on building 2 in Figure 3 with LabraNet network active devices. Network topology was as in Figure 2. JDSU MTS-6000A traffic generator connected to c3750 switch was used to generate test traffic and the traffic was routed to front end of SmartClass Ethernet connected to a customer device. JDSU MTS-6000A traffic generator was controlled with VNC application from a NetSpan server connected to the control network.

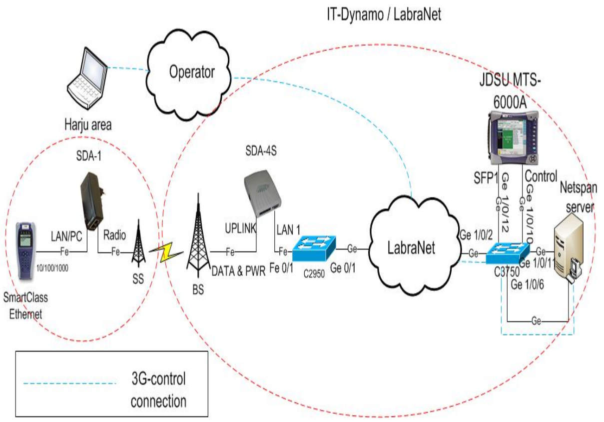

Figure 2. Network topology used in the measurements.

Table 1 shows the most important settings for the WiMAX devices.

Settings of the test environment	
Frequency	5.8 GHz
Channeling	FDD
Transmitting power	17.00dBm / 22.00 dBm
Frame duration	5 ms
Cyclic Prefix (Ratio G)	1/16
Distance of SS and BS devices	1 km
Test environment	City

Table 1 Test environment settings

Figure 3 shows the location and direction of the BS and SS device.

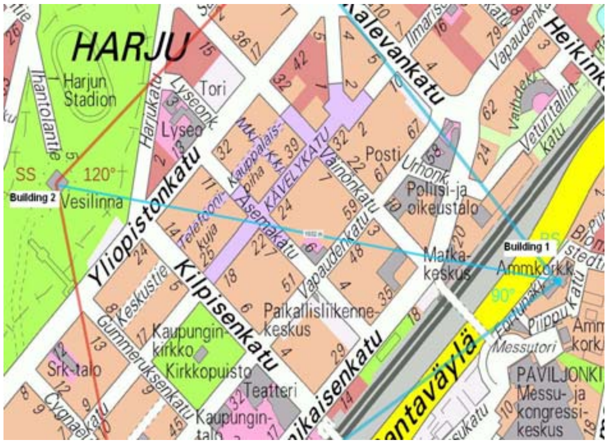

Figure 3. Location and direction of the BS and SS device.

Table 2 shows the main results of the measurement.

Modulation	Channel width	Data Transmission speed
16QAM 3/4	10 MHz	18.7 Mbps
16QAM 3/4	5 MHz	7.6 Mbps
16QAM 3/4	2.5MHz	2.2 Mbps
16QAM 1/2	10 MHz	12.5 Mbps
16QAM 1/2	5 MHz	5.1 Mbps
16QAM 1/2	2.5MHz	1.4 Mbps
QPSK 3/4	10 MHz	9.3 Mbps
QPSK 3/4	5 MHz	3.8 Mbps
QPSK 3/4	2.5MHz	1 Mbps
QPSK 1/2	10 MHz	6.2 Mbps
QPSK 1/2	5 MHz	2.5 Mbps
QPSK 1/2	2.5MHz	0.7 Mbps
BPSK 1/2	10 MHz	3.1 Mbps
BPSK 1/2	5 MHz	1.2 Mbps
BPSK 1/2	2.5MHz	0.3 Mbps

Table 2 Measurement results

The theoretical results of mathematical modeling (see Table 3) presented in [10] were compared with the actual measurement results shown in Table 2. A significant disparity was found between the theoretical and measured results in terms of the effect of channel width to data transfer speed per MHz.

Modulation	Channel width	Data transmission speed
16QAM 3/4	14 MHz	34.91 Mbps
16QAM 3/4	7 MHz	17.46 Mbps
16QAM 3/4	3.5 MHz	8.73 Mbps
16QAM 3/4	1.75 MHz	4.36 Mbps
16QAM 1/2	14 MHz	23.28 Mbps
16QAM 1/2	7 MHz	11.64 Mbps
16QAM 1/2	3.5 MHz	5.82 Mbps
16QAM 1/2	1.75 MHz	2.91 Mbps
QPSK 3/4	14 MHz	17.46 Mbps
QPSK 3/4	7 MHz	8.73 Mbps
QPSK 3/4	3.5 MHz	4.36 Mbps
QPSK 3/4	1.75 MHz	2.18 Mbps
QPSK 1/2	14 MHz	11.64 Mbps
QPSK 1/2	7 MHz	5.82 Mbps
QPSK 1/2	3.5 MHz	2.91 Mbps
QPSK 1/2	1.75 MHz	1.45 Mbps
BPSK 1/2	14 MHz	5.82 Mbps

BPSK 1/2	7 MHz	2.91 Mbps
BPSK 1/2	3.5 MHz	1.45 Mbps
BPSK 1/2	1.75 MHz	0.73 Mbps

Table 3 The theoretical results of mathematical modeling

In the measurements, the data transfer speed per MHz was highest at a channel width of 10 MHz. The speed was more than two times lower at a channel width of 2.5 MHz when measured with every available modulation. In the results of the mathematical modeling, the data transfer speed per MHz remained constant when the channel width was changed. On the other hand, the effect of modulation on data transfer speeds was found to be nearly identical between the theoretical and measured results. Table 4 shows the most important parameters of the mathematical modeling.

Parameters of mathematical modeling	
Channeling	FDD
Cyclic exponent	3
Frame duration	20 ms

Table 4 Parameters of mathematical modeling [10].

1) Measurement 2

The aim of the measurement was to compare the measurement results to the results of measurements conducted in a short-distance LOS environment in a laboratory. The equipment and topology used in the measurement are shown in Figure 2. Table 1 shows the most important settings for the WiMAX devices.

Table 5 lists the data transfer speeds achieved with the 64QAM, 16QAM, QPSK and BPSK modulations.

Modulation	**Coding level**	**Bit rate (Mbps)**
64QAM	¾	28.0
16QAM	¾	18.7
QPSK	¾	9.3
BPSK	½	3.1

Table 5 Measurement results for modulations

With 64QAM modulation, the results received in the urban environment showed only negligible disparity when compared to the measurement results obtained in the laboratory: a 28 Mbps downstream speed, as limited by the traffic profile, was achieved in both environments. With lower modulations, the laboratory speeds were 13-14% higher. The laboratory results are shown in Table 6.

Modulation	**Coding level**	**Bit rate max (Mbps)**	**Average bit rate (Mbps)**
64QAM	¾	28.0	26.0
16QAM	¾	21.2	21.2
QPSK	¾	10.6	10.6
BPSK	½	3.5	3.5

Table 6 Laboratory results

Table 8 shows the effect of channel width on the data transfer speed in an urban environment. The effect of channel width on the data transfer speed was nearly identical with the laboratory results listed in Table 7.

Channel width (MHz)	**Modulation**	**Coding level**	**Bit rate (MHz)**	**Average bit rate (Mbps)**
10	64QAM	¾	28.0	26,0
5	64QAM	¾	14.5	14,5
2.5	64QAM	¾	5,9	5,9

Table 7 The effect of channel width on the data transfer speed

The difference between the laboratory and urban environments when moving from a 2.5 MHz channel to a 5 MHz channel is only 0.1 Mbps. The transfer to 10 MHz cannot be taken into consideration as the 28 Mbps limit imposed by the traffic profile was reached in both environments.

Channel width (MHz)	**Modulation**	**Coding level**	**Bit rate (MHz)**
10	64QAM	¾	28.0
5	64QAM	¾	12.0
2.5	64QAM	¾	3.3

Table 8. Measurement results for channel widths

2) Measurement 3

The measurement tested the effect of direction, line-of-sight obstructions caused by trees, and transmission power on signal noise ratio in an LOS environment. The measurement examined downstream SNR values. The equipment and topology used in the measurement is as in measurement 1.

BS and SS device location and direction are shown in Figure 2. The SS device was directed to both sides of the BS device at horizontal angles of 15°- 45° in different phases of the measurement. Initially, the measurements were conducted in three locations in the Harju (Figure 3) neighborhood where the line of sight to the BS device was obstructed in varying degrees by tree trunks and branches. The antenna element was aimed directly at the BS device through the obstructions.

The density of the line-of-sight obstruction caused by the tree trunks and branches did not have a significant effect on the results. Nearly identical values for downstream SNR were measured in all three locations. Only increasing the transmission power notably affected the downstream SNR values in a partial NLOS environment. We were able to increase the SNR value by directing the antenna element towards a tall building 15° to the southwest of the BS device, which means that the best SNR result was achieved by means of reflection. Table 9 shows the effect of line-of-sight obstructions and transmission power on the SNR value.

Coverage of the trees	Transmit power (dBm)	SNR
Large	17	24
Mean	17	24,2
Small	17	24,4
Large	22	27,6
Mean	22	28,0
Small	22	28,0

Table 9. The effect of LOS obstructions and transmission power on the SNR value

The subsequent measurements were conducted on the terrace of the building 2 in Figure 3 where a perfect LOS environment was achieved. When measuring from the terrace, the best SNR value was achieved when the antenna element was directed significantly to the side of the BS device's beam as this allowed reflections from the surrounding metal structures to strengthen the signal. Increasing the transmission power notably affected the SNR values in a perfect LOS environment, as well. After moving from a partial NLOS environment to a LOS environment, considerable differences were measured in the SNR values. Table 10 lists the SNR values measured in the LOS environment.

Transmission power (dBm)	SNR
17	28,5
22	33

Table 10. SNR values measured in the LOS environment

V. SUMMARY OF THE MEASUREMENT RESULTS

The results of the measurement were slightly marred by the behavior of the UGS class, for which many remedies were tried over several months. Airspan recommends that, for the UGS class, the employed VoIP codec's sample rate, which is 30 ms with the G.729 codec, should be used as the polling time. The recommendation proved to be sound, as the UGS traffic began running without background traffic after the polling time was changed even though no VoIP traffic was present in the class. However, changing the polling time did not resolve the entire problem, as a new obstacle presented itself. With the new 30 ms polling value, traffic ran even without background traffic, but if BE traffic, which overloaded the link, was added to the background, the UGS class delay and delay variation decreased while the frame loss throughput increased against all logic.

According to the manufacturer, the UGS class allows for reserving a certain amount of bandwidth within the framework of a particular polling time, as in the example below. Example: 64,000 bits per second (Max Sustained Rate and Min Reserved Rate) equals 8,000 bytes per second. Therefore, a bandwidth reservation of 800 bytes can be made for each polling cycle by setting the polling time to 100 milliseconds. With these settings, the packet size would be 800 bytes, from which overheads must also be subtracted. With the PING – lXXX command, the result can be confirmed at 601 bytes with headers, which is approx. 743 bytes over the link [11].

We tested the class' behavior with different polling values and found the limit to be 31 ms. After this, the class will not function without BE background traffic. However, overloading the link with BE traffic does not diminish the values of the UGS. In fact, it does the opposite: delays, delay variation and packet loss decrease while throughput increases.

VoIP service products should be created in such a way that the classifier directs all SIP (session initiation protocol) signaling that passes through port 5060 to the BE class, whose traffic priority is lower than that of VoIP traffic directed to the UGS class. However, in all of the devices concerned, signaling over the WiMAX link is assigned to predefined, locked control traffic classes whose traffic priority is 8 or 9, which is higher than the priority of any other traffic class [12].

Despite countless attempts, we were unable to get the UGS class to function properly independently. At this stage, the software on the base station device and subscriber stations was updated to its latest versions. In addition, the new Netspan server application was updated to its latest version. However, the updates did not have any apparent effect on the functioning of the classes. An error report describing the problem was sent to the manufacturer, but we never received a reply. The manufacturer's suggestion to direct the signaling to the BE flow and other VoIP traffic to the UGS flow would possibly enable the class to function without BE background traffic but it would not solve or explain the problems with the class' other behavior. In the absence of a reply from the manufacturer, it remains unclear as to why this important signaling should be incorporated into the BE flow, which contains no attributes pertaining to quality of service, using a lower priority than that of VoIP traffic in the UGS class. The manufacturer established a remote connection to the Netspan server, but the problems were still not resolved and the solution suggestions were too short and ambiguous to be helpful.

In the earlier stages, when we were struggling with throughput problems, the manufacturer provided us with default configurations with which the devices were supposed to work as well as possible. However, the configurations proved to be unusable as, after they were implemented, the link functioned even worse than with our own configurations and the speeds dropped to a mere few hundred kilobits per second. After a more careful scrutiny of the manufacturer's website, we found that the 5.8 GHz licence-free frequency devices in our use had not been directly tested by Airspan. The test results represented similar devices using licensed frequencies.

Summary

In the course of the measurements, it was noted that the UGS class does not function without BE traffic in the background. Not even PING requests (packet internet groper) passed through the link in the UGS class alone without any background traffic. The UGS class traffic activated immediately after the introduction of 40 Mbps background traffic. Therefore, the activity of the class did not affect the measurements.

However, excluding the above-mentioned characteristic, the classes functioned properly. When using adaptive modulation for the measurements, the UGS class' delays remained approximately at a constant 22 milliseconds, whereas the delays of the RTP class rose significantly higher to over 90 milliseconds. Moreover, the RTP class presented a notably lower throughput – approx. 0.5 Mbps – compared to the nearly full 2 Mbps throughput of the UGS. This was directly reflected on the RTP class' frame loss, which was measured at 1.6.

Nevertheless, with 16QAM3/4 modulation, the differences between the classes reduced slightly. The delays of both classes dropped to below 20 milliseconds, but significant spikes occurred in the delay variation of the RTP class as opposed to the UGS class, which remained at a steady 2 milliseconds throughout the measurement. The same disparity was found regarding the frame loss, with the UGS class remaining near 0.1 and the RTP class presenting repeated spikes as high as 0.7.

VI. CONCLUSIONS AND FUTURE WORKS

Based on the results of the practical measurements, technology utilizing the licence-free frequency range could well be used to replace ADSL (asymmetric digital subscriber line) connections over copper cables in rural areas. At a distance of one kilometer, we reached a downstream data transfer speed of 28 Mbps, whereas with ADSL2+ technology, the data transfer speed a kilometer away from the DSLAM (digital subscriber line access multiplexer) is slightly over 20 Mbps, after which the speeds begin to drop dramatically as the distance increases. Currently, traffic at the 5.8 GHz frequency range is low in Finland. Therefore, the technology could also be used in urban areas, for instance, to connect two offices of a small or medium-sized business with a wireless WiMAX link with no monthly charge and with quality of service capability to ensure the uninterrupted flow of VoIP traffic, for example. After conducting various tests with the devices in a variety of environments, we found that the devices were best suited for use by businesses for Point-to-Point connections in an urban environment or for educational purposes due to their price and ease of use. Particularly in cities, businesses could replace costly ADSL connections that must be leased from operators with their own WiMAX devices. However, using the devices for the above-mentioned purposes is hindered by the abnormal behavior of the UGS class, which, without an update that remedies the problem, presents problems for placing VoIP calls and examining QoS classes.

Our future research will aim at optimizing the problem of cost-effective coverage area extension by using relays and consider novel resource management algorithms for multi-hop WiMAX networks.

ACKNOWLEDGEMENTS

We express our acknowledgements to Aku Aho and Juha Kuusenmäki from JAMK University of Applied Sciences Jyväskylä, Finland for contributing the practical measurements.

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