

# Fixed WiMAX Field Trial Measurements and Analyses

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**Abstract**—Much hype is spread about the performance of WiMAX, and many contrary statements are put forward. A reason for the confusion is that little or no published material exists about WiMAX performance based on measurements in real life field trials. We therefore set up a test-bed using WiMAX equipment now on the market, and did extensive, real life field trial measurements. This paper presents measured throughput and received signal strength under conditions typical for fixed WiMAX systems. Based on the results, throughput is analyzed and analytical expressions representing the measurements are derived for easy use in models.

**Index Terms**—Fixed WiMAX, Measurements, Throughput, Field Trial

## I. INTRODUCTION

WiMAX is an emerging wireless access system that can provide fixed and nomadic, and soon also portable and mobile wireless broadband connectivity without requiring line-of-sight (LOS) to the Base Station (BS). High throughput, good coverage and good support for Quality of Service (QoS) and security are some of the advantages of WiMAX.

WiMAX (formally WiMAX Forum certified [1]) is a certification mark for products based on the IEEE 802.16 standard [2] that pass a set of conformity and interoperability tests. The certification ensures interoperability of equipment from different vendors as well as a minimum performance and functionality. This will reduce costs, enhance performance, and facilitate market adoption.

There are two main classes of WiMAX systems called fixed WiMAX and mobile WiMAX. Fixed WiMAX is targeted for providing fixed and nomadic services, while mobile WiMAX can be used also for providing portable and (simple and full) mobile services. The system studied here is a fixed WiMAX system. It uses an air interface based on orthogonal frequency division multiplexing (OFDM), which is very robust against multi-path propagation and frequency selective fading. An adaptive modulation technique is used to enhance performance when the link characteristics vary. Our system used Frequency Division Duplexing (FDD), where the base stations and the user terminals transmit in different frequency bands. The MAC layer is connection oriented and uses Time Division Multiplex (TDM) for the downlink (DL) and a Time Division Multiple Access (TDMA) scheme for the uplink (UL). This reflects the

Point to Multipoint (PMP) architecture. QoS is extensively supported through four QoS classes with opportunities for constant bitrate, guaranteed bandwidths and best effort.

When the first WiMAX Forum certified equipment was released in early 2006, we decided to set up a testbed and present real life measurements together with comprehensive analyses of performance. As far as we know, little or no published material exists about WiMAX performance based on measurements in real life field trials.

We developed an extensive procedure to measure throughput and physical parameters. These measurements were performed at a range of locations with differing conditions, distances and sight capabilities.

Throughput was measured for the widely used transport protocols UDP and TCP, as well as for the popular application protocol FTP. Since physical parameters are of great importance when analyzing system performance, we measured the attributes signal strength and signal to noise ratio (SNR).

The main contribution of this paper is to present measurement results from real life WiMAX field trial together with comprehensive analyses. A second contribution is analytical expressions that represent the measurements in a convenient way for use in new and comparison with existing models.

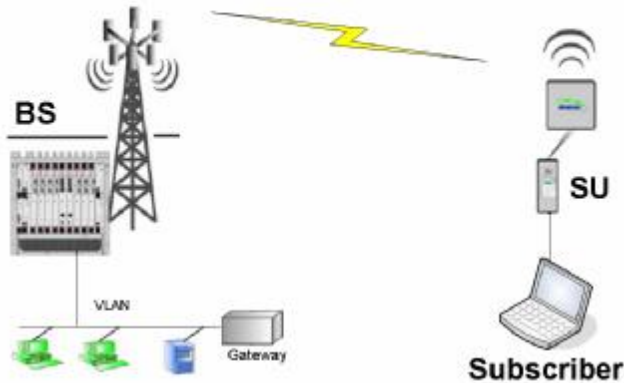
The organization of the rest of this paper is as follows: Chapter II presents the measurement setup and procedure. The physical performance and throughput performance are presented and analyzed in Chapter III and IV, respectively. Analyses of the UDP bitrate are given in Chapter V, where analytical expressions of UDP bitrate are derived. The conclusions are drawn in Chapter VI.

## II. MEASUREMENTS

### A. Setup

The test bed was set up with a WiMAX system operating in the 3.5 GHz frequency band. An overview of the measurement setup was roughly a Point to Multipoint (PMP) radio access system, where a WiMAX Base Station (BS) was connected to a VLAN, and a Subscriber Unit (SU) was connected to a subscriber as illustrated in Fig. 1. A Frequency Division Duplexing (FDD) technique utilizing 3.5 MHz channels was used, where the BS operated in full duplex and the SU in half

duplex mode. The measurements were performed with one SU connected to one BS.



**Fig. 1 WiMAX System Setup**

Transmitting power for the BS was 28 dBm and the antenna gain was 14 dBi. The BS was placed at the roof of a tall building 32 meters high. A network processing unit (NPU) was the heart of the BS which connected to the VLAN. The NPU controlled an Access Unit (AU) which interfaced to the wireless domain via an antenna.

The SU consisted of an indoor unit where power was added, and an outdoor unit containing the active components and an integral flat antenna. The maximum transmitted power was 20 dBm and Automatic Transmitter Power Control (ATPC) was used. The antenna gain was 18 dBi and the antenna height was 5 meters.

A Subscriber using the SU was given a Service which was configured with a QoS profile. Since only one Subscriber was operating alone in these measurements, a Best Effort profile performing 12 Mbps, was considered sufficient.

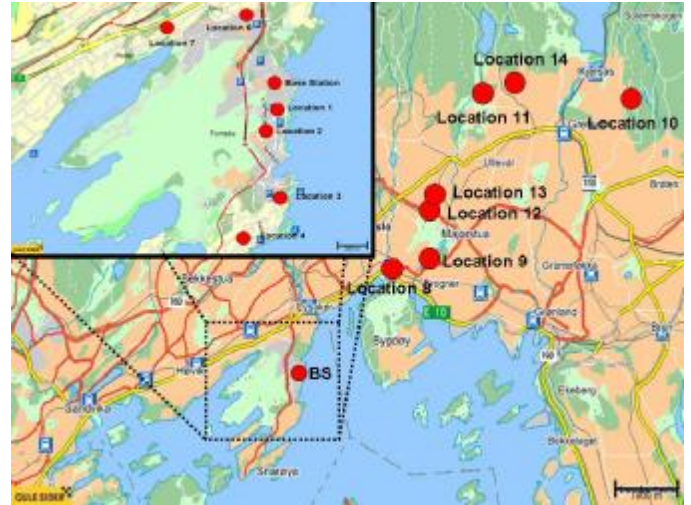
The measurements were performed in late summer, where the vegetation was dense with massive leaves on the trees, which is considered as a worst case scenario for signal propagation.

### B. Procedure

The measurements were done at 15 locations representing both urban and suburban environments, some of them close to the BS and some in suburban areas of Oslo. The selection of locations was based on various criteria, where distance, elevation and sight capabilities were the main differing attributes at each location. The locations are illustrated in Fig. 2. "Location 10" was the farthest off at 11.4 km, and also had the highest elevation, i.e. 251 m over the sea level. The small map in the corner shows the closest locations, and the area of the map is approximately 4 square km. We considered two types of sight capabilities, namely Line-of-Sight (LOS) and Non-Line-of-Sight (non-LOS).

The terrain around the BS was first flat, before it gradually increased in height as the distance from the BS increased. Such

a terrain was advantageous for the radio propagation pattern.



**Fig. 2 Measurement locations**

The measurements were divided into physical measurements and throughput measurements. The physical measurements included Received Signal Strength Indication (RSSI) and Signal to Noise Ratio (SNR). Throughput measurements were performed with the two transport layer protocols UDP and TCP, and the application layer protocol FTP which uses TCP. An automated procedure was developed in the programming language Python. All the measurements mentioned here were performed at each location by the subscriber station.

GPS was used at each location, thus a terrain profile could be constructed to fully determine the obstacles that may interfere with the line of sight.

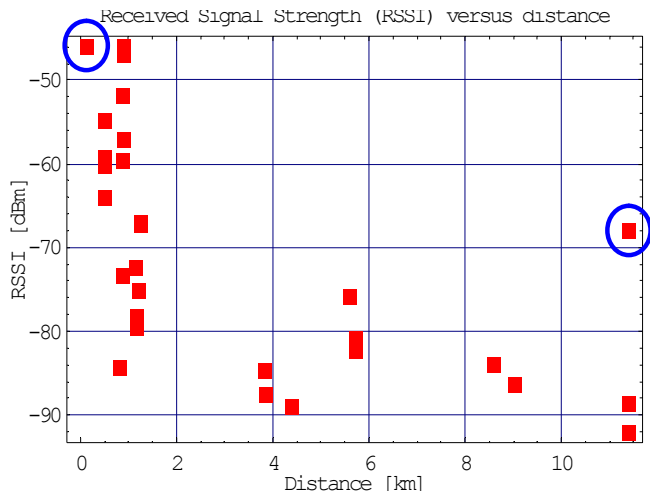
## III. PHYSICAL PERFORMANCE

The equipment reported the RSSI values, which represent the received signal strength in dBm. The RSSI is specified in the IEEE 802.16-2004 standard, sect. 8.3.9.

When analyzing signal strength it is useful to relate the received signal strength to the distance between the BS and the SU. This section analyses the signal strength for DL and UL.

### A. Downlink Signal Strength

Fig. 3 shows the measured RSSI values for all downlink measurements. The points inside the blue circles are Line-Of-Sight (LOS) measurements. The LOS measurement on the top left was performed with the receiving antenna directed towards a side lobe of the base station antenna to avoid saturating the receiver.

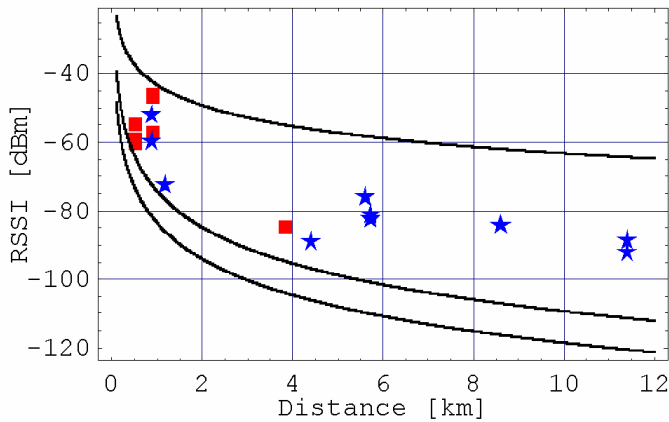


**Fig. 3 Downlink received Signal Strength Indicator (RSSI) values as a function of the distance between the base station and the user terminal**

The measurements were classified according to whether they represented a LOS or non-LOS condition, whether the receiving conditions were considered as better, typical or worse than average receiving conditions in the area and whether the environment was urban or suburban.

It is interesting to compare the measured received signal strength to what is predicted by path loss models.

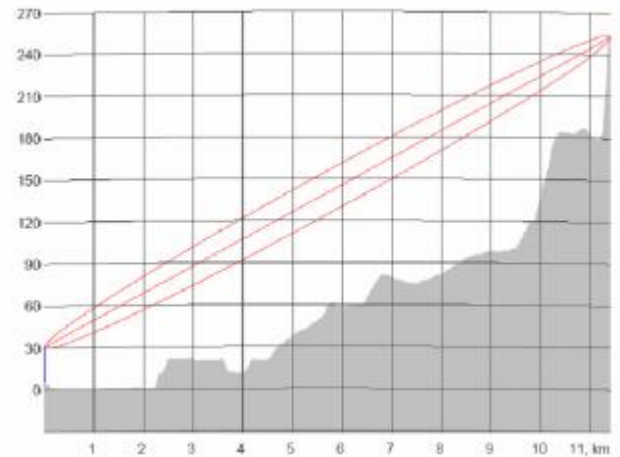
In Fig. 4 the measured RSSI values, classified as typical and non-LOS, are plotted together with the RSSI values corresponding to the COST-231 Hata models [3] for Path Loss in urban and suburban environments and the values corresponding to the Free Space Path Loss model.



**Fig. 4 DL RSSI values compared to three Path Loss models (lines): Free Space Loss (topmost), Cost-231 Hata Suburban (middle) and Cost-231 Hata Urban (lowest)**

Fig. 4 shows that all signal strength measurements classified as typical are better than the Cost-231 models for Path Loss in urban and suburban environments. There are two reasons for this: Firstly, the terrain around the BS was very favorable with respect to radio propagation since it was first flat and then gradually increased in height as the distance from the BS

increased as illustrated in Fig. 5. Secondly, the antenna placement was optimized somewhat at each measurement site. This corresponds to finding the optimum placement of the antenna on a house and therefore represents a realistic situation.

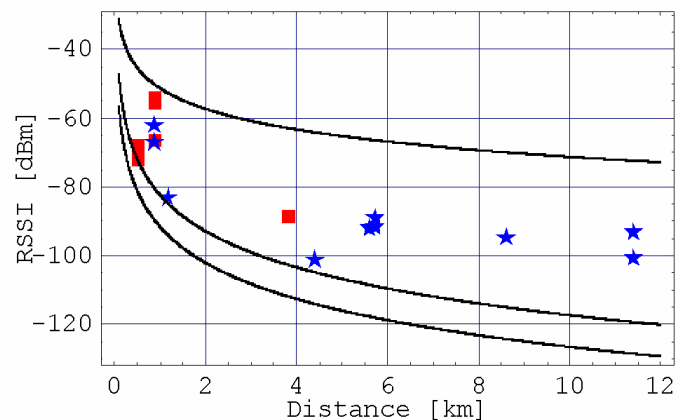


**Fig. 5 A typical terrain profile, where the SU is placed above the BS. This was the farthest distance (11.4 km) and highest elevated (251 m) location.**

### B. Uplink Signal Strength

The same classification of results is performed in UL as for the DL case. The actual transmission power used by the user terminals was also registered.

As for the DL case, it is interesting to compare the measured received signal strength to what is predicted by Path Loss models. Fig. 6 shows that the normalized UL signal strength values classified as typical non-LOS are better than the COST-231 models for Path Loss in urban and suburban environments. The normalization is done by adding the transmission power back-off (relative to the maximum value of 20 dBm) to the measured RSSI values.



**Fig. 6 Normalized UL RSSI values compared to three path loss models (lines): free space loss (topmost), Cost-231 Hata suburban (middle) and Cost-231 Hata urban (lowest)**

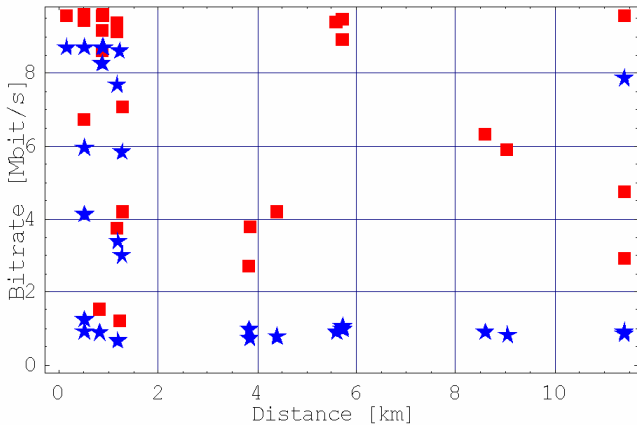
#### IV. THROUGHPUT PERFORMANCE

The protocols UDP, TCP and FTP were measured. FTP is not presented since it uses TCP. Some overhead is introduced by the FTP protocol, but the results are similar. This section analyses throughput for the protocols UDP and TCP.

##### A. UDP

Compared to TCP and FTP, the UDP performance is the most appropriate protocol to use to determine the real UL and DL system capacity. UDP does not use acknowledgments so there is no interdependency between the bitrates in the two directions. Since the SU used was a half duplex unit, the UL and DL were tested consecutively and not simultaneously.

Fig. 7 shows the measured UL and DL UDP performance for all locations.

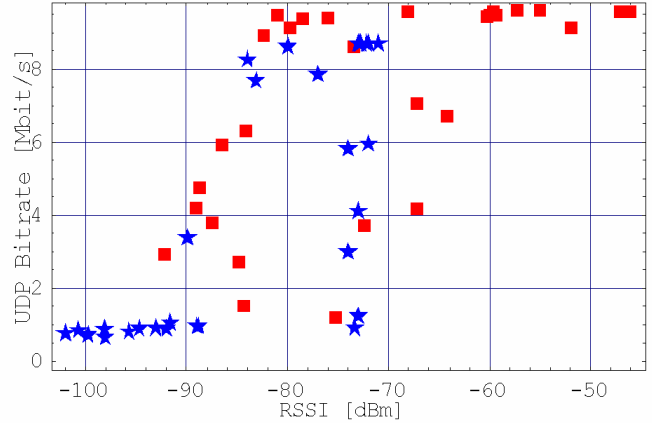


**Fig. 7 Measured UL (stars) and DL (squares) UDP performance for all locations**

In the manufacturer’s manuals, the maximum bitrate is listed as 12.71 Mbit/s for 64-QAM with  $\frac{3}{4}$ -rate FEC. The maximum measured UDP bitrate was 9.6 Mbit/s, so the useful bitrate was only 76 % of the maximum bitrate. This may have many explanations, such as UDP overhead and that some of the capacity is used for management traffic.

Fig. 7 shows that the measured UL bitrates are much lower than the corresponding DL bitrates for distances above about 2 km. The main reason for this is that the power amplifier in the user terminal can only deliver maximum 20 dBm, compared to the 28 dBm for the amplifier in the Base Station.

To verify that it is the difference in UL and DL transmission power that is the reason and not differences in sensitivity, the measured UDP bitrates for both UL and DL are plotted against RSSI values in Fig. 8. The figure shows that the UL and DL mainly have the same performance for the same RSSI. But the DL bitrates are marginally higher than the corresponding UL bitrates.

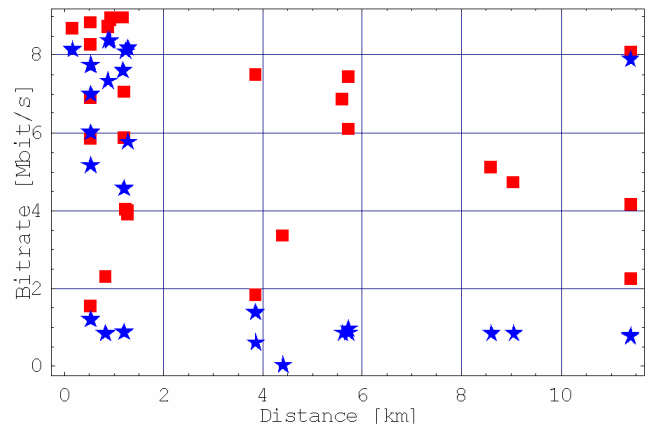


**Fig. 8 UDP bitrates as a function RSSI for the UL (stars) and DL (squares)**

##### B. TCP

Any TCP connection involves both UL and DL communication since acknowledgment messages must be sent in the opposite direction of the information stream. Hence, the bitrate in one direction depends on the channel conditions in both directions. Since the SU used was a half duplex unit, the UL and DL were tested consecutively and not simultaneously.

Fig. 9 shows a plot of the measured TCP bitrates as a function of the distance between the BS and SU. The maximum measured UL and DL TCP bitrates were 8.4 and 9.0 Mbit/s respectively.

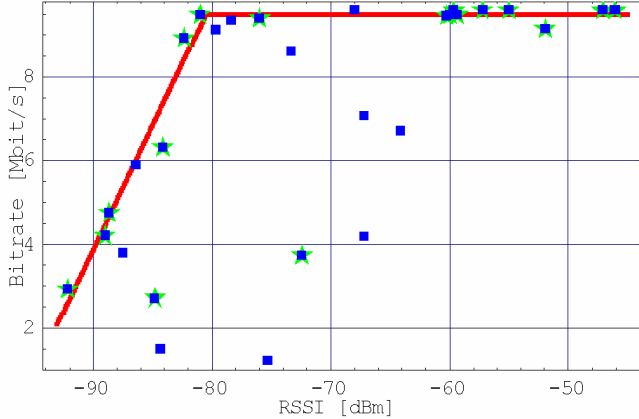


**Fig. 9 Measured TCP performance for all locations for UL (stars) and DL (squares). Six simultaneous TCP connections were used in the measurement and the bitrate is the aggregate bitrate for these connections.**

## V. ANALYSES OF THE UDP BITRATE

### A. UDP Bitrate as a Function of Signal Strength

Fig. 10 shows the measured DL UDP bitrate as a function of the RSSI. The most interesting measurements are those that are classified as typical, i.e. locations where the channel conditions are evaluated as neither significantly better nor significantly worse than the average conditions in the area. These measurements are shown overlaid by stars in Fig. 10.



**Fig. 10 Measured UDP bitrate as a function of RSSI. The analytical approximation to the bitrate versus RSSI relationship from equation, (1) is also shown (line) for typical, non-LOS situations. The measurements classified as typical and non-LOS are shown overlaid by stars.**

In many situations it can be useful to have a mathematical expression that can be used to estimate the bitrate as a function of RSSI for typical non-LOS situations. By using linear regression on the appropriate measurements in Fig. 10, an estimate of the bitrate was found to be:

$$UDP\ bitrate = \text{Min}[57.2 + 0.59 \cdot RSSI, 9.5], \quad (1)$$

where the RSSI is in dBm and the resulting UDP bitrate will be in Mbit/s. This estimate is plotted along with the measured data points in Fig. 10.

### B. UDP Bitrate as a Function of Distance

To obtain an analytical expression for the DL UDP bitrate as a function of distance, an analytical expression for RSSI versus distance derived from regression on the points in Fig. 4:

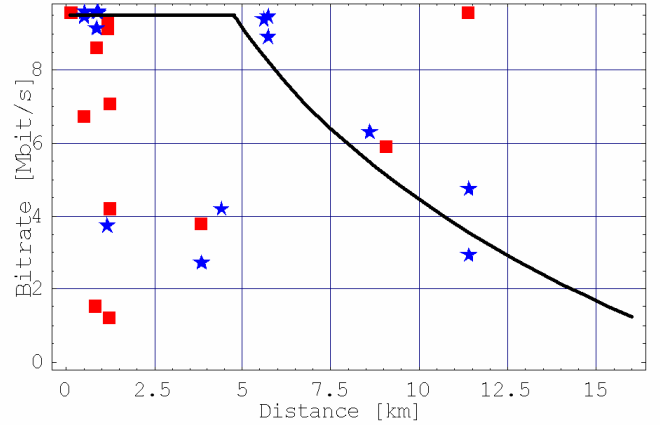
$$RSSI = -62.5 - 26.5 \cdot \log_{10}(r), \quad (2)$$

and the analytical expression for DL UDP bitrate versus RSSI can be combined. The resulting expression is:

$$UDP\ bitrate = \text{Min}[20.2 - 15.7 \cdot \log_{10}(r), 9.5], \quad (3)$$

where  $r$  is the distance between the BS and SU in km and the

resulting estimate of DL UDP bitrate is in Mbit/s.



**Fig. 11 All DL UDP bitrate measurements, both non-LOS and typical (stars) and others. The analytical approximation given by equation, (3) is also shown (line)**

It should be emphasized that the expression given by equation, (3) is based on relatively few measurements. But the equation summarizes the measurement results in a very convenient form that can be used for further analysis.

The equation only represents the measurements characterized as typical and non-LOS.

The measurements were also made in a terrain that is very favourable with respect to radio propagation, since it is flat out to a certain distance and then rises gradually with increasing distance.

## VI. CONCLUSION

A trial has been performed with a fixed WiMAX certified wireless access system. At various locations the link quality (e.g. RSSI) and the throughput for UDP, TCP and FTP traffic were measured for both the UL and the DL in suburban and urban areas. This paper presents an in depth analysis of these parameters based on measurements performed at locations classified as non-LOS and typical. Analytical expressions are derived for the DL UDP bitrate as a function of the distance between the BS and SU, and as a function of RSSI.

## REFERENCES

- [1] [www.wimaxforum.org](http://www.wimaxforum.org).
- [2] *IEEE Standard for Local and Metropolitan Area Networks Part 16: Air Interface for Fixed Broadband Wireless Access Systems - IEEE Std 802.16-2004 (Revision of IEEE Std 802.16-2001)*. 2004: p. 1--893.
- [3] COST, *Digital mobile radio towards future generation systems, final report COST Action 231*, 1999.