

Measurements and Comparison of WiMAX Radio Coverage at 2.5 GHz and 3.5 GHz

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Abstract— The performance of co-located WiMAX transmitter sites operating at 2.5 and 3.5GHz are compared, based on coverage assessments. The study showed that the 2.5GHz performed marginally better than the 3.5GHz under the same RF conditions and clutter environments. In general, the 2.5GHz was found to provide slightly better coverage at the edge of the cell, with an average of 2dB less loss at 1km from the transmitter location. Comparisons of the path loss difference between these two frequencies with various empirical propagation models (COST-Hata, ECC-33, WINNER II-Suburban, SUI Flat) were made, and differences from 2.9 dB to 6.2 dB are reported from these models, which are much larger than those reported here (around 2 dB for outdoor). These differences are also dependent on the distance to the site. Indoor penetration loss was found to be around 1 dB.

Keywords: radio propagation, mobile communication

I. INTRODUCTION

WiMAX, or *Worldwide Interoperability for Microwave Access*, is a telecommunications technology which enables wireless transmission of voice and data in many ways, ranging from point-to-point links to full mobile access, the so-called Broadband Wireless Access (BWA), where availability of bandwidth combined with the mobility should provide the users with a better experience of high data rate services such as web browsing or video streaming. Besides approving WiMAX as an IMT-2000 technology, the ITU-R has also identified the 2.5 GHz and 3.5 GHz frequency bands for the deployment of IMT-2000 technologies. Some countries such as the United Kingdom have started to offer WiMAX services at 3.5 GHz, but due to the increasing interest in the use of the 2.5 GHz band, the comparative benefits of WiMAX networks at these two frequencies need to be analysed.

The performance of co-located WiMAX transmitter sites operating at 2.5 and 3.5GHz are compared in this paper. The comparison criterion is based mainly on coverage assessments, including:

- Comparison of outdoor coverage footprints
- Indoor coverage

- Impact on site configuration
- Impact of local clutter

Section 2 of this paper goes through the data collection methodology applied during the measurement campaign. Section 3 provides the results of the comprehensive data set collected during the surveys. In section 4, we summarise the results and attempt to give an indication of what the results translate to in terms of network infrastructure requirement.

II. METHODOLOGY

Two types of tests were performed: *drive* tests for the coverage comparison, where the collection system was placed in the back of a test vehicle to replicate user experience; and *walk* tests for indoor penetration loss measurements, where the test equipment was carried by a radio field engineer. These in-building measurements were collected consistently, with the need of walking the length of the building along the wall adjacent to the room where the indoor measurements were to be taken.

The tests were carried out in Kingston, a town located south west of London. The location is typical of suburban towns found around the United Kingdom. An exhaustive drive test was performed around the site location. Measurements were also taken indoors and compared to the outdoor levels just outside the building, for indoor penetration loss. For this study, residential sites were particularly targeted, with the indoor measurements generally being taken in the “front” room of the house with a window to the outside.

After the transmit systems were fitted on the rooftop, the transmit antennas were adjusted to point at the required azimuth direction/tilt, since two directions were tested at the site for the survey (to gather data from different type of clutter having the same site). The street level receivers were then moved at the required positions and measurements were collected from those positions. Positions of the receiver were recorded using a GPS receiver. The transmit antennas' orientation was switched to a new azimuth and the process was repeated collecting new data at different positions.

Note that this collection process ran over a number of days at each of the two azimuths tested and consisted of measuring either from a survey vehicle, or using a walk-test kit (indoor penetration). The test set-ups for these two types of tests, locations where the measurements were taken and the type of measurements made are given in more detail in the corresponding sections of this paper. Walk tests and drive tests were carried out independently from each other as sufficient PC cards were available at the two frequencies of interest.

A. Survey Equipment

A number of PCs and laptops were fitted with the latest mobile *Accton* PC cards [1], shown in Fig. 1. Dedicated walk test laptop for the building penetration and internal loss tests was used. This laptop was also fitted with the current firmware upgrade and the necessary monitoring and network connection manager software. A GPS receiver and logging software to record position of measurements was used during drive tests.



Fig. 1 *Accton* PC cards used in the tests

B. Base Station Setup

The location of the test site was primarily selected because it offered a good mix of building type in its footprint: a residential area with two-storey buildings of types semi-detached and terraced to the north, and a mixture of 3-4 floors apartment blocks, 2 storey residential and large retail centre to the west. The antennas deployed had similar radiation patterns at the 2 frequencies and were arranged as shown in Fig. 2, with their centre of radiation at the same height.



Fig. 2 Close-in view from the back of the WiMAX antennas as arranged on the supporting frame (left) and view from the opposite end of the roof (right)

On Fig. 2, a 3.5GHz *Compact* antenna is at the centre of the frame and a 2.5GHz *Compact* and *Lite* antennas are on either side of the frame. The *Compact* base-stations, manufactured

by Alcatel-Lucent [2], use 4-port antennas whilst the *Lite* base-station, also manufactured by Alcatel, uses a 2-port cross-polar antenna. The former is mainly used for digital beamforming, whereas the latter is often employed for MIMO. Although the base stations were fitted with these features, a static beamforming configuration was used in the tests to disable any gains that would be made from either technology.

Also, note in Fig. 2 the difference in size of the 2.5 GHz and 3.5 GHz antennas – the 2.5 GHz antennas are slightly longer than the 3.5 GHz ones. These differences did not enter into consideration in this study but might be limiting factors in a commercial deployment situation where size and appearance might impact on the planning process of the site.

The antennas used in the tests were manufactured by Andrew Corp. [3]; the APW435_BC_3500 was used for 3.5 GHz, and the APW425_BC_2500 for 2.5 GHz. These antennas were chosen to guarantee a near perfect match between the two antennas' front lobe in the test area.

C. Base Station Configuration

For the base station configuration parameters, a transmit power of 35 dBm was used for each of the ports, with a channel bandwidth of 10 MHz. These settings were used for both frequencies.

III. RESULTS

A. Coverage Comparison

Fig. 3 shows the results of the drive-route around the designated site. The site location is indicated with a red symbol. The plots are the “best-server” of the RSSI (Received Signal Strength Indication) values measured on each of the North and West sectors. The extent of the coverage at 2.5 and 3.5GHz looks very similar, particularly close to the transmitter where fine details reveal a close match (within the range of the colour scale) between the two base stations' RSSI. Only at distances of a kilometre or beyond does a difference between the two begin to emerge. To analyse the difference between the two sets, the CDF (Cumulative Density Function) of the measured RSSI at the two frequencies in the interval 0-1.5km is shown in Fig. 4. This interval represents a rough estimate of the cell boundary at the lower frequency.

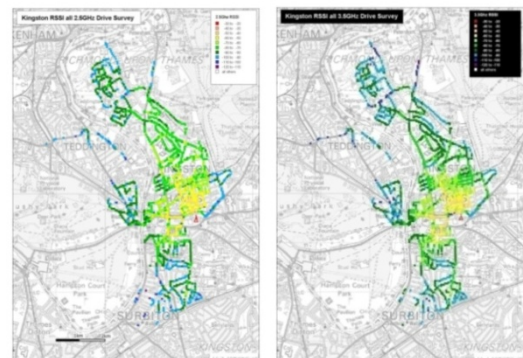


Fig. 3 RSSI measured around the Kingston site from the 2.5GHz-C (left) and 3.5GHz-C (right) combined from the North and West sectors

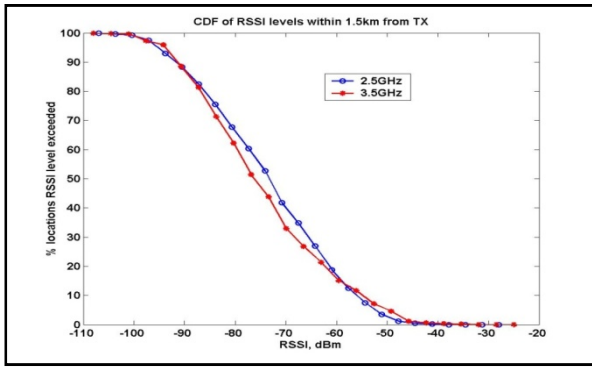


Fig. 4 CDFs of the RSSI levels measured at 2.5 and 3.5GHz in the distance range 0-1.5km from site

The CDFs in Fig. 4 confirm the close match between the two coverage levels' distributions, with the difference, in 50% of the locations being of the order of 3dB.

The difference in measured RSSI was subsequently analysed to determine the extent of the extra coverage provided by the 2.5GHz site. Fig. 5 shows the difference between the measured RSSI levels at the two frequencies. The bar heights show the mean within the distance interval covered by the bar widths. The red curve shows the best fit through the data scatter.

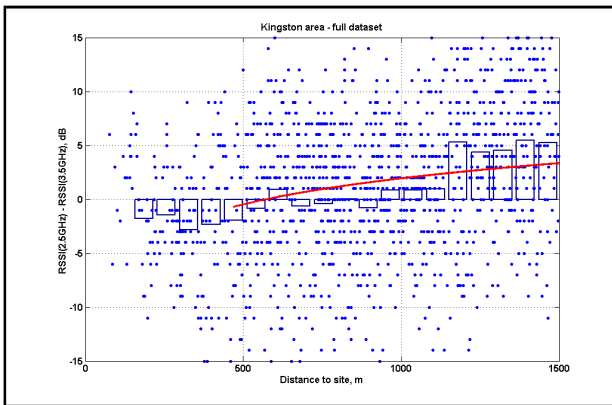


Fig. 5 Difference between the measured RSSI levels in decibels (2.5GHz minus 3.5GHz) showing mean differences (bars) and least-squares fit (red line)

It is clear from the scatter plot in Fig. 6, that the difference between the two frequencies is dependent on the distance from the transmitter. This is the result of a slightly higher path loss distance power law at 3.5GHz.

It can be observed from the plot that there is little difference between the two frequencies at a distance of up to about 500m from the site. In fact, the data shows a negative difference in this region, but this was ignored from the analysis due to a reduced data sample. From about 500m outward, the difference increases by around 1dB every 250m in the first 1.25km.

The theoretical difference predicted between the path loss at 2.5 and 3.5GHz obtained using a selection of the most popular propagation models is plotted in Fig. 6. Unlike what was observed from the measurements, the majority of these models predict a constant difference as a function of distance.

This low difference between the two bands is predicted to be 2.9dB by free-space, the SUI model [4] for a flat environment and the WINNER-II suburban model [5]. The Okumura-Hata model [6] on the other hand predicts the difference to be 4.5dB, and up to 6.2dB is predicted by the ECC-33 model [7].

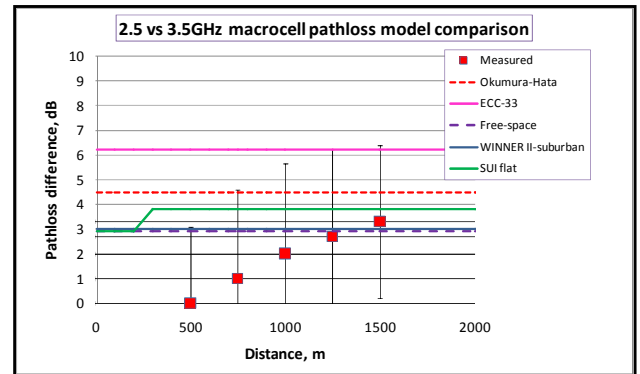


Fig. 6 Predicted difference between 2.5 and 3.5GHz outdoor path loss according to some empirical propagation models

Fig. 6 also shows the measured difference between the two frequencies' RSSI at given distances. The size of the error bar on the plot represents the standard deviation of the difference at those distances. The results of the campaign therefore appear to suggest that the effective loss in the type of environment where the measurements took place would lie at or slightly below the lower end of the range predicted by models.

A difference between the residential and business-retail environments when comparing the RSSI at both frequencies was also observed. Apart from the greater variability measured in the residential area, which might be due to the data being collected over a wider range of azimuths, the main feature is the relatively small difference between 2.5 and 3.5GHz RSSI in the range up to about 1km. The measured difference between the two frequencies' RSSI was computed over small distance intervals from the site rather than by using the best fit curve of the earlier analysis. This feature is less pronounced in the business-retail environment made up primarily of high-rise buildings, where the difference gradually becomes larger as distance increases, unlike in the residential environment which exhibits a sudden step beyond about 1.1km. It should be highlighted that this analysis was carried out only at positions where data from both frequencies was captured so there is no artificial effect linked to non-uniform data collection.

B. Indoor Penetration Loss

For the indoor measurements, the field engineer was required to walk over the length of the room facing the outside wall. The measuring system was set to record the levels during about 30s and the levels were subsequently averaged at the post-processing stage. For the North sector, 26 samples were collected. The buildings in that area mainly consisted of residential dwellings with brick walls and PVC or wooden windows. The indoor measurements were taken in the front room of the house. On the other hand, as shown in Fig. 7, 40

samples were collected in the West sector, wherein the buildings surveyed consisted mainly of retail units. Their frontage would generally be made of large open glass window.

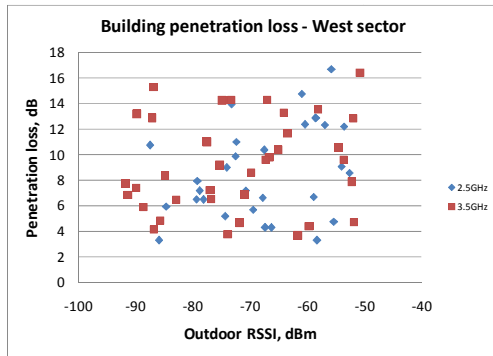


Fig. 7 Scatter plot of the measured indoor penetration loss over the West sector

The overall penetration loss estimated over the two sets of azimuths and summarised in Table 1, shows an additional loss of about 1dB at 3.5GHz compared to 2.5GHz. This translates, for the 90% locations to an equivalent 1.2dB difference between the two frequencies as shown. The 90th percentile results were derived directly from the measurements.

TABLE I
STATISTICS OF THE BUILDING PENETRATION LOSS MEASURED OVER THE TWO AZIMUTHS

	2.5 GHz	3.5 GHz	Difference
Mean [dB]	8.3	9.2	0.8
Std deviation [dB]	3.5	4.0	0.5
90 th percentile [%]	13.0	14.2	1.2

C. Summary of Results

The results presented in this paper provide a valuable insight into the similarities and differences in coverage to be expected between a mobile WiMAX network operating at 2.5 and at 3.5GHz. Tables 2 and 3 summarise the measured differences in received RSSI levels (labelled loss difference) at various distances from the site and the loss measured between outside and inside a building. Based on these findings, the difference in number of cells that would be required to cover an area of similar morphology to Kingston was estimated.

TABLE II
MEAN LOSS DIFFERENCE BETWEEN THE OUTDOOR AND INDOOR PENETRATION LOSSES AT 2.5 AND 3.5GHZ

Distance to site [m]	Mean loss difference between 2.5 and 3.5GHz		
	Outdoor [dB]	Indoor [dB]	Combined [dB]
500	0	0.8	0.8
1000	2.0	0.8	2.8
1500	3.3	0.8	4.1

According to service requirements, a minimum sensitivity at the MS (Mobile Station) antenna port of -75.5dBm is

required to provide a nominal rate of 5Mbps (effective rate of about 4Mbps). This sensitivity includes a 9dB fade margin for extra propagation losses, such as shadowing. The required -75.5dBm level would be achieved at a maximum distance of 953m at 2.5GHz and 803m at 3.5GHz. The 3.5GHz cell radius was estimated by taking into account an additional 0.8dB required to compensate for the additional indoor penetration loss experienced at that frequency. Thus, the difference in footprint area is expressed in terms of the ratio between the two areas and is approximated by

$$\frac{(953)^2}{(803)^2} = 1.40 \quad (1)$$

It would therefore require about 40% more sites at 3.5GHz to provide the equivalent indoor mobile coverage achieved by a network operating at 2.5GHz. These results are in good agreement with simulations carried out separately using a network planning tool with radio propagation based on deterministic models.

TABLE III
STANDARD DEVIATION OF LOSS DIFFERENCE BETWEEN THE OUTDOOR AND INDOOR PENETRATION LOSSES AT 2.5 AND 3.5GHZ

Distance to site [m]	Std Dev loss difference		
	Outdoor [dB]	Indoor [dB]	Difference [dB]
500	6.2	5.3	8.2
1000	7.3	5.3	8.9
1500	6.2	5.3	8.2

IV. ADDITIONAL ISSUES

Other aspects that were not taken into account in this study and which will have an impact on the cost and performance of the network are reviewed hereafter.

A. Antenna Gain

The antenna gain is proportional to the antenna aperture, and the higher the frequency the smaller the wavelength (hence the aperture) as illustrated in Fig. 8. The transmit and receive antennas at 3.5GHz would therefore have smaller profiles that those at 2.5GHz. At equal physical size, the 3.5GHz antennas could give up to 3dB extra gain compared to 2.5GHz antennas. This additional gain is partly compensated by additional loss through the feeder/connectors, but a net gain of about 1dB overall should be expected.

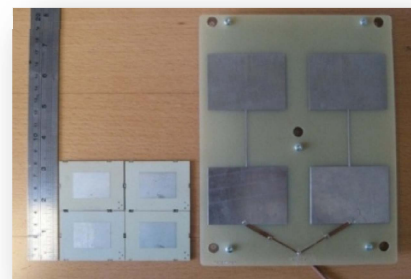


Fig. 8 Difference in size between 2.5 GHz (left) and 3.5GHz (right) patch antennas

B. Impact of Interference

This study was conducted in an interference-free environment due to the nature of the deployment. This type of analysis could be potentially conducted using a radio planning tool. It is anticipated however that, because propagation at 2.5GHz is less hindered than at 3.5GHz, and in view of the results showing a sudden increase in 2.5GHz performance beyond about 1km, that a network at 3.5GHz could potentially experience less interference at the edge of the cell because of the increased propagation loss at that distance.

V. CONCLUSIONS AND FUTURE WORK

The results presented in this paper provide a valuable insight into the similarities and differences in coverage for outdoor and indoor environments to be expected between a mobile WiMAX network operating at 2.5 and at 3.5GHz. Comparisons of the path loss difference between these two frequencies with various empirical propagation models were made, and differences from 2.9 dB to 6.2 dB are reported from these models. The results shown here show a difference of around 2 dB for outdoor and 1 dB for indoor penetration loss, which also are dependent on the distance to the site. This indicates that coverage differences may therefore be less than those anticipated by standard empirical propagation models.

Based on these findings, the difference in number of cells that would be required to cover an area of similar morphology to Kingston was estimated, resulting in 40% more sites needed at 3.5 GHz. The impact of other factors which could determine the overall performance of the network at 2.5 GHz and 3.5 GHz was also assessed and fully explained. These results were obtained in a suburban UK town, and findings in other types of environments might deviate from these results.

Further work is envisaged and could include:

- Perform throughput measurements, to assess the impact of coverage differences in network performance at these two frequencies
- Measurements in a different environment, such as adense-urban or urban location
- Use of a higher (umbrella cell) or lower antennas (microcell) to establish impact of transmit height
- Extend the work to include MIMO vs. dynamic beam-forming systems to assess any benefit of MIMO and whether that benefit would be spatially biased towards the edge of the cell
- Assessment of how the loss increases with indoor distance from external wall

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