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Solutions in Radiocommunications

ATDI

White Paper

Getting from Base Station to Subscriber: Exploring the Planning Myths

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Solutions in Radiocommunications

The search for new propagation modelling methods for WiMAX networks is largely a waste of time and effort, this paper asserts. Claims by many vendors that existing knowledge of propagation modelling is not applicable to WiMax networks is a contention that does not stand scrutiny. Rather, this paper suggests, a greater understanding of vendor equipment (transmitter, receiver and antenna system) and how it operates in real, multipath environments is needed. Counter arguments outlined in this paper are developed from existing knowledge of propagation at frequencies of up to 10GHz over paths of up to about 50km. A brief contrast is made with propagation above 10GHz.

INTRODUCTION

WiMAX provides broadband connection between base stations in a given area. This scenario is shown in Figure 1. WiMAX has its roots in the previous generation of fixed wireless technologies back in early 2000. Those in turn have their roots in the narrow band systems from the DECT era. All are deployed with a point to multi-point, or star, architecture, which were recently modified by mesh, and in some cases where customer premise equipment (CPE) are used as onward repeaters. They require that each path is modelled to determine its likely performance.

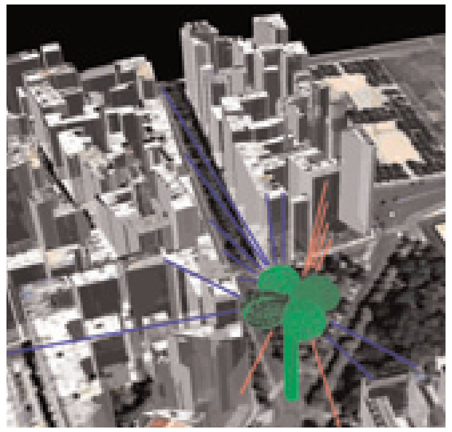

Figure 1: Point to Multipoint architecture

So what exactly are we talking about? What is different about WiMAX compared to the previous generation of broadband wireless technologies? The answer is not a lot. Broadly, planning will proceed as before. The lifecycle will demand minor modifications to methods according to the particular deployment. It will demand an overview plan and then plans, region by region. The quality concepts of validation (of methods) and verification (between design and implementation) are still completely appropriate. In addition, a feedback loop between design and implementation to hone methods to fit the needs of the deployment is needed. No changes at the macro level means that the significant body of knowledge about planning can be put to good use to reduce both cost and risk.

At the micro level, however, changes affect the way in which the planning and modelling tools model the technology path by path. Orthogonal frequency division multiplex (OFDM) is a modulation scheme developed in the 60s. Today's integration permits its realisation. In this case, the information to be transmitted is spread across a large number of carriers. The information is coded onto the carriers in such a way that no information loss occurs even if some of the carriers fail to reach their destination. Thus OFDM performs well in multi-path environments where the signal is victim to frequency selective fading (fading by varying degrees across the signal bandwidth). It still cannot cope with a flat fade, though, and needs the old fashioned high fade margin to avoid total loss. Several variants of WiMAX will use OFDM, particularly below 10GHz. Later WiMAX will use multiple-in, multiple-out (MIMO) antenna systems where the information is split, to be transmitted over several paths thereby offering a powerful diversity. So just what do these two technologies offer and what makes them different?

In approaching the question of how to plan WiMAX systems, I intend to discuss the signal environment and the modelling environment. I will describe how OFDM and MIMO perform and how to model their effects. Also I will discuss the nature and implications of various path types, linking this to other work on path dependent performance. Finally, I will discuss the concept of 'chance' and some of the probability distributions that affect WiMAX modelling. The conclusion will bring all this together to determine a prescriptive method for propagation modelling and I will also show several parameters that vendors need to provide to planners – something that few have been capable of doing to date.

SIGNAL ENVIRONMENT

In the case of a single high sited transmitting antenna and single high sited receiving antenna, the signal is diffused as it propagates from transmit antenna to receive. This spreading causes signal loss. Where 60% of the First Fresnel zone is free from terrain, building or vegetation obstruction, we say that we have a 'free space path' with the loss known as Free Space loss and defined by a simple equation. At higher frequencies we simply need assure this free space path and then the planning is straightforward. This has been an industry practice for many years, initially in microwave link planning and later in planning 26GHz and 42GHz FWA systems. This means that the body of knowledge acquired from WiMAX planning above 10GHz can be applied for such systems.

As the receiver descends such that the path becomes obstructed, the propagation is by diffraction with a loss over Free Space, calculable from the nature of the diffraction edges along the path. This loss modelling is well advanced, dating back to 1946 and culminating with accurate calculation methods lending themselves to computer applications with up to 5,000 diffraction edges considered numerically in every path profile. This body of knowledge is sound and needs no defence. We just need an adequately defined path profile.

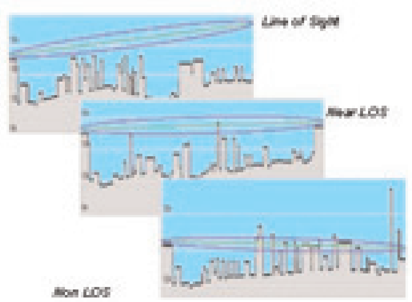

Figure 2: Path profiles

The signal is reflected from various surfaces along the path. To explain this mechanism, we need to consider that there are two separate environments: that in mid path and that in close proximity to the terminals. These reflection-rich environments are well documented. It is known that as a result of both terminal end reflections and mid path reflections, a narrow band signal experiences extreme fading in space, were the terminal to move, and in time, as the environment changes as people and vehicles move. Since the reflection path lengths vary widely, a wide band signal experiences different fading across the frequency bandwidth and the result is the much-documented delay spread profile that is a function of the path, varying path by path.

MODELLING THE ENVIRONMENT

All planning and modelling tools need a model of the environment; that is, a statement of the terrain with some representation of buildings and vegetation. High resolution data sets are expensive varying from £250/£420 per square kilometre for a resolution of between 1metre and 5 metres. There are lower resolution data sets at 5 metres but these sometimes suffer poor fidelity. Cellular type data sets (comprising terrain and a statement of urbanisation and vegetation rather than actual buildings and trees) are ubiquitous in most countries at modest prices. I want to explore whether it really is essential to spend £250 per sq.km or whether in reality WiMAX needs something else. Whatever we do, we must complete the modelling on an approximation to the real world. If we can get very close to reality for a realistic sum then clearly that is preferable. If not, then how far from reality can we go and still complete meaningful planning?

DEPLOYMENT STRATEGIES

There are two deployment strategies that appear to be popular: indoor, self install and outdoor, professional install. The indoor, self install will probably use monopole antennas whilst the outdoor will have the benefit of a medium gain panel. Let's consider the reflection environments of both.

Firstly, we need to establish some dimensions as a reference. The wavelength at 5.8GHz is around 5cm. Typical antenna spacing for MIMO is around 4 wavelengths at 20cm. The dimensions of the CPE are likely to be around 25cm by 15cm and hence the antennas will be mounted on the terminal, whether indoor or mounted outdoor, as a WiMAX/WiFi gateway.

In the case of indoor, self install, reflections are arriving at the terminal from all around the room and from the rooms and buildings around; in fact, from just about everything in the vicinity. For outdoor, professional install, the signal arrivals are mainly from the environment in front of the panel antenna. In both cases, if we are to model the reflections we need a terrain, buildings and vegetation data set with a resolution commensurate with the antenna footprint – about 5cm. This is not a practical reality.

The practical, if expensive, resolution is 1 metre. The problem there is that with an antenna footprint of 5cm we are not modelling all reflections; our model of reality is just too coarse. We also need to consider the processing time needed to model a multi-base station network with a resolution of sub-1 metre. The extraction of the path profile to the terrain point and its loss calculation will not be the limiting calculation; it will be consideration of the huge number of reflections. This scenario is almost impossible given the practical constraints of time and money. What, then, is the alternative?

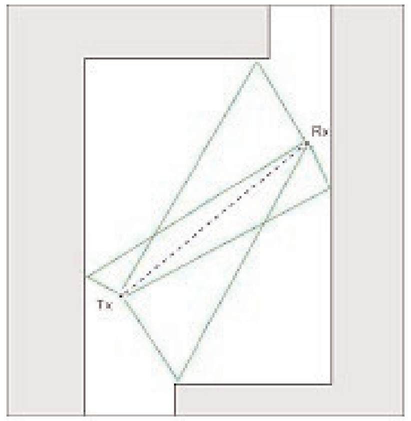

Figure 3: Reflection environment with a fraction of all reflections shown modifying the path from TX to RX

Let's approach the problem with the assumption that we have 10 metre resolution terrain data with associated 10 metres resolution clutter data. There is therefore one height point on the terrain every 10m and at that point we have a statement of the degree of urbanisation or vegetation. This statement is quantised into, say, 16 levels. This allows us to constrain the problem. We can consider that most of the reflections in the immediate vicinity of the CPE will be constrained within the terrain point. We don't have to model them but we do need to know by test how the WiMAX terminal will perform in each of the urbanisation/vegetation classes.

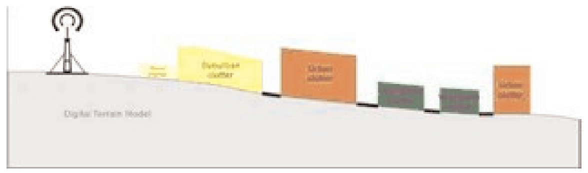

Figure 4: Clutter expression on terrain

We do, however, need to consider reflections from along the path. We can draw some parallel here from the SUI models so often cited in WiMAX documents. Previously I noted that the SUI models were much too general. I also noted that the degree of reflection along a path depends on the nature of the path and that the nature of the path and the volume of multipath from the path itself were described by the Ricean K factor. K will be covered in detail later but for now consider that the higher K, the more multipath and hence the better WiMAX performs. We can therefore determine a path dependent factor for multipath which combines with the local clutter factor described above. How then does all of this come together to give a reliability for the WiMAX equipment on that path?

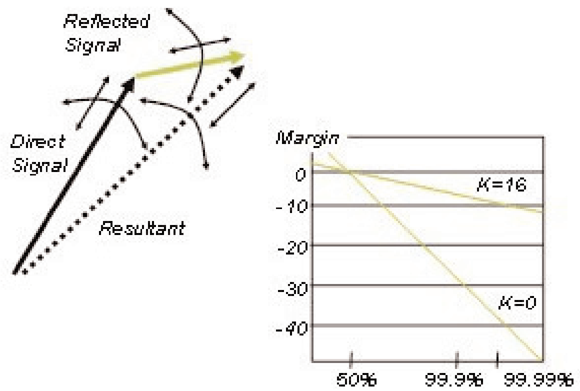

Figure 5: Ricean fading; Lognormal and Rayleigh combined

CONSIDERING THE FLAT FADE

Fading at low frequencies on line of sight, unobstructed paths, is well documented and needs no introduction. It has been proposed by many that as paths become obstructed, the reliability reduces. It is likely that this is as a result of multipath and can result in the slow fading that is described by Vigants and others from the 70s. This leaves us with slow fading computable using Rec. 530. This recommendation yields about 10dB fade margin needed to achieve a reliability of 99.99% on a 20km path at 5.8GHz in Western Europe.

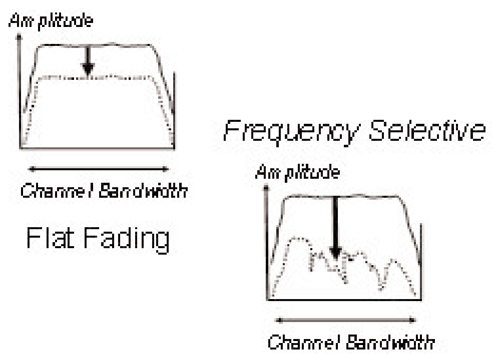

Figure 6: Flat and frequency selective fading

PATH PREDICTION

Path prediction is a mature science. Significant evidence suggests that as an industry we have been developing methods since 1946. I don't want to spend time on this again; suffice to say that methods after Deygout and others yield good accuracy with median error of around 1dB with a standard deviation of error at 5.8GHz of a few dB. We do not need more propagation models to compute the median path loss from a complex profile.

Studies show that the difference in path loss computed between high resolution terrain and building models and the same with medium resolution is not high (for a clear foreground near the terminals). Indeed, because most elevation processing tends to take the highest point in the 10 metre DEM point, coarser models tend to yield a more pessimistic result. For a 10km path at 5.8GHz we should therefore not consider that we would be degrading the error hugely by describing the mid path with a 10 metre DTM and 16 level clutter models. Given our practical terrain and clutter data, we can therefore predict the median path loss with some accuracy.

A FINAL NOTE ON PATH GEOMETRY

There is much said in error about WiMAX and other technologies and their ability to work over various path geometries. Previously, I have made the following comments:

We can designate paths by three very broad categories. A line of sight (LOS) path is where a stated percentage of the first Fresnel zone is free from obstructions. It is likely that with single modulated carrier operation, this is the requirement for successful WiMAX operation above 10GHz. A near-LOS path is one with minimal obstructions and in any case only the bottom half of the first Fresnel zone clear. A non-LOS path is one with heavy obstruction and with the line of sight breached and intrusion into the top half of the Fresnel zone.

Fundamentally, provided that there is enough in hand in the budget, typical WiMAX paths will work with both single carrier and OFDM modulation. LOS paths have no diffraction loss and hence no excess loss over free space yielding a good range. They have little multi-path and need higher margins for a given required reliability when compared to non-LOS paths. Non-LOS paths using single carrier modulation perform poorly since these systems dislike the delay spread experienced in a multi-path field. Non-LOS paths have high diffraction loss and hence high excess loss over free space thus reducing range. They are rich in multi-path and, therefore, need smaller margins (providing that the budget allows operation in the first place to overcome the diffraction loss). Near-LOS paths fall somewhere in the middle.

Generally, LOS paths have a low Ricean K factor in that most of the energy received at the distant terminal comes directly from the transmitting antenna. Non-LOS paths have high Ricean K factor in that the energy received is an aggregate of all of the arrivals from a vast number of reflections. The higher the K factor the more multipath and the easier it is for OFDM to recover the bitstream from the signal.

Figure 7: Penetration loss graphically

Finally, for indoor operation, we have yet another loss over free space: The penetration loss measured as the median signal level indoors (in a specified environment, normally one wall in and on the ground floor) when compared to the median value in the street. Values vary but seem to centre on 14dB (from a brief web search) and this further constrains the budget, reducing the path length from the base station to typically around 1km. One point to note for planning is that the standard deviation indoors increases over that found outside. To achieve the same chance of success indoors takes an increased confidence margin.

BRINGING IT ALL TOGETHER

In conclusion we can make the following statements:

- Provided that the budget will fund it, all path types can be worked with any modulation scheme. There are constraints, though. Some mixes are better than others.

- The degree of multipath varies as the CPE terminal environment. Urban areas provide more multipath than rural areas. The nature of the urbanisation or vegetation is given by a clutter attribute (heavy urban, urban, suburban etc) and this is a proxy for multipath degree.

- The degree of multipath varies according to the nature of the path. Obstructed paths offer more multipath than LOS paths. The degree of multipath can be determined by the Ricean K factor, itself dependent to some degree on the diffraction loss.

- We still need a fade margin to overcome flat fading amounting to, say, 10dB over a 20km path. One does, however, see benefit in making use of and processing multipath arrivals when compared to the median path loss. This benefit varies between 2 and 3dB for a LOS path to about 8dB for a rich multipath. The result of these two cancel one another to give the low net fade margins of between 2dB (for non-LOS) and 7dB (for LOS) cited by some vendors. All of this needs to be computed as a fade margin per path.

To effect planning, the engineer needs to define the budget. He needs also to know how the equipment (terminals and antenna systems) perform in varying degrees of urbanisation and path obstruction and hence what fade margins to apply for each path. I have defined this performance as occurring in a single terrain point of around 10-25 metres square. Once these parameters are known for given equipment then planning using the medium resolution terrain and clutter data can begin.

CONCLUSION

I believe the industry knows a lot about planning wireless networks and that the work that some were doing to 'invent' new propagation models was, in my view, wasted. Recent developments have only reinforced my view. I also think that the planning and modelling industry needs to know how various pre-WiMAX and WiMAX equipment operates in varying richness of multi-path. Recenty I've have tried to obtain data on this from several vendors. With one or two exceptions, few understand the problem, let alone have the ability to provide answers.

I must therefore repeat my assertion that there is a huge body of knowledge in propagation modelling. It is not the path modelling that needs reinventing. It is the vendor equipment that needs parameterising so that performance and fade margin requirements for given paths and in given terminal environments are specified.

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