NORTEL

White Paper

Considerations for deploying mobile WiMAX at various frequencies

Introduction

The explosive growth of the Internet over the last decade has led to an increasing demand for high-speed, ubiquitous Internet access. Broadband Wireless Access (BWA) is increasingly gaining popularity as an alternative "last mile" technology in this domain. Following the successful global deployment of the IEEE 802.11 Wireless Local Area Network standard known as "WiFi", deployment of the IEEE 802.16-2004 standard (802.16d, generally known as Fixed WiMAX) Wireless Metropolitan Access Network (MAN) is now underway. This technology aims to provide low-cost, high-performance broadband wireless access to residential and small business applications. Standardization was also completed recently for IEEE 802.16-2005 (802.16e, generally known as Mobile WiMAX), which will provide mobility to end users in a MAN environment.

As technology evolves to address portable and mobile applications, the required features and performance of the system will increase. Evolution toward the phase called "full mobility" provides incremental support for low latency, low packet loss and real-time handoff of subscriber terminals operating at high speeds. This requires enhancement to both the radio and network infrastructure. Mobile WiMAX technology is optimized to deliver high, bursty data rates to mobile subscribers, and the advanced Medium Access Control (MAC) architecture can simultaneously support real-time multimedia and isochronous applications such as Voice over IP (VoIP). Mobile WiMAX technology is uniquely positioned to extend broadband wireless beyond the limits of existing technologies. In this white paper, key considerations associated with deploying and operating mobile networks in different radio frequency bands are discussed.

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Spectral considerations

The 802.16-2005 standard supports the frequency range of 2 to 6 GHz, although other frequency bands can also be accommodated. Figure 1 shows the various frequency bands available around the world. It is anticipated that additional frequency bands on a regional basis will also be auctioned.

WiMAX operates in a mixture of licensed and unlicensed bands. The unlicensed bands are typically the 2.4 GHz and 5.8 GHz bands. Licensed spectrum provides operators control over the usage of the band, allowing them to build a high-quality network. The unlicensed band, on the other hand, allows independents to provide backhaul services for hotspots. For the purposes of this white paper, 3.5 GHz and higher are defined as higher frequency bands.

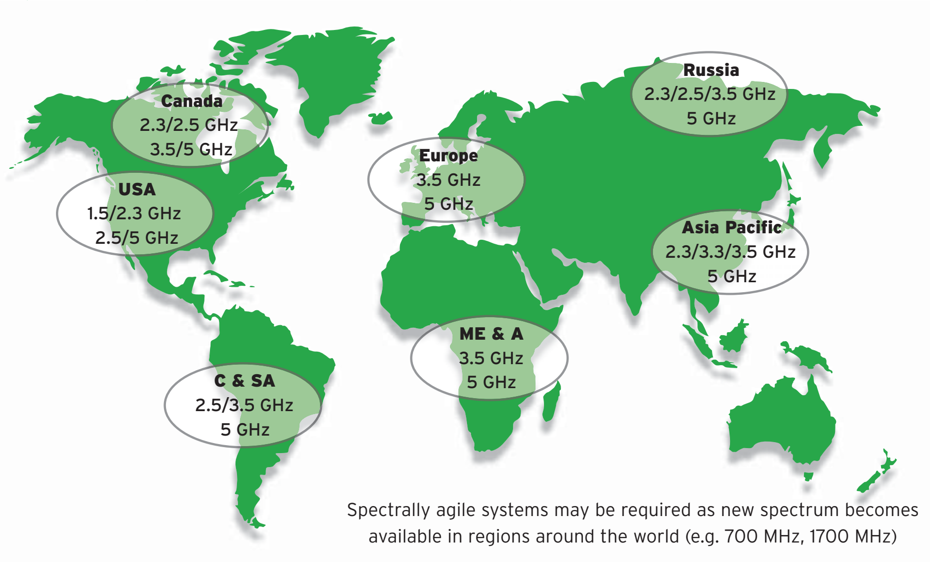
Currently, significant activity is underway in the 2.5 GHz and 3.5 GHz bands and Table 1 shows a comparison of the two.

Mobile WiMAX system considerations

The 802.16-2005 standard will introduce the OFDMA (Orthogonal Frequency Division Multiplex Access) method and MIMO (Multiple Input Multiple Output) antenna technology. One of the major advantages of OFDM is its extreme robustness in multi-path environments. The basic operating principle for OFDM is as follows:

- A transmit channel is divided into a large number of parallel sub-channels (N>>1).
- The data stream from the source is split into each sub-channel.
- Consequently, the data rate of each sub-channel becomes 1/N of the main string and the symbol duration becomes N times longer.
- Also, each sub-channel is transmitted via a very narrow bandwidth so the signal fading is basically flat within the sub-channel.

Figure 1. Frequencies available for WiMAX deployments



Spectrally agile systems may be required as new spectrum becomes available in regions around the world (e.g. 700 MHz, 1700 MHz)

Table 1. Comparison of 2.5 and 3.5 GHz bands

	2.5 GHz	3.5 GHz
Total spectrum	195 MHz	Around 200 MHz
Spectrum/license	16.5 paired with 6 MHz	2x5 MHz to 2x 56 MHz
License aggregation	Yes	Some countries
TDD/FDD	TDD/FDD	Some are FDD only
Allocation	U.S., Canada, some in Latin America, Australia, expected in Asia	Worldwide except U.S.
Services	Fixed, mobile	Fixed; some may allow mobile

As a result, the longer symbol duration and flat fading make OFDM robust under multi-path fading with no inter-symbol interference. Combining advanced MIMO antenna technology for data transmission with OFDM enables a number of key operational benefits that can translate into significant cost savings and advantages, namely:

- Powerful spectral efficiency and throughput gains
- More efficient utilization of power — for the same power output per sector, MIMO provides greater capacity with the same coverage as single output systems
- Decreased required footprint through the design of a compact BTS with higher reliability and throughput

The system supports adaptive modulation in the downlink and uplink. Modulations ranging from BPSK 1/2 to 64QAM 3/4 may be employed. Adaptive modulation techniques, such as monitoring link quality between the transmitter and receiver and selecting the highest usable data rate, are used throughout the product range.

Designing a mobile WiMAX network: a step-by-step perspective

One of the most important technical and business issues of any wireless technology is efficiently (cost and performance) providing coverage and capacity, while avoiding the build-out of a large number of new cell sites.

Given that the 802.16-2005 standard operates in the higher frequency bands, the impact to coverage and range at various frequency bands should be considered.

Developing the link budget

The first step in designing a wireless system is to develop a link budget. Link budget is the loss and gain sum of signal strength as it travels through different components in the path between a transmitter and receiver. As with any transmission system, the received power must be sufficiently greater than the noise power to allow adequate reception of the signal. Therefore, the transmitted power must be sufficient to allow for losses in the transmission medium and still provide sufficient power to the receiver. The link budget determines the maximum cell radius of each base station for a given level of reliability and is comprised of two types of components:

- **System related components** are power level, receiver sensitivity and modulation efficiency — none of which are expected to vary significantly across the different frequency bands.
- **Non-system related components** are expected to vary at the different frequencies and include the following:
  - > *Path loss:* An RF signal experiences propagation loss, also known as path loss, and the degree of loss is frequency dependent. The lower the frequency, the smaller the path loss and the further distance a signal can propagate. Also, different frequency bands may have different propagation characteristics. Extremely high frequencies (>10 GHz) cannot go around obstacles and require Line-Of-Sight (LOS) conditions. At low frequencies, RF waves can go around small obstacles.
  - > *Physical environment:* Building penetration loss does not seem to vary significantly in the 1.9/2.5/3/3.5 GHz frequency bands. Higher frequency bands have shorter wavelengths, which can enter buildings through small openings, but suffer significant losses along metal and concrete surfaces. In contrast, these shorter wavelengths suffer lower losses through glass.
  - > *Cable loss:* Cable loss increases monotonically with frequency. In higher frequency bands, this could severely disadvantage coverage in places where tall towers are used (rural). There are products that place the entire transceivers on tower top, eliminating the cable losses.
  - > *Shadow margin:* Terrain and man-made objects can cause significant variation in signal power; hence, additional margin can be added to the path loss to achieve a desired coverage reliability. The shadow fade margin increases with increasing frequency.

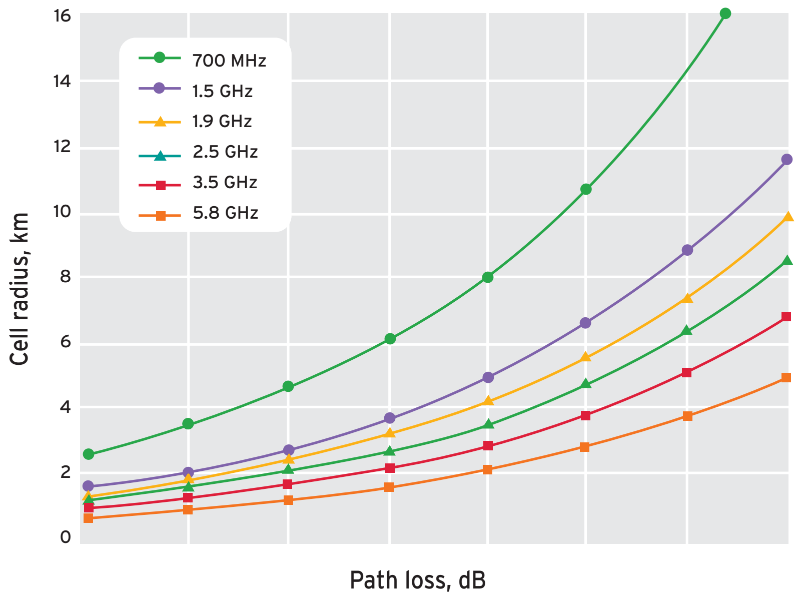
As such, these components are important factors when evaluating the complexity and speed in deploying at higher frequency bands, especially in unlicensed bands such as 5.8 GHz (licensed in some countries such as Russia) where other factors like interference from other surrounding networks will also impact network performance and quality of service.

Step 1. Consider the impact of frequency band on range — link budget and path loss

Evaluation of each of these non-system components in greater detail demonstrates the importance of considering path loss, shadow margin and physical environment when developing a link budget to design for optimal range and coverage. Higher path losses can substantially increase the site count in higher frequency bands. Figure 2 shows a comparison of coverage versus path loss at different frequency bands. This example assumes a link budget of 142 dB, which provides a cell radius of 3 km in the 1900 MHz band.

In this example, to obtain the same cell radius in the 2.5 GHz band, an additional link budget of 4 dB is needed. In a coverage-limited design, this corresponds to a 21 to 24 percent reduction in cell radius and a 62 to 75 percent increase in the cell count across different environments (urban, suburban and rural). For the 3.5 GHz band, you would need an additional link budget of 9 dB. In a coverage-limited design, this corresponds to a 42 to 46 percent decrease in cell radius and a 200 to 250 percent increase in cell count. This example illustrates the impact that path loss can have, especially when deploying in higher frequency bands.

Figure 2. Cell radius vs. path loss



Step 2. Consider the impact of frequency band on range — link budget and shadowing margin

Given the impact of terrain and man-made objects on signal power, additional margin is needed to achieve a given reliability of service. Without this additional margin, shadowing can cause outages in large areas of the cell. The higher the reliability required, the higher the shadowing margin and the cell count. Most wireless systems are designed for 95 percent reliability, which requires a budget of 7 dB shadow margin. To avoid the 5 percent outages, solutions such as indoor distributed antenna or deployment of antennas at the terminals can provide coverage for the shadowed areas.

Step 3. Consider the impact of physical environment on coverage and link budget

The physical surroundings of a cell site play a major role in determining the cell radius. Factors such as flatness of terrain and density of trees and foliage have significant impact on RF propagation. Figure 3 depicts the coverage range at 2.5 GHz for three different topologies.

The cell radius ranges from 3 km in a harsh propagation environment such as scenario A to 5.2 km in scenario C (good propagation environment). This means that the cell count is nearly cut by one third if the WiMAX service is deployed in scenario C compared to scenario A.

Figure 3 also shows the impact of MIMO on cell radius, increasing cell radius depending on the MIMO configuration in the different topologies, demonstrating the advantage of deploying MIMO/OFDM 802.16e-based systems.

Figure 3. Cell radius in different topologies

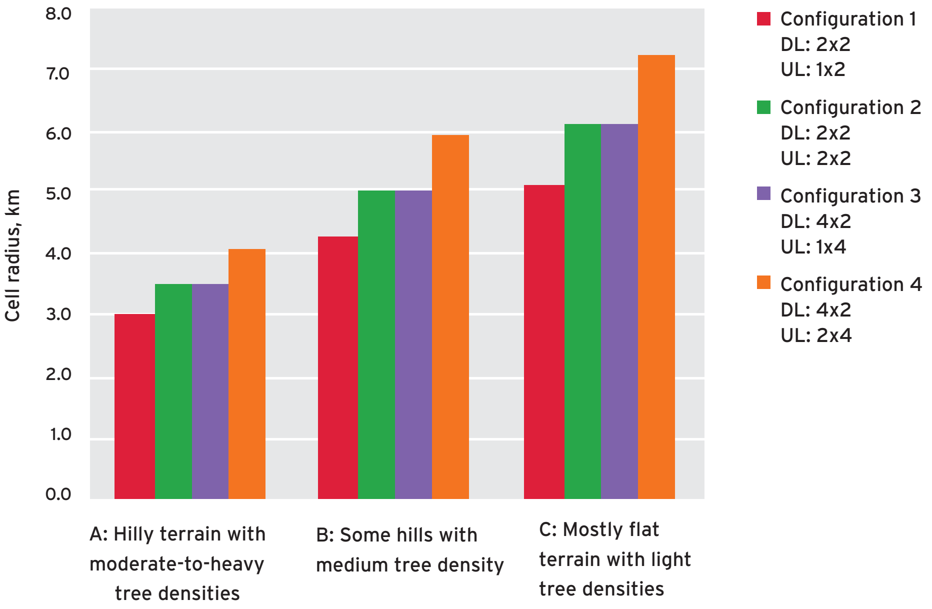


Table 2. Factors affecting coverage and range in mobile WiMAX deployments

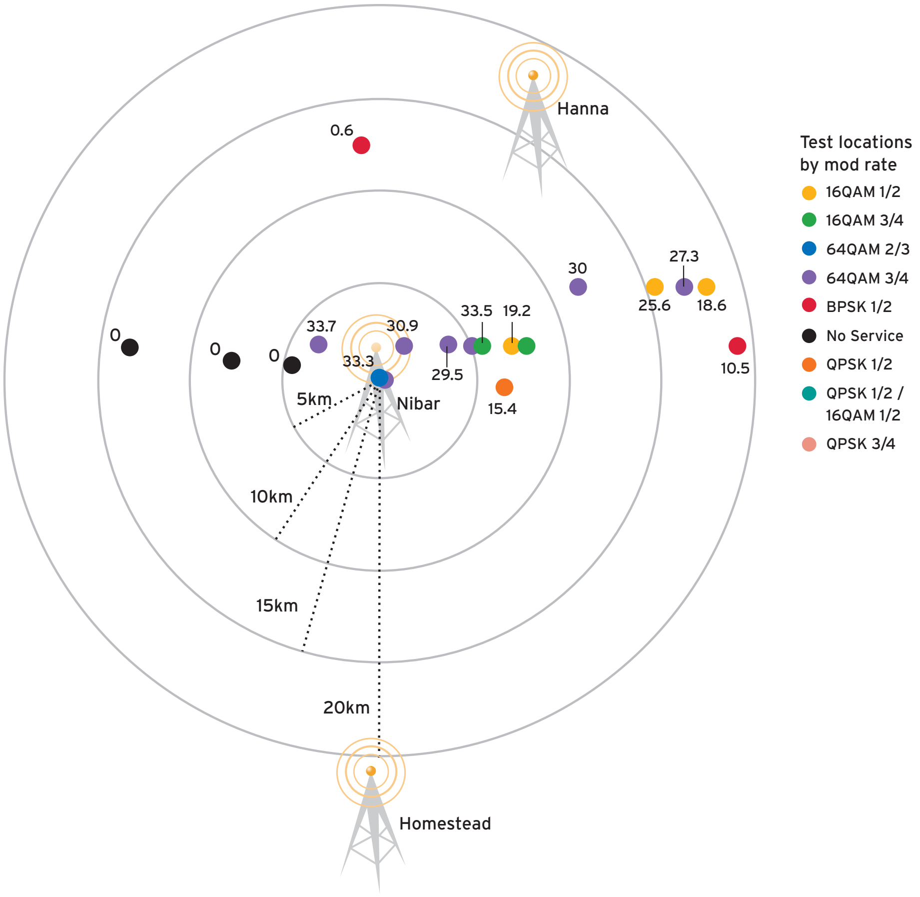
Factor	Variation with frequency	Impact at higher frequencies
Power level	No	None
Receiver sensitivity	No	None
Modulation efficiency	No	None
Shadow margin	Yes	Related to path loss and shadowing variance, both increasing as frequency increases.
Path loss	Yes	The lower the frequency, the smaller the path loss and the greater distance a signal can propagate. Higher frequencies are expected to experience greater path loss and therefore a reduction in signal range.
Physical environment	Yes	Higher frequency bands tend to experience higher losses in metal and concrete surfaces but lower losses through glass.
Cable loss	Yes	Cable loss increases as frequency increases and therefore, where tall towers are deployed, transceivers on the tower top should be used to reduce cable losses.

A simplified check list for deployments of mobile WiMAX at higher frequency bands

As previously discussed, there are several factors to consider when deploying Mobile WiMAX, which are summarized in Table 2.

A number of these factors will vary and potentially increase the complexity and cost of deployment at higher frequency bands and, as a result, must be considered when designing the link budget for optimal coverage and range.

Figure 4. 802.16-2004 trial results



A case study: spectral considerations at 3.5 GHz

Nortel is partnering with the Alberta Special Areas Board (SAB) and Netago Wireless to build Canada's first commercial WiMAX network at 3.5 GHz in Canada, and recently completed a live-air trial.

The main goal of the trial was to determine the performance, configuration and operation of the technology. Tests were performed to determine data rates, signal-to-noise ratio, modulation rate, received signal strength indicator, transmit power and range. This trial used an FFT size of 256.

Two types of CPE were used: an outdoor unit with 15 dBi antenna gain and maximum transmit power of 23 dBm and an indoor unit with a 6-7 dBi antenna gain with a maximum transmit power of 24 dBm.

Data throughput performance using UDP, TCP and FTP protocols were tested in the down and up links. The trial measured 9 Mbps data throughput using UDP and 5 Mbps using FTP/TCP. The maximum coverage range observed was about 20 km using BPSK 1/2 burst profile in line-of-sight propagation path. Figure 4 depicts the range and data rate performance.

This network will launch in the summer of 2006 and will deliver services to 80 percent of SAB residents. It will enable affordable broadband services to underserved, rural communities in Southeastern Alberta, including residents and businesses across more than 8,000 square miles (21,000 square kilometers). This solution also extends the reach of the Alberta SuperNet, a government initiative, reaching roughly 4,200 government, health, library and educational facilities in 429 communities across Alberta.

This case study highlights that WiMAX networks can be successfully deployed at 3.5 GHz but require sophisticated expertise in RF engineering and networks. This knowledge becomes even more important when deploying mobile WiMAX networks.

Proven experience in MIMO and OFDM is essential to deliver the cost savings and efficiencies network operators expect. In addition, understanding how to leverage the existing 3G cellular structure to an operator's advantage and to reduce the foot required is paramount.

Nortel is delivering a complete portfolio of WiMAX solutions, including products, services and devices, to serve any global market and customer scenario. Nortel's WiMAX products will be designed to allow wireless and wireline carriers, cable providers, media companies and other ISPs to deliver broadband connectivity to consumer and enterprise users by leveraging existing networks and 'last mile' wireless links. They will also complement and extend the reach of existing 3G cellular networks and accommodate greenfield service providers with newly acquired spectrum. Nortel is a key contributor to the 802.16-2005 standard and its implementation of OFDM/MIMO was selected by the industry as the basis for mobile WiMAX.

Conclusion

Mobile WiMAX technology is designed to provide high-quality, mobile broadband multimedia services; however, it presents challenges that operators need to consider before deploying their networks. In particular, at higher frequency bands such as 3.5 GHz, RF signals can experience propagation and building penetration losses combined with physical environment considerations which may impact coverage and range reach. By leveraging advanced technology innovations like MIMO/OFDM, a number of these challenges can be addressed to deliver a more spectral efficient, robust, and higher performance mobile WiMAX network.

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Glossary

16 QAM: 16 array Quadrature Amplitude Modulation

64QAM: 64 array Quadrature Amplitude Modulation

Adaptive Modulation: Modulation is the process by which the base band signal (speech, image, data, etc.) gets impressed over a carrier signal. If the RF signal quality is high, the modulation is done at a higher level providing faster data rates. Conversely if the RF signal quality is poor, the modulation is done at a lower level.

BPSK: Binary Phase Shift Keying

dB: Decibel

Downlink (DL): Base station transmit and mobile receive path

Fading: Fading occurs when a signal travels in multipath environments (see below), and is either cancelled out by another or experiences a drop in strength.

FDD: Frequency Division Duplexing

FFT: Fast Fourier Transfer

Link budget: A power budget to determine RF power level and maximum range

MIMO: Multiple Input, Multiple Output (Multiple transmitter/receiver)

Multipath environment: An RF signal will travel from a transmitter around obstructions such as man-made objects or trees and foliage to a receiver, which combines the signal.

NLOS: Non Line of Sight

OFDMA: Orthogonal Frequency Division Multiplexing Access

QPSK: Quadrature Phase Shift Keying

RF: Radio Frequency

Shadow margin: Additional loss added to path loss to account for shadowing by terrain and building

TDD: Time Division Duplexing

Uplink (UL): Mobile transmit and base station receive path

WiFi: Wireless Fidelity

WiMAX: Worldwide Interoperability for Microwave Access

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