

Choosing a WiMAX Base Station Antenna

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WiMAX, while not strictly limited to deployments above 2 GHz, is generally associated with the frequency bands 2,300 to 2,700 MHz and 3,300 to 3,800 MHz. We will assume for the purposes of this article, that WiMAX is deployed in the 2,300 to 2,700 MHz band. For base station antennas (BSAs), this frequency band has some advantages due to smaller wavelengths that allow for higher gains in acceptable sizes. The smaller wavelengths also make multiple column arrays more attractive because these advanced antennas can be pro-

duced in smaller sizes. However, there are some serious disadvantages for these higher frequency ranges, including poor signal propagation characteristics and higher losses in the RF path.

As such, when it comes to choosing a BSA for WiMAX deployments, the first thought is to use higher gain antennas, but this can easily lead to poorly designed and poorly performing networks. A number of factors need to be considered when choosing an antenna for WiMAX deployments beyond the common specifications. When considering more advanced antenna configurations the RF performance improvements must be traded off against higher complexity, higher cost and lower reliability. Finally, to minimize RF path losses and balance some of the propagation loss within the system's overall loss budget, techniques are emerging that minimize the RF path loss, while keeping the first Intermediate Frequency (IF) of the base transceiver station (BTS) as close to the antenna as possible.

Signal Propagation Challenges at 2.5 GHz

One of the primary challenges faced by engineers when deploying macro cellular sites above 2 GHz is signal propagation. In point-to-point (P2P) communication over short distances, the power received at the receive antenna can be calculated using the Friis formula:

$$P_{RX}(dBm) = P_{TX}(dBm) + 20 \log \left(\frac{\lambda}{4\pi R} \right)^*$$

*Where λ is wavelength and R is the distance between transmitter and receiver

However, when considering the link between a BSA and mobile device, the expression for the power received must consider multi-path, building penetration, scattering, diffraction and refraction. To account for these more complicated propagation effects, various formulas have been developed, but all result in a dependence that is degraded from R^{*2} where R is the physical (in terms of wavelength) distance from transmitter to receiver. For purposes of this article, we will use a factor of $R^{*2.5}$, and if additional RF path loss from the base station to the antenna is considered a factor of 2.5 may well be conservative.

Using the above dependence, comparing traditional cellular deployments in the 850 MHz frequency bands, deployments around 2,500 MHz are subject to a propagation penalty of nearly 15 fold (about 12 dB when expressed as a loss in dB), which can severely handicap the network. How can system designers overcome this propagation penalty? What role does the antenna play? And, how does the system designer avoid choosing the wrong antenna system?

Choosing the Right Antenna Approach

Installing 15 times more cell sites than are deployed at 850 MHz is one option for overcoming signal propagation issues. However, unless this can be done at a fraction of the cost of traditional cellular sites, this technique is not viable.

Another approach that may seem viable at first, is the use of antennas with higher gain. This method was successful in the late 1990s, when wireless networks were evolving from around 850 MHz to around 1,900 MHz, primarily because the common cellular sector antenna was 12 dBi gain and four foot high, and provided about 15° of vertical beam width, and 105° of horizontal beam width.

When deploying systems at 1,900 MHz compared to 850 MHz, the propagation penalty is about 7.5, which translates into about 9 dB of loss. Some of this loss can be mitigated by narrowing the vertical beam width to about 6° to 7°, which then results in a 3 dB gain improvement. Additionally, by narrowing

the azimuth beam width to around 60° to 65°, designers can achieve another 2.5 dB. For example, at PCS frequencies, a standard antenna is 18 dBi gain, a 6° to 7° vertical beam width, and a 60° to 65° horizontal beam width. The narrowing of the azimuth beam width requires cell sites to be nested like petals of a cloverleaf. This technique has become pervasive worldwide and is preferred to wide azimuth beam widths and higher sector to sector cross over levels. During the past 10 years, PCS deployments have seen additional benefits from antennas with variable beam tilt where the peak of the vertical beam can be optimized for best coverage.

Other techniques that have been leveraged to overcome the cellular to PCS propagation penalty include the use tower mounted amplifiers (TMAs), single carrier power amplifiers (SCPAs) and multi carrier power amplifiers (MCPAs).

Still, with all of these improvements, it is a challenge to deploy at 1,900 MHz compared to 850 MHz, particularly in rural and less densely populated areas where systems are coverage limited. System designers still prefer 850 MHz to 1,900 MHz in coverage limited applications.

The Migration to 2.5 GHz Key Design Considerations

To deploy macro cells at 2.5 GHz, system designers need to overcome an additional 3 dB of propagation loss compared to PCS. There is also greater RF cable loss per unit length, and maintaining high efficiencies for common RF devices including TMAs, duplexers and filter combiners, let alone antennas, becomes increasingly difficult. So a natural first step is to ask more from the antenna in higher gain, and this can be achieved by further narrowing the antenna beam widths. However, several issues must be considered: 1) the accuracy of the mechanical and electrical tilt setting; 2) the coverage at the base of the tower; and, 3) limited or no improvement due to decreasing "Field of View" gain.

Most BSAs use a combination of mechanical and electrical tilt to set the precise down tilt required to optimize performance in a given sector. For wide beam 850 MHz antennas with greater than 15° vertical beam width, an error of 1° or even 2° has negligible effect on the overall coverage, even a 2° pointing error changes the pattern around beam peak by less than 0.2 dB. However, when high gain antennas with very narrow vertical beam widths are used, for example 4° 3 dB beam widths, a 1° to 2° error in the combination of mechanical and electrical tilt can change the pattern by up to 1 dB, which completely negates the advantage of using the higher gain.

Another concern with higher gain antennas with very narrow vertical beam widths is coverage at the base of the tower. Near in coverage is highly susceptible to multipath, scattering and diffraction. All these propagation effects help to "smudge" the pattern of the antenna close in to the tower. Therefore, as long as there are significant side lobes – roughly greater than 20 dB – at elevation angles around 45° downtilt, good coverage is created to the base of the tower. The ideal base station antenna vertical pattern is the classic "cosecant squared" pattern used for radar antennas; low upper side lobes but higher lower side lobes that degrade along a cosecant squared envelope. However, when a very narrow vertical beam is used, the side lobe levels at 45° and greater are often much lower than 20 dB, resulting in poor coverage at the base of the tower. In this case, coverage must be provided by neighboring cells, which can complicate the system design and increase the possibility of dropped calls.

Another concern with high gain antennas with narrow vertical beam widths is effect on overall sector coverage. The Base Station Antenna Industry has traditional-

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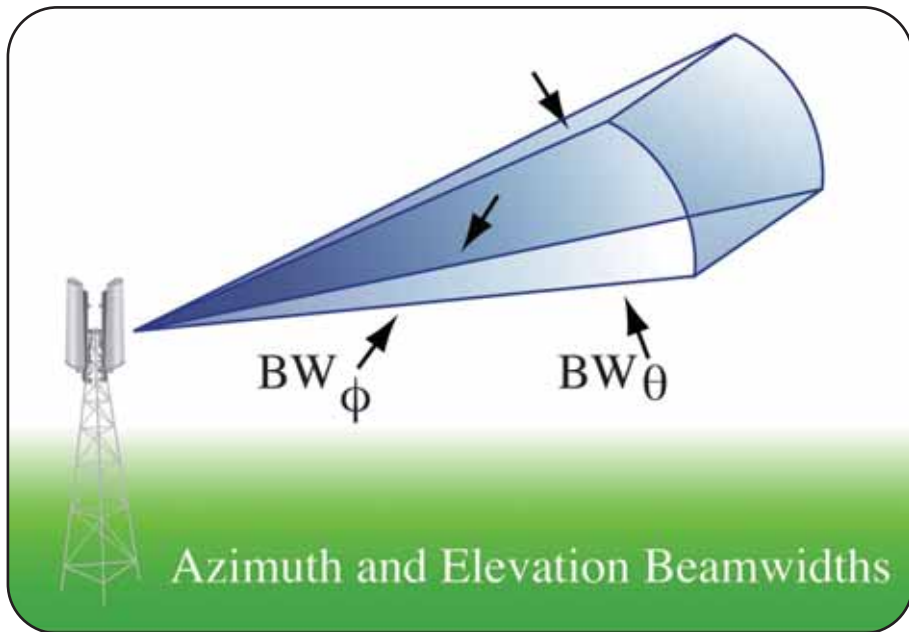
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ly used peak gain as the most important specification. This is naïve, particularly at higher frequencies where higher gains are sought at the expense of coverage. Focusing on peak gain can mask how efficient a given antenna covers the typical solid angle of coverage. A better specification is Field of View (FOV) gain.

FOV gain expresses a gain requirement in terms of a minimum gain that must be achieved over a solid angle of coverage. For example, a common peak gain for base station antennas is 18 dBi. Using the approximate formula, where π is efficiency:

$$\text{Gain} = 10 \log [41,253/BW_{az} * BW_{el}] - \eta \text{ dBi}$$

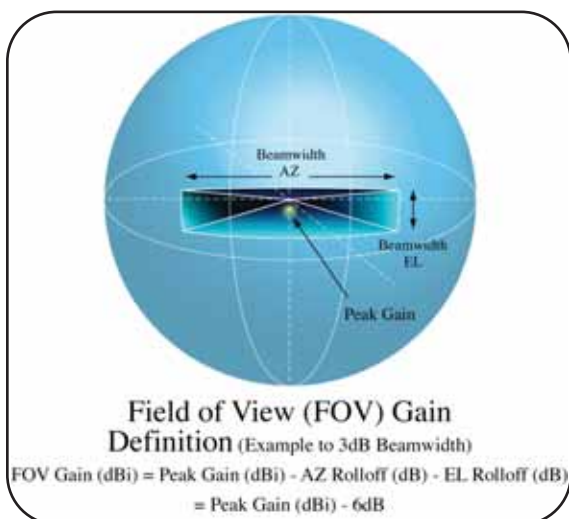
This formula is easily derived from the definition of directivity, assuming all radiated energy is captured in the solid angle defined by the azimuth and elevation beam widths.



This formula is more appropriate for a high gain antenna with narrow azimuth and elevation beam widths, where π is typically in the range of 1.5 dB, but can be crudely applied to base station antennas, where π is more in the range of 2.5 dB. A more accurate approach, used by antenna designers, is to measure the complete radiation performance, calculate directivity precisely, measure gain (typically by comparison to a standard) and compute efficiency using the formula:

$$\text{Efficiency (dB)} = \text{Peak Directivity (dBi)} - \text{Peak Gain (dBi)}$$

However, the approximate gain formula can be used to demonstrate the importance of FOV gain. For example, take two common cases of a BSA with 18 dBi gain and 65° azimuth beam widths. In the first case, the BSA is highly efficient with π of 2.2 dB, using the above formula, and calculating for elevation beam width gives a result of 6.0°. However a less efficient antenna with a π of 2.7 dB, still maintaining 18 dBi gain, results in an elevation beam width of 5.4°. When expressed as a 12 dBi FOV gain, assuming the requirement is over a 65° azimuth and 6° elevation, the results are quite different. In the first case, antenna meets the 12 dBi FOV gain requirement, whereas in the second case by the edge of the +/- 3° range, the absolute pattern level has fallen to approximately 11 dBi. Both antennas have peak gain of 18 dBi, but the less efficient antenna provides an inferior FOV gain.



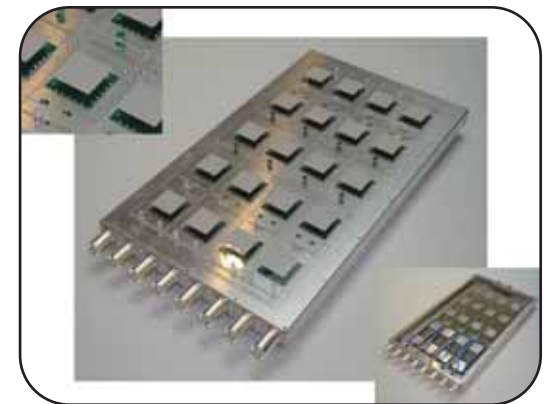
Still, to achieve higher and higher gains, cellular planners have continuously pushed to narrower elevation beam widths. Therefore, how can the network designer still use traditional antennas with azimuth beam width no greater than 60° and vertical beam width no greater than 6°? The key is to use antennas that offer the greatest efficiency. This is increasingly difficult at higher frequencies. Recently, antennas operating above 2 GHz have been developed to use feed networks based on airline, or coaxial cable with air as the dielectric. These techniques are expensive and subject to manufacturing difficulties, as dielectric spacers must be used to suspend the center conductor, while being accurately placed along the transmission line. Also, the outer conductor diameter is often changed to maintain 50 ohms. This method does yield a more efficient antenna, and research continues on techniques to provide very low loss feed networks at costs competitive with traditional methods. For example, with the trough guide technique, an extrusion is used for the outer conductor to reduce costs.

Other Techniques for Overcoming 2.5 GHz Design Limitations

A system design that has been used in some deployments at higher frequencies is narrowing of azimuth beam widths, in the range 30° to 45°. This will result in a larger antenna width, about the width of a 60° 850 MHz antenna, which is not unreasonable.

Narrowing to 30° azimuth beam width requires six sectors per site compared to the traditional three, adding cost and complexity to the system. A compromise that has generated some interest is to use a dual beam antenna with a beam former to select between the two beams. The antenna consists of two beams at +/- 30° off the antenna bore sight with typically 30° azimuth beam width. Narrowing the azimuth beam width to 30° can provide the additional 3 dB gain requirement to compensate for the higher frequency band around 2.5 GHz, but the two beams are created using a beam forming network and must be processed by the BTS creating additional complexity and losses in the RF path.

Antennas above 2 GHz that are several wavelengths wide meet typical size restrictions. This allows for deployment of multiple column arrays (see photo below). The most common are four and eight columns spaced horizontally at about 1/2 wavelength. These arrays support more advanced techniques for MIMO (multiple input, multiple output) and beam forming. The downside, however, is the complexity of these arrays, which can result in higher costs and MTBF, as well as the need for a custom beam former and calibration network, typically integrated into the base station. This can also create the need to develop custom antenna solutions for a particular base station, further increasing the cost of deployment.



When multiple columns are arranged on a flat back plane the individual element and columns must be carefully designed to avoid a condition known as “scan blindness” where at particular scan angles mutual coupling significantly deteriorates the matching network performance. This results in severe pattern degradation. Also, planar arrays must be designed to account for gain loss with scan due to wider azimuth beam widths at wide scan angles. Multiple column arrays arranged on a circular arc can avoid these performance drawbacks but at the price of increased complexity and lower aesthetics, since they will be more pronounced on building sides and flat structures.

Mesh Networks and Remote Radio Heads (RRH)

To overcome the challenges associated with deploying traditional cellular architectures within the 2.5 GHz band designers should also consider non-traditional system architectures such as mesh networks and remote radio heads, both of which have seen considerable interest in recent years. While a thorough discussion of these two technologies is outside the scope of this article, it is important to note that mesh networks

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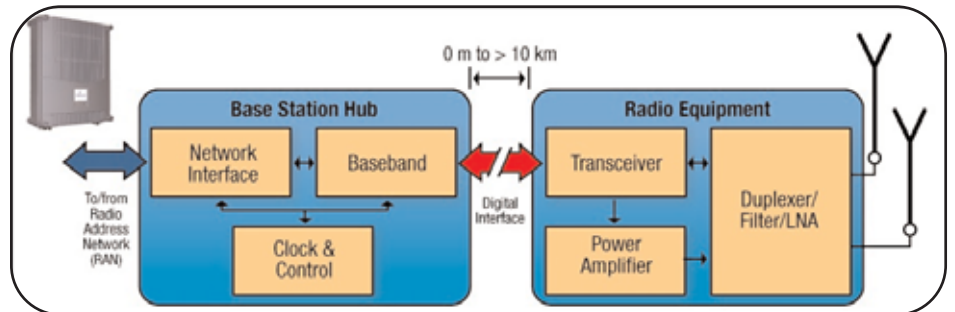
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make extensive use of omni-directional antennas. Unfortunately, again to achieve reasonable elevation beam widths, omni antennas are restricted to a maximum gain of around 10 dBi, which creates the need for a greater density of nodes, as well as the need to further reduce the cost of each node, which can be a difficult tradeoff. Also, greater node density requires each node to process a greater number of backhauls.

Remote Radio Head (RRH) technology is a recently emerging system design approach that is more promising. The concept involves deployment of numerous RRH in a macro cellular environment. Each RRH processes the RF down to an efficient transport mechanism such as in optical communications, where a central hub connects clusters of RRH. The key advantage of RRH technology is the extremely close proximity, and even integrating of antennas. The RF path loss can be improved typically between 2 and 3 dB, which alone can overcome much of the propagation penalty going from 1,900 MHz to 2,500 MHz. The RRH method at 2.5 GHz allows the system designer to use more typical base station antennas while maintaining acceptable loss budgets. This means less cell sites are needed to cover the same population.

The diagram below illustrates a typical remote radio head implementation



In summary, when choosing antennas for WiMAX macro cellular deployments, designers should strive for a highly efficient antenna system that maintains not just a high peak gain, but also a high field of view gain. To get the extra few dB needed to overcome the additional propagation losses at 2.5 GHz, several techniques can be used including a six sector system or dual beam method. Finally, a straightforward and robust technique is to keep losses at RF to an absolute minimum by mixing to an intermediate frequency (IF) as close to the antenna as possible using a remote radio head or similar approach.

For each of these methods, a cost effective method is needed, a challenge at 2.5 GHz, but as the frequency band becomes more pervasive, economies of scale should drive costs lower. And, similar to the 1,900 MHz band a decade earlier, successful techniques will emerge.

Scott Wilson leads the Antenna Product Unit for Powerwave and is responsible for strategic direction and management of the base station antenna product portfolio, including remote electrical tilt (RET) and Clean Site concealment solutions. Scott holds four US Patents for antenna design. Scott holds Masters of Science degrees in Electrical Engineering and Physics, and a Bachelor of Science degree in Engineering Physics from University of Illinois, Champaign.

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Lockheed Breaks Ground on \$15 Million Advanced Radar Test and Measurement Facility

Lockheed Martin recently broke ground on a \$15 million, 9,600 square foot radar test facility that will provide the company with one of the world's most advanced, large-antenna measurement systems.

The new 80-foot tall structure will be added on to the existing EP-6 building at Lockheed Martin's Radar Systems facility in Syracuse, NY. Once complete in summer 2009, the facility will house one of the largest high-precision, spherical near-field radar test and measurement systems.

The new facility will house state-of-the-art measurement equipment that will be used to design, analyze, characterize and test future radar systems ranging from the smallest systems to next-generation digital phased array systems. It will have the capability to perform highly-accurate antenna, radar system and radar cross-section measurements at a wide range of frequencies. The equipment will allow users to fully automate a precision antenna measurement process from set-up through analysis and report generation.

A key component of the facility will be its electromagnetically-shielded anechoic chamber. Lined with special foam to absorb radio frequency (RF) radiation and suppress potentially interfering external acoustics and frequencies, the chamber will provide greater test security of sensitive government equipment.

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