

A Practical Guide to WiMAX Antennas: MIMO and Beamforming Technical Overview



Multi-antenna implementations such as MIMO and beamforming offer opportunities to enhance in-building penetration, coverage and capacity in even the most challenging environments. By pairing the performance advantages of WiMAX with sophisticated antenna implementations, WiMAX operators can rapidly deploy an optimized network tuned to the varying requirements in their service footprint today and easily grow and scale to meet the growing demands of tomorrow.

Introduction

Wireless operators are increasingly pressured to enhance their networks and service capabilities in order to keep pace with the accelerating growth in wireless utilization and increasing demand for high performing connections. As bandwidth intensive, rich media applications are introduced, larger volumes of subscribers consume ever-growing quantities of data packets while continuing to utilize more minutes of voice. Simply acquiring more spectrum channels and deploying more sites to resolve capacity issues can be decidedly inefficient and costly.

Revolutionary multiple antenna techniques at the base station and end-user device, paired with sophisticated signal processing, can dramatically improve the communications link for the most demanding application scenarios including heavily obstructed propagation environments and high speed mobility service. Where conventional wireless network design has long used base site sectorization and single, omni-directional antennas at the end-user device to serve the communications link, with advanced multi-antenna implementations operators have a new suite of tools to develop the robust wireless networks of the future.

Mobile WiMAX has offered the industry a very capable platform by which to deliver the demanding service requirements for wireless access today and tomorrow. With the added support for a variety of advanced multi-antenna implementations, Mobile WiMAX offers the wireless operator considerable relief in meeting their growing network demands with higher performance, fewer sites, less spectrum, and reduced cost.

The Challenges of Multipath

One of the greatest challenges to traditional wireless systems has been managing multi-path fading environments. Multi-path fading is the resulting signal degradation due to obstructions between a wireless transmitter and its intended destination. In a Non Line of Sight (NLOS) environment, a transmitted signal may bounce off of a myriad of obstacles including buildings, roads, and man-made structures as well as trees, hills, and naturally occurring impediments. With each bounce, a separate instance of the signal makes its way to the destination receiver with a variation in time. These multiple, "bounced" signals may interfere with one another resulting in a degraded signal at the receiver.

Perhaps somewhat counter-intuitive, where multipath and challenging propagation environments were once considered an adversary to wireless systems, with multi-antenna implementations, the wireless system actually benefits from the multipath phenomenon – leveraging multipath to create a more robust communications channel.

Multiple Antenna Technologies

Industry vendors and sources have created a host of naming conventions to refer to multi-antenna implementations. Simply put, the term MIMO (multiple input multiple output) can be used to reference any multiantenna technologies.

Textbook MIMO configurations are represented as either "Open Loop" or "Closed Loop". In application, the commonly used MIMO terminology has most often been in reference to Open Loop MIMO techniques. The WiMAX standard includes two versions of Open Loop MIMO techniques referred to as Matrix A and Matrix B.

Closed Loop MIMO techniques, also known as Transmitter Adaptive Antenna (TX-AA) techniques, are simply referred to by the industry as "beamforming".

WiMAX infrastructure portfolios delivered today from leading industry vendors consider approaches to MIMO Matrix A, MIMO Matrix B and beamforming as a means to capitalize on the tremendous performance capabilities of these techniques.

MIMO Matrix A & MIMO Matrix B

Open Loop MIMO

With Open Loop MIMO, the communications channel does not utilize explicit information regarding the propagation channel. Common Open Loop MIMO techniques include Space Time Block Coding (STBC) and Spatial Multiplexing (SM-MIMO), and Collaborative Uplink MIMO. In WiMAX systems MIMO Matrix A refers to the STBC technique and MIMO Matrix B refers to the SM-MIMO technique.

Beamforming

Closed Loop MIMO

With Closed Loop MIMO, the transmitter collects information regarding the channel to optimize communications to the intended receiver. Closed Loop MIMO typically utilizes Maximum Ratio Transmission (MRT) or Statistical Eigen Beamforming (EBF) techniques leading to the shorthand name for this approach – beamforming.



MIMO Matrix A & Matrix B

MIMO Matrix A (STBC) and MIMO Matrix B (SM-MIMO) leverages multiantenna operations at the base station and the end-user device. Matrix A and Matrix B with two antenna receivers is a required Wave 2 WiMAX Forum certification feature for WiMAX devices and will be a supported capability in the broad pool of certified equipment.

Enhancing Coverage

MIMO Matrix A (STBC)

With MIMO Matrix A, a single data stream is replicated and transmitted over multiple antennas. The redundant data streams are each encoded using a mathematical algorithm known as Space Time Block Codes. With such coding, each transmitted signal is orthogonal to the rest reducing self-interference and improving the capability of the receiver to distinguish between the multiple signals. With the multiple transmissions of the coded data stream, there is increased opportunity for the receiver to identify a strong signal that is less adversely affected by the physical path. The receiver additionally can use Maximal-Ratio Combining (MRC) techniques to combine the multiple signals for more robust reception. MIMO Matrix A is fundamentally used to enhance system coverage.

Increasing Capacity MIMO Matrix B (SM-MIMO)

With MIMO Matrix B, the signal to be transmitted is split into multiple data streams and each data stream is transmitted from a different base station transmit antenna operating in the same time-frequency resource allocated for the receiver. In the presence of a multipath environment, the multiple signals will arrive at the receiver antenna array with sufficiently different spatial signatures allowing the receiver to readily discern the multiple data streams. Spatial multiplexing provides a very capable means for increasing the channel capacity.

The Best of Both Techniques

Adaptive Mode Selection

In those environments where the Signal to Noise Ratio (SNR) is low, such as the edge of the cell or where the signal is weak, MIMO Matrix A outperforms MIMO Matrix B. At higher SNR, where the system is more prone to be bandwidth limited rather than signal strength limited, MIMO Matrix B outperforms MIMO Matrix A. An ideal WiMAX system employing MIMO techniques will support both Matrix A and Matrix B. The system will calculate an optimal switching point and dynamically shift between the two approaches to offer the necessary coverage or capacity gains demanded from the network at any given time or location.

Collaborative Uplink MIMO

Collaborative Uplink MIMO is an additional open-loop MIMO technique considered by WiMAX vendors to increase the spectral efficiency and capacity of the uplink communications path. A practical realization of this technique would allow for two separate end-user WiMAX devices, each having a single transmit lineup, to utilize the same frequency allocation to communicate with the dual-antenna WiMAX base station. This technique can effectively double the uplink capacity of the WiMAX system.

MIMO Matrix A Space Time Block Coding (STBC)







Beamforming

WiMAX systems that use beamforming as a means to further increase system coverage and capacity can surpass the capabilities of MIMO techniques. Beamforming techniques such as Statistical Eigen Beamforming (EBF) and Maximum Ratio Transmission (MRT) are optional features in the 802.16e WiMAX standard, but leading vendors are taking advantage of its strong performance characteristics.

Beamforming techniques leverage arrays of transmit and receive antennas to control the directionality and shape of the radiation pattern. The antenna elements have spatial separation dictated by the wavelength of transmission and are supported by sophisticated signal processing.

Channel information is communicated from the WiMAX subscriber to the WiMAX base station using the "uplink sounding response" – a mandated device feature for WiMAX certification. Based on the understanding of the channel characteristics, the WiMAX base station utilizes signal processing techniques to calculate weights to be assigned to each transmitter controlling the phase and relative amplitude of the signals. By leveraging constructive and destructive interference, the radiation pattern is steered and formed to provide an optimal radiation pattern focused in the direction of communication.

When transmitting a signal, beamforming can increase the power in the direction the signal is to be sent. When receiving a signal, beamforming can increase the receiver sensitivity in the direction of the wanted signals and decrease the sensitivity in the direction of interference and noise. While the processing requirements for beamforming can be quite sophisticated and resource intensive depending on the complexity of the channel and the number of subscribers on the system, today's implementations can resolve the beam weights within 5 to 10 ms allowing for practical WiMAX solutions.

Beamforming techniques allow the WiMAX system to realize increased range with higher antenna gain in the desired direction of communications and better connectivity between the base station and device. Simultaneously, the narrower beamwidth and reduced interference increases the capacity and throughput offered by the system.

While both MRT and EBF are similar techniques in principal, the algorithms supporting each offer advantages in varying application scenarios. For MRT to deliver strong system gains, the technique requires a more exact measurement and understanding of the channel conditions. As such, MRT is a more opportune technique when communicating with static receivers. For mobile receivers, the delay between measuring the channel condition and forming the beam becomes a significant factor for delivering the necessary system gains. In these mobile environments, EBF offers a more robust technique. Ideally, WiMAX beamforming solutions would adopt both MRT and EBF techniques to provide a more holistic beamforming solution that capably addresses both fixed and mobile applications.



WiMAX Device Requirements

Multi-antenna implementations in WiMAX systems are most efficient when the WiMAX subscriber also has multiple antennas and the necessary receiver capabilities. While techniques such as MIMO Matrix A and beamforming can demonstrate some improvements in the communications link, even with a single antenna subscriber, multi-antenna implementation will deliver the full advantages of the advanced antenna techniques.

On the other hand, MIMO Matrix B implementation requires parity in the number of antennas at the base station and the subscriber. The full benefit of MIMO Matrix B is limited to the lesser of the number of transmit and receive chains at the base station or device.

Two receive antenna systems are mandated for WiMAX Wave 2 device certification and this capability is likely to be most readily supported by chipset and device manufacturers. As such, two transmit and two receive MIMO implementation at the base station provides an efficient means for designing a WiMAX system.

When a WiMAX subscriber registers onto a WiMAX network, the subscriber informs the WiMAX base station what its capabilities are. This information may include support for MIMO Matrix A, MIMO Matrix B, or beamforming. Based on this information, the WiMAX base station will recognize how to best communicate with that WiMAX subscriber to optimally manage the communications link.

Flexible Deployment Scenarios

WiMAX is a versatile technology with relevance to a wide variety of application scenarios spanning from fixed, nomadic, mobile, indoor and outdoor communications. When designing a WiMAX system, factors including capacity or coverage requirements, fixed or mobile application, sectorization and reuse schemes will all contribute to determining the right feature set and capability requirements at the WiMAX base station.

MIMO Matrix B becomes an attractive option in urban environments where there is a rich multipath condition. Additionally, indoor communications where signals are likely to bounce off the walls, ceiling, and floor also provides a good environment for Matrix B. With a two antenna implementation, MIMO Matrix B can double the throughput over a single antenna implementation.

MIMO Matrix A is a good choice for suburban and rural geographies where there is less likelihood for strong multipath and the signal to noise ratio might be weaker. Additionally, MIMO Matrix A can be an effective choice for higher speed mobility applications where, again, the signal to noise ratio might be reduced. In these scenarios MIMO Matrix A with a two antenna implementation can double the system link budget over a single antenna implementation substantially boosting the coverage area.

While Matrix A is primarily used to realize coverage gains and Matrix B is used to offer capacity increase, an ideal system will dynamically switch between Matrix A and Matrix B depending on the specific application, geography, or link condition.

For those environments where further gains in coverage or capacity are required beyond what can be delivered by Matrix A and Matrix B implementations, beamforming solutions should be considered. With a four antenna implementation, the WiMAX system can realize up to a 12 to 16dB gain in link budget over a single antenna system – that amounts to well over a sixteen-fold improvement.

Of course, the throughput and coverage capabilities of WiMAX systems are highly influenced by the radio environment, the profile of data and voice traffic on the network, frequency planning, and subscriber loading. Careful profiling of the service requirements for the WiMAX network combined with sophisticated RF modeling using detailed topological information of the service geography are a critical component for planning a deployment approach. Experienced analysis can provide the necessary insights as to the optimal combination of RF solutions and multi-antenna techniques on a site-per-site basis - ultimately resulting in an optimized business model.

Conclusion

An optimized WiMAX system design must address the operator's market-specific requirements including frequency planning, deployment geography and planned service offerings. Additionally, these requirements may vary throughout an operator's service perimeter and may evolve over time.

Operators can design the best-fit network – mixing and matching across a host of base station types - when they have access to a range of infrastructure options with varying capabilities that address diverse deployment scenarios and operate under common management and controls.

WiMAX operators can select the right base station to serve a particular site requirement and configure it to support a wide assortment of coverage, capacity, and application scenarios. With a broad portfolio of infrastructure choices including macro/micro, outdoor/indoor, sectorized/omni, tower-top electron-ics/distributed electronics, MIMO and beamforming techniques, WiMAX operators can rapidly deploy an optimized network tuned to the varying requirements in their service footprint today and easily grow and scale to meet the growing demands of tomorrow.





The information presented herein is to the best of our knowledge true and accurate. No warranty or guarantee expressed or implied is made regarding the capacity, performance or suitability of any product. MOTOROLA and the Stylized M Logo are registered in the U.S. Patent and Trademark Office. All other product or service names are the property of their respective owners. © Motorola, Inc. 2007