Beamforming Boosts the Range and Capacity of WiMAX Networks

**By Paul Sergeant, Cisco Systems, and
Tong Swan Pang, Fujitsu Microelectronics America, Inc.**

Implementing directive antennas and MIMO techniques can greatly increase the throughput of wireless communications systems such as WiMAX

Having gained much momentum over the past few years, WiMAX is now widely viewed as a leading candidate for fourth-generation (4G) wireless data communication. Because WiMAX is based on Internet Protocol (IP), the technology builds on principles that have proven versatile and cost-effective in the Internet. Compared to traditional 3G cellular networks, WiMAX offers a more affordable technology for transferring large amounts of data with high throughput.

A technology known as *adaptive beamforming* can magnify this WiMAX advantage considerably. At a relatively low implementation cost, beamforming improves both the range and capacity of a WiMAX network. In fact, beamforming reduces capital and operating expenses for WiMAX implementations by minimizing the number of base stations needed in a network.

Fujitsu and Cisco are strongly committed to the use of beamforming in WiMAX networks, and both companies use beamforming in their WiMAX products. This white paper outlines the operation and advantages of beamforming.

Opportunity and Challenge

Dynamic business and social applications have driven the popularity of mobile data services and created a need for all-time connectivity. Beyond simple voice communication, today's wireless networks must furnish better security and the high data rates needed for video streaming and high-definition image display.

MIMO

Multiple Input,
Multiple Output

_____

An Advanced Antenna system (AAS) technique that uses multiple signals to either:

· Improve mobile signal robusness (MIMO A), or
· Increase throughput (MIMO B)
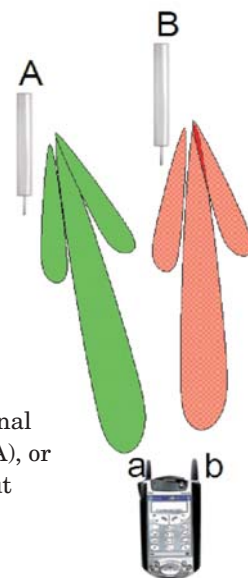
• Uses multipath reflections from structures to provide signal diversity
• Increases system capacity by 20 to 40%
• Requires multiple (two or more) antennas and RF paths on both base station and subscriber devices
• Included in IEEE standards and in WiMAX certification profiles (optional for networks, mandatory for subscriber devices)
• Can be combined with Beamforming for optimal results

Figure 1 · Multiple Input, Multiple Output (MIMO) capabilities.

Demand for quadruple play—video, Internet access, and voice telephone service via wireless data networks—is pushing broad-

band wireless technology to become a necessity rather than a luxury. Coupled with security, quality of service (QoS) and other robust wireless broadband properties, WiMAX has emerged as the new technology that will make broadband wireless an affordable reality in the very near future.

With the increasing popularity of mobile applications, however, the already crowded wireless spectrum becomes even more crowded. Robust techniques are required to ensure the integrity of the desired signal and deal with the noise, interference, multipath and other nuisances of wireless implementations.

Much work has been done to ensure better radio designs, and these methods have matured over the years. The operating environment in today's extremely crowded wireless space has rendered these earlier efforts acceptable but insufficient for demanding users. Moving from narrowband to broadband results in greater susceptibility to noise and interference. More advanced technologies are desperately needed.

Several technologies are currently available to help ensure better signal-to-noise ratio and better replication of desired signals at receiving terminals. The leading technologies include smart antennas, beamforming and multiple-in/multiple-out (MIMO) technology.

MIMO Background

MIMO systems use multiple smart antennas and/or multiple transmitters and receivers to achieve several advantages over simpler wireless systems. MIMO has been in development since 1985 (based on original work at Bell Labs) and is widely used today in robust wireless data networks.

In a MIMO system, two antennas receive different data streams via different spatial paths in the physical environment (Figure 1). Even if the data streams are transmitted at the
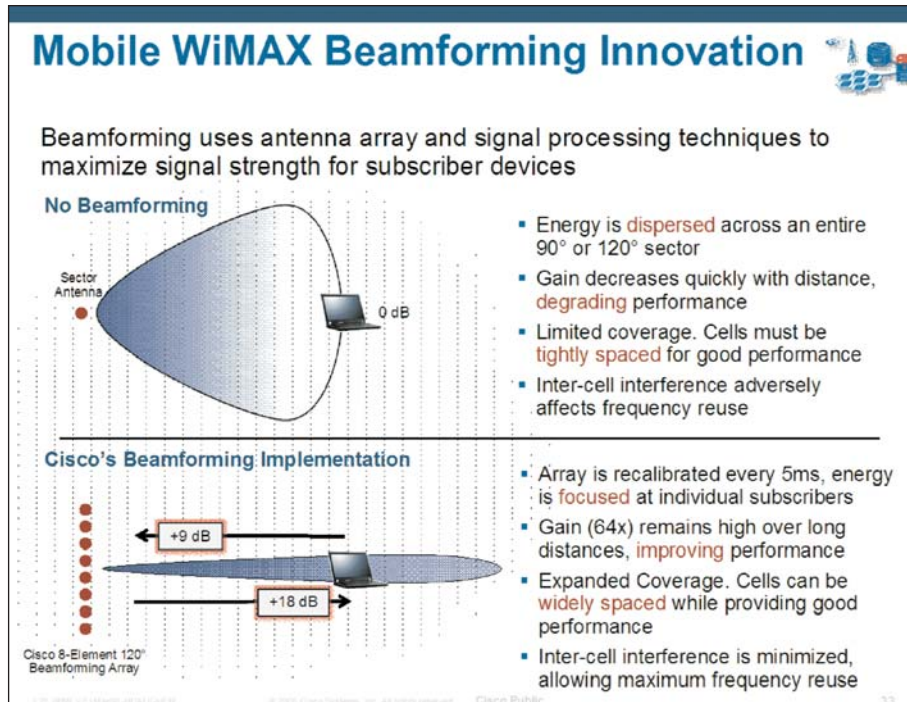

Figure 2 · Beamforming equals ILnk budget gains.

same frequency, they follow different spatial paths. The receiver can use signal processing to sort out the two streams and recover the original data. MIMO systems are not limited to two inputs and two outputs. Within limits, increasing the number of inputs and outputs increases the system's ability to take advantage of multiple spatial paths to improve data transmission.

When using MIMO, multipath radio signals can actually be beneficial. Multipath signals travel by different spatial paths due to reflections from buildings and other objects. These multipath signals create reception difficulties for traditional wireless systems. In contrast, MIMO systems can use additional multipath as more spatial "channels" for data transmission.

Beamforming Background

MIMO opens a number of possibilities for improving wireless data communications, and beamforming is one of the most powerful. This transmitter technique sends data on the

best available path between the transmitter and receiver. To target this path, the transmitter drives multiple antennas with a phase-shifting algorithm that focuses most of the radio power toward the intended receiver (Figure 2).

How well does beamforming work? Initially deployed cellular beamforming systems (circa 1995) were moderately successful, especially in rural areas where the beamed energy did achieve better coverage. The technology was far from optimal, however, especially in terms of CPU processing.

To do beamforming well, the system needs to take "sounding" measurements on the uplink and apply corrections based on these measurements to the downlink. This feedback-based approach is adaptive beamforming, and it demands a great deal of signal processing. 1995-era processor chips were too slow and expensive for this task.

Another drawback to the early beamforming technology was the use of frequency division duplex (FDD),
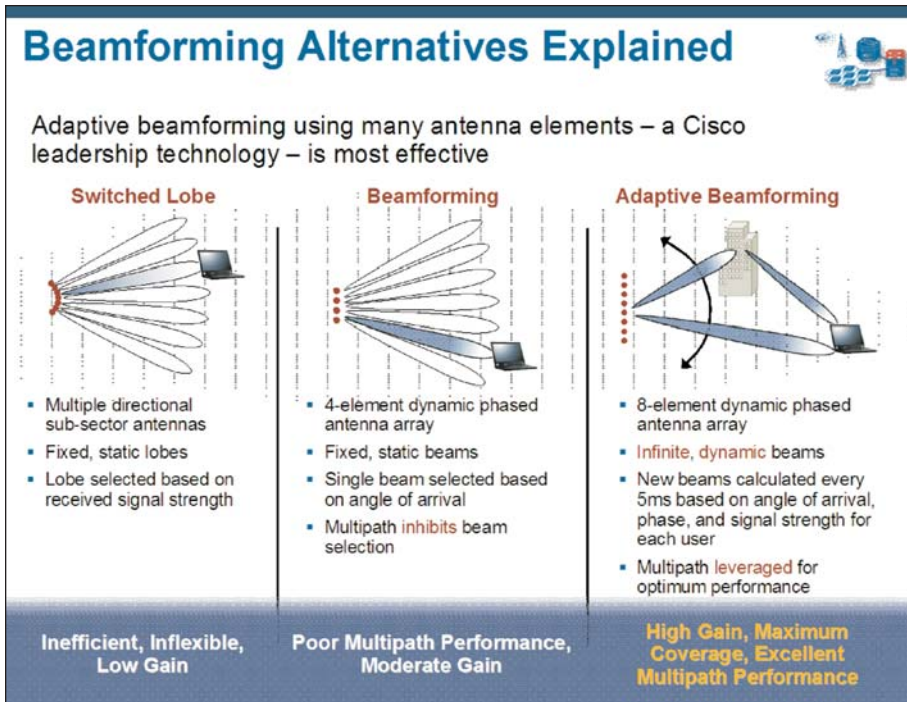
Figure 3 · Beamforming alternatives: multiple antennas, selection of multiple fixed beams, and adaptive beamforming.

Figure 4 · Relative downlink performance.

which has the uplink and downlink on different frequencies (more on FDD later). Since signals at different frequencies may behave differently in a particular environment, beamforming corrections made based on uplink measurements might be invalid for the downlink.

To accommodate these limitations, cellular system designers chose a less effective but cheaper solution called beam steering. Several types of beam steering systems are available, but they all send out a single downlink beam to a subscriber device, based on measurements of the arrival angle from the uplink. Because these systems do not adapt to multipath interference—in contrast to true MIMO systems— receiving devices get a stronger downlink signal at the expense of higher interference noise levels.

As a result, beam steering systems achieve no performance improvement in many environments, such as the urban canyons of Boston, New York and Chicago. The increased

multipath noise level simply cancels out the signal gain.

Adaptive Beamforming's Time Has Come

Today's technologies eliminate the limits on beamforming. Powerful CPUs are cheap, and Mobile WiMAX enables adaptive beamforming on the same frequency for uplink and downlink.

The incentive for using beamforming has also grown. Wireless has moved from voice only or voice with data to mobile broadband wireless using adaptive modulation. This application trend has created a perfect environment for smart antenna systems and beamforming to flourish, since beamforming is no longer just for coverage but for increasing capacity as well.

Advanced beamforming systems can now sound the uplink and accurately predict the downlink multipath conditions. These systems perform such tasks extremely quickly, at a cost easily justified by the improved
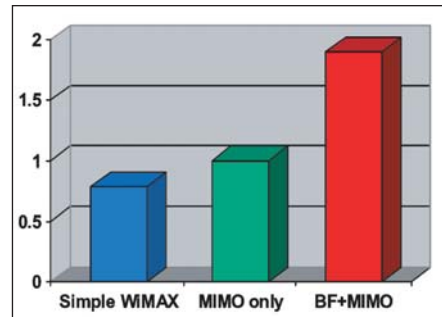
performance. This advantage permits the use of fewer cell sites for both coverage and capacity.

Beamforming Boosts Spectrum Efficiency

Spectrum is increasingly valuable and less readily available. More efficient use of the limited and dauntingly expensive spectrum has become critically important.

The need for effective spectrum utilization has driven a shift from the traditional frequency division duplex (FDD) technology to time division duplex (TDD) technology. With the latter, transmit and receive signals use the same frequency. TDD communications thus fit into smaller blocks of spectrum and require less guard band between active channels. TDD therefore improves spectrum efficiency. WiMAX is a TDD system.

Today's applications are moving toward transmitting only packetized data, and it is wasteful to use FDD for burst-like data traffic. TDD requires more high-speed signal processing, but the necessary circuitry has become inexpensive with today's silicon technology.

Combined with TDD implementations, advanced wireless methods such as beamforming and MIMO are by far the most cost-effective methods for meeting goals for efficiency, capacity, enhanced range and non-line-of-sight wireless operation. Poor indoor reception has long been an impediment to the wide adoption of

wireless broadband implementation. With beamforming, indoor penetration can be significantly improved.

Along with better indoor penetration, beamforming with MIMO on a TDD system allows for expanded capacity and extended range. Broadband service providers can roll out fewer base stations to effectively cover a larger area (Figure 4), resulting in lower capital and operating expenses.

Improved S/N: Another Beamforming Advantage

An adaptive beamforming system measures the characteristics of signals arriving by multiple paths (multipaths) from a subscriber device. These characteristics include relative signal strengths, phases, and angles of arrival. The system then creates a map of the best downlink paths to the device. The downlink signal is sent using all available multipaths, such that the reflected signals all arrive at the subscriber device together and in phase.

The result is a much higher signal-to-noise ratio than is possible without adaptive beamforming. The technology often averages up to two orders of magnitude (60 to 100 times)

improvement.

A stronger signal-to-noise ratio (C/I) enables the use of higher orders of modulation, meaning that the signal can be transmitted and decoded using higher-order symbols, such as 64 QAM. Bottom line, this advantage means better signal strength and lower interference, which equals much faster data downloads.

Higher-order symbol use has evolved over time. While simple digital cellular networks used binary code, more advanced networks used QPSK (4 QAM) for 3G services. Early WiMAX systems added 16 QAM, and with the IEEE 802.16e-2005 standard (used for mobility), WiMAX now uses 64 QAM as well. Each higher QAM version is twice as fast as the lower version, making 64 QAM run at 64 times higher throughput than binary.

Beamforming Today

Each 3 dB of additional gain from beamforming equates to 37% higher coverage for the wireless network. For voice calls, adaptive beamforming married to TDD systems therefore means much higher coverage.

For data networks, adaptive beamforming also means much higher data rates, regardless of the types

of terrain involved. Adaptive beamforming is as useful in urban and dense urban capacity-driven environments as for rural areas. Enhancements are underway that will combine beamforming with MIMO, which promises startlingly better capacity and performance. Beamforming is not just for coverage—combined with Adaptive QAM Modulation it's now a powerful capacity enhancer, too.

Adaptive beamforming systems have been globally deployed. Beamforming is part of the Mobile WiMAX interoperability profiles, along with MIMO, and the support for TDD uplink sounding is mandatory for certified Mobile WiMAX devices. Beamforming is also expected to be high on the priority list for other 4G technologies as the standards continue to evolve over the next few years.

The new conventional wisdom is clear: Beamforming boosts both capacity and coverage.

Fujitsu and Cisco's Support of Mobile WiMAX with Beamforming

Beamforming, MIMO and other advanced techniques help close the performance gap between wireless and wired connectivity, by allowing
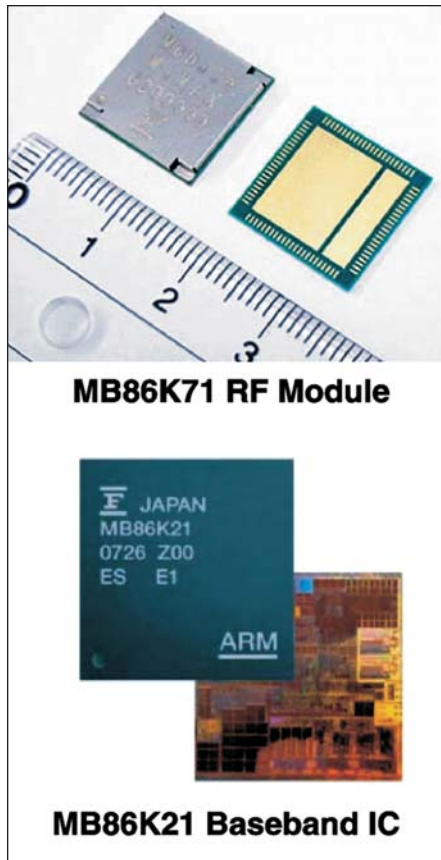
MB86K71 RF Module

MB86K21 Baseband IC

Figure 5 · Fujitsu's mobile WiMAX chip solutions.

Figure 6 · Cisco's mobile WiMAX solutions with adaptive beamforming.

wireless to offer broadband services with similar speeds at a competitive price. Cisco and Fujitsu have taken the lead in implementing adaptive beamforming with MIMO in the companies' WiMAX systems. Cisco and Fujitsu will continue to strive to improve the performance of broadband wireless technology.

The Fujitsu mobile WiMAX baseband SoC (MB86K21) and radio-frequency module (MB86K71) feature low power consumption and a high-performance 90 nm process technology. These devices with carefully designed circuits have greatly simplified TDD implementation.

Cisco Systems offers BWX Mobile WiMAX solutions such as the BWX 8300 Base-station and BWX 100 Desktop Modem. These solutions are deployed in commercial service with support for adaptive beamforming.

Cisco chairs the beamforming sub-committee of the WiMAX Forum's Technical Working group.

Fujitsu and Cisco have both enthusiastically backed the combination of adaptive beamforming with MIMO, based on the companies' belief that beamforming makes MIMO practical in a wider array of RF environments, and adds substantially to WIMAX throughput.

For More Information

More information on the IEEE 802.16 standard for broadband wireless access and the WiMAX Forum is available at www.ieee802.org/16 and www.wimaxforum.org, respectively.

For more information on Fujitsu's broadband wireless SoC, please go to http://us.fujitsu.com/micro/wimax, or e-mail: inquiry.bwa@fma.fujitsu.com.

For more information on Cisco Systems' BWX Mobile solutions, please go to: www.cisco.com/go/wimax

Author Information

Paul Sergeant has been in the telecom industry for over 20 years, with the last 15 in wireless. At Cisco, he is responsible for marketing Mobile WiMAX systems using Cisco's beamforming technology and end to end IP Next Generation Network. Paul is vice-chair of the WiMAX Forum's Marketing Working Group, and participates in several task groups. Paul joined Cisco in 2007 when Navini Networks was purchased by Cisco. Paul was born and educated in the United Kingdom, and holds a bachelor of science degree with honors in Aeronautical Engineering from the City University in London, England.

Tong Swan Pang is a product manager in the Wireless Business Group of Fujitsu Microelectronics America, Inc. (FMA). As such, he is responsible for marketing and sales of WiMAX ICs and FRAMs (Ferroelectric Random Access Memory). Pang joined FMA in June 2003 to develop the FRAM business in the U.S., and became a member of the WiMAX marketing team in 2004. Before being transferred to FMA, he had been a member of the marketing group in Fujitsu Limited, supporting overseas business for logic products and supporting business development of FRAM products worldwide. He received his bachelor's degree in electrical engineering from the National University of Singapore.