MIMO and Related Diversity Techniques Improve Wireless Range and Reliability

From June 2007 *High Frequency Electronics*

Multiple Input/Multiple Output (MIMO) techniques, as well as related diversity and "smart antenna" systems, are getting ready to make a significant impact on wireless technology. Although true MIMO is only deployed in the latest WLAN hardware, it is expected to be used widely in broadband networks, with deployments expected to begin in mid to late 2008.

The impetus for the development of MIMO is simple—higher data rate for a given amount of radio spectrum, compared to single channel, single antenna systems. Under practical conditions, MIMO will provide an improvement in data rate approaching the total number of antennas at either end. For example, with two antennas at the transmitter, there are two distinct data channels being sent. Ideally, two channels can carry twice the data of a single channel. If the receiver can accurately distinguish between the two channels, the net capacity can approach that doubled rate. With four channels, the rate can approach quadruple that of a single channel.

Since MIMO is a single-frequency system, it can be considered another form of frequency re-use, but implemented within a single cell. As such, it provides a dramatic improvement in the capacity of a system per unit bandwidth. The sidebar below describes MIMO operation.

What is MIMO?

True MIMO (Multiple Input/Multiple Output) is sometimes confused with simple antenna diversity, so we provide this short summary of the technology. MIMO uses *space-time* diversity, transmitting different portions of the data via separate antennas. These multiple signals are summed at the receiver to recover the entire data stream. A block diagram is shown in Figure 1.

Because the transmitted data is divided among two or more channels, the net data rate can be higher than a single channel, single antenna system. The difficulty is that the channels use the same frequency—the separation is accomplished by the different time delays as the signal travels between each transmit antenna and each receive antenna.

There is some functional similarity to OFDM (Orthogonal Frequency Domain Multiplexing), which also divides the data into multiple channels. However, in OFDM, channels are separated in frequency and phase, but are transmitted by a single transmitter and anten-

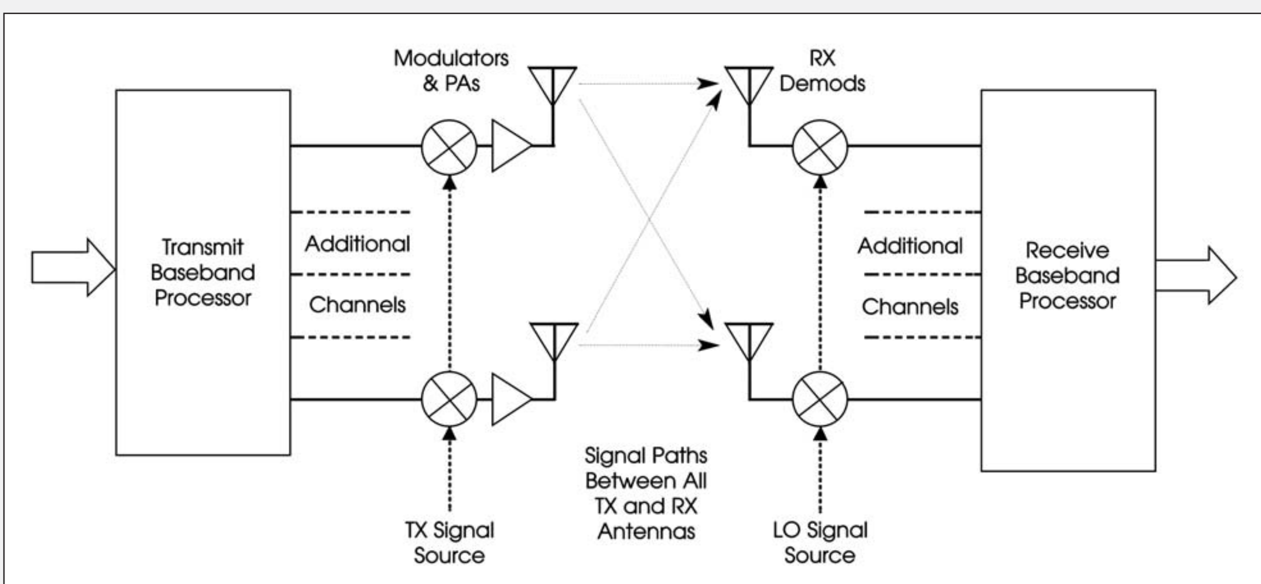

Figure 1 · Block diagram of a MIMO system, where each transmit antenna sends different data.

What is MIMO? *(continued)*

na. The biggest differences are that OFDM requires more bandwidth for its total signal, while MIMO requires more antennas, with a separate transmitter and receiver for each antenna.

The mathematical description of MIMO is more complex than would be useful here, but we can briefly summarize the key factors that influence a MIMO system:

Antenna separation—With wider separation between transmit antennas, and between receive antennas, there is a greater time difference among the various signal paths. With greater separation in propagation time, the receiver can more easily distinguish between those paths and recover the data with fewer errors than with closely-spaced antennas. Of course, the key problem is that a handset cannot offer much antenna separation, which can limit the maximum performance for a typical mobile user.

Signal path knowledge—Signals in mobile and portable environments change rapidly with the movement of the user, and with the movement of objects that can change reflected signal characteristics (multipath). To coordinate the decoding of transmitted signals, and to adjust the transmitted signal for impairments in the signal path, additional information must be communicated between the transmitter and receiver. In some systems, the receiver may periodically send information back to the transmitter regarding the channel status. In other systems, the transmitter sends a "training signal" in addition to the normal data content, to enable synchronization of the receiver with all transmitted channels.

These additional coordinating signals can consume a significant portion of the total data stream when operation is in a difficult propagation environment with deep, rapid propagation changes, or when the receiver is using very closely spaced multiple antennas (or just one antenna) and is unable to reliably separate the arriving channels. MIMO will not work at all times, but it can still offer a useful increase in data rate under moderately poor conditions.

Equipment complexity—The enhanced performance of MIMO comes at the cost of complexity. Each channel requires most of a transmitter's or receiver's circuitry—modulator through power amplifier in a transmitter, LNA through demodulator in a receiver. In addition, the antennas for each channel should be separated by two or three wavelengths at the base station, and as much as possible in a handset. The single biggest challenge for MIMO may be incorporating multiple transmit/receive channels in a handset that is already packed with other power-consuming features.

Smart Antennas and Diversity Systems

Another means of increasing system throughput and reliability lies in the antenna system alone. Most wireless systems operate well below their theoretical single-channel data throughput, due to fading, interference and weak signals (poor signal-to-noise ratio). In practice, a significant increase in typical data rate can be accomplished if a user has a strong, stable signal path to the base station.

Diversity systems can combat signal impairments by allowing the receiver (whether at the handset or base station) to monitor signals on two antennas. With separation of a reasonable distance, multipath fading will not occur on both antennas at the same time. The required spacing must be at least 1/4 wavelength (about 1.5 inches at 2 GHz), preferably 1/2 to 1 wavelength. A handset may allow 1/2 wavelength antenna separation, which is enough for a basic diversity system. Antennas with differing polarization can also help, so additional improvement may be obtained with the second antenna having orthogonal polarization relative to the first antenna.

Extending this concept to a larger array, adaptive beamforming (the "smart antenna" principle) can focus the gain of a multi-element antenna array on a single user. The "smart" part of this technology is tracking the user during movement and across base station handoffs. Beamforming can greatly increase the signal-to-noise ratio of a channel, while simultaneously reducing off-axis interference. Smart antennas are currently deployed in a few systems (notably in China), with imminent deployment in many others.

An advantage to smart antennas and diversity techniques is that they can be implemented solely as a base station upgrade, with no change to handset operation. The improvement does not match the capabilities of MIMO, but the cost and complexity are significantly less.

Some wireless providers are considering smart antennas as an interim improvement, since the same set of multiple antennas can become part of a MIMO system in the future.

Competing Technologies

There are other means of increasing wireless system bandwidth, including deployment of a large number of pico cells to increase frequency re-use. There are also alternatives to the channelized systems derived from the original "cellular" concepts, such as WiMAX, which may play a part in the distribution of high data rate services. These alternatives may limit the extent that MIMO is deployed, but in the future, even these systems might employ MIMO principles to increase their performance and meet demand for higher data rates.

Conclusions

Current estimates are that roughly 20 to 25 percent of wireless subscribers will require the maximum data rate offered by advanced systems such as MIMO, but those users place a high priority on that capability and are willing to pay the required fees. To achieve higher data rates, MIMO and other technologies can greatly increase wireless performance without needing additional bandwidth. This makes them attractive enhancement solutions for current wireless service providers.