OVERVIEW

In the last article, Quadrature Amplitude Modulation, we explored modulation techniques used to increase data rates. QAM is used in DSL, cable, and wireless – even Bluetooth uses it. In this article we’ll take a look at how MIMO creates separate streams of data (which use QAM) to further increase capacity over wireless. In the past, reflected signals were always a bad thing for wireless but this interesting technology uses multiple signal paths to its advantage for improved signal quality, speed, or both. It has been a part of cell phones for a long time and today is a requirement for reliable cell phone use given the very high frequency they operate on.

MIMO is also used in wireless LAN equipment for the same reasons – signal quality improvement and speed. Before MIMO, wireless LAN equipment would suffer from being in corners of rooms or any situation where reflected signals met at the receiving antenna around the same time. This spatial difference in waveforms would cause interference or complete wave cancellation.

UNDERSTANDING THE PURPOSE OF MIMO

The original purpose for MIMO was to solve the problem of interference and crosstalk between wires transmitting digital information. Digital signals are especially prone to problems with interference so researchers worked to find a solution to reduce interference. Eventually this led to the concept of using the interfering signal for a purpose – either to improve the signal by analyzing two out-of-phase waveforms (spatial diversity) or using the out-of-phase waveforms as separate data streams (spatial multiplexing). On the surface this might not seem like a big deal but MIMO can create multiple data streams without increasing bandwidth. This is critical considering the need to conserve bandwidth while improving performance.

SPATIAL DIVERSITY AND MULTIPLEXING

Two significant advantages can be found in MIMO wireless. The first is spatial diversity. Spatial diversity refers to the way two or more antennas are used to improve the signal quality. By analyzing two separate in-coming waveforms, one antenna can compensate for any lack of reception on the other. This improves the distance that the receiver can receive the transmitted signal by filling in momentary loss of reception. This inherently improves performance since the transmitting device is not asked to repeat packets of data.

The other, newer, advantage found in MIMO is spatial multiplexing. Spatial multiplexing is specific to wireless systems and can allow for multiple transmit antennas to communicate with multiple receive antennas simultaneously. This effectively creates many separate streams of data between two devices using signals received at slightly different times at each antenna. The data is compiled at the receiving device using complex algorithms running on a processor inside the unit. Theoretically, the speed of the wireless link would double for every doubling of the number of antennas.

Both diversity and multiplexing require some fairly sophisticated coding, processing hardware, and algorithms. This technology also requires that the two (or more) antennas are at least one wavelength apart from the other. Since wavelength is inversely related to frequency, the distance between antennas decreases with an increase of frequency.
COMMON ANTENNA ARRANGEMENTS

There are various antenna configurations for wireless that are tailored to the need of the system being design. Below is a diagram of the most common ones. There are also three and four antenna configurations on the market.

Possible Number Of Spatial Multiplexing & Diversity Paths

<table>
<thead>
<tr>
<th>Transmitter</th>
<th>Receiver</th>
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<tr>
<td><img src="image.png" alt="Diagram" /></td>
<td>Single Input Single Output</td>
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<tr>
<td><img src="image.png" alt="Diagram" /></td>
<td>Single Input Multiple Output</td>
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<td>Multiple Input Single Output</td>
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<td><img src="image.png" alt="Diagram" /></td>
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(SISO) **Single Input Single Output**: Simplest wireless link, no diversity and no multiplexing

(SIMO) **Single Input Multiple Output**: Transmitter with one antenna, receiver with two antennas. Diversity only at the receiver. Two forms of diversity can be achieved at the receiver. The first, switched diversity, switches to the antenna with the best signal quality. The second is maximum ratio combining and combines the multiple signal paths from each antennas to create one stronger signal.

(MISO) **Multiple Input Single Output**: Common in cellular networks, the transmitter sends the same data/signal from both antennas simultaneously. This relieves the processing burden from the receiver which saves on battery use at the receiving device.

(MIMO) **Multiple Input Multiple Output**: Both transmitter and receiver have two antennas each. In this case, separate channels and coding are used for each stream of data between pairs of antennas for multiplexing and diversity.
BEAMFORMING

Beamforming refers to the electromagnetic properties of the signal leaving the antenna. Beamforming directs the signal from the antenna in the most optimal direction for the given circumstances. There are two common systems designed for this purpose – Adaptive Array and Phased Array.

The Adaptive Array system analyzes conditions and automatically adapts to the given circumstances. This requires some advanced technology but allows for the system to adjust, on the fly, to ever changing conditions in any direction. This is an ideal system for providing services to mobile receivers.

The Phased Array system does the job in a similar way but has preset directions for the antenna pattern to adjust to. The advantage to the Phased Array is primarily cost since it is a simpler system.

FINAL THOUGHTS...

MIMO has become commonplace for many wireless applications. The benefits of performance concerning speed and distance have improved wireless service quality beyond what could have been achieved by other methods. One limiting factor of MIMO is the number of antennas vs. frequency used. Consumer products will be limited in the number of antennas due to the size of the unit required to keep the antennas at least one wavelength apart. Very high frequencies must be used in order to reasonably utilize more antennas and very high frequencies have difficulty reaching further distances – so as with anything, there is always something working against the positive qualities! That being said, MIMO is here to stay and there is no doubt that work will continue to improve it further with better coding and algorithms.