

SISO to MIMO: Moving Communications from Single-Input Single-Output to Multiple-Input Multiple-Output

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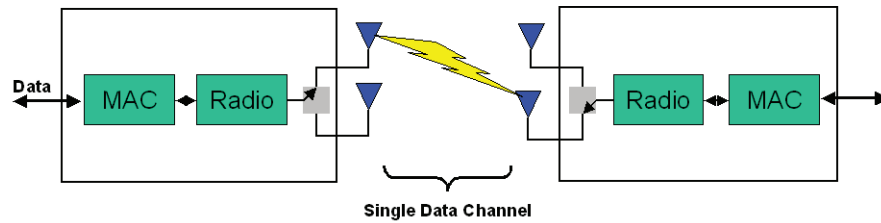
Commercial radio technology has reached an inflection point, similar to the transition from analog to digital, when we invented a whole range of digital technology; now we're moving from single carrier technologies, where we transmit one digital symbol at a time, to a new paradigm, where we're potentially transmitting hundreds of symbols simultaneously. The change has been driven by both customer demand for more mobile services and the decreasing cost of the digital signal processing technology required to deploy high bandwidth broadband wireless systems; the technology can now be used in the variety of commercial communications devices: the phones, PDAs, and the laptops on which we have become so dependent.

The technology of choice for this broadband connection is based on a modulation scheme called Orthogonal Frequency Division Multiplexing (OFDM). OFDM offers very good spectral efficiency and is quite tolerant of the ever-present interference in the bands where it is used. One of the key reasons for this is that it transmits hundreds of symbols simultaneously, yet at a low rate per symbol.

SISO: Single-Input Single-Output

Figure 1 shows a typical SISO radio with one transmitter and one receiver and information sent over a single data channel. This configuration is used in almost all radio products today. While there may be an extra antenna for spatial diversity (constantly switched for the best signal path), there is a single

up converter and a single down converter, a single demodulator/modulator in the radio, and a single data stream in the higher levels of the product's communications stack.



- One radio, only one antenna used at a time (e.g., 1 x 1)
- Antennas constantly switched for best signal path
- Only one data “stream” and a single data channel

Figure 1. A typical SISO radio with one transmitter and one receiver and information sent over a single data channel.

Multi-Path

Multi-path adds another layer of complexity to our SISO transmission. *Figure 2* shows a Bluetooth signal with a symbol rate of 1M symbols per second. That means that the receiver will expect a specific symbol within a window of one microsecond. If multi-path delays the signal by more than one microsecond, the receiver will receive the symbol in the next symbol period, causing a significant symbol error.

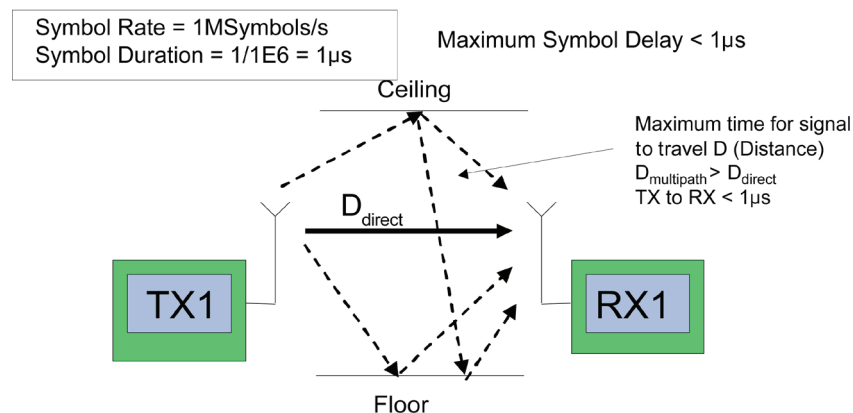


Figure 2. If the difference in path length between direct and reflected paths exceeds 1 microsecond, the receiver will receive the symbol in the next symbol period.

MIMO: Multiple-Input Multiple-Output

MIMO is a more significant change to radio architecture than anything that has happened in radio history so far. It is really quite simple in principle: If you have one transmitter, you can transmit some data from point A to point B; if you have four transmitters (or four carriers) the likelihood of the data getting there would be increased by close to four times, but the transmission would take up four times as much bandwidth. MIMO takes those four independent OFDM carriers, all independently modulated, and puts them on top of each other, so really you have four separate transmissions, all sharing the same frequency. You can carry up to 3.5 times as much information in the same bandwidth as a single carrier (*Figure 3*). The challenge at the receivers is to be able to get back to four independent radio signals. While the principle is not new, the cost of the technology has decreased to the point that it is now commercially viable.

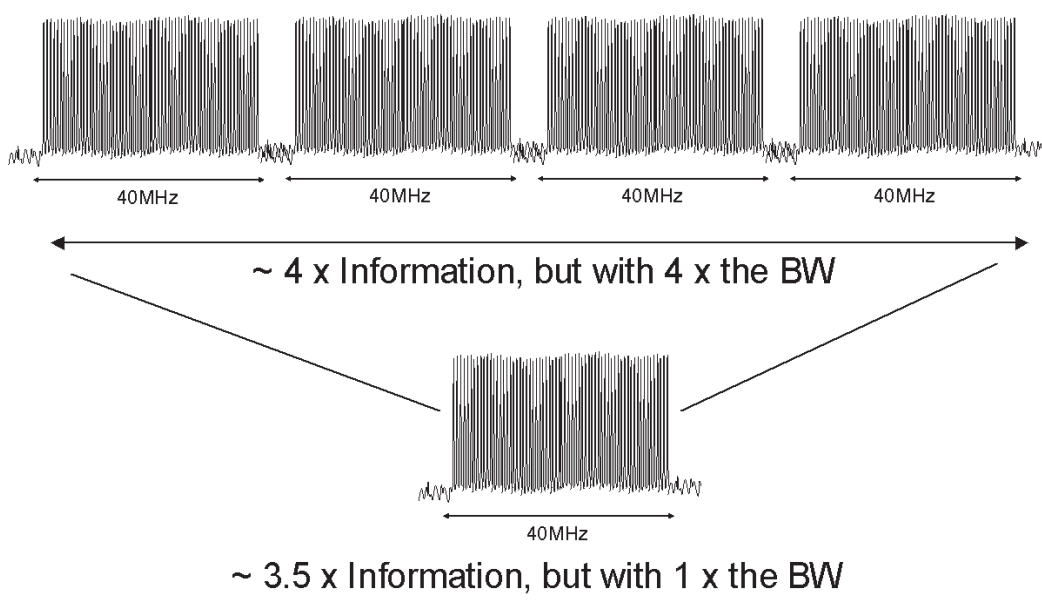


Figure 3. MIMO transmits multiple OFDM signals on the same channel. The challenge at the receivers is to be able to get back to the independent radio signals.

As for spectral efficiency, by using somewhere between two and four carriers to transmit the data, and having two and four receivers, the likelihood of receiving everything is much better, so the spectral efficiency rises dramatically (*Figure 4*), although that efficiency comes with a higher level of complexity.

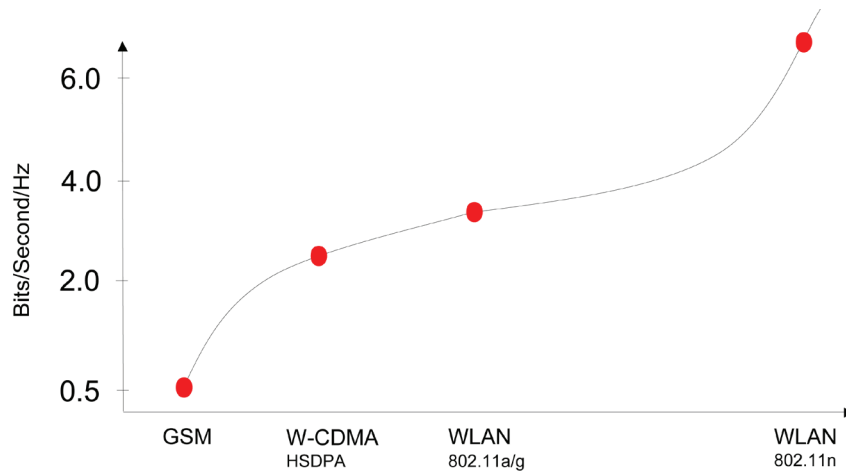


Figure 4. MIMO takes spectral efficiency to a new level, but with that efficiency comes a higher level of complexity.

MIMO radio configuration

Figure 5 shows some typical MIMO configurations. A 2×2 system contains two transmitters and two receivers, a 4×4 has four transmitters and four receivers. Many commercial WLAN devices today employ a 3×2 configuration of three transmitters and two receivers.

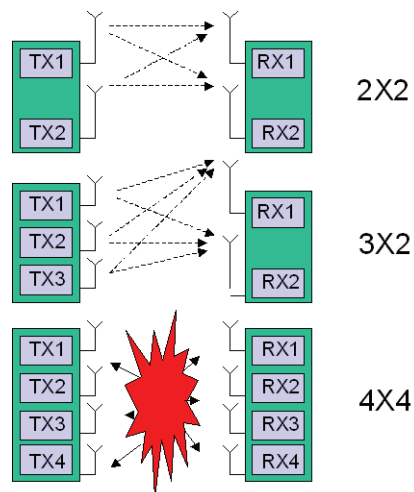


Figure 5. A 2×2 MIMO system contains two transmitters and two receivers, a 4×4 has four transmitters and four receivers. Many commercial WLAN devices today employ a 3×2 configuration of three transmitters and two receivers.

While SISO systems are degraded by the presence of multiple paths, MIMO systems require multiple paths. If there are two unknown transmitted signals and two measurements at the receivers, and the two measurements are sufficiently independent, it is possible to solve for the transmitted symbols. For example, if a MIMO transmitter transmits two signals on the same frequency, each signal takes a slightly different path to the receiver and each signal's characteristics diverge from the originally transmitted signals, mainly due to multi-path distortion. Both receivers receive a mixture of both the original signals. As the two receivers are independent, we can use simultaneous equations on the two received signals and solve for the transmitted symbols.

Hardware

Transmission of multiple signals requires accurate synchronization of multiple channels in phase and sampling alignment. This can easily be achieved by using two Model 2920 Vector Signal Generators (VSGs) with the Keithley MIMO synchronization unit. Conversely, to independently receive MIMO signals, it is necessary to synchronize two Model 2820 Vector Signal Analyzers (VSAs). In such a test setup all Model 28/2920s are identical standard units. The system also provides the flexibility to use Model 2920 VSGs as stand-alone generators (*Figure 6*).

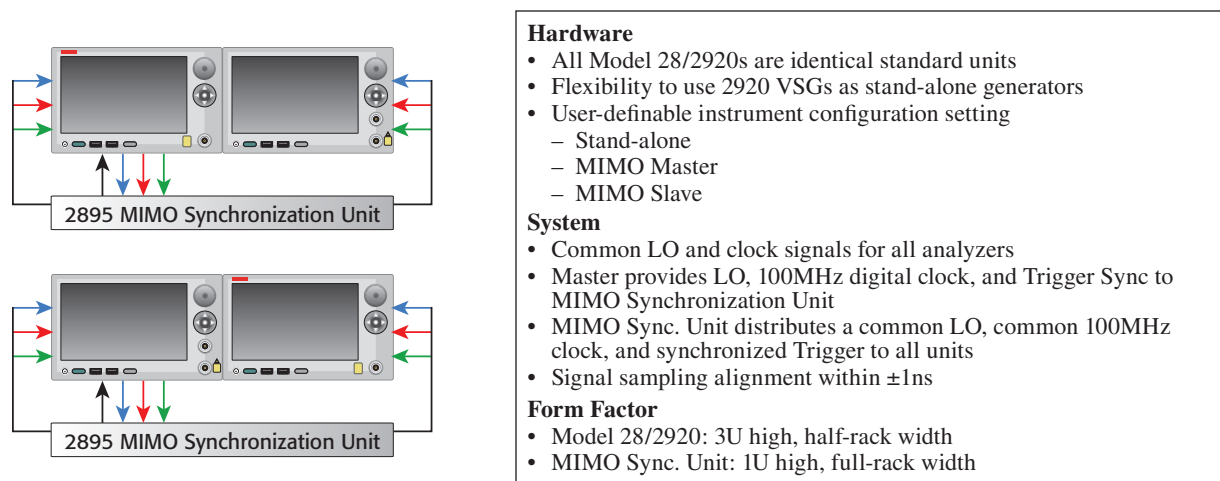


Figure 6. To transmit multiple signals, you need to accurately synchronize multiple channels in phase and sampling alignment. This can easily be achieved by using two Model 2920 Vector Signal Generators with the Keithley MIMO synchronization unit. Conversely, to independently receive MIMO signals you need to synchronize two Model 2820 Vector Signal Analyzers.

When configured as a system, all the analyzers share common local oscillator and clock signals. The master provides the LO, a 100MHz digital clock and trigger synchronization to the MIMO synchronization unit. The latter unit distributes those signals to all the other units. Signal sampling should be aligned within $\pm 1\text{ns}$.

Figure 7 shows three MIMO measurements on a two-channel system. The upper measurement is EVM across the OFDM subcarriers on each channel shown by the yellow and red plots. Underneath that we can see the channel frequency response over 60 sub-carriers. Finally, we see the constellation of a channel.

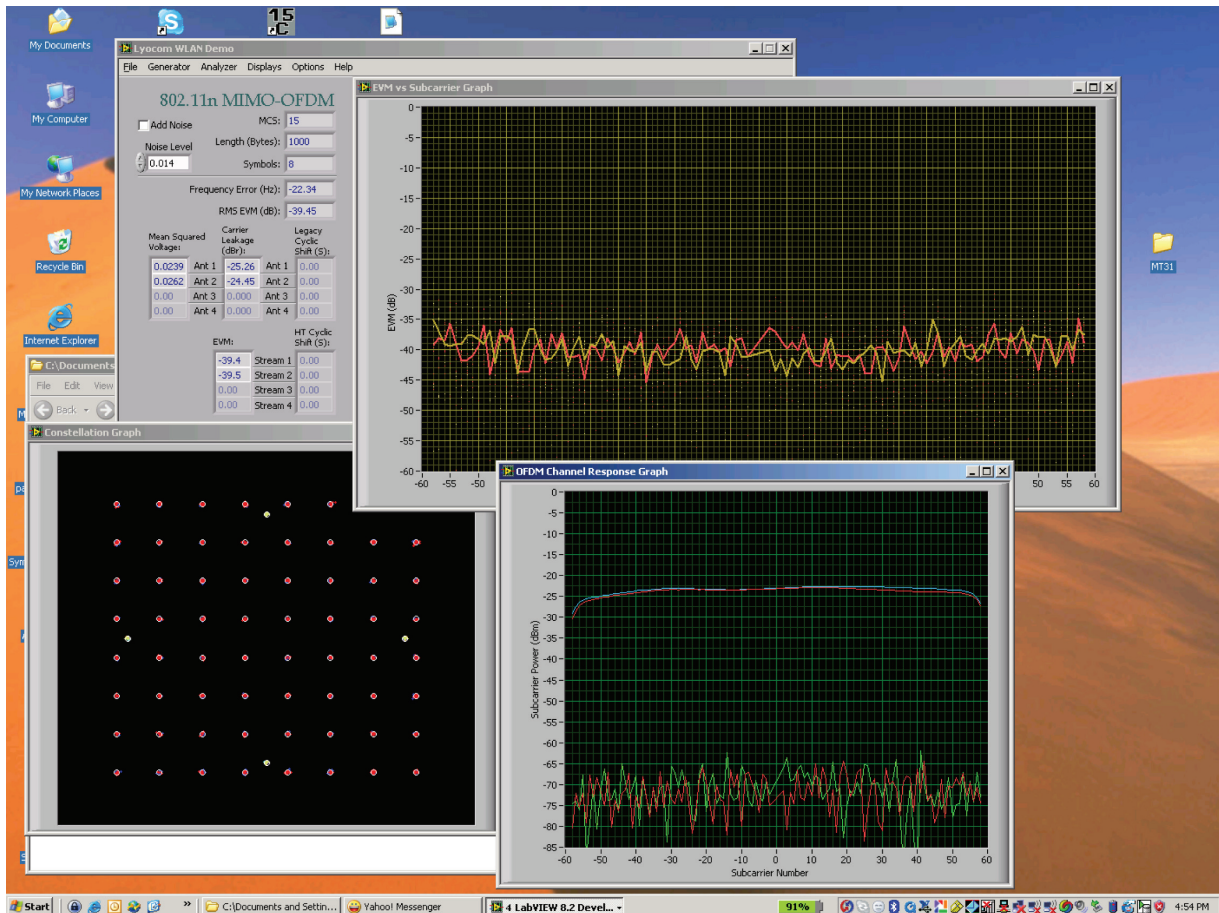


Figure 7. Three MIMO measurements on a two-channel system. The upper measurement is EVM across the OFDM subcarriers on each channel shown by the yellow and red plots. Underneath that we can see the channel frequency response over 60 sub-carriers. Finally, we see the constellation of a channel.

The Long Term Evolution of Wireless

The Long Term Evolution of wireless (LTE), also known as Ultra Mobile Broadband (UMB) for cellular devices (*Figure 8*), is the migration from 3G technology to 4G technology. The proposal right now is that the fourth generation technology of radios – cellular phones or cellular data devices or cellular terminals — or whatever we choose to call them – will be based on OFDM technology and MIMO radio configurations. Right now the commercial

application is wireless LAN; they've moved to 4G. Cellular technology will be based on all this, and that's what the LTE program is all about. When choosing test equipment for testing today's radio standards, it's important to consider the evolution of wireless technology and to ensure that your purchases are forward compatible.

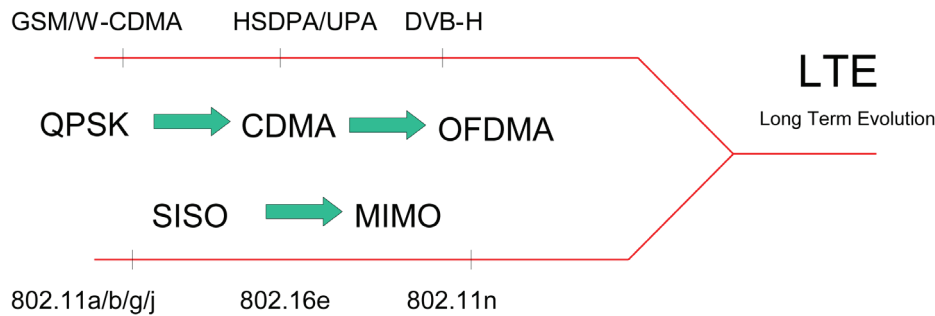


Figure 8. The Long Term Evolution of wireless (LTE), also known as Ultra Mobile Broadband (UMB) for cellular devices, will be based on a combination of OFDM types of modulation and MIMO radio configurations. When choosing test equipment for testing today's radio standards, it's important to consider the evolution of wireless technology and to ensure that your purchases are forward compatible.

Summary

To be a winner in MIMO requires driving the cost per channel down to a point where it's commercially viable. The bandwidths are very large in some of the systems, so it's necessary to position the D/As and A/Ds at a cost point and dynamic range where it's possible not only to successfully transmit these signals but to be able to sell devices for less than \$100. This is the challenge for the industry. It's a significant change; right now there's cost pressure just on the regular cell phone of one transmitter and one receiver; if you go up to 4x4, a lot of work must be done in the industry to make this commercially viable. Some of it has already been proven with the wireless LAN work that's been done, but it's a challenge and it's a big change to radio architecture as we know it today.

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