**MIMO: A General Overview**

MIMO technology is one of the most important technologies to improve the system performance in capacity, coverage and the user data rates. The performance gains depend on the propagation characteristics of each scenario. Wi-Fi, LTE, and many other radio both RF as well as wireless technologies use the new MIMO wireless technology to increase the link capacity, spectral efficiency and the link reliability using interference paths.

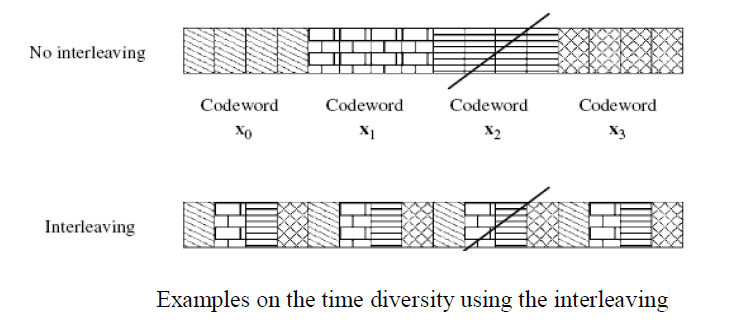
A channel will be affected by fading and this will in turn have an adverse impact on the SNR. This will then impact the error rate, if the data transmitted is digital. Diversity is the principle in which we give the receiver multiple versions of the same signal. If they can be made to be affected in many ways by a signal path the probability that they will be affected at the same time is reduced. Hence we can see that diversity is crucial in improving the performance of the link, stabilizing it as well as reducing the error rate.

There are several diversity modes that are available and provide a number of advantages.

* ***Time diversity:*** In time diversity, a message is transmitted at different times, e.g. using different timeslots and channel coding.
* ***Frequency diversity:*** In this form we use different frequencies. It may be in the form of using different channels, or technologies such as spread spectrum OFDM.
* ***Space diversity:*** Space diversity is used as the basis for MIMO. It uses the antennas that are located in multiple positions to take advantage of the different radio paths that exist in a typical environment.

***Time diversity***:

In this type of diversity we averaging the fading of the channel over time by using the channel coding and interleaving to let every part of the code word affected by different fading along the time so if a deep fading occurs only part of the code word will being missing not all the code word to explain this we will see an example:



***Frequency diversity:***

1. ***Frequency hop spread-spectrum:***

Frequency hopping is one of two basic modulation techniques used in spread spectrum signal transmission. It is the repeated switching of frequencies during radio transmission, often to minimize the effectiveness of "electronic warfare" - that is, the unauthorized interception or jamming of telecommunications. It also is known as frequency- hopping code division multiple access (FH-CDMA).

In an FH-CDMA system, a transmitter "hops" between available frequencies according to a specified algorithm, which can be either random or preplanned. The transmitter operates in synchronization with a receiver, which remains tuned to the same center frequency as the transmitter. A short burst of data is transmitted on a narrowband. Then, the transmitter tunes to another frequency and transmits again. The receiver thus is capable of hopping its frequency over a given bandwidth several times a second, transmitting on one frequency for a certain period of time, then hopping to another frequency and transmitting again. Frequency hopping requires a much wider bandwidth than is needed to transmit the same information using only one carrier frequency.

1. ***Direct sequence spread-spectrum***

In direct sequence spread spectrum, the stream of information to be transmitted is divided into small pieces, each of which is allocated across to a frequency channel across the spectrum. A data signal at the point of transmission is combined with a higher data-rate bit sequence (also known as a chipping code) that divides the data according to a spreading ratio. The redundant chipping code helps the signal resist interference and also enables the original data to be recovered if data bits are damaged during transmission.

In general, frequency-hopping devices use less power and are cheaper, but the performance of DS-CDMA systems is usually better and more reliable.

***Spatial (antenna) diversity:***

In this type of diversity we assures that we will have many copies of the transmitted signal or a coded versions effects with different fading over the space as we use multi antenna systems at the transmitter or the receiver to have finally at the receiver many copies of the transmitted signal suffers from different fading and the type of the diversity defined by where the multi antenna system so we have this types of the spatial diversity.

MIMO is a radio antenna technology as it uses multiple antennas placed at the transmitter as well as receiver so that a variety of signals carry data through different paths and we choose the separate paths for each antenna so that the multiple paths can be used.



**Figure 8***. MIMO System*

It is found that in between a transmitter and receiver, the signal can travel through multiple paths. So moving the antennas by even a small amount will lead to a change. The different number of paths that are available occurs as a result of a number of objects that appear in the direct path between the transmitter and receiver. Before these paths were just used to introduce interference but now using MIMO they can be used as an advantage. The two main formats of MIMO are:

* ***Spatial diversity:*** This refers to transmit and receive diversity. They provide improvement in the SNR and are characterized by boosting the reliability of the system with respect to fading.
* ***Spatial multiplexing:*** This provides additional data capacity by using the different paths to carry traffic, thereby increasing the total throughput of the system.

Since we use multiple antennas, MIMO can increase the capacity of a channel and still obey Shannon’s Law. With every pair of antennas that are added to the network, it is possible to linearly boost the throughput by increasing the receive and transmit antennas. Since the spectrum bandwidth is a very valuable commodity, such techniques are necessary to use the bandwidth that is available more efficiently and MIMO is one of those valuable techniques.

There are a number of MIMO configurations or formats that have been used. Each format has its own advantages and disadvantages and they can be used and balanced to provide the optimum solution for a particular application. The different MIMO formats – SISO, SIMO, MISO, MIMO all require different number of antennas and each requires different complexity. Depending on the format post processing might be required at one end or the other.

The different forms of antenna technology refer to the single or multiple inputs or outputs which are related to the radio link. In this way the input is the transmitter as it transmits into the system and the output is receiver.

The different forms of single / multiple antenna links are defined as below:

* SISO - Single Input Single Output
* SIMO - Single Input Multiple output
* MISO - Multiple Input Single Output
* MIMO - Multiple Input multiple Output





***A. MIMO-SISO***

The simplest form of radio link is SISO- Single Input Single Output. In this the transmitter operates with one antenna with the receiver. In this scheme no diversity and no additional processing is required. This can be viewed from the first figure.

***B. MIMO-SIMO***

In this scheme the transmitter has a single antenna while the receiver has multiple ones. This is called as receiver diversity. This is used to support a receiver system that receives signals from a number of sources to counter the effects of fading. This scheme has been in use for a long time with short wave listening/ receiving stations to fight ionospheric fading and interference. This is represented by the second figure. The main advantage is that is easy to implement however some processing is required at the receiver side. The use of SIMO is widespread but the receiver is located as a handset, hence it may be limited by size, cost and drain. There are two forms of SIMO that can be used:

* ***Switched diversity SIMO:*** Here it finds the strongest signal and switches to antenna.
* ***Maximum ratio combining SIMO:*** It collects both the signals and combines them to give a combination. Hence the signal from both contributes to the total signal.

***C. MIMO-MISO:***

MISO is also called as transmit diversity, where the same data is transmitted repeatedly from two transmitters. The receiver can then extract the needed data from the optimum signal. This is represented by the third figure. The main advantage of this scheme is that the multiple antennas and the repeated coding/processing is shifted from the receiver to the transmitter. If we take the case of cellphones, this results in massive savings in terms of space and reduces the processing required for coding. Again this results in reduced batter consumption, costs and smaller size.

***D. MIMO:***

In this case there are multiple antennas at the transmitter as well as the receiver. It provides advantages in total channel throughput. This scheme has been represented by the fourth and final figure. This requires coding to separate the data from the multiple paths which requires processing but boosts the total throughput and capacity.

There are many types of MIMO that can be used from SISO, through SIMO and MISO to complete MIMO networks. These are all able to provide heavy gains in performance, but usually at the expense of processing and total number of antennas. Tradeoffs have to be made between cost, performance, size, battery life before we choose the correct scheme.

**LTE**

LTE, an abbreviation for Long-Term Evolution, commonly marketed as 4G LTE, is a standard for wireless communication of high-speed data for mobile phones and data terminals. It is based on the GSM/EDGE and UMTS/HSPA network technologies, increasing the capacity and speed using a different radio interface together with core network improvements. The standard is developed by the 3GPP (3rd Generation Partnership Project). LTE is the natural upgrade path for carriers with both GSM/UMTS networks and CDMA2000 networks. The different LTE frequencies and bands used in different countries will mean that only multi-band phones will be able to use LTE in all countries where it is supported.

LTE stands for Long Term Evolution and is a registered trademark owned by ETSI (European Telecommunications Standards Institute) for the wireless data communications technology and a development of the GSM/UMTS standards. The goal of LTE was to increase the capacity and speed of wireless data networks using new DSP (digital signal processing) techniques and modulations that were developed around the turn of the millennium. A further goal was the redesign and simplification of the network architecture to an IP-based system with significantly reduced transfer latency compared to the 3G architecture. The LTE wireless interface is incompatible with 2G and 3G networks, so that it must be operated on a separate radio spectrum. The LTE specification provides downlink peak rates of 300 Mbit/s, uplink peak rates of 75 Mbit/s and QoS provisions permitting a transfer latency of less than 5ms in the radio access network. LTE has the ability to manage fast-moving mobiles and supports multi-cast and broadcast streams. LTE supports scalable carrier bandwidths, from 1.4 MHz to 20 MHz and supports both frequency division duplexing (FDD) and time-division duplexing (TDD). The IP-based network architecture, called the Evolved Packet Core (EPC) designed to replace the GPRS Core Network, supports seamless handovers for both voice and data to cell towers with older network technology such as GSM, UMTS and CDMA2000. The simpler architecture results in lower operating costs (for example, each E-UTRA cell will support up to four times the data and voice capacity supported by HSPA)

**How is LTE configured for deployment?**

LTE supports deployment on different frequency bandwidths. The current specification outlines the following bandwidth blocks: 1.4MHz, 3MHz, 5MHz, 10MHz, 15MHz, and 20MHz. Frequency bandwidth blocks are essentially the amount of space a network operator dedicates to a network. Depending on the type of LTE being deployed, these bandwidths have slightly different meaning in terms of capacity. That will be covered later, though. An operator may choose to deploy LTE in a smaller bandwidth and grow it to a larger one as it transitions subscribers off of its legacy networks (GSM, CDMA, etc.)

**How LTE actually works?**

LTE uses two different types of air interfaces (radio links), one for downlink (from tower to device), and one for uplink (from device to tower). By using different types of interfaces for the downlink and uplink, LTE utilizes the optimal way to do wireless connections both ways, which makes a better-optimized network and better battery life on LTE devices.

For the downlink, LTE uses an OFDMA (orthogonal frequency division multiple access) air interface as opposed to the CDMA (code division multiple access) and TDMA (time division multiple access) air interfaces . OFDMA (unlike CDMA and TDMA) mandates that MIMO (multiple in, multiple out) is used. Having MIMO means that devices have multiple connections to a single cell, which increases the stability of the connection and reduces latency tremendously. It also increases the total throughput of a connection. MIMO is what lets 802.11n WiFi reach speeds of up to 600Mbps, though most advertise up to 300-400Mbps. There is a significant disadvantage though. MIMO works better the further apart the individual carrier antennae are. On smaller phones, the noise caused by the antennae being so close to each other will cause LTE performance to drop.

For the uplink (from device to tower), LTE uses the DFTS-OFDMA (discrete Fourier transform spread orthogonal frequency division multiple access) scheme of generating a SC-FDMA (single carrier frequency division multiple access) signal. As opposed to regular OFDMA, SC-FDMA is better for uplink because it has a better peak-to-average power ratio over OFDMA for uplink. LTE-enabled devices, in order to conserve battery life, typically don’t have a strong and powerful signal going back to the tower, so a lot of the benefits of normal OFDMA would be lost with a weak signal. Despite the name, SC-FDMA is still a MIMO system. LTE uses a SC-FDMA 1×2 configuration, which means that for every one antenna on the transmitting device, there are two antennae on the base station for receiving.

Discrete Fourier transform functions are often used to convert digital data into analog waveforms for decoding audio and video, but it can be used for outputting the proper radio frequencies too. However, LTE-Advanced uses higher order MIMO configurations for downlink and uplink.

The LTE technology itself also comes in two flavors: an FDD (frequency division duplex) variant and a TDD (time division duplex) variant. The most common variant being used is the FDD variant. The FDD variant uses separate frequencies for downlink and uplink in the form of a band pair. That means for every band that a phone supports, it actually uses two frequency ranges. These are known as paired frequency bands. For example, Verizon’s 10MHz network is in FDD, so the bandwidth is allocated for uplink and downlink. This is commonly noted as a 2x10MHz or 10+10 MHz configuration. Some also call it 10x10MHz, but this is mathematically incorrect, but they mean 10+10MHz. Some will also call it a 20MHz network, but this can be ambiguous. The TDD variant uses one single range of frequencies in a frequency band, but that band is segmented to support transmit and receive signals in a single frequency range.

For example, an LTE TDD network deployed on 20MHz of spectrum uses the whole chunk as one large block for frequency allocation purposes. For network bandwidth purposes, a LTE TDD network’s spectrum can be further divided to optimize for the type of network traffic (half up and half down, mostly down and a bit up, mostly up and a bit down, and so on).

**4G Effects on Battery Life**

By itself, LTE devices should last roughly as long as their HSPA+ equivalents because of the optimized radios for both downlink and uplink operations. The reason why LTE devices right now eat batteries for breakfast is because the network operators are forcing many of these devices into active dual-mode operation.

For Verizon Wireless, this means that most of their LTE devices connect to both CDMA2000 and LTE simultaneously and stay connected to both. This consumes twice the amount of battery for every minute we are connected than we would if we were connected only to CDMA2000 or LTE. Additionally, when we make calls on Verizon Wireless LTE phones, the CDMA2000 radio sucks down more power because you are talking. Sending and receiving text messages causes pulses of CDMA2000 activity, which cuts battery life more. Arguably, constantly changing radio states could be worse for battery life than a switch into one mode for a period of time and switching back, so text messages may actually kill the batteries faster.

Then there is handover. Handover is the operation in which a device switches from one network to another or from one tower to another. Handover is the critical component that makes any cellular wireless network possible. Without handover, a user would have to manually select a new tower every time the user leaves the range of a tower. For cellular networks, this is even more critical because the range of a tower is not very predictable due to factors outside of anyone’s control (like the weather, etc.). LTE supports handover like all other cellular wireless networks, but it improves on it by doing it much faster when handing over to a supported type of network or cell.