MIMO:

MIMO (Multiple Input Multiple Output) is a technology used in wireless communication systems to increase data throughput and improve link reliability by transmitting multiple data streams simultaneously over multiple antennas.

MIMO systems exploit multipath propagation, where signals reflect off obstacles and arrive at the receiver via multiple paths. By using multiple antennas at both the transmitter and receiver, MIMO takes advantage of these multipath signals to enhance communication performance.

Components:

1. Transmitter: The transmitter in a MIMO system consists of multiple antennas, each transmitting an independent data stream. The data streams are typically modulated and combined before transmission.

2. Channel: The wireless channel comprises the space between the transmitter and receiver through which the signals propagate. In MIMO systems, the channel is characterized by multiple paths, each with different delays and attenuations.

3. Receiver: At the receiver, multiple antennas are used to capture the transmitted signals. These signals are then demodulated and processed to extract the original data streams.

Operation:

In a MIMO system, data streams are transmitted simultaneously from the multiple antennas at the transmitter. Due to the different paths taken by the signals, each antenna at the receiver receives a combination of all transmitted signals. By exploiting the spatial diversity of these signals, MIMO systems can mitigate fading and interference effects, thereby improving communication reliability.

Advantages of MIMO:

1. Increased Data Rate: By transmitting multiple data streams simultaneously, MIMO systems can achieve higher data rates compared to traditional SISO (Single Input Single Output) systems.

2. Improved Reliability: MIMO exploits spatial diversity to mitigate fading and interference, resulting in improved link reliability and coverage.

3. Enhanced Spectral Efficiency: MIMO enables more efficient use of the available spectrum by transmitting multiple data streams in the same frequency band.

In radio, **multiple-input and multiple-output**, or **MIMO** is a method for multiplying the capacity of a radio link using multiple transmission and receiving antennas to exploit multipath propagation. MIMO has become an essential element of wireless communication.

In wireless the term "MIMO" referred to the use of multiple antennas at the transmitter and the receiver. In modern usage, "MIMO" specifically refers to a practical technique for sending and receiving more than one data signal simultaneously over the same radio channel by exploiting multipath propagation. MIMO is fundamentally different from smart antenna techniques developed to enhance the performance of a single data signal, such as diversity.

MIMO can be sub-divided into three main categories: precoding, spatial multiplexing (SM), and diversity coding.

Precoding is multi-stream beamforming, in the narrowest definition. In more general terms, it is considered to be all spatial processing that occurs at the transmitter. In (single-stream) beamforming, the same signal is emitted from each of the transmit antennas with appropriate phase and gain weighting such that the signal power is maximized at the receiver input. The benefits of beamforming are to increase the received signal gain – by making signals emitted from different antennas add up constructively – and to reduce the multipath fading effect. In line-of-sight propagation, beamforming results in a well-defined directional pattern. However, conventional beams are not a good analogy in cellular networks, which are mainly characterized by multipath propagation. When the receiver has multiple antennas, the transmit beamforming cannot simultaneously maximize the signal level at all of the receive antennas, and precoding with multiple streams is often beneficial. Note that precoding requires knowledge of channel state information (CSI) at the transmitter and the receiver.

Spatial multiplexing requires MIMO antenna configuration. In spatial multiplexing, a high-rate signal is split into multiple lower-rate streams and each stream is transmitted from a different transmit antenna in the same frequency channel. If these signals arrive at the receiver antenna array with sufficiently different spatial signatures and the receiver has accurate CSI, it can separate these streams into (almost) parallel channels. Spatial multiplexing is a very powerful technique for increasing channel capacity at higher signal-to-noise ratios (SNR). The maximum number of spatial streams is limited by the lesser of the number of antennas at the transmitter or receiver. Spatial multiplexing can be used without CSI at the transmitter, but can be combined with precoding if CSI is available. Spatial multiplexing can also be used for simultaneous transmission to multiple receivers, known as space-division multiple access or multi-user MIMO, in which case CSI is required at the transmitter. The scheduling of receivers with different spatial signatures allows good separability.

Diversity coding techniques are used when there is no channel knowledge at the transmitter. In diversity methods, a single stream (unlike multiple streams in spatial multiplexing) is transmitted, but the signal is coded using techniques called space-time coding. The signal is emitted from each of the transmit antennas with full or near orthogonal coding. Diversity coding exploits the independent fading in the multiple antenna links to enhance signal diversity. Because there is no channel knowledge, there is no beamforming or array gain from diversity coding. Diversity coding can be combined with spatial multiplexing when some channel knowledge is available at the transmitter.

Recently, results of research on multi-user MIMO technology have been emerging. While full multi-user MIMO (or network MIMO) can have a higher potential, practically, the research on (partial) multi-user MIMO (or multi-user and multi-antenna MIMO) technology is more active.

Multi-user MIMO (MU-MIMO)

- In recent 3GPP and WiMAX standards, MU-MIMO is being treated as one of the candidate technologies adoptable in the specification by a number of companies, including Samsung, Intel, Qualcomm, Ericsson, TI, Huawei, Philips, Nokia, and Freescale. For these and other firms active in the mobile hardware market, MU-MIMO is more feasible for low-complexity cell phones with a small number of reception antennas, whereas single-user SU-MIMO's higher per-user throughput is better suited to more complex user devices with more antennas.

Multi-user MIMO (**MU-MIMO**) is a set of multiple-input and multiple-output (MIMO) technologies for wireless communication, in which a set of users or wireless terminals, each with one or more antennas, communicate with each other. In contrast, single-user MIMO considers a single multi-antenna transmitter communicating with a single multi-antenna receiver. In a similar way that OFDMA adds multiple access (multi-user) capabilities to OFDM, MU-MIMO adds multiple access (multi-user) capabilities to MIMO. MU-MIMO has been investigated since the beginning of research into multi-antenna communication, including work by Telatar on the capacity of the MU-MIMO uplink.

SDMA, massive MIMO, coordinated multipoint (CoMP), and ad hoc MIMO are all related to MU-MIMO; each of those technologies often leverage spatial degrees of freedom to separate users.

Multi-user MIMO (MU-MIMO) can leverage multiple users as spatially distributed transmission resources, at the cost of somewhat more expensive signal processing. In comparison, conventional, or single-user MIMO considers only local device multiple antenna dimensions. Multi-user MIMO algorithms are developed to enhance MIMO systems when the number of users or connections is greater than one. Multi-user MIMO can be generalized into two categories: MIMO broadcast channels (MIMO BC) and MIMO multiple access channels (MIMO MAC) for downlink and uplink situations, respectively. Single-user MIMO can be represented as point-to-point, pairwise MIMO.

To remove ambiguity of the words *receiver* and *transmitter*, we can adopt the terms *access point* (AP; or, *base station*), and *user*. An AP is the transmitter and a user is the receiver for downlink environments, whereas an AP is the receiver and a user is the transmitter for uplink environments. Homogeneous networks are somewhat freed from this distinction.

MIMO Formats:

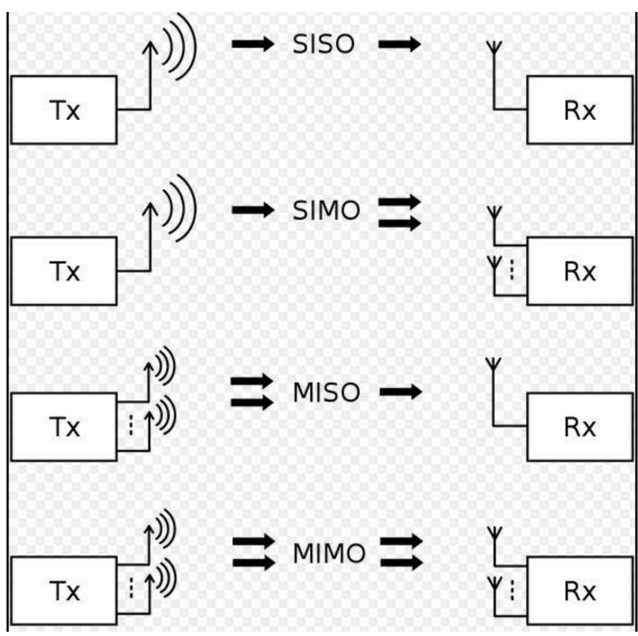
There is a number of different MIMO configurations or formats that can be used. These are termed SISO, SIMO, MISO and MIMO. These different MIMO formats offer different advantages and disadvantages - these can be balanced to provide the optimum solution for any given application.

The different MIMO formats - SISO, SIMO, MISO and MIMO require different numbers of antennas as well as having different levels of complexity. Also dependent upon the format, processing may be needed at one end of the link or the other - this can have an impact on any decisions made.

The different forms of antenna technology refer to single or multiple inputs and outputs. These are related to the radio link. In this way the input is the transmitter as it transmits into the link or signal path, and the output is the receiver. It is at the output of the wireless link.

therefore, 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



MIMO - SISO

The simplest form of radio link can be defined in MIMO terms as SISO - Single Input Single Output. This is effectively a standard radio channel - this transmitter operates with one antenna as does the receiver. There is no diversity and no additional processing required.

SISO - Single Input Single Output

The advantage of a SIS system is its simplicity. SISO requires no processing in terms of the various forms of diversity that may be used. However the SISO channel is limited in its performance. Interference and fading will impact the system more than a MIMO system using some form of diversity, and the channel bandwidth is limited by Shannon's law - the throughput being dependent upon the channel bandwidth and the signal to noise ratio.

MIMO - SIMO

The SIMO or Single Input Multiple Output version of MIMO occurs where the transmitter has a single antenna and the receiver has multiple antennas. This is also known as receive diversity. It is often used to enable a receiver system that receives signals from a number of independent sources to combat the effects of fading. It has been used for many years with short wave listening / receiving stations to combat the effects of ionospheric fading and interference.

SIMO - Single Input Multiple Output

SIMO has the advantage that it is relatively easy to implement although it does have some disadvantages in that the processing is required in the receiver. The use of SIMO may be quite acceptable in many applications, but where the receiver is located in a mobile device such as a cellphone handset, the levels of processing may be limited by size, cost and battery drain.

There are two forms of SIMO that can be used:

- ***Switched diversity SIMO:*** This form of SIMO looks for the strongest signal and switches to that antenna.

- ***Maximum ratio combining SIMO:*** This form of SIMO takes both signals and sums them to give the a combination. In this way, the signals from both antennas contribute to the overall signal.

MIMO - MISO

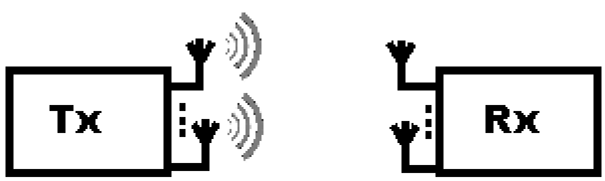
MISO is also termed transmit diversity. In this case, the same data is transmitted redundantly from the two transmitter antennas. The receiver is then able to receive the optimum signal which it can then use to receive extract the required data.

MISO - Multiple Input Single Output

The advantage of using MISO is that the multiple antennas and the redundancy coding / processing is moved from the receiver to the transmitter. In instances such as cellphone UEs, this can be a significant advantage in terms of space for the antennas and reducing the level of processing required in the receiver for the redundancy coding. This has a positive impact on size, cost and battery life as the lower level of processing requires less battery consumption.

MIMO

Where there are more than one antenna at either end of the radio link, this is termed MIMO - Multiple Input Multiple Output. MIMO can be used to provide improvements in both channel robustness as well as channel throughput.



MIMO - Multiple Input Multiple Output

In order to be able to benefit from MIMO fully it is necessary to be able to utilise coding on the channels to separate the data from the different paths. This requires processing, but provides additional channel robustness / data throughput capacity.

There are many formats of MIMO that can be used from SISO, through SIMO and MISO to the full MIMO systems. These are all able to provide significant improvements of performance, but generally at the cost of additional processing and the number of antennas used. Balances of performance against costs, size, processing available and the resulting battery life need to be made when choosing the correct option.

MIMO technology plays a crucial role in modern wireless communication systems, offering increased data rates, improved reliability, and enhanced spectral efficiency. By leveraging multiple antennas at both the transmitter and receiver, MIMO enables efficient utilization of the wireless channel, making it suitable for various applications, including 4G LTE, 5G, Wi-Fi, and more.