

## Chapter Two

### 2. Background

The concept of air interface wireless communication is based on **Antennas**, Antennas are required by any radio receiver or transmitter to couple its electrical connection to the electromagnetic field. Radio waves are electromagnetic waves which carry signals through the air (or through space) at the speed of light with almost no transmission loss. Radio transmitters and receivers are used to convey signals (information) in systems including broadcast (audio) radio, television, mobile telephones, Wi-Fi (WLAN) data networks. Demand for wireless throughput, both mobile and fixed, will always increase. Methods were developed to improve the performance of cellular radio networks and enable more aggressive frequency reuse in the early 1990s.

During the last years, data traffic (both mobile and fixed) has grown exponentially due to the dramatic growth of smart phones, tablets, laptops, and many other wireless data consuming devices. The demand for wireless data traffic will be even more in future. Global mobile data traffic is expected to increase to 15.9 Exabyte per month by 2018, which is about a 6-fold increase over 2014. In addition, the number of mobile devices and connections are expected to grow to 10.2 billion by 2018. New technologies are required to meet this demand.

#### 2.1 Wireless Communication LTE-A

LTE-A is a 4th generation mobile telecommunication technology. LTE-A was finalized by the third Generation Partnership Project (3GPP) in March 2011. LTE-A is not a completely new technology, rather it is an enhancement to LTE. The main objective of LTE-A is to increase the peak data rate to 1 Gbps on the downlink and 500 Mbps on the uplink, improve spectral efficiency from a maximum of 16 bps/Hz in Release 8 to 30 bps/Hz in Release 10, increase the number of concurrently active subscribers, and improve performance at cell edges [6]. Many technologies applied in LTE continue to be

used in LTE-A, such as orthogonal frequency division multiplexing (OFDM), OFDMA, MIMO, and SC-FDMA. The aims of LTE are to ensure the continued competitiveness of 3G systems for the future and to offer high user data rates and low latency.

In wireless communication, the transmitted signals are being attenuated by obstacles between the transmitter and the receiver, yielding a fundamental challenge for reliable communication.

## **2.2 Types of antennas technology:**

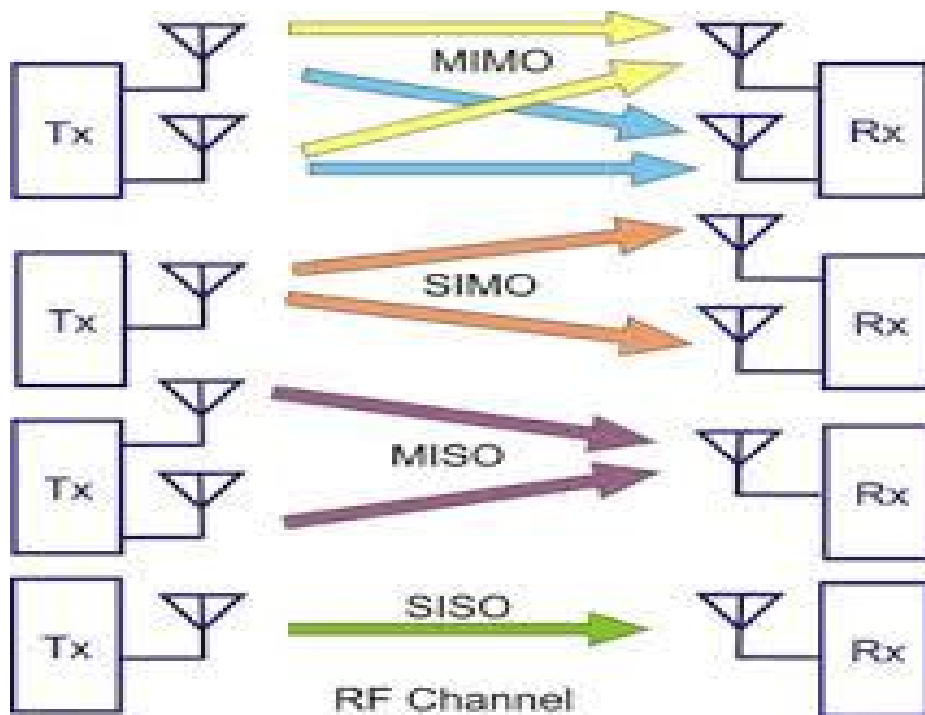
**2.2.1 SISO** (single input, single output) refers to a wireless communications system in which one antenna is used at the source (transmitter) and one antenna is used at the destination (receiver). SISO is the simplest antenna technology. In some environments, SISO systems are vulnerable to problems caused by multipath effects. When an electromagnetic field (EM field) is met with obstructions such as hills, canyons, buildings, and utility wires, the wavefronts are scattered, and thus they take many paths to reach the destination. The late arrival of scattered portions of the signal causes problems such as fading, cut-out (cliff effect), and intermittent reception (picket fencing). In a digital communications system, it can cause a reduction in data speed and an increase in the number of errors.

**2.2.2 SIMO** (single input, multiple output) is an antenna technology for wireless communications in which multiple antennas are used at the destination (receiver). The antennas are combined to minimize errors and optimize data speed. The source (transmitter) has only one antenna..

**2.2.3 MISO** (multiple input, single output) is an antenna technology for wireless communications in which multiple antennas are used at the source (transmitter). The antennas are combined to minimize errors and optimize data speed. The destination (receiver) has only one antenna..

And

**2.2.4 MIMO**(multiple input, multiple output) multiple-input multiple-output (MIMO) antennas is a well-known diversity technique to enhance the reliability of the communication. Furthermore, with multiple antennas, multiple streams can be sent out and hence, we can obtain a multiplexing gain which significantly improves the communication capacity. MIMO systems have gained significant attention for the past decades, and are now being incorporated into several new generation wireless standards (e.g., LTE-Advanced, 802.16m). Figure(2.1) shows the four types of antenna technology



Figure(2.1)the four types of antenna technology

Introducing multiple antennas at the tx and rx improves both the capacity and reliability of the communication system without any extra bandwidth or power needed.

Three types of gain can be provided by a mimo system:

1. Beamforming gain.
2. Multiplexing gain.
3. Diversity gain.

## **2.3 Types of MIMO technology:**

### **2.3.1 SU-MIMO(Single User MIMO)**

The base understanding of the single user technology. It came along as an optional technology with the 802.11n wireless standard in 2007. It enabled multiple streams of data to be simultaneously transmitted or received between two Wi-Fi devices using multiple antennas and beamforming technology. It helps increase the speed at which data passes between those two Wi-Fi devices. Single-user MIMO can only talk to one client at a time. All the work necessary to multiplex those data streams require the full attention of a single access point for the period in time that the client is transmitting. That means that crowded wireless networks can see reduced throughput because of shorter transmit windows.

The most obvious down side to single user MIMO is that the multiple streams of data must be sent or received between just one device at time. However, there are more cons as well. For instance, single user MIMO requires both the transmitting and receiving Wi-Fi radios support the MIMO technology, along with having multiple antennas. The multiple antennas add cost, weight, and size to the Wi-Fi devices and the processing of the MIMO signals requires more resources as well. These are especially evident with the smaller devices, like smartphones and tablets.

### **2.3.2MU-MIMO(Multi User MIMO)**

Where several users are simultaneously served by a multiple-antenna base station (BS). With MU-MIMO setups, a spatial multiplexing gain can be achieved even if each user has a single antenna. This is important since users cannot support many antennas due to the small physical size and low cost requirements of the terminals, whereas the BS can support many antennas,Multi user MIMO is being released in the second wave of the 802.11ac wireless standard. It enhances the MIMO technology by enabling Wi-Fi to simultaneously

transmit those multiple streams to different Wi-Fi devices, instead of just one single device as with the older version as shown in Figure (2.2).

So for instance, say an access point is capable of sending four data streams simultaneously, it could send all four to a device that can accept four. Alternatively, it could send two streams to one device and the other two streams to two different devices. In all, three different devices would be receiving streams simultaneously.

MU-MIMO in cellular systems brings improvements on four fronts:

- increased data rate, because the more antennas, the more independent data streams can be sent out and the more terminals can be served simultaneously;
- enhanced reliability because the more antennas the more distinct paths that the radio signal can propagate over;
- improved energy efficiency, because the base station can focus its emitted energy into the spatial directions where it knows that the terminals are located .
- reduced interference because the base station can purposely avoid transmitting into directions where spreading interference would be harmful.

All improvements cannot be achieved simultaneously, and there are requirements on the propagation conditions, but the four above bullets are the general benefits. MU-MIMO technology for wireless communications in its conventional form is maturing, and incorporated into recent and evolving wireless broadband standards like 4G LTE and LTE-Advanced (LTE-A). The more antennas the base station (or terminals) are equipped with, the better performance in all the above four respects—at least for operation in time-division duplexing (TDD) mode. However, the number of antennas used today is modest. The most modern standard, LTE-Advanced, allows for up to 8 antenna ports at the base station and equipment being built today has much fewer antennas than that.

For instance with multi user MIMO, Wi-Fi devices receiving one of the MIMO data streams doesn't have to have multiple antennas. The receiving Wi-Fi devices must support the multi user MIMO technology, but if there's only one antenna then it could still receive one of the multiple data streams from the wireless router or access point.

Furthermore, the wireless router or access point is the device that does the heavy processing of the MIMO signals, thus it's less taxing on the processors of the Wi-Fi devices. This all means saved cost, weight, and size for the devices supporting the multi user MIMO technology.

In addition to increase speeds, multi user MIMO also has the potential to increase the capacity of wireless networks. Since Wi-Fi devices can be served quicker, the more devices there can be. A noticeable difference could be especially realized on public Wi-Fi hotspot networks with a dense amount of users in certain area.

One very interesting side effect of the signal processing of multi user MIMO is that the data is scrambled while traveling from the wireless router or access points through the airwaves to the Wi-Fi devices. This basically means unsecure or unencrypted connections, such as when on public Wi-Fi hotspots, can see an increase in security. Any eavesdroppers nearby capturing the Wi-Fi traffic won't be able to make use of any of the data that's transmitted as multi user MIMO. This is also useful on private networks as well that are using the personal (PSK) mode of Wi-Fi security. Normally, any eavesdropper nearby that knows the Wi-Fi password can decrypt the wireless traffic from the other users, but that won't be the case for multi user MIMO traffic.

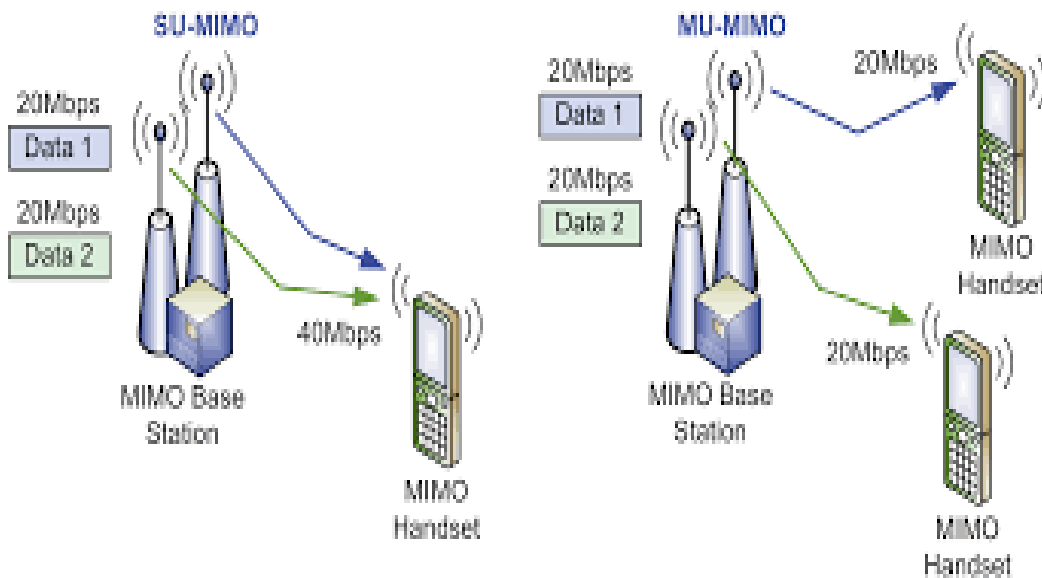


Figure (2.2) shows SU MIMO vs MU MIMO

The rules and regulations for single MIMO and beamforming that were designed with the 802.11n wireless standard weren't as standardized as they are with the multi user MIMO and the 802.11ac standard. Having a more standardized technology means that products from different manufacturers will all support the same technology and methods. More products with the technology, means the better the chance the technology will make a difference on your network.

The major stipulation of multi user MIMO is that it currently only works on the downlink connection of Wi-Fi: the transmissions from the wireless router or access point to the Wi-Fi devices users have connected. Right now Wi-Fi devices can only transmit a single stream of data to the wireless router or access point with the multi user MIMO technology no matter how many antennas there are on either device. Though single user MIMO actually worked on both the uplink and downlink connection, multi user MIMO is typically seen as a better option overall when you weigh all the pros and cons of each technology.

Another important fact about multi user MIMO is that it only works on the 5GHz Wi-Fi band. Though 802.11ac devices also support the older standards, like 802.11n or even 802.11b/g, this newer MIMO technology only works for connections utilizing the actual 802.11ac standard, which is a 5GHz-only technology. Thus other than the positive side effects like I discussed, increased total throughput, the multi user MIMO technology doesn't directly affect devices using 802.11n or earlier.

Apart of the MIMO technology is beamforming, where the Wi-Fi signals are directed towards the intended recipient rather than always being sent equally in all areas. This raises a potential issue for rapidly moving Wi-Fi devices. The movement can complicate and slow the MU-MIMO performance. However, the wireless router or access point should detect this when it arises and will likely revert to single user MIMO, which isn't so sensitive to movement, for any problem devices when needed, while continuing multi user MIMO with any other devices. It's safe to say multi MIMO won't be much of a benefit to networks with a majority of roaming devices.

There are two scenarios associated with MU-MIMO, Multi-user MIMO:

- Uplink - Multiple Access Channel, MAC: The development of the MIMO-MAC is based on the known single user MIMO concepts broadened out to account for multiple users.
- Downlink - Broadcast Channel, BC : The MIMO-BC is the more challenging scenario. The optimum strategy involves pre-interference cancellation techniques known as "Dirty Paper Coding". This is complemented by implicit user scheduling and a power loading algorithm

MU-MIMO does not only reap all benefits' of MIMO systems, but also overcomes most of propagation limitations in MIMO such as ill-behaved channels. Specifically, by using scheduling schemes, we can reduce the limitations of ill-behaved channels. Line-of-sight propagation, which causes significant reduction of the performance of MIMO systems, is no longer a problem in MU-MIMO systems. Thus, MU-MIMO has attracted substantial interest .

There always exists a tradeoff between the system performance and the implementation complexity.

## **2.4Massive mimo**

Massive Multiple Input-Multiple Output (Massive MIMO) systems have turned out to be necessity of wireless communication systems to conquer bandwidth restrictions. Massive-MIMO systems are capable of improving the channel capability of the system. Massive MIMO communications refers to the idea of equipping the base station with a very large number of antennas that is in order of 100 or more antennas.The massive mimo system is also called "large scale antenna system LSAS".In massive mimo system is done by dividing the multi users into cells where each has a base station with multi antennas serving the single antenna users in the cell see figure (2.3), with massive MIMO, we think of systems that use antenna arrays with a few hundred antennas, simultaneously



serving many tens of terminals in the same time-frequency resource. The basic premise behind massive MIMO is to reap all the benefits of conventional MIMO, but on a much greater scale. Overall, massive MIMO is an enabler for the development of broadband (fixed and mobile) networks which will be energy efficient, secure, and robust, and use the spectrum efficiently. As such, it is an enabler for the digital society infrastructure that will connect the Internet of people, Internet of things, with clouds and other network infrastructure.

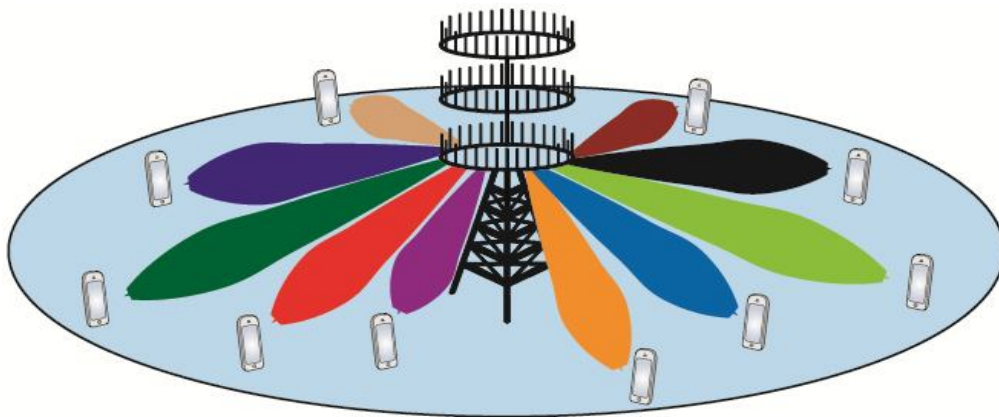
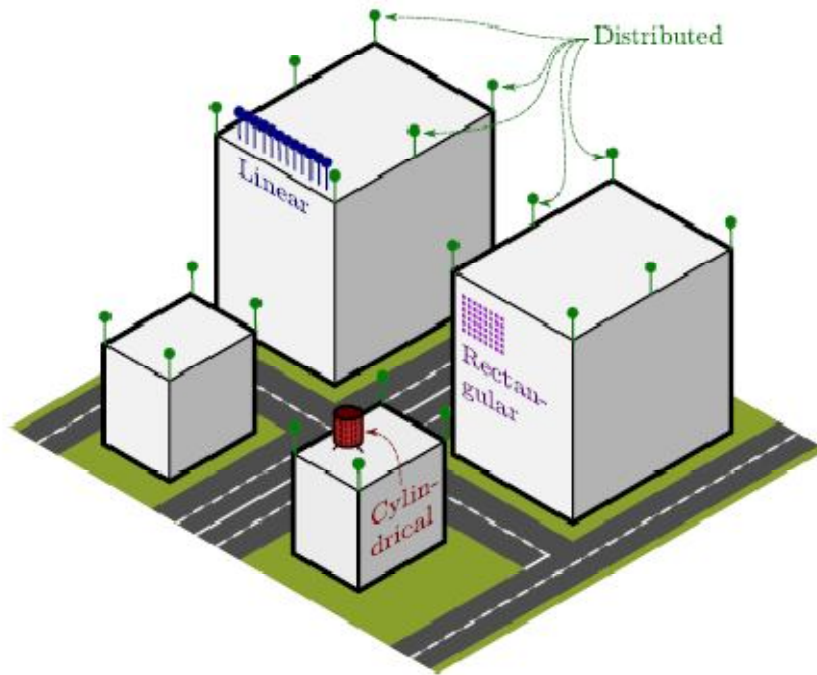


Figure (2.3): massive mimo system is done by dividing the multi users into cells where each has a base station with multi antennas serving the single antenna users in the cell.

Many different configurations and deployment scenarios for the actual antenna arrays used by Figure (2.4):



Figure(2.4): distribution of Massive MIMO

Some possible antenna configurations and deployment scenarios for a massive MIMO base station. a massive MIMO system can be envisioned, see figure(2.4). Each antenna unit would be small, and active, preferably fed via an optical or electric digital bus.

It is well known that, on the downlink (DL), increasing the number of antennas at the base station (BS), i.e., at the TX, can result in large increases in data rate, link reliability, and energy efficiency, In MU systems, increased TX antenna numbers reduce inter-user interference and increase system diversity through multiplexing gains .Massive MIMO, which scales up the number of TX and RX antennas by at least an order of magnitude relative to conventional MU-MIMO systems, leverages the spatial dimension providing significant increases in data rate, link reliability, energy efficiency, and multiplexing gains while reducing inter-user interference, massive MIMO systems are the additional channel properties which arise when operating with large numbers of TX antennas. These properties arise as a result of random matrix theory asymptotics . For example, as the number of TX antennas becomes large, users' channels become mutually orthogonal. This is known as favourable propagation, and under these conditions simple linear

processing techniques, such as matched-filter (MF) and zero-forcing (ZF) precoding, and minimum mean squared error (MMSE) processing can maximize the sum rate, Massive MIMO is the currently most compelling sub-6 GHz physical-layer technology for future wireless access. The main concept is to use large antenna arrays at base stations to simultaneously serve many autonomous terminals, as illustrated in Figure (2.5). The rich and unique propagation signatures of the terminals are exploited with smart processing at the array to achieve superior capacity.

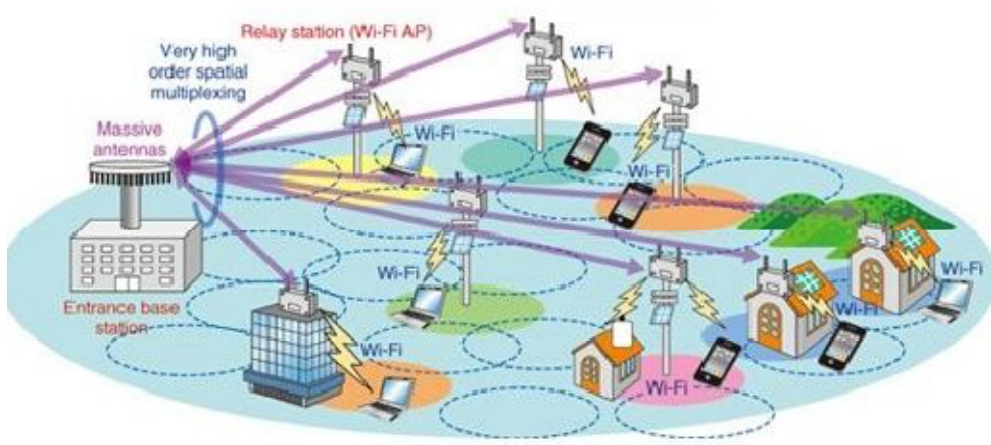


Figure (2.5) large antenna arrays at base stations to simultaneously serve many autonomous terminals

#### 2.4.1 How massive MIMO works

Massive MIMO is a multi-user MIMO technology in which  $K$  single-antenna user equipments (UEs) are serviced simultaneously on the same time-frequency resource by a

base station (BS) equipped with a relatively large number  $M$  of antennas, i.e.,  $M \gg K \gg 1$ . In general, the UEs in a massive MIMO system can be equipped with more than one antennas.

Massive MIMO relies on spatial multiplexing that in turn relies on the base station having good enough channel knowledge, both on the uplink and the downlink. On the uplink, this is easy to accomplish by having the terminals send pilots, based on which the base station estimates the channel responses to each of the terminals. The downlink is more difficult. In conventional MIMO systems, like the LTE standard, the base station sends out pilot waveforms based on which the terminals estimate the channel responses, quantize the so-obtained estimates and feed them back to the base station. This will not be feasible in massive MIMO systems, at least not when operating in a high-mobility environment, for two reasons. First, optimal downlink pilots should be mutually orthogonal between the antennas. This means that the amount of time-frequency resources needed for downlink pilots scales as the number of antennas, so a massive MIMO system would require up to a hundred times more such resources than a conventional system. Second, the number of channel responses that each terminal must estimate is also proportional to the number of base station antennas. Hence, the uplink resources needed to inform the base station about the channel responses would be up to a hundred times larger than in conventional systems. Generally, the solution is to operate in TDD mode, and rely on reciprocity between the uplink and downlink channels—although FDD operation may be possible in certain cases .

As the number of antennas on the BS side increases, so too does the number of channels that require training. To avoid infeasible training overheads and reach maximum capacity, Massive MIMO must operate in time-division duplex (TDD) mode and exploit channel reciprocity. In doing so the number of orthogonal training signals required is no longer dependent upon  $M$  but solely the number of user terminals present. However, frequency-division duplex (FDD) Massive MIMO solutions are being explored as a large percentage of the world's 4G networks currently operate in this mode.