NOVEMBRE

WIRELESS ACCESS

LTE and LAE - Advanced

LTE stands for LONG TERM EVOLUTION there are two versions
LTE and LTE-A
The idea was that of satisfy some important demands: try to provide as much as possibee devices services, giving the fact that users where interessed in increasing the amount of data exchanging with the cellular network.

~~That~~ Initially there was a big interess in the East part of the world for having video on demand and new applications.

In Previous generation we wanted to support data (GSM, UNTS) but not for video streaming.
Then video streaming started to be an application of interest for the mobile networks.

This was not available in UNTS. There were only MMS (images) instead of SMS but they were quite heavy.
So this is why the wanted to find new applications.
The interest was also in supporting intercommection everywhere

This is achieved changing important features:

- Using features like adaptive modulation and coding HARQ
- Using higher bandwidths, but flexibee and scalabee, only possibee by using another transmission scheme
- Using MIMO and smart antennas

1) In general, the important things we have to know is to improve the data rate
To do that we use larger bandwidth. So starting from bandwidth ~~changing from~~ of size 1.4 MHz, we arrive to 3, 5, 10 up to 20MHz

1,4 MHz

20MHz → somewhere in the spectrum we could have bandwidth of size 20 MHz

2) It is possibee to use different modulation schemes. A modulation scheme is a way to transmitt our data in our spectrum and we can modulate (so we can send more or less data) in accordance to the characteristics of the spectrum.
So we can use different modulation schemes (QPSK, 16QAM, 64QAM) and as the modulation increases, the data rate increases.

N.B the bandwidths (Downlink and Uplink) have different configurations
So in the LTE the communication IS ASYMMETRIC, so as we have seen for ADSL we have more bandwidth and higher data rate in the down link (from the BS to the mobile user) and in the Uplink (from user to BS) less bandwidth, so lower data rate

PEAK DATA RATE

So ~~we have~~, depends up on kind of configurations of some transmission characteristics, we can support in the maximum bandwidth 20MHz up to 150 Mbps in the Downlink and we have with another configuration (4x4 MIMO) in 20MHz bandwidth up to 300 Mbps in the Downlink.

→ 2x2 MIMO

These are quite ~~[illegible]~~ high rates considering the fact that we are working on WIRELESS DOMAIN toward mobile system
On the contrary, on the Uplink we have 75 ~~Kbp~~ Mbps for 20 MHz

What we expect if the bandwidth available is less than 20MHz?

We expect lower speed because accordingly to Shannon formula, we know that the capacity C is proportional to B
$C = B \log_2 (1 + SNR)$ so if we decrease the bandwidth B, the Capacity C decreases

The carrier frequency of the LTE is 800MHz, 18000MHz

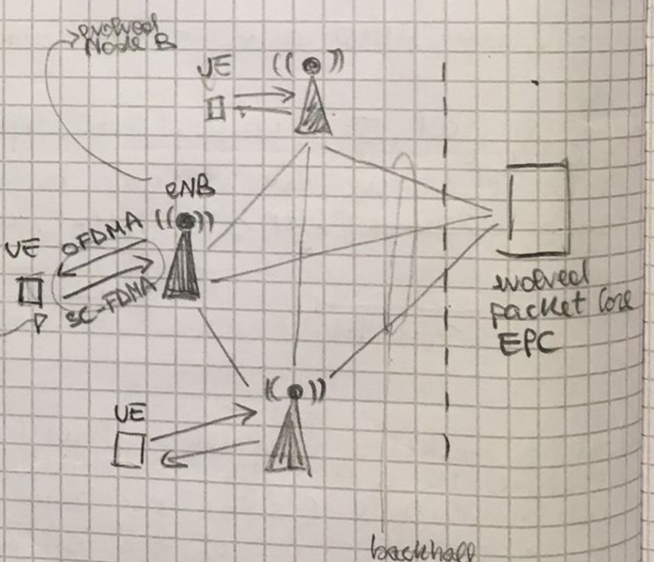
~~this is the most used~~

is the position in the spectrum where my bandwidth is centered

These carrier frequencies 800MHz and 18000 MHz are still used in 5G partially, but in the 5G we use higher carrier frequency and we have the availability of even larger bandwidths

So the fact that we have lower data rate depends on decreasing bandwidth B.

BASIS ARCHITECTURE OF LTE



The structure is based on a classical cellular network. So we have CELLS in correspondance of Base Stations called eNB, where NB was used in UMTS and "e" stands for evolved

Then there is the wireless interface and the mobile element is called USER EQUIPMENT UE

The BACKHALL is the interconnection between these eNB toward a central element EPC which is the CORE NETWORK
EPC is designed to transfer packets.

The difference is in how the wireless interface is managed
~~In the LTE big emphasys is given to~~, We want to improve data rate in the wireless interface, so we want also ~~to increase~~ that the backhall is able to support high ~~data~~ rate
So for example if I have an eNB which is connected to hundreds of UEs, we expect Mbits on wireless interface and Gbits on backhall, and this is quite challenging.

WHICH ARE MAIN FEATURES

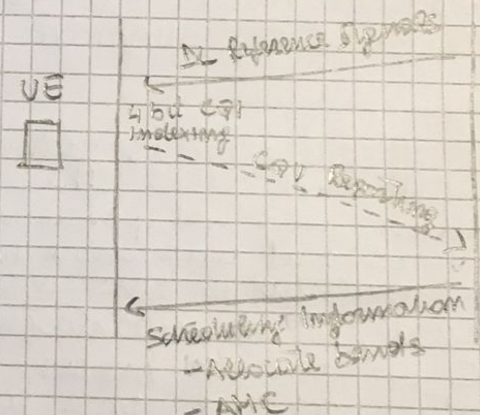
- Adaptive Modulation and Coding (AMC)
- Hybrid ARQ (HARQ)
- Spectrum ~~flexi~~ flexibility OFDMA and SC-FDMA
- MIMO Transmission

] LTE

ADAPTIVE MODULATION and CODING (AMC)

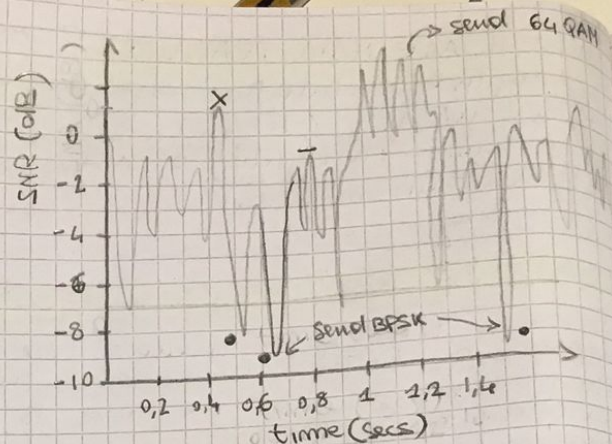
We know that if we increase the modulation scheme, we can achieve a better throughput and data rate.
The problem is that we have to adapt our modulation scheme to the channel conditions.
Channel conditions may have bit error rate (BER). So if I ~~...~~ transmit ~~in~~ a wireless communication I can have the path loss, the multi path, interference and so on and I have a certain BER.
How is this managed in the LTE?

If we have a bad BER we also ~~o~~ have to provide a coding that is the amount of extra information we provide in our data in order to be able to correct the data.
Which is the novelty here?
The novelty is the CHANNEL QUALITY INDICATOR (CQI) that is transmitted by the end user. The end user codifies in a channel that is a field of a packet of 4 bits ~~o~~ the CQI
So the quality of the channel ~~(...)~~ is measured and this is represented by 4 bits. So this means that we have 16 possible values of quality. And this quality is something measured by the user.



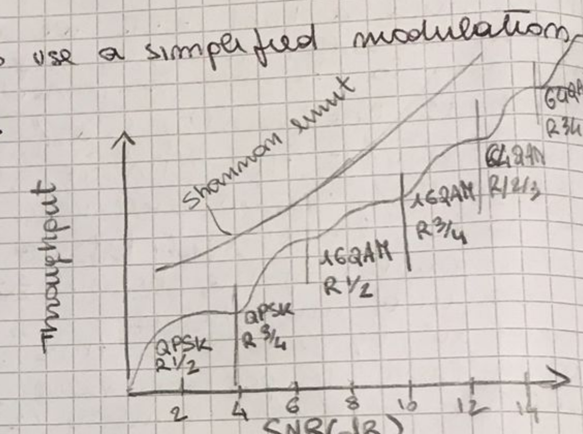
How does the system work~~s~~?
The eNB sends a Reference signal (a well known signal).
The UE measures the achieved quality ~~(...)~~, ~~...~~ it codifies the ~~...~~ quality in a channel quality indicator (CQI) and puts this ~~...~~ measurement in a packet and reports this information to the eNB
On the base of this information what the eNB does is to allocate the modulation (the way the signal will be modulated) in accordance to the current user condition.
Notice that this exchange happens frequently during the communication
This is novel for two reasons:
1) There is a sort of personalization of the modulation to the specific user. So this means that each of our smartphones crossing an area where is a base station receives a different data rate and different ~~data rate~~ modulation encoding depending on our channel condition.
2) This modulation encoding is done continuousely (it changes continuousely in time)

2) Modulation encoding changes continuously in time.
So we measure in time our channel condition, so we we have better condition ×
worse condition •
medium condition –
And depending on the conditions that we are measuring, we can use better modulation (64 QAM) (so we send more bits) or lower efficient modulation (BPSK)

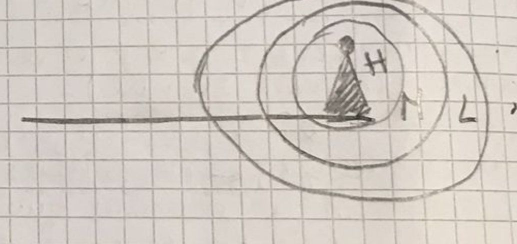


- The concept is: if I measure HIGH SNR I can push more bits in my modulation → M-QUAM with large M + high code rates and I can achieve better performances.
- If I measure LOW SNR I have to use a simplified modulation like BPSK + low code rates.
So we have different performances

The idea is try to follow (depending on the measure of SNR) with our modulation scheme the teoretical curve that is the one given by SHANNON LIMIT



Notice that the previous standards like GSM and UMTS the modulation was not personalized to the users, but was done in a way implemented in this way:
in the cell, in an area close to the BS we can use higher modulation scheme. In a larger area we use medium modulation scheme and in further area we use low one
So it was based on the area



HYBRID AUTOMATIC REPEAT REQUEST (HARQ)

What happens when there are errors packets received on UE or eNB?
We use HARQ

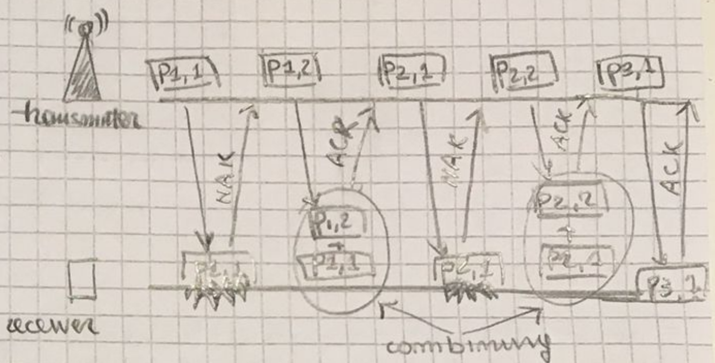
It is a combination of FEC and ARQ
- FEC: is a method correct some errors in our transmitted data
- ARQ: is a way to ask back again our information if the error cannot be corrected

So in general in all communication systems there is a combination of these two.

So on one end we want to ~~correct~~ recover errors with Forward error correction but this is not always possible because teoretically we would ~~have~~ put a lot of overhead to correct all possible errors.
On the other side we would like to use ARQ but it includes retransmission ~~of~~ and this ~~[illegible]~~ implies more time.
So we want a trade-off of the two

In a wireless system, where we want high data rate and high speed, we can't outplan a priori which is the best use of these two techniques. So the ~~[illegible]~~ HARQ exploits both.

- On a side it adapts the transmissions and FEC to the specific condition.
  So instead of give extra bits X in my data to correct the ~~[illegible]~~ data, the number of bits X is changed dinamically on the basis of what is measured as final performance.



- On the other, if a transmitter sends a packet and it arrives to the other side wrong, (so I have checked FEC and I have ~~[illegible]~~ understood that the packet is wrong), instead of descarg (scartare) the packet, ~~[illegible]~~ the system keeps the packet and sends back a feedback saying the packet was wrong.
  Once the transmitter retransmi~~[illegible]~~t the packet, the retrasmission is used to combine what was kept from previous transmission with a new one (SOFT COMBINED).
  The goal is that if I keep the bits of the previous one and the second one arrives, maybe this too could be wrong but maybe not in the same points, so I can combine the good points of both to obtain the original packet. (so I can recover the original pkt).
  In this way we do not waste the bandwidth ~~[illegible]~~ while we transmit.

- Another idea of HARQ is to split the bits to be transmitted in different packets. In this way, ~~without distribute the good~~ we do not lose the ~~[illegible]~~ whole information in one single packet.
  So we combine information of different packets in multiple packets.
  ~~and then we expect to~~

In LTE there are usually 8 parallel processes of retransmission 8 HARQ. So we split our information in 8 parallel branches and thanks to this we expect to be able to recover to this ~~[illegible]~~ soft combining to our original data.
This is novel because of the possibility with the current system to perform this process

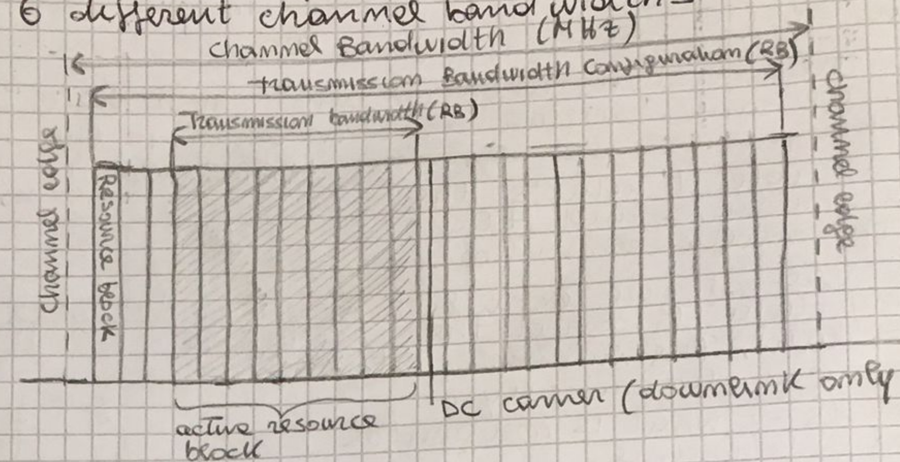
→

SPECTRUM FLEXIBILITY OFDMA and SC-FDMA

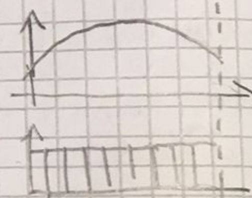
How the bandwidth is managed:

LTE physical layer supports any bandwidth from 1.4 to 20 MHz
In LTE we have 6 different channel bandwidths

MULTI-CARRIER MODULATION



These channel bandwidth are centred around central carrier. the idea is to divide the bandw. in subcarriers. Because in general the multi carrier transmission is more effective than the single carrier one. It is better because in this way we can do a sort of parallel transmission of our information and we can consider each of these subbands as behaving in an ideal manner → FLAT CHANNEL.
And that is not true if we use total bandwidth
So having the same occupation of the spectrum bandwidth, the multi carrier solution performs in a better way.
(This is called multi-carrier modulation)



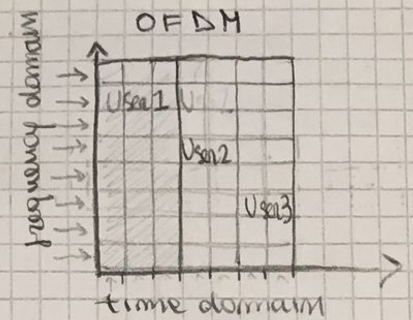
In particular, this is a Frequency division multiple Access FDMA.
So it is a frequency division as we saw above and it is multiple access because the difference from ADSL is that here we are transmitting considering different users transmitting to a base station. (Multiple access means that more users share resources and share by accessing them in a distributed way from different positions)

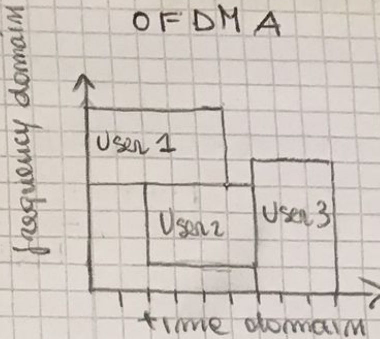
There are two different schemes of FDMA: SC-FDMA and OFDMA
- SC-FDMA: (single carrier) is used in Uplink
- OFDMA: (Orthogonal) in Downlink

↓

Differences between OFDMA and OFDM → Orthogonal single carrier

Differences between OFDMA and OFDM





We can consider our resources like a matrix. In this matrix we have two dimensions: one is time and the other is the frequency.
Let's look at the frequency:

In OFDM: in the freq. domain we have different subcarriers (N) ⇒ and in time different slots.
The combination of the two allows us to identify an ~~ab~~ element called RESOURCE BLOCK that is a specific time slot and a specific subcarrier.
So users transmit in all subcarriers and they can transmit ~~one~~ in one or more consecutive time slots.
In this case a user may obtain a portion of the bandwidth that may be different from another user.
So the bandwidth can be splitted in a different manner for different users. This means that instead of designing our system in order to leave the same data rate to all the users, ~~so~~ users can ask the system for different data rate because of their services.
~~And this can~~ (So it allocates users just in time domain)

In OFDMA: We have more flexibility. In fact we can use the same spectrum in the same time slot by different users.
It allocates users in time and frequency domain

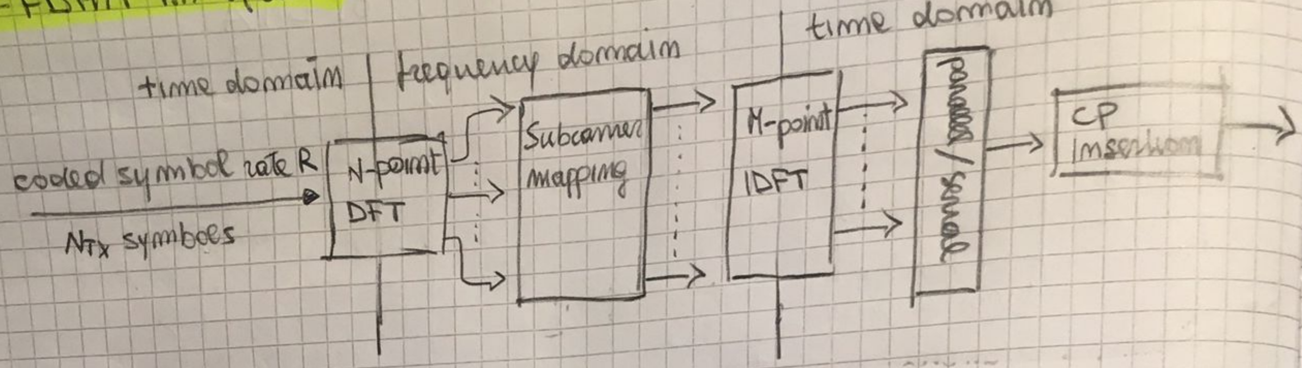
RESOURCE ALLOCATION
How is this implemented? in a more complex way

SLIDE

time slots in 0,5 ms
time slots are ~~organized in subframes of 0.1 ms~~

There is the separation ~~between up and downlink~~

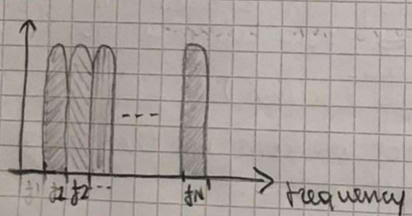
SC-FDMA in Uplink



we build up this symbol (the transmission of bits in different subcarriers (N)) by using a well-known processing mechanism that is DFT (Discrete Fourier Transform). So DFT are used to provide the symbols that is the set of bits that are spelled in the different subcarriers
Thanks to the possibility to implement DFT and IDTF on a chip in a very fast way to provide the symbol and the mapping of the bits on the subcarriers.
This is a novel technological aspect.

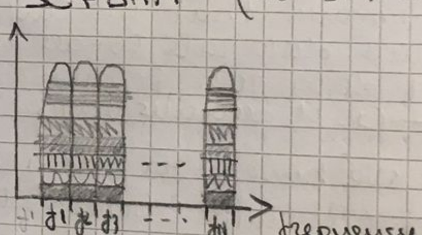
OFDMA VS SC-FDMA

OFDMA

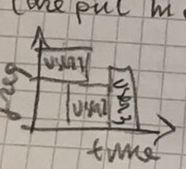


SC-FDMA (or DFT-S OFDM)

single carrier



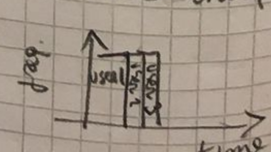
In the downlink we use the more complicated solution because the downlink is prepared by the base station.
So for the bs is easy to prepare a symbol, a composition of the bandwidth in this way, because is the bs itself that puts informations there (are put in a centralized manner)



NB the fact that one is used in centralized and the other in distributed is the reason why we use these two different schemes in the two directions.

I divide my spectrum in subcarriers but the subcarriers are used by the same user represented by a color
This is single carrier because the effect of modulation that is based on the multicarrier, at the end results in a modulation where a user occupies the whole spectrum slot by slot.
So in a slot the user occupies the whole spectrum. (And this is why it is called single carrier
This scheme is used for the uplink because in the uplink is easy to see to indicate to a user that for a certain number of slots he can occupy the whole spectrum with the OFDM symbol and when it accesses the spectrum it is alone

Informations are put in the system in a distributed manner

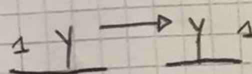


MIMO TRANSMISSION

MIMO = multiple input multiple output

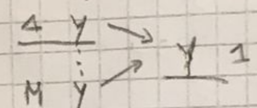
There are different configurations in the wireless communication

SISO
Single input, single output



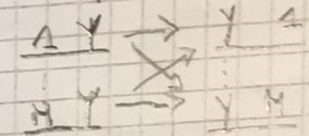
a transmitting antenna on a side and a receiving one on the other

MISO
multiple input single output



multiple transmitting one receiving

MIMO
multiple input multiple output

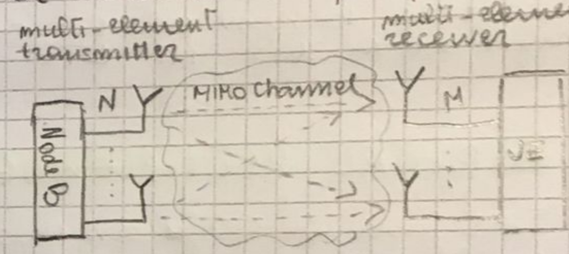


multiple transmitting and receiving

More powerful. We can improve our capacity

LTE requires high data rate, and this can be obtained only by MIMO

What are the possibilities of using MIMO:



- TRANSMIT DIVERSITY (TxD)

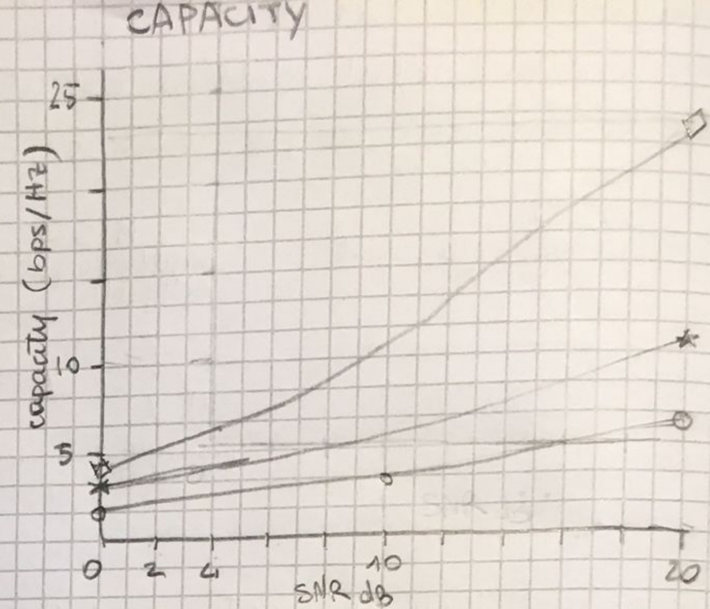
we have multiple antennas in the eNB and there are multiple antennas in the receiving side. This means the UE (like the smartphone) has in the system not only ~~~~ 1 antenna like in the past technologies, but multiple antennas.
Notice that those antennas are in a small object. So the technology channel was to put multiple antennas in a small object.
~~So this means that the smartphone needs more energy to work.~~
Transmit diversity means that the signal (that we tipically transmit with only 1 antenna toward 1 antenna) is transmitted by multiple antennas and it arrives also to multiple antennas.
It is called transm. div. because we transmit the ~~~~ replica of the same signal on different paths.
This can be advantagious because if we are able to combine in a positive manner the different signals, we are able to sum up their power and achieve a higher signal to noise ratio SNR
To do this we ~~~~ module the channel, so the challenge here

If I receive a direct path and a path that is not direct, I need to understand which is the delay of the ~~previous pa~~ second path with respect to the previous one to sincronize the data that arrives.
So this is represented by a matrix (channel matrix H). So the channel is represented by paths that ~~~~ vary in time and in the dimension.
This channel matrix is estimated (we have to model it). ~~to have~~
Then we are able to combine and process at the destination the signals and we are able to improve the performances.

- classical one-to-one
  $M_T = 1$ $M_R = 1$ O

- 2-to-2
  $M_T = 2$ $M_R = 2$ ★
  In this way I can improve much more

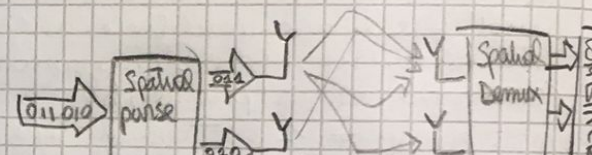
- 4-to-4
  $M_T = 4$ $M_R = 4$ ◇
  We have big increment in performance
  (so having the same SNR, I can boost my capacity of a big amount).



And this is how we can achieve high data rate in LTE

- STPATIAL MULTIPLEXING (SM)

This time we split our information in M parts and a part is transmitted on an antenna and the other on the other antenna.



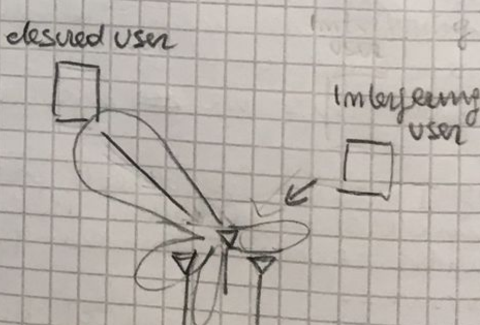
This time we do not have DIVERSITY GAIN but we parallelize our transmission

The system has a performance that depends on how efficient are the two separated transmission (011 and 010 in this example)

In Spatial multiplexing we can also have also multiple paths. So we need some capacity to manage the multiple path

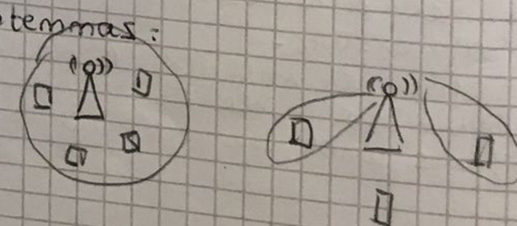
- BEAMFORMING (→ fascio, raggio)

What is beamforming? By operating with the transmission parameters instead of transmitting our information in a omnidirectional way, we transmit our information in a BEAM shape.



So we can provide a specific shape of the beam where our signal is spread.

So in general there are two kinds of antennas:
omnidirectional one where there is an antenna transmitting everywhere
or ~~an~~ antenna that transmit in a beam shape and the beam can be directed toward a specific user

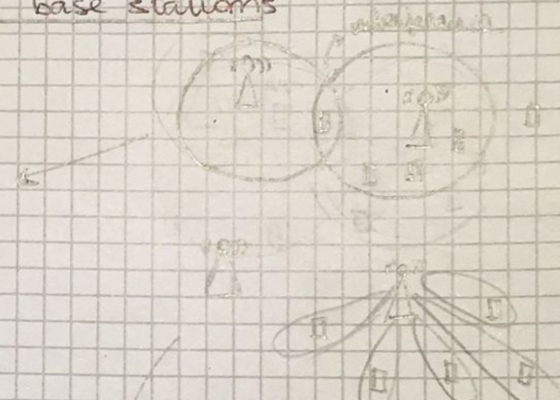


If I form a beam toward a direction I concentrate the power that I want to spend in a transmission toward a certain direction.
The result is that I have more power toward the users and I do not waste power where the user is not present. So this is another way to improve SNR

IN LTE-A the beam forming can be used in a better way.
Instead of providing data rates $\begin{cases} 300 \text{ Mbps DL} \\ 75 \text{ Mbps UL} \end{cases}$ we can provide much higher data rates $\begin{cases} 1 \text{ Gbps DL} \\ 500 \text{ Mbps UL} \end{cases}$ for different reasons:

- we can use in a better way the spectrum, because we can use larger bandwidths, they exploit much more the MIMO configuration and they provide a cooperation of base stations

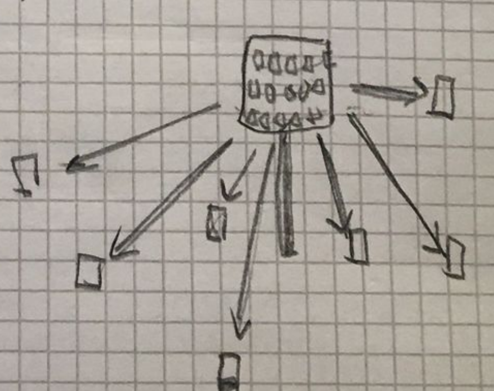
CARRIER AGGREGATION



Let consider the classical system.
The problem is that cells are close one to the other and it may happen that a user that is at the border of two multiple cells, receives the signal of two cells. If these signals are transmitted in the same frequency band, there is an interference of the two cells.

Why the beam forming is advantageous in this case? because I can concentrate the power toward my users. And if there is a cooperation of the two base stations, if one concentrate the power toward a user, the other may avoid to concentrate the power to that user, avoiding interference.
So I can provide a higher coverage to the set of users that I have in my area.
The novelty is the COORDINATION PROTOCOL between base stations to improve capacity in the system.
The complexity in the technology is to form the beam, it requires multiple antennas and processing capabilities that are not available in the previous technologies.
Remember that is important to grant mobility for users. This means that this beamforming must be DYNAMICALLY ADAPTED.
The adaptation of the beam forming is complicate because passes through the dynamic modelling of the matrix H using machine learning techniques to derive parameters.

MASSIVE MIMO



the base station has not only 4 antennas configured dynamically toward the users but are hundreds of antennas (mini-antennas) at the base station
And this matrix of antennas is used to provide the coverage of much more users.
This changes the concept of cellular network because the cell is not any more the area, but each specific beam becomes a cell.
We can consider that these antennas are computing servers. In some architectures the computing is done in the CLOUD or in the EDGE.