LTE

Long Term Evolution or LTE or 4G networks is the most sought after technology in the telecommunications domain now-a-days. The reason being simple enough from a user's perspective : Very high peak data rates (upto 299.6 Mbit/s in downlink and up kto 75.4 Mbit/s in uplink with 4X4 MIMO antennae, using 20 MHz spectrum). Rest of the capabilities like improved mobility (Huawei demo'ed LTE communications while traveling up to 268 miles per hour (431 km/h) on the Shanghai Maglev Train), higher number of simultaneous active data clients, support for both FDD and TDD, improved spectrum usage , simplified network architecture, less data transfer latency, support for different cell sizes (varying from a few metres to 100km radius), all IP based network, varied spectrum support (1.4 MHz, 3 MHz, 5 MHz, 10 MHz, 15 MHz and 20 MHz) etc etc, probably concerns to people who are more interested in slicing up the technology to know it better.

So lets start briefly with what has been changed from UMTS to LTE that has caused these data rates achievable.

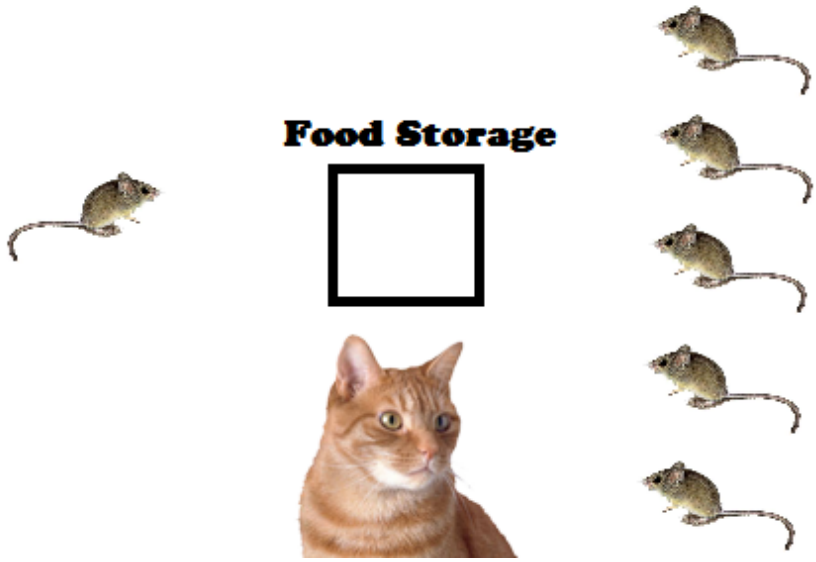
There are three major changes in LTE which are responsible for such high data rates :

1. OFDM-OFDMA-SCFDMA
2. MIMO
3. SAE

OFDM or Orthogonal Frequency Division Multiplexing

The basic idea of OFDM is to use a large number of parallel narrow-band subcarriers instead of a single wide-band carrier to transport information over the network.

OFDM can be explained in a very simple and effective way using this example:

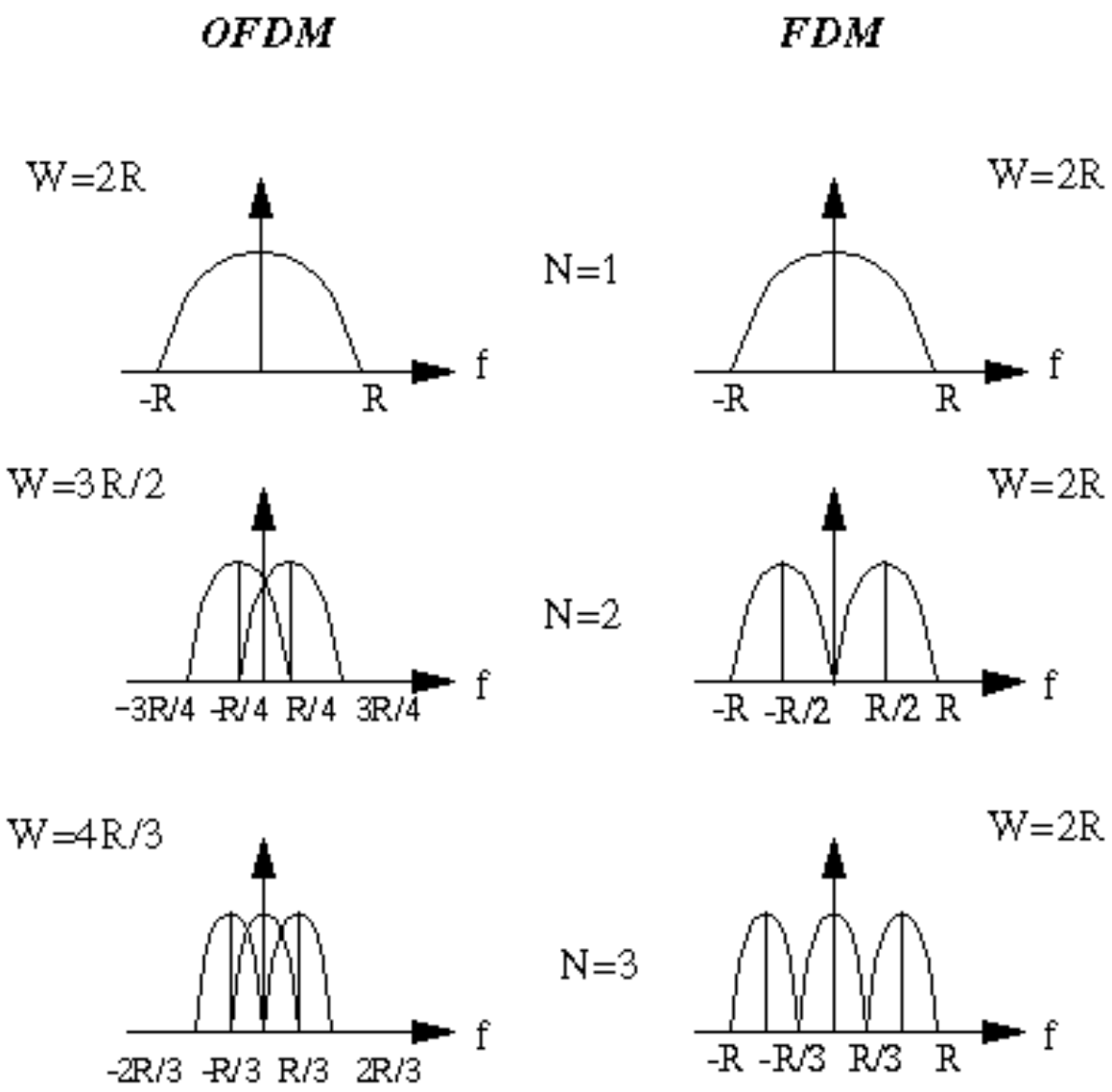


[http://4.bp.blogspot.com/-xdFmK5odb9U/T0d5QPHvznI/AAAAAAAAAI0/S5FrgakE3uo/s1600/Mouse.png]

Suppose a mouse was given a task to collect X foodgrains from somewhere and store it into secret Mouse Food Storage. Similar task can be given to five other mice and the amount of foodgrains was divided among them . So each mouse among the five of them would have to carry X/5 amount of foodgrains and store it to food storage. The storage of food grains is extremely critical as the King of the mice is in desperate need of it.
But something mishap occurs in between , a cat comes in the way. The mouse with all X food grains is caught by the cat and the King of the mice dies. But consider the case when five mice are assigned the same task , the probability of losing all the food grains is much less since the cat would be able to catch only one mouse at a time. In the meanwhile 4X/5 food grains are still delivered to the store.

Now talking in more technical terms OFDM uses closely spaced orthogonal sub-carriers to carry the data. These sub-carriers even being closely spaced, do not interfere with each other. Fast Fourier Transform is used to design and separate these sub-carriers.

Advantage of OFDM over FDM



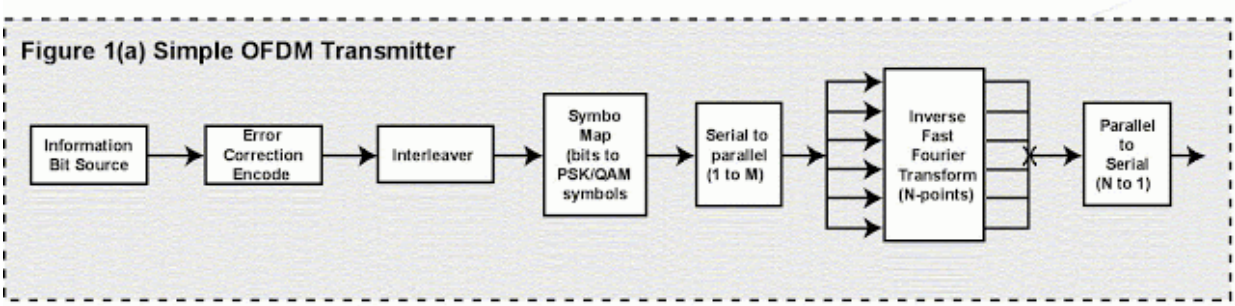
[http://4.bp.blogspot.com/-h_QTMB75T60/T0yXoXYDquI/AAAAAAAAERQ/etgHnjP-PXA/s1600/O_FDM.gif]

Image courtesy : http://www.tml.tkk.fi [http://www.tml.tkk.fi/]

1. The image above shows one of the advantages of OFDM over FDM (Frequency Division Multiplexing). The bandwidth needed for OFDM is less than FDM in case the number of carriers increase in the same spectrum. The reason of being able to use less bandwidth for more carriers is that the carriers can overlap each other orthogonally (90 degrees/perpendicular). Inverse fast fourier transform(IFFT) is used to encode a OFDM frame and Fast Fourier Transform (FFT) can be used to decode the frame at the receiving end.

2. Flat fading per carrier.
3. Inter Symbol Interference is shorter due to use of cyclic prefix.
4. No inter-carrier guard bands , so improved spectral efficiency (Nyquist rate).
5. Can easily adapt to severe channel conditions without complex equalization.
6. OFDM can be used for high-speed multimedia applications with lower service cost.
7. It is possible to significantly enhance the capacity by adapting the data rate per sub-carrier according to SNR of that particular sub-carrier.
8. Smart antennas can be integrated with OFDM. MIMO systems and space-time coding can be realized on OFDM and all the benefits of MIMO systems can be obtained easily. Adaptive modulation and tone/power allocation are also realizable on OFDM.

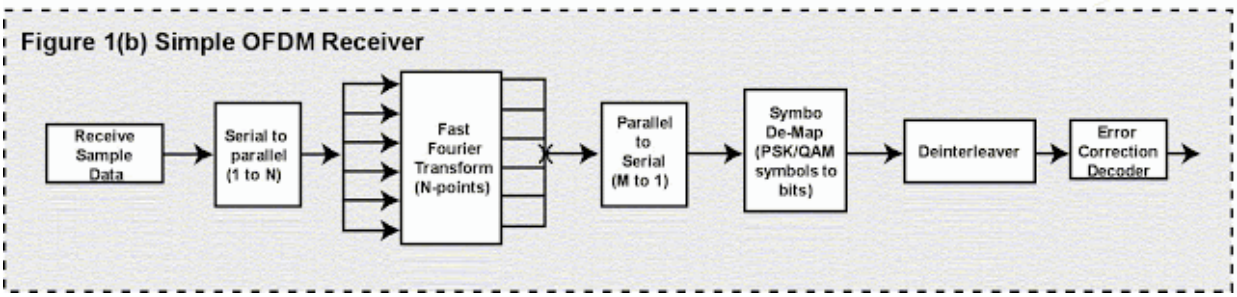
We will provide a block diagram of how the transmitter and receiver work in OFDM.



[http://3.bp.blogspot.com/-DgsTDDAk5P8/T0ygzCV7ayI/AAAAAAAAERY/lfTV6nGwTTE/s1600/ofdmxmt.gif]

Image courtesy : http://www.eetimes.com [http://www.eetimes.com/]

The OFDM transmitter converts the serial bit stream into a parallel stream of size M. These M sub-streams are then modulated into M sub-carriers using the IFFT mechanism. The parallel sub-carriers are again serialized and transmitted.



[http://2.bp.blogspot.com/-rk_xTH_AprQ/T0yg1Z8tUZI/AAAAAAAAERg/dwvJVPcZLzQ/s1600/ofdmrcv.gif]

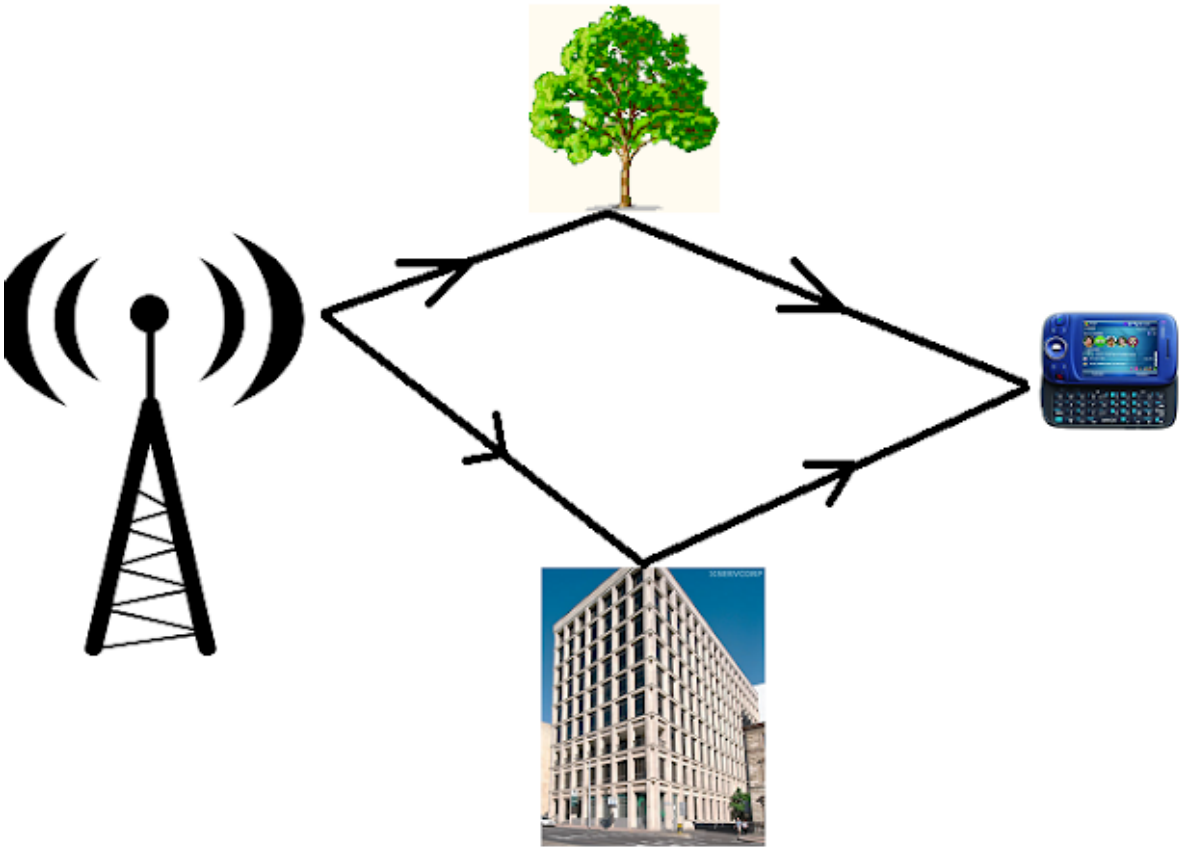
Image courtesy : http://www.eetimes.com [http://www.eetimes.com/]

At the receiver end , there is serial-to-parallel conversion and FFT is applied on the resulting

parallel sub-carriers to fetch the data.

How OFDM deals with Multipath fading

Multipath fading is an effect in the terrestrial telecommunications system where a signal is transmitted from one end and gets reflected following different paths to the receiver (Fig. 1). The overall signal received is the sum of all the signals appearing at the antenna of the receiver. The effects can be anything ranging from getting a very strong signal due to addition of same phased signals to an interfered signal due to out of phase reception of the same signal along different paths. Some times even the data may get corrupted due to inter-symbol interference (ISI) in case digital transmission.

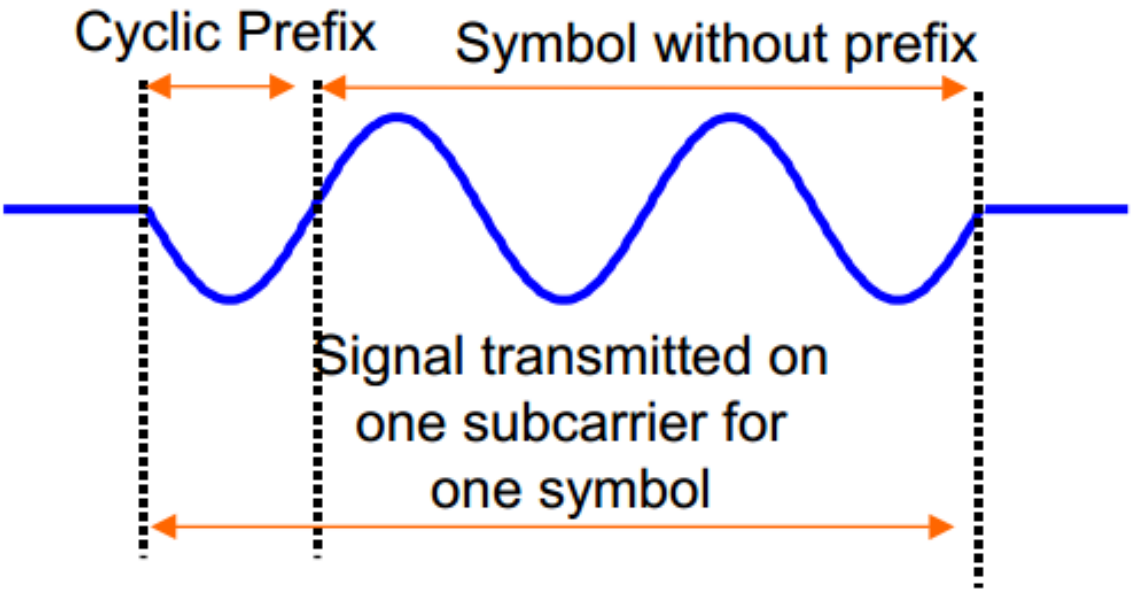


[http://2.bp.blogspot.com/-yrwNCBowcO0/T0y866SYp8I/AAAAAAAAESA/Zq_FD3P9F1I/s1600/multipath.png]

Fig. 1. Multipath Effect

OFDM uses cyclic prefix in order to deal with multipath fading. The intersymbolic interference is almost completely eliminated by introducing a guard time for a each OFDM symbol. The guard time is chosen larger than the expected delay spread such that multipath components from one symbol cannot interfere with the next symbol. This guard time could be no signal at all but the problem of inter carrier interference (ICI) would arise. Then, the OFDM symbol is cyclically extended in the guard time. Using this method, the delay replicas of the OFDM

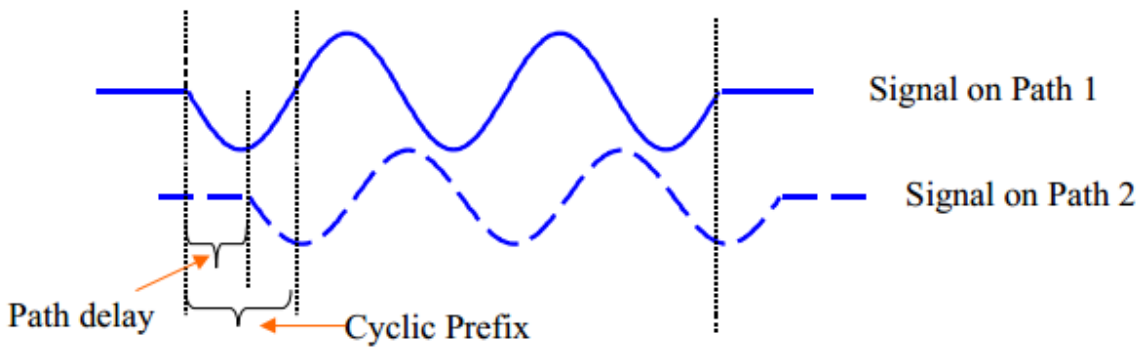
symbol always have an integer number of cycles within the FFT interval, as long as the delay is smaller than the guard time. Multipath signals with delays smaller than the guard time cannot cause ICI. If multipath delay exceeds the guard time by a small fraction of the FFT interval (for example 3%), the subcarriers are not orthogonal anymore, but the interference is still small enough to get a reasonable constellation. There may be some loss in efficiency since no new information is present in the prefix.



[http://4.bp.blogspot.com/-iR73690QC9w/T0y7vy7qfeI/AAAAAAAAERw/t-zOOdz3csM/s1600/cp1.png]

Fig. 2. Addition of cyclic prefix (CP) in a signal(Courtesy: http://www.ctie.monash.edu.au/ [http://www.ctie.monash.edu.au/])

If the multipath delay is less than the CP, then no ISI or ICI is observed, though the amplitude of the signal may increase or decrease based on the phase.

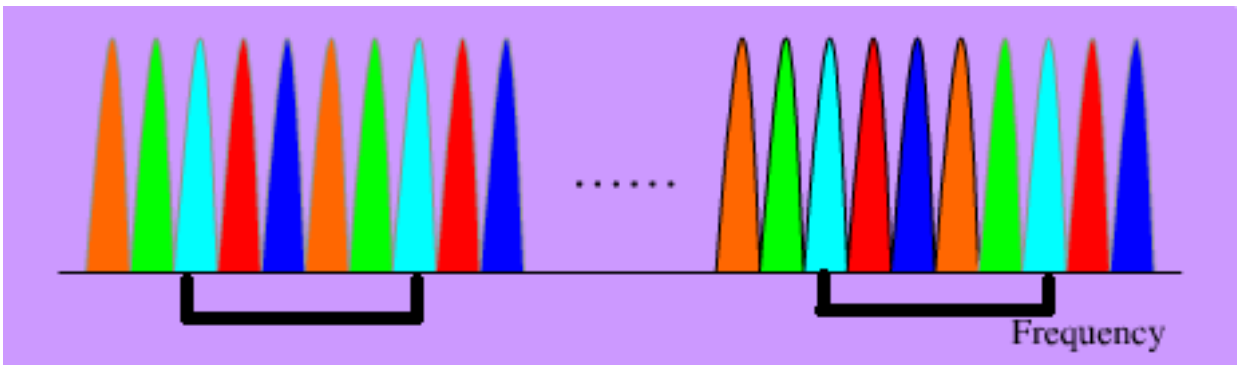


[http://1.bp.blogspot.com/-NiO3l0N5rAA/T0y7yzaZF8I/AAAAAAAAER4/gmIAKCEUOkQ/s1600/cp2.png]

Fig. 3. A signal with CP on multiple paths(Courtesy: http://www.ctie.monash.edu.au/ [http://www.ctie.monash.edu.au/]).

OFDMA

Orthogonal Frequency Division Multiplexing Access is an access technology as compared to OFDM which is a modulation technique. When OFDM is combined with multiple access , it gives rise to a new multiple access technology which employs multiple sets of multiple sub-carriers to form a sub-channel.



[http://4.bp.blogspot.com/-423-QqEtKt8/T03QqWyglrI/AAAAAAAAESQ/nBq_RoXnWiA/s1600/ofdma.png]

Here the sub-carriers of same color form a sub-channel. OFDMA multiplexes the data streams from multiple users onto the down-link sub-channels and uplink multiple access by means of uplink sub-channels. The multiple access is achieved by assigning different OFDM sub - channels to different users.

Here is a representation of OFDMA sub-carrier structure :

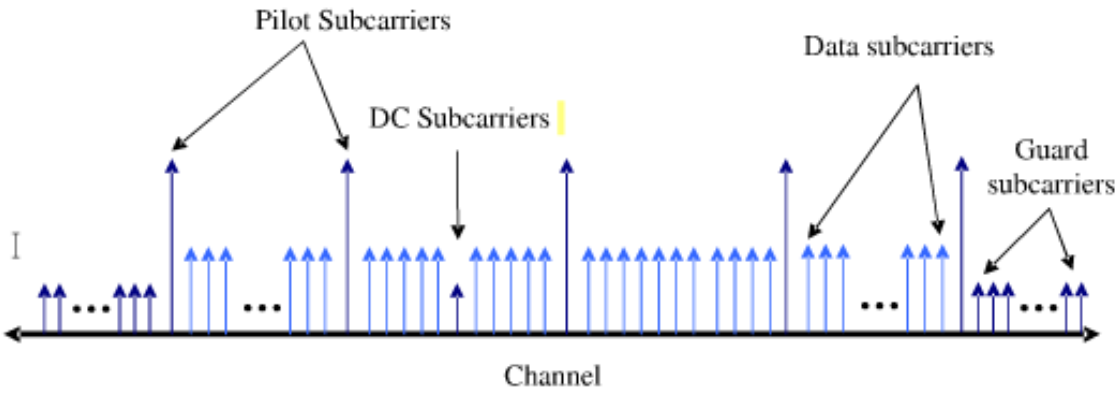


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Fig. 4. OFDMA symbol structure

OFDMA symbol consists of sub-channels that carry data sub-carriers carrying information, pilot sub-carriers as reference frequencies and for various estimation purposes, DC sub-

carrier as the center frequency, and guard bands for keeping the space between OFDMA signals.

Like every technology has some disadvantages too , OFDM has also got some problems:

1. OFDMA is highly sensitive to time and frequency synchronization errors.
2. An OFDM system with large number of sub-carriers will have a very large Peak Average Power Ratio(PAPR). Large PAPR of a system makes the implementation of Digital-to-Analog Converter (DAC) and Analog-to-Digital Converter (ADC) to be extremely difficult.

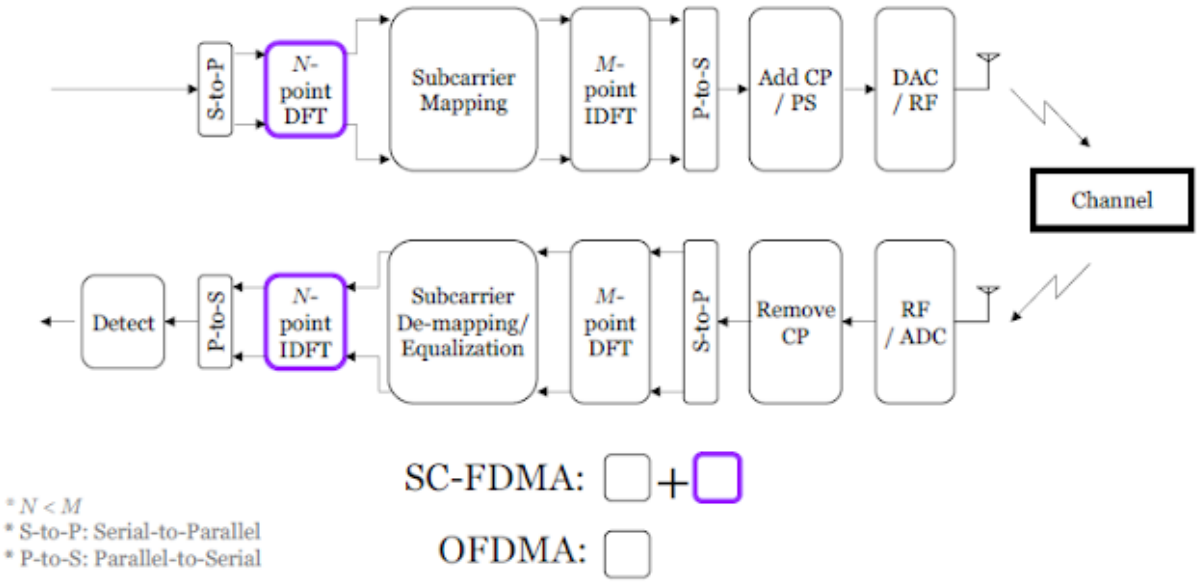
SCFDMA

LTE uses Single-Carrier FDMA with cyclic prefix technique for uplink transmissions. The reason for using SCFDMA is due to following reasons:

1. SCFDMA delivers performance similar to OFDM with essentially the same overall complexity, even for long channel delay.
2. It generates low PAPR.
3. It is more robust to spectral null situations.
4. SCFDMA has less sensitivity to carrier frequency offset.

Lets discuss more about SCFDMA. SCFDMA utilizes single carrier modulation, DFT-spread orthogonal
frequency multiplexing, and frequency domain equalization.

Following is TX/RX structure for SCFDMA



[http://4.bp.blogspot.com/-GzgcIdOWjNU/T03oDM7vcMI/AAAAAAAAESg/eMl6Z1WxW8I/s1600/scfdmatxrx.png]

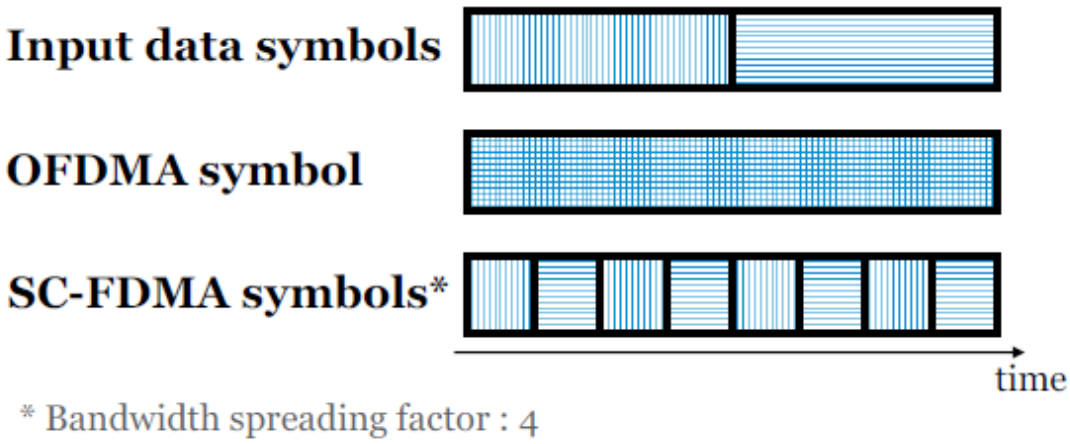
Fig. 5. TX/RX for SCFDMA(Courtesy: https://sites.google.com/site/hgmyung/scfdma [https://sites.google.com/site/hgmyung/scfdma])

Here the data stream is converted from serial to parallel and then N-point Discrete Fourier Transform(DFT) is applied to the resulting parallel sub carriers. After the sub-carriers mapping, M-point Inverse DFT is applied and the stream is converted to serial again. After that cyclic prefix is added to the resulting stream and it is transmitted onto the radio interface.

At the receiver side cyclic prefix is removed , stream is converted to parallel, DFT is applied to it , equalization or de-mapping is done and finally N-point IDFT is performed and data stream is converted back to serial stream.

Difference between OFDMA and SCFDMA

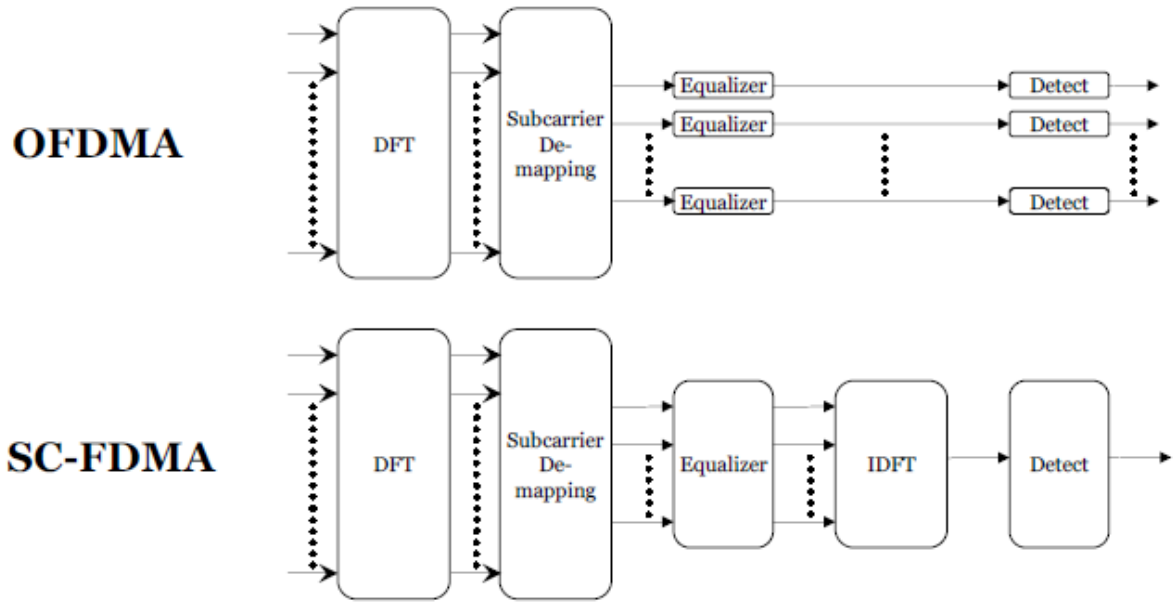
1. Difference in time domain



[http://3.bp.blogspot.com/-1G2l1LIAjVQ/T03q5hy-LeI/AAAAAAAAESo/sa0er-1qeLU/s1600/scfdmatd.png]

Fig.6. SCFDMA and OFDMA in time domain(Courtesy: https://sites.google.com/site/hgmyung/scfdma [https://sites.google.com/site/hgmyung/scfdma])

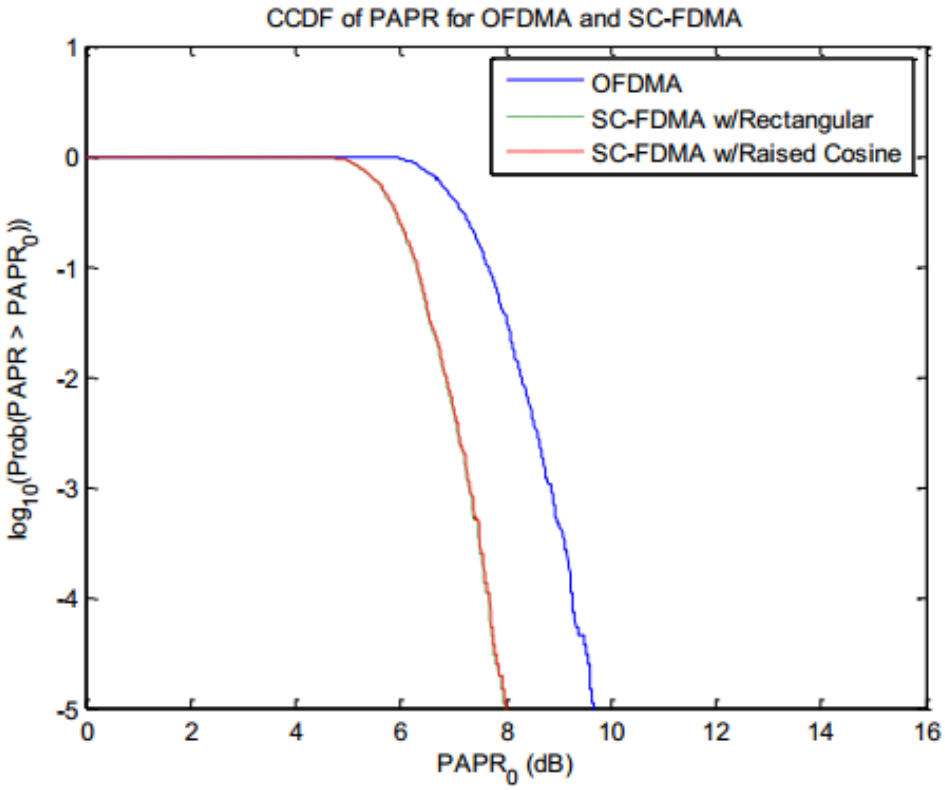
2. Difference in equalization/detection aspect



[http://4.bp.blogspot.com/-tf8mmbJlMBw/T03rfW-WjHI/AAAAAAAAESw/7glnMP4BaNY/s1600/scfdmaeq.png]

Fig. 7. Difference in detection/equalization methods(Courtesy: https://sites.google.com/site/hgmyung/scfdma [https://sites.google.com/site/hgmyung/scfdma])

3. In SCFDMA PAPRs achieve lower values on average, mainly due to the fact that they map their input bits to time symbols, as opposed to OFDM and OFDMA which map them directly to frequency symbols.



[http://1.bp.blogspot.com/-B-KmQWe39wg/T03uMOWZXsI/AAAAAAAAES4/4rNznyvahMo/s1600/scfdmapapr.png]

Fig. 8. PAPR comparison of OFDMA and SC-FDMA

We will come back to MIMO and SAE very soon.....