IEE2650: Cellular Communication Technologies

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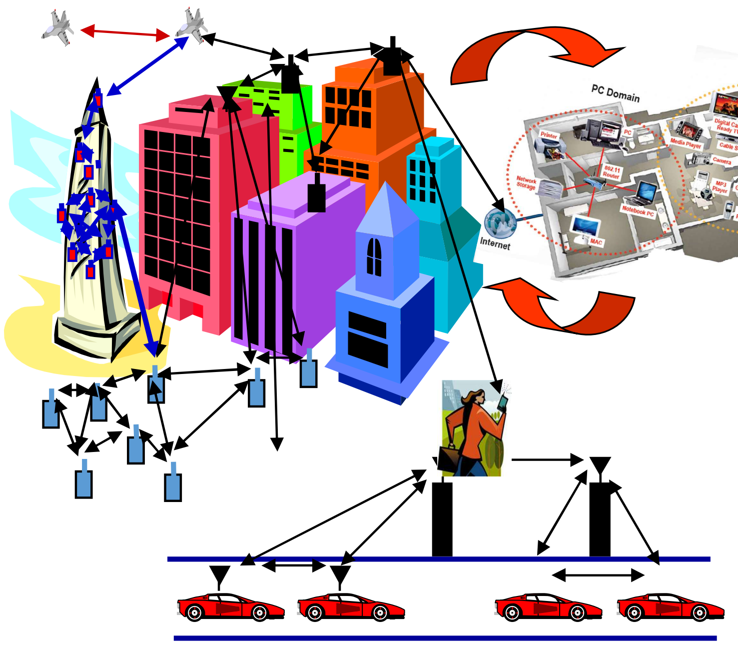
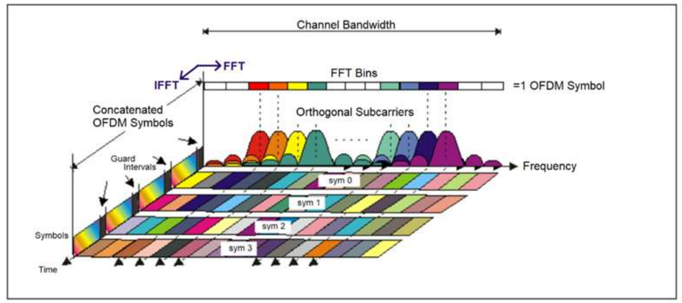
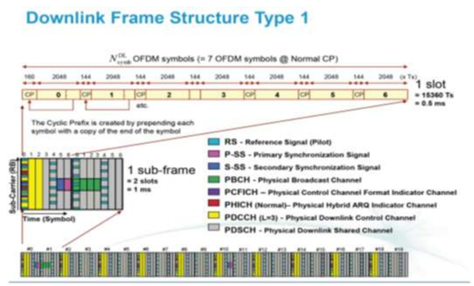
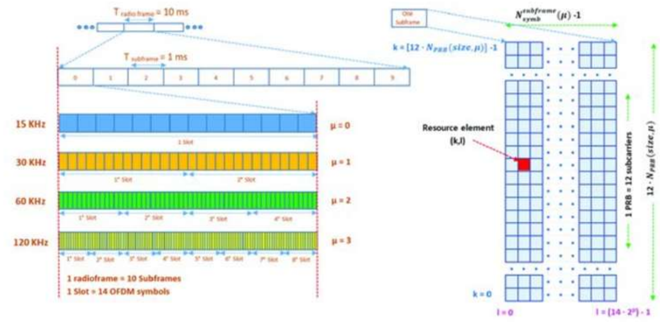




Frequency-Time Representative of an OFDM signal





Outline

- Brief follow-up from last lecture
- Radio Access Techniques
  - Multiple Access (MA) Methods
    - FDMA
    - TDMA
    - CDMA
- Orthogonal Frequency Division Multiplexing (OFDM) Based Multiple Access (OFDMA)
  - Orthogonality Principle
  - OFDM
  - OFDM-FDMA
  - MC/SC-FDMA
- Comparisons
- Summary

Wireless Channel Characteristics (1/4)

- When the signal is transmitted over the wireless channel, it encounters four main effects:
  - Attenuation
  - Delay
  - Multipath
  - Doppler Effect (if there is any relative motion between transmitter and receiver).

Wireless Channel Characteristics (2/4)

- Attenuation and Delay
  - Due to the unavoidable physical disturbances, these effects are present in almost every wireless system. This may be rain drops, trees etc. The electromagnetic waves travel through the atmosphere and they loose energy and take some time to reach the receiver.
  - For example, in case of rain drops, the waves collide with the rain drops, heat them up and loose a part of energy.

Wireless Channel Characteristics (3/4)

- Multipath phenomena
  - Due to various scatters and obstacles, the transmitted signal reaches the receiver in one or more versions.
  - Each version with a different time delay. These different versions form the composite signal at the receiver which may vary in amplitude and phase.

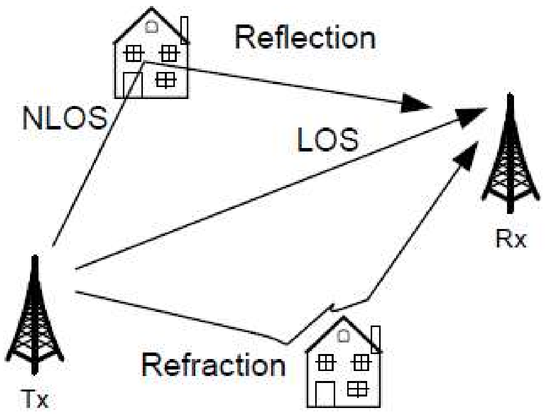


Illustration of multipath propagation. NLOS means non-line of sight and LOS is simply line of sight.

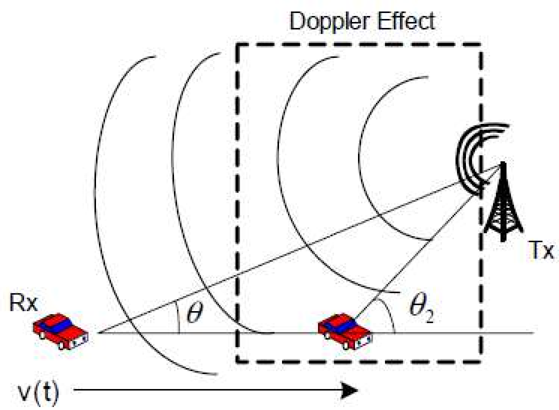
Wireless Channel Characteristics (3/4)

- Doppler Effect
  - This effect occurs when there is a relative motion between the transmitter and the receiver.
  - Due to this effect, there is a phase change in the received signal and hence the shift in frequency. This shift in frequency, also known as the Doppler shift is [Rappaport, 1996]:

$$f_d = (v/\lambda)\dot{c}os\theta$$

  - where fd is the Doppler shift, v is the velocity at which transmitter or receiver is moving, λ is the wavelength and is the angle of arrival of the received signal with respect to the direction of motion.
  - The illustration of the Doppler effect can be

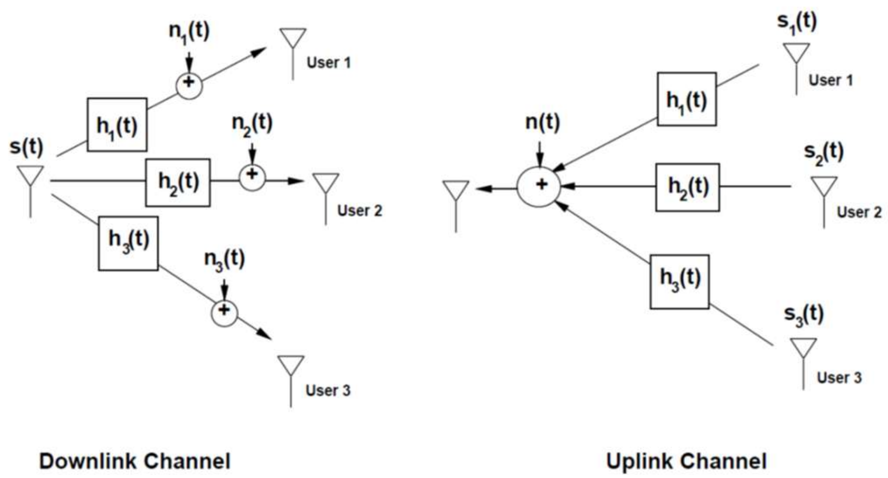
seen in the Figure.



Radio Access Methods and Techniques

Fundamentals

- In multiuser systems the system resources must be divided among multiple users
- A multiuser channel refers to any channel that must be shared among multiple users. There are two different types of multiuser channels:
  - The uplink channel
  - The downlink channel



What is Multiple Access?

- Efficient allocation of signaling dimensions between users is a key design aspect of both uplink and downlink channels, since bandwidth is usually scarce and/or very expensive. When dedicated channels are allocated to users it is often called multiple access. Multiple access techniques divide up the total signaling dimensions into channels and then assign these channels to different users. The most common methods to divide up the signal space are along the time, frequency, and/or code axes.
- Radio resource are limited
  - Limited Bandwidth
  - Limited number of channels
- The radio resource must be shared among multiple users
- Multiple Access Control (MAC) needed
  - Contention-based
  - Non-contention-based

Contention-based Multiple Access(MA)

- Contention-based
  - Each terminal transmits in a decentralized way
  - No central controller (Base stations or access points)
  - Example:
    - ALOHA
    - Carrier Sensing Multiple Access (CSMA)

  Standard:
  - GSM [I] uses the slotted ALOHA in the terminal's initial access process
  - IEEE 802.11 uses CSMA/CA based contention access scheme

Non-channelization Contention-based MA

- Terminals transmit sequentially using the same channel
- Example:
  - Polling based medium access
- Standard:
  - IEEE 802.15(WPAN)
  - IEEE 802.11(WLAN)

Non-contention-based Multiple Access (MA)

- A logic controller (BS or AP) is needed to coordinate the transmissions of all the terminals
- The controller informs each device when and on which channel it can transmit
- Collisions can be avoided entirely
- Two Subdivisions
  1. **Non-channelization**
  2. **Channelization**

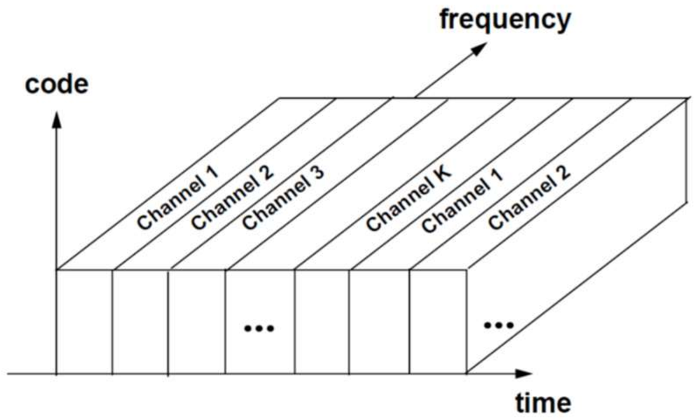
Channelization

Non-contention-based MA

- Terminals transmit simultaneously using different channels
- Most commonly used protocols in cellular systems
- Example:
  - 1. Time Division Multiple Access (TDMA)
  - 2. Code Division Multiple Access (CDMA)
  - 3. Frequency Division Multiple Access (FDMA)
- Time-division multiple access (TDMA) and frequency-division multiple access (FDMA) are orthogonal channelization methods whereas code-division multiple access (CDMA) can be orthogonal or non-orthogonal, depending on the code design

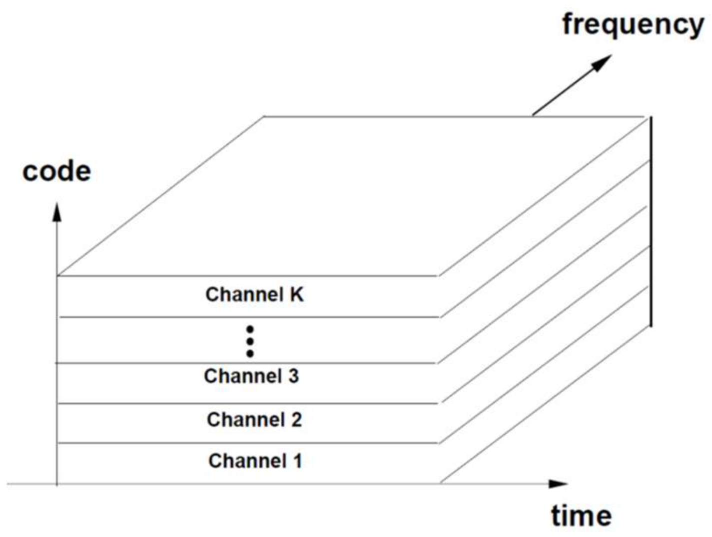
Time Division Multiple Access (TDMA)

- In TDMA the system dimensions are divided along the time axis into non-over lapping channels, and each user is assigned a different cyclically-repeating timeslot, as shown in Figure
- These TDMA channels occupy the entire system bandwidth, which is typically wideband, so some form of ISI mitigation is required. The cyclically repeating timeslots imply that transmission is not continuous for any user. Therefore, digital transmission techniques which allow for buffering are required
- Global System for Mobile Communication (GSM)
- (Some Specs.)
    - Time slot 0.577 ms
    - Frame 4.6 ms
    - 8 time slots per frame
    - Frequency band 20 KHz



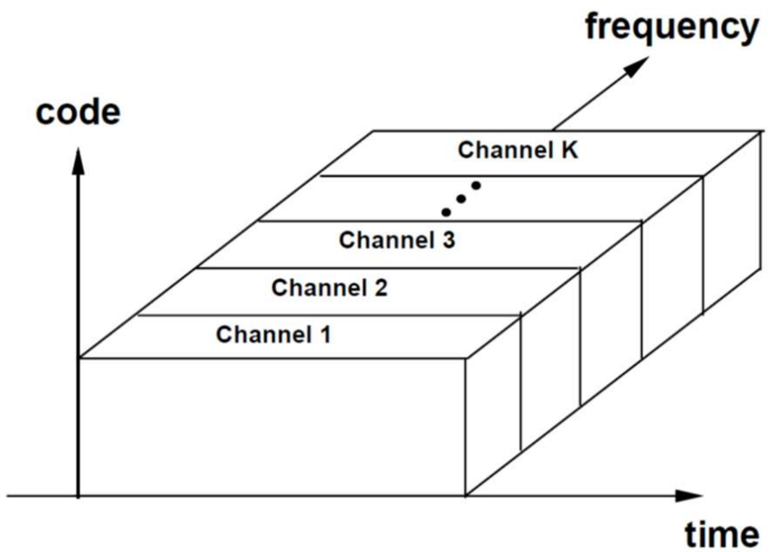
Code Division Multiple Access (CDMA)

- In CDMA the information signals of different users are modulated by orthogonal or non-orthogonal spreading codes. The resulting spread signals simultaneously occupy the same time and bandwidth, as shown in Figure below.
- The receiver uses the spreading code structure to separate out the different users. The most common form of CDMA is multiuser spread spectrum with either direct sequence (DS) or frequency hopping (FH)
- IS-95 (Some Specs.)
  - Orthogonal Walsh codes
  - 64 codes (channels)
  - One pilot channel
  - Seven paging channels
  - 55 traffic channels
  - Each carrier 1.25 MHz



Frequency Division Multiple Access (FDMA)

- In FDMA the system signaling dimensions are divided along the frequency axis into "non-overlapping channels", and each user is assigned a different frequency channel, as shown in Figure below.
- The channels often have guard bands between them to compensate for imperfect filters, adjacent channel interference, and spectral spreading due to Doppler.
- Multiple access in OFDM systems, called OFDMA, implements FDMA by assigning different subcarriers to different users.
- Some Specs.
  - Total Bandwidth 25 MHz
  - Each Channel 30 KHz



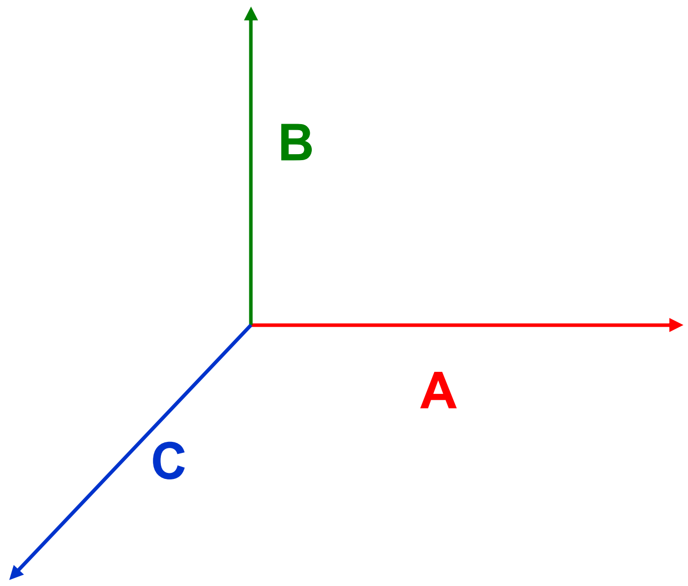
Orthogonal Frequency Division Multiplexing (OFDM) Based Multiple Access (OFDMA)

OFDM is a frequency-division multiplexing (FDM) scheme used as a digital multi-carrier modulation method. A large number of closely spaced orthogonal sub-carrier signals are used to carry data on several parallel data streams or channels.

- **Orthogonality Principle**
- **OFDM**
- **OFDM-FDMA**

Orthogonality Principle (1/3)

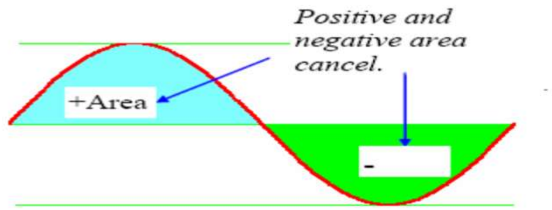
- **Vector space**
- The angle between two vectors
  - If θ is the angle between the vectors a and b, then:
    - $a \cdot b = |a||b|\cos\theta$
  - **A**, **B** and **C** vectors in space are orthogonal to each other (if):
  - **A.B**=**B.C**=**C.A**=0

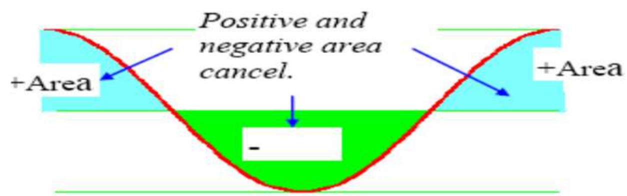


Orthogonality Principle (2/3)

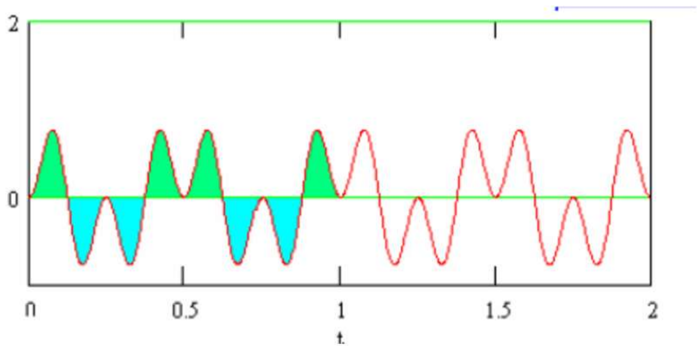
- Real Function space

$$f_1(t) = A\sin(wt)$$
$$f_2(t) = B\cos(wt)$$
$$\int_{\tau}^{\tau+T} f_1(t)f_2(t)dt = 0$$
$$f_m(t) = M\sin(mwt)$$
$$f_n(t) = N\cos(nwt)$$
$$\int_{\tau}^{\tau+T} f_m(t)f_n(t)dt = 0$$





Orthogonality Principle (3/3)



$$f(t) = \sin(wt)\sin(2wt)$$

$\forall m.n \in N$

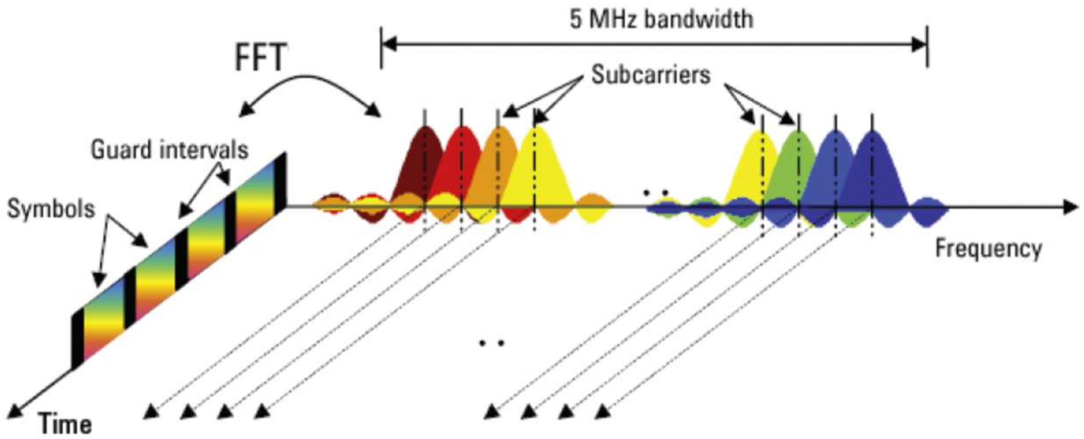
$$\int_0^T sin(mwt)sin(nwt)dt = 0 \; where \; m \neq n$$

$$\int_0^T sin(mwt)cos(nwt)dt = 0$$

Here *mw* and *nw* are called *m-th* and *n-th* harmonics of *w respectively*

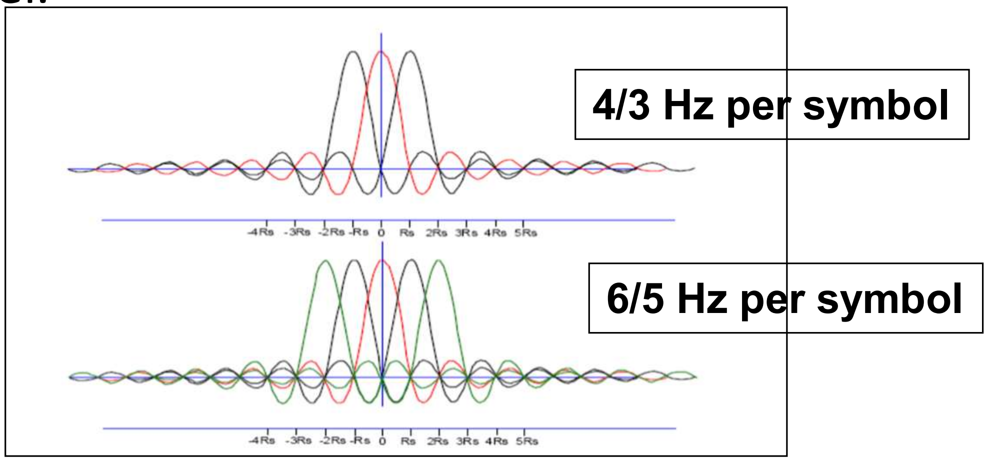
Orthogonal frequency division multiple access OFDM

- The Figure below illustrates the key features of an OFDM signal in frequency and time.
  - In the frequency domain, multiple adjacent tones or subcarriers are each independently modulated with data
  - Then in the time domain, guard intervals are inserted between each of the symbols to prevent inter-symbol interference at the receiver caused by multi-path delay spread in the radio channel.



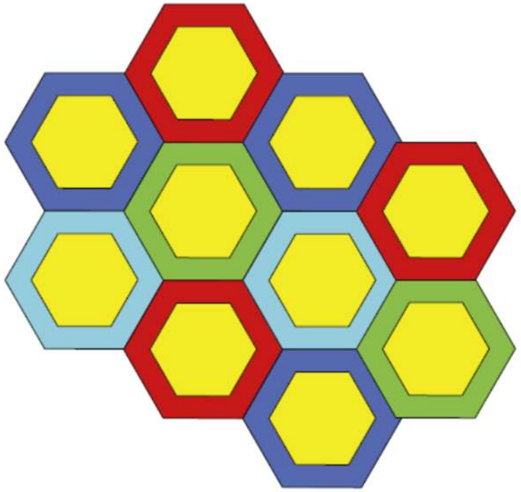
Advantages of OFDM

- When compared to the CDMA technology upon which UMTS is based, OFDM offers a number of distinct advantages:
  - OFDM can easily be scaled up to wide channels that are more resistant to fading.
  - OFDM can be made completely resistant to multi-path delay spread. This is possible because the long symbols used for OFDM can be separated by a guard interval known as the cyclic prefix (CP). “The CP is a copy of the end of a symbol inserted at the beginning”. By sampling the received signal at the optimum time, the receiver can remove the time domain interference between adjacent symbols caused by multi-path delay spread in the radio channel.
  - Efficient use of Spectrum



Disadvantages of OFDM

- OFDM does have some disadvantages.
  - The subcarriers are closely spaced making OFDM sensitive to frequency errors and phase noise.
  - For the same reason, OFDM is also sensitive to Doppler shift, which causes interference between the subcarriers.
  - Pure OFDM also creates high peak-to-average signals, and that is why a modification of the technology called SC-FDMA is used in the uplink.
- It is known that OFDM will be more difficult to operate than CDMA at the edge of cells.
  - CDMA uses scrambling codes to provide protection from inter-cell interference at the cell edge whereas OFDM has no such feature. Therefore, some form of frequency planning at the cell edges will be always required.



CDMA Vs OFDM

Attribute	CDMA	OFDM
Transmission bandwidth	Full system bandwidth	Variable up to full system bandwidth
Frequency-selective scheduling	Not possible	A key advantage of OFDM although it requires accurate real-time feedback of channel conditions from receiver to transmitter
Symbol period	Very short—inverse of the system bandwidth	Very long—defined by subcarrier spacing and independent of system bandwidth
Equalization	Difficult above 5 MHz	Easy for any bandwidth due to signal representation in the frequency domain
Resistance to multipath	Difficult above 5 MHz	Completely free of multipath distortion up to the CP length
Suitability for MIMO	Requires significant computing power due to signal being defined in the time domain	Ideal for MIMO due to signal representation in the frequency domain and possibility of narrowband allocation to follow real-time variations in the channel
Sensitivity to frequency domain distortion and interference	Averaged across the channel by the spreading process	Vulnerable to narrow-band distortion and interference
Separation of users	Scrambling and orthogonal spreading codes	Frequency and time although scrambling and spreading can be added as well

Comparison

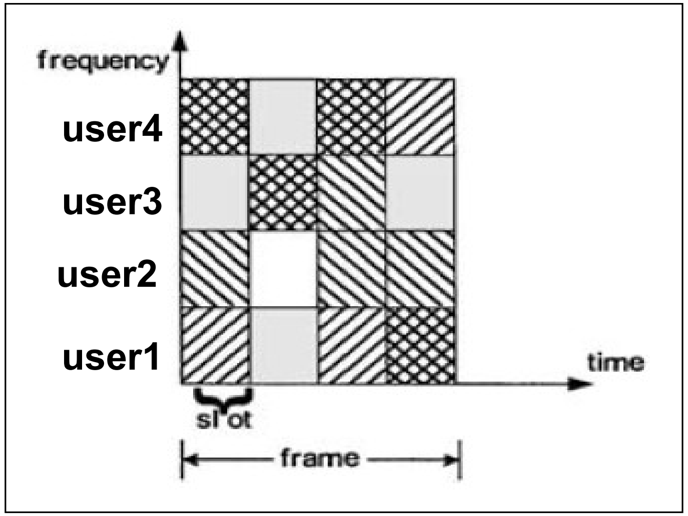
- **Frequency division multiple access** or **FDMA** is a channel access method used in multiple-access protocols as a channelization protocol.
- **FDMA** gives users an individual allocation of one or several frequency bands, or channels. ... **FDMA** requires high-performing filters in the radio hardware, in contrast to **TDMA and CDMA**

Multiple access technology – Downlink/Uplink

- Downlink and uplink transmission in 4G and 5G are based on the use of multiple access technologies, specifically:
  - orthogonal frequency division multiple access (OFDMA) for the downlink
  - single-carrier frequency division multiple access (SC-FDMA) for the uplink

OFDM-FDMA (OFDMA)

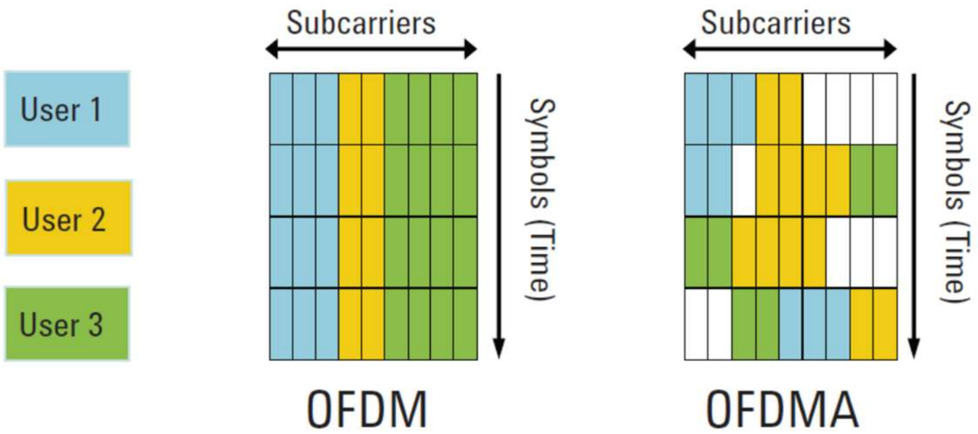
- Each terminal occupies a subset of sub-carriers
- Subset is called an OFDMA traffic channel
- Each traffic channel is assigned exclusively to one user at any time



- *The IEEE 802.16e/ WiMax use OFDMA as Multiple access technique*
  - *Bandwidth options 1.25, 5, 10, or 20 MHz*
  - *Entire bandwidth divided into 128, 512, 1024 or 2048 sub carriers*
  - *20 MHz bandwidth with 2048 sub carriers has 9.8 KHz spacing between sub carriers*

OFDM Vs OFDMA

- With standard OFDM, very narrow UE-specific transmissions can suffer from narrowband fading and interference.
- That is why for the downlink 3GPP chose OFDMA, which incorporates elements of time division multiple access (TDMA).
- OFDMA allows subsets of the subcarriers to be allocated dynamically among the different users on the channel, as shown below.
  - The result is a more robust system with increased capacity.
  - This is due to the trunking efficiency of multiplexing low rate users and the ability to schedule users by frequency, which provides resistance to frequency-selective fading.

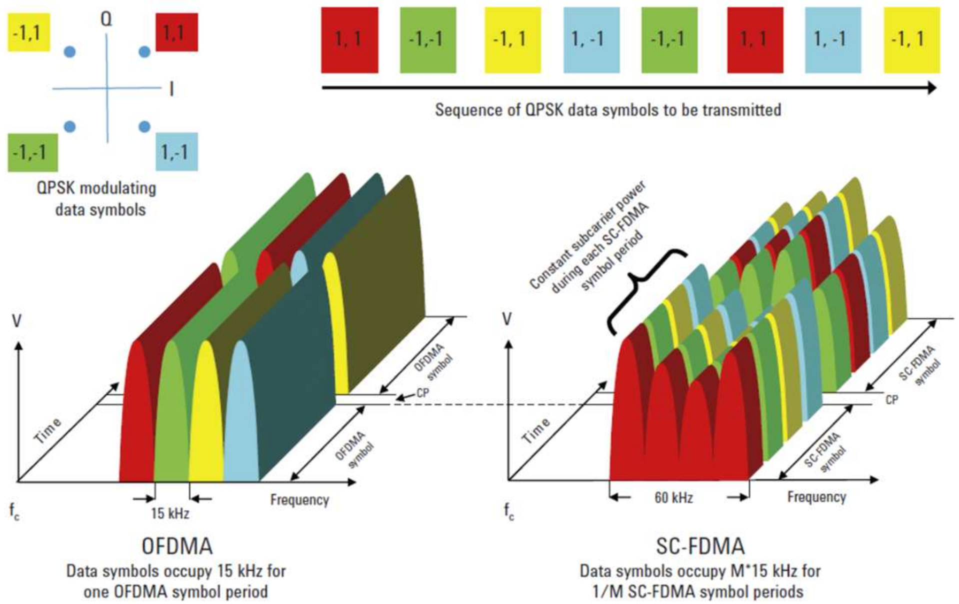


Multi Access Technology In Uplink

- The high peak-to-average ratio (PAR) associated with OFDM led 3GPP to look for a different transmission scheme for the LTE uplink.
- SC-FDMA was chosen because it combines the low PAR techniques of single-carrier transmission systems, such as GSM and CDMA, with the multi-path resistance and flexible frequency allocation of OFDMA.
- A brief description is as follows:
  - data symbols in the time domain are converted to the frequency domain using a discrete Fourier transform (DFT);
  - then in the frequency domain they are mapped to the desired location in the overall channel bandwidth
  - before being converted back to the time domain using an inverse FFT (IFFT). Finally, the CP is inserted. Because SC-FDMA uses this technique, it is sometimes called discrete Fourier transform spread OFDM or (DFT-SOFDM)

OFDMA (Multi-Carrier vs Single Carrier)

- For clarity this example uses only four (M) subcarriers over two symbol periods with the payload data represented by quadrature phase shift keying (QPSK) modulation.
- On the left side of Figure, M adjacent 15 kHz subcarriers—already positioned at the desired place in the channel bandwidth—each modulated for the OFDMA symbol period of 66.7 µs by one QPSK data symbol. In this four subcarrier example, four symbols are taken in parallel.
- After one OFDMA symbol period has elapsed, the CP is inserted and the next four symbols are transmitted in parallel.
  - For visual clarity, the CP is shown as a gap; however, it is actually filled with a copy of the end of the next symbol.
  - To create the transmitted signal, an IFFT is performed on each subcarrier to create M time-domain signals.
  - These in turn are vector-summed to create the final time-domain waveform used for transmission

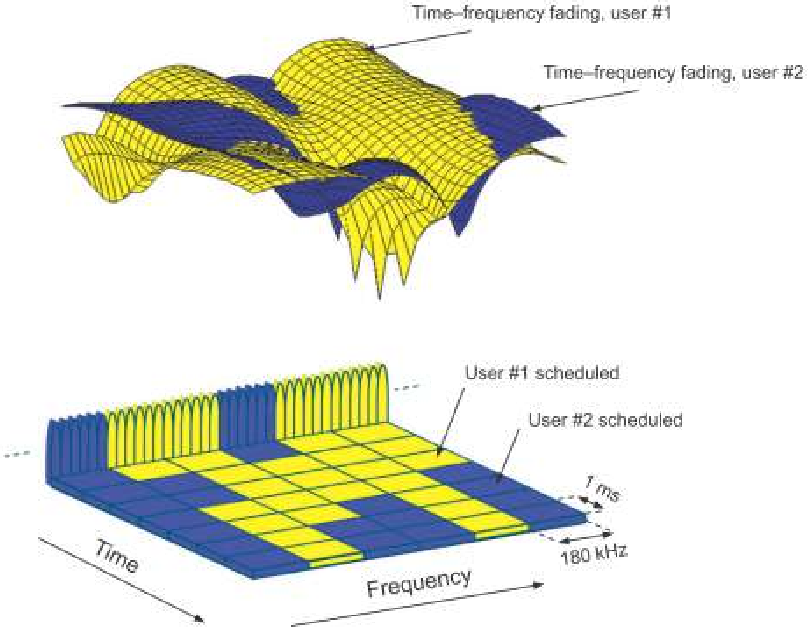


OFDMA (Multi-Carrier vs Single Carrier)

- The most obvious difference between the two schemes is that OFDMA transmits the four QPSK data symbols in parallel, one per subcarrier, while SC-FDMA transmits the four QPSK data symbols in series at four times the rate, with each data symbol occupying M x 15 kHz
- Note that OFDMA and SC-FDMA symbol lengths are the same at 66.7 μs; however, the SC-FDMA symbol contains M "sub-symbols" that represent the modulating data.
- It is the parallel transmission of multiple symbols that creates the undesirable high PAR of OFDMA. By transmitting the M data symbols in series at M times the rate, the SC-FDMA occupied bandwidth is the same as multi-carrier OFDMA but, crucially, the PAR is the same as that used for the original data symbols.

Channel dependent Scheduling and Rate adaptation

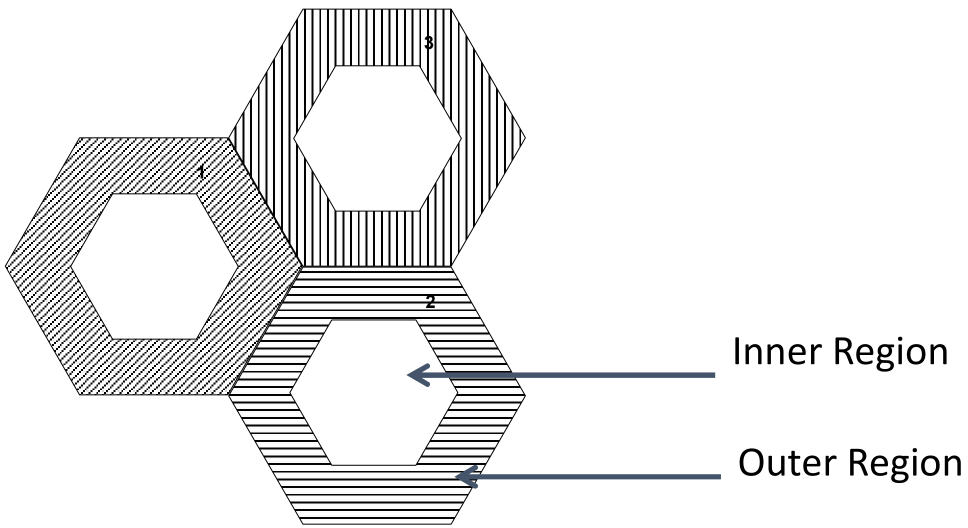
- Depending on the channel conditions, time – frequency resources are allocated to users by the scheduler
- Scheduling decisions taken once every **1ms** with frequency domain granularity of **180 kHz**.
- Scheduler allocates resources depending on the **Channel State Information**(CSI) provided by the UE



Inter Cell interference Coordination (ICIC)

- In LTE, Frequency Reuse Factor equals to one (full spectrum availability at each Cell)
- This leads to high performance degradation specially the Users in cell edge.
- ICIC reduce ICI at cell edge applying certain restrictions on resource assignment.

Adaptive Fractional Frequency Reuse Coordination:



Special Features in LTE – A (Rel.10)

Carrier Aggregation :

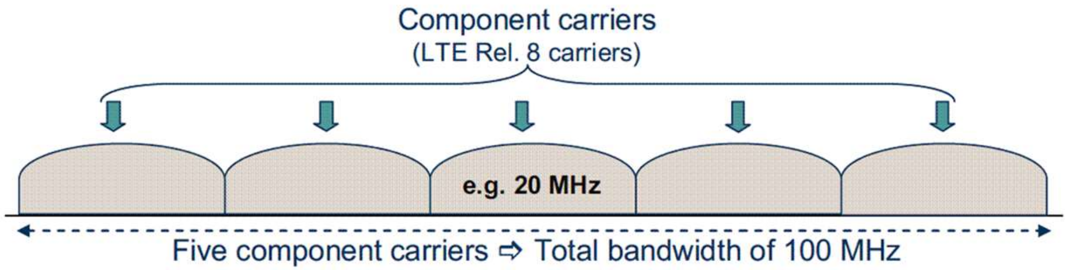
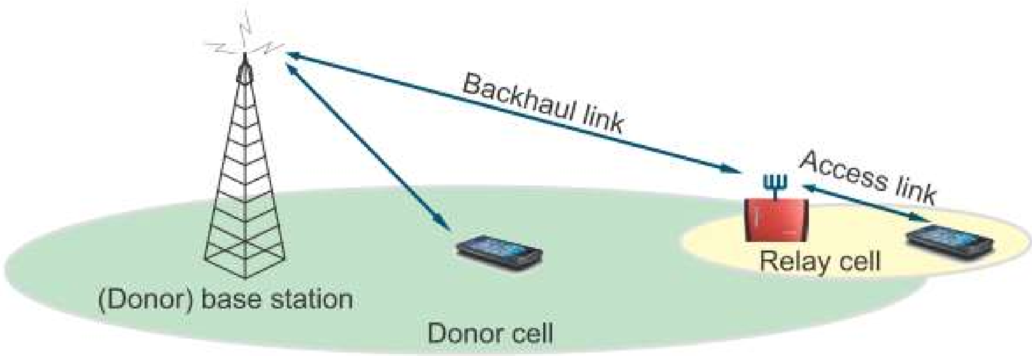


Figure 1. Example of carrier aggregation.

Relaying:



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