OFDMA Modulation Technique in 4G LTE Mobile Networks

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Contents

Abstract

The last two decades have seen the technologies and needs in mobile communications evolve together. This report tries to explain how the principles of OFDMA (*Orthogonal Frequency Division Multiple Access*) in 4G LTE networks allow for answering the current needs both in high data rate and high user capacity.

1 | From OFDM to OFDMA

To be able to transmit a lot of data to many users, the physical resources, i.e. space, time and electromagnetic (frequency) spectrum, need to be used and shared in an optimal way.

1.1 Introduction to Modern Mobile Communications

When talking about mobile communications, the space resource is usually managed by using fixed BS (*Base Stations*) placed in a certain pattern similar to bee-hive cells. These BS are placed so that they can deliver information wirelessly to mobile stations within the range of their cell or seemlessly moving from a cell to another.

To achieve high data rates and multiple user services within a cell, it is however necessary to design techniques making smart use of time and frequency resources. ODFM is one of these techniques and is being used in several applications both in cable and wireless network such as ADSL, VDSL or WLAN and 4G LTE.

1.2 Description of OFDM

OFDM stands for *Orthogonal Frequency Division Multiplexing*. It relies on different principles used together to combine advantages.

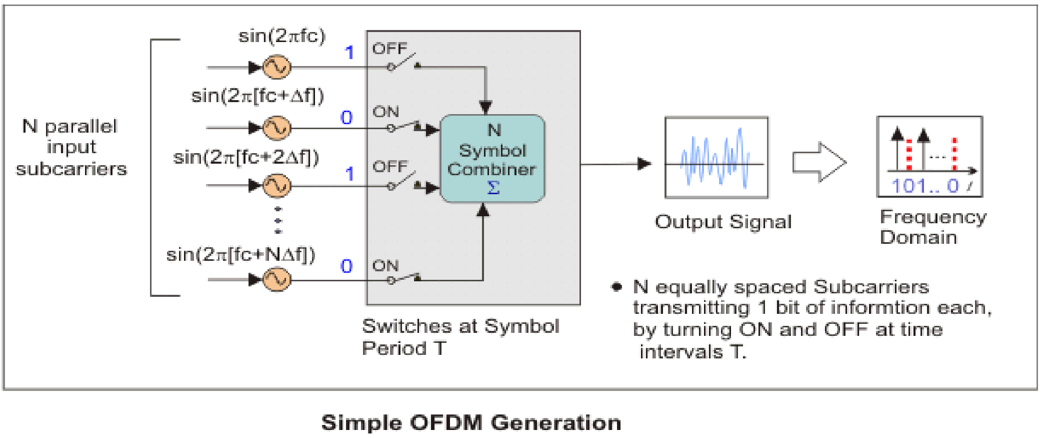

Figure 1.1: Modulation of signals using OFDM technique [**source: Keysight**]

The most basic of these principles is the FDM (*Frequency Division Multiplexing*). It consists in modulating several (N) signals using a QAM (*Quadrature Amplitude Modulation*) scheme, with sub-carriers that are regularly spaced by Δf, see *Figure 1.1*. All these modulated signals are then put into an IFFT (*Inverse Fast Fourier Transform*) and summed into a single signal, updated periodicly according to the symbol period T and sent through the desired medium. At the receiver end, the inverse procedure is applied.

The second main concept is the orthogonality of the sub-carriers. When passing to the frequency domain, each sub-carrier will result in a sinc function. Therefore, the spacing, Δf, between each of them is chosen so that, in frequency domain, each sub-carrier overlap the others orthogonally, which means all the sinc functions have zero crossing and their side-loops cancel each other, while peaks remain distinguishable, see *Figure 1.2*.

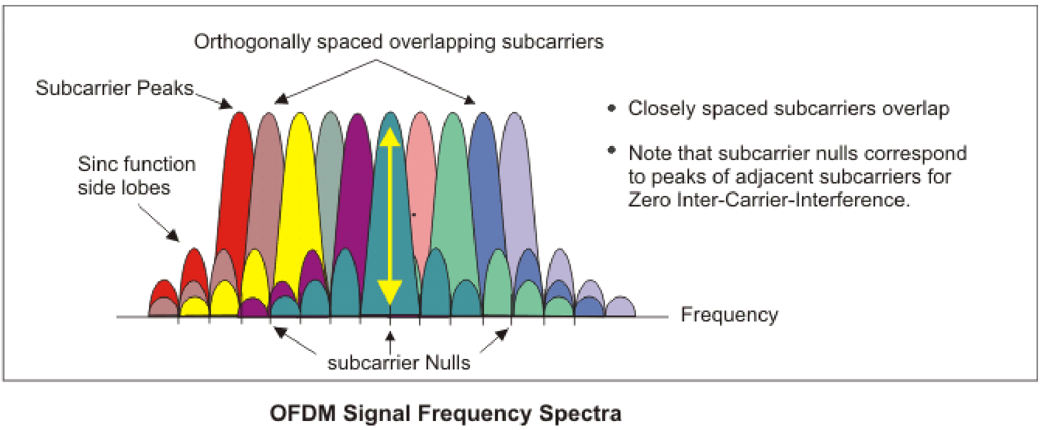

Figure 1.2: Frequency spectrum of OFDM signal [**source: Keysight**]

Since, there is no undesirable interference due to frequency overlapping, the spacing between each sub-carrier can be very short. To maintain the orthogonality, this spacing, Δf, actually has to be the inverse of a symbol period, T :

$$\Delta \mathrm{f} = 1/\mathrm{T_S} \qquad [\mathrm{Hz}] \quad (1.1)$$

Coming from this relation, and by sending information on parallel channels, it is possible to increase the overall data rate and therefore, the spectral efficiency, while decreasing the data rate on each subchannel. This helps to reduce potential ISI (*Inter-Symbol Interferences*) at the receiver end, that could happen due to wave reflection, refraction or other multi-path phenomena [1] and is reinforced by a guard interval between each symbol.

OFDM is very efficient in high data rate communcations. However, it requires some modifications to be usable in multi-user environments and OFDMA tries to address this issue.

1.3 What does OFDMA bring ?

OFDMA stands for *Orthogonal Frequency Division Multiple Access*. It allows multiple users to communicate at the same time while keeping the high data rates offered by OFDM.

The base principle of OFDMA consists in sharing the time and frequency resources between users. It can somehow be compared to a combination of OFDM, FDMA (*Frequency Division Multiple Access*) and TDMA (*Time Division Multiple Access*)[2]. Users are assigned a subset of sub-carriers in the given frequency range and use it for a certain time before it is attributed to another user.

All communications can happen in parallel and the attribution of sub-channels is made independently one from another : they can take place at different times and involve different size of sub-channels, see *Figure 1.3*.

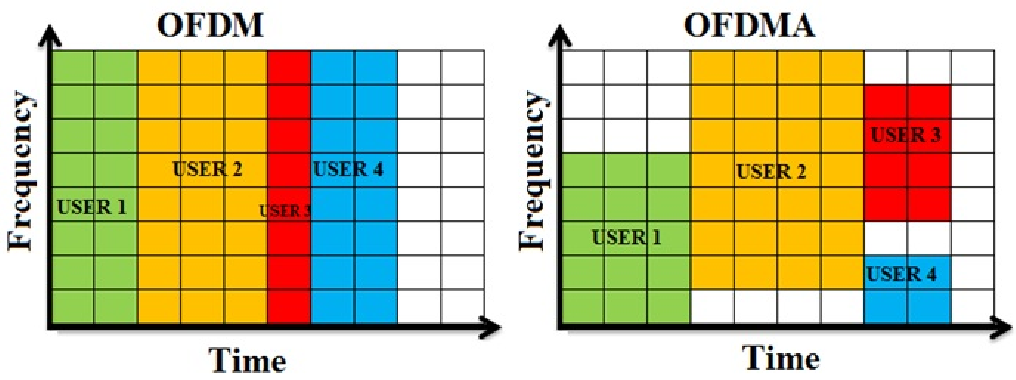

Figure 1.3: Comparison between OFDM and OFDMA [**source: differencebetween.com**]

OFDMA still keeps a strong disadvantage from OFDM which is the high peak-to-average power ratio which makes the use of this technique inefficient in terms of energy for small and portable devices. Despite this fact, OFDMA communication technique has been chosen for 4G LTE networks, designed especially for mobile communications (voice calls, video calls and streaming, World Wide Web access, ...). The next chapter explains briefly how this is achieved.

See also, [3, Chap. 19].

2 | OFDM in 4G-LTE Mobile Networks

4G-LTE (*4th Generation-Long Term Evolution*, or *3GPP-LTE*, here designated as LTE) is the commercial name of a standard for a communication protocol (physical layer), developed by the 3GPP (*3rd Generation Partnership Project*) and released progressively in different countries around the world, since first launch in Stockholm and Oslo in 2009.

2.1 4G-LTE Overview

LTE has been designed as an evolution to former mobile communication techniques (GSM, UMTS, CDMA2000) 'to increase data rates, improve spectrum efficiency, improve coverage, and reduce latency'[4]. 4G-LTE was not actually intended to be a proper 4th Generation technology by the 3GPP consortium. However, the initial goal of this *Long Term Evolution* technology is to ensure that 3G can stay competitive throughout years.

For instance, one of its definition items actually states that it should reach a 100 Mbps for the downlink and 50 Mbps for the uplink and can therefore be used both for voice and data. The difference between the uplink and downlink can be explained with the fact that two slightly different technologies are used.

2.2 LTE Technical Considerations

Since, mobile communications usually operate between a BS and a MS (*Mobile Station*), the LTE standard defines rules that accounts for the constraints and advantages of both sides. While, BS don't face the issues from high power-consumption, MS for instance, need a communication technology that doesn't drain all their available power.

Thus, OFDMA communication technique, described in *Section 1.3*, is used as is on the BS side, which allows for *Muliple Access*, to respond a network cell's needs in high traffic and convenient data rates.

These throughputs can be achieved by chosing the right symbol rate, which is directly influenced by the frequency separation between each subcarrier and therefore, by the number of subcarriers in a channel. Different channel bandwidths are defined in LTE[5]:

- 1.4 MHz
- 3 MHz

- 5 MHz
- 10 MHz
- 15 MHz
- 20 MHz.

Meanwhile, the sub-carrier spacing, Δf, is set to 15 kHz, which yields 15 ksps and a symbol time of:

$$\mathrm{T_S} = \frac{1}{15 \cdot 10^3}$$
$$\mathrm{T_S} = 66,7 \cdot 10^{-6}\mathrm{s}$$
$$\mathrm{T_S} = 66,7\mu\mathrm{s}.$$

Eventually, using a 20 MHz channel bandwidth (which allows for 100 frequency resource blocks of 12 subcarriers) and a 64QAM (which means 6 bits are used to map bits of data in one symbol), results in having a theoretical data rate of 108 Mbps. However, the signal being affected by several physical and environmental factors, the real data rate is actually lower.

Moreover, the cycling prefix, T_{CP}, used by OFDM to reduce ISI even more than allowed by the low symbol time, is defined for LTE as :

$$\mathrm{T_{CP}} = 4,69\mu\mathrm{s}.$$

While simple OFDMA happens at BS side, and the previously defined standards remain the same, the technique used on the MS side is slightly modified into what is called SC-FDMA (*Single Carrier - Frequency Division Multiple Access*), which allows to lower the peak-to-average ratio and thus, reduce the power consumption over time. This is achieved by having the users (MS) to apply a supplementary DFT before bit mapping (compensated on the receiver end by an IDFT after de-mapping) and use a single-carrier structure, see *Figure 2.1*.

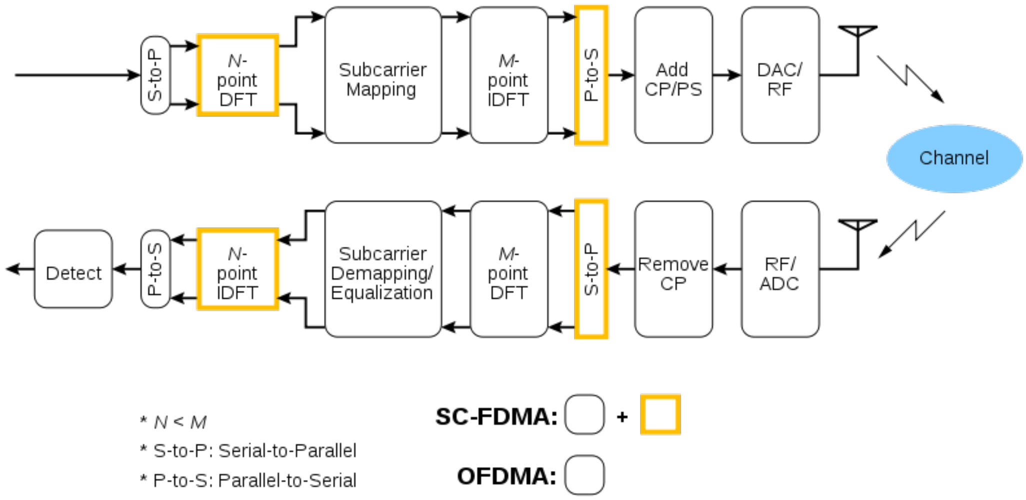

Figure 2.1: SC-FDMA signal generation[**source: Wikipedia**]

See also, [3, Chap. 27] and [6].

Bibliography

[1] Ian Poole. *OFDM Orthogonal Frequency Division Multiplexing Tutorial*. Ed. by Radio Electronics. 2015. URL: http://www.radio-electronics.com/info/rf-technology-design/ofdm/ofdm-basics-tutorial.php.

[2] Contributors. *Orthogonal frequency-division multiple access*. Ed. by Wikipedia. Oct. 20, 2015. URL: https://en.wikipedia.org/wiki/Orthogonal_frequency-division_multiple_access.

[3] Andreas F. Molisch. *Wireless Communications*. Ed. by John Wiley & Sons. 2nd Edition. 2011.

[4] Erik Dahlman et al. "The 3G Long-Term Evolution - Radio Interface Concepts and Performance Evaluation." In: *VTC Spring*. IEEE, May 31, 2010, pp. 137–141. URL: http://dblp.uni-trier.de/db/conf/vtc/vtc2006s.html#DahlmanEFJKLP06.

[5] Ian Poole. *LTE OFDM, OFDMA SC-FDMA & Modulation*. Ed. by Radio Electronics. 2015. URL: http://www.radio-electronics.com/info/cellulartelecomms/lte-long-term-evolution/lte-ofdm-ofdma-scfdma.php.

[6] Contributors. *LTE(telecommunications)*. Ed. by Wikipedia. 2015. URL: https://en.wikipedia.org/wiki/LTE_(telecommunication).