The Principle of OFDM and Use in 4g Radio Cellular Systems

SB. A. Mohammed
Department of Electrical and Electronics Engineering, Kebbi State University of Science and Technology, Aliero

Abdulrahman Muhammad
Department of ICT Engineering, Kebbi State University of Science and Technology, Aliero

ABSTRACT
The 4G (fourth generation) radio cellular communication systems are projected to overcome deficiencies of 3G (third generation) systems and to enhance variety of new services, such as spectral efficiency, high data rates transfer, multimedia, mobile TV, high network capacity, digital video broadcasting (DVB), quality of service and other services that utilize bandwidth. The Orthogonal Frequency Division Multiple (OFDM) access schemes have been adapted as suitable technique for 4th generation cellular radio systems due to its immunity to the multipath frequency selective fading and effective spectrum utilization. This paper will present the basic principles of OFDM and why is it suited for 4th generation radio cellular systems. The technical history of cellular radio system was first presented followed by the basic principles and fundamentals of OFDM. The effect of insertion of cyclic prefix for OFDM was also briefly discussed.

General Terms
The principle of OFDM and use in 4G radio cellular systems

Keywords
Orthogonal Frequency Division Multiple (OFDM, Code Division Multiple Access (CDMA) and Time Division Multiple Access (TDMA)

1. INTRODUCTION
For a long period of time, the ability to send large volumes of data or rather to communicate with people is crucial. For the past ten years the mobile radio communication industries has grown rapidly by orders of magnitude. The cellular radio systems and personal communication services has enormous impact to our society. The design objective of early mobile radio system was achieved a large coverage area by using a single high powered transmitter with an antenna mounted on top of high building or tower. While this method achieved very good coverage. As the demands of services increase and poor utilization of frequency spectrum, which the system could no longer handle, led to development of cellular networks. The essential feature of all cellular networks is that the final link between the subscriber and fixed network is by radio. This has a number of consequences 1-Radio spectrum is a finite resources and the amount of spectrum available for mobile communication is strictly limited 2-The radio environment is subjected to multipath propagation, fading and interference and is not therefore ideal transmission medium [5].

3- The subscriber is able to move and the movement must be accommodated by the communication system. Based on the above mentioned consequences, there has been a paradigm shift in mobile communications systems every decade. The first generation (1G) systems in the 1980s which were based on analog technologies and the second generation (2G) systems in the 1990s, such as Global Systems for Mobile Telecommunications (GSM), and the 3G systems which are also based on digital technologies for mobile TV due to high data transfer, video conferencing, voice, data, and multimedia.

The fourth generation mobile communication systems are aimed to overcome some of the deficiencies of 3G systems and to provide a wide variety of new services, from high data rate to high definition and high quality of service. Communication resources (CR) represent the frequency or bandwidth available for communication. For the efficient management of communication resources, it is usually important that, we have ensured that the bandwidth of the channel is utilized to its fullest capacity so that the user can share the resources at equitable manner, so that no frequency is wasted. The term multiplexing refers to the sharing of communication resources

The key to all multiplexing and multiple access schemes is that various signals share communication resources without creating unmanageable interference to each other in the detection process. The principle of orthogonal frequency division multiplexing (OFDM) modulation involves the transmitting of large amount of data over a radio channel. The techniques are employed in data delivery systems over the telephone line, radio and television, and wireless systems. This review discusses the basic principle of orthogonal frequency division multiplexing (OFDM) and its application to 4th generation cellular radio system. [8].

2. INTRODUCTION TO 4G CELLULAR RADIO SYSTEMS
This chapter gives a brief introduction and technical history of mobile radio cellular systems ranging from first (1st) to fourth generation (4G).

2.1 Mobile Communication System: A Brief History
The initial ideas for cellular radio were developed by Bell Laboratories (US) soon after the Second World War. The first generation (1G) systems in the 1980s which were based on analog technologies and the second generation (2G) digital standard were being defined with the hope of developing Pan-European services. This system known as GSM (Global System for mobile Communications) was launched in 1991 and has proven enormously successful in expanding to serve nearly 4 billion people via nearly 900 networks in approximately 220 countries areas worldwide. To improve services offered by the 2G networks, particularly for data transfer, several enhancements to the GSM networks have been designed and implemented. The most important of these are the General Packet Radio Service (GPRS) and (HSPA)

which have proved very successful in facilitating internet access on the mobile network. A third generation system UMTS (Universal Mobile Telecommunication System), will provide even higher data rates than GPRS, in theory up to 2Mbps for non-enhanced 3G, but in practice data rates of up to 384kbps may be possible with limited mobility [3].

2.2 Fourth Generation (4G)

The 4G (fourth generation) radio cellular communication systems are projected to overcome deficiencies of 3G (third generation) systems and to enhance variety of new services, such as spectral efficiency, high data rates transfer, multimedia, mobile TV, high network capacity, digital video broadcasting (DVB), quality of service and other services that utilize bandwidth. 4G systems, that is, cellular broadband wireless access systems have been attracting much interest in the mobile communication arena. The 4G systems not only will support the next generation of mobile service, but also will support the fixed wireless networks. The table below shows the brief history and technical requirement of mobile communication systems. [4]

Table 1: Short History of Mobile Telephone Technologies [4]

Technology	1G	2G	2.5G	3G	4G
Design Began	1970	1980	1985	1990	2000
Implementation	1984	1991	1999	2002	2010?
Service	Analog voice synchronous data up to 9.6kbps	Digital voice, short messages	Higher capacity packetized data	Higher capacity broadband data up to 2Mbps	Higher capacity completely IP oriented, multimedia data to hundreds of Megabits
Standard	AMPS, TACS, NMT e.t.c	TDMA,CDMA,GSM, PDC	GPRS, EDGE, 1xRTT	WCDMA, CDMA2000	Single standard
Data Bandwidth	1.9 kbps	14.4 kbps	384 kbps	2 Mbps	200 Mbps
Multiplexing	FDMA	TDMA, CDMA	TDMA, CDMA	CDMA	OFDM?
Core Network	PSTN	PSTN	PSTN, packet network	Packet network	Internet

In summary, our objective is to convey information, intelligence or data to a distance location over the communication channel with minimal error due to channel imperfections. The channel has imperfections such has noise, disturbances that may affects the signal and distort or attenuate the information carried by the signal. The 4G system should dynamically share and utilize network resources to meet the minimal requirements of all the 4Genables users and improves error performance and quality of service

3. BASIC PRINCIPLE OF ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING (OFDM)

These chapters explain the basic theory and principles of OFDM and its application to 4G radio cellular systems

3.1 Introduction:

As already discussed, Communication resources (CR) represent the frequency or bandwidth available for communication. For the efficient management of communication resources, it is usually important that, we have ensured that the bandwidth of the channel is utilized to its fullest capacity so that the user can share the resources at equitable manner, so that no frequency is wasted. Multiple access is a technique used to make best use of the transmission medium. In multiple access, multiple terminals or users shared the bandwidth of the transmission medium. While the concept of multiplexing involves the simultaneous transmission of multiple signals across a single link or channel. There are three major multiple access technique widely employed in radio cellular communication systems, these are: frequency division multiple access (FDMA), code division multiple access (CDMA) and time division multiple access (TDMA). In TDMA system, one frequency is shared by a number of the users or terminals.

Each station is given a time slot in which it can transmit the number of slot is fixed, and the terminals transmit in the time slot allocated by them. In standard GSM communication is eight (8) time slot. In CDMA system, both the frequency and time are shared between the different users while each haven a unique code that can be recognized and differentiated from other users at the receiver. In an FDMA system, users access the communication channel simultaneously, utilizing different parts of the spectrum. [6]

3.2 The Single-Carrier and multicarrier Modulation System

Single carrier system of modulation is a technique employed to modulate the signal onto a single carrier using frequency, phase, or amplitude and then transmitted over the radio link. This system is not effectively efficient because the signal can easily be affected by transmission impairments which can either lead to loss of information from impulse noise, scattering (Mie and Rayleigh are the commonest), signal reflections, interference with other signals multipath fading and other. These impairments can cause distortion, attenuation, deviation, dissipation or even dispersion to the signal which can lead to error or difficulties at the receiving end. For digital systems this signals are sent in the form of bits, and the collections of those bits are called symbols, that are modulated onto the carrier. The concept of multicarrier modulation (MCM), where involved to remedy some deficiencies of single carrier modulation technique. The multicarrier modulation technique (MCM) is the transmission of a single data stream over a number of lower rate subcarriers. The figure 1 below show the schematic diagram

of single and multicarrier modulation techniques

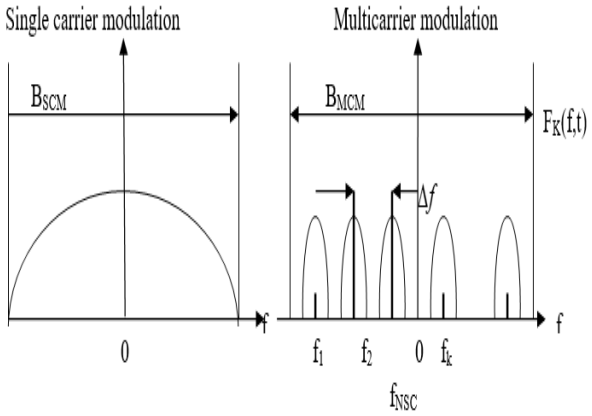

Figure 1: Comparison of SCM and MCM: frequency spectra of transmitted signals [1]

3.3 Fundamentals of OFDM

Orthogonal frequency division multiplexing (OFDM) is an analog technique that enables the transmission of large amount of information or data over a radio channel. This can be applied when the bandwidth of a link or channel is greater than the combined bandwidths of the signal to be transmitted. It works by subdividing or splitting the radio signal into multiple smaller subcarriers that are then transmitted simultaneously at different allocated frequencies to the receiver. In OFDM, signal generated by each sending device modulates different carrier frequencies. These modulated signals are then combined into single composite signals that can be transported by the link. The bandwidth ranges are the channels through which the various signals travel. The channels must then be separated by strips of unused bandwidth called **guard bands** to prevent signals from overlapping. In addition, the frequencies must not interfere with the original data frequencies. Failure to adhere to either conditions results in the unsuccessful recovery of the original signals. One of the main reasons to use OFDM in 4G cellular radio system is to increase the robustness against frequency selective fading and narrowband interference. It also helps to reduce the amount of cross talk in transmitting signal which is a cause of disturbances that affect the signal and may distort the information carried. In a single carrier system, a single fade or interference can cause the entire link to fail, but in a multicarrier system, only a small percentage of subcarriers will be affected. Due to varying in time of the channel, the orthogonal frequency division multiplexing(OFDM) signals tends to suffered some level of interference called the inter carrier interference (ICI). These have serious effect to the signals. To minimized or eliminate this effect, a guard time with a large period or duration is inserted this brings about the concept of cyclic prefix insertion. Details can be found in [1]

3.4 Orthogonality and Ofdm

The principle of orthogonality helps to provide proper understanding of multiple access signals. It also helps to ensure that cross talk does not occur between the carrier frequencies. Despite the fact that the signals overlap in the frequency domain for ideal receiver it must completely reject arbitrary unwanted signals or noise that may interfere with the real signals. If the dot product of two deterministic signals is equal to zero, these signals are said to be orthogonal to each other. Mathematically,

Both in time and frequency domain, below the diagram of the signal

$$\int_{-\infty}^{\infty} x_i(t)x_j^*(t)\,dt = \begin{cases} 1, & i=j \\ 0, & i\neq j \end{cases}$$

$$\int_{-\infty}^{\infty} X_i(f)X_j^*(f)\,df = \begin{cases} 1, & i=j \\ 0, & i\neq j \end{cases}$$

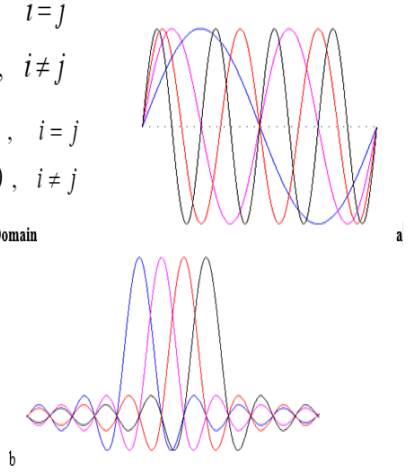

Fig 2: (a) Four subcarriers within one OFDM system (b) Spectra of individual subcarriers

Frequency Domain

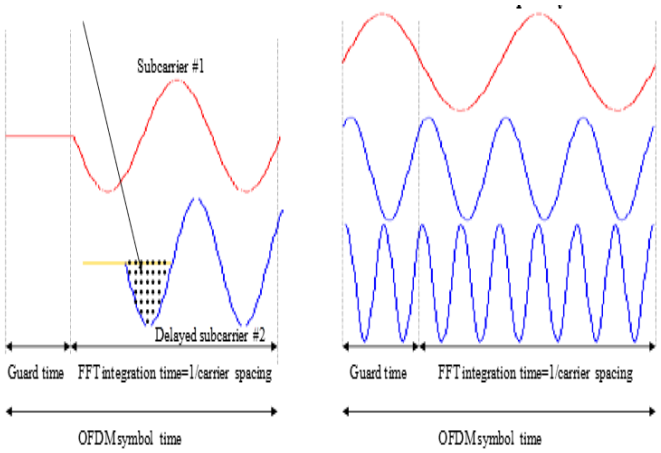

Fig 3 shows the effect of multipath with zero signals in the guard interval, [8]

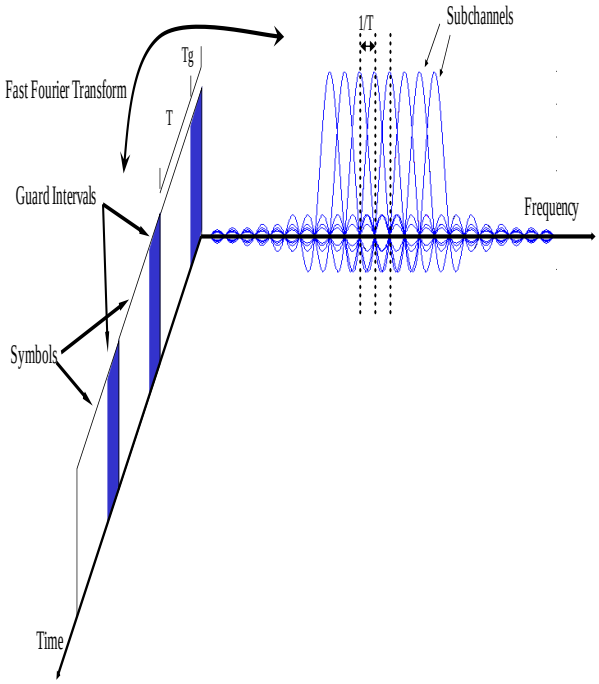

Fig 4 shows the time and frequency representation of OFDM with guard intervals [8]

4. CONCLUSIONS

A communication resources (CR) represent the time and bandwidth that is available for communication Signaling associated with a given system**.** The 4G (fourth generation) radio cellular communication systems are projected to overcome deficiencies of 3G (third generation) systems and to enhance variety of new services. Such as spectral efficiency, high data rates transfer, multimedia, mobile TV and etc.**,** OFDM techniques has long been studied and implemented to combat transmission channel impairments. OFDM has high spectral efficiency, Fast Fourier transforms (IFFT/FFT)) operation ensures that sub-carriers do not interference with each other. OFDM has an inherent robustness against narrowband interference. OFDM has excellent immunity to the multipath frequency selective fading and effective spectrum utilization.

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