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The Multicarrier OFDM Code Division Multiple Access Scheme

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ABSTRACT

The combination of the orthogonal frequency division multiplexing (OFDM) and the code division multiple access (CDMA) to form the OFDM-CDMA scheme has gained popularity in the field of mobile communication because of its numerous advantages, which include its ability to combat multiple access interference and its high efficiency in the transmission of high data rate signals. However, this scheme is plagued by multiple access interference (MAI) which affects the efficiency of the scheme. Various multiuser detection techniques have been proposed to combat this challenge but most of the techniques rather lead to higher system complexity. Recently, some papers have investigated and reported the artificial neural network based multiuser detection techniques, which is quite promising. Hence, a comprehensive review is carried out on this important scheme of OFDM-IDMA. Major drawbacks and challenges are highlighted as well, to enhance further studies and research work in this laudable scheme.

Keywords: *OFDM, CDMA, OFDM-CDMA*

1. INTRODUCTION

The increased growth in traffic and advent of new features and services in wireless mobile networks, have intensified the search for mobile communication techniques, characterized by flexibility and high throughput, to meet these demands.

Arising from its history as a prominent technique for military communication [1], Spread Spectrum Code Division Multiple Access (CDMA) was proffered as a scheme to meet these demands and challenges majorly because of its potential high spectrum efficiency and radio resource management flexibility. CDMA was also stated as an attractive multiuser technique in [2], largely because of its support for a large number of users and high flexibility.

The major idea in Spread Spectrum CDMA is to transmit data over a bandwidth that is way greater than the required information data rate bandwidth. The transmission over a wide bandwidth results in frequency diversity, which makes CDMA to be robust against multipath and interference. A signal with bandwidth C_s is transformed into a noise-like signal of much greater bandwidth C_{ss}, as shown in Fig. 1.0. With the assumption that the total power transmitted by the spread spectrum is the same as that in the original signal, the power spectral density of the spread spectrum signal is given as $P_s*(C_s/C_{ss})$, where the ratio C_{ss}/C_s is the processing gain and P_s is the signal power. The power of the radiated spread spectrum signal is thus spread over 10-1000 times the original bandwidth [3]. This explains basically, the characteristic advantage inherent in spread spectrum systems and its attractiveness in wireless communication systems as mentioned earlier.

In spread spectrum CDMA scheme, all users share the available spectrum, and each user is assigned a specific and distinct spreading code. This scheme employs a waveform that is not conspicuous to any other except the intended receiver of the transmitted waveform. The process of spreading the transmitted signal involves the multiplication of the input data by a pseudo-noise sequence (PN) whose bit-rate is greater than the bit-rate of the input data. The ratio of the PN sequence bit rate to the input data bit rate is called the spreading factor (SF). At the receiver, the spreading code is reversed by multiplying with the same PN code. However, it is noteworthy that the CDMA spreading code has cross-correlation characteristics [4] that makes dispreading has no effect on the interference generated by the signals of other users.

The result presented in [4] gives more insight and basic analysis on the main characteristics of some important PN sequence. Various sequences such as Maximal-Length, Gold, and Kasami sequences were described in details in the paper. Also, different techniques to spread information signals in CDMA systems were presented.

Furthermore, in [3], two major approaches to spread spectrum signal processing were highlighted, which are the direct sequence and the frequency hopping spread spectrum. The direct sequence is an amplitude modulation based technique while the frequency hopping spread spectrum employs frequency modulation. However, the aim of either technique is to spread the power to be transmitted over a wide bandwidth. This ensures the power per unit bandwidth is reduced. More details are given in the paper, about the principles of operation, adaptability and other application of CDMA scheme.

The rest of the paper is organized as follows: Section 2 describes the principles of OFDM-CDMA. In section 3, multiuser detection in OFDM-CDMA is reviewed. Section 4 discusses time and frequency synchronization in OFDM-CDMA systems and finally section 5 gives the conclusion and future work.

2. THE PRINCIPLES OF OFDM-CDMA

OFDM-CDMA represents an amalgamation of two different mobile communication schemes. These schemes are the orthogonal frequency division multiplexing (OFDM) and code division multiple access (CDMA). The combined scheme came to the forefront in the 1990s, when a number of proposals were proffered for the implementation of the scheme [5, 6, 7]. A lot of attention was drawn to this scheme because of the growing need to transmit high data rate signals in a majorly unfriendly communication channel as well as to

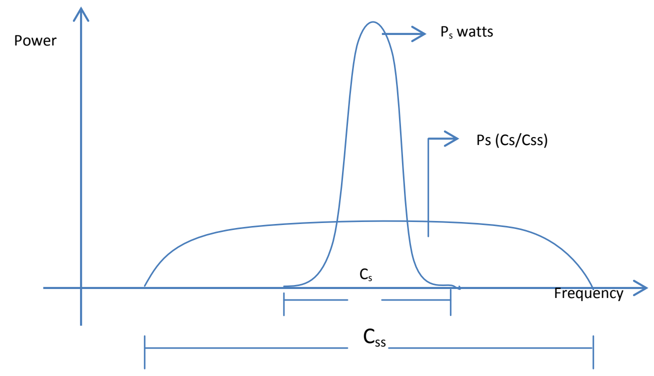

Fig. 1.0 The spectra of a spread spectrum signal before and after spreading

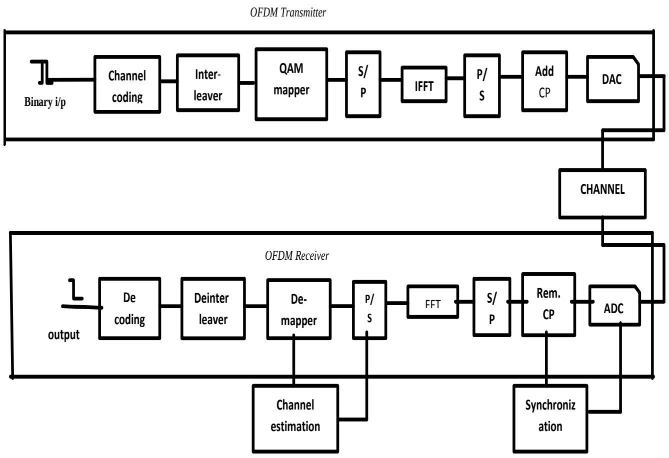

Fig. 2.0 A typical OFDM-CDMA transceiver: An adaption of an OFDM transceiver

utilize efficiently the valuable ‘fixed’ spectrum, in the face of a rapidly growing demand by an increasing number of mobile users.

OFDM technique [8], which involves the splitting of high-rate data streams into a large number of lower-rate data streams, which are transmitted, while maintaining orthogonality, across multiple narrowband sub-carriers, solves the problems of inter-symbol Interference (ISI) and inter-channel Interference (ICI), which are encountered while transmitting high-rate data streams across multipath channels. As long as orthogonality is maintained, there will be no interference between sub-carriers and this will enable the receiver to separate signals carried by each sub-carrier.

Thus, OFDM scheme, which is easily implemented using the Fast Fourier Transforms (FFTs), proffers a host of advantages, which include high spectral efficiency, low receiver complexity, robustness against fading caused by multipath, among others.

The CDMA scheme, which is the major technology behind the third generation mobile networks and mostly implemented using the RAKE receivers [9], has a number of advantages which has been mentioned earlier. It offers better spectrum utilization, diversity, and flexibility in radio resource management. Hence, OFDM-CDMA scheme exploits the combined advantages inherent in both OFDM and CDMA to provide a better and more efficient communication system.

Although there are various means of combining OFDM and CDMA as pointed out in [10, 11], but typically in multi-carrier CDMA systems, the signal goes through spreading, using a given spreading code and then converted into a parallel data stream which is transmitted over multiple sub-carriers. As shown in Fig. 2.0, the transceiver structure of an OFDM-CDMA is similar to the transceiver of an OFDM scheme. The transmitter model is an OFDM transmitter with an additional spreading operation at the input and the receiver model as well has a combiner at the output to isolate the transmitted data of any user of interest [12]. In [13], detailed study of the operation and the various processes involved in the transmission and reception of an MC-CDMA signal are presented.

3. MULTI-USER DETECTION IN OFDM-CMDA SYSTEMS

Although users in OFDM-CDMA scheme are separated by distinct spreading codes, different sub-carriers are affected by diverse fading and this destroys orthogonality between users. This leads to Multiple Access Interference (MAI) at the receiver, causing degradation in the performance of the system. System degradation becomes severe as the number of active users increases. Thus, importance must be placed on the mitigation of this undesired Multiple Access Interference (MAI) to enhance overall system efficiency. Multi-user detection (MUD) techniques, which subtract interfering signals from the baseband signal, are broadly employed to combat MAI in OFDM-CDMA systems.

Several multi-user detection techniques have been studied with the aim of achieving a reasonable level of complexity with some compromise in the system performance [14]-[19]. In [12], different MUD algorithms are compared in an uplink scenario, but the complexity of these detection schemes tends to grow exponentially as the number of users increases. In [14], four types of algorithms deployed for interference cancellation are stated. These include Optimum MUD, Linear MUD, Iterative Approximation of linear MUD and Non-Linear interference cancellation. Also, the turbo MUD algorithm, which offers an improvement on the system efficiency, was presented. Other recent works have also attempted to employ the artificial neural networks for multiuser detection [20]-[23]. But the fact remains that the OFDM-CDMA systems still suffers from complexity in the detection and interference cancellation processes performed at the receiver. In a bid to address this complexity, a new multi-user scheme named Interleave Division Multiple Access, with associated lower MUD complexity in comparison with CDMA scheme has been proposed and major research are now focused on this new scheme.

4. TIME AND FREQUENCY SYNCHRONIZATION IN OFDM-CDMA

OFDM-CDMA inherits the advantages together with the downsides of OFDM and CDMA as it is a literal combination of both. As in OFDM, the OFDM-CDMA signals

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are transmitted in a large number of orthogonal sub-carriers, making them susceptible to synchronization errors [24]. OFDM-CDMA systems therefore experience performance degradation caused by ICI [25], if the carrier frequency and the timing offset errors are not adequately and accurately compensated.

Since the downlink transmission is synchronous, time and frequency synchronization might not be much of a problem to solve, as various techniques, as used in OFDM, can be adapted directly. However, the major problem lies in the uplink because of the fact that different users are transmitting asynchronously, experiencing different level of channel fading and delays. Various schemes are already in place to combat this undesirable system degradation in MC-CDMA. In [26], a signal format for establishment of quasi-synchronous transmission is proposed, along with time synchronization technique. Also in [27], a bandwidth efficient method for synchronization in quasi-synchronous uplink of MC-CDMA systems is proposed, stating that the method adopted in [26] is spectrum inefficient. Other method for adequate time and frequency synchronization in OFDM-CDMA systems are studied in [28]-[32].

5. CONCLUSION

OFDM-CDMA, which is a multi-carrier spread spectrum scheme, has been studied. The scheme offers great advantages and attractiveness. However, the multiple access interference (MAI) experienced remains a major challenge, as the multiuser detection (MUD) techniques that are employed to combat MAI, either increase system complexity or result in major communication trade-offs. This has informed the search for an alternative scheme that will circumvent the challenges. A new multi-user scheme named Interleave Division Multiple Access (IDMA), with associated lower MUD complexity in comparison with the CDMA scheme has been proposed recently and the scheme is a promising candidate for fourth generation (4G) communication systems. However only few research have been carried out on this new scheme so far.

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