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Prevalence Synchronization in Numerous OFDM-IDMA Benefit Structure

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Abstract: **Various multiuser schemes have been proposed to efficiently utilize the available bandwidth while ensuring an acceptable service delivery and flexibility. The multicarrier CDMA became an attractive solution to the major challenges confronting the wireless communication system. However, the scheme is plagued with multiple access interference (MAI), which causes conspicuous performance deterioration at the receiver. A low-complexity multiuser scheme called the Interleave Division Multiple Access (IDMA) was proposed recently as a capable solution to the drawback in the multicarrier CDMA scheme. A combined scheme of OFDMIDMA was later introduced to enhance the performance of the earlier proposed IDMA scheme. The multicarrier IDMA scheme therefore combats inter-symbol interference (ISI) and MAI effectively over multipath with low complexity while ensuring a better cellular performance, high diversity order, and spectral efficiency. Major studies on the OFDM-IDMA scheme emphasis only on the implementation of the scheme in a perfect scenario, where there are no synchronization errors in the system. Like other multicarrier schemes, the OFDM-IDMA scheme however suffers from carrier frequency offset (CFO) errors, which is inherent in the OFDM technique. This research work therefore examines, and analyzes the effect of synchronization errors on the performance of the new OFDM-based hybrid scheme called the OFDM-IDMA. The design of the OFDM-IDMA system developed is such that the cyclic prefix duration of the OFDM component is longer than the maximum channel delay spread of the multipath channel model used.**

Keywords: **CDMA, OFDM-IDMA, CFO, 2G, FDMA, TDMA, 3G-LTE**

1. INTRODUCTION

Wireless communication has recorded a phenomenal and exponential growth especially in recent decades. After some initial as well as important breakthrough in radio wave research at the twilight of the nineteenth century, wireless communication and its applications have become an integral part of the modern world. Although there are many applications of the wireless communication, the mobile cellular systems have enjoyed the most popularity and unprecedented growth. Mobile communication systems as shown in Fig. 1-1 have however experienced some metamorphoses over the years with the aim of providing consumers with reliable and improved services. The earlier mobile communication systems, usually referred to as 1G systems [1], were analog based. A decade before the end of the twentieth century, the 2G mobile communication systems were introduced, based on digital communication technology, and expectedly offered better services [2]. The 2G systems, rolled out on the GSM standard, support both wireless transmissions of voice as well as data services unlike the earlier generations that only provide voice transmission. An improvement on the typical 2G system, which could only offer slow data transmission, is the 2.5G cellular system [3]. The 2.5G systems offer expanded services such as short messages, multimedia messages, and basic internet access with improved speed and quality. These generations of communication systems still have great popularity especially in the developing countries. The mobile communication market continues to enjoy overwhelming growth and popularity such that developers have to keep pace with growing demands and services. The 3G systems were launched as a solution to high data-rate transmission and users' demand for multiuser services. The 3G networks are based on the International Mobile Telecommunications-2000 (IMT-2000) standards, supporting data transmission of up to 2Mbits/s. Three major multiple access schemes, namely; FDMA, TDMA and CDMA are supported by the IMT-2000 standard, allowing about five radio interface which account for the high flexibility of the 3G communication systems [3]. The need for an improved performance and cellular capacity informed the introduction of the 3G-LTE systems, meant to serve as a temporal solution before the full roll out of the 4G systems. The features and specifications of the 4G systems have been comprehensively stated and 2 approved by the ITU [4], to ensure that efficient architecture as well as state-of-art technologies, which offer high data-rate transmission, reliability, and system flexibility, are adopted. Various multiple access schemes have been considered for the 4G communication systems with special focus on spectral efficiency and system complexity. OFDM-based multiple access schemes and associated hybrid technologies have become popular and have been the focus of recent mobile communications research because of their inherent advantages which include efficient and reliable high data-rate transmission as well as low system complexity.

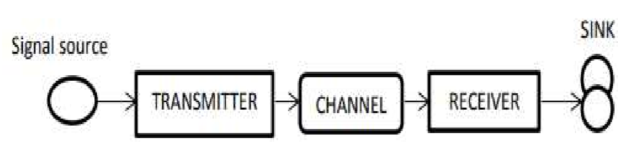

Fig. 1-1 Simple block diagram of a Communication System

2. RESEARCH OBJECTIVE

The unprecedented growth and demand for wireless communication services has been overwhelming especially in recent decades. There has been a surge, more than ever before in the number of subscribers, desiring improved and reliable communication services even in the face of a limited spectrum. Also, wireless communication comes with its own peculiarity and challenges, which must be addressed in order to provide good quality of service to users. Effective mobile communication schemes are therefore needed to be put in place to ensure the continuous provision of reliable services while ensuring an efficient management of the scarce spectrum. Various multicarrier schemes have been used in the past to enable multiple users access the available spectrum simultaneously. However, the need for better quality of service, improved capacity and high data-rate transmission, which has become nonnegotiable, has informed the continuous search for a reliable and efficient multicarrier scheme. The Code Division Multiple Access (CDMA) and the Orthogonal Frequency Division Multiplexing (OFDM) techniques rank high above other multiuser schemes due to their inherent advantages. The OFDM technique has particularly become difficult to ignore and almost indispensible because of its support for high data rate transmission and the ability to suppress ISI without much difficulty. Thus, OFDM has now become the bedrock of most recent multicarrier schemes in wireless communication. The combination of the CDMA and the OFDM technique to form a hybrid scheme of OFDMCDMA has gained prominence and considered attractive due to the diversity and radio resource management flexibility offered. As studied in [13, 14], there are various methods of combining the OFDM and the CDMA scheme, but the main idea behind the multicarrier CDMA hybrid scheme is to perform a spreading operation on transmitted signals which are then converted into parallel streams. The serial-to-parallel converted data are then modulated over different subcarriers, which are mutually orthogonal, and transmitted over the radio channel. The spreading code assigned to each user is to enable signal separation at the receiver. However, due 11 to diverse level of fading and attenuation experienced by the transmitted signals, orthogonality is lost among subcarriers. This leads to Multiple Access Interference (MAI), causing high degradation in cellular performance, which becomes severe as the number of simultaneous users increases. In an effort to address the MAI in multicarrier CDMA (MC-CDMA), the Multiuser Detection (MUD) technique was introduced. The priority of the MUD is to subtract interfering signals from the input signal of each user in the system. However, the MUD technique utilized in MC-CDMA comes with associated complexities and high cost [15, 16]. Various MUD techniques have been proposed to address the high complexity of the MUD technique, but with little success. The complexity of the MUD tends to increase exponentially as the number of active subscribers increases. Recent studies have explored the possibility of the artificial neural network for multiuser detection [17] but these techniques tend to compromise system performance and efficiency for reduced complexity. The MUD challenge in MC-CDMA therefore remains and there has been a continuous search for an efficient and reliable scheme with low complexity. To this end, a new multiuser scheme was recently proposed by Li Ping called the Interleave Division Multiple Access (IDMA) [18]. This scheme employs a simple low cost chip-by-chip iterative method for its multiuser detection. The IDMA scheme, which offers a lower system complexity compared to MC-CDMA [19], relies solely on interleaving as the only means of identifying signals from active users in the system. In a bid to achieve an improved cellular performance of the IDMA over multipath, Mahafeno in 2006 proposed an OFDM-based hybrid scheme called the OFDM-IDMA scheme [20]. The newly proposed multicarrier IDMA (MCIDMA) scheme therefore combats ISI and MAI effectively over multipath with low complexity. The multicarrier scheme ensures a better cellular performance, high diversity order, and spectral efficiency compared to the MC-CDMA scheme. Thus, the scheme combines all the inherent advantages of the conventional IDMA and the OFDM technique. The associated MUD is of low cost and low complexity per user, which is independent of the number of simultaneous users in the system [21]. Major studies on the OFDM-IDMA scheme focus only on the implementation of the scheme in a perfect scenario, assuming that there are no synchronization errors in the system. This is not obtainable in practice. Recent studies however show that the OFDM component introduced 12 makes the multicarrier system susceptible to synchronization errors, especially at the uplink. Synchronization errors, which results mainly from Doppler shifts and local oscillator instabilities [22], cause inter channel interference and loss of orthogonality among users. This subsequently leads to an overall reduced throughput and degraded cellular performance. Hence, the impact of synchronization errors on the recently proposed scheme must be addressed to obtain the best performance out of this noble scheme. This work therefore focuses thoroughly on the development and the implementation of synchronization algorithms, to combat the degrading impact of carrier frequency offset errors, thereby greatly improving the overall throughput of the multicarrier IDMA system.

3. THE OFDM-IDMA MULTIUSER SYSTEM

The multicarrier CDMA scheme, as discussed earlier, is largely limited by ISI and MAI. The IDMA scheme was proposed as a solution to the challenges confronting the MC-CDMA scheme. The proposed multicarrier IDMA scheme, which has been the focus of recent studies in wireless communications, is seen as a serious contender for the 4G and LTE cellular networks. Just as in the case of MC-CDMA, the multicarrier IDMA scheme is an OFDM-based hybrid multiuser scheme, which is a combination of the OFDM and the IDMA technique. The idea of combining OFDM with IDMA was to significantly improve the performance of the conventional IDMA system over multipath channels [20]. The combined scheme offers the advantages inherent in both

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OFDM and IDMA schemes and achieves a better performance than the MC-CDMA scheme, as studied in [19]. This section therefore gives a detailed review of the major studies on OFDM and the IDMA techniques.

3.1. Principles of OFDM

The orthogonal frequency division multiplexing technique dates back to about some four decades ago when a paper was published on the synthesis of band-limited orthogonal signals for multichannel data transmission by Chang [23], which was also patented in 1966. He proffered a principle where messages are transmitted via a linear band-limited channel without inter-carrier interference and inter-symbol interference. A year later, Saltzberg [24] presented a performance analysis of effective signal transmission in parallel form. There were other important contributions to OFDM in the following years by Weinstein and Ebert [25], Peled and Ruiz [26] among others, but OFDM, was first proffered as a wireless communication solution by Cimini in 1985 [27]. With the OFDM now realistic, practicable and widely accepted, it is now being employed in several wireless technologies and standards such as digital audio broadcasting (DAB), digital video broadcasting (DVB), high-rate wireless LAN standard [28, 29] (IEEE 802.11a) and the IEEE 802.16a metropolitan area network (MAN) standard.

In OFDM, high data rate streams are essentially divided into N parallel streams, each of a lower data rate, which are modulated by different sub-carriers while the symbol duration is being prolonged N times. The lower data rate streams are transmitted in parallel, over multiplexed subcarriers, which are mutually orthogonal. As long as orthogonality is maintained, there will be no interference between sub-carriers i.e. Inter carrier interference (ICI) and this will as well enable the receiver to separate signals carried by each sub-carriers [28]. Unlike the conventional Frequency Division Multiplexing (FDM) scheme, the spectra of the different modulated sub-carriers overlap in OFDM (Fig. 2-1b). This makes OFDM an appropriate scheme for optimum and efficient use of valuable spectrum. Also, the conversion of frequency-selective fading channel into a collection of parallel flat fading sub-channels simplifies the receiver structure of the OFDM system.

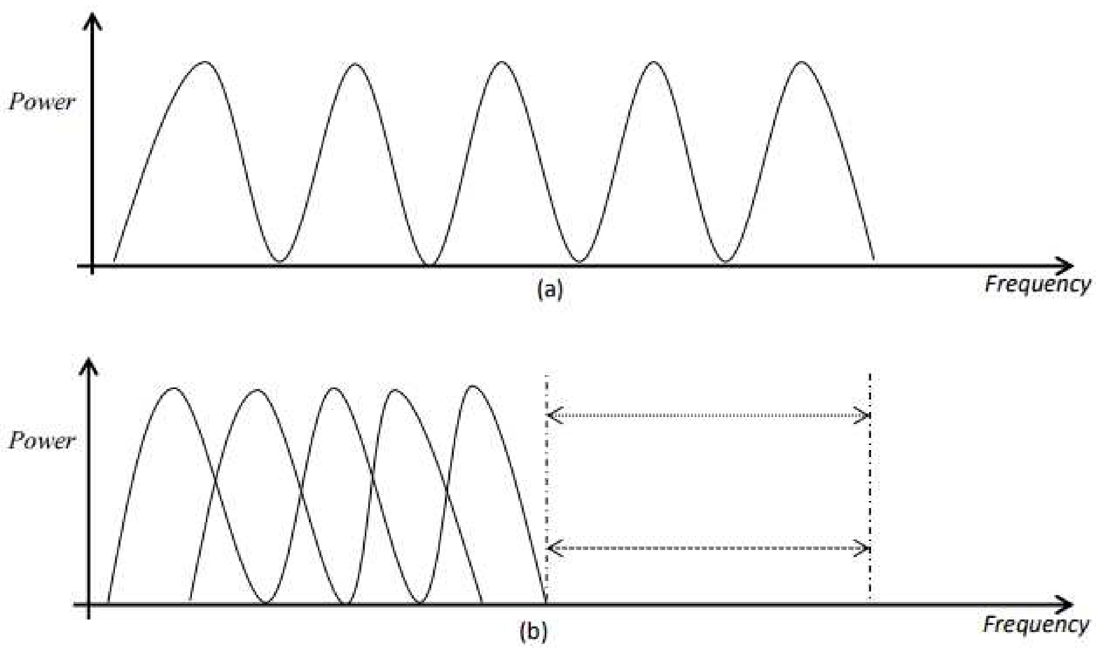

Fig. 2-1 Illustration of the spectrum-saving concept of the OFDM technique (b) compared with the regular FDM scheme (a)

Local Oscillators (LOs) were used earlier in OFDM implementation. However, the associated complexity and high cost, made real-life implementation unsuitable. The idea behind the analog implementation was extended to the digital domain by using the DFT and IDFT [25], being employed mainly to transform data between time domain and frequency domain. The introduction and the eventual use of the discrete Fourier transform and its inverse was a major breakthrough in OFDM implementation. In practice, however, OFDM systems are implemented using a combination of FFT and IFFT blocks that are mathematical equivalent versions of the DFT and IDFT, respectively, but more efficient to implement. Recent advances in very large scale integration technologies (VLSI) also have ensured an easy, cheap, and fast implementation using FFTs and IFFTs. In this approach, the data stream is divided into blocks of N symbols. Each block of data is then subjected to an IFFT and then transmitted. The immediate output of the IFFT has to be transmitted one at a time, hence, a

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parallel to serial conversion after the operation. This process, however, is reversed (i.e. serial to parallel conversion) and an inverse operation FFT is performed at the receiver [28].

Figure 2-2 illustrates in block diagram the adaptation of the IEEE standard 802.11a [29] for a baseband OFDM Transceiver. Each sub-carrier is modulated in phase and amplitude by the data bits in the OFDM system. One or more bits are being used in the modulation of each sub-carrier, depending on the kind of modulation method adopted (QPSK, 16/64 QAM, BPSK are most commonly used). Different coding schemes are used to achieve low SNR and to obtain better system efficiency. The encoded data stream is interleaved. This process involves assigning adjacent data bits to non-adjacent bits to reduce the burst symbol error. Interleaving reorders the data stream to avoid burst error. In the mapping process, modulated data are assigned to subcarriers based on sub-carrier assignment information obtained from sub-carrier level sensing [30]. These are then serial-to-parallel converted and fed into the IFFT, which transforms the data from frequency domain to time domain. Each time-domain OFDM symbol is extended by the socalled cyclic prefix [31] or guard interval of Ng samples duration in order to combat intersymbol interference. The samples of the guard interval are copied from the end of the time domain OFDM symbols as shown in Fig. 2-3. Typically, guard interval or the cyclic prefix of not more than 10% of the OFDM symbol's duration is employed though this is discarded at the receiver. Passing through the Digital-to-analog (DAC) converter, the signal is amplified and upconverted to desired center frequency before transmission in the frequency selective fading channel [32].

At the receiver, the CP symbols are removed after analog to digital conversion. A crucial synchronization process as indicated in Fig. 2-2 is carried out to estimate and correct carrier frequency offsets of the received signal as well as to find the symbol boundaries to prevent ISI and ICI. The FFT of the signal is taken before channel estimation is carried out to estimate the time and frequency domain response, in order to correctly detect and recover the transmitted data. The reverse of the other processes at the transmitter are executed at the receiver, as shown in Fig. 2-2, before the final process of decoding takes place in order to give the binary output signal [33].

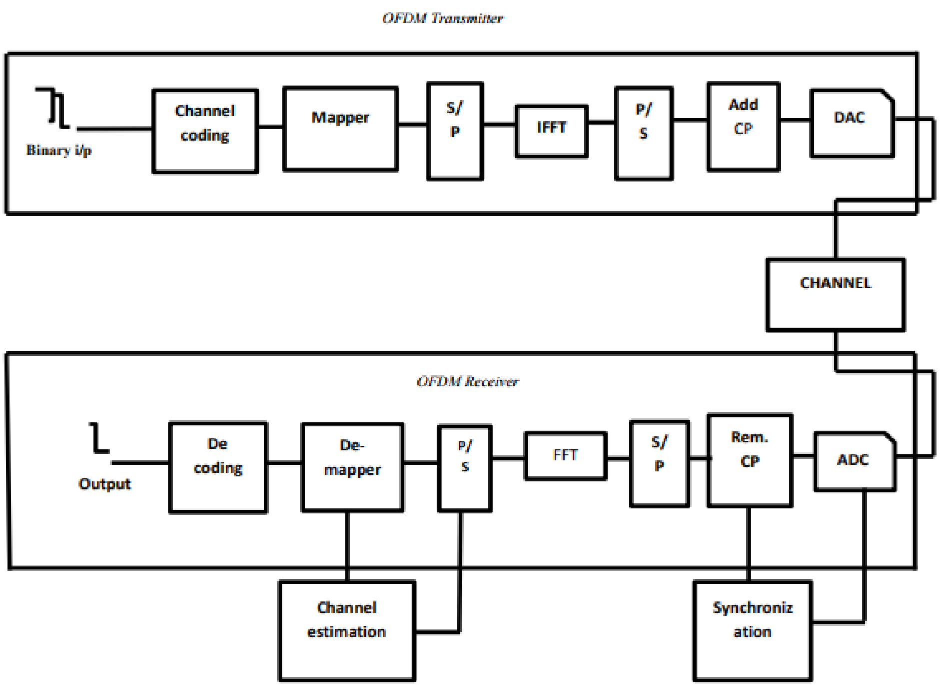

Fig. 2-2 Block diagram of a typical OFDM transceiver

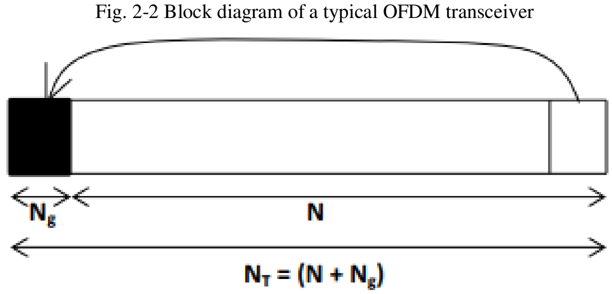

Fig. 2-3 Cyclic extension concept showing N sub-carrier OFDM signal with guard interval Ng

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3.2. The IDMA Scheme

The IDMA technique as recently proposed is a multiuser scheme where interleavers serve as the sole means of distinguishing signals from different users at the receiver. The interleavers, which are randomly generated, are essentially different for each active user in the system [18]. The IDMA achieves all the inherent advantages of the CDMA such as dynamic channel sharing, robustness against multipath, system flexibility, and ease of cell planning [19]. The IDMA also offers improved capacity, and effectively combats MAI with low complexity, which is independent of the number of simultaneous users in the system. In a bid to achieve an enhanced cellular performance of the conventional IDMA over multipath, the OFDM-IDMA scheme was introduced in [20]. The combined OFDM-IDMA scheme therefore combats ISI and MAI effectively over multipath with low complexity and effectively supports high data rate transmission. The multicarrier scheme ensures a better cellular performance, higher diversity order, and spectral efficiency with associated low cost MUD [21].

3.3. The Transmitter Structure

The transceiver structure of the conventional IDMA scheme is shown in Fig. 2-4. The transmitter and the receiver structures of the OFDM-IDMA scheme is the same as the conventional IDMA structure plus the OFDM component as shown in Fig. 2-5. Considering the transmitter part of Fig. 2-5, with K users transmitting simultaneously, for anyone of the users denoted by k, the input data array is first encoded using a Forward Error Correction (FEC) code. The low-rate FEC technique, which replaces the spreading operation carried out in MC-CDMA, is used for controlling errors in the input data propagation over the fading channel and to increase the coding gain of the multiuser system. Each of the chips are then assigned distinct interleavers represented as . The assigned interleavers are randomly generated and a chip sequence results [52]. This process represents an important part of the multicarrier IDMA scheme, as the interleavers are the sole means of identifying different users in the system, ensuring ease of separation of signals coming from the various users at the receiver.

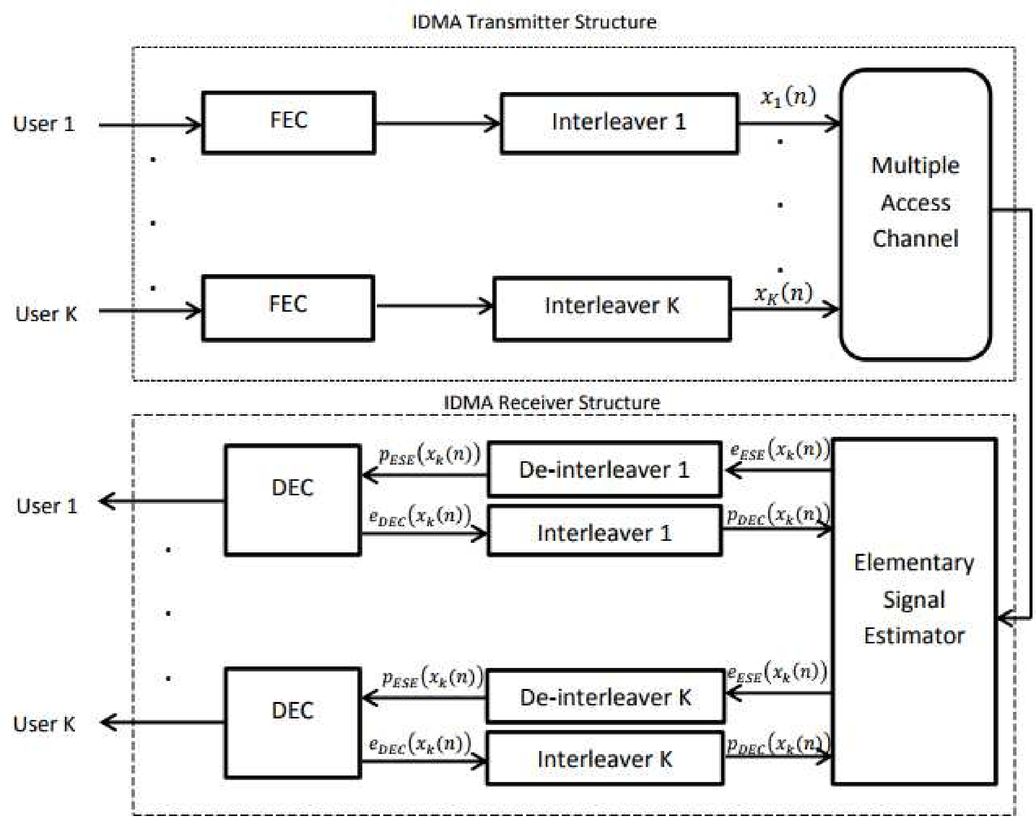

Fig. 2-4 Conventional IDMA Transceiver

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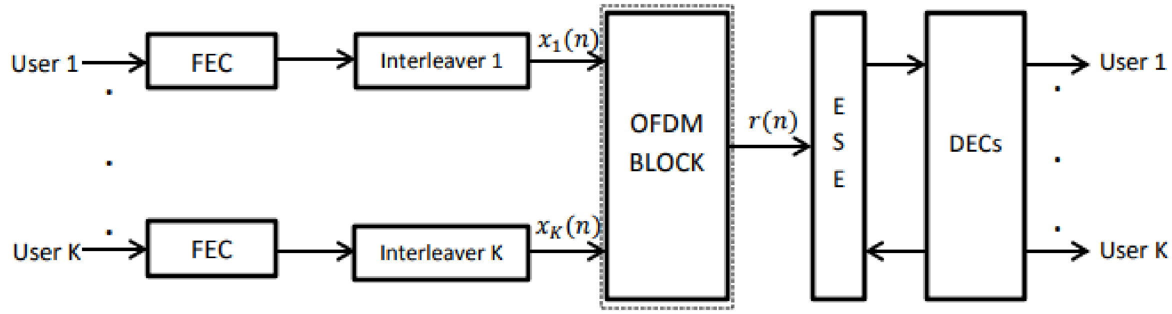

Fig. 2-5 OFDM-IDMA Transceiver

3.4. The Receiver Structure

The OFDM-IDMA scheme has a unique sub-optimal receiver structure [53], which consists mainly of the Elementary Signal Estimator (ESE) and a posteriori probability decoders (DECs). At the transmitter, the resulting sampled radio signal is transmitted over the multipath channel after the inverse fast Fourier transforms (IFFT) process, and the received signal is given as

$$r(n) = \sum_{k=1}^{K} x_k(n) h_k(n) + d(n),$$

$$= x_k(n) h_k(n) + \beth_k(n),$$

where hk(n), is the fading channel coefficient for an active user k, (n) is the additive white Gaussian noise with zero mean and variance σ 2 . The symbol represents the multiuser interference due to other users combined with the Gaussian noise (n), with respect to user k and can be expressed as

$$\beth_k(n) = \sum_{k' \neq k} x_{k'}(n) h_{k'}(n) + d(n),$$

The ESE, which operates on a chip-by-chip order and a posteriori probability (APP) decoders are present at the receiver of system model for each active user k [54]. The presence of the ESE and the APP decoders represents a crucial aspect of the OFDM-IDMA process, which will be explained in detail.

4. FREQUENCY SYNCHRONIZATION IN OFDM-IDMA SYSTEMS

The OFDM-IDMA scheme offers an improved performance over the conventional IDMA scheme, and its main objective is to mitigate MAI and ISI over multipath channels, with low complexity [20]. The OFDM component in the system effectively combats ISI, but makes the system susceptible to synchronization errors. Thus, the OFDM-IDMA scheme becomes sensitive to synchronization errors due to the OFDM technique especially in the uplink channel, where different users are transmitting asynchronously, experiencing different levels of fading and delays. Most studies on OFDM-IDMA system assume perfect synchronization scenario, but this is not feasible in practice. Therefore, a comprehensive performance analysis on the OFDMIDMA is in order, to verify the performance of the system in the presence of synchronization error. As stated earlier, the ISI caused by timing offsets is effectively addressed by the OFDM component, as the guard interval is made longer than the maximum channel delay spread. Hence, focus is on the more challenging impact of the carrier frequency offset error on the multicarrier IDMA scheme and a linear MMSE-based synchronization algorithm is presented to address the deteriorating effect of synchronization errors on the overall output of the system.

The OFDM-IDMA scheme has been considered under ideal conditions. In practice, the scheme is subjected to synchronization errors, which reduce the overall performance of the system. Synchronization errors between the transmitter and the receiver of any mobile communication system increase the number of errors in the received bits of the radio signal. Carrier Frequency offset results mainly from two sources; mismatch between the transmitted and the received sampling clocks as well as the misalignment between the reference radio frequencies of the transmitter and receiver [58, 59]. The impact of carrier frequency offsets on OFDM-IDMA scheme was examined in [60] by Yong Liu et al. It was stated there, that the performance of the OFDM-IDMA scheme degrades with an increasing ratio between the maximum frequency offset and carrier spacing [60]. Also, a report on the OFDM-IDMA communication scheme with carrier frequency offsets is given in [61], focusing mainly on underwater acoustic channels (UWA). The sub-carriers in the OFDM component are essentially closely spaced in frequency compared to the spectrum bandwidth. Thus, the allowable frequency offset becomes a very small fraction of the available spectrum bandwidth [58, 62]. This makes the OFDM-IDMA system highly sensitive and maintaining sufficient open loop frequency accuracy therefore becomes difficult in the system, resulting in a significant Doppler shift [63, 64]. Carrier frequency offset errors cause inter-channel interference (ICI) and loss of orthogonality among the sub-carriers, leading to the overall performance degradation of the system.

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5. CONCLUSION

A comprehensive research work has been carried out on the newly proposed OFDM-IDMA scheme. This noble scheme ensures an efficient utilization of the scarce spectrum as the demand for mobile communication increases. Wireless communication has recorded an extraordinary and exponential growth especially in recent decades. As a result, different schemes have been proposed in a bid to improve the overall efficiency of the cellular system. The various multiple access schemes used in the past generations were discussed in chapter 1, as well as the general peculiarity of the wireless channel. In chapter 2, the multicarrier IDMA multiuser scheme and the major studies pertaining to this scheme was introduced and reviewed. The OFDM technique, which forms the bedrock of the hybrid OFDM-IDMA scheme, was discussed, pointing out the major challenges in this modulation technique. The concept of the multicarrier IDMA, as well as the ESE function, which carries out a coarse chip-by-chip detection to roughly remove interference among users in the system, were also examined and explained in detail. The design of the multicarrier IDMA system used is such that the cyclic prefix duration of the OFDM component is longer than the maximum channel delay spread of the multipath channel model. This effectively eliminates ISI as well as timing offsets in the system model. However, this scheme is susceptible to synchronization errors especially at the uplink due to the OFDM component present in the system. A thorough investigation and analysis was therefore carried out focusing on the more challenging impact of carrier frequency offset errors on the OFDM-IDMA scheme.

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