Performance Comparison of OFDM, MC-CDMA and OFCDM for 4G Wireless Broadband Access and Beyond

Syed M. Zafar S. Shah, A. W. Umbrani, and Aftab A. Memon
Institute of Information and Communication Technologies
Mehran University of Engineering and Technology
Jamshoro 76062, Pakistan

Abstract—The performance comparison of the three most feasible multiple access techniques proposed for fourth generation wireless communication systems, i.e., Orthogonal Frequency and Code Division Multiplexing (OFCDM), Orthogonal Frequency Division Multiplexing (OFDM), and Multi-Carrier Code Division Multiple Access (MC-CDMA) is evaluated. The objective is to find the most suitable technique for implementation in 4G Communication Systems. The modems of OFDM, MC-CDMA and OFCDM have been redesigned and performance is analyzed in terms of probability of error. The results reveal that OFCDM provides the lowest BER for a given SNR.

1. INTRODUCTION

The two main candidates for fourth generation (4G) mobile communication systems are WiMAX 802.16e and Long Term Evolution (LTE) Advanced initially endorsed by ITU-R enabling true broadband services with transmission rates up to 100 Mbps with full mobility and 1 Gbps with limited mobility [1–3]. However, none of these systems support such higher transmission rates. The major hindrance is the weak ‘Resource Accessing’ techniques used at the physical layer of the incumbent systems, which either rely on FDMA, TDMA and DS-CDMA or combination of them, to provide access to multiple users. There have been several proposals including Orthogonal Frequency Division Multiplexing (OFDM), Multi-Carrier Code Division Multiple-Access (MC-CDMA) and Orthogonal Frequency & Code Division Multiplexing (OFCDM) for the adoption as multiple access techniques [4–6]. MC-CDMA has been thoroughly explained in [4, 6]. The motivation was to combine the advantages of multicarrier transmission with the ability of CDMA to accommodate a greater number of users. Later, a combination of multicarrier transmission with two-dimensional spreading named Orthogonal Frequency & Code Division Multiplexing (OFCDM) is introduced by [5]. The authors in [5] have advocated the use of OFCDM for future 4G mobile communications by providing its basic structure and main functions over OFDM system. However, the authors do not take into account the consideration that the MC-CDMA is also a potential technique for 4G mobile communications. A comparison of OFCDM with MC-CDMA would have been more appropriate. Motivated by their work we compare, in this paper, the performance of OFCDM, OFDM and MC-CDMA systems, keeping the aim to find the suitable technique for implementation in 4G systems. The modems of OFDM, MC-CDMA and OFCDM have been redesigned and the performance is simulated under a practical 6-tap frequency-selective Rayleigh fading channel.

2. SIGNAL STRUCTURE COMPARISON

The structure for an OFDM symbol is shown in Figure 1, where it is assumed that the multicarrier transmission consists of four subcarriers, i.e., \( N_c = 4 \). Multiple access can be provided to users by either allocating each user a particular subcarrier for transmission, i.e., FDMA, illustrated in Figure 1(a), or by allocating all subcarriers to a user for a particular yet a reasonable amount of time, i.e., TDMA, illustrated in Figure 1(b). The signal structure for an MC-CDMA symbol accommodating a single user is illustrated in Figure 2(a). The MC-CDMA symbol is generated as follows: A block of real-valued BPSK modulated symbol, assuming \{+1\} here from \{+1, -1\}, is repeated onto the subcarriers. The data is then spread by a frequency-domain spreading sequence, \{+1, -1, +1, -1\} with the spreading factor \(SF_{freq} = 4\). The number of subcarriers \(N_c\) and \(SF_{freq}\) have been chosen to be equal, however, \(SF_{freq} < N_c\) is also possible. A key observation in the signal structure of MC-CDMA is that spreading in frequency domain does not require additional bandwidth, which is in contrast to DS-CDMA [4]. Figure 2(b) shows the signal structure of an MC-CDMA symbol that accommodates four users over the same number of subcarriers; by multiplexing the data of each user over the frequency-power axis. Since there is a requirement for a synchronous
OFDM-TDMA signal structure. (b) OFDM-FDMA signal structure.

Figure 1: (a) OFDM-TDMA signal structure. (b) OFDM-FDMA signal structure.

An illustration of signal structure of an OFCDM symbol is shown in Figure 3(a). OFCDM can be implemented in two basic ways, i.e., by first implementing DS-CDMA followed by MC-CDMA or vice versa. For our implementation we have chosen the former, with the generation of symbol as follows: A block of BPSK modulated symbol, assuming \{+1\} here from \{+1, -1\} is spread in time domain, over the power-time axes, by a spreading code \{+1, -1\}, with a spreading factor \(SF_{time} = 2\). Next, every chip of the spread sequence is repeated onto the four subcarriers. This data is subsequently spread in the frequency-domain by a spreading sequence \{+1, -1, -1, -1\} with the spreading factor \(SF_{freq} = 4\) to yield a signal whose power has been spread over two dimensions.

OFCDM provides access to users by allocating a block of the 2D symbol. The spreading factor for a user is therefore the product of the factors of both domains, given as \(SF = SF_{time} \times SF_{freq}\). In Figure 3(b), the signal structure for an OFCDM symbol is shown, which accommodates 8 users with \(SF_{time} = 2\) and \(SF_{freq} = 4\) (\(SF = 8\)). It can be inferred by comparison between the signal structures of the three techniques that OFCDM provides the best utilization of physical layer resources by accommodating a greater number of users. Another significant revelation is that an OFCDM symbol can be downgraded to either an MC-CDMA symbol by using \(SF_{time} = 1\) and even to an OFDM symbol by using \(SF_{time} = 1\) and \(SF_{freq} = 1\). For comparison between OFDM and OFCDMA the reader is advised to [6, Figure 1].

3. SYSTEM COMPARISON

The transmitter structure for OFDM is shown in Figure 4(a), where user data, as a serial stream of bits, is modulated by a suitable digital modulation technique and then converted from a serial stream in to \(N_c\) parallel sub-streams. Each stream will be up-converted by carriers that are orthogonal to each other. This is performed by applying the IDFT algorithm onto the parallel sub-
streams. A part of the signal’s tail is copied to its front, therefore prefix, before sending it through the channel. This helps in creating a guard space in the time-domain for delayed multipath signals and prevents successive symbols interfering with each other. The transmitter for MC-CDMA, illustrated in Figure 4(b), is similar to that of OFDM. Data bits are modulated and repeated onto $N_c$ parallel streams. After that, each sub-stream is multiplied by a chip of a unique spreading sequence. This step would perform the objective of multiplexing in the frequency-domain. The transmitter for OFCDM is illustrated in Figure 4(b). Data bits are modulated and spread in the time domain by a sequence of spreading factor $SF_{time}$. This step would perform the objective of multiplexing in the time domain. The second part of 2D spreading is in the frequency domain, which can be implemented by repeating each chip of the spread sequence onto $N_c$ parallel streams. Similar to MC-CDMA, each stream is multiplied by a chip of a spreading sequence. The final part of the OFCDM transmitter is to implement OFDM transmission described in the previous section.

4. SIMULATION RESULTS

The bit error rate was computed by varying the Energy-of-Bit-to-Noise-ratio ($E_b/N_0$) over a 6-tap Rayleigh distributed static channel with taps, $[0.89, 0.71, 0.56, 0.45, 0.35, 0.28]$. Perfect channel estimation was assumed for equalization at the receiver so that the BER performance of the access techniques alone could be observed. The performance comparison for the equalizers has been illustrated in Figure 5, where OFDM, MC-CDMA and OFCDM transceivers have been designed with both types of equalizers. The spreading factor for MC-CDMA and OFCDM was kept constant at 8.
It was observed that MMSE equalizer in general performs better than ZF equalizer. Interestingly, OFCDM with ZF equalizer had a better performance than MC-CDMA MMSE at low values of $E_b/N_0$, but beyond 12 dB, MC-CDMA MMSE’s BER fell drastically with respect to $E_b/N_0$. However, OFCDM MMSE continues to perform better than MC-CDMA MMSE. With the Zero Forcing equalizer, the performance of MC-CDMA is similar to that of the performance of OFDM.

5. CONCLUSIONS

We elaborated in detail the signal structure of OFDM, MC-CDMA and OFCDM and it was established that OFCDM is in fact, a superset for OFDM and MC-CDMA. The techniques were then compared in terms of bit-error-rate performance, which was estimated over a 6-tap frequency-selective Rayleigh fading channel using the Monte Carlo randomization method. The results demonstrated that OFCDM provides the lowest BER for a given $E_b/N_0$ as compared to the other two techniques. Results also show that the selection of a higher spreading factor for frequency-domain spreading led to an increase in the BER when the channel chosen to be highly frequency-selective and a higher spreading factor for time-domain spreading led to an increase in the requirement for the number of subcarriers.

REFERENCES