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Research Paper

ADAPTIVE MODULATION OF OFDM AND MC-CDMA SYSTEM

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Recently, intense interest has focused on the transmission techniques which can support high data rate transmission over wireless channels for applications including wireless multimedia, wireless Internet access, and future-generation mobile communication systems. However, high data rate transmission is limited by inter-symbol interference (ISI) due to the frequency selective fading in multipath fading channels. To meet the strong demand for broadband multimedia services by both nomadic and mobile users, it is important to increase the bit rate of future mobile communications systems. To enhance system capacity, novel technologies or new concepts for improving bandwidth efficiency are indispensable. Orthogonal frequency division multiplexing (OFDM) is one of the promising solutions to this problem. The combination of MC-CDMA and OFDM is an effective way to further improve the performance. In this work, an adaptive downlink modulation using OFDM and MC-CDMA is presented for maximizing the system capacity and actualizing QoS (Quality of Service) control of future mobile communications. The basic concept of the proposal method is that a time frame is divided into two sub-frames, one is for OFDM and the other is for MC- CDMA, and the base station (BS) allocates a preferable modulation scheme to each user per each time slot in accordance with their service requirements and link conditions such as the received signal strength indication (RSSI) level and interference signal strength.

Keywords: OFDM, MC-CDMA, RSSI, CINR

TECHNOLOGY CONCEPT

Many modulation schemes such as Single Carrier (SC), CDMA, OFDM, and Multi-Carrier (MC)-CDMA have been proposed for mobile systems, nomadic wireless access and fixed wireless access (Jingtao Zhang and David W Matolak, 2008; Kasas and Leung, xxxx; Carl W Baum and Keith F Conner, 1996; and Faze,

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1993). The selection of radio interface depends on the specifications of the system. OFDM is an attractive modulation scheme because of its high immunity to multi-path fading and its capability of offering a high transmission rate. However, the link quality of the OFDM system could be degraded when the co-channel interference signal strength from adjacent cells is increased.

OFDM and CDMA combined modulation schemes such as MC-CDMA and MC-DS/CDMA are attractive techniques that increase the processing gain in the frequency domain and time domain, respectively (Jingtao Zhang and David W Matolak, 2008). In addition, the OFDM and CDMA combined scheme offers high transmission rate under multi- path fading environments and mitigates co-channel interference from adjacent cells. However, it is difficult to enhance its transmission rate per user by restricting the allocated bandwidth when the spreading factor (SF) is very large.

As explained above, each modulation scheme has distinct physical features. Namely, schemes have advantages and disadvantages in accordance with channel conditions such as the Carrier to Noise Ratio (CNR), Carrier to Interference Ratio (CIR), delay spread, and other parameters. The time and frequency spreading technique proposed in (Kasas and Leung, xxxx) is one method for adjusting the spreading factors in accordance with channel conditions. However, this method requires both a time and frequency spreading function for the user terminal and the base station has to be able to manage the complicated spreading codes to maintain the orthogonality between users.

The adaptive downlink modulation scheme using OFDM and MC-CDMA is a candidate for maximizing the system capacity of future mobile communications systems (Jigisha et al., 2007). The basic concept of the method is that a time frame is divided into two sub-frames, one is for OFDM and the other is for MC- CDMA. In this scheme, the BS allocates a preferable modulation scheme and its parameters such as spreading factor, sub-carrier modulation and coding rate to each user per each time slot in accordance with the RSSI level and interference signal strength. As the hardware structures of OFDM and MC-CDMA are basically identical, the hardware complexity of the proposed method is much smaller than that of the time and frequency spreading techniques. In addition, the BS will allocate the modulation scheme and its parameters depending on user request (QoS).

Using the adaptive downlink modulation scheme, the same channel frequency will be reused in every radio cell by allocating the OFDM scheme to users located in optimum RSSI and CIR conditions and the MC-CDMA scheme to users in harsh conditions, respectively. This feature also offers different service quality to different users in accordance with their requirements and channel conditions. By allocating the modulation scheme and its parameters (mapping pattern, coding rate, spreading factor, etc.) adaptively, users will be able to maintain their communications even in harsh wireless environments.

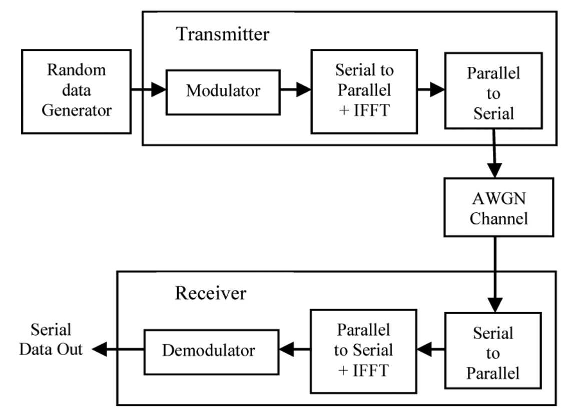
INTRODUCTION OF OFDM

Many methods are proposed to combat the multipath effects in wireless communication.

One of the solutions to combat Inter Symbol Interference (ISI) is multicarrier modulation for data transmission (Jigisha et al., 2007; and Kasas and Leung, 1999), that is Orthogonal Frequency Division Multiplexing (OFDM). The analysis of Bit Error Rate (BER) performance suggests, OFDM is better than Code Division Multiple Access (CDMA) which is mostly incorporated in existing 3G systems (Jingtao Zhang and David W Matolak, 2008).

The aim of OFDM is to divide the wide frequency selectivity of fading channels into multiple flat fading channels (Jigisha et al., 2007). The idea of using a Discrete Fourier Transform (DFT) for the generation and reception of OFDM signals eliminates the requirement of banks of analog sub carrier oscillators ingtao (Jingtao Zhang and David W Matolak, 2008). Orthogonality property allows multiple information signals to be transmitted in parallel over a common channel and detected, without interference. In OFDM spectrum each subchannel has a peak at the subcarrier frequency and nulls evenly spaced with a frequency gap equal to the carrier spacing $\Delta f = 1/Ts$, where Ts is OFDM symbol duration. Another characteristic of orthogonality is that each carrier has an integer number of sine wave cycles in one bit period. Although OFDM enables simple equalization, it is sensitive to carrier frequency offset (Jingtao Zhang and David W Matolak, 2008). The peak to average ratio (PAR) of the transmitted signal power is large. OFDM system performance can be improved by channel coding. Figure 1 shows the block diagram of OFDM.

Figure 1: Block Diagram of OFDM Transceiver



OFDM TRANSCEIVER

Binary source: The random data generator generates binary data that is frame based. In data output, 48 samples per frame are used, and data rate is 1 Mbps.

Data Mapping: The input data stream is available serially, converted into parallel stream according to digital modulation scheme. The data is transmitted in parallel by assigning each data word to one carrier in the transmission. Once each subcarrier has been allocated symbols, they are phase mapped according to modulation scheme, which is then represented by a complex In-phase and Quadrature-phase (I-Q) vector. M- QAM modulation can be considered as combination of ASK (Amplitude Shift Keying) and M-PSK. Digital M-PSK is a special case of M-QAM, where the amplitude of the modulated signal is constant. In general, the selection of modulation scheme applied to each subchannel depends solely on the compromise between the data rate requirement and transmission robustness.

IFFT-Frequency Domain to Time Domain Conversion: The IFFT converts frequency domain data into time domain signal and at the same time maintains the orthogonality of subcarriers. The real signal output can be generated by arranging conjugate subcarriers (Jigisha et al., 2007) as shown in Figure 1. In this stage, IFFT mapping, zero pad, and selector blocks are included. Zero pad blocks adds zeros to adjust the IFFT bin size of length L, as the number of subcarriers may be less than bin size. Selector block reorders the subcarriers.

Guard Period: The effect of ISI on an OFDM signal can be eliminated by the addition of a guard period at the start of each symbol (Faze, 1993). The guard period adds time overhead, decreasing the overall spectral efficiency of the system. Guard duration should be longer than channel delay spread (Jingtao Zhang and David W Matolak, 2008). After the guard band has been added, the symbols are converted into serial form. One frame length duration T = Ts+Tg, where Ts = NT, N = number of carriers. This is the OFDM base band signal, which can be up converted to required transmission frequency.

An AWGN channel model is then applied to transmitted signal. The model allows for the Signal to Noise Ratio (SNR) variation. The receiver performs the reverse operation of the transmitter. The receiver consists of removal of guard band, FFT, removal of zero padding and demapping of data.

INTRODUCTION OF MC-CDMA

OFDM is an extremely successful technology in dealing with frequency selective fading and intersymbol interference. It is robust in multipath mobile environments and is tolerant to delay spreading. CDMA uses spreading a narrowband signal over a wide spectrum with a spreading sequence unique to each user. The major classification is based on spreading operation that takes place either in time or frequency domain. There are three types of multicarrier CDMA techniques.

- Multicarrier CDMA (MC-CDMA) Scheme.
- Multicarrier Direct Sequence CDMA (MC DS-CDMA) Scheme.
- Multitone CDMA (MT-CDMA) Scheme.

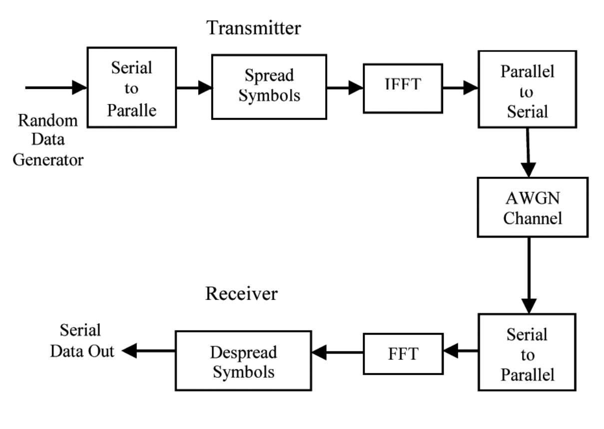
MC-CDMA combines the advantages of both OFDM and CDMA. The lower the symbol rates in each subcarrier, the longer the symbol duration and thus the easier to synchronize the transmissions. The serial input data stream is converted into parallel streams and are spread using CDMA spreading sequences in the frequency domain. This ensures frequency non-selective fading in the subcarriers.

MC-CDMA takes the advantages of both OFDM and CDMA and makes an efficient transmission system by spreading the input data symbols with spreading codes in the frequency domain. It uses a number of narrowband orthogonal subcarriers with symbol duration longer than the delay spread. This makes it unlikely for all the subcarriers to be affected by the same deep fades of the channel at the same time thereby improving performance. Synchronization during transmission becomes easier with longer symbol durations.

MODEL DESIGN OF MC-CDMA TRANSCEIVER

The block diagram of the MC-CDMA system is shown in Figure 2. Binary data is first

Figure 2: Block Diagram of MC-CDMA Transceiver

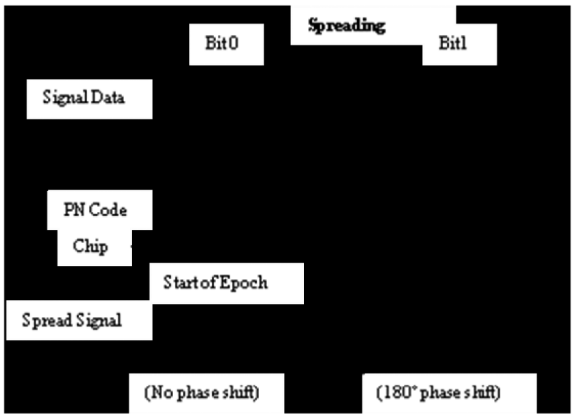


encoded using Turbo coding, followed by serial-to-parallel conversion to produce low bit-rate streams. Each stream is then modulated using a suitable digital modulation method, such as, BPSK, QPSK, 8 PSK, 16QAM etc, depending on the channel estimate information provided by the receiver (Carl W Baum and Keith F Conner, 1996; Faze, 1993; and John A C Bingham, 1990).

The adaptively modulated streams are then passed through the MCCDMA transmitter block, up-converted by an RF amplifier (not shown in this figure) and transmitted. The receiver performs the reverse operation to demodulate and decode the original information. The channel estimator estimates the quality of the channel (Carrier-to-Noise Ratio, CNR) from the pilot symbols which are known QPSK symbols and informs the transmitter. Based on this channel quality estimate, the transmitter decides the modulation format to be used for the next transmission (Masato Saito *et al*., 2005; and Masui and Fujii, 2003). Moreover, it has been assumed that the receiver is aware of the modulation scheme in use.

Spreading Code: The heart of CDMA is the spread spectrum technique, which uses a higher data rate signature pulse to enhance the signal bandwidth far beyond what is necessary for a given data rate. Spreading is obtained via a multiplication of the baseband data information by a spreading sequence of pseudorandom signs, sometimes called pseudo noise (PN) or code signal, before transmission. An example of spreading is illustrated in Figure 3.

Figure 3: Spreading Code in CDMA

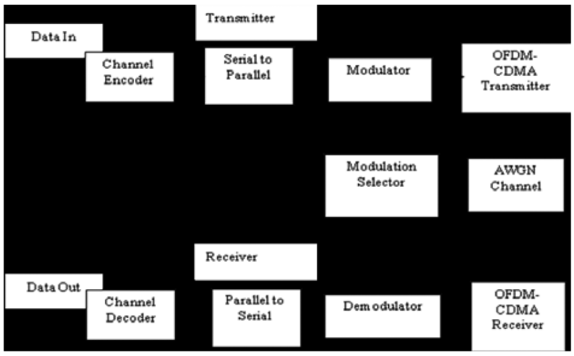


ADAPTIVE MODULATION OF OFDM AND MC-CDMA SYSTEM

Figure 4 represents the adaptive downlink modulation scheme using OFDM and MCCDMA. In this figure, a frame is divided into multiple slots. Some slots are allocated to OFDM and others to MC-CDMA. The transmission power for OFDM slots and MC-CDMA slots is set to be identical to maintain the continuity of the signal level between two modulation schemes.

The concept of this algorithm is based on the combination of adaptively allocating the

Figure 4: Block Diagram of Adaptive Modulation of OFDM and MC-CDMA Transceiver



radio interface and adaptive selection of its parameters. Moreover, the selection of the modulation scheme and its parameters will also be established with regard to the user's QoS. Consequently, the adaptive downlink modulation scheme will maximize the system capacity for wireless communications systems and respond to a user request by allocating a preferable modulation scheme to each time slot per user. Figure 5 shows the Frame structure of time slots of the signal.

Figure 5: Frame Structure

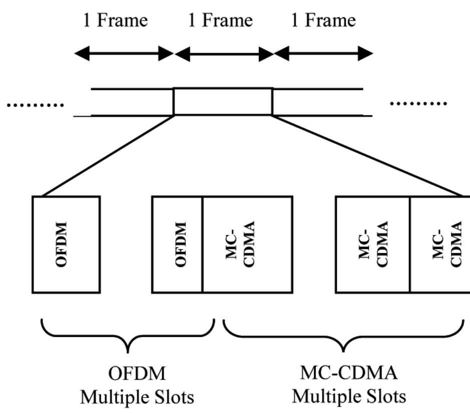
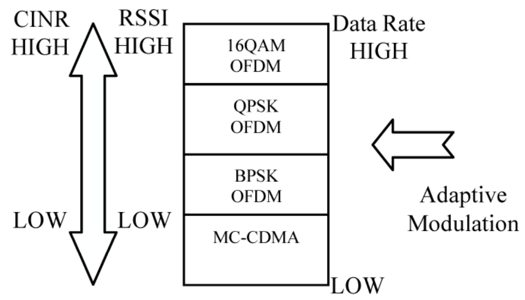


Figure 6 shows the Selection Algorithm of Modulation Scheme. In this case, service areas of OFDM slots should be restricted around the BS and not overlap. Therefore, the same channel frequency can be allocated in every cell, which will enhance the efficiency of channel utilization. In contrast, the service area of MC-CDMA will be overlapped because co-channel interference between adjacent cells is mitigated using the spreading code in the frequency domain. The selection of the spreading code per user should consider the orthogonality between the other codes used in the same cell. As the same service areas of MC-CDMA signals are deployed as the current cellular systems, users will be able to establish their communication link in high mobility environments.

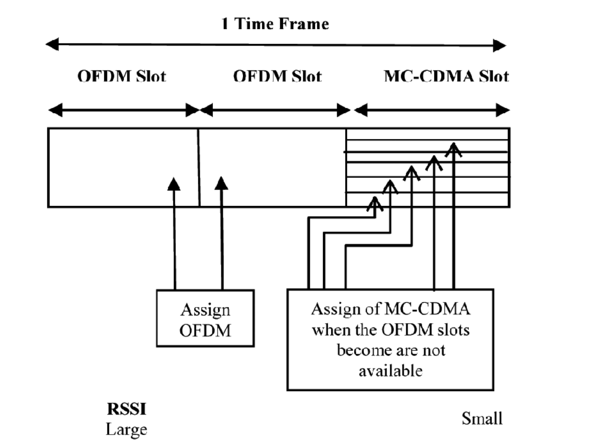
Figure 6: Selection Algorithm of Modulation Scheme



COMPUTER SIMULATION

Computer simulation was conducted to evaluate the throughput performance of a wireless communications system using adaptive down link modulation technology. In each frame, OFDM or MCCDMA slots are assigned to users independently in accordance with channel conditions under fast Rayleigh fading environments. Figure 7 shows the allocation diagram of the modulation scheme per each user. The users close to the BS (RSSI level is high) should be allocated OFDM to provide higher bit rate, and other users far from

Figure 7: Allocation Diagram of Modulation Scheme



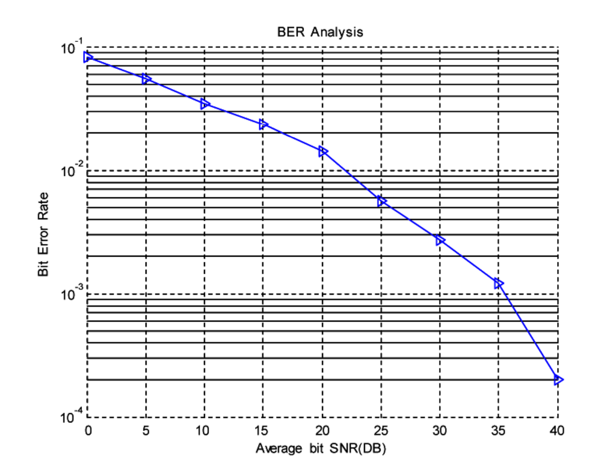
the BS (RSSI level is low) should be allocated MC- CDMA to enhance immunity to cochannel interference.

If the number of OFDM slots is insufficient, MC-CDMA should be allocated to the users. At the same time, the modulation type for subcarriers, coding rate and spreading factor (MCCDMA), is selected at each slot by monitoring the RSSI and CIR level of the control channel transmitted from BS. These procedures actualize a QoS control that allocates high-speed data channels for the users located near the BS.

SIMULATION RESULTS

Figure 9 shows the BER performance analysis of the Adaptive Modulation System of OFDM and MC-CDMA. When the CNIR of the channel is high and the distance of the wireless link is short (RSSI level is high), the BS assigns an OFDM slot with high rate sub-carrier modulation such as 16QAM with a high coding rate. If the CINR is very low, the BS allocates an MC-CDMA slot with high spreading factor and low coding rate to maintain the communication link.

Figure 9: BER Analysis



For this type of transmission achieves the BER of 10-4 with Bandwidth of 40 MHz. Table 1 gives the Average Bit Error Rate for various modulation schemes with Adaptive Modulation of OFDM and MC-CDMA for different number of users. Table 2 gives the Comparison Bit Error Rate analysis for various modulation schemes with Adaptive Modulation of OFDM and MC-CDMA.

By this Adaptive modulation system, input of 8 bit generated and those data can be given to the system. The *data_b* as the input data which as given to the transmitter unit, which can produce output as named as *output0*. The below Figure 10 shows the simulation result of transmitter unit.

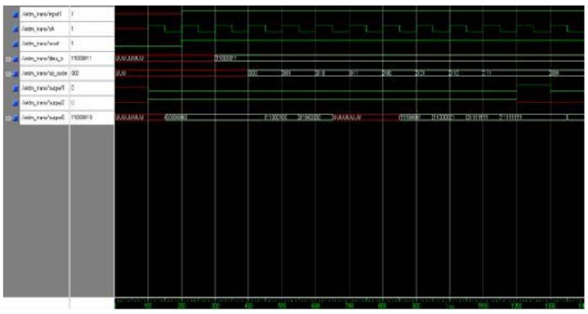
Table 1: Average BER Analysis for Different Modulation Scheme

Number of Users	OFDM	MC-CDMA	Adaptive Modulation for OFDM and MC-CDMA
64	0.0586	0.0577	0.0559
256	0.0398	0.0412	0.0360
512	0.0246	0.0228	0.0208

Table 2: Comparison of BER Analysis for Various Modulation

Average SNR value in dB	OFDM	MC-CDMA	Adaptive Modulation for OFDM and MC-CDMA
1	0.0858	0.0853	0.0770
2	0.0586	0.0577	0.0559
3	0.0398	0.0412	0.0360
4	0.0246	0.0228	0.0208
5	0.0129	0.0137	0.0104
6	0.0098	0.0087	0.0063
7	0.0033	0.0029	0.0013
8	0.0011	0.0009	0.0003

Figure 10: Simulation Result of Transmitter in VLSI



The data from the output at the transmitter unit can be applied to receiver unit. The noise can be added at transmitter end, those data stored in *data_a*, *data_b*.Those data can be transmitted to receiver unit, which can produce serial data out at the receiver end, those can stored in *serial_output*. The below Figure 11 shows the simulation result of receiver unit.

The power consumption for this Adaptive Modulation System can be calculated by using Xilinx ISE7.1i version. The power comparison table for OFDM, MC-CDMA and this Adaptive Modulation system as given below Table 3.

Figure 11: Simulation Result of Receiver in VLSI

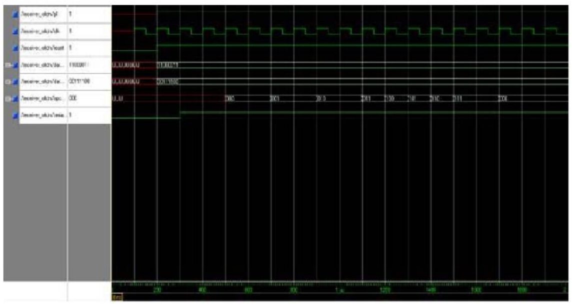


Table 3: Power Consumption Comparison

Modulation Methodology	Power Consumption
OFDM	27.40 mW
MC-CDMA	25.60 mW
Adaptive Modulation of OFDM and MC-CDMA	24.60 mW

CONCLUSION

This paper presents an adaptive downlink modulation scheme using OFDM and MC-CDMA for future mobile communications systems. The proposed scheme maximizes the system capacity by allocating a preferable modulation scheme to each time slot per user and offers types of QoS services depending on user locations and channel conditions. The detailed adaptive modulation technique and selection algorithm were explained in this paper. Computer simulation was conducted to evaluate the throughput performance of the proposed system by changing the number of users, OFDM slots and MC-CDMA slots. From the simulation results, according to the number of users, the proposed scheme using OFDM and MC-CDMA exceeds the throughput performance of the OFDM system or MC-CDMA system when the number of OFDM slots and MC-CDMA slots are selected as one respectively. The simulation results also indicate that the proportion of high-speed users and lower rate users is adjustable without decreasing the total throughput performance of the system. Thus, the proposed adaptive downlink modulation scheme provides flexible and high performance broadband communications services for mobile and nomadic users. Examination of other cases considering the QoS algorithm based on user requests and other communication environments are due to be advanced in the future. Furthermore, practical channel estimation schemes should be also considered in the future research.

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