Adaptive Modulation Techniques for COFDM–CDMA Based Wireless Networks

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Abstract: Orthogonal Frequency Division Multiplexing (OFDM), which employs orthogonal overlapping sub-carriers to modulate the signals, has been attracted much attention in recent time as a favorable option for future generation wireless networks due to its ability to overcome many impairments in wireless channels. Since OFDM is a multi-carrier system adaptive modulation techniques can be effectively and efficiently used to enhance the system performance in terms of both BER and overall system capacity. This paper discusses a COFDM-CDMA system with adaptive modulation schemes for future generation wireless networks.

1. Introduction

Today the demand for high bandwidth with mobility at an affordable price is the major challenge faced by researchers in wireless industry. Current cellular systems mostly 2G, such as GPRS are capable of providing high coverage and mobility but with very low throughput in comparison to bandwidth demanded by the modern day applications like Internet Access, Video Conferencing, and Virtual Office etc. On the other hand Wireless Local Area Networks (WLANs) such as IEEE 802.11b and Hiperlan/2 can provide high throughputs over limited distances with limited mobility. Since the upcoming 3G systems based on Wideband Code Division Multiple Access (WCDMA) will only allow a limited increase in through put (144Kbps for vehicle, 384Kbps for pedestrian and 2Mbps for indoor) the gap seems to be remaining between the capacity demanded by modern applications and capacity offered by cellular wide area coverage systems.

Orthogonal Frequency Division Multiplexing (OFDM), which employs orthogonal sub-carriers to modulate the signals, is under consideration for future generation wireless systems due to following advantages [1].

1) The achievable throughput may be impossible to achieve using single carrier systems.
2) Reduced susceptibility to most forms of impulse noise.
3) Less Inter-Symbol Interference (ISI) than, if the overall throughput was attempted on a single carrier system.
4) The almost rectangular shape of the OFDM spectrum allows for close packing of adjacent OFDM systems.

Uniform average spectral density, capability of handling very strong echoes and less non linear distortion are among the other favorite properties of OFDM, while high Peak-to-Average-Power-Ratio (PAPR) and sensitivity to frequency offset remain as major drawbacks.

Even though OFDM is robust against frequency selective fading, in a deep fade a few sub-carriers may be completely lost with others detected without errors, making the overall Bit Error Rate (BER) to be largely dominated by the few sub-carriers which completely lost or whose amplitude is too small to detect without errors. This problem can effectively be tackled by having more robust modulation format, which can yield better BER performance even under low Signal to Noise Ratio (SNR) conditions on those highly faded channels i.e., the modulation format in subcarriers must be changed dynamically based on the channel condition of each subcarrier.

Channel coding, spreading techniques and Multiple Input Multiple Output (MIMO) can be incorporated in the physical layer, while Forward Error Correction (FEC) coding and Automatic Repeat Request (ARQ) techniques can be used in the data link layer to further enhance the system performance provided the processing delay and system complexity are within the limits and fully justifiable for desired applications. This paper mainly concentrates on the concept of adaptive modulation techniques for downlink of OFDM-CDMA systems and issues related to its successful implementation.

The rest of the paper is organized as follows. Section 2 briefly discusses about basics of OFDM-CDMA system. In section 3, adaptive modulations and important issues related to it are presented. Details of the proposed system and adaptive modulation techniques are discussed in Section 4. Finally section 5 presents the conclusion.

2. COFDM-CDMA System

The general COFDM-CDMA system block diagram is as shown in Figure 1 [2]. The incoming serial data is first converted into N parallel data streams and grouped in to b bits. Each group is then spread over the frequency domain. The signal mapper does the mapping depending on the modulation format selected and IFFT generates the samples of corresponding OFDM signal. The parallel data is then converted back to serial for transmission. Guard interval is inserted to avoid possible Inter-Sysmbol Interference (ISI) caused by multipath distortion. The discrete symbols are converted to analog by lowpass filtering and then fed to RF up-converter. The receiver performs exactly the reverse as illustrated in the Figure 1.

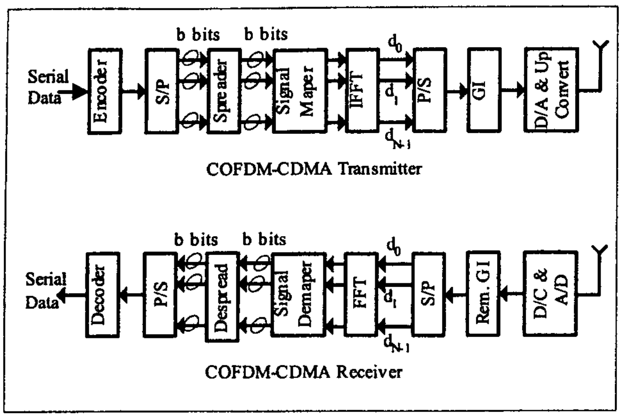

Figure 1: COFDM-CDMA System [2]

2.1 Signal Representation of OFDM-CDMA

Let $(D_0 \ \ D_1 . \ . \ D_{N-1})$ be the output of the signal mapper, which is mapped in to N number of subcarriers. The modulated symbol at n[th] subcarrier is transformed in to time domain by N point Inverse Discrete Fourier Transform (IDFT). The IDFT of this symbol sequence takes the form of:

$$d_k = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} D_n \exp(j\frac{2\pi nk}{N}) \qquad (1)$$

where k=0, 1.....N-1 and n=0, 1,......N-1.

The signal in continuous time domain can be written as;

$$Y(t) = \sum_{n=0}^{N-1} D_n \exp(j\omega_n t) \qquad (2)$$

where $\omega_n = 2\pi f_n$

Sampling this at a rate of 1/T gives;

$$Y(kT) = \sum_{n=0}^{N-1} D_n \exp(j\omega_n kT) \qquad (3)$$

By restricting the number of samples to be N in the analysis, while maintaining the same sampling rate 1/N, also making symbol period T_s equals to NT and $f_n = \Delta f \times n$, where Δf is the frequency spacing between subcarriers.

With $\Delta f = 1/NT$, $Y(kT)$ can be further simplified as follows.

$$\begin{aligned} Y(kT) &= \sum_{n=0}^{N-1} D_n \exp(j2\pi n\Delta f kT) \\ &= \sum_{n=0}^{N-1} D_n \exp(j\frac{2\pi nk}{N}) \qquad (4) \\ &= \sqrt{N} \times IDFT\{D_n\} = \sqrt{N} \times d_k \end{aligned}$$

It is therefore, clear from above that IDFT can be used to modulate OFDM-CDMA signal. Finally the samples d_k are transmitted using T spaced pulse amplitude modulation.

2.2 Channel coding and Frequency Spreading codes

Turbo coding is considered to be one of the most effective and high performing coding techniques under very low Signal to Noise Ratio (SNR) conditions. Hence Turbo coding can be used in this system. Figure 2 illustrates a typical Turbo encoder.

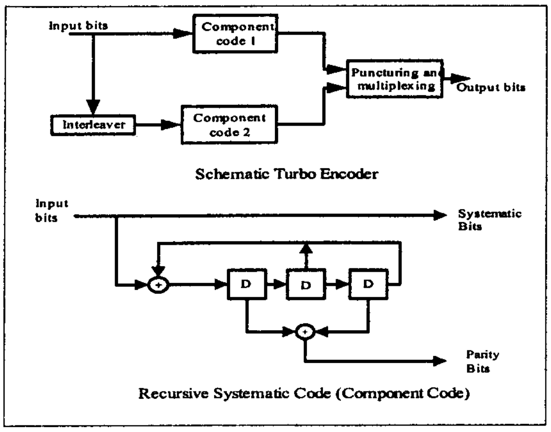

Figure 2: Turbo Encoder

Walsh-Hadamard codes are proposed for the frequency spreading coding to achieve the orthogonality among the users. This code can be simply generated by taking the rows of Hadamard matrix as code words. The fundamental unit and higher order Hadamard matrix are as follows.

$$H_2 = \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} \text{ and } H_{2n} = \begin{bmatrix} H_n & H_n \\ H_n & -H_n \end{bmatrix} \quad (5)$$

where n is an even integer. The Hadamard matrix H_n is a $n \times n$ matrix with the property of any row differs from any the other rows in exactly $n/2$ positions making all rows orthogonal to each other.

3. Adaptive Modulation

Adaptive modulation techniques have become an attractive option in order to achieve both spectral efficiency and better BER performance in digital communication systems. In particular this technique can easily be incorporated in multi-carrier systems, in which each subcarrier or group of subcarriers is modulated with a modulation technique selected on the basis of dynamically estimated channel quality. This leads to obvious spectral efficiency, better BER performance or both over and above fixed modulation format based multi-carrier systems, as in such systems, the selection of modulation format is mostly governed by the conditions of the worst channel for a given BER criteria making better channels spectrally inefficient. Important issues related to adaptive modulation based systems are:

1) Selection of suitable set of modulation formats: Depends on the type of the system, expected or targeted performance criteria and affordable system complexity.
2) Channel estimation and modulation switching level estimation: Channel estimation in wireless systems is a very complex subject and there are many techniques and algorithms presented in literature [3-5]. Appropriate technique must be deployed in order to achieve desired performance as the channel estimate largely contributes to the successful operation of the system. Estimate of switching levels can be done either by trial and error method or based on analytical work and simulation work as presented in [6] for a given set of modulation formats.
3) Signaling: This addresses the issue of how to inform the transmitter about the desired modulation by the receiver format for next transmission. A detailed description of this issue is presented in [7].

4. Proposed System Model

This paper proposes a COFDM-CDMA system with adaptive modulation techniques for future generation wireless networks. The research work associated with this system model mainly investigates the performance of different Continuous Phase Modulation (CPM) schemes as adaptive techniques to achieve a given BER performance. The proposed system block diagram is as shown in Figure 3.

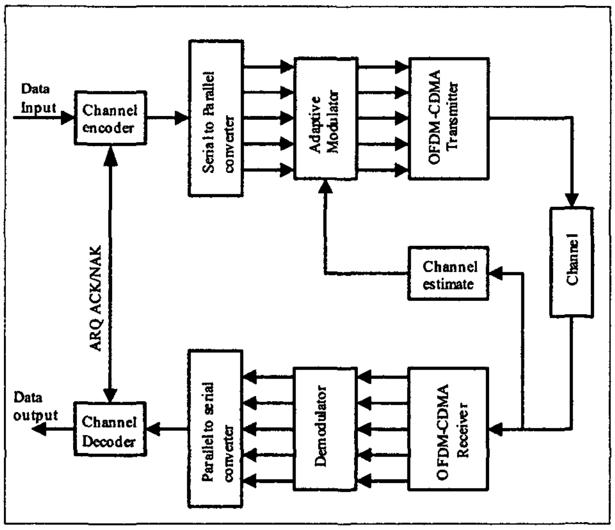

Figure 3: Proposed system model

Quadrature Amplitude Modulation (QAM) and Phase Shift Keying (PSK) are the most popular modulation techniques used in OFDM systems. Sets of QAM and PSK have been proposed and investigated as adaptive modulation schemes for OFDM/COFDM systems in [7-9].

Even though QAM provides higher spectrum efficiency, it would not be the best option as an adaptive modulation technique to be used in the downlink of future generation OFDM based wireless networks due to following facts.

1) Non constant nature of power spectrum of QAM demands power amplifier to be operated in the linear region preventing maximum power efficiency of the amplifier. This may make power amplifier in the Base Station (BS) transmitter very expensive especially when BS is meant to handle higher overall system capacity with high data rate per user, which is the case with future generation wireless networks. Dynamic change in the order of modulation format even further demand large back off in the power amplifier in order to prevent non linear distortion when it is likely to get more subcarriers with high order modulation formats. Otherwise there must be some monitoring and controlling mechanisms to control the number of subcarriers with each modulation format input to each power amplifier for the successful operation, which makes the system further complicated and expensive.
2) In QAM based adaptive systems the required performance criteria is maintained by lowering the order of the modulation format (which reduces number of bits per symbol) when channel conditions become poor. This means that the system capacity becomes very sensitive to the channel conditions for a given performance criteria.
3) Buffer memory must be maintained at the transmitter side in order to change modulation format dynamically. During worst channel conditions either buffer overflow is inevitable or very high capacity buffer memory is necessary to prevent overflow. This would also be cost prohibitive especially in Base Station side as it is intended to serve a larger customer base.

4.1 Multi-h CPM Techniques

The continuous time domain representation of multi-h CPM signal is as follows.

$$S(t) = A\cos(2\pi f_c t + \Phi(t,a)) \quad (6)$$

where f_c is the carrier frequency and the phase is:

$$\Phi(t,a) = 2\pi \sum_{k=-\infty}^{\infty} h_k a_k q(t-kT) \quad (7)$$

where T is the symbol period and:

$$q(t) = \int_{-\infty}^{t} g(\tau)d\tau \quad (8)$$

$$\int_{-\infty}^{\infty} g(t)dt = 1/2$$

The M-ary data a_k takes the form $\pm 1, \pm 2, ... \pm M-1$ and $h_k = (h_1, h_2 ..... h_K)$ cyclically changes from symbol to symbol with a period with K.

In contrast to QAM, CPM techniques having constant envelop do not demand such linearity in power amplifier while there is a provision to enhance BER performance by changing some of the associated parameters, for example in Multi-h CPM, BER performance can be improved by changing the parameter set (h_k) [10] without changing the order of the modulation format, but of course with added complexity in the decoder.

Further higher order CPM formats can be selected to achieve better spectral efficiency if necessary. Hence this paper proposes multi-h CPM techniques to be used adaptively in the proposed system for the downlink with following main objectives.

1) To achieve a desired BER performance by dynamically changing the parameter set (h_i) in the modulation format based on the estimated channel conditions. It has been found there are many sets of values for (h_k), which do not increase the required channel bandwidth significantly [10].
2) Switch the order of the modulation format to achieve more capacity in the system. Selection of number of higher order modulation formats must be done carefully not to loose the overall bandwidth efficiency of the system.

The most unique feature of this proposal is that, when the channel conditions are good the system can have set of higher order modulation formats on a particular group of subcarriers. When the channel condition starts deteriorating the system can initially start changing the parameters (mainly h_k) to improve the BER performance rather than straight away switching to a set of lower order modulation formats. This does not cause any degradation in system capacity or does not demand higher buffer memory storage. When it becomes impossible to maintain the performance only, the system will have to change the set of modulation formats to a lower order set, which in turn effects to overall system capacity or the data rate that can be delivered with given number of subcarrier set as exactly the case with QAM techniques.

5. Conclusion

In this paper, COFDM-CDMA with adaptive modulation techniques is proposed as an attractive contender for future generation wireless networks. Details of main features of OFDM-CDMA are discussed and some of the related research work that has been done is briefly presented.

The proposal mainly considers a new set of modulation schemes (multi-h CPM) to be used adaptively in the downlink of the system. Other techniques in both physical layer (channel coding, MIMO) and data link layer (mainly ARQ) are proposed to enhance the performance further with the reservation of affordable system complexity.

Authors are currently working on system simulation and results are expected to be published in near future. The major task related to this proposal is to find out modulation parameter sets (h_k) for multi-h CPM with the favorable properties such as high coding gain, low decision depth in the decoder and nearly the same bandwith in the power spectrum. Xiong [10] presents many options in this regard but further researches would be worthwhile to find more options with significant performance enhancement properties mentioned above.

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