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A novel algorithm for link adaptation using fuzzy rule based system for wideband networking waveform of SDR

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ABSTRACT

Adaptive and high speed communication with changing user requirements and environment conditions are the future needs of wireless networks. This is achieved by using the available resources optimally to increase the overall throughput by satisfying specific constraints. In this paper, a link adaptation algorithm for a hybrid multicode CDMA/adaptive TDMA based wideband networking waveform of SDR is proposed. The requirement of link adaptation increases when the transmissions are in the form of network packets. A low value of bit error rate can drastically increase packet error rate and thus packet re-transmissions, if the signal and protocol parameters are not dynamically changed according to the channel conditions and tolerable bit error rate. A constrained optimization problem has been formulated under the Quality of Service and throughput constraints. The optimization problem has been solved using fuzzy rule based system by dynamically changing the modulation technique and the number of multicodes assigned to each user. Simulation results are presented to demonstrate the effectiveness of the proposed algorithm in achieving better throughput by efficiently reducing the packet re-transmissions overhead.

1. Introduction

The future wireless networks and devices demand high speed seamless communication by ensuring desired Quality of Service (QoS) requirements. A substantial research effort has been made for several years to investigate the potential of applying the Software Defined Radio (SDR) approach to achieve these goals [1]. The SDR-based networks of the future will have to support a wide variety of applications such as biometrics, streaming video, IP data, voice Push To Talk (PTT), situational awareness, while offering a high degree of mobility, security and survivability. Due to these requirements, the developments for the future networks are moving toward wideband and digital signal based networking capable of providing adaptive and high speed communication [2].

Efficient algorithms for resource allocation/utilization are required to optimize the use of scarce SDR resources. This involves adapting the transmission parameters of the SDR waveform to changing channel conditions, QoS and data rate requirements. This process is called link adaptation. A simple example is the transmit power control algorithm, in which the transmission power is altered based on channel variations and fading because a low transmit power is sufficient under good channel conditions. The requirement of link adaptation increases when the transmissions are in the form of network packets. A low value of bit error rate can drastically increase packet error rate and thus packet re-transmissions, if the signal and protocol parameters are not dynamically changed according the channel conditions and tolerable bit error rate. A well-known link adaptation strategy is adaptive modulation and coding (AMC) [3,4]. In AMC, the channel coding rate and modulation technique are changed according to the changing channel behavior. Many varieties of AMC strategies are proposed by many researchers in recent years. One such technique is proposed in [5] for mobile-WiMax technology using software defined radio to achieve maximum throughput by retaining a threshold bit error rate. A protocol for adaptive modulation and coding is developed in [6] for a typical wireless communication system. The limitation of this paper is the assumption that the channel is a slow Nakagami-m. The performance of the proposed algorithm in achieving a target packet error rate is analyzed. An algorithm for achieving interference alignment through adaptive modulation and coding is proposed in [7] based on channel state information. Interference alignment is a technique that tries to align all the interfering signals frequency, time or space domain. It requires accurate channel state information which is not available in practical systems. An adaptive scheme is proposed which tries to obtain perfect channel state information from the imperfect channel state information. An efficient scheduling algorithm for

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adaptive modulation and coding that guarantees the QoS requirements of individual users is proposed in [8]. The information from both the data link and physical layers are used to schedule the system parameters and protocols to achieve maximum throughput. This is why the proposed algorithm is called QoS-based cross layer scheduling. Orthogonal multicode transmission which is primarily used to enhance the data rate in the 3rd Generation Partnership Project (3GPP) standard [3,9], has also been used for link adaptation.

A fundamental scheme for achieving variable data rates by changing the set of spreading sequences in multicode CDMA is proposed in [10]. The expressions for Multiple Access Interference (MAI) have also been derived. This paper lacks the scheduling algorithm for multicode transmission. A scheduling algorithm for both the adaptive modulation and coding (AMC) and multicode transmission is proposed in [11], which maximizes the Carrier-to-Interference Ratio (CIR) to increase the throughput. A link adaptation for High Speed Packet Data Access (HSPDA) is presented in [12] by adaptive modulation and coding, multicode transmissions and Hybrid Automatic Repeat Request (HARQ). The paper also compares the throughput of multicarrier CDMA and direct sequence CDMA technologies using the proposed method. The average bit error rate performance of the AMC and multicode scheme for Nakagami fading channel is studied in [13]. For uplink CDMA system, the problem of maximizing the total throughput under a bit error rate constraint is investigated in [14]. The realization of variable data rate is achieved by parametrizing the number of signature waveforms (multicodes) and constellation points in Quadrature Amplitude Modulation (QAM) for each user. The solution is optimal and potentially complex. A sub-optimal approach of deriving the expressions for optimal resource allocation based on single user is proposed in [15]. The single user solution is then extended to form a sub-optimal sequential optimization procedure for multiple users.

In this paper, a novel algorithm for link adaptation using fuzzy rule based system (FRBS) for packet-based wideband networking waveform of SDR is proposed. The waveform uses multicode CDMA and adaptive TDMA as multiple access schemes. To reduce the packet re-transmissions overhead, the configurable system parameters need to be changed dynamically according to the channel conditions. Moreover, different applications (e.g. Push To Talk (PTT), position tracking, point-to-point calls, messages, file transfer, video communication, etc.) have different QoS requirements. This varying QoS requirement is fulfilled by link adaptation which usually comprises two parts: (1) varying the system parameters at the physical layer and (2) adaptive TDMA. The focus of this paper is on the first part with multicode CDMA at the physical layer. A novel scheme based on fuzzy rules is presented which is capable of selecting the most suitable parameters based on the heuristics. A constrained optimization problem with Quality of Service (QoS) and throughput constraints has been solved by dynamically changing the modulation technique and the number of multicodes through FRBS. The proposed algorithm reduces the complexity and thus power consumption by restricting the throughput to the value required by user or application, even if the channel conditions are fair enough to allow higher throughput. Results have been presented to demonstrate the effectiveness of the proposed algorithm. It has been shown that the proposed link adaptation scheme achieves better throughput by efficiently reducing the packet re-transmissions overhead.

2. System overview

In conventional wideband SDR waveforms, multiuser support is provided by Time Division Multiple Access (TDMA), Carrier Sense Multiple Access (CSMA) or other protocols and spreading is used for security purpose only. The overall capacity and throughput of these networks can be increased by providing multiuser support at physical layer using multicode CDMA along with TDMA. The concept of multicode CDMA is illustrated in Fig. 1. The proposed link adaptation scheme is shown in Fig. 2. At the transmitter side, within each allocated time slot, the data stream is first mapped using M-PSK symbol mapping, where M is the modulation index. Bursts of the symbols are formed in which specific training sequence is inserted prior to each data burst. After multicode direct sequence spreading, upsampling and Root Raised Cosine (RRC) filtering, the data are modulated with the carrier generated from the reference oscillator. After passing through channel, the data are received at the receivers front-end. The crystal oscillator of the receiving device generates Carrier Frequency Offset (CFO) and Sampling Clock Offset (SCO). At the digital front end, sampling clock offset is estimated and compensated followed by burst detection. Both these operations are collectively termed as timing synchronization in this paper. After the detection of each valid burst, multicode despreading operation is performed. Then channel estimation block includes both the estimation of Signal-to-Noise Ratio (SNR) and channel state. The proposed link adaptation algorithm generates a new pair of modulation and multicode indices for the next transmission through FRBS based on the estimated received SNR, QoS and throughput requirements. The next blocks including CFO recovery, RAKE receiver and symbol de-mapping are also part of the wideband waveform. Efficient algorithms for all the synchronization operations have also been proposed, implemented and tested. At the end, symbol demapping is performed to retrieve the data.

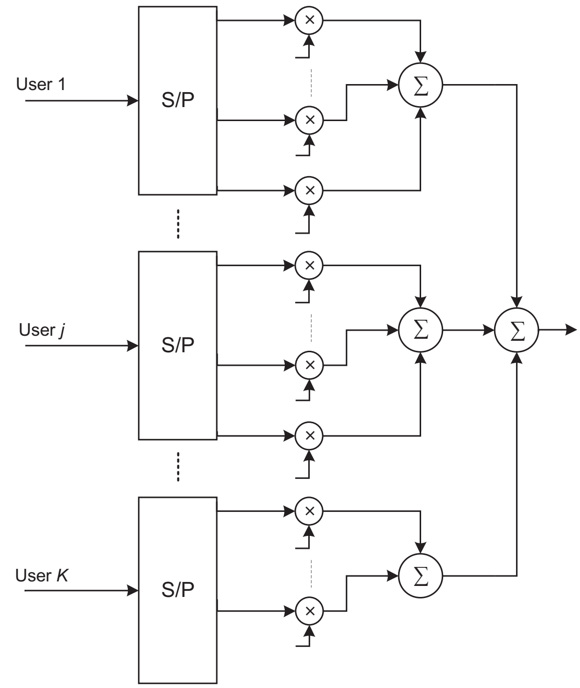

Fig. 1. Multicode CDMA concept.

3. System model

We consider a maximum of K users at the physical layer of multicode CDMA/adaptive TDMA-based SDR network in the current time slot. The spreading waveform corresponding to the rth code assigned to kth user is given by

$$z_{k,r}(t) = \sum_{n=0}^{G-1} c_{k,r}[n]p(t - nT_c) \quad r = 0, 1, \ldots, I_M - 1 \tag{1}$$