Cross-layer design for Multiple access techniques in wireless communications

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***Abstract*— The classical communication networks are modeled as a protocols stack, often referring to the ISO/OSI stack. Each protocol is belonging to a certain layer, and it is independent from the other layers. In the modern telecommunication networks, especially for the wireless communication, the protocol division in layers can be a strong limitation to the network optimization. For this reason future standards foresee an interaction between layers, named cross-layer design. This is one of the first step toward the 4G systems.**

I. Introduction

The last decade has been characterized by a continuous growth in wireless technologies. The introduction of 2.5G (such as GPRS - General Packet Radio System) and 3G (such as UMTS - Universal Mobile Telecommunication System) has carried out the packet switching connections, that allow a more feasible solution for data traffic. The data rate achievable is up to 144 kb/s for 2.5G systems and 2 Mb/s for 3G systems.

Moreover, in the last years, the continuous growth of internet-enabled devices (such as laptop and palmtop) has lead to the beginning of the WLANs (Wireless Local Area Networks) that make feasible an easy implementation of classical LAN without the necessity to bring a cable for each terminal. The data rate achievable with WLANs is comparable to the classical Ethernet LANs; the IEEE 802.11x family allows a data rate up to 54 Mb/s.

In the meanwhile, the operating transmission systems have been developed in order to meet a better integration with other transmission systems. In particular, in the wireless wide are networks it is expected an evolution in the standard that can raise the allowable data rate until value comparable to that achievable with WLANs. This evolution is foreseen for GSM/GPRS (to the EDGE technology) and UMTS (to the HSDPA technology). Similarly, also private telecommunication systems, such as TETRA, are expected to evolve in order to carry on higher data rate; in the case of TETRA, the evolution is called TETRA Release 2.

The research topics briefly introduced in the following include a discussion about multiuser detection; in particular some multiuser detection schemes that exploit neural network algorithms have been studied. In the second part, the knowledge about the physical layer have been used in order to optimize some upper layer algorithms. In particular it has been considered HSDPA, TETRA Release 2 and Ad-hoc systems, in order to develop some throughput maximization methods based on the knowledge of some physical layer parameters.

II. Multiuser Detection (MUD)

Wireless communications have gained a great importance, in particular for the possibility for a lot of people to be always connected. Code Division Multiple Access (CDMA) has been chosen as the most promising technique for sharing the radio resources among users. The upcoming UMTS is based on the code division access in order to allow efficient multiple users communications, with different bit rates and specified Quality of Service (QoS) as requested by advanced multimedia services, such as videoconference, file downloading and internet surfing.

Multiple access in CDMA systems gives rise to mutual interference among active users, increasing the error rate since user spreading codes (signature sequences) are nonorthogonal. In particular, this drawback, known as multiple-access interference (MAI) phenomenon increases the symbol error rate at the receiving end and reduces the communication quality. In addition to this, the performance of the classical receiver (i.e., the matched filter receiver) is strongly influenced by the power unbalancing among users. For these reasons, several advanced receiving schemes have been proposed in the literature [1].

A. Blind MUD with Neural Networks

Many research activities were focused on the most suitable receiving techniques for W-CDMA mobile systems. In particular, the multiuser adaptive blind detection algorithm seems to be a suitable approach to improve bit error rate (BER) performance at the receiving end. This receiver has the main advantage of achieving minimum mean squared error (MMSE) performance without requiring any kind of training sequence, hence improving bandwidth use.

However, blind receivers need a certain number of bit times to achieve the optimal solution, since the optimum filter coefficients definition is performed according to a step by step approximation method, based on the steepest gradient-descent technique. This behavior has a dramatic impact on the receiver BER performance, in particular under typical multipath-fading propagation conditions.

An interesting approach to mitigate this drawback seems to be that of using neural networks that usually have a low convergence time, being based on parallel-processing algorithms. The idea proposed herein is to use the neural network approach in order to speed-up the convergence process of the adaptive filter-coefficient set toward the optimum solution by minimizing the cost function. Among the many types of neural networks studied in the literature, that proposed by Kennedy and Chua [2] has appeared as the most attractive for our task. This network is an extension of the classical Hopfield neural network [3], to solve nonlinear programming problems.

In particular, we deal herein with a modified Kennedy and Chua model so that the nonlinear optimization is performed subject to two nonlinear constraints, one for the energy and one for the orthogonality of the solving variable. A possible DSP (Digital Signal Processor) implementation of neural algorithm will be also considered.

B. MMSE MUD with Neural Networks

Furthermore, Minimum Mean Squared Error (MMSE) receivers represent a promising approach, due to their low implementation complexity and good performance [4]. This type of receiver mainly consists of an adaptive filter whose coefficients are derived by minimizing the mean square error between the filter output and a known sequence. This type of receivers needs of a training sequence assumed at the receiving end as known sequence for the initial setting of the filter coefficients. Conversely, during the transmission phase, the known sequence is obtained from the output of the receiver. The filter coefficients definition and, hence, the filter adaptation, is achieved by resorting to the use of the descendant gradient algorithm or recursive least-squared algorithm. Based on the fact that neural networks are well known for their capabilities of minimizing error functions, this paper deals with an advanced implementation of a MMSE receiver where a suitable neural network is used to derive the adaptive filter coefficients. In particular, the Kennedy-Chua networks [2], that are a special type of the classical Hopfield network [3], has been considered.

III. Physical-Layer aware Techniques

A. Link Adaptation

The basic idea behind Link Adaptation techniques is to adapt the transmission parameters to take advantage of the channel conditions. The fundamental parameters to be adapted include modulation and coding levels, but other quantities can be adjusted for the benefit of the systems such as power levels (as in power control), spreading factors, signaling bandwidth, and more [5].

The principle of Link Adaptation is to exploit the variations of the wireless channel by dynamically adjusting certain key transmission parameters to the changing environmental and interference conditions observed between the transmitter and the receiver. In practical implementations, the values for the transmission parameters are quantized and grouped together in some schemes. Since each scheme has a different data rate (expressed in bits per second) and robustness level (minimum signal-to-noise ratio (SNR) needed to activate the mode), they are optimal for use in different channel/link quality regions. The goal of a Link Adaptation algorithm is to ensure that the most efficient scheme is always used, over varying channel conditions, based on a mode selection criterion (maximum data rate, minimum transmit power, etc).

It has been studied the throughput maximization allowable for HSDPA system by considering the effect of multipath fading channel; moreover it has been proposed ad adaptive link control algorithm for its inclusion in TETRA Release 2 standard, that allows a higher throughput by exploiting the adaptive modulation and coding feature.

B. CDMA-MAC Technique for Ad Hoc Networks

The Wireless Local Area Networks (WLANs) have become in the recent years one of the most promising area for telecommunication development. A lot of *hot spot* are actually accessible all over the world in both public and private areas for business and leisure. The used communication standards belong to one of the IEEE 802.11x family.

Aside the centralized networks, where an access point is used as a gateway to the internet, nowadays the wireless networks without infrastructure, or ad-hoc networks, have become of interest, due to the growth of their practical application. The ad-hoc networks are self-organizing networks without the aid of a centralized network controller, allowing to set-up a WLAN everywhere.

One of the most important challenge in the field of decentralized WLAN is the Medium Access Control (MAC) layer because of the difficulties typical of the wireless medium combined with the absence of a coordination device [6]. Moreover, the typical devices working in an ad-hoc scenario have to take into account the power consumption.

A new MAC protocol for ad-hoc networks that exploits the CSMA/CA (Carrier Sensing Multiple Access / Collision Avoidance) technique jointly with a Code Division Multiple Access (CDMA) is discussed hereinafter. The control packets and the data packets of each node are supposed to be sent on different spreading codes whit small cross-correlations value.

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