

Performance Analysis of Neural Network Detectors in DS/CDMA Systems

Mahrokh G. Shayesteh and Hamidreza Amindavar

Abstract: In this paper, we consider neural networks as the detectors of signals of users in DS/CDMA systems. We apply multilayer perceptron neural network with back propagation learning algorithm in AWGN and multipath fading channels. Our analysis results in significant reduction in the receiver complexity over the previous studies. We compare the performance of neural network with the conventional and suboptimal detectors in AWGN channel and with the RAKE and single user lower bound receivers in fading channels. We also apply different criterion for training the network such as the decision based, fuzzy decision, discriminative learning, minimum classification, and entropy neural networks in AWGN channels and compare their performance. Further, we propose modified decision based network which improves the performance of the decision based network. A comparison between multilayer perceptron and Hopfield neural detectors is presented.

Keywords: Multiuser detection, DS/CDMA, Neural network (NN), MAI (Multiple Access Interference), Near-far effect

1. Introduction

DS/CDMA (Direct Sequence Code Division Multiple Access) is considered as the third generation of cellular mobile, indoor wireless and personal communication systems. CDMA offers attractive features such as frequency reuse, soft handoff, increased capacity, and multipath combating [1]. In a CDMA system, several users simultaneously transmit information over a common channel using pre-assigned codes. The conventional single user detector consists of a bank of filters matched to the spreading codes. This detector suffers from two problems. First, multiple access interference (MAI) produced by the other co-channel users is a significant limitation to the capacity of this detector. The second problem is the near-far effect which occurs when the relative received power of interfering signals becomes larger. A potential solution is multiuser detection [2] which exploits the information of signals of interfering users. The optimum multiuser detector evaluates a log-likelihood function over the set of all possible information sequences. It achieves low error probability at the expense of high computational complexity that increases exponentially with the

number of users. Therefore, this method is extremely complex for a realistic number of users. Consequently, there has been considerable research into suboptimal detectors. These detectors achieve significant performance gains over the conventional detector without the exponential increase in the receiver complexity. Several factors motivate us to apply neural networks (NN) as multiuser detectors. They are adaptive and computationally efficient. Also the cyclo-stationary structure of MAI and nonlinear decision boundaries formed by the optimal receiver in CDMA can be estimated by NN [3], [4]. The first paper that considered the application of NN in CDMA systems is due to Aazhang et al. [3]. They show by applying a complicated training method called "assisted back propagation", where the number of neurons grows exponentially with the number of nodes, the performance of multilayer perceptron is close to that of the optimum receiver in both synchronous and asynchronous Gaussian channels. Although the simulation results show that back propagation (BP) learning rule outperforms the conventional detector, it still remains as an open problem. The receiver proposed in [4] uses radial basis unction (RBF) net where its complexity in terms of centers (neurons, nodes) grows exponentially with the number of users, and, becomes too complex under the multipath environment. In [5], it is shown that the energy function of Hopfield recurrent neural network is identical to the likelihood function encountered in multiuser detection. However, the desired optimal solutions are not guaranteed because a combinatorial optimization problem always involves a large number of local minimums. Also the number of connections grows with the square number of users and the number of neurons increases for asynchronous transmission. However, in these papers multipath fading channels are not considered. In this paper, we analyze and examine the performance of two-layer perceptron neural net using BP [6] learning rule for multiuser detection of DS/CDMA signals in AWGN (Additive White Gaussian Noise) and multipath fading channels. The results show superior improvement over the previous studies in terms of the receiver complexity. We compare the performance of BP network in AWGN channel with the conventional, decorrelator [7], multistage [8], and optimum detectors widely used for comparative analysis. In fading channel the rake and single user lower bound receivers are considered for comparison. Since our goal is to improve the performance of BP net, we consider different neural networks. We apply decision based neural network (DBNN) [9], [10], fuzzy decision neural network (FDNN) [9], [10], discrim-

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inative learning [11], [12], minimum classification [13], and cross entropy [14] neural nets that have better performance than BP in radar, sonar, pattern recognition, and speech processing applications. We also propose modified DBNN that outperforms DBNN. A comparison between BP perceptron and Hopfield neural nets is presented. This paper is organized as follows. Section 2 describes the model of DS/CDMA system in AWGN and fading channels. In Section 3, we explain different neural nets used in our study. In Section 4 simulations and results are discussed. Finally Section 5 presents the conclusion.

2. The model of DS/CDMA system

The system model consists of K independent simultaneous users. The k th user's transmitted signal assuming BPSK data modulation is of the form

$$Y_k(t) = \sum_k \sqrt{E_k(i)} b_k(i) s_k(t - iT) \quad (1)$$

where $E_k(i)$ is the power of the k th user at time iT , $1/T$ is the data rate, $b_k \in \{\pm 1\}$ is the data bit of user k during the i th interval, and $s_k(t)$ is the spreading (signature) waveform of duration T and normalized power which is composed of a spreading sequence of N chips (code length) as

$$s_k(t) = \sum_{n=0}^{N-1} a_n^k(t) p(t - nT_c) \quad (2)$$

where $a_n^k \in (-1, 1)$ is the spreading sequence, $p(t)$ is the rectangular waveform of duration T_c , and $T = NT_c$. We obtain the receiver input and output in AWGN and fading channels.

2.1 AWGN channel

We consider asynchronous and synchronous transmissions.

Asynchronous transmission: The baseband received signal is obtained as

$$\begin{aligned} r(t) &= \sum_{i=-P}^{i=P} \sum_{k=1}^K \sqrt{E_k(i)} b_k(i) s_k(t - iT - \tau_k) + n(t) \\ &= S(t, b) + n(t) \end{aligned} \quad (3)$$

where τ_k is the k th user time delay which is in the interval $[0, T)$, $2P + 1$ is the number of transmitted bits (packet length) in each transmission, and $n(t)$ represents white Gaussian noise with two-sided spectral density equal to N_0 . The conventional single user detector consists of a bank of filters matched to the spreading codes

of users. The matrix form of the outputs of matched filters can be expressed as

$$Y = RWb + n \quad (4)$$

where Y , R , W , b , and n are defined as

$$\begin{cases} Y = [Y^T(-P), \dots, Y^T(P)]^T \\ Y(i) = [Y_1(i), \dots, Y_k(i)]^T \\ Y_k(i) = \int_{iT+\tau_k}^{(i+1)T+\tau_k} r(t) s_k(t - iT - \tau_k) dt \end{cases} \quad (5)$$

$$\begin{cases} b = [b^T(-P), \dots, b^T(P)]^T \\ b(i) = [b_1(i), \dots, b_k(i)]^T \end{cases} \quad (6)$$

$$\begin{cases} W = \text{diag}(W(-P), \dots, W(P)) \\ W(i) = \text{diag}(\sqrt{E_1(i)}, \dots, \sqrt{E_k(i)}) \end{cases} \quad (7)$$

$$\begin{cases} n = [n^T(-P), \dots, n^T(P)]^T \\ n(i) = [n_1(i), \dots, n_k(i)]^T \\ n_k(i) = \int_{iT+\tau_k}^{(i+1)T+\tau_k} n(t) s_k(t - iT - \tau_k) dt \end{cases} \quad (8)$$

$$\begin{aligned} R &= \begin{bmatrix} R(0) & R(-1) & 0 & \dots & 0 \\ R(1) & R(0) & R(-1) & & \vdots \\ 0 & R(1) & R(0) & & 0 \\ \vdots & & & \ddots & \ddots \\ 0 & \dots & 0 & R(1) & R(0) \end{bmatrix} \\ R(1) &= R(-1)^T \end{aligned} \quad (9)$$

$$R(i) = \{R_{jk}(i)\}_{K \times K} \quad (10)$$

$$R_{jk}(i) = \int_{-\infty}^{\infty} s_j(t - \tau_j) s_k(t + iT - \tau_k) dt, i = 0, \pm 1$$

In 10, $Y_k(i)$ is the output of matched filter of user k at time iT , W is a diagonal matrix containing users' signal power, R is the correlation matrix, $R_{jk}(i)$ is the correlation between spreading codes of users j and k at time iT , and n is Gaussian noise vector with covariance matrix $N_0 R$.

Synchronous transmission: In this case $\tau_k = 0 \forall k$, and it is seen from (3) that the received signal at time iT depends on the transmitted bits of that time, so that we can drop the index i :

$$\begin{aligned} r(t) &= \sum_{k=1}^K \sqrt{E_k} b_k(t) s_k(t) + n(t) \\ &= S(t, b) + n(t) \end{aligned} \quad (11)$$

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