Neural Networks 80 (2016) 9–18

Contents lists available at ScienceDirect

Neural Networks

journal homepage: www.elsevier.com/locate/neunet

MIMO transmit scheme based on morphological perceptron with competitive learning

Raul Ambrozio Valente, Taufik Abrão *

Department of Electrical Engineering, State University of Londrina (DEEL-UEL), Rod. Celso Garcia Cid - PR445, s/n, Campus Universitário, P.O. Box 10.011, 86057-970, Londrina, PR, Brazil

HIGHLIGHTS

- New transmit MIMO scheme with no CSI aided by artificial neural network (ANN).
- Apply morphological perceptron with competitive learning (MP/CL) NN approach.
- MIMO symbols recovering with spectral efficiency improvement (double).
- Proposed MP/CL MIMO scheme complexity is polynomial with modulation order.
- Complexity becomes linear when the data stream length greater than modulation order.

ARTICLE INFO

Article history:
Received 9 November 2015
Received in revised form 22 March 2016
Accepted 29 March 2016
Available online 12 April 2016

Keywords:
MIMO transmit
Neural networks
Multi-layer perceptron
Morphological perceptron with competitive learning
Alamouti scheme
Channel state information

ABSTRACT

This paper proposes a new multi-input multi-output (MIMO) transmit scheme aided by artificial neural network (ANN). The morphological perceptron with competitive learning (MP/CL) concept is deployed as a decision rule in the MIMO detection stage. The proposed MIMO transmission scheme is able to achieve double spectral efficiency; hence, in each time-slot the receiver decodes two symbols at a time instead one as Alamouti scheme. Other advantage of the proposed transmit scheme with MP/CL-aided detector is its polynomial complexity according to modulation order, while it becomes linear when the data stream length is greater than modulation order. The performance of the proposed scheme is compared to the traditional MIMO schemes, namely Alamouti scheme and maximum-likelihood MIMO (ML-MIMO) detector. Also, the proposed scheme is evaluated in a scenario with variable channel information along the frame. Numerical results have shown that the diversity gain under space-time coding Alamouti scheme is partially lost, which slightly reduces the bit-error rate (BER) performance of the proposed MP/CL-NN MIMO scheme.

1. Introduction

Neural networks (NNs) are machines partially inspired by the human brain where the basic processing units are neurons (Haykin, 2009). In the middle of 1990s, Sussner and Ritter introduced the first morphological neural networks (Kaburlasos & Ritter, 2007; Ritter & Sussner, 1996) using the so-called image algebra (Ritter, Wilson, & Davidson, 1990), a theory that unifies several techniques for image processing, including traditional linear algebra, the minimax algebra of Cuninghame-Green (1979), and mathematical morphology (Soille, 1999). Usually, a morphological neural network is defined as a type of ANN that performs an elementary operation of mathematical morphology at every node, possibly followed by the application of an activation function.

Recently, Sussner and Esmi introduced the MP/CL neural network structure which arises by incorporating a winner-take-all (WTA) output layer into the original morphological perceptron (Sussner & Esmi, 2011). The main difference between our morphological perceptron with competitive learning (MP/CL) approach (Valente & Valle, 2013) and the WTA technique consists of our new training algorithm does not generate indecision areas neither depends on the order that the training set is presented to the network; on the other hand, both the MP/CL and WTA techniques pick the neuron with the maximum value as the winner neuron. The reader interested in the details of such type of neural networks is invited to see Sussner and Esmi (2011), Valente and Valle (2013) and references inside.

* Corresponding author.
E-mail addresses: raulavalente@gmail.com (R.A. Valente), taufik@uel.br (T. Abrão).

http://dx.doi.org/10.1016/j.neunet.2016.03.009

Next, a discussion on multiple-input multiple-output communication systems is promoted to introduce the reader in the application scenario of the MP/CL. In this contribution, the MP/CL technique is applied as the signal detector in a real data transmission of a MIMO communication system.

1.1. MIMO communication systems

Multiple-input multiple-output (MIMO) communication systems deploy multiple antennas at both transmitter and receiver side aiming to improve performance and/or spectral efficiency (SE) on wire or wireless communication systems. MIMO and space-time coding (STC) are important transmission techniques which can improve communication system capacity and/or reliability when operating in fading channel environments. For instance, substantial diversity gains and coding gains can be obtained with multiple antennas combined to space-time block code (STBC) (Zheng, Qiu, & Zhu, 2004).

The applicability of MIMO techniques aiming to improve the reliability and/or throughput of practical wire and wireless third, fourth and next fifth generation (3G, 4G and 5G, respectively) communication systems is abundant, for instance the IEEE 802.11 wireless local area networks (WLAN), one of the most successful standard in wireless communication systems, as well as broadband MIMO power line communication (PLC) standards. A review on the history of WLAN standards, as well as technical overviews on the recent development of MIMO-WLAN systems are provided in Kim and Lee (2015), while a comprehensive tutorial-oriented review on broadband wire MIMO-PLC including standardization and practical issues is provided in Berger, Schwager, Pagani, and Schneider (2014) and Berger, Schwager, Pagani, and Schneider (2015).

The Alamouti transmission scheme is a simple and effective space-time transmit diversity scheme (Alamouti, 1998), providing the same diversity order of maximal ratio receiver combining[1] (MRRC) using two transmit antennas and one receive antenna. However, the channel state information (CSI) must be perfectly known at the receiver for decoding in order to achieve the full diversity. A generalized scheme to a higher number of antennas was proposed initially in Tarokh, Jafarkhani, and Calderbank (1999), while extensions considering partial CSI or no CSI knowledge, quasi-orthogonal spatial–temporal schemes and so forth have been proposed in several works in the last two decades (Gesbert, Shafi, shan Shiu, Smith, & Naguib, 2003a; Jafarkhani, 2001; Shi & Zhang, 2004; Wang & Xia, 2003).

Particularly, two MIMO detection methods suitable for the simple Alamouti transmit diversity scheme, but with pilot-aided imperfect CSI knowledge at the receiver side was proposed in Tarokh, Alamouti, and Poon (1998). The CSI is estimated at receiver side using two known pilot received signals. It means that two known signals must be transmitted at the beginning of each frame. As a consequence, the proposed scheme namely no-CSI on a symbol decision basis suffers a 3 dB penalty compared to the original scheme using equal energy modulation and perfect CSI knowledge at the receiver side.

The space-time block coding (STBC) proposed by Alamouti achieves full diversity gain with two transmit antennas, while keeps full transmission rate with simple linear processing at the receiver. However, when the number of transmit antennas increases the desirable unitary transmission rate feature is lost (Gesbert et al., 2003a).

Upper bounds of $3/4$ for complex orthogonal STBCs and $4/5$ for generalized complex orthogonal STBCs on transmission rates have been derived in Wang and Xia (2003). Currently, many researches were done attempting to overcome this limitation. As a consequence, the quasi-orthogonal (QO) STBCs schemes have been proposed. Indeed, in the last decade, proposed QO-STBC schemes were able to achieve rate one but just only half diversity gain (Jafarkhani, 2001). These MIMO schemes relax the constraint on orthogonality. Therefore, there is a trade-off between orthogonality and performance. For instance, more recently, a 4×4 nonorthogonal space-time block codes of rate one and full diversity was proposed in Shi and Zhang (2004). Those optimized codes have been obtained using heuristic genetic algorithm (GA) approach.

It is of paramount importance for the next generation of communication systems (5G) to obtain higher spectral efficiency (SE) and energy efficiency (EE) solutions. Hence, a natural configuration consists in combining a large number of antennas (hundreds of transmit/receive antennas) with higher order modulations formats at the base stations (BS), the so called *dense* (or *large scale* or *massive*) MIMO systems (Chockalingam & Rajan, 2014; Hoydis, ten Brink, & Debbah, 2013; Larsson, Edfors, & Tufvesson, 2014; Mohammed, Vardhan, Chockalingam, & Rajan, 2008b; Rusek et al., 2013). However, there are several challenges and implementation issues in such systems, including: (i) lack of practical low-complexity detectors and precoders for such massive base-station (BS) antennas, and (ii) channel estimation issues, including pilot contamination (Jose, Ashikhmin, Marzetta, & Vishwanath, 2011). Recently, several MIMO detectors strategies have been proposed to cope with those difficulties (Chockalingam, 2010; Datta, Srinidhi, Chockalingam, & Rajan, 2012; Mohammed et al., 2008b). Other approach consists in increasing substantially the spectral efficiency of the system with not so large number of antennas (Chockalingam & Rajan, 2014; Hoydis et al., 2013).

1.2. Related works

There is a lack of the contributions available in the literature regarding the neural networks-aided STC-MIMO detection. Recently, Hopfield neural network (HNN) has been used in a near-ML performance detection algorithm for large MIMO system applications (Mohammed, Chockalingam, & Sundar Rajan, 2008a). In Ma, Hu, and Zhang (2012), the complex-valued neural network is deployed to implement a detector for MIMO-OFDM systems in frequency domain. The output of the NN-aided detector is just the output of all neurons. Authors claim that while holds near-optimum performance such detector has the advantage of low complexity since neuro-computing is a low computational complexity process compared with exhaustive search approach.

Recently, in Li, Zhou, and Li (2011) a signal detector based on *quantum* heuristic GA (QGA) and *radial basis functions* (RBF) networks was proposed in order to solve efficiently the MIMO-OFDM signal detection problem. Multilayered perceptron neural network has been deployed in Seyman and Taspinarb (2013) to aid detection and estimation tasks in MIMO systems. In fact, the feed-forward multilayered perceptron neural network has been applied to estimate channel parameters in multi-carrier MIMO systems.

1.3. Proposed method at a glance and differences with existing methods

In this work, we address the performance and spectral efficiency of size-constrained MIMO arrays. While most works on MIMO communication focus on arrays with a small number of sufficiently spaced and uncorrelated (or low-correlated) antenna elements, we are interested in analyzing application scenarios where a fixed small space is being filled up with antenna elements.

[1] MRRC is a scheme of detection where the output is a weighted sum of signal replicas from each transmit and receiver antenna, as well as multi-path signals; thus, coherently combining faded paths at receiver improves detection.