Chapter 16
Application of Soft Computing Tools in Wireless Communication—A Review

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Abstract The proliferation of number of users in a limited wireless spectrum have raised the levels of inter symbol interference (ISI) and have also contributed towards probable degradation of quality of service (QoS). The key challenges faced by upcoming wireless communication systems is to provide high-data-rate wireless access with better QoS. Also, the fast shrinking spectrum for such communication have necessitated the development of methods to increase spectral efficiency. Multiple input multiple output (MIMO) wireless technology is a viable option in such a situation and is likely to be able to meet the demands of these ever-expanding mobile networks. Many researchers have explored this field over a considerable period of time. A sizable portion of the research have been on the application of traditional statistical methods in such areas. Over the years, soft computational tools like artificial neural network (ANN), fuzzy systems and their combinations have received attention in the diverse segments of wireless communication. This is because of the fact that these are learning based systems. These learn from the environment, retain the knowledge and use it subsequently. This paper highlights some of the important application areas in wireless communication which have reported the use of soft computing tools in wireless communication that are in circulation in open literature.

Keywords Multiple input multiple output (MIMO) technology · Soft computation · Wireless communication · Multi layer perceptron (MLP) · Recurrent neural network (RNN) · Fuzzy · Fuzzy-neural · Neuro-fuzzy

16.1 Introduction

The proliferation of mobile communication networks over the last decade has increased the use of the wireless spectrum in exponential terms. Increase in number of users in a limited spectrum have raised the levels of inter symbol interference

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(ISI) and also have increased the possibility of degraded quality of service (QoS). The key challenge faced by upcoming wireless communication systems is to provide high-data-rate wireless access at better QoS. Also, destructive addition of multipath components within the fast shrinking spectrum available for wireless communication have necessitated the development of methods to increase spectral efficiency and explore innovative solutions. Additionally, there is a constant demand for higher bandwidth, increased data rates, lower cost, greater coverage etc. for which the mobile networks are creating congestion in the available spectrum. Multiple-input multiple-output (MIMO) wireless technology is a viable option in such a situation and is likely to be able to meet the demands of these ever-expanding mobile networks. Many researchers have explored this field over a considerable period of time. A sizeable portion of the research have been on the application of traditional statistical methods in such areas. Over the years, soft computing tools like artificial neural network (ANN), fuzzy systems and their combinations have received attention in wireless communication. This is because of the fact that these are learning based systems. These learn from the environment, hold back the learning and use it subsequently. This paper highlights some of the important application areas in wireless communication which have reported the use of soft computing tools in wireless communication. As MIMO is a viable option to meet the demands of expanding mobile networks, a larger section of the research have focused on the application of soft computing tools in this area as well.

The rest of the paper is organized as follows. In Sect. 16.2, the importance of soft-computing tools in wireless communication is highlighted. We discuss about the application of the ANN in feedforward form in Sect. 16.3. Application of recurrent structures in wireless communication is discussed in Sect. 16.4. The important works reported in the domain of fuzzy based applications in wireless communication are included in Sect. 16.5. The work is concluded in Sect. 16.6.

16.2 Importance of Soft Computing Tools in Wireless Communication

Soft computing tools like ANN, fuzzy systems and their combinations have become important segments of systems related to wireless communication. This is because of the fact that these being learning based systems, are better placed to use channel side information (CSI) for improved performance. ANNs have already received considerable attention as an optional technique for equalization and other such applications in wireless communication. The most preferable aspects of the ANN in these applications have been parallelism, adaptive processing, self-organization, universal approximation and ability of tackling highly nonlinear problems. Also, as the ANN learn complex patterns, it acts as a reliable estimator and hence is used for the modeling a host of phenomena observed in wireless systems and MIMO channels.

ANN uses model free data to capture changes [1] which have been effectively used in design of systems for channel estimation and symbol recovery simultaneously.

On the other hand, fuzzy systems are rule driven tools suitable for uncertain conditions executing minute regulations for improved control and decision-making. This is somewhat different to that observed in ANNs. ANNs are nonparametric prediction tools that have the ability to replicate biological cognitive behaviour but cannot explain to the user how the system derives a decision. Hidden knowledge in ANN is not associated with a single aspect of a given problem. Fuzzy systems, on the other hand, attempt to extract expert-level knowledge embedded in a process. The rule generation process is critical in extracting knowledge and arrive at decisions from near random or unknown situations. Fuzzy systems are applicable where sufficient expert knowledge about a process in available while ANN is comfortable with situations that have sufficient process data. Therefore, while ANNs have numeric-quantitative capability, fuzzy systems exhibit symbolic-qualitative capacity. Thus, hybrid systems formed by combinations of ANN and fuzzy methods have adaptability, parallelism, non-linear processing, robustness and learning in data rich environment acquired from ANNs and modeling uncertainty and qualitative knowledge related to fuzzy systems. It provides neuro-fuzzy (NF) or fuzzy-neural (FN) systems the ability to acquire numeric-qualitative expert-level decision-making and demonstrate greater adaptability and robustness while handling unknown process or situations.

16.3 Application of Feedforward ANN and MLP in Wireless Communication

ANNs are available in a host of forms [1]. In the rudimentary feedforward form, the ANN is configured as a multi layer perceptron (MLP) which is trained by (error) back propagation (BP) algorithm [1]. In this section, we highlight some of the important applications of ANN in feedforward form related to wireless communication.

For single input single output (SISO) and single input multi output (SIMO) setups, MLPs have been extensively used. As an extension to the application of SISO and SIMO, MIMO systems also have attracted considerable employment of ANN for a range of situations like channel equalization, interference cancellation, identification and estimation. A few such works are included below:

1. A three layer ANN along with feedback is used for MIMO channel estimation and equalization and is reported in [2]. The work uses a Kalman filter and a feedforward ANN to perform MIMO channel estimation.
2. Another work cited in [3] reports the application of ANN for location estimation and CCI suppression in cellular networks.
3. A work related to blind equalization of a noisy channel by linear ANN is reported in [4].
4. Another work of similar nature is available as cited in [5] where blind channel equalization and estimation is performed using ANN. This work discusses

application of ANN mainly with a time invariant SISO channel. Along with CCI cancelation and equalization, estimation of MIMO channels have also received attention with regards to application of ANN and related tools.

5. A method based on iterative estimation of MIMO channels using support vector machine (SVM) is reported in [6].
6. Another work [7] reports the application of singular value decomposition (SVD) based adaptive channel estimation for MIMO-OFDM systems.
7. SVD has also been used for subchannel CCI cancelation in a MIMO system as described in the work cited in [8].
8. Like SVD, ANN has always been a preferred tool for developing applications in high data rate systems like MIMO-OFDM systems. Following these applications, identification of nonlinear MIMO channels using ANNs has also been reported. One such work is [9].
9. The work [10] reports the use of a MLP for multipath Rayleigh channel estimation in a MIMO set-up.
10. Works of similar nature that deals with static and slowly varying MIMO channels has already been reported. A work [11], reports the use of ANN for MIMO-OFDM channel estimation. The work uses pilots to estimate the channel impulse response based on LS criteria. To improve the estimation performance, an ANN approach is applied to track the variations of the channel using a variable step-size RLS.
11. Application of Multi-ADAptive LINear Element (MADALINE) which is a feed-forward ANN, for parameter estimation of linear time invariant (LTI) MIMO systems is reported in [12].
12. As channel estimation is a time varying phenomenon, dynamic ANNs are more suitable. The work [13] reports the use of a dynamic ANN topology for MIMO-OFDM systems. The MLPs are tested to check their ability to perform symbol recovery as well under fluctuating conditions shown by the MIMO channels.
13. MLPs capturing time—varying patterns of input data must have temporal characteristics [14] which can be developed by building memory into an ANN [1]. There are two basic methods which can be used to introduce memory into an ANN. The first one is to introduce time delays in the ANN and to adjust parameters during learning phase. The second way is to use positive feedback which can make the ANN recurrent. Recurrent networks use global feed-forward and local feedback sections [1].

In the above cases we have seen a number of reported works which have used ANN in feedforward form to deal with certain phenomenon observed in wireless channels. In these cases it is seen that an ANN can be specially configured to mitigate some of the deficiencies of multi-user transmission. The advantage of these schemes is that no pilot symbol bits are required to be inserted with such transmissions which can contribute towards preserving bandwidth and increasing spectral efficiency.

16.4 Application of Recurrent Neural Network (RNN) in Wireless Communication

Another form of ANN is recurrent neural network (RNN) which possesses better ability to deal with time varying systems than the MLP. This is because of the fact that the RNN has local and global feedback paths which enable contextual processing of applied samples [1]. RNNs have also been used for a diverse range of applications in wireless communication. Some of the relevant literature are cited between [15–29].

1. Blind equalization has been the most common area in which RNNs have been applied. A work cited in [15] uses a RNN for blind equalization which proves to be effective.
2. A more extensive application of the RNN is observed in case of a system developed for MIMO channel prediction using a particle swarm optimization (PSO)-evolutionary algorithm (EA)-differential evolution PSO (DEPSO) (PSO-EA-DEPSO) off-line training algorithm. This predictor is shown to be robust to varying channel scenarios [16]. The work only concentrates on MIMO channels and is not directed towards recovery of data symbols transmitted through the channel.
3. Another related work cited in [17] improves the effort reported in [16] by using an on-line approach. A new hybrid PSO-EA-DEPSO algorithm is presented for training a RNN for MIMO channel prediction. This algorithm is shown to outperform RNN predictors trained off-line by PSO, EA, and DEPSO as well as a linear predictor. This work also is not directed towards recovery of transmitted signal content. Further, the work doesn't specify if real and complex signals are considered in split form or in coupled form.
4. A work [18] provides a new adaptive neural predictor for GPS jamming suppression applications designed using the efficient square-root extended Kalman filter (SREKF) algorithm to adjust the synaptic weights in a RNN architecture and thereby estimate the stationary and non-stationary narrowband/FM waveforms.
5. A novel approach to adaptive channel equalization with RNN for a QSPK signal constellation is given in [19]. The work deals with wireless communications in non linear channels for M-PSK and M-QAM modulation schemes.
6. RNNs with extended Kalman filter (EKF) algorithm has also been used for nonlinear equalization in satellite communication. This is reported by a work as indicated by [20].
7. Another work cited in [21] applied complex real time recurrent learning fully RNN extended Kalman filter trained (CRTRLEKF) in adaptive equalization for cellular communications. Results illustrate the strength of the method in wide sense stationary-uncorrelated scattering (WSS-US) channel model.
8. Accurate and timely estimation of CSI will guarantee the QoS by admission control, inter and intra network handovers in non line of sight (NLOS) channels. For such a problem, bit error rate (BER) is predicted by two different RNN architectures such as recurrent radial basis function network (RRBFN) and echo state network (ESN) [22].

9. RNNs trained with gradient-based algorithms such as real-time recurrent learning (RTRL) or back-propagation through time (BPTT) have a drawback of slow convergence rate. A derivative-free Kalman filter, also called the unscented Kalman filter (UKF), for training a fully connected RNN is presented for nonlinear equalization in [23, 24].
10. A work on the use of Kalman filter-trained RNN equalizers for time-varying channels is reported in [25].
11. A decision feedback RNN based equalization with fast convergence rate for time-varying channels is described in [26].
12. In the work described in [27], the application of fully connected RNNs (FCRNNs) is investigated in the context of narrow-band channel prediction using three different algorithms, namely the RTRL, the global extended Kalman filter (GEKF) and the decoupled extended Kalman filter (DEKF). The system is designed for training the RNN—based channel predictor. The work shows that GEKF and DEKF training are faster than the RTRL based learning.
13. A new method for pruning the complex bilinear recurrent neural network (CBLRNN) using genetic algorithm is proposed in [28] and is applied to equalization of wireless asynchronous transfer mode (ATM) channels.
14. Use of Kalman filter and RNN in hybrid form is reported in [29].

The most preferable aspects of the RNN in these applications have been parallelism, adaptive processing, self-organization, universal approximation and ability of tracking highly nonlinear problems. Here too, the reported works of application of RNN for wireless and MIMO channel modeling have not crossed the traditional limits of experimenting with the training−testing realm. In particular, no reported works have dealt with architectural expansion of the RNN which would have been a natural modification over traditional RNN structures. The training time complexity and design issues are important challenges observed in these works.

16.5 Application of Fuzzy, Fuzzy-Neural and Neuro-Fuzzy Systems in Wireless Communication

Fuzzy systems provide expert-level knowledge for control and decision-making while ANNs are non-parametric prediction tools that have the ability to replicate biological behaviour. Therefore, while ANNs have numeric-quantitative capability, fuzzy systems exhibit symbolic-qualitative capacity. It provides fuzzy-based systems the ability to acquire numeric-qualitative expert-level decision-making and demonstrate greater adaptability and robustness while handling unknown process or situations. These attributes of fuzzy based systems in combination with ANNs have been explored and configured for wireless channel modeling and related phenomenon. Fuzzy and related hybrid systems namely FN and NF systems provide adaptive expert-level decision-making capacity, hence are suitable for a wide range of applications. Fuzzy based systems are efficient tools to be utilized in problems for which either information or knowledge of all factors is insufficient or impossible to obtain. Fuzzy and related hybrid systems have also received attention for application in wireless communication.

1. A work cited in [30] is a must read description for all fuzzy related implementation. The description provides an exhaustive survey of neuro-fuzzy rule generation algorithms together under a unified soft computing framework. The work includes some important works related to rule generation of NFS and relates them to certain real world applications. Another work of similar nature is [31].
2. Some nobel efforts have been put into a publication cited in [32], which contains a survey of fuzzy logic applications and principles in wireless communications. It is reported with the aim of highlighting successful usage of fuzzy logic techniques in telecommunications and signal processing. The authors claimed this is to be the first such study of its kind. This paper focuses firstly on discerning prevalent fuzzy logic or fuzzy-hybrid approaches in the areas of channel estimation, equalization and decoding, and secondly outlining what conditions and situations for which fuzzy logic techniques are most suited for these approaches.
3. A detailed account of some applications of fuzzy systems in communication is provided in this report. One of the earliest reported applications of fuzzy systems in wireless communication in [33]. It reports the use of an RLS fuzzy adaptive filter for non-linear channel equalization.
4. A work of similar nature that can also be considered to be among the few earliest reported is [34] and it deals in some detail with a fuzzy based channel equalization problem.
5. Another contemporary work is [35] which shows the use of fuzzy systems to carry out channel estimation. A similar survey paper is [36].
6. Another work [37] reports the use of fuzzy systems to perform channel estimation in CDMA based wireless communication.
7. A simple method reported in [38] shows that data sequence and estimates of the channel condition can be carried out at the same time using the Viterbi algorithm and fuzzy logic for the convolutional code. After a fixed number of decoding steps, the fuzzy logic unit reads the branch metric value of the survivor and the difference between maximum and minimum survivor path metric values at the Viterbi decoder and estimates the channel condition with the signal-to-noise ratio (SNR). The proposed method enables the channel estimation regardless of what kinds of modulator and demodulator are used.
8. Another work referred in [39] presents the equalization of channel distortion by using NF network. The structure and learning algorithm of NF network have been described. Using learning algorithm of NF network an adaptive equalizer have been developed. The developed equalizer recovers transmitted signal efficiently. The use of NF equalizer in digital signal transmission allows to decrease training time of parameters and the complexity of network.
9. A work cited in [40] discusses about a Takagi Sugeno Kang (TSK) fuzzy approach to channel estimation for OFDM systems.

10. Fuzzy systems can be used to update LMS algorithm for OFDM channel estimation in time-variant mobile channels. Such a work is reported in [41].
11. The workers of the publication cited in [40] extends the work further using a TSK fuzzy approach to channel estimation for MIMO-OFDM systems [42].
12. An adaptive NF inference for OFDM channel estimation is reported in [43].
13. Use of fuzzy logic as the core of the reasoning engine to determine different parameters used by the WiMAX system is reported in [44]. This work focuses on one of the main functions of the reasoning engine i.e. determination of the channel type and the number of pilots used for channel estimation.
14. Another work introduces an adaptive neural fuzzy channel equalizer (ANFCE) based on adaptive neural fuzzy filter (ANFF) [45]. The ANFF is a five layer ANN which is able to use the expert knowledge in its structure. The structure and parameters of this network are adjusted according to the training data and the available expert knowledge.
15. A work cited in [46] propose a computationally efficient NF system based equalizer for use in communication channels. This equalizer performs close to the optimum maximum a-posteriori probability (MAP) equalizer with a substantial reduction in computational complexity and can be trained with a supervised scalar clustering algorithm.
16 The work [47] proposes an adaptive NF inference system (ANFIS) for channel estimation in OFDM systems. To evaluate the performance of this estimator, the authors compare the ANFIS with LS algorithm, MMSE algorithm by using BER and mean square error (MSE) criteria.
17. The authors report the design of a fuzzy MLP for application in stochastic MIMO channels [48].

Here, we noticed that the major literature have been restricted to the popular NFS or FNS learning and decision-making arena with the focus to improve performance of such systems with applications in time-varying MIMO channel modeling and wireless communication. These works have highlighted how fuzzy based systems are able to deal with the uncertainty observed in wireless channels and also track minute variations which are created due to the time dependent nature of such channels.

16.6 Conclusion

Here, we have discussed about the application of soft computing tools for wireless communication applications. We focussed on the use of ANN in both feedforward and recurrent forms for dealing with a range of issues like channel equalization and estimation, interference cancelation, user identification etc. related to wireless communication. Fuzzy systems are able to deal with uncertainty, hence are useful for dealing with the stochastic nature observed in wireless channels. Fuzzy in combination of ANN form constitute a reliable framework for application in wireless channel.

Some recent works reported in this arena has been highlighted in this review. All the reported works, in totality, indicate that soft computing frameworks in form can be effective ingredients of receiver design suitable for data intensive mobile applications.

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