Random neural network based cognitive engines for adaptive modulation and coding in LTE downlink systems

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\textbf{A B S T R A C T}

This paper presents two random neural network (RNN) based context-aware decision making frameworks to improve adaptive modulation and coding (AMC) in long-term evolution (LTE) downlink systems. In the first framework, AMC is modelled as a traditional classification problem with the aim to maximize the probability of correct classification. The second framework seeks to optimize the throughput as opposed to simply maximizing the probability of the correct classification. To model the second framework, we developed a hybrid cognitive engine (CE) architecture by integrating an RNN based learning algorithm with genetic algorithm (GA) based reasoning. RNN inherent properties help CE to comply with the essential CE design requirement (i.e. concurrent long-term-learning, low computational complexity, and fast decision making). The performance of RNN is compared with artificial neural networks (ANN) and state-of-the-art effective exponential SINR mapping (EESM) algorithm. A comprehensive analysis of the proposed RNN based AMC scheme is presented by jointly incorporating the effect of different schedulers, feedback delays, and multi-antenna diversity on the throughput of an orthogonal frequency-division multiple access (OFDMA) system. The critical analysis of the first framework revealed that RNN based CE can achieve comparable results with faster adaptation, even in severe environment changes without the need of retraining compared to ANN. The analysis of the second approach demonstrated RNNs faster adaptation as compared to ANN and showed up to 253% gain in user throughput. RNN based CE efficiently exploited the channel quality information feedback delay to improve system throughput and helped cell-edge and cell-centre users to experience much better services in terms of achieved throughput as compared to EESM.

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1. Introduction

To achieve the desired spectral efficiency, the 3G, 4G, and beyond have employed adaptive approaches to dynamically adapt radio configuration parameters. These techniques are generally known as link adaptation or channel-aware scheduling. One important method for doing so is AMC. AMC aims to maximize the data rate by selecting an optimal modulation and coding scheme (MCS) under block-error-rate (BLER) reliability constraint. According to the 3rd generation partnership project...
(3GPP) specification [1], user equipment (UE) periodically reports its channel state information (CSI) to the base station (BS). Based on this feedback, BS performs the process of AMC.

In an orthogonal-frequency-division multiplexing (OFDM) system, a transport block (TP) is encoded over several sub-carriers. Therefore, AMC can’t be done for individual sub-carriers, because it proportionally increases the control and signalling overhead. This difficulty motivates the extensive use of EESM technique. The EESM technique translates signal-to-interference-and-noise ratios (SINR) of multiple sub-carriers into an effective one-dimensional SINR ($\gamma_{\text{eff}}$). Based on $\gamma_{\text{eff}}$, same MCS for all assigned sub-carriers (sub-band) to each UE is selected [2,3]. The $\gamma_{\text{eff}}$ can be calculated by performing a following non liner averaging over several sub-carriers SINRs:

$$\gamma_{\text{eff}} = EESM(\gamma_i, \beta) = -\beta \ln \left( \frac{1}{N} \sum_{i=1}^{N} \exp \left( \frac{\text{SINR}_i}{\gamma_{\text{ref}}} \right) \right)$$

where $N$ is the total number of subcarriers to be averaged and $\beta$ is calibrated to fit the compression function to the Additive White Gaussian Noise BLER results [4]. The UE uses EESM to compute the $\gamma_{\text{eff}}$, which represents the channel quality. However, the reduction of N subcarriers SINRs to a single effective SINR is not information lossless that needs to be dealt with the rate adaptation and scheduling.

It is to be noted that (1) is a non-linear function and no exact closed-form expression for its statistics is known [5,6]. The difficulty in constructing an exact closed-form expression is due to the high dimensions of transmission parameters (e.g. frequency, time, spatial domain) and environmental parameters (e.g. signal energy, noise variance, channel variations per subcarrier, time tap etc.). These multi-dimensions make it almost impossible to come up with a closed form mapping of environmental measurements to transmission parameters. Moreover, the factors such as non-linearities of system, quantization errors, and non-Gaussian noise add more to this difficulty and correspondingly the selection of optimal or even near optimal MCS. Therefore, for effective link adaptation, a flexible framework is desired to enable AMC using as few assumptions on the mathematical model of the physical layer as possible.

Recently, machine learning (ML) based link adaptation approaches have been extensively studied in literature. ML translates AMC in to a decision making process, because for ML AMC is nothing more than a transfer between data observation and system state [7]. ML algorithms make no mathematical assumptions and learn the input-output relationship using the training process. Therefore, ML based AMC approaches have better ability to capture the environmental effects as compared to the classical EESM method. In addition, ML based AMC approaches are capable to address the limitations of analytical modelling such as their limited modelling assumption, limited ability to deal with dynamic communication behaviours, poor scalability etc.

Application of machine learning to AMC has been studied widely using both supervised and unsupervised learning approaches such as ANN [8], k-nearest neighbours (k-nn) [7], support vector machine (SVM) [9], reinforcement learning (RL) [10] etc. However, none of the existing ML based CE design fully complies with the CE design requirement. In addition, most of the proposed ML based approaches have translated AMC as a classification problem.

In this paper, we utilized an advanced artificial intelligence (AI)/ML technique such as RNN to address the limitations of existing ML based AMC approaches. In our previous work [11, 12, and 13], we addressed LTE uplink power control problem using RNN. The use of RNN in [11–13] helped CEs to comply fully with the essential CE design requirements. Consequently, it was proved that RNNs inherent properties such as: (a) low complexity of standard learning algorithm (b) strong generalization capability even with small training dataset (c) energy-efficient hardware implementation (d) less dependence on network structure (e) easy and efficient computation, makes RNN a potential candidate for CE design [14]. In this paper, we extend our previous research and presented first RNN based CE for link adaptation in LTE downlink system. In rest of the paper, Sections 2–4 have briefly described the related work, motivations, and contributions respectively. Section 5 has described the system model, Section 6 presented the proposed CE design 1 and its evaluation. Section 7 presented the proposed CE design 2 and its evaluation. Finally, Section 8 has concluded this work.

2. Related work

Motivated by the goal of analysing the channel quality information (CQI) feedback, the authors in [5] proposed the use of an analytically traceable logarithmic distribution to characterize the probability distribution function of $\gamma_{\text{eff}}$ in a Rayleigh channel distribution. Similarly, the authors in [6] proposed a novel statistical model for EESM based on the Beta distribution. More recently, the authors in [15] derived a closed-form expression of the optimal target BLER which increased the effective throughput by dynamically adjusting the target BLER. However, these solutions are based on sound theoretical principles and their implementation require large amount of calculations. In addition, these schemes suffer from the limitations of analytical modelling as highlighted in Section 1 [7].

The authors in [8] presented an ANN based AMC process for multi-input-multi-output (MIMO)-OFDM wireless system using Levenberg-Marquardt (LM) training algorithm. However, ANNs suffer from training and local-minima problems, high computational complexity, limited generalization, slow calculation rate during run-time, and sensitivity to the number of hidden neurons/available training samples. The authors in [7] proposed a k-NN based AMC approach to exploit the past observation of CSI and predict the best MCS. This approach provided accurate mapping from features to MCS and outperformed other compared link adaptation algorithms. However, the practical application of this approach is limited by exces-
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