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A cooperative modulation recognition: New paradigm for power line networks in smart grid

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ABSTRACT

Power Line communication (PLC) is an attractive approach to provide information transfer services for future smart grids. However, since various modulations are adopted, it is a great challenge to add new nodes to collect the data from the devices or sensors in in-home PLC networks. In this paper, we propose an approach to automatically access to the PLC network by identifying the modulation of signals. To improve the correct recognition rate on identification of modulations, we propose a multiple input and multiple output (MIMO) based cooperative modulation identification scheme. After receiving the recognition results from accessing nodes, the central server makes the comprehensive and accurate recognition decision on the modulation of the PLC network. Furthermore, the fourth-order cumulants for multiple users are adopted as the feature for this modulation classifier. With the feature, we propose an improved modulation classification algorithm based on the maximum likelihood. Simulations show that a high detection rate and low false positive rate can be achieved as we employ the cooperative modulation identifying scheme and the improved recognition algorithm.

1. Introduction

Increasing interest in smart home automation systems, in-home networks, or multimedia systems requires a new network paradigm to connect all indoor communication devices, such as an indoor local-area network (LAN) [1]. This requirement has driven the use of low-voltage power lines as a high-speed communication channel because the power-line grid over a house is a better and more widely distributed pre-deployed network than any other communication networks in the home [2–4]. Hence, the power line communication (PLC) is an appropriate network technology for in-home applications when compared to other communication methods.

In order to achieve high spectral efficiency, differential modulations are employed in the PLC networks. The differential phase shift keying (DPSK), as in [5], is an effective approach for PLC, where the constellation has one magnitude and different phase changes. In order to improve its efficiency, researchers often increase the points in the constellation. However, the performance of this modulation is degraded as its points exceed sixteen due to the close points location. Thus, authors in [6] prove the constellation with 8PSK is most effective. Additionally, authors of [7] address the usage of M-QAM modulation for PLC systems under impulsive noise. By adopting M-QAM, PLC systems with Orthogonal Frequency Division Multiplexing (OFDM) scheme can achieve a better performance on bit error rate than those of systems without OFDM. Unfortunately, various modulations used in PLC networks bring a great challenge to add new sensors into the system, since the added sensors cannot communicate with original nodes in PLC network – this limits the scope of PLC networks.

For the sake of providing automatic access for sensors, the practical scheme for the PLC network is designed as a cognitive sensor network. With this approach, sensors can add in PLC networks as nodes by identifying the adopting demodulation and estimating demodulation parameter [8]. Hence, in these added sensors, we need to install a modulation recognizing component. Generally, the modulation recognizing component is composed by two subsystems, feature extraction subsystem and pattern recognizing subsystem. The feature extraction subsystem extracts the key features from received signals [9]. According to [10], the most appropriate feature for modulation recognition are higher-order statistics (HOS), including cumulants and moments. To improve the performance of a classifier, the combination of second and fourth order cyclic cumulants (CC) magnitudes has been proposed

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in [11]. Similarly, the higher-order up to eighth-order CC magnitudes is adopted in [12] and *n*th-order warped CC magnitudes are utilized in [13] in order to improve the recognizing rate. Validating the results in [14] shows cumulants are preferred as the features due to their favorable properties. However, when adopting cumulants with order higher than four, longer time is needed to train data and process recognition.

The second subsystem is the pattern recognizer, which processes features and determines the modulation of signals according to pre-designed decision rules. There are two classes of algorithms that can be used to identify modulations, the likelihood-based (LB) [15,16] and feature-based (FB) [17] methods. The former is based on the likelihood function of received signals and its decision is made by comparing the likelihood ratio against a threshold. A solution offered by the LB algorithm is optimal in the Bayesian sense, which minimizes the probability of false classification [18]. Unfortunately, the optimal solution often suffers from computational complexity, which in many cases of interest naturally gives rise to suboptimal classifiers. However, the FB method can identify the modulation with a different scheme [19]. First, it extracts several features of various given modulations with a prepared training data set. By capturing signals, the modulation identification algorithm can then calculate values for the features of the modulation used in the specified network. At last, the algorithm makes a choice on the modulation by comparing the calculated results with the training ones. Hence, a FB method may not be optimal. Nonetheless, according to [15,20], it is usually simple to be implemented, with near-optimal performance, if designed properly.

Automatic recognition can identify the modulated signal within specific frequency range, which makes the users change corresponding mechanism of transmission and reception according to the external spectral environment, and thus improves the spectrum utilization [21]. However, the existing ways of modulation modes recognition mainly focus on monitoring and identifying the single signal whereas little attention was paid to study the recognition of multiuser signal modulation mode. In order to solve the aforementioned problem, the technology of recognizing multiuser signal modulation mode is automatically developed in [22]. However, modulation identification for a PLC system is a challenging task, especially in a non-cooperative environment, where in addition to multi-path propagation, frequency-selectivity and no prior knowledge of the incoming signal is available [23].

In this paper, we propose to use the modulation identification to help sensors to automatically access to the PLC in-home networks. To the best of the authors knowledge, our work is the first of its kind to construct a PLC in-home network with MIMO to aid the cooperative modulation recognition. Compared to many other modulation identification method, we build fourth order cumulants of multiple nodes as the feature, with which we can identify modulations with received recognition results from several accessed nodes. In particular, we propose the following five-fold contributions:

- We design a model for PLC in-home networks, where sensors can access the network as new nodes via PLC sockets. This scheme provides a new way to collect information from PLC sensors network.
- We propose a cooperative modulation identification method in PLC in-home network based on PLC MIMO channel, where several wires are used for communication. The central server can simultaneously receive the modulation recognition information from accessing nodes.
- We adopt the fourth-order cumulants of multiple nodes as the feature for the modulation classifier, which can recognize modulation of signals by collecting samples from several accessing nodes.

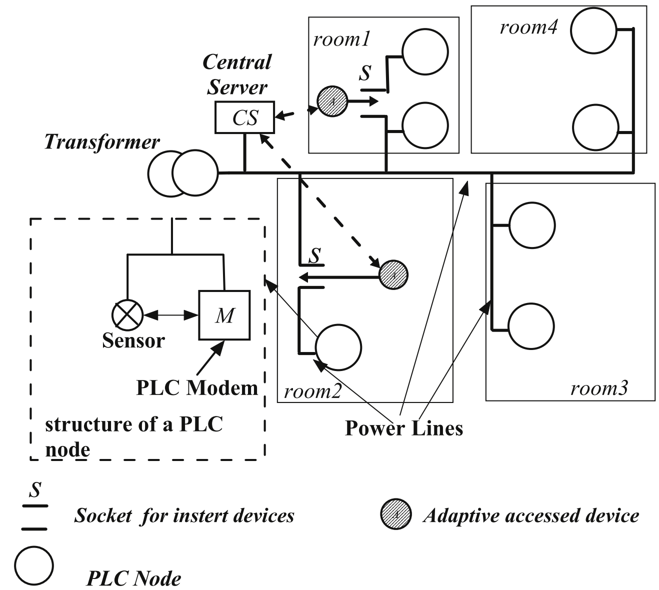

Fig. 1. A typical structure of an in-home PLC network by using the cooperative modulation recognition. The adaptively accessed sensor is the new adding node which need to identify modulation of the system, the central server *CS* is the central node which can receive modulation identification results from multiple ASs, and PLC FNs can be composed by a sensor and a PLC modem.

- We design an improved modulation recognition algorithm based on maximum likelihood by introducing the weighting factor.
- Simulations show that a higher recognition rate and a lower false positive rate are achieved when adopting the proposed cooperative modulation recognition algorithm.

The remainder of this paper are organized as follows. Section 2 describes the cooperative modulation identification scheme for the PLC in-home network systems. Section 3 formulates the feature extraction method for the modulation classifier. Then, Section 4 presents the improved modulation classification algorithm. In Section 5, we present numerical results to demonstrate the performance of proposed algorithms. Finally, Section 6 concludes the paper.

2. System model and assumptions

In the PLC network system, as shown in Fig. 1, the PLC flexed nodes (FN) are installed at the loads, such as the meters or electrical lights. The automatically accessed sensor (AS) is a new node added into PLC network, which needs to identify the modulation used by FN to transmit signals. These ASes sent their results about the modulation identification to a central server (CS). That is, by obtained the feature of signals, the ASes can estimate the modulation primitively and send the estimated results to the CS. According to these received features from ASs, CS makes the final decision on the modulation used in the system. At last, CS feeds back the final identification results to ASs.

Since the CS can collect primitive modulation identification results from independent ASes, it can make a comprehensive judgment on the modulation. In this way, the cooperative modulation recognition approach can improve the performance of correct recognition rate and false positives rate i.e., a modulation of the signals being detected as one when it was not. However, in our model, the CS is required to receive signals from several ASes quickly, so that the training and recognizing process would not be