Spectrum Assignment in Narrowband Power Line Communication

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Abstract

Spectrum assignment is the process of allocating parts of the available spectrum to data transmission. A proper spectrum assignment can improve the performance and reliability of the transmission by selecting the transmission spectrum in a certain way in order to avoid deep fades and interferences of the power line channel. In this paper, we focus on the spectrum assignment problem in FCC-above-CENELC frequency band of narrowband power line communication. Since obtaining the channel state information at transmitter is a challenging task in power line networks, machine learning is introduced in order to solve the spectrum assignment problem without channel knowledge at transmitter. Simulation results are presented to compare the proposed technique with other spectrum allocation techniques.

Index Terms

Spectrum assignment, narrowband PLC, FCC-above-CENELEC.

I. Introduction

NARROWBAND power line communication (NB-PLC) has been standardized by standardization committees such as IEEE and ITU-T [1], [2] to be used in frequencies less than 500 kHz. In fulfillment of these standards, the FCC-above-CENELEC frequency range of NB-PLC (between 154 and 488 kHz) is dedicated to 72 subcarriers for data transmission in an OFDM based power line communication (PLC) transmitter. However, the use of only parts of this frequency band as apposed to the frequency band in its entirety for data transmission has been proposed in the standards as well. Changing the transmission band to just a portion of the entire spectrum can help to avoid the narrowband interference and deep fades of the PLC channel, and consequently improves the performance with the same amount of transmission power. The PLC channel suffers from frequency-selective noise and interference as well as deep fades. Therefore, a proper spectrum assignment process must help the PLC transmitter to select and dedicate the part of the spectrum for data transmission which suffers the least from deep fades and interference, and hence improve the reliability of the channel. However this selection needs full knowledge of the PLC channel in all the spectrum and at all times for all links in the network. This introduces a tremendous amount of overhead into the system and makes communication very inefficient. Therefore, the channel conditions are assumed to be unknown at the transmitter.

The problem of spectrum assignment has been studied extensively in wireless communication [3]. Dynamic spectrum assignment has been introduced to PLC applications in [4] where the authors study the problem with weighted statistical analysis. In this paper we consider the problem of spectrum assignment in FCC-above-CENELEC frequency band of NB-PLC where the channel is frequency-selective and suffers from narrowband interference. We divide the available spectrum into seven sub-bands with different numbers of subcarriers at each sub-band. The transmitter selects the best frequency band to transmit to, based on the performance in each sub-band without any a priori knowledge of the channel conditions in the entire spectrum. To achieve a proper selection policy at the transmitter without any a priori information, probability matching technique as a machine learning algorithm has been proposed. The probability matching technique is a reinforcement learning algorithm which provides a solution to a selection problem in an environment of incomplete information. Reinforcement learning has been introduced in PLC channel selection problem in [5]. Numerical results are presented and it is shown that the transmitter is able to adapt itself in a reasonable time to the conditions of the channel and select the best frequency band throughout the transmission.

II. System Model

The frequencies between 154.6875 kHz and 487.5 KHz have been dedicated to the FCC-above-CENELEC band. According to the standards, this frequency range is divided into a total of 72 data subcarriers in OFDM-based PLC

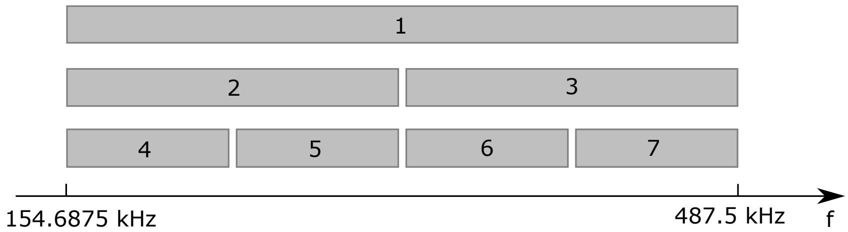

Fig. 1: FCC-above-CENELEC spectrum partitions with seven different frequency bands available.

devices. However, this frequency range can be further divided into two sub-bands with 36 subcarriers each, and each of these sub-bands can be further divided into two sub-bands with 18 subcarriers each [1]. Therefore, seven different frequency bands are available which contain 72, 36, or 18 data subcarriers as depicted in Figure 1. Transmitting in smaller frequency bands results in a lower data throughput, but on the other hand it can improve the performance and reliability of the system if the selected band avoids deep fades and narrowband interferences. Therefore, in cases when the performance of the system must fulfill a certain quality of service, transmitting in a less-disturbed sub-band is preferred.

The PLC channel changes with frequency, time, and location. Moreover, we assume that the PLC transmitter does not have the a priori channel state information of the entire spectrum, since obtaining such information requires the constant transmission of pilot signals which in turn produces a tremendous amount of overhead and cannot be efficiently done. Let us call the duration in which a data frame is transmitted an episode. At each episode, a sub-band is selected by the transmitter, among the seven available sub-bands according to a selection policy and a data frame is transmitted through the selected channel. After each frame transmission, the PLC receiver calculates a notion of reward and feeds back the reward through the acknowledgment packet back to the transmitter. The reward is directly proportional to the bit error rate of the transmission. The objective of the selection policy is to find the best sub-band of transmission based on the observed rewards throughout the transmission and with no a priori knowledge of the spectrum. In the following we propose a method of machine learning for this purpose.

III. The Assignment Technique

To solve the spectrum assignment problem in narrowband PLC, we propose the *probability matching technique* [6] in which a probability is assigned to each of the seven sub-bands and the selection of the transmission band is based on these probabilities. In the initialization phase, the available sub-bands are considered to be equiprobable. Then the transmitter selects one of the sub-bands based on their probabilities and transmits a data frame in the selected sub-band. After each episode, the reward is calculated for that episode based on the number of corrected errors at the receiver and it is fed back to the transmitter. Note that the higher the reward, the better is the performance of the sub-band. Based of the collected rewards, the transmitter calculates an action value estimate for each sub-band as

$$Q_q(a_i) = Q_{q-1}(a_i) + \beta \left[R - Q_{q-1}(a_i)\right], \tag{1}$$

where a_i is the selected sub-band, q is the number of episodes that a_i has been selected, β is a decaying function, and R is the observed reward of that episode. β is chosen in a way that the most recent observations of the reward would have a higher weight compared to the old ones. After updating the action value estimate of the selected sub-band, all the probabilities are updated according to the following probability matching rule

$$P(a_i) = P_{min} + (1 - nP_{min})\frac{Q_q(a_i)}{\sum_n Q_q(a_n)}, \tag{2}$$

where $n = 7$ is the number of available sub-bands, and P_{min} is the minimum probability assigned to each sub-band to ensure the availability of that band even after a long time of idleness. The PLC transmitter selects the next sub-band for the next episode based on the updated probabilities. After a few iterations, the probabilities match the performances of the sub-bands and hence result in the best band being selected more frequently and as a result increasing the average reward obtained by the transmission. However, the probability of the sub-optimal sub-bands are not completely eliminated after some episodes of un-use, due to the existence of P_{min}, and therefore sub-optimal sub-bands have a chance to be chosen as well. This can ensure that the algorithm can find the changes in the channel and choose a new optimal sub-band in case the environment changes. This makes this algorithm a proper solution for PLC, due to the time-variant nature of the PLC channels.

IV. Performance Evaluation

In this section we present the simulation results, in which NB-PLC has been considered with an OFDM-based transmitter and receiver. The probability matching technique has been applied to the seven pre-defined sub-bands of the FCC-above-CENELEC frequency range. The decaying parameter of the algorithm is defined as $\beta = 1/q$. In order to be able to evaluate the assignment algorithm, we have simulated less noise on the the sixth sub-band which results in the best performance in terms of average rewards. Three assignment schemes has been presented in the simulations: first the scenario in which the entire spectrum is used for data transmission, second the random selection of the transmission band regardless of its performance, and third the proposed probability matching technique.

Figure 2 shows the accumulated average rewards throughout the first 200 selection episodes. It can be seen that the probability matching technique results in a significantly higher accumulated reward at large operation times. The random spectrum assignment scheme performs better compared to the transmission in the entire spectrum, since by randomly assigning the transmission band, there is a chance to unknowingly use the better frequency bands. Figure 3 shows the number of episodes in which each of the sub-bands have been selected when the probability matching technique has been used. Based on our simulations, the sixth sub-band is the best option and provides the least amount of noise and interference. As shown in this figure, this sub-band has been selected more often compared to the other sub-bands resulting in an overall higher reliability of transmission.

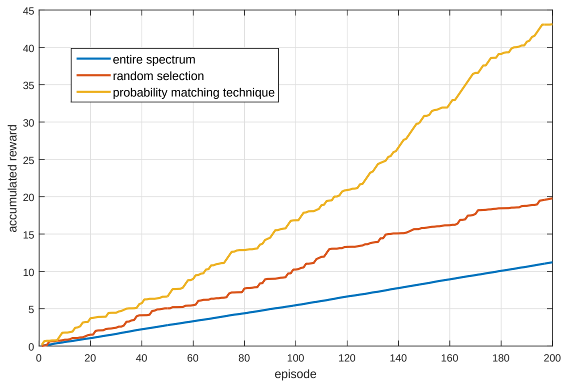

Fig. 2: Accumulated rewards of the three schemes.

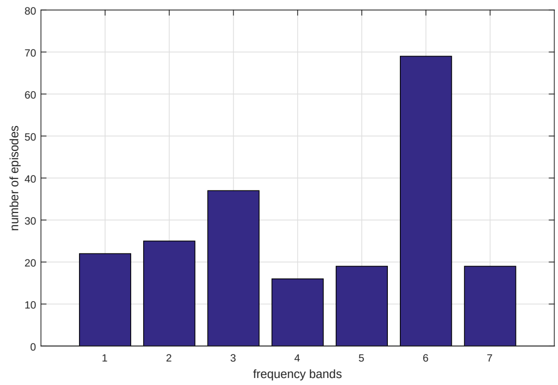

Fig. 3: Band selection based on probability matching.

V. Conclusion

We proposed the probability matching technique to solve the problem of spectrum assignment without a priori knowledge of the spectrum in narrowband PLC. Simulation results have shown that spectrum assignment can improve the performance and reliability of the narrowband PLC with selecting the parts of the spectrum which corrupted by noise and interference less than the other parts. Furthermore, the probability matching technique can provide an efficient selection policy when obtaining the channel state information is not possible and the channel is unknown at the PLC transmitter.

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