Adaptive Modulation and Coding Technique under Multipath Fading and Impulsive Noise in Broadband Power-line Communication

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Abstract

Power-line networks are a great candidate for broadband communication systems. However, a power-line channel suffers from multipath effects, and impulsive noise due to changing load in the network. This paper attempts to overcome these obstacles and increase the bit error rate performance by using adaptive modulation and coding. In this study QPSK, 16-QAM, and 64-QAM schemes and turbo coding at 1/2 and 3/4 coding rates are used. As a result, it is observed that adaptive modulation and coding technique performs better than fixed modulation schemes under multipath fading and impulsive noise in broadband power-line communication.

Index Terms- Broadband power-line communication (BPLC), adaptive modulation and coding, multipath fading, impulsive noise

1. Introduction

In the last few decades, there is an increasing interest to operate the power-line infrastructure for communication. The most significant advantage of the power-line communication (PLC) is very apparent since existing power-line networks are currently available in any zone. Moreover, broadband power-line communication (BPLC) allowing a reliable high-rate transmission over the cables can be obtained at a low cost as it does not require any additional infrastructure [1]. Furthermore, there has been an expanding interest in numerous BPLC implementations including; broadband internet, home networks, HDTV, telephone, and fax services. However, the power lines have been designed for transmitting electrical power without considering communication. Thereby, in such a system there are several major channel distortions along with impulsive noise and multipath fading owing to the changing load on the power line. With this feature, a power-line communication system is similar to wireless communication systems.

To evaluate the performance of BPLC system, proper channel characteristics should be modeled. In the literature, there are a number of different forms of channel models. In this study, we implement the Zimmermann's multipath channel model to exhibit the power-line multipath fading [2].

Additionally, the noise, added by the channel, distorts the communication signals. The noise in the power-line communication system may be divided into two branches just as background noise and impulsive noise. Similar to the conditions of channel models, there are some different forms of noise models for impulsive and background noise in the literature. In this study, we implement one of the most popular noise model is Middleton class A [3] noise model.

These distortions caused by channel conditions lead to degradation of the communication signals in the network. To deal with this phenomenon and to achieve a broadband transmission, multicarrier modulation such as orthogonal frequency-division multiplexing (OFDM) is utilized. OFDM is also an effective technique for BPLC. In [4] the performance analysis of OFDM for a broadband PLC channel under multipath effects and impulsive noise are examined and compared to a single carrier modulation system. The study indicates that OFDM system functions better than the single carrier system under BPLC channel conditions. However, most of the available research on BPLC does not focus on adaptive modulation and coding (AMC). Fixed modulation scheme cannot maximize the data rate in harsh channel conditions like BPLC channel. Through using variable modulation order and coding rate, one can boost the spectral efficiency.

This study aims to illustrate that adaptive modulation and coding technique improves the bit error rate (BER) performance on broadband PLC under multipath fading and impulsive noise. In the following section of the article, the power-line noise in PLC channels and required systems for channel modeling are explored in detail. The section further continues to explain OFDM as an effective modulation technique and presents the parameters of path models, coding tables and amplitude response charts showing the results of this study. In the third section, simulation results are evaluated verifying the efficiency of the adaptive modulation and coding in broadband power-line communication. The conclusion focuses on show performance changes in different variations of modulation orders in relation to data rate and BER performance.

2. System Model

2.1. Noise Model

A PLC channel suffers highly distortive noise due to changing conditions in the power-line network. A detailed study [5] lists the power-line noise as follows:

1) Colored background noise with comparatively low power spectral density (PSD) varies with frequency. A summation of various low power noise sources primarily causes this sort of noise. In this respect, the PSD modifies in time with regards to minutes or hours.

2) Narrow-band noise and especially sinusoidal signals that have modulated amplitudes are results of ingress of broadcast stations. The level often changes through daytime.

3) Periodic impulsive noise asynchronous to the mains frequency with a repetition rate between 50 and 200 kHz, with a discrete line spectrum located in accordance with the impulse

repetition rate. Switched power supplies are generally the reason for this sort of noise.

4) In Europe, periodic impulsive noise synchronous to the mains frequency with a repetition rate of 50 or 100 Hz. The impulses have short life span lasting around microseconds and their PSDdeclines with frequency. Power supplies are the reason for this sort of noise especially through switching of rectifier diodes and this emerges synchronously with the mains cycle.

5) Asynchronous impulsive noise is stimulated by switching transients in the network. The impulses endure from some microseconds to milliseconds and occur randomly. The PSD of this kind of noise is able to attain values more than 50 dB above the background noise.

The features of first two noise types remain constant over long periods of time lasting for seconds, minutes, and may be hours. Therefore, they can be defined as background noise. On the contrary, the last three types can be summarized as impulsive noise since their root mean square (RMS) amplitudes vary rapidly over time (microseconds, milliseconds). Thus, the power-line noise can be considered as the summation of background noise and impulsive noise. In this study, we implement Middleton's class-A impulsive noise model [6] since it satisfies all the fundamental requirements in noise modeling.

According to Middleton's class-A noise model, the mixture of background and impulsive noise is a series of independent and identically distributed complex random variables. The model with probability density function (PDF) is defined as [7]:

$$p_z(z) = \sum_{m=0}^{\infty} \frac{\alpha_m}{2\pi\sigma_m^2} exp\left(-\frac{z^2}{2\sigma_m^2}\right), \tag{1}$$

$$\alpha_m = e^{-A}\frac{A^m}{m!}, \tag{2}$$

$$\sigma_m^2 = \sigma_g^2 \frac{\left(\frac{m}{A}\right)+\Gamma}{\Gamma}, \tag{3}$$

$$\sigma_z^2 = E\{z^2\} = \frac{e^{-A}\sigma_g^2}{\Gamma}\sum_{m=0}^{\infty}\frac{A^m}{m!}\left(\frac{m}{A}+\Gamma\right), \tag{4}$$

where m is the number of impulsive noise sources, A is impulsive index (If A is increased, the impulsiveness becomes weaker and the noise approaches to Gaussian noise), Γ is the Gaussian to impulsive noise ratio (GIR), and $\Gamma = {\sigma_g}^2/\sigma_m^2$ where ${\sigma_g}^2$ is the variance of Gaussian noise components, and σ_m^2 is the impulsive noise power. Finally, σ_z^2 represents the variance of Middleton's Class a noise.

2.2. Multipath Fading Channel Model

The data signals in power-line network do not track a single path; rather they follow a multipath in line with the channel conditions. Although the power-line communication is a wire-based communication, depending upon the channel conditions in the system, it is very similar to wireless communication.

In the literature, there are different models present for PLC channel such as Philipps model [8], the Zimmermann and Dosteret model [2], and the Anatory et al [9]. model. In this study, Zimmerman's multipath model is implemented for simulation. The multipath fading model proposed by Zimmermann is illustrated as [2]:

$$H(f) = \sum_{i}^{N} g_i . e^{-(a0+a1f^k)di} . e^{-\wedge j2\pi f(di/Vp)} \tag{5}$$

where *H(f)* is the frequency response of the multipath channel, d_i is the length of path, g_i is the weighting factor, k is the attenuation factor, $a_0$and $a_1$are attenuation parameters.

Equation (5) stands for parametric model, explaining the frequency response of multipath fading power-line channel, it covers all significant effects of the transfer properties in the frequency interval from 1 MHz to 20 MHz via minor set of parameters, given in the study [2], and shown in Table 1 and Table 2. Furthermore, the number of paths, *N*, makes it possible to control the sensitivity of the model, which is very important for analyzing PLC system performance.

Table 1. Parameters of 4-path model (*N=4*) [2]

Attenuation Parameters					
$k = 1$		$a_0 = 0$		$a_1 = 7.8 * 10^{-10}\, s/m$	
Path Parameters					
I	gi	d_i/m	I	gi	d_i/m
1	0.64	200	3	-0.15	244.8
2	0.38	222.4	4	0.05	267.5

Table 2. Parameters of 15-path model (*N=15*) [2]

Attenuation Parameters					
$k = 1$		$a_0 = 0$		$a_1 = 7.8 * 10^{-10}\, s/m$	
Path Parameters					
I	gi	d_i/m	I	gi	d_i/m
1	0.029	90	9	0.071	411
2	0.043	102	10	-0.035	490
3	0.103	113	11	0.065	567
4	-0.058	143	12	-0.055	740
5	-0.045	148	13	0.042	960
6	-0.040	200	14	-0.059	1130
7	0.038	260	15	0.049	1250
8	0.038	322			

In this study, two different Zimmermann multipath models that are 4-path and 15-path are performed. According to the parameters for those models; the amplitude responses are shown in Fig. 1, and Fig. 2,respectively.

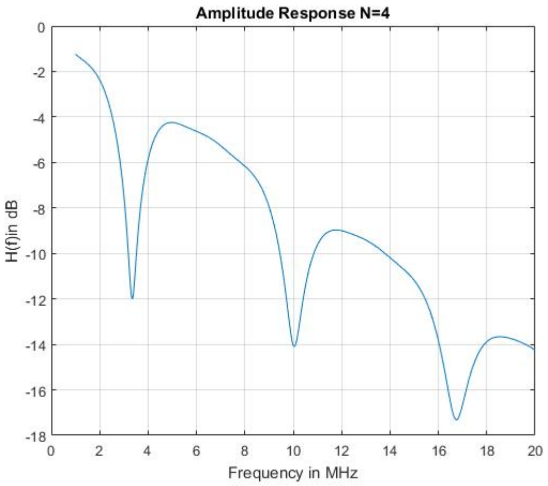

Fig. 1. Amplitude response of 4-path channel

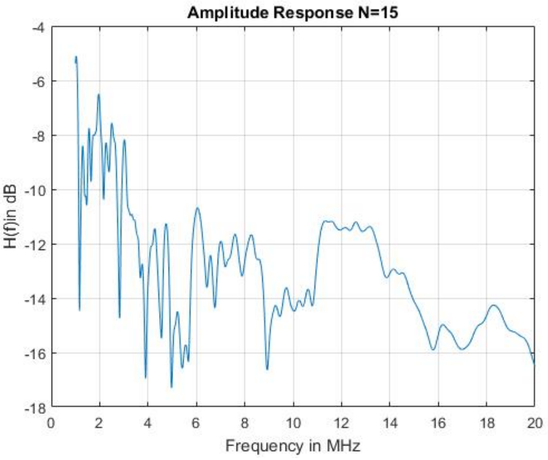

Fig. 2. Amplitude response of 15-path channel

2.3. OFDM System and Adaptive Modulation Coding

OFDM is a very efficient modulation technique, which is widely used in broadband communication, to handle with the inter-symbol interference (ISI), and it also reduces the results of multipath. It presents a perfect spectral efficiency which is necessary for a channel with barely restricted spectral resources such as PLC. OFDM also shows better performance in the presence of impulsive noise conditions than single-carrier modulation techniques. Moreover, the most important property of OFDM is its adaptability. According to the PLC channel terms, several parameters, such as; transmit power, data rate, code rate, and constellation size can be adjusted to optimize the efficiency of the system based on the channel conditions through adaptive modulation algorithms.

In order to improve the performance of BPLC system adaptive modulation coding (AMC) can be utilized. AMC technique allows controlling each sub-channels' constellation size depending on the channel conditions. In AMC, some parameters can be controlled such as data rate, instantaneous BER, channel code/scheme, and constellation size. To control those parameters, AMC requires up-to-date channel quality information (CQI) at the transmitter. This information shows the signal condition in the link from the transmitter to receiver ending.

Channel quality information (CQI) should be estimated at the receiver. In this study, the minimum mean square error (MMSE) estimator [10] is utilized to obtain CQI at the receiver. Once the MMSE estimator evaluates the instantaneous SNR in the channel, the mode selector gives feedback to the transmitter in order to adapt constellation scheme and coding rate. The coding rate and modulation scheme is adjusted according to SNR thresholds are acquired from the performance of each scheme in the PLC channel possessing target BER of 0.001. The SNR thresholds are given in Table 3.

Table 3. SNR Threshold Modulation Coding Table

Modulation Formats	SNR (dB)	
	4-path	15-path
QPSK ½	8,96	11,72
QPSK ¾	11,88	14,8
16QAM ½	13,94	17,38
16QAM ¾	17,4	20,82
64QAM ½	21,08	24,18
64QAM ¾	25,86	27,56

Likewise, the receiver should also be given feedback about which demodulation and decoding parameters are required to be used for the following frame. The diagram of the OFDM-AMC system model is shown in Fig. 3.

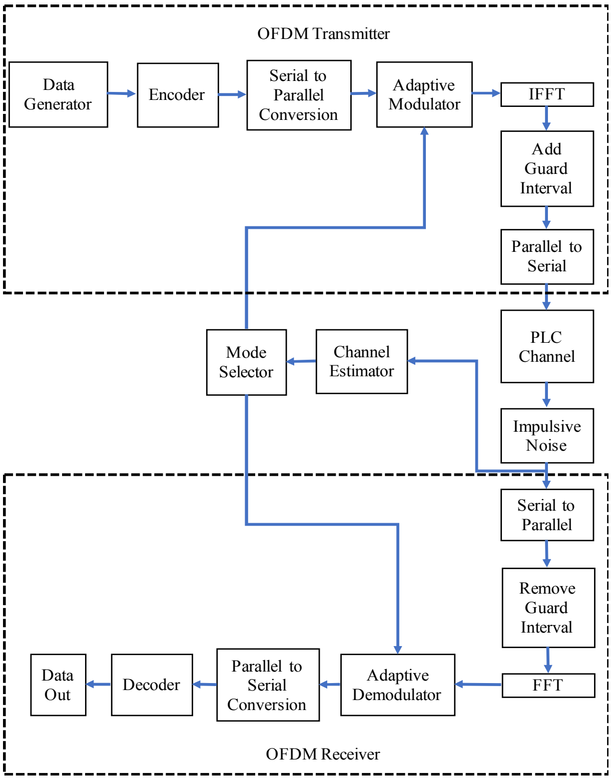

Fig. 3. OFDM-AMC system model

3. Simulation Results

This study aims to verify the effectiveness of the adaptive modulation and coding in broadband power-line communication. To demonstrate this, we focus on the bit error rate performance of AMC schemes using with target BER of 10^{-3}. To select accurate modulation scheme and coding rate, MMSE channel estimator utilized at the receiver. We also use QPSK, 16-QAM, and 64-QAM modulation schemes and compare the results to demonstrate BER performance based on modulation order. Additionally, we employ turbo coding which consists of 1/2, 3/4 coding rate and the soft output Viterbi algorithm (SOVA) is operated to improve BER performance.We implement the simulation by combining the aforementioned modulation schemes and coding rates (1/2 QPSK, 3/4 QPSK, 1/2 16-QAM, 3/4 16-QAM,1/2 64-QAM, 3/4 64-QAM) and demonstrate the results for 4-path and 15-path fading channels in Fig. 4 and Fig. 5, respectively.

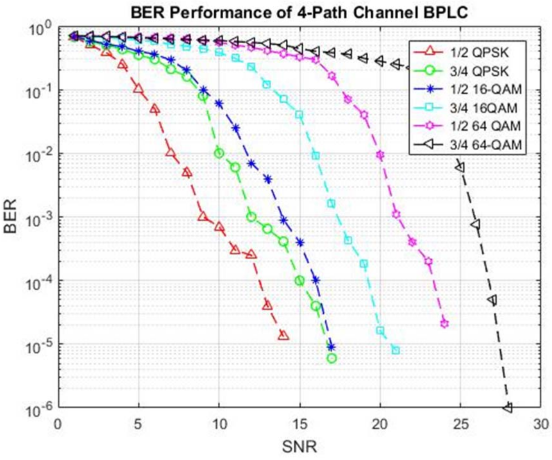

Fig. 4. 4-path fading channel BER performance

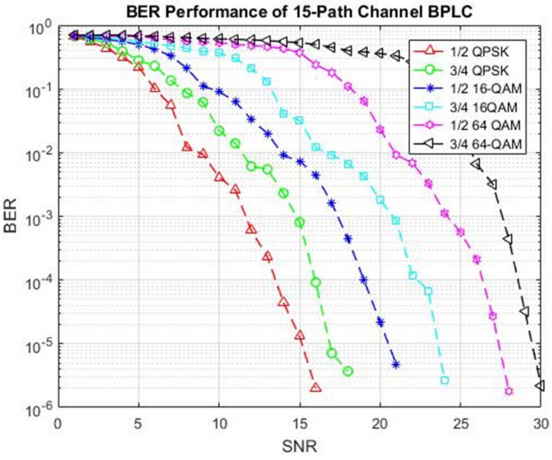

Fig. 5. 15-path fading channel BER performance

According to the results, QPSK with 1/2 and 3/4 coding rate have better BER performance than 16-QAM and 64-QAM with 1/2 and 3/4 coding rate, under 4-path and 15-path fading channel. Besides, each modulation scheme has a better performance when 1/2 coding rate compared to 3/4 coding rate are used. Thus, one may assume that the lower modulation orders and coding rates are more suitable for better BER performance. Likewise, higher modulation orders and coding rates are more preferable to get higher throughput, which is a trade-off. Therefore, the system continues to work at lower modulation order scheme till it reaches the target BER from that point on it accumulates higher modulation transmission scheme in order to achieve a more yielding spectral efficiency.

4. Conclusion

This paper shows the performance analysis of adaptive modulation coding in broadband powerline communication. We explore the effect of utilizing AMC techniques under highly distorted channel conditions which include multipath fading and impulsive noise. It is seen that lower modulation orders and coding rates perform better than higher modulation orders and coding rates at low SNR values. Additionally, higher modulation order and coding rate can give higher data rate, but gives lower bit error rate performance. It is also seen that the multipath fading effect worsens the BER performance. So, 15-path fading channel has lower BER performance compared to 4-path fading channel in AMC system.

5. References

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