Power Allocation for Relay-Assisted Indoor Power Line Communication Systems

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I. Introduction

Using the worldwide already existing power lines as a communication medium for local area networking (LAN) has received much interest for many indoor information sharing applications. However, the indoor power line communication (PLC) channels demonstrate hostile characteristics for broadband signal transmission. A lot of efforts have been made in order to apply some advanced technologies, which were originally developed for wireless environment, into PLC channels. In this work, we address a simple but practical cooperative transmission strategy in indoor PLC environment. Our main contributions can be summarized as: *(1)* The theoretical optimal condition for power allocation between transmitter and relay device has been derived. *(2)* The performance improvement of the cooperative amplify-and-forward (CAF) scheme has been investigated, with respect to the conventional direct transmission (DT) scheme.

II. System Model

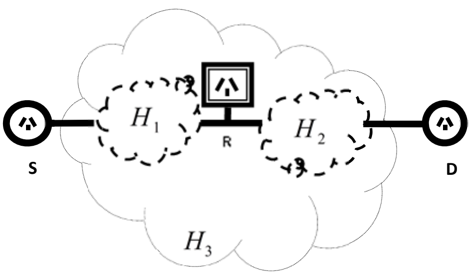

Figure 1. A relay-assisted indoor PLC system

Let us consider a PLC system where a source outlet *S* sends messages to a destination outlet *D* through PLC channel H_3, as shown in Figure 1. It is often possible to find another outlet *R* located somewhere in the middle of *S* and *D*, which enables us to introduce a relay device. From the relay point of view, the whole direct channel H_3 has been separated into two parts, i.e. source-to-relay channel H_1 and relay-to-destination channel H_2. Let us denote α_1, α_2 and α_3 as the power attenuation of channels H_1, H_2 and H_3 respectively. It is obvious that

$$\alpha_3 = \alpha_1 \alpha_2 . \tag{1}$$

As there is no generally accepted PLC channel model, we use a well-examined channel simulator in [1] to randomly generate an example of channel H_3. Its frequency and impulse responses are shown in Figure 2.

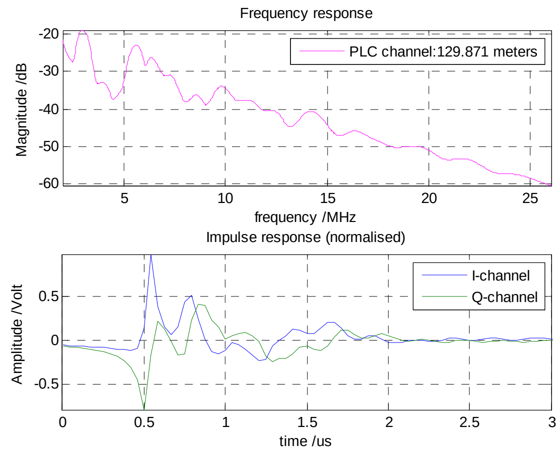

Figure 2. Direct (*S*-to-*D*) channel H_3

The noise in PLC has been studied in [2] and [3]. In general it can be classified into two catalogues: general coloured background noise (GBN) and impulsive noise. In this paper, we only consider the impact of the GBN. Based on extensive measurement campaign, a synthesis process published in [4] is used to approximate the general background noise. An example of this noise is given by its power spectral density (PSD) in Figure 3.

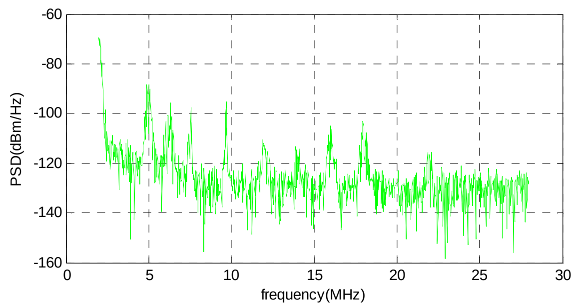

Figure 3. PSD of GBN in PLC channel

By assuming that the channel condition information (CCI) is known at both the relay and the receiver, orthogonal-frequency-division-multiplexing (OFDM) technique has been adopted to eliminate the inter-symbol interference (ISI) in the PLC channel. We also assume that the time division duplexing (TDD) mode is used in our scheme, and coherent signal combination is used at the receiver. In order not to cause more electromagnetic interference (EMI) to the environment, the total power consumption of relay and transmitter in our scheme is assumed to be equal to the transmitting power of the DT system.

At the first time slot, the source sends message signal X out with power P_s. The relay and the destination receive this signal with different channel attenuations and noises. In frequency domain, they can be written as

$$Y_r(f) = H_1(f)X(f) + N_r(f) \tag{2}$$

$$Y_d(f) = H_3(f)X(f) + N_d(f)\,. \tag{3}$$

The signal-to-noise ratio (SNR) at the input of destination is

$$SNR_d^{<1>} = \frac{P_s\alpha_3}{P_{N_d}} \tag{4}$$

where P_{N_d} is the noise power at destination.

At the second time slot, the relay node amplifies its received signal $Y_r(f)$ with power gain β, and forward it to the destination with power P_r. Thus the received signal at destination at this phase is written as

$$Y_d'(f) = \sqrt{\beta}H_1(f)H_2(f)X(f) + \sqrt{\beta}H_2(f)N_r(f) + N_d'(f)\,. \tag{5}$$

As the power of signal $Y_r(f)$ can be calculated as $P_s\alpha_1 + P_{N_r}$, we have

$$\beta = \frac{P_r}{P_s\alpha_1 + P_{N_r}} \tag{6}$$

where P_{N_r} is the noise power at the input of the relay. The SNR at the input of destination at this second phase is

$$SNR_d^{<2>} = \frac{P_s\beta\alpha_3}{P_{N_d} + P_{N_r}\beta\alpha_2}\,. \tag{7}$$

Finally, the receiver combines the signals in (3) and (5) with the maximum ratio combing (MRC) technique, so that the effectively cooperative-signal-to-noise ratio (*CSNR*) can be expressed as $CSNR = SNR_d^{<1>} + SNR_d^{<2>}$. For simplicity we assume $P_{N_d} = P_{N_r} = P_n$, so that

$$CSNR = \frac{P_s\alpha_3}{P_n} + \frac{P_sP_r\alpha_3}{P_sP_n\alpha_1 + P_n^2 + P_nP_r\alpha_2}\,. \tag{8}$$

III. Optimal Power Allocation

For given α_1, α_2, P_n and system total available power P_t to find the best power allocation between P_s and P_r is essentially to solve the optimisation problem of

$$\max_{P_s,P_r} \; CSNR$$

$$= \max_{P_s,P_r} \; \frac{P_s\alpha_3}{P_n} + \frac{P_sP_r\alpha_3}{P_nP_s\alpha_1 + P_n^2 + P_nP_r\alpha_2}$$

$$\begin{aligned} s.t. \quad & P_s + P_r = P_t \\ & 0 < P_s \le P_t,\quad 0 \le P_r < P_t \end{aligned}\,. \tag{9}$$

It can be shown that

$$P_s = \frac{-\sqrt{(P_n + P_t\alpha_1)(P_n + P_t\alpha_2)(\alpha_2 - \alpha_1 + 1)} + P_n(1 - \alpha_1 + \alpha_2) + P_t\alpha_2(1 + \alpha_2 - \alpha_1)}{\alpha_1^2 - 2\alpha_3 - \alpha_1 + \alpha_2 + \alpha_2^2}$$

$$P_r = \frac{\sqrt{(P_n + P_t\alpha_1)(P_n + P_t\alpha_2)(\alpha_2 - \alpha_1 + 1)} - P_n(1 - \alpha_1 + \alpha_2) - P_t\alpha_1(1 - \alpha_1 + \alpha_2)}{\alpha_1^2 - 2\alpha_3 - \alpha_1 + \alpha_2 + \alpha_2^2} \tag{10}$$

is the solution to the problem (9).

IV. Numerical Results

Figure 4 shows the comparison of *CSNR* (8) and $SNR_d^{<1>}$ (4) versus P_s. Note that for fair comparison, in (4) $P_s = P_t$. We observe that *(1)* For most of the time there is a better performance if a relay node has been introduced to assist the transmitter. And if the power allocation has been set optimally as (10), the performance improvement is significant. *(2)* Only when too less power has been allocated to the transmitter, the CAF scheme fails to improve SNR, so this situation should be avoided.

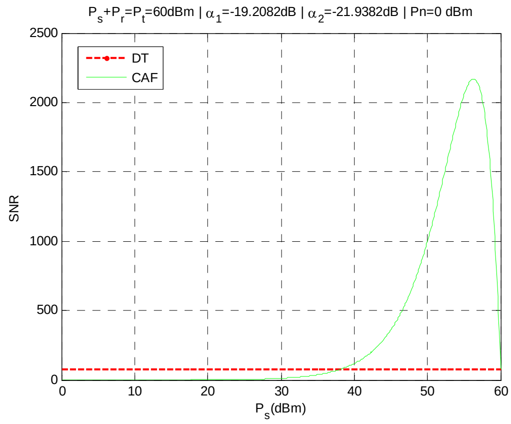

Figure 4. SNR of the CAF scheme with varying power allocation, compared with the DT scheme

Setting power allocation optimally as (10), Figure 5 shows the system bit-error-rate (BER) versus P_t of the DT and CAF schemes. We observe that for the same modulation technique used the BER performance of CAF is generally better than the DT. Considering the TDD restriction of the CAF scheme, the system throughput is only half of that in the DT case. This can be compensated by increasing the modulation level (e.g. from BPSK to QPSK here). It can be seen that with this throughput compensation, the CAF still outperforms the DT scheme with more than 10dB *SNR* gain.

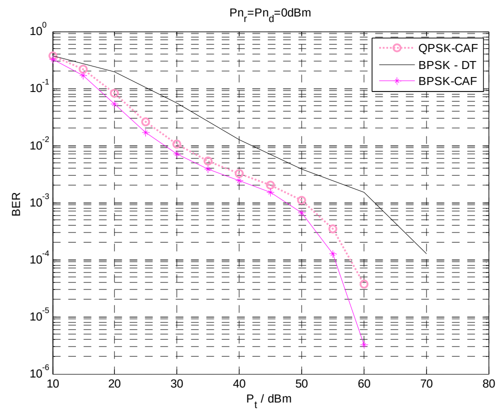

Figure 5. BER performance of the CAF and DT schemes with optimal power allocation

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