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# Analysis and improvement of multicast communications in HomePlug AV-based in-home networks

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ABSTRACT

The increasing number of home devices with communication capabilities is propelling the research into new communication technologies for in-home networks. Power Line Communications (PLC) has proven to be a feasible alternative for this purpose, and the HomePlug AV standard has become one of its most popular solutions. However, while multicast communications are demanded by many services commonly used in home scenarios, the HomePlug AV implements an inefficient mechanism in which they are carried out as successive point-to-point transmissions. The aim of this paper is to outline the limitations of such scheme and to propose algorithms that improve the multicast performance of the standard. To this end, we have developed a simulation tool for HomePlug AV-based in-home networks. It implements the physical and MAC layers, as well as traffic models for the most common home network services. One of its distinctive features is the ability to generate PLC channels with similar correlation to the ones established in a given home. This correlation has been traditionally neglected, leading to inaccurate performance estimations and to discard suitable multicast algorithms. The considered multicast schemes are firstly compared in terms of their physical bit rate. Finally, their capacity to deliver a video streaming service is assessed.



## 1. Introduction

Nowadays there is an increasing number of home devices equipped with communication capabilities. From computers and mobile phones to traditional home appliances, all of them can be interconnected to share information or simply be connected to the Internet through the home access point. For these reasons, home networks (also called in-home networks) have recently attracted a significant interest in both the industry and the scientific community.

Several technologies can be used to deploy a home network, from traditional approaches like wired and wireless technologies, to the recently introduced no-new-wires solutions, which use existing infrastructures at homes to lay out the network. This category includes technologies that use the telephone line, the coaxial cable or the low voltage power grid inside the user premises to exchange data. The disadvantage of the former is that the number of telephone and cable sockets is very limited in most homes outside the US.

In-home Power Line Communications (PLC) networks may provide a large catalogue of services. Many of them require multicast communications, e.g. music and video streaming, online computer gaming, gaming consoles, or even video conferencing. However the most popular PLC standard, HomePlug AV (HomePlug Audio and Video, or simply HPAV) [1], does not implement real multicast data transmission. This is probably due because its bit-loaded

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OFDM physical layer has been designed to exploit the frequency selectivity of the channel, which is a very link dependent feature. Therefore, multicast transmissions in HPAV networks are implemented as a set of consecutive point-to-point transmissions that are carried out in a transparent way to end users.

The multicast problem has been widely explored in wireless scenarios, and some solutions have been recently proposed. They can be divided into two categories, solutions that try to minimize the total power consumption under the fixed system throughput constraint [2,3], and solutions that maximize the total system throughput under the power consumption constraint [4–6]. However, these results cannot be directly applied to PLC, since the maximum power spectral density (PSD) is the most restrictive constraint in this technology. In fact, all carriers are usually transmitted at the maximum power level allowed by the PSD mask. Hence, decreasing the power level used in one carrier does not allow increasing it in another one. Therefore, the contributions to this area in PLC networks are very limited. To the authors' best knowledge, the only relevant contribution related to multicast communications in these networks can be found in [7], where the use of pre-coded OFDM is proposed. This solution improves the multicast throughput but requires significant changes at the physical layer, which discards it as a real alternative for the HPAV standard. Moreover, these works only evaluate the physical layer transmission rates, but do not consider their implications at higher layer services.

A common feature of the aforementioned multicast works is that they have been accomplished in wireless scenarios or using PLC channel models that generate uncorrelated channels. Nevertheless, all the links established in a given in-home PLC network share a common network layout, which causes the channels to exhibit some degree of correlation. This correlation has been traditionally neglected because it has no influence on the physical layer analysis in point-to-point communications. However, it cannot be disregarded when assessing multicast algorithms, since their performance is strongly dependent on the differences among the involved channels. The larger the dissimilarities among them, the poorer the multicast performance.

In this context, we make three main contributions:

- We present a PLC simulator based on the HPAV standard that takes into account the correlation among the channels established in the same in-home network. It implements the physical and MAC layers, as well as traffic models for the most common home network services. Channel responses are obtained using a bottom-up model in which a simplified random topology is generated for each in-home network. Hence, the user is released from the burden task of defining the grid layout. However, since all the links established in this network share some layout elements, the resulting channels will exhibit a similar degree of correlation to the actual ones.
- We evaluate the multicast performance of the HPAV. We show that it can be significantly improved even by means of the classical multicast algorithm in which the number of bits per carrier is determined by the user with the worst signal to noise ratio (SNR). In addition, a more elaborated multicast algorithm is proposed for scenarios with higher number of users.
- We assess the performance of a video streaming service using the multicast strategy implemented in the HPAV standard and a modified version that includes the classical multicast algorithm.

The remainder of the paper is structured as follows. In Section 2, the different multicast protocols considered in this paper are described. Then, in Section 3 a brief description of the simulation environment is presented and the performance evaluation results are shown in Section 4. Finally, Section 5 concludes the paper.

## 2. Multicast communications algorithms

### 2.1. Multicast communications in the HPAV standard

The PLC medium exhibits remarkable variations among locations. The characteristics of the communication links depend on the network topology, the type of wires and the connected loads. Even in a specific in-home network, significant differences in the characteristics of the links can be found depending on the selected transmission path or the status of the electrical appliances. In order to adapt the physical layer modulation to this medium, the HPAV standard uses an OFDM modulation with $N = 917$ useful carriers in the 2–28 MHz frequency band. Each of these carriers can be independently modulated from a simple BPSK constellation (one bit of information per symbol) to 1024 QAM (ten bits of information per symbol). Since the channel characteristics among each transmitter–receiver pair are different, so do the used constellations.

In order to send a multicast frame to a multicast group, the current version of the HPAV standard sends one point-to-point frame to each member of the multicast group. This technique clearly degrades the performance of multicast services as the number of receivers increases. Its effective multicast transmission bit rate can be calculated by means of expression (1). Since transmissions are serially accomplished, the time required to accomplish the multicast transmission, $T_M$, is the sum of the transmission times of the $M$ multicast clients, $t_m$, with $m = 1, \ldots, M$. Therefore, assuming that the transmitted data has size $L$, and that the channel conditions remain invariable during the transmissions, the inverse of the multicast bit rate, $C_M$, will be the sum of the inverse of the different clients bitrates, $C_m$.

$$T_M = \sum_{m=1}^{M} t_m \;\Rightarrow\; C_M = \frac{L}{T_M} = \frac{L}{\sum_{m=1}^{M} t_m} \;\Rightarrow\; \frac{1}{C_M} = \frac{\sum_{m=1}^{M} t_m}{L} = \sum_{m=1}^{M} \frac{1}{C_m}. \quad (1)$$

It will be shown in this paper that this poor performance can be improved even with a multicast algorithm that selects a common tone map for all the multicast clients. This is the most straightforward multicast strategy and will be referred to as Greatest Common Tonemap (GCT). Although its performance in PLC networks is much better than in