Bit Rate Maximization for Multicast LP-OFDM Systems in PLC Context

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Abstract

In this paper, we propose a new resource allocation algorithm based on linear precoding technique for multicast OFDM systems. Linear precoding technique applied to OFDM systems has already proved its ability to significantly increase the system throughput in a powerline communication (PLC) context. Simulations through PLC channels show that this algorithm outperforms the classical multicast method (up to 7.3% bit rate gain) and gives better performance than the hierarchical data method in a realistic number of multicast users.

Index Terms

Multicast OFDM, Linear Precoding, Resource Allocation, PLC.

I. Introduction

MULTICASTING is a network addressing method for the delivery of data to a group of users simultaneously using less network resources. For multimedia applications, this technique offers a significant improvement compared to unicasting. Over the physical layer, resources have to be allocated in order to satisfy requirements of each multicast user. The classical resource allocation method in multicast orthogonal frequency division multiplexing (OFDM) is to serve the "worst" user on each subcarrier. Consequently, the final multicast bit rate is limited by the "worst" user channel conditions and all users receive the same bit rate.

To increase the multicast bit rate, the multicast data is compressed into a number of layers, arranged in a hierarchy, which provides progressive refinement. Thus, each user receives its corresponding data quality version according to its channel conditions. This method significantly increases the total multicast bit rate compared to classical multicast method, in wireless communications [1]. But, when channel conditions of users are very different, the algorithm may finish without assigning any bit rate to a user.

In this paper, we consider a new resource allocation algorithm based on linear precoding (LP) technique for multicast OFDM systems. This algorithm aims at increasing the bit rate allocated to each multicast user. Our proposed algorithm significantly enhances the performance of the classical multicast OFDM method by exploiting the LP technique in a powerline communication (PLC) context. Performance comparison with the hierarchical data method is also addressed over PLC channels.

II. LP-OFDM system description and problem formulation

A. LP-OFDM system description

The LP technique consists in connecting a set of subcarriers with precoding sequences to mutually exploit their channel conditions. This set of subcarriers is called block in the following and the subcarriers are not necessary adjacent. The number of blocks is defined as the ratio of total number of subcarriers N to the precoding sequence length L. We assume the same precoding sequence length L for all blocks. The optimum achieved bit rate of the LP-OFDM system using ZF detection writes [2], [3]

$$\mathcal{R}_b = L \log_2 \left(1 + \frac{1}{\Gamma} \frac{L}{\sum\limits_{n \in S_b} 1/|h_n|^2} \frac{E}{N_0} \right), \quad (1)$$

where $|h_n|^2$ is the channel amplitude of subcarrier n, E is the PSD constraint, Γ is the SNR gap, N_0 is the background noise level and S_b is the set of subcarriers within the bth block. The classical OFDM system is obtained for $L = 1$.

B. Bit rate maximization problem in multicast OFDM systems

In multicast OFDM systems and in non-hierarchical data context, the modulation should be adjusted to serve the user with the worst channel conditions. The classical method in multicast OFDM, LCG (low channel gain, [1]), sets the number of loaded bits per subcarrier with the lowest number of loaded bit over this subcarrier, considering all the channels of users. Hence, the loaded bit with LCG method over subcarrier n in PLC context writes

$$\mathcal{R}_n^{\mathrm{LCG}} = \min_u \log_2(1 + \frac{E}{\Gamma N_0}\, |h_{u,n}|^2)\,. \tag{2}$$

When considering the LP-OFDM system, the multicast loaded bits over the block S_b of subcarriers will be the lowest bit rate of users over this block. This bit rate writes

$$\mathcal{R}_b^{\mathrm{LP}} = \min_u \mathcal{R}_{u,b} = \min_u L\, \log_2\left(1 + \frac{1}{\Gamma}\frac{L}{\displaystyle\sum_{n\in S_b}\frac{1}{|h_{u,n}|^2}}\frac{E}{N_0}\right). \tag{3}$$

Due to PSD constraint in PLC systems, all users have the same peak power constraint E on each subcarrier. Hence, there is no power allocation. To maximize the multicast bit rate, we need to choose the block S_b that maximizes the "worst" user bit rate.

As,

$$\min \mathcal{R}_{u,b} \Leftrightarrow \max \sum_{n\in S_b}\frac{1}{|h_{u,n}|^2}\,, \tag{4}$$

the optimization problem writes

$$\min_{S_b}\ \max_u \sum_{n\in S_b} 1/|h_{u,n}|^2\,. \tag{5}$$

This is a combinatorial and min-max-sum resource allocation problem which is NP-hard [4].

III. The proposed algorithm

The basic and optimal solution to the maximization problem is to test all possibilities of gathering subcarriers in blocks and then to choose the best case. This solution becomes unfeasible when the number of subcarriers increases.

In the LCG method, the multicast bit rate can be considered as the bit rate computed over an equivalent channel in single user context. This equivalent multicast channel is the combination of channel conditions of different users and writes $\left|h_n^{\mathrm{eq}}\right|^2 = \min_u |h_{u,n}|^2$. Computing this equivalent multicast channel, the multicast resource allocation is the same as the single link resource allocation. Bit loading algorithms in single user context can then be applied to this channel. LCG method gives results for classical OFDM bit loading algorithm. To increase the bit rate of this LCG method, the LP-OFDM bit loading in single user context, is applied on the equivalent channel and this method will be considered as linear precoding based LCG (LP-LCG) method. Then, subcarriers of the equivalent channel are sorted in descending order and best available subcarriers are gathered in a block. It has been shown that LP-OFDM outperformed classical OFDM in single link context [2], [3].

Our proposed algorithm, considered as the new LP-LCG, consists in sorting the subcarriers of the equivalent channel in descending order and the indexes of sorted subcarriers define the different blocks. This method gives better results than LP-LCG method. Actually, when considering blocks of subcarriers, we show, for all $n \in S_b$ and for all u,

$$|h_{u,n}|^2 \geq |h_n^{\mathrm{eq}}|^2 \ \Leftrightarrow\ \max_u \sum_{n\in S_b}\frac{1}{|h_{u,n}|^2} \leq \sum_{n\in S_b}\frac{1}{\left|h_n^{\mathrm{eq}}\right|^2} \Leftrightarrow \min_{S_b}\max_u \sum_{n\in S_b}\frac{1}{|h_{u,n}|^2} \leq \min_{S_b}\sum_{n\in S_b}\frac{1}{\left|h_n^{\mathrm{eq}}\right|^2}\,. \tag{6}$$

From (6), we derive that the "worst" user over block S_b offers a better bit rate than the LP-LCG method. We aim at finding the solution of the left hand side of inequality (6) according to (5). Minimize the right hand side of the inequality reduces the left hand side and using the best available L subcarriers of the equivalent channel to form S_b minimizes the right hand side. This solution consists in sorting the subcarriers of the equivalent channel in descending order and the indexes of sorted subcarriers define the different blocks.

Compared to the classical LCG method, the additional complexity brought by the LP-LCG method is the utilization of the precoding matrix which is composed of Hadamard orthogonal matrices. The new LP-LCG method also needs the computation of different harmonic sums of channel gains of users ($\sum_{n\in S_b} 1/|h_{u,n}|^2$). The additional complexity remains marginal compared to the overall system complexity.

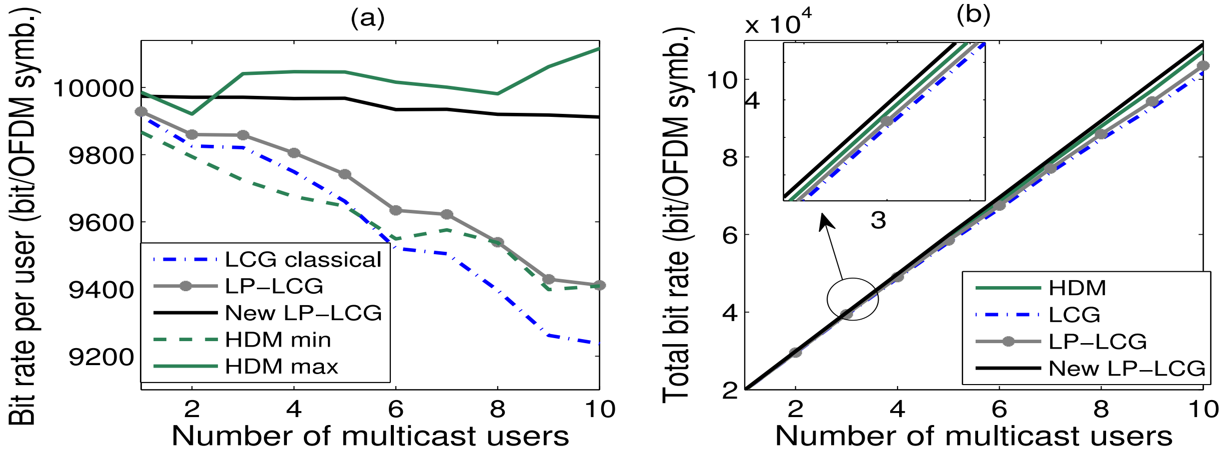

Fig. 1. Achieved bit rate, in bit per OFDM symbol, with different methods: (a) bit rate received by each multicast user and (b) total bit rate.

IV. Simulation results

In this section, we compare the proposed resource allocation algorithm for LP-OFDM with classical multicast OFDM method in the context of PLC. For the sake of comparison, we consider the hierarchical data method (HDM) proposed in [1]. The generated signal is composed of $N = 1024$ subcarriers transmitted in the $[0; 30]$ MHz band. The background noise level is set to -110 dBm/Hz and the transmitted PSD constraint is -50 dBm/Hz for all users. We use the PLC channel generator proposed in [5]. Fig 1 show the achieved bit rate with different methods. The curves HDM, HDM-min and HDM-max represent respectively the total, the minimum and the maximum bit rate offered by the hierarchical data method. In HDM method multicast users are separated in frequency domain in order to increase the total multicast bit rate. Actually, each subcarrier is assigned to a group of users which receive the same data symbols on this subcarrier. And then, the number of loaded bits on each subcarrier is determined considering the lowest one among the channel amplitudes of all the users allocated to this subcarrier. This assignment explains the gap between HDM-min and HDM-max. Note that, all users share the same resources and have the same bit rate in LCG, LP-LCG and new LP-LCG methods. The bit rate received by the best user in HDM method is greater than the bit rate he receives with other methods. By cons, the worst user receives less bit rate in HDM method in the same conditions.

As expected, linear precoding based methods outperforms the classical LCG method and the gain offered for the new LP-LCG method can reach 7.3% for a 10-user system. Compared to HDM method, the new LP-LCG method gives the best total bit rate and guaranties good level of bit rate for all users in a realistic 10-user system.

V. Conclusion

In this paper, we have proposed a new resource allocation algorithm based on linear precoding technique for multicast OFDM systems. This algorithm outperforms the classical multicast method and gives better performance than the hierarchical data method for a realistic number of multicast users.

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