Power Engineering Letters

Fair Resource Allocation With Improved Diversity Performance for Indoor Power-Line Networks

Nikolaos Papandreou, *Member, IEEE*, and Theodore Antonakopoulos, *Senior Member, IEEE*

***Abstract*—The problem of fair resource allocation in power-line networks with multiple links is considered. A new bandwidth allocation criterion with improved multiuser diversity characteristics is presented, which provides an increased total data rate compared with other existing solutions. Simulation results demonstrate the effectiveness of the proposed method under different network loading conditions.**

***Index Terms*—Bit loading, diversity, fairness, orthogonal frequency-division multiplexing (OFDM), power-line communications (PLC).**

I. Introduction

POWER-LINE COMMUNICATIONS (PLC) have gained increasing interest as a potential technology for inhome networking as well as for the last mile access [1]. Recently, industry specifications for data rates up to 200 Mb/s have been ratified and a lot of effort has been devoted toward the standardization of PLC technology [2]. In order to confront the power-line channel limitations, such as multipath fading, intersymbol interference, and impulse noise [3], orthogonal frequency-division multiplexing (OFDM) is used since it provides high capacity, efficient spectrum utilization and multiple access capabilities [4].

The inhome PLC network consists of data-communicating devices connected at various sockets and a central device that provides Internet access and routes the internal data traffic [1]. Communication is realized via multiple point-to-point links between the central device and the data terminals. A fundamental issue in OFDM transmission is the allocation of the available bandwidth and power resources to the network links, so that the overall data rate is maximized, while a target quality of service (QoS) per link is guaranteed. This task is accomplished via a multiuser resource allocation algorithm [5], [6]. Due to the time-varying behavior of the indoor PLC network [7], a computationally efficient algorithm is needed.

In this letter, we examine the problem of fair resource allocation in PLC networks with power spectral density (PSD) limitations and we present a low-complexity algorithm based on a new subcarrier allocation criterion that results in total data-rate improvement compared with existing solutions.

II. Problem Formulation

Consider an OFDM system with N subcarriers and K users. For user k, the channel gain-to-noise ratio (CNR) of subcarrier n is $g_{k,n} = |H_{k,n}|^2/(\mathcal{N}_{k,n}\cdot\Gamma)$, where $H_{k,n}$ is the channel gain, $\mathcal{N}_{k,n}$ is the noise power, and Γ is the signal-to-noise ratio (SNR) gap [8]. The resource allocation problem in the downlink (i.e., from the central device to the user terminals) is formulated as

$$\begin{aligned}
&\max_{p_{k,n},A_k} \sum_{k=1}^{K}\sum_{n\in A_k} \log_2\left(1+p_{k,n}\cdot g_{k,n}\right)\\
&\text{subject to}(\mathrm{C1}) \sum_{k=1}^{K}\sum_{n\in A_k} p_{k,n} \le P_{\text{total}}\\
&\quad(\mathrm{C2})\ 0 \le p_{k,n} \le \bar{p} \text{ for all } k,n\\
&\quad(\mathrm{C3})\ A_1, A_2, \ldots, A_K \text{ are all disjoint}\\
&\quad(\mathrm{C4})\ A_1 \cup A_2 \cup \cdots \cup A_K \subseteq \{1,2,\ldots,N\}\\
&\quad(\mathrm{C5})\ R_1 : R_2 : \cdots : R_K = \gamma_1 : \gamma_2 : \cdots : \gamma_K \quad (1)
\end{aligned}$$

where P_{total} is the power budget, $\bar{p}$ is the PSD constraint, $p_{k,n}$ is the power allocated to subcarrier n of user k, A_k is the set of subcarriers assigned to user k, $R_k = \sum_{n\in A_k}\log_2(1+p_{k,n}\cdot g_{k,n})$ is the rate of user k, and γ_k are predefined constants imposing proportional rate fairness.

In general, the values of γ_k represent higher-level priorities based on the type of service supported by each link. Constraints (C3), (C4) impose that each subcarrier be assigned, at most, to one user. The PSD constraint (C2) is a linear function of $p_{k,n}$; thus, (1) can be transformed into a minimization problem, where the objective function is convex [9]. Calculating the optimal solutions in time-varying channels is computationally prohibitive, while the suboptimal algorithms in [9] and [10] do not encounter the PSD constraint.

III. Proposed Solution

The proposed algorithm is a modified version of the joint subcarrier and power allocation method in [10], where the water-filling power allocation is replaced by cap-limited water-filling [8] in order to account for the PSD constraint, and a new subcarrier allocation rule with improved multiuser diversity performance is introduced.

In [10], the user with the less proportional rate $i = \arg\min(R_k/\gamma_k)$ selects from the available subcarriers the one with the maximum CNR $m = \arg\max(g_{i,n})$. Although the above "max-CNR" criterion implies that m is the subcarrier with the maximum contribution to the rate of user i, it does not take into account the potential rate that the other users lose due to this allocation. The latter is related to the multiuser diversity characteristics of the selected subcarrier (i.e., the CNR of the other users with respect to user i).

For each user k, $\bar{r}_{k,n} = \log_2(1+\bar{p}\cdot g_{k,n})$ is the rate of subcarrier n under maximum power allocation. We denote $w_{k,n} =$

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The authors are with the Department of Electrical and Computer Engineering, University of Patras, Rio – Patras 26500, Greece (e-mail: npapandr@ece.upatras.gr; antonako@upatras.gr).

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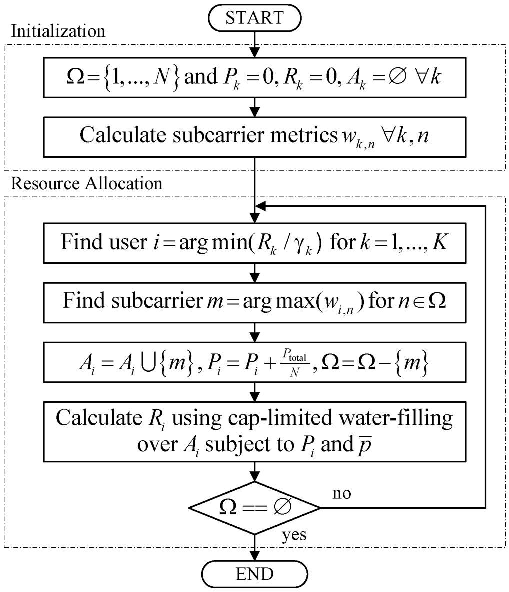

Fig. 1. Multiuser resource allocation algorithm.

$\bar{r}_{k,n}/\sum_{i=1}^{K}\bar{r}_{i,n}$ as the relative quality factor of user k in subcarrier n with respect to the other users: a small value of $w_{k,n}$ indicates that the respective subcarrier is not the best choice in terms of global benefit; the subcarrier's rate contribution is lower for user k than for other users. The proposed subcarrier selection criterion is $m = \arg\max(w_{i,n})$ (i.e., the new criterion selects the subcarrier with the maximum gain for the rate of user i and with the minimum waste of potential rate for the other users). Fig. 1 shows a flowchart of the new algorithm, where Ω is the set of available subcarriers and $P_k = \sum_{n \in A_k} p_{k,n}$ is the total power allocated to user k.

IV. Simulation Results

In order to evaluate the new algorithm, we provide simulation results using the indoor PLC network topology and loading scenarios described in [6]. In this study, we use: fast Fourier transform (FFT) size 1024, subcarrier spacing 20 kHz, sampling frequency 20.48 MHz, frequency band of interest 1–10 MHz with $N = 450$ available subcarriers, PSD mask -50 dBm/Hz, and $\Gamma = 15.8$ dB for all users.

Fig. 2 shows the average total data-rate improvement achieved with the proposed subcarrier allocation compared to the "max-CNR" method as a function of the normalized power budget $P_{\text{total}}/\sum_{n=1}^{N}\bar{p}$. Results are given for different numbers of users and noise levels. The new method presents an average gain of 5%—15%. The gain increases as more power budget is available with respect to the total power of the PSD limit and, in general, the improvement achieved with the new method is higher for low CNR conditions. In Fig. 2, γ_k is equal to the rate achieved when user k utilizes all of the available power and bandwidth resources (i.e., fairness is related to the quality of each link [6]). Similar results are obtained with γ_k that is equal to all users (i.e., (1) corresponds to the "max-min" problem [11]).

The "max-CNR" criterion first utilizes the high-quality subcarriers of each user. When the remaining subcarriers are of low CNR, it is the successive increase of power P_k that improves the user rate and not the subcarrier selection. However, due to the PSD constraint, this improvement may be low. On the other hand, the new criterion provides a better balance between the rate increase for the user of interest and the rate loss of the other users, who also compete for resources, and the rate improvement is higher.

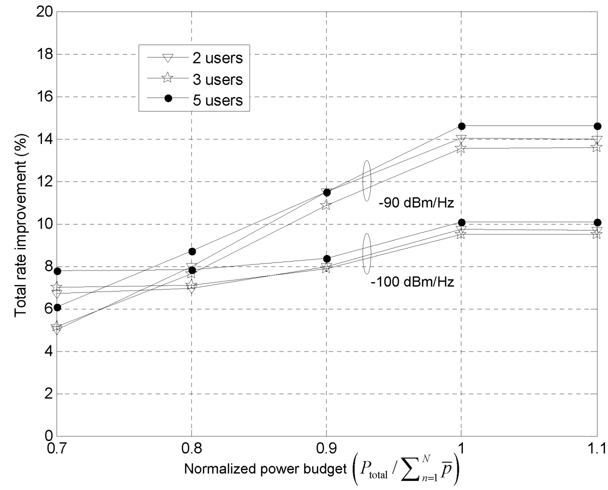

Fig. 2. Total rate improvement with respect to the normalized power budget.

V. Conclusion

In this letter, we presented a multiuser resource allocation algorithm for OFDM PLC networks based on a new subcarrier allocation criterion, which exploits the multiuser diversity of each subcarrier for the best tradeoff between the local (user) and global (network) benefit. In wideband channels with a large number of subcarriers and strong multiuser diversity characteristics, the proposed method shows improved performance in terms of the total data rate.

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