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Fair Resource Allocation in Multiuser Indoor Power Line Communications

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Fair Resource Allocation in Multiuser Indoor Power Line Communications

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Abstract— **Multicarrier modulation is one of the most promising technologies for achieving high performance communications in the indoor power line network. Due to the fading and time-varying characteristics of the power line channel, the various users experience different channel conditions, thus the application of efficient multiuser transmission schemes will enhance multiuser diversity. This paper addresses the problem of fairness in bandwidth and power allocation for the indoor power line channel with multiple multicarrier links and presents a multiuser discrete loading algorithm that consists of two phases: First, a set of minimum data rates is provided to all users, and then, the available resources are allocated with fairness according to the quality of each link. We examine the proposed algorithm using an illustrative example of an indoor power line network and we demonstrate its performance. Comparative numerical results of various allocation strategies are also presented.**

I. Introduction

Power line communications (PLC) receive increasing interest as a potential solution and a promising technology for the last mile access network, as well as for indoor communications [1], [2]. The utilization of the power line medium in order to deliver broadband services is now investigated from many aspects, e.g. efficient physical layer transmission and medium access control. The PLC channel is a hostile environment that exhibits strong multipath fading with time-varying characteristics [3]. Multicarrier modulation (MCM) techniques have shown enhanced system performance [2], [4], while the experience gained in other well-established wireless [5] and wired [6] applications is exploited in the investigation of various MCM techniques, like multiuser transmission, under the particular characteristics of the PLC environment. This paper addresses the problem of fairness in bandwidth and bit allocation for multiuser PLC networks consisting of multiple point-to-point links.

We consider the indoor power line network, where several data communications devices establish bidirectional multicarrier links with a central networking device. The channel response of each link depends on the topology of the power grid and on the network's loading conditions [7]. Generally, due to multipath fading, each link experiences different channel characteristics. In MCM, the entire bandwidth is divided into orthogonal narrowband subchannels. The problem under investigation is the allocation of the available bandwidth and power resources to the different users in the context of frequency-division multiple-access (FDMA). The FDMA rule imposes that each subchannel is assigned to one user only. FDMA involves less decoding complexity at the receiver and also implies that, as long as synchronization is maintained, the interference caused when users transmit in the same frequency bands is avoided.

Recently, great attention has been devoted to multiuser loading techniques in multicarrier systems [8]–[15]. In a frequency selective environment, the FDMA scheme has shown enhanced channel utilization compared with static time-division multiple-access (TDMA) [11]. The multiuser loading is a constraint optimization problem, where usually the optimization objective is the maximization of the sum of user rates given a power budget [8], or the minimization of the total power given a set of user rates [9], [10]. In the latter case, it is assumed that the requested rates can be supported. However, the channel conditions of all links in the indoor PLC network may exhibit significant variations when the network's loading changes. As a result, the a priori definition of a guaranteed high target-rate set for all links is not possible. Therefore, the strategy of maximizing the overall network rate subject to a minimum rate requirement for each user seems more appropriate for the indoor PLC environment.

In a multiuser system, maximizing the sum of rates imposes that each subchannel is assigned to the user with the best channel quality [8]. Such an allocation rule may penalize the users with poor or even moderate channel conditions, thus a fairness issue is raised. In [11] and [12], the FDMA allocation problem is formulated subject to a set of nonlinear constraints, which impose proportional fairness to the achievable rates, i.e. $R_1 : R_2 : \ldots : R_K = \gamma_1 : \gamma_2 : \ldots : \gamma_K$, where R_k is the rate of user k, K is the total number of users and $\{\gamma_1, \gamma_2, \ldots, \gamma_K\}$ are constants to ensure proportional fairness. In [13], the concept of balanced capacity is associated with $\gamma_k = R'_k$, where R'_k is the maximum achievable rate of user k in single-user communications, i.e. the data rate achieved by fully utilizing all available bandwidth. However, the allocation problem in [13] is not FDMA, rather it considers the multiuser capacity region achieved with successive message decoding and cancellation at each receiver.

In this work, we investigate the bandwidth and power allocation in multiuser PLC networks over the indoor power grid and we present a discrete multiuser loading algorithm. The proposed algorithm is based on a 'best effort and fairness' (BEAF) allocation scheme that provides joint subcarrier and

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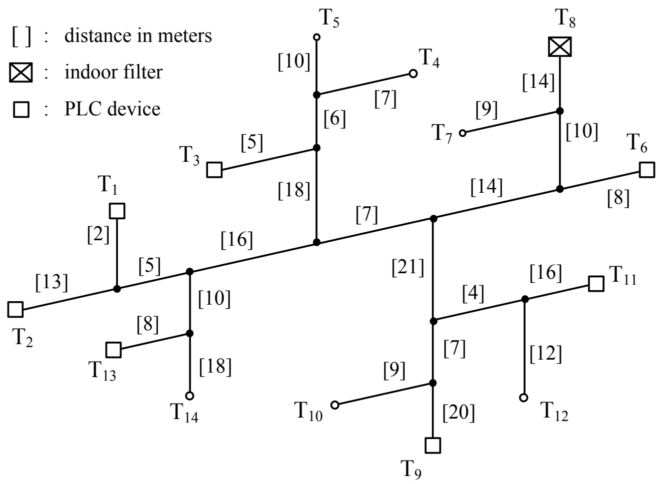

Fig. 1. Example topology of an indoor PLC network.

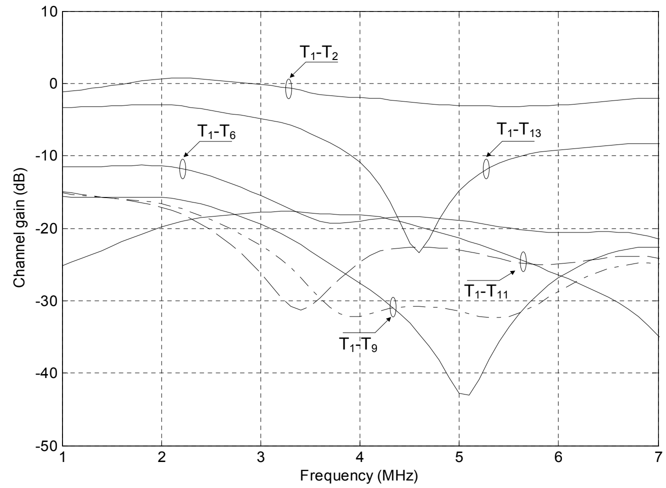

Fig. 2. Channel response between various termination points.

power allocation. The loading process satisfies two different requirements: first, a set of minimum user rates has to be satisfied, and then, the available resources have to be allocated according to each user's channel quality. This paper considers downlink FDMA, where the central unit broadcasts data to all terminals in the network, however it can be easily expanded to cover also uplink transmission.

Section II presents the multiple access channel environment in the indoor PLC network using a typical power grid infrastructure and formulates the multiuser loading problem. Section III describes the discrete multiuser loading algorithm. Section IV provides numerical results that demonstrate the performance of the proposed algorithm for different network's loading scenarios and presents comparative results of various allocation strategies.

II. PLC MULTIACCESS CHANNEL

Fig. 1 shows the topology of an indoor PLC network, where the power grid consists of several interconnected cable sections. There are 14 termination points. At T_8, an appropriate coupling power filter with constant impedance is assumed between the indoor and outdoor power grid infrastructures. In our example, we consider the central networking device at T_1 and a data communications device at termination points $T_{2,3,6,9,11,13}$. In such a network, the channel response between any two termination points depends on the topology and on the network's loading conditions [7]. In Fig. 2 we present the channel response in the frequency range $1-7$ MHz of 5 different network links. The solid curves correspond to the loading scenario 5 of Table I in Section IV. We have considered the VVF $(2\times\phi 1.6\text{mm})$ wiring cable and a $100\angle 0$ impedance for the PLC devices. Fig. 2 shows that each link exhibits different channel characteristics. We also observe that there exists significant attenuation level difference between the links, e.g. links T_1-T_2 and T_1-T_6 present a mean attenuation level difference of 15 dB. This behavior depends not only on the relative distance between the communicating devices, but also on the specific network loading conditions. The dashed curves in Fig. 2 correspond to the loading scenario 8 and show a significant change in the spectral characteristics for links T_1-T_9 and T_1-T_{11} compared with scenario 5. The other links display similar characteristics in both scenarios.

As several links experience much poorer channel quality than others, it is important to introduce fairness constraints in order to ensure a minimum quality of service (QoS) for each user. One approach is to define a set of minimum rates for all users and then to use a fair allocation rule for the remaining resources. The channel conditions for each link change as the network loading conditions change, however this is a rather slow time-varying process. Therefore, the following analysis is based on the channel conditions for a given scenario.

A. The Multiuser Loading Problem for Downlink FDMA

Let K be the number of users and N be the number of available subchannels. For each user k, we denote as $g_{k,n}=|H_{k,n}|^2/N_{k,n}$ the channel gain-to-noise ratio of subchannel n. Since each subchannel is assigned to a single user, we define the subchannel allocation matrix $\mathbf{AT}=[a_{k,n}]_{K\times N}$, where $a_{k,n}=1$, when subchannel n is allocated to user k, otherwise $a_{k,n}=0$. If $r_{k,n}$ and $p_{k,n}$ denote the number of bits and the power allocated to subchannel n of user k, then $R_k=\sum_{n=1}^{N}a_{k,n}\cdot r_{k,n}$ and $P_k=\sum_{n=1}^{N}a_{k,n}\cdot p_{k,n}$ are the rate (in bits per symbol) and the total power of user k respectively. The multiuser loading problem is formulated as follows:

$$\begin{aligned}
\text{maximize:}\quad & \sum\nolimits_{k=1}^{K}R_k \qquad (1)\\
\text{subject to:}\quad & \sum\nolimits_{k=1}^{K}P_k\le P_{budget},\\
& R_k\ge R_k^m,\quad \forall k=1,\ldots,K,\\
& 0\le r_{k,n}\le \overline{r}_{k,n},\qquad r_{k,n}\in\mathbb{Z}_+,\\
& \sum\nolimits_{k=1}^{K}a_{k,n}=1,\quad \forall n=1,\ldots,N,\\
& R_1:R_2:\ldots:R_K=\gamma_1:\gamma_2:\ldots:\gamma_K
\end{aligned}$$

In (1), R_k^m is the minimum target-rate for user k and P_{budget} is the available power budget at the central device. The number of bits and the power allocated to subchannel n of user k are related by $r_{k,n} = f(p_{k,n} \cdot g_{k,n})$, where f depends on the target probability of error and the applied modulation and coding schemes. In addition, f is a concave and increasing function with respect to $p_{k,n}$ and $f(0) = 0$. These conditions are valid for the majority of modulation and coding schemes used in MCM systems. We also consider, that in (1) all users exhibit the same target probability of error. Note, that the bit allocation in (1) is restricted to integer values and is upper-bounded by a maximum number of $\overline{r}_{k,n}$ bits in each subchannel defined as the minimum between the bit value that corresponds to the maximum size of the signal constellations, and the bit value $\lfloor f(\overline{p}_{k,n} \cdot g_{k,n}) \rfloor$ that corresponds to a maximum allowable power $\overline{p}_{k,n}$ in each subchannel. The FDMA rule is imposed by the constraint on the sum of $a_{k,n}$ over k. The last constraint in (1) imposes the proportional fairness rule, where γ_k represents the channel quality of link k.

B. Channel Quality and Proportional Fairness

The definition of explicit values for the constants γ_k is not straightforward. A reasonable and practical assumption is to relate the channel quality of each link with the total rate achieved in the single-user scenario [13], i.e. $\gamma_k = R'_k$. Assuming that the central unit knows the channel conditions $g_{k,n}$ of all active links in the network, then the rates R'_k can be computed using a single-user bit-loading algorithm [16]. Given the constants γ_k, the FDMA bandwidth allocation methods in [11] and [12] assign an additional subchannel to the user with the less proportional rate. However, these methods do not guarantee a minimum of rate requirements.

In the next section, we propose a multiuser loading algorithm that employs the notion of fairness according to a user-priority scheme based on allocation rounds. The new algorithm consists of two phases: first the minimum rate requirements are satisfied for all users, and then the available resources are allocated proportionally to the users according to the quality of each link. In order to describe the algorithm, we introduce the following arrays: $\mathbf{G} = [g_{k,n}]_{K \times N}$, $\mathbf{R}^m = [R_k^m]_{K \times 1}$, $\mathbf{P_{max}} = [\overline{p}_{k,n}]_{K \times N}$, $\mathbf{R_{max}} = [\overline{r}_{k,n}]_{K \times N}$, $\mathbf{R} = [r_{k,n}]_{K \times N}$, $\mathbf{P} = [p_{k,n}]_{K \times N}$.

III. The Multiuser Loading Algorithm

The proposed algorithm is based on an iterative process of allocation rounds. In each round, the algorithm assigns subchannels, bits and power to all users according to a user-priority order. Specifically, we define the vector $\mathbf{C} = [C_k]_{K \times 1}$, where the quantities C_k determine the objects on which the priority criterion is applied. At the beginning of each allocation round, the users are ordered in descending order according to the C_k values. The result of this process is that several groups of users with the same C_k values are formed. Let $\mathbf{U} = [U_{i,j}]_{K \times K}$ contain the order of users. The row index i indicates the user priority, with $i = 1$ having the higher priority. The dimensions of $\mathbf{U}$ ensure that the array can describe all possible arrangements that can be formed by ordering the K users. In each row, the elements of $\mathbf{U}$ are equal to a value between 1 and K (the respective users with the same priority) or equal to zero. Given $\mathbf{U}$, the allocation rule is the following: for a single-user group, allocate the subchannel with the maximum supported rate to that particular user; for a multi-user group, choose the best subchannels that support the maximum rate.

Given $\mathbf{U}$, the allocation steps in each allocation round are described by the following 'best effort and fairness' (BEAF) scheme, where $\mathcal{N} \subseteq \{1, 2, 3, \ldots, N\}$ denotes the set of the available subchannels.

The BEAF Allocation Round:

1. Start with the group of users having the highest priority, i.e. $i = 1$.
2. For the users $[k_1^*, \ldots, k_K^*] = [U_{i,1}, \ldots, U_{i,K}]$, find subchannel $n^* \in \mathcal{N}$ with the maximum $\overline{r}_{k,n}$ within the rows $k_1^*, \ldots, k_K^*$ of $\mathbf{R_{max}}$. Let n^* belong to row k^*.
3. Assign subchannel n^* to user k^* of group $[k_1^*, \ldots, k_K^*]$, i.e. $a_{k^*,n^*} = 1$ and $\mathcal{N} = \mathcal{N} - \{n^*\}$.
4. Update $\mathbf{R}$ and $\mathbf{P}$, i.e. $r_{k^*,n^*} = \overline{r}_{k^*,n^*}$ and $p_{k^*,n^*} = f^{-1}(\overline{r}_{k^*,n^*}) \cdot g_{k^*,n^*}^{-1}$.
5. Repeat steps 2-4 with the remaining users in group $[U_{i,1}, \ldots, U_{i,K}]$.
6. Repeat steps 2-5 with the remaining groups in $\mathbf{U}$, i.e. $i = 2, \ldots, K$.

The BEAF allocation process provides a fair allocation scheme where all users participate once in the allocation round according to the priority rule. In order to enhance spectrum utilization, each user is assigned the subchannel with best performance. Using the BEAF allocation scheme we can describe the main multiuser loading algorithm. In the first phase, the algorithm provides a minimum QoS allocation. During that phase, the $\mathbf{C}$ array corresponds to the total rate remained to be allocated to each user after every allocation round, i.e. we assign higher priority to the users with the highest remained rate requirements.

Phase A: Minimum Rate Allocation

1. Initialize **AT**, **P** and **R** with zero entries $\forall k, n$.
2. Calculate $\mathbf{R_{max}}$ based on $\mathbf{G}$ and $\mathbf{P_{max}}$.
3. Set $\mathbf{C} = \mathbf{R}^m$.
4. Calculate the user priority array $\mathbf{U}$.
5. Perform a BEAF allocation round.
6. Update $\mathbf{C}$ by $C_k = R_k^m - \sum_{n=1}^{N} a_{k,n} \cdot r_{k,n}$.
7. If minimum rate R_k^m achieved for user k, i.e. $C_k \leq 0$, then remove user k from the next allocation round.
8. Repeat steps 4-7 until all minimum rates are met, or until the bandwidth or power resources are exhausted.

In the second phase, the algorithm provides allocation of the remaining resources with proportional rate fairness. In that phase, the $\mathbf{C}$ array corresponds to the ratios of R_k/R'_k, where

$R_k = \sum_{n=1}^{N} a_{k,n} \cdot r_{k,n}$ is the total rate allocated to user k after every allocation round, i.e. we assign higher priority to the users with the lowest proportional rate so far. Note that the rate achieved in the first phase is encountered in the second phase.

Phase B: Proportional Rate Allocation

1. Determine the single-user rates R'_k $\forall k$.
2. Calculate **C** by $C_k = R_k / R'_k$ $\forall k$.
3. Calculate the user priority array **U**.
4. Perform a BEAF allocation round.
5. Update **C** by $C_k = (\sum_{n=1}^{N} a_{k,n} \cdot r_{k,n}) / R'_k$.
6. Repeat steps 3-5 until the bandwidth or power resources are exhausted.

With reference to the above algorithm, we provide some remarks.

Remark 1: The multiuser loading problem in both phases A and B is resolved using an iterative process of BEAF allocation rounds. The total number of iterations is limited due to successful loading (target-rates in Phase A) or limited resources.

Remark 2: Step A.4 and B.3 provide a fair user allocation order, so that the least satisfied user is the first to be assigned resources in the next allocation round. In contrast to [12], where the next user to be allocated resources is always the one with less proportional rate, the proposed allocation round scheme embodies itself the notion of proportional fairness as will be evident in the numerical results section.

Remark 3: Due to strong frequency-selectivity of the PLC channel, the minimum target-rates in Phase A cannot be specified in advance. One approach is to request a proportion α of the single-user rate R'_k for each particular user, i.e. $R^m_k = \alpha \cdot R'_k$. In general, R'_k represents the quality of the link, therefore the $\alpha \cdot R'_k$ rule determines a minimum QoS set that is proportional to the channel quality of the links. Another approach is to specify the same value for all R^m_k. Such a rule will reduce the total rate of the high quality links, so that more resources are allocated to the users with poor channel conditions in order to meet the target-rate constraint. Both minimum rate strategies are investigated in the numerical results section.

IV. Numerical Results

This section presents numerical results that demonstrate the performance of the proposed multiuser loading algorithm. We consider the indoor PLC network topology of Fig. 1, where $K = 5$ links are examined: the central device is at T_1 and the PLC devices are at $\mathrm{T}_{2,6,9,11,13}$. We consider the following parameters: frequency band $1 - 7.4$ MHz with $N = 64$ available subchannels and 100 kHz/subchannel, Gaussian noise floor -120 dBm/Hz, transmit power spectral density (PSD) mask -60 dBm/Hz. In order to investigate the system performance, we use the different loading scenarios presented in Table I.

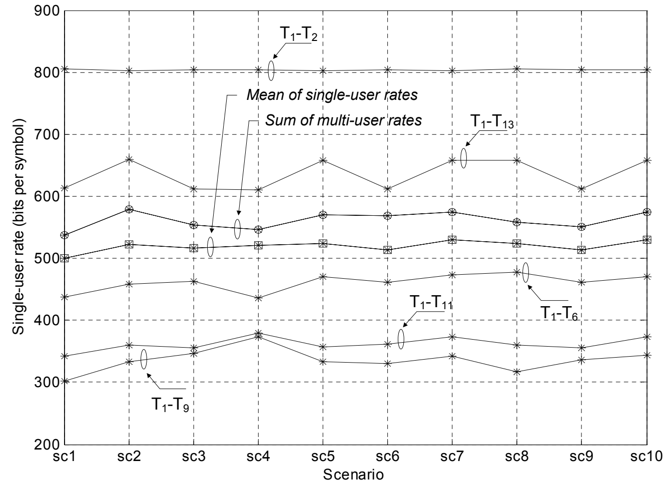

Fig. 3. User rates for different loading scenarios in the single-user system.

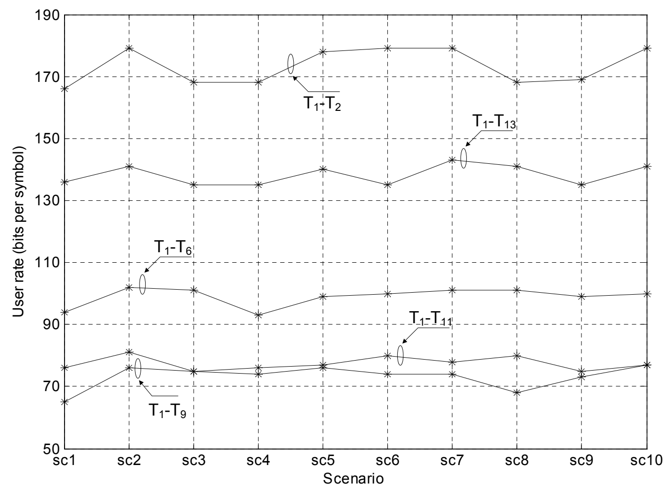

Fig. 4. User rates for different loading scenarios in the multi-user system.

A. Multiuser Loading Performance

Fig. 3 shows the single-user rates R'_k for the different scenarios, i.e. when the total bandwidth is utilized by the respective user only. Fig. 4 shows the user rates R_k using the proposed algorithm for proportional minimum rate rule in Phase A with $\alpha = 10\%$, which correspond to 45% of the final user rates. Fig. 3 also displays the mean of the R'_k rates of each scenario, as well as the sum of the user rates R_k in Fig. 4. Note that the mean of the R'_k rates corresponds to the total average rate in bits per symbol of a fixed TDMA in a multiuser system with equal time slots, while the sum of the user rates R_k is the total rate in FDMA.

We observe that in each scenario, the single-user rates R'_k display significant difference between the various links as a result of each link's different channel quality. In the multiuser system, the user rates R_k are far below from the corresponding R'_k values, since the total bandwidth is shared among all users. However, the FDMA scheme outperforms fixed TDMA, i.e. the total network rate is higher in all scenarios, by exploiting

TABLE I
NETWORK LOADING SCENARIOS (SC) FOR THE INDOOR PLC NETWORK IN FIG. 1, (∞ DENOTES OPEN CIRCUIT)

	sc1	sc2	sc3	sc4	sc5	sc6	sc7	sc8	sc9	sc10
T_4	∞	$30\angle{-90}$	∞	$30\angle{-90}$	∞	$10\angle{-90}$	∞	$10\angle{-90}$	$20\angle{-90}$	$20\angle{-90}$
T_5	∞	∞	$20\angle{-90}$	$20\angle{-90}$	$30\angle{-90}$	$30\angle{-90}$	∞	∞	$10\angle{-90}$	$10\angle{-90}$
T_7	∞	∞	$10\angle{-90}$	∞	$20\angle{-90}$	$20\angle{-90}$	$20\angle{-90}$	$10\angle{-90}$	$30\angle{-90}$	$30\angle{-90}$
T_{10}	∞	∞	$10\angle{-90}$	$10\angle{-90}$	∞	∞	$20\angle{-90}$	∞	$20\angle{-90}$	$20\angle{-90}$
T_{12}	∞	$20\angle{-90}$	∞	$20\angle{-90}$	$30\angle{-90}$	$30\angle{-90}$	∞	∞	∞	∞
T_{14}	∞	$20\angle{-90}$	∞	∞	$10\angle{-90}$	∞	$30\angle{-90}$	$10\angle{-90}$	∞	$10\angle{-90}$

TABLE II
RATIO R_k/R'_k FOR SCENARIO 5 AND $R_k^m = \alpha \cdot R'_k$, ($\alpha$ IN %)

α	T_1-T_2	T_1-T_6	T_1-T_9	T_1-T_{11}	T_1-T_{13}
0	0.207	0.211	0.228	0.227	0.213
5	0.223	0.211	0.225	0.224	0.213
10	0.222	0.211	0.228	0.216	0.213
15	0.222	0.211	0.228	0.216	0.213
20	0.222	0.221	0.213	0.218	0.213

TABLE III
RATIO R_k/R'_k FOR $\alpha = 15\%$ AND $R_k^m = \alpha \cdot R'_k$

sc	T_1-T_2	T_1-T_6	T_1-T_9	T_1-T_{11}	T_1-T_{13}
1	0.221	0.215	0.202	0.222	0.222
2	0.223	0.223	0.228	0.222	0.214
3	0.209	0.214	0.213	0.211	0.221
4	0.223	0.213	0.204	0.198	0.223
5	0.222	0.211	0.228	0.216	0.213
6	0.223	0.216	0.221	0.224	0.225
7	0.223	0.214	0.216	0.209	0.217
8	0.209	0.211	0.215	0.222	0.214
9	0.209	0.210	0.214	0.211	0.222
10	0.223	0.212	0.210	0.219	0.214

TABLE IV
RATIO R_k/R'_k FOR SCENARIO 5 AND $R_k^m = \min(\alpha \cdot R'_k)$, ($\alpha$ IN %)

α	T_1-T_2	T_1-T_6	T_1-T_9	T_1-T_{11}	T_1-T_{13}
0	0.207	0.211	0.228	0.227	0.213
5	0.207	0.206	0.228	0.241	0.211
10	0.191	0.211	0.249	0.246	0.195
15	0.174	0.211	0.263	0.263	0.196
20	0.173	0.221	0.266	0.261	0.181

TABLE V
RATIO R_k/R'_k FOR $\alpha = 15\%$ AND $R_k^m = \min(\alpha \cdot R'_k)$

sc	T_1-T_2	T_1-T_6	T_1-T_9	T_1-T_{11}	T_1-T_{13}
1	0.174	0.217	0.255	0.260	0.186
2	0.174	0.223	0.269	0.264	0.195
3	0.175	0.216	0.242	0.248	0.203
4	0.190	0.220	0.233	0.222	0.203
5	0.174	0.211	0.263	0.263	0.196
6	0.174	0.216	0.264	0.260	0.208
7	0.174	0.214	0.251	0.241	0.199
8	0.191	0.211	0.256	0.242	0.181
9	0.177	0.213	0.255	0.230	0.203
10	0.175	0.214	0.268	0.243	0.198

the multiuser diversity. We also observe that the distributions of the R'_k and R_k values, in Fig. 3 and Fig. 4 respectively, are proportional to each other for all scenarios, as a result of the fairness priority rule in the loading algorithm.

In Tables II-V, we investigate the R_k/R'_k ratio of each link for different minimum rate policies in Phase A of the loading algorithm. Tables II and III correspond to the case where $R_k^m = \alpha \cdot R'_k$, while in Tables IV and V the R_k^m is the same for all users; we have used $R_k^m = \min(\alpha \cdot R'_k)$, so that the resultant rate is supported by all links.

Tables II and IV present the ratios R_k/R'_k for different values of α when the network loading scenario 5 is considered. The higher the value of α, the higher are the rates that have to be achieved in Phase A, and as a result, less rate remains to be allocated in Phase B. When R_k^m is proportional to R'_k, we observe in Table II that the ratios are almost equal with respect to α, since a proportional allocation policy is followed in both phases of the loading algorithm. However, when R_k^m is the same for all users, we observe in Table IV that the ratios are smaller for some links, and greater for the others, with respect to α. The constant rate allocation policy in Phase A violates the proportional fairness, since more rate, and therefore more subchannels, are allocated to users with poor channel quality in order to meet the R_k^m constraint. For higher values of α the users with poor channel quality achieve higher rates compared with the proportional allocation policy, and as a result, the ratio values in Table IV are increasing for the links with poor channel quality, while they are decreasing for the links with high channel quality. Note, that $\alpha = 0$ corresponds to the case where only Phase B of the loading algorithm is executed, while the value of $\alpha = 20\%$ is a gross estimate of the percentage of the total bandwidth that is allocate to each user ($K = 5$). Practically, above that value, Phase B is not executed since there are not any available resources.

Tables III and V present the ratios R_k/R'_k for the different loading scenarios when $\alpha = 15\%$. We observe that the values

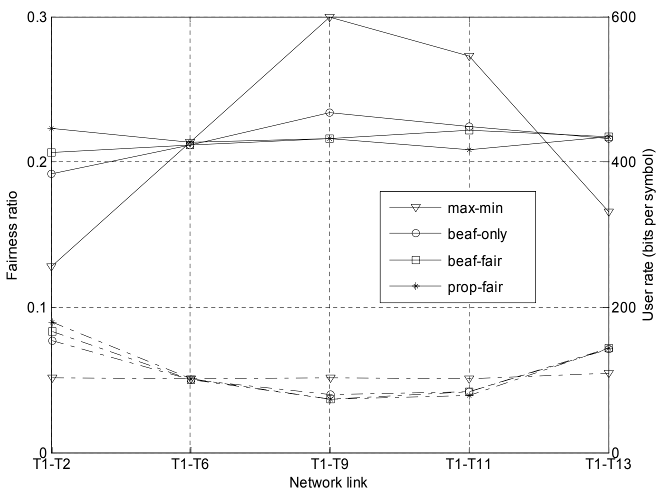

Fig. 5. Fairness and total user rates for different allocation strategies.

in Table III are similar for all users in each scenario, while in Table V the differences are due to the high value of α and the constant R_k^m policy.

B. Comparative Results on Fairness

Fig. 5 compares the fairness of the algorithm in Section III, denoted as *beaf-fair*, with that of other allocation strategies. In particular we consider the following resource allocation schemes:

- *max-sum*: corresponds to the maximization of the sum of user rates [8]; each subchannel is allocated to the user with the best channel quality.
- *max-min*: corresponds to the maximization of the minimum of the user rates [14], [15]; at each allocation step, the user with the less rate selects the best of the available subchannels.
- *beaf-only*: corresponds to the algorithm in Section III, but the priority criterion in each allocation round is the less rate achieved so far.
- *prop-fair*: corresponds to the allocation method in [12] using a constant power allocation policy; at each allocation step the user with the less proportional rate selects the best of the available subchannels.

The results in Fig. 5 correspond to the loading scenario 7 and $\alpha = 0$. The solid curves show the fairness ratio R_k/R'_k for the different strategies, while the dashed curves show the corresponding rate of each user. The *max-sum* strategy is not shown, since it allocates all available resources to link $T_1 - T_2$, the link with the best quality, i.e. the corresponding ratio R_k/R'_k is one, and penalizes all other users. On the contrary, we observe that the *max-min* strategy results in almost equal rates for all users by allocating more resources to the links with poor quality, thus suppressing the rate of links with good quality. On the other hand, we observe that the other strategies provide a fair allocation, i.e. the R_k/R'_k ratio curves are quite linear and the links obtain a total rate proportional to their quality.

We also observe, that the *beaf-only* scheme provides fairness results similar to those of the *beaf-fair* and *prop-fair* strategies. This is due to the fact that the proposed allocation round scheme with priorities embodies itself the notion of fairness. Moreover, the *beaf-only* scheme does not require the computation of the single-user rates R'_k, thus it involves less computational load. Also note, that the *prop-fair* strategy does not guarantee a minimum QoS for each user.

V. Conclusion

In this paper, we addressed the problem of fair resource allocation in the indoor PLC network with multiple links and we presented a multiuser loading algorithm. The proposed algorithm uses an allocation rounds scheme with priorities and provides fair resource allocation according to the channel quality of each user. Numerical results using different network's loading scenarios demonstrated the performance of the proposed algorithm, as well as its effectiveness compared with different allocation strategies.

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