Cooperative Strategies and Fairness-Aware Resource Allocation in Selection-Based OFDM Networks

Kianoush Hosseini and Raviraj Adve

The Edward S. Rogers Sr. Department of Electrical and Computer Engineering, University of Toronto
10 King’s College Road, Toronto, ON M5S 3G4, Canada
Email: {kianoush, rsadve}@comm.utoronto.ca

Abstract—This paper considers a multi-source orthogonal frequency division multiplexing (OFDM)-based network of access points wherein dedicated relays use the decode-and-forward relaying. We investigate the joint problem of transmission strategy selection (relaying vs direct), relay assignment, and power allocation to maximize the minimum rate across sources in two different cooperative scenarios: subcarrier-based and block-based relaying. In the subcarrier-based scheme, each subcarrier is treated as an independent transmission; however, in addition to the synchronization problems caused, it is likely impractical for a relay to decode a subset of subcarriers. Thus, we study relay selection for the entire OFDM block. The key difference from previous work is that we consider resource allocation across source-relay, relay-destination, and source-destination channels. Second, a simple, distributed, block-based scheme is proposed. Simulation results using the COST-231 channel model reveals that the performance of this heuristic scheme tracks that of the optimum block-based scheme while it significantly decreases the required computational complexity.

I. INTRODUCTION

In wireless networks, cooperative transmission via distributed relay nodes can improve the performance of the network [1]–[3]. Different versions of relaying protocols including decode-and-forward (DF - the relay node decodes and re-encodes source’s data) and amplify-and-forward (AF - the relay amplifies its received signal) are examined in [2]. The work in [4], [5] proposed selection cooperation wherein only a single relay contributes to the communication of each source-destination pair. This simple scheme therefore needs no coordination between relay nodes while providing all the benefits of cooperative communication. The relay assignment problem has been addressed for both DF [4]–[6] and AF [7] in single source-destination pair networks. However, in multi-source networks, the relay selection problem is not immediate. To meet its power constraint, each relay must distribute its available power amongst all source nodes that it supports and a relay that improves the performance of a source may not remain the best overall. Relay assignment is, therefore, a combinatorial problem with exponential complexity. We focus here on DF networks. Beres and Adve proposed low complexity relay selection schemes in multi-source networks in [5]; however, power allocation at the relays has not been addressed. Kadloor and Adve in [8] investigated the performance of a single-carrier cellular network under the assumption of perfect source-destination channels.

In a separate tack, orthogonal frequency division multiplexing (OFDM) is widely considered to be the accepted approach to deal with frequency selective fading [9]–[12]. The combination of OFDM and cooperative systems such as mesh networks is considered critical and has recently attracted an intense attention. However, relay assignment and subcarrier and power allocation problems need to be re-examined in such networks. The authors in [13] proposed a graph-based approach in order to maximize the sum rate by limiting the number of sources a relay node can help. The work in [14] addressed the max-min resource allocation problem in a two-hop cooperative network while allowing for subcarrier permutation at relays. In [15], Ng and Yu constructed a utility maximization framework for solving relaying strategies and resource allocation problem in cellular OFDMA-based networks using the decomposition method. By assuming only a discrete set of rates, authors use a brute-force search to solve the problem. Weng and Murch in [16] employed the same solution methodology to minimize power consumption in a multiuser OFDMA system. The authors of [17] proposed a resource allocation scheme for a two-hop clustered-based cellular network with relays chosen a priori.

All aforementioned approaches deal with the relay assignment problem in a subcarrier-based fashion, i.e., each subcarrier can be transmitted independently. Although subcarrier-based relaying is theoretically optimal, it is impractical. First, given the importance of the time and frequency synchronization in OFDM, it is not realistic to expect distributed nodes to relay individual subcarriers independently. Second, the raw data is channel encoded before data modulation and the Inverse Fast Fourier Transform; DF therefore requires the relay to decode the entire OFDM block.

We consider a OFDM-based mesh network of access points (APs) with a selection constraint. Relaying is restricted to the DF protocol. Some crucial questions that arise in the design of such networks are: who helps whom? Should we cooperate or is the overhead worse than the gains? How loud should a source or a relay shout over each data stream (power allocation)? As in [18], we investigate these problems for both subcarrier-based and block-based relaying schemes. However, unlike that work and [8], our problem formulation does not assume a perfect source-relay channel.

Since this is a combinatorial optimization problem in
multi-source networks, by introducing a set of time-sharing coefficients, we transform the original problem into a standard convex optimization problem which provides an upper bound on the network performance. Moreover, applying a heuristic method to impose selection on each flow, a tight lower bound for both relaying schemes is resulted. Finally, we propose a simple, decentralized, block-based relaying scheme which has a close-to-optimal performance while offering huge computational advantages. It is also worth mentioning that, in this paper, neither the transmission strategy nor the relay nodes are chosen a priori.

The remainder of this paper is organized as follows. Section II describes the system model. Section III deals with the resource allocation issue in a subcarrier-based fashion. In Section IV, the block-based resource allocation is investigated. Section V is presented the simulation results. Finally, Section VI wraps up this paper.

II. SYSTEM MODEL

This work considers a static OFDM-based mesh network of APs as shown in Fig. 1. The network comprises $K$ source nodes assisted by $J$ dedicated relays. Each source node has its own destination (D). Let $K = \{1, 2, \ldots, K\}$, $J = \{1, 2, \ldots, J\}$, and $N_k = \{1, 2, \ldots, N\}$ be the set of source (S) nodes, relay (R) nodes, and subcarriers of source $k$, respectively. All transmissions use OFDM within their own frequency band, i.e., simultaneous transmissions do not interfere. We further assume that OFDM blocks are synchronized; hence, distributive transmission is possible. The inter-node wireless channels are modeled as frequency-selective fading channels. Thus, individual subcarriers of each source node experiences a different channel realization; an adaptive transmission strategy and implementing power allocation at the sources and relays can enhance the system performance. We further assume that inter-node channels vary slowly enough for the channel state information (CSI) to be fed back to a centralized unit with limited overhead, making centralized resource allocation possible. All APs and relays are attached to a power supply state information (CSI) to be fed back to a centralized unit with constant and maximum total power of $P$. We consider a two-stage selection-based DF protocol at the relays wherein at most one relay node contributes to the communication of each source node. The system employs time division duplex and all communications occur in two time slots. The first, data-sharing, stage is indicated by the solid arrows while the dashed arrows represent the second phase. Finally, the destination node combines messages received in the two phases to decode the original information.

The main objective of this paper is to achieve max-min fairness, i.e., to maximize the minimum rate across sources.

III. SUBCARRIER-BASED RESOURCE ALLOCATION

This section considers subcarrier-based resource allocation across the S-R, S-D, and R-D channels in a cooperative OFDM-based network. Furthermore, due to the extra degree of freedom that frequency diversity provides, resource allocation at both source nodes and relays becomes crucial. It is important to note that each subcarrier is transmitted either directly or cooperatively using only one of the relays. Moreover, the solution to this optimization problem answers the question, which transmission strategy maximizes the minimum rate across source nodes?

In a cooperative network with $K$ sources and $J$ relays, the maximum achievable rate of source $k$ over its $n^{th}$ subcarrier can be stated as

$$R_k^{(n)} = \max \left\{ I^{(n)}_{sk,dk}, \right. \min \left\{ I^{(n)}_{sk,kr}, I^{(n)}_{sk,rj} \right\} \right\},$$

$$\log_2 \left( 1 + \text{SNR}_k \alpha_k^{(n)} |h_k^{(n)}|^2 \right),$$

$$I^{(n)}_{sk,kr} = \frac{1}{2} \log_2 \left( 1 + \text{SNR}_k \alpha_k^{(n)} |h_k^{(n)}|^2 \right),$$

$$I^{(n)}_{sk,rj} = \frac{1}{2} \log_2 \left( 1 + \text{SNR}_k \alpha_k^{(n)} |h_k^{(n)}|^2 + \text{SNR}_j \alpha_j^{(n)} |h_j^{(n)}|^2 \right),$$

where $\text{SNR}_k$ and $\text{SNR}_j$ are the ratios of the transmitted power to the power of noise at the destination of $s_k$ and relay $j$, respectively. $\alpha_k^{(n)}$ and $\alpha_j^{(n)}$ are, respectively, the fraction of the allocated power to the $n^{th}$ subcarrier of source $k$ at the source node and relay $j$. $|h_k^{(n)}|^2$, $|h_j^{(n)}|^2$, and $|h_{kj}^{(n)}|^2$ are, respectively, S-D, S-R, and R-D channel gains.

Eqn. (1) declares that the rate of each source node over its individual subcarriers is the maximum of the direct and cooperative transmission rates; in turn, the cooperative rate requires that both the relay and destination fully decode the received data. The total rate for source $k$ is then $R_k = \sum_{n} R_k^{(n)}$.

Therefore, the formal optimization problem that we wish to solve is

$$\max_{\alpha_k} \min_k R_k$$

subject to

$$C_1: \alpha_{jk}^{(n)} \alpha_{j,k}^{(n)} = 0, \forall k, n, \{j_1, j_2\} \in J,$$

$$C_2: \alpha_{jk}^{(n)} \geq 0, \forall k, n, j \in J_+,$$

$$C_3: \sum_k \alpha_{jk}^{(n)} \leq 1, \forall j \in J,$$

$$C_4: \sum_k \alpha_{0k}^{(n)} = 1, \forall k,$$

wherein $J_+ = \{0, 1, 2, \ldots, J\}$ is defined as extended set of relays. $C_1$ imposes selection constraint on each subcarrier. $C_2$ imposes...
is the power non-negativity constraint. $C_3$ and $C_4$ limit the available power at the relays and sources, respectively.

Due to the selection constraint, (2)-(6) is an, essentially intractable, mixed-integer programming optimization problem with exponential complexity which cannot be solved using the usual gradient based methods.

A. Approximate Solution and Upper Bound

Since the objective function is not differentiable, we introduce $|\mathcal{K}| |\mathcal{N}||J_+|$ indicator variables to the objective function. As a result, the new optimization problem can be expressed as

$$
\max_{\{\alpha, \rho \in \{0,1\}\}} \min_k R_k
$$

s.t. 

$$
C_1 : \alpha_{jk}^{(n)} \geq 0, \rho_{jk}^{(n)} \geq 0, \forall k, n, j \in J_+,
$$

$$
C_2 : \sum_{K, N_k} \rho_{jk}^{(n)} \alpha_{jk}^{(n)} \leq 1, \forall j \in J,
$$

$$
C_3 : \sum_{N_k} \rho_{jk}^{(n)} \alpha_{0k}^{(n)} = 1, \forall k,
$$

$$
C_4 : \sum_{j} \rho_{jk}^{(n)} = 1, \forall j, n
$$

wherein

$$
R_k = \sum_{N_k} \rho_{0k}^{(n)} \log_2 \left(1 + \text{SNR}_k \alpha_{0k}^{(n)} |h_{0k}^{(n)}|^2 \right)
$$

$$
\sum_{J} \sum_{N_k} \rho_{jk}^{(n)} \min \left\{ \frac{1}{2} \log_2 \left(1 + \text{SNR}_j \alpha_{0k}^{(n)} |h_{jk}^{(n)}|^2 \right), \frac{1}{2} \log_2 \left(1 + \text{SNR}_k \alpha_{0k}^{(n)} |h_{0k}^{(n)}|^2 + \text{SNR}_j \alpha_{jk}^{(n)} |h_{jk}^{(n)}|^2 \right) \right\}.
$$

Note that, $\rho_{jk}^{(n)}$ can be interpreted as a fraction of time that $s_k$ transmits over its $n^{th}$ subcarrier directly, $j = 0$, and cooperatively, $j \in J$. From this revised problem, one can conclude that if $s_k$ allocates a fraction of its available power to the $n^{th}$ subcarrier, $\alpha_{0k}^{(n)} \neq 0$, for any set of $\alpha_{jk}^{(n)}$ satisfying (3)-(5), we have

$$
\rho_{jk}^{(n)} = \begin{cases} 
1, & \alpha_{jk}^{(n)} \neq 0, \\
0, & \alpha_{jk}^{(n)} = 0.
\end{cases}
$$

Eqn. (11)-(13) enforce selection on each subcarrier. However, since time-sharing coefficients can only take integer values, the problem is still mixed-integer programming. Our strategy to solve this problem is to relax the selection constraint and allow each subcarrier to be transmitted both directly and cooperatively through multiple relays. Thus, time-sharing coefficients can take any rational value on the convex hull of the original discrete set. Consequently, the resulting solution from the relaxed problem is an upper bound to the min-rate of the original problem formulated in (2)-(6).

As can be seen from (12), $R_k$ consists of three different terms: the S-D, S-R, and S-R-D rates. One can easily show that none of them is jointly concave in the set of variables. Using the approach of [9], we set

$$
\rho_{jk}^{(n)} \alpha_{0k}^{(n)} = r_{jk}^{(n)}, j \in J_+,
$$

$$
\rho_{jk}^{(n)} \alpha_{jk}^{(n)} = p_{jk}^{(n)}, j \in J.
$$

Thus, the new optimization problem in terms of $\rho$, $r$, and $p$ can be formulated as

$$
\max \min_{\{\rho, r, p\}} \frac{R_k}{k}
$$

s.t. 

$$
C_1 : r_{jk}^{(n)} \geq 0, \forall k, n, j \in J_+,
$$

$$
C_2 : p_{jk}^{(n)} \geq 0, \forall k, n, j \in J,
$$

$$
C_3 : \sum_{K, N_k} r_{jk}^{(n)} \leq 1, \forall j \in J,
$$

$$
C_4 : \sum_{J_+} p_{jk}^{(n)} = 1, \forall j, n.
$$

Also, $R_k$ is rewritten as

$$
R_k = \sum_{N_k} \rho_{0k}^{(n)} \log_2 \left(1 + \frac{\text{SNR}_k \alpha_{0k}^{(n)} |h_{0k}^{(n)}|^2}{\rho_{0k}^{(n)}} \right) +
$$

$$
\sum_{J} \sum_{N_k} \rho_{jk}^{(n)} \min \left\{ \frac{1}{2} \log_2 \left(1 + \frac{\text{SNR}_j \alpha_{0k}^{(n)} |h_{jk}^{(n)}|^2}{\rho_{jk}^{(n)}} \right), \frac{1}{2} \log_2 \left(1 + \frac{\text{SNR}_k \alpha_{0k}^{(n)} |h_{0k}^{(n)}|^2 + \text{SNR}_j \alpha_{jk}^{(n)} |h_{jk}^{(n)}|^2}{\rho_{jk}^{(n)}} \right) \right\}.
$$

(20)

Theorem 1. The objective function in (14) is jointly concave in $\rho$, $r$, and $p$.

Proof: As can be seen from (20), the achievable rate of each source node consists of three terms, wherein S-D and S-R rates are in the form of $f(x, y) = x \log(1 + y/x)$ and the rate of the compound S-R-D channel is in the form of $g(x, y, z) = x \log(1 + y/x + z/x)$. In addition, $x$, $y$, and $z$ are non-negative variables. The Hessian of $f$ is

$$
\nabla^2 f = \frac{1}{(1+x/y)^2} \begin{bmatrix}
-y^2/x^3 & y/x^2 \\
y/x^2 & -1/x
\end{bmatrix}.
$$

The determinant of $\nabla^2 f$, the product of the eigenvalues, is zero. Furthermore, the trace of the $\nabla^2 f$, the sum of the eigenvalues, is negative. As a result, one of the two eigenvalues is zero and the other one is negative, which proves that the $\nabla^2 f \leq 0$, i.e., the Hessian evaluated within the optimization region, is a negative semi-definite matrix. Thus, the first two terms in (20) are jointly concave in $(\rho, r)$.

Now, let us follow the same strategy to show that the third term is also jointly concave in the set of consisting variables. Therefore

$$
\nabla^2 g = c \begin{bmatrix}
-(y+z)^2/x^3 & (y+z)/x^2 & (y+z)/x^2 \\
(y+z)/x^2 & -1/x & -1/x \\
(y+z)/x^2 & -1/x & -1/x
\end{bmatrix},
$$

Thus, this term is also jointly concave in the set of variables.
and \( c = \frac{1}{(1+y/x+z/x)^2} \). Similar to the previous case, the determinant and the trace of \( \nabla^2 y \) are zero and negative, respectively. Moreover, \( \nabla^2 g \) is a rank one matrix, i.e., it has one negative eigenvalue and two zero eigenvalues. Thus, \( \nabla^2 y \) is a negative semi-definite matrix which shows that the rate of the S-R-D channel is jointly concave in \((r, r, p)\).

It is also known that a point-wise minimum as well as the non-negative summation of a set of concave functions are also concave functions [19]. Hence, the underlying objective function is concave in \((r, r, p)\). The proof is complete.

Although the objective function is jointly concave, it is not differentiable. By rewriting the objective function in the epigraph form, the final optimization problem can be stated as

\[
\max_{\{t, c, \alpha, r, p\}} t \quad \text{s.t.} \\
C_1 : (15) - (19) \\
C_2 : \sum_{j \in J_+} \sum_{k \in N_k} c_{jk}^{(n)} \geq t, \forall k, \\
C_3 : \rho_{0k}^{(n)} C \left( \frac{\text{SNR}_{k0k} h_{0k}^{(n)} |^2}{\rho_{0k}^{(n)}} \right) \geq c_{0k}^{(n)}, \forall k, n, \\
C_4 : \frac{\rho_{jk}^{(n)}}{2} C \left( \frac{\text{SNR}_{jk} h_{jk}^{(n)} |^2}{\rho_{jk}^{(n)}} \right) \geq c_{jk}^{(n)}, \forall k, n, j \in J, \\
C_5 : \frac{\rho_{jk}^{(n)}}{2} C \left( \frac{\text{SNR}_{jk} h_{jk}^{(n)} |^2 + \text{SNR}_{rjk} h_{rjk}^{(n)} |^2}{\rho_{jk}^{(n)}} \right) \geq c_{jk}^{(n)}, \forall k, n, j \in J.
\]

where \( C(x) = \log_2(1 + x) \). The optimization problem formulated in (21)-(27) is a standard convex optimization problem which can be solved using well established and efficient iterative algorithms [19].

### B. A Heuristic Algorithm and a Lower Bound

Our strategy to impose selection is to assign to each subcarrier the transmission strategy and relay that provides the maximum achievable rate. Succinctly, the selection constraint can be applied as

\[
R_k^{(n)} = \max \left\{ f_{s_k d_k}, \min \left\{ f_{s_k r_m}, f_{s_k r_m d_k} \right\} \right\}, \\
m = \arg \max_j \left\{ f_{s_k r_m j}, f_{s_k r_m d_k j} \right\},
\]

using the obtained power allocation matrices from the convex optimization problem formulated in (21)-(27). Since this solution satisfies all constraints of the original problem in (2)-(6), this heuristic scheme also provides a lower bound on the achievable minimum rate across sources. Note that if direct transmission were optimal for \( s_k \), the amount of power allocated to this source would be zero at all relays. Moreover, the amount of power freed up by the selection step can be reused by waterfilling over other source nodes which are helped by each individual relays.

### IV. BLOCK-BASED RELAY SELECTION

While the previous section worked on a per-subcarrier basis, this section deals with the block-based node selection and power allocation across S-R, S-D, and R-D communication channels. Moreover, as in Section III, the solution to this problem optimizes the transmission strategy for each individual source nodes. By generalizing (1) to the achievable rate of each source node across the entire OFDM block, it follows that

\[
R_k = \max \left\{ \sum_{N_k} f_{s_k d_k}, \max_j \min \left\{ \sum_{N_k} f_{s_k r_j}, \sum_{N_k} f_{s_k r_j d_k} \right\} \right\},
\]

which states that each block of OFDM can be transmitted either directly or via the relay node which supports a higher data rate across all subcarriers. The formal optimization problem therefore is

\[
\max \min R_k \quad \text{s.t.} \\
C_1 : \sum_{N_k} a_{jk}^{(n)} \times \sum_{N_k} a_{jk}^{(n)} = 0, \forall k, n, \{j_1, j_2\} \in J, \\
C_2 : a_{jk}^{(n)} \geq 0, \forall k, n, j \in J_+, \\
C_3 : \sum_{J} \sum_{N_k} a_{jk}^{(n)} \leq 1, \forall j \in J, \\
C_4 : \sum_{N_k} a_{0k}^{(n)} = 1, \forall k.
\]

\( C_1 \) states that each OFDM block can be helped by at most one relay node. Eqn. (30)-(32) are similar to those of the original subcarrier-based scheme formulated in Section III.

#### A. An Approximate Solution and Upper Bound

Since the original problem formulated in (28)-(32) is a mixed integer programming with exponential complexity, as with the subcarrier-based cooperative method, we introduce \(|K||J_+|\) time-sharing coefficients to the objective function. Hence, the achievable rate of source \( k \) can be written as

\[
R_k = \rho_{0k} \sum_{N_k} \log_2 \left( 1 + \text{SNR}_{k0k} a_{0k}^{(n)} |h_{0k}^{(n)}|^2 \right) + \\
\frac{1}{2} \sum_{J} \sum_{N_k} \log_2 \left( 1 + \text{SNR}_{rjk} a_{0k}^{(n)} |h_{rjk}^{(n)}|^2 \right) + \\
\frac{1}{2} \sum_{N_k} \log_2 \left( 1 + \text{SNR}_{rjk} a_{0k}^{(n)} |h_{rjk}^{(n)}|^2 \right).
\]

Our solution methodology is similar to that of the Section III, i.e., we again relax the selection constraint and then define

\[
\rho_{jk} a_{0k}^{(n)} = r_{jk}^{(n)}, j \in J_+, \\
\rho_{jk} a_{0k}^{(n)} = p_{jk}^{(n)}, j \in J.
\]

Using the approach of Theorem 1, it is straightforward to prove that the resulting optimization problem is jointly concave in \((r, r, p)\). Finally, by rewriting the objective function in the epigraph form, the standard convex optimization
problem can be formulated. Similar to Section III, the solution of the relaxed convex programming results by allowing each block of OFDM to be sent both directly as well as through multiple relays; thus, it is an upper bound to the minimum rate of the original problem.

B. A Heuristic Algorithm and a Lower Bound

Having generalized our approach in Section III-B to the block-based cooperative strategy, the selection can be applied as

$$R_k = \max \left\{ \sum_{N_k} I_{s_kd_k}, \min \left( \sum_{N_k} I_{s_kr_m}, \sum_{N_k} I_{s_kr_m} d_k \right) \right\},$$

$$m = \arg \max \min_j \left\{ \sum_{N_k} I_{s_kr_j}, \sum_{N_k} I_{s_kr_j} d_k \right\}.$$  

C. Decentralized Resource Allocation Scheme

The optimization problem and solution detailed in the previous section, jointly selects the transmission strategy, assigns a relay, and allocates power across subcarriers at the sources and relays. Thus, this is a centralized scheme which requires full CSI at some central unit. In this section, we develop a simplified three-stage decentralized scheme wherein at the first stage each source selects its best relay independently

$$r_k = r_m,$$

$$m = \arg \max_j \left\{ \min \left( \sum_{N_k} I_{s_kr_j}, \sum_{N_k} I_{s_kr_j} d_k \right) \right\}.$$  

Second, the transmission strategy is chosen by comparing the rates of the direct and relaying strategies. Note that at both stages, we only consider equal power allocation at the sources and relays. Given that each individual source node has already selected its transmission strategy, at most $J$ waterfilling problems need to be solved in order to maximize the minimum rate across source nodes at the relays. Finally, if a source node has selected the direct transmission strategy, optimal power allocation is solved based on the S-D channel state.

V. SIMULATION RESULTS

This section compares the efficiency of various resource allocation strategies under two different network geometries. In the first scenario all inter-node channels are modeled as independent and identically distributed (i.i.d.) random variables. In the second scenario, communication channels are characterized based on their locations by the COST-231 channel model recommended by the IEEE 802.16j working group [20]. The chosen parameters for the COST-231 are given in Table I.

A. I.I.D. Channels

Figures 2-3 plot the achievable minimum rate across source nodes for various values of R-D SNRs. The SNR of the S-R and S-D channels are set to 10dB and 5dB, respectively. In this section, we compare the performance of upper and lower bounds to the subcarrier-based scheme (UBSB and LBSB), upper and lower bounds to the block-based scheme (UBBB and LBBB), and decentralized selection scheme. Both figures show that at high SNRs, subcarrier-based methods outperform other resource allocation schemes. This is expected since subcarrier-based methods exploit the frequency diversity across relays provided by the assumption that individual subcarriers can be transmitted independently. Also, at low SNR, UBBB and decentralized selection schemes have better performance than LBSB and LBBB, respectively. This can be explained considering the fact that our heuristic method to impose selection on individual flows does not use all available power at the relay nodes. If we apply a second round of power allocation at the relays, the amount of power freed up from enforcing selection can be distributed amongst all other source nodes which are assigned to those relays and a tighter lower bound will result.

B. Network Performance for a Distributed Scenario

Figure 4 plots the minimum rate across users versus the maximum available power of the sources and relays wherein wireless channels are characterized based on node positions using the COST-231 channel model. As it is expected, the UBBBB scheme outperforms both LBBB and decentralized selection schemes. Although the decentralized scheme has local CSI, it has a close-to-optimal performance. This method...
also decreases the computation and coordination burden of the network. Again, since LBBBB does not use the total available power, it is probable that its achievable rate is less than that of the decentralized scheme.

VI. CONCLUSION

This paper deals with two types of relaying schemes in the context of selection-based OFDM networks: subcarrier-based and block-based. The detailed solutions for both problems jointly solve the transmission strategy, relay assignment, and power allocation problems and provide upper bounds for both schemes. Moreover, by enforcing selection constraint on each flow, lower bounds on the performance of both schemes are found. Furthermore, we introduce a simple, distributed, scheme in which each source-destination pair independently selects its best transmission strategy and relay. Power allocation problem then is solved at the sources and relays. Although this scheme uses only local information and resource allocation problem is solved at individual nodes independently, its performance is close to that of the upper bound for the block based scheme.

REFERENCES