Energy-Efficient Resource Optimization for Relay-Aided Uplink OFDMA Systems

Yun Jiang, Jianhua Zhang, Xiaofan Li, Wei Xu
Wireless Technology Innovation Institute, Key Laboratory of Universal Wireless Communication, Ministry of Education
Beijing University of Posts and Telecommunications, Beijing 100876, P. R. China
Email: jiangyun@mail.wtilabs.cn

Abstract—**In this paper, the energy-efficient resource allocation in relay-aided uplink multiuser system is studied. We adopt the orthogonal frequency division multiplexing (OFDM) as the physical layer modulation technique. Assuming that the BS has all the channel state information (CSI), an energy-efficiency optimization problem through joint subcarrier assignment, bit and power allocation is formulated. Due to the computational complexity restriction, a suboptimal solution based on decomposition is presented to solve the problem with low complexity. Considering the fairness constraint, a joint resource allocation algorithm is further proposed, which is proved to achieve a considerable improvement in terms of energy-saving and simultaneously decreases rate outage probability by simulation results.**

I. INTRODUCTION

Environmental concerns and the need for energy-efficient protocols in all types networks [1] become increasingly important since the growth of energy consumption has contributed substantially to the global warming, which may cause disastrous consequences [2]. Particularly, energy-efficiency maximization problem has become a new trend in wireless communication system due to the limited battery resources in mobile devices and the growing requirements of anytime and anywhere multimedia applications [3].

In the wireless communication system, the combination of cooperative transmission and orthogonal frequency division multiplexing (OFDM) becomes a natural candidate to cope with the practical frequency selective fading. The performance of multiuser systems can be significantly improved by efficiently allocating the available resources, which becomes quite challenging due to the complexity caused by joint subcarrier, bit and power allocation, and also, due to fairness constraint among users. Fairness constraint here implies that all users should be allocated a sufficient amount of system resources to guarantee the requirement of quality of service (QoS). Efficient subcarrier allocation algorithms are mainly discussed in [4]. In [5], power optimization for a joint power constraint and a separate power constraint at source and relay nodes are considered respectively. In [6], aiming to minimize the total transmission power under target rate constraint in a cooperative orthogonal frequency division multiple access (OFDMA) system, both centralized and decentralized resource allocation schemes are proposed. It should be mentioned that all the above works aim to improve system throughput or minimize transmit power. However, there are still few works addressing the energy-efficient communication, which is defined as the number of bits transmitted per Joule of energy [7]. As wireless stations are typically battery-powered, energy-efficiency is one of the critical performance measures for wireless networks and energy-efficient resource allocation is worthy to focus on.

In this paper, the energy-efficiency maximization problem is considered for relay-aided OFDMA systems by optimal resource allocation. We formulate a mixed optimization problem through joint subcarrier, bit and power allocation, which is NP-hard and difficult to find the global optimum. Thus, an efficient algorithm is proposed based on decomposing the optimization problem into two subproblems and solve it in two steps: (1) subcarrier allocation with a given power allocation; (2) bit and power allocation for allocated subcarriers. Considering the fairness constraint, a heuristic algorithm is further proposed, which is proved to achieve a considerable energy-saving improvement while guaranteeing each user's QoS by simulation results.

The remainder of the paper is organized as follows. The system model is described in section II. In section III, we give the optimization problem formulation. Two energy-efficient resource allocation algorithms are proposed in section IV, and the simulation results are shown in section IV. Finally, section V summarizes the paper.

II. SYSTEM MODEL

Consider a two-hop OFDMA uplink network aided by decode-and-forward (DF) relays with M source nodes (S), L relay nodes (R), and a single destination node (D), as shown in Fig. 1. It is assumed that each node employs a single antenna. A two-stage transmission protocol is adopted. In the first stage, all Ss transmit and the other nodes listen. In the second stage, the selected Rs retransmit the messages to D.

Let $n \in \{1, 2, ...N\}$ be the set of orthogonal subcarriers. The channel response on the nth subcarrier from the mth S ($m \in \{1, 2, ..., M\}$) to the lth R ($l \in \{1, 2, ..., L\}$), from the mth S to D, and from the lth R to D are denoted as $H_{s_m r_l}(n)$, $H_{s_m d}(n)$ and $H_{r_l d}(n)$, respectively. Then, we define the channel power gain as follows:

$$\begin{cases} G_{s_m r_l}(n) = ||H_{s_m r_l}(n)||^2 \\ G_{s_m d}(n) \;= ||H_{s_m d}(n)||^2 \\ G_{r_l d}(n) \;\;= ||H_{r_l d}(n)||^2. \end{cases} \tag{1}$$

978-1-4673-0990-5/12/$31.00 ©2012 IEEE

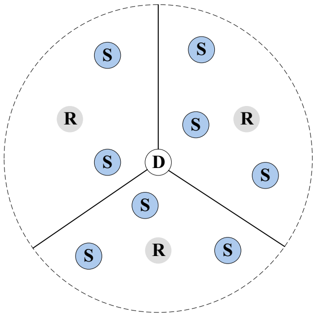

Fig. 1. The relay-aided OFDMA network: a single D is located in the center of the cell, there are L fixed Rs and M randomly distributed Ss.

Let b_{mn} be the the number of bits assigned to the mth S on the nth subcarrier. As in [8], the required received signal-to-noise ratio (SNR) per symbol on the nth subcarrier for reliable reception of b_{mn} bits/symbol is

$$\gamma(b_{mn}) = \rho(2^{2b_{mn}} - 1), \tag{2}$$

where ρ is the SNR gap. Thus, for reliable transmission of b_{mn} bits/symbol for the mth S, the required received power can be written as

$$P_{req}(b_{mn}) = \gamma(b_{mn})\frac{N_0 B}{N} = (2^{2b_{mn}} - 1)\frac{N_0 B\rho}{N}, \tag{3}$$

where B is the total system bandwidth and N_0 is denoted as the single-side power spectral density (PSD) of the additive white Gaussian noise (AWGN), which are the same for all Ss, Rs and D.

Next, we propose the subcarrier cooperation criterion. Each subcarrier can be operated in three different modes as follows:
1) Direct Mode, the mth S transmits directly to D on the nth subcarrier with the channel power gain $G^D_{s_m d}(n)$;
2) Cooperative Mode, D combines the directly received signal and the relayed signal by maximal ratio combining (MRC). We assume the lth R uses the jth subcarrier to forward the information from the mth S on the nth subcarrier. The equivalent channel power gain can be given as [9]

$$G^C_{s_m r_l d}(n,j) = \frac{G_{s_m r_l}(n) G_{r_l d}(j)}{G_{s_m r_l}(n) + G_{r_l d}(j) - G_{s_m d}(n)}; \tag{4}$$

3) Relay Mode, we assume there is no direct link between any S and D. The equivalent channel power gain can be given as

$$G^R_{s_m r_l d}(n,j) = \frac{G_{s_m r_l}(n) G_{r_l d}(j)}{G_{s_m r_l}(n) + G_{r_l d}(j)}. \tag{5}$$

It should be noted that the subcarrier cooperation criterion will increase the resource optimization complexity considerably. For analysis simplification, we divide the subcarrier operation mode according to thresholds set based on the channel power gain between each S and D. The particular thresholds $\mathrm{th1}$ and $\mathrm{th2}$ can be set as $\mathrm{th1} = 2/3 \arg_m \max \sum_{n\in N} G^D_{s_m d}(n)$ and $\mathrm{th2} = 1/3 \arg_m \max \sum_{n\in N} G^D_{s_m d}(n)$ ($\mathrm{th1} > \mathrm{th2}$). In accord with the subcarrier operation mode, the users can be divided into three groups: users transmit in direct mode ($m \in M_D$), cooperative mode ($m \in M_C$), and relay mode ($m \in M_R$), where $M_D, M_C, M_R \subset \{1,2,...,M\}$. Hence, the equivalent channel power gain on the nth subcarrier is given as

$$G_{eq}(n) = \begin{cases} G^D_{s_m d}(n), & if \sum\limits_{n\in N} G^D_{s_m d}(n) > \mathrm{th1} \\ & \quad (m \in M_D) \\ G^C_{s_m r_l d}(n,j), & if\ \mathrm{th2} < \sum\limits_{n\in N} G^D_{s_m d}(n) < \mathrm{th1} \\ & \quad (m \in M_C) \\ G^R_{s_m r_l d}(n,j), & if \sum\limits_{n\in N} G^D_{s_m d}(n) < \mathrm{th2}. \\ & \quad (m \in M_R) \end{cases} \tag{6}$$

Let $\beta_m(n) \in \{0,1\}$ indicates whether or not the nth subcarrier is used at the mth S, $m \in M_D$. $\alpha_{s_m r_l}(n,j) \in \{0,1\}$ and $\gamma_{s_m r_l}(n,j) \in \{0,1\}$ indicate whether or not the nth subcarrier is used in cooperation with the jth subcarrier at the lth R for the mth S, $m \in M_C$ and $m \in M_R$, respectively. Define $P_m(n)$ as the amount of power transmitted on the nth subcarrier assigned to the mth S. In addition to transmit power, mobile devices also incur additional circuit power during transmission, which is relatively independent of the transmission rate [10]. Denoting the circuit power as P_c, the overall power consumption can be expressed as $P_c + P_m(n)$.

$\boldsymbol{S_m} \subset \{1,2,...,N\}$ denotes the set of subcarriers assigned to the mth S. As each subcarrier can only belong to one user exclusively, all $\boldsymbol{S_m}$ ($m \in \{1,2,...,M\}$) should be disjointed at each slot. R_t denotes the target data rate per user for transmitting one OFDM block. The data rate vector on $\boldsymbol{S_m}$ subcarriers of the mth S is denoted as $\boldsymbol{R_m} = [b_{mn}]^T, n \in \boldsymbol{S_m}$, where $[\ ]^T$ represents the transpose of a vector. Correspondingly, the overall data rate of the mth S is $R_m = \Sigma_{n\in \boldsymbol{S_m}} b_{mn}$.

III. PROBLEM FORMULATION AND ANALYSIS

Based on the above discussions, the energy-efficient resource optimization problem is formulated in this section. Mathematically, the maximization problem can be given as

$$\max_{b_{mn}, P_m(n), \boldsymbol{S_m}} \sum_{m=1}^{M} \frac{B R_m}{P_c + \sum_{n\in \boldsymbol{S_m}} P_m(n)}, \tag{7}$$

where

$$P_m(n) = \frac{P_{req}(b_{mn})}{G_{eq}(n)}, \tag{8}$$

subject to

$$\sum_m \{\beta_m(n) + \sum_l \alpha_{s_m r_l}(n,j) + \sum_l \gamma_{s_m r_l}(n,j)\} \le 1, \forall n, \tag{9}$$

$$\sum_m \sum_l \sum_n \alpha_{s_m r_l}(n,j) \le 1, \sum_m \sum_l \sum_n \gamma_{s_m r_l}(n,j) \le 1, \forall j, \tag{10}$$

$$b_{mn} \ge 0, \forall m, n. \tag{11}$$

Note that (9) indicates that each subcarrier can only be used by one S and relayed by at most one R at a given time, and

(10) means that each subchannel in $R-D$ links can be used by at most one R.

The joint optimization of all variables in (7) gives an optimal energy-efficiency, however, it can be found that the optimization problem (7) is NP-hard and involves both continuous and discrete variables, which prohibits the joint optimization to find the global optimum due to the computational complexity. Based on the above consideration, we propose a decomposition based resource allocation algorithm to obtain suboptimal solution with low algorithm complexity. A joint resource allocation algorithm is further proposed to improve energy performance under data rate constraint.

IV. ENERGY-EFFICIENT RESOURCE ALLOCATION ALGORITHMS

A. *Decomposition based Energy-Efficient Resource Allocation*

Observing that the optimization problem (7) involves two different types of constraints, we divide the problem into two separate subproblems and solve them independently. We define this method as decomposition based energy-efficient resource allocation (DB-ERA) algorithm.

1) Subcarrier Allocation

We assume that bit and power are equally distributed, then the optimization problem can be simplified as

$$\max_{\boldsymbol{S_m}} \sum_{m=1}^{M} \frac{BR_m}{P_c+\sum_{n\in\boldsymbol{S_m}} P_m(n)}, \tag{12}$$

subject to

$$\sum_m \{\beta_m(n)+\sum_l \alpha_{s_m r_l}(n,j)+\sum_l \gamma_{s_m r_l}(n,j)\} \leq 1, \forall n,$$

$$\sum_m\sum_l\sum_n \alpha_{s_m r_l}(n,j) \leq 1, \sum_m\sum_l\sum_n \gamma_{s_m r_l}(n,j) \leq 1, \forall j.$$

Each $S-R$ channel and $R-D$ channel has been divided into N subchannels by OFDM scheme. We need to assign a subcarrier to a user who has the best channel power gain for that subcarrier at the first hop such that the energy-efficiency is maximized according to (7) and (8), no matter to which subcarrier it will couple at the second hop of transmission [11]. To further improve the performance gain, good (bad) subcarriers on $S-R$ links should be paired with good (bad) subcarriers on $R-D$ links [12]. The subcarrier assignment can be described as follows.

***Algorithm 1**. Subcarrier allocation criterion.*

Step 1: sort a set of MLN subcarriers at the first hop according to their channel power gains in descending order.

Step 2: allocate subcarrier to each S and R according to the sorted subcarrier order until the sum of subcarriers allocated to all Ss is equal to N. S_l ($l \in \{1,2,...,L\}$) denotes the amount of subcarriers allocated to the lth R at the first hop.

Step 3: for each $R-D$ channel, sort a set of N subcarriers according to their channel power gains in descending order.

Step 4: for l = 1: 1: L, allocate subcarrier to the lth R according to the sorted subcarrier order until the sum of subcarriers allocated to the lth R is equal to S_l.

Step 5: for each R, sort the allocated subcarriers at the first hop and the allocated subcarriers at the second hop in descending order and then pair them accordingly.

---

2) Bit and Power Allocation

The bit and power distribution for allocated subcarriers at the mth S can be separately formulated as

$$\max_{b_{mn},P_m(n)} \frac{BR_m}{P_c+\sum_{n\in\boldsymbol{S_m}} P_m(n)}, \tag{13}$$

subject to

$$b_{mn} \geq 0, \forall m, n.$$

As $P_m(n)=\frac{P_{req}(b_n)}{G_{eq}(n)}=\frac{\rho(2^{2b_{mn}}-1)N_0B}{G_{eq}(n)N}$ is strictly convex and monotonically increasing with b_{mn}, the objective function in (13) is strictly quasi-concave [13], which is equivalent to

$$\min_{b_{mn},P_m(n)} \frac{P_c+\sum_{n\in\boldsymbol{S_m}} P_m(n)}{BR_m}. \tag{14}$$

Thus the optimization problem (13) is transformed to a quasi-convex optimization problem with simple constraint. The optimal solution can be efficiently obtained by using bisection method [14] via a sequence of convex feasibility problems. In order to let the bisection method work, it is important that we initialize an interval that contains b_{mn}^*. Denote $f(b_{mn}) = \frac{P_c+\Sigma_{n\in\boldsymbol{S_m}}P_m(n)}{BR_m}$, the method can be summarized as follows.

***Algorithm 2**. Bisection method.*

Step 1: initial upper bound $u = f(b_{mn}^{(\min)})$, lower bound $l = f(b_{mn}^{(\max)})$, where $f(b_{mn}^{(\min)})$ and $f(b_{mn}^{(\max)})$ define a range of relevant values of $f(b_{mn})$. Set tolerance $\epsilon > 0$.

Step 2: set t=$(l+u)/2$, solve the feasibility problem (15).

Step 3: if feasible then set $u=t$ else $l=t$, repeat *step 2* until $u-l \leq \epsilon$.

Step 4: output b_{mn}^* obtained from solving the feasibility problem in *step 2*.

The feasibility problem in *Algorithm 2* can be written as

$$Find\ b_{mn}, \tag{15}$$

subject to

$$\frac{P_c+\sum_{n\in\boldsymbol{S_m}} P_m(n)}{BR_m} \leq t,$$

$$b_{mn} \geq 0, \forall n.$$

It takes exactly $\lceil \log_2((u-l)/\varepsilon) \rceil$ iterations before the algorithm terminates [14]. The system energy-efficiency can be maximized after all the subcarriers and bits are allocated.

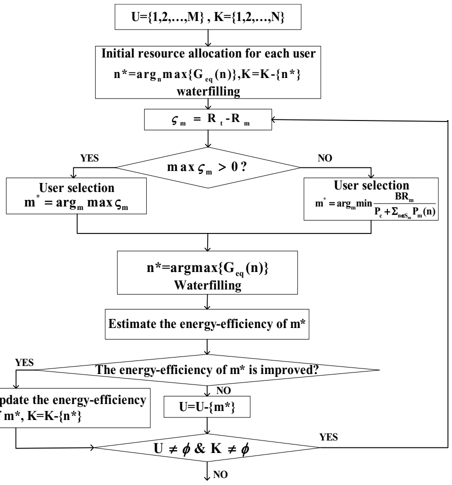

Fig. 2. Joint resource allocation algorithm for relay-aided OFDMA network.

B. Fairness constrained energy-efficient resource allocation

In this subsection, we devise a fairness constrained energy-efficient resource allocation (FC-ERA) algorithm which jointly allocates subcarrier, bit and power.

Algorithm 3. *FC-ERA*.

Step 1: for m = 1: 1: M, allocate the most favorable subcarrier n^* to the mth S based on equivalent channel power gains, then exclude n^* from the remaining subcarrier set. Distribute the transmit power for each S using water-filling algorithm, where more power is allocated to "better" subcarriers while less power is allocated to "worse" subcarriers. Water-filling power allocation approach is the optimal power distribution method in OFDM systems [15].

Step 2: to guarantee user's QoS or maximize the system energy-efficiency, the remaining subcarrier allocation is conducted based on the value of $\zeta_m = R_t - R_m$. If $max\zeta_m > 0$, select $m^* = arg_m max\zeta_m$ who has not met the minimum date rate requirement. Otherwise, select the least privileged user $m^* = arg_m min\frac{BR_m}{P_c+\Sigma_{n\in \boldsymbol{S_m}}P_m(n)}$ who has the worst energy performance.

Step 3: assign the most favorable subcarrier n^* to m^*, in such a way that the rate constraint R_t is satisfied or the overall energy performance is improved. The n^*th subcarrier is removed from the remaining subcarrier set afterwards. Then power and bits are distributed for the allocated subcarriers of m^* according to the water-filling algorithm.

Step 4: during the algorithm process, if the energy performance of m^* could not be improved anymore , remove m^* from the allocation process. Repeat *step* 2 until all Ss leave the process or all subcarriers have been occupied.

Fig. 2 displays our proposed algorithm structure. Let U be the set of users whose energy-efficiency can still be increased at a certain stage. And K is the set of remaining subcarriers. The algorithm is ended when either U or K is empty.

V. SIMULATION RESULTS AND PERFORMANCE ANALYSIS

In this section, the simulation results demonstrate the performance improvements of the two proposed allocation strategies compared with the equal power allocation (EPA) algorithm and greedy algorithm. The EPA algorithm represents random subcarrier distribution among Ss and equal power allocation over subcarriers at each S and R. In greedy algorithm, we first allocate subcarriers among Ss based on channel gains considering subcarrier permutation, in which each subcarrier in the $S-R$ links need to be paired with the best available subcarrier in the $R-D$ links. For allocated subcarriers of each S, each bit is then allocated to the subcarrier with the maximum energy-efficiency increase. The performance of the greedy algorithm serves as a bound for the performance of the suboptimal algorithms, but the comparisons in each step make the greedy algorithm complex.

We consider a wireless relay-aided multiuser OFDMA network with total bandwidth B = 5 MHz and rate constraint R_t = 5 bits/s/Hz. L=3 fixed Rs are employed. Each R is located on the axis of the corresponding sector with angle of $2\pi/L$. The distance between each R and D is $2/3$ of the cell radius. M=10 Ss are randomly distributed over the cell. In each node, an OFDM transceiver with N = 300 available subcarriers is adopted. We employ the 3GPP Spatial Channel Model (SCM) [16] to evaluate the achievable energy-saving for different algorithms.

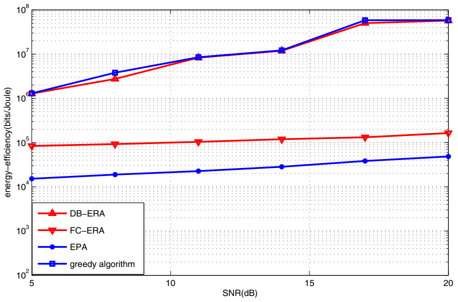

Fig. 3. Energy-efficiency performances versus SNR with cell radius=500m.

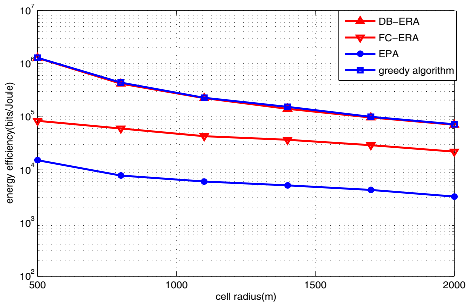

Fig. 4. Energy-efficiency performances versus cell radius with SNR=5 dB.

In Fig. 3 and Fig. 4, we investigate the energy performances of different resource allocation algorithms versus SNR and cell

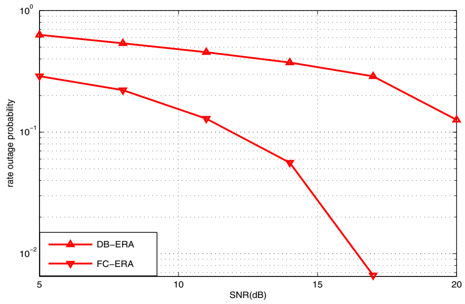

Fig. 5. Rate outage probability versus SNR with cell radius=500m.

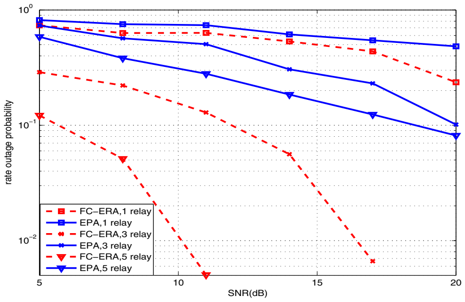

Fig. 6. Rate outage probability versus SNR with cell radius=500m (including the effect of relay numbers).

radius, respectively. It is obvious that the energy-efficiency increase with the SNR and decrease with the cell radius. The energy-saving achieved by using the DB-ERA algorithm closely approaches that by using greedy algorithm. The number of iterations in DB-ERA approach is much smaller than that in greedy algorithm, especially when the number of subcarriers and target bits is high. Thus, a comparable performance can be achieved by this computationally efficient algorithm. It can be further discovered that compared with the EPA algorithm, a dramatic energy-saving can be achieved by both DB-ERA algorithm and FC-ERA algorithm.

In Fig. 5 and Fig. 6, we measure the performance of different algorithms by rate outage probability, which is defined as the achievable data rate is lower than the target data rate. Although the DB-ERA algorithm develops preferable energy-efficiency as compared to the FC-ERA algorithm, Fig. 5 shows that the rate outage performance of the FC-EPA algorithm is apparently superior to that of the DB-ERA algorithm. This means the FC-ERA algorithm can acquire a valid tradeoff between energy-efficiency and rate outage probability of the overall system. In Fig. 6, the rate outage probability versus varying SNR is provided including the effect of relay numbers. The benefit of rate outage performance seems to be enlarged with the increase of relay numbers.

VI. CONCLUSION

In this paper, we have investigated the problem of resource allocation in multiuser OFDMA systems aided by DF relays. Aiming at maximizing the overall energy-efficiency rather than throughput or transmit power, we present subcarrier, bit and power assignment algorithms. The initial joint resource optimization problem can be formulated as a NP-hard problem which is prohibitive to find the global optimum. So we separately solve the decomposed subproblems to perform as the substitute of the optimal one. Furthermore, the data rate constrained energy-efficiency maximization problem is considered and a joint subcarrier, bit and power allocation algorithm is proposed. Simulation results show that the joint resource allocation algorithm gains tradeoff of the energy performance and the fairness among users.

ACKNOWLEDGMENT

This work is supported in part by National Natural Science Foundation of China under Grant No. 61171105, and by Sino-Finland International Cooperation Program of MOST under Grant No. 2010DFB10410.

REFERENCES

[1] T. Kelly, “ICTs and climate change,” *ITU-T Technology*, Tech. Rep., Dec. 2007.

[2] J. Hansen, M. Sato, P. Kharecha, G. Russell, D. W. Lea, and M. Siddall, “Climate change and trace gases,” *Philosophical transactions of the royal society A*, vol. 365, pp. 1925-1954, May 2007.

[3] K. Lahiri, A. Raghunathan, S. Dey, and D. Panigrahi, “Battery-driven system design: A new frontier in low power design,” in *Proc. International Conference on VLSI Design*, Bangalore, India, Jan. 2002, pp. 261-267.

[4] M. Kaneko and P. Popovski, “Radio resource allocation algorithm for relay-aided cellular OFDMA system,” in *Proc. IEEE International Conference on Communications*, Jun. 2008, pp. 4831-4836.

[5] I. Hammerstrom and A. Wittneben, “Power allocation schemes for amplify-and-forward MIMO-OFDM relay links,” *IEEE Transactions on Wireless Communications*, vol. 6, pp. 2798-2802, Aug. 2007.

[6] B. Gui and L. J. Cimini, “Resource allocation algorithms for multiuser cooperative OFDMA systems with subcarrier permutation,” *CISS 2008. 42nd Annual Conference on Information Sciences and Systems*, Mar. 2008, pp. 692-697.

[7] S. Verdu, “Spectral efficiency in the wideband regime,” *IEEE Transactions on Information Theory*, vol. 48, no. 6, pp. 1319-1343, Jun. 2002.

[8] S. Catreux, P. Driessen, and L. Greenstein, “Data throughputs using multiple-input multiple-output (MIMO) techniques in a noise-limited cellular environment,” *IEEE Transactions on Wireless Communications*, vol. 1, pp. 226-239, Apr. 2002.

[9] J. Li, L. Guan, J. Zhang, X. Li, and P. Zhang, “Subcarrier Power Allocation in OFDM Multi-Hop Relaying System,” in *Journal of Beijing University of Posts and Telecommunications*, vol. 31, no. 2, pp. 2727-2731, Apr. 2008.

[10] S. Cui, A. Goldsmith, and A. Bahai, “Energy-efficiency of MIMO and cooperative MIMO techniques in sensor networks,” in *IEEE Journal on Selected Areas in Communnications*, vol. 22, no. 6, pp. 1089-1098, Aug. 2004.

[11] J. Jang and K. B. Lee, “Transmit power adaptation for multiuser OFDM systems,” *IEEE Journal on Selected Areas in Communicarions*, vol. 21, pp. 171-178, Feb. 2003.

[12] W. Wang, S. Yan, and S. Yang, “Optimally joint subcarrier matching and power allocation in OFDM multihop system,” *EURASIP Journal on Advances in Signal Processing*, vol. 2008, Jan. 2008.

[13] G. Miao, N. Himayat, and G. Y. Li, “Energy-efficient link adaptation in frequency-selective channels,” *IEEE Transactions on communications*, vol. 58, pp. 545-554, Feb. 2010.

[14] S. Boyd and L. Vandenberghe, *Convex Optimization*. NewYork, NY: Cambridge University Press, 2004.

[15] T. J. Willink and P. H. Wittke, “Optimization and performance evaluation of multicarrier transmission”, *IEEE Transactions on Information Theory*, vol. 43, pp. 426-440, 1997.

[16] “Spatial channel model for multiple input multi output (mimo) simulation,” Tech. Rep. TR 25.996 V8.0.0. 3rd Generation Partnership Project (3GPP), Jan. 2009.