A SIMPLE NETWORK-POWER-SAVING RESOURCE ALLOCATION METHOD FOR OFDMA CELLULAR NETWORKS WITH MULTIPLE RELAYS

Jingon Joung and Sunmei Sun

Institute for Infocomm Research (I2R), A*STAR
I Fusionopolis Way, #21-01 Connexis (South Tower), Singapore 138632
{jgoung, sunsm}@i2r.a-star.edu.sg

ABSTRACT

General signal model for orthogonal-frequency-division multiple access cellular networks with multiple amplify-and-forward relays has been introduced. An optimization problem minimizing network power is formulated to allocate subchannels and to design relay processing, and it is simplified to achieve a suboptimal solution. Numerical results show that the proposed resource allocation method achieves network power reduction and performance improvement.

Index Terms— Resource allocation, amplify-and-forward relay, OFDMA, cellular networks.

1. INTRODUCTION

Recently, a statistical amplify-and-forward (AF) relay processing method has been designed to reduce interferences in multi-cell environment [1], in which relay-transmit-power is managed to minimize each cell’s network power under the quality of service (QoS) and relay power constraints. In [1], the authors assume that multiple one- and two-hop users can coexist without co-channel interference through orthogonal frequency resources, i.e., orthogonal-frequency-division multiple access (OFDMA). For the OFDMA multihop cellular networks, resource allocation methods have been vigorously studied in the literature [2, 3]. To the best of our knowledge, however, there is no work which has simultaneously considered a frequency resource allocation and the relay processing design for the interference-limited OFDMA cellular networks. This has motivated our work.

In this paper, we introduce a general signal model for OFDMA cellular networks with multiple AF relays. An optimization problem minimizing network power is then formulated to allocate subchannels (subcarriers or subbands) with communication mode (one- or two-hop) and to design the AF relay processing. The optimization problem imposes three constraints for an orthogonal subchannel assignment, relay transmit power, and a signal-to-interference-plus-noise ratio (SINR). To circumvent an enormous combinatorial search problem, the original joint problem is divided into an assignment problem for the subchannels and design problem for the relay processing. A suboptimal approach that performs subchannel allocation and relay power allocation sequentially is then proposed. From computer simulation, we verify that the proposed resource allocation methods can contain immediate increase of network power and achieve performance improvement of interference-limited OFDMA cellular networks.

Notation. Throughout this paper, for any vector or matrix, the superscripts ‘T’ and ‘*’ denote transposition and complex conjugate transposition, respectively. For any scalar $\alpha$ and vector $\mathbf{a}$, the notation $|\alpha|$ and $\|\mathbf{a}\|$ denote the absolute value and the Euclidean norm, respectively; $I_n$ is an $n$-by-$n$ identity matrix; $\text{diag}(\mathbf{a})$ denotes a diagonal matrix with the elements of the vector $\mathbf{a}$ as its diagonal entries; and ‘$\E$’ stands for the expectation.

2. SYSTEM AND SIGNAL MODELS

The OFDMA cellular network model with multiple relays is described as follows. The ith cell has one base station (BS), $K_i$ relay stations (RS’s), and $M_i$ user equipments (UE’s), which are denoted by $B_i$ ($i \in \{1, \cdots, C\}$), $R_{i,k}$ ($k \in \{1, \cdots, K_i\}$), and $U_{m,i}$ ($m \in \{1, \cdots, M_i\}$), respectively. Cell radius is $L$ Km and normalized position of RS by $L$ is $\ell$, i.e., RS is located at $\ell L$ Km apart from the BS and $0 < \ell < 1$. There are two types of users: one communicating with BS directly and the other communicating with Bi through $\{R_{i,k}\}$. The former and the latter are denoted by one-hop and two-hop communications, respectively. Here, we assume a direct link from BS to UE is available only for the one-hop UE due to the relatively long distance between BS and two-hop UE. Each node has a single antenna. A direct channel from $B_i$ to $U_{m,i}$ is denoted by $h_{n_1}^{k_1,i}(n_1)$, where the index $n_1 \in \{1, \cdots, N\}$ represents subchannels assigned for one-hop communications. The first-hop $n_2$th subchannel from $B_i$ to $R_{i,k}$ is represented by $f_{k,i}^{n_2}(n_2)$, where the index $n_2 \in \{1, \cdots, N\}$ represents subchannels assigned for two-hop communications. The $n_2$th second-hop subchannel from $R_{i,k}$ to $U_{m,i}$ is represented by $g_{m,i}^{k_1,n_2}(n_2)$, where $m \neq m_1$. The channels $h_{n_1}^{k_1,i}(n_1)$, $f_{k,i}^{n_2}(n_2)$, and $g_{m,i}^{k_1,n_2}(n_2)$ are divided into two parts as $h_{n_1}^{k_1,i}(n_1) = \sigma_{h,m_1,i}^{k_1,n_1}(n_1) \times \mathbf{b}_{m_1,i}^{k_1}(n_1)$, $f_{k,i}^{n_2}(n_2) = \sigma_{f,k,i}^{n_2}(n_2) \times \mathbf{f}_{k,i}^{n_2}(n_2)$, and $g_{m,i}^{k_1,n_2}(n_2) = \sigma_{g,m,i}^{k_1,n_2}(n_2) \times \mathbf{g}_{m,i}^{k_1,n_2}(n_2)$, respectively, where $\sigma_{h,m_1,i}^{k_1,n_1}(n_1)$, $\sigma_{f,k,i}^{n_2}(n_2)$, and $\sigma_{g,m,i}^{k_1,n_2}(n_2)$ are path loss terms generally depending on the distance between the transmitter and the receiver; and $\mathbf{b}_{m_1,i}^{k_1}(n_1)$, $\mathbf{f}_{k,i}^{n_2}(n_2)$, and $\mathbf{g}_{m,i}^{k_1,n_2}(n_2)$ are normalized channel responses modeled as i.i.d and zero-mean complex Gaussian random variables with unit variances. Thus, the second order statistics for the channels are represented as $E[|h_{n_1}^{k_1,i}(n_1)|^2] = (\sigma_{h,m_1,i}^{k_1,n_1}(n_1))^2$, $E[|f_{k,i}^{n_2}(n_2)|^2] = (\sigma_{f,k,i}^{n_2}(n_2))^2$ and $E[|g_{m,i}^{k_1,n_2}(n_2)|^2] = (\sigma_{g,m,i}^{k_1,n_2}(n_2))^2$, respectively. The data symbol in the $n$th subchannel of $B_i$ is denoted by $d_i(n)$ with $E[|d_i(n)|^2] = 1$. Note that a time index is omitted for notational simplicity.

Communication procedure is composed of two consecutive phases. In the first-phase, every BS broadcasts signals to its own one-hop UE’s and RS’s. In the second-phase, every RS retransmits the signals to its own two-hop UE’s. Noting that the subchannels...
n_1 and n_2 are allocated to the one-hop and two-hop users, \( U_{m,1} \) and \( U_{m,2} \), respectively, the received signal at \( U_{m,1,i} \), through the first-phase is written as

\[
y_{m,1,i}(n_1) = \sum_{j=1}^{C} h_{m,1,i}^j(n_1) \sqrt{P_B} d_j(n_1) + \nu_{m,1,i}(n_1),
\]

where \( P_B \) is a fixed transmit power of BS and \( \nu_{m,1,i}(n_1) \) is \( U_{m,1} \)'s zero-mean additive white Gaussian noise (AWGN) with a variance \( \sigma_n^2 \). At the same time, the received signal vector of the relays in the \( i \)th cell for two-hop users is written as

\[
y_i(n_2) = \sum_{j=1}^{C} f_j^i(n_2) \sqrt{P_B} d_j(n_2) + \nu_{R,i}(n_2) \in \mathbb{C}^{K_i \times 1},
\]

where \( f_j^i(n_2) = [f_{1,i}^j(n_2) \ldots f_{K_i,i}^j(n_2)]^T \in \mathbb{C}^{K_i \times 1} \) is a channel vector; \( \nu_{R,i}(n_2) \in \mathbb{C}^{K_i \times 1} \) is relay's AWGN vector; and \( E \{ \nu_{R,i}(n_2)\nu_{R,i}^H(n_2) \} = \sigma_n^2 I_{K_i} \). Next, \( R_{k,i} \) multiplies the received signal by a complex valued weight \( \nu_{k,i} \), and forwards it to \( U_{m,2} \), through the second-phase. During the second-phase, BS is silent to reduce the direct interference from BS to intra-UE and save the network power. Denoting a relay weight vector for the \( n_2 \)th subchannel by \( \nu_{n_2}(n_2) = [\nu_{1,i}(n_2) \ldots \nu_{K_i,i}(n_2)]^T \in \mathbb{C}^{K_i \times 1} \) for all relays in the \( i \)th cell, therefore, a received signal at \( U_{m,2,i} \) can be represented as

\[
y_{m,2,i}(n_2) = \sum_{j=1}^{C} \left( g_{n_2,i}^j(n_2) \right)^T W_j(n_2) r_j(n_2) + \nu_{U_{m,2,i}}(n_2),
\]

where \( g_{n_2,i}^j(n_2) = [g_{1,i}^j(n_2) \ldots g_{K_i,i}^j(n_2)]^T \in \mathbb{C}^{K_i \times 1} \) is the second-hop channel vector; and the diagonal matrix \( W_j(n_2) = \text{diag}(\nu_{j,i}(n_2)) \in \mathbb{C}^{K_i \times K_i} \). Substituting (2) into (3) and ignoring the first-hop interference, i.e., \( \{ \sigma_{j,1,i}(n), \ldots, \sigma_{j,K_i,i}(n) \} \approx 0 \) \((i \neq j)\), we can derive the received signal at \( U_{m,2,i} \) as

\[
y_{m,2,i}(n_2) = \sqrt{P_B} \left( g_{n_2,i}^j(n_2) \right)^T W_j(n_2) r_j(n_2) + \nu_{U_{m,2,i}}(n_2)
\]

\[
+ \sqrt{P_B} \sum_{j=1, j \neq i}^{C} \left( g_{n_2,i}^j(n_2) \right)^T W_j(n_2) f_j^i(n_2) d_j(n_2)
\]

\[
+ \sum_{j=1}^{C} \left( g_{n_2,i}^j(n_2) \right)^T W_j(n_2) \nu_{R,j}(n_2) + \nu_{U_{m,2,i}}(n_2)
\]

In (4), the first-hop interference can be ignored under the assumption that every relay employs directional receive antenna focusing on the intra-cell BS for the downlink communications (from BS to RS's).

### 3. Optimization Problem Formulation

Before formulating an optimization problem, we introduce three constraints for the subchannel allocation, the relay processing, and the system performance.

#### 3.1. Constraints on Subchannel Allocation

An indicating variable \( \delta_{m,i}(n) \) is denoted by ‘1’ if the \( n \)th subchannel is allocated to \( U_{m,i} \), by ‘0’ otherwise. Here, two constraints on \( \delta_{m,i}(n) \) are required as

\[
\sum_{m=1}^{M_i} \delta_{m,i}(n) = 1 \quad \text{and} \quad \sum_{n=1}^{N_i} \delta_{m,i}(n) = 1.
\]

where \( A_i \) is the number of assigned subchannels (or users), which is the minimum value between \( M_i \) and \( N_i \). The first constraint in (5) means that a subchannel can be occupied by one user to prevent co-channel interferences among the users who are in the same cell, and the second constraint in (5) implies that every user occupies one subchannel for the fairness among the users. Again, for the \( n_i \)th subchannel of \( U_{m,i} \), a communication mode is denoted by \( \xi_{m,i}(n) \), and it is set by ‘1’ for one-hop communication and ‘2’ for two-hop communications. We can then define a new indicator variable \( u_{m,i}(n) = \xi_{m,i}(n) \delta_{m,i}(n) \in \{0, 1\} \) and multiuser indicating vector \( u_i = [u_{1,i}^T \ldots u_{M_i,i}^T]^T \in \mathbb{R}^{A_i \times 1} \), where \( u_{m,i} = [u_{m,i}(1) \ldots u_{m,i}(A_i)]^T \in \mathbb{R}^{A_i \times 1} \).

#### 3.2. Constraint on Relay Processing

From a transmit power constraint on \( R_{k,i} \), i.e., \( E \{ \nu_{k,i}(n_2) r_k(n_2) \}^2 \leq P_B, \forall k, i, \) and \( n, \) where \( r_{k,i}(n) \) is the \( k \)th element of \( r_i(n) \) in (2), a constraint on relay weight can be derived as

\[
\|w_{k,i}(n)\|_2^2 \leq \frac{P_B}{P_B \sigma_f^2(n) + \sigma_n^2} \triangleq \omega_{\text{max}}(n), \forall k, i, \) and \( n, \)

where the maximum value of relay amplification factor is denoted by \( \omega_{\text{max}}(n) \). In (6), we assume that i) every relay is deployed to obtain the same received signal power from its BS, i.e., \( \{ \sigma_{j,1,i}(n) = \ldots = \sigma_{j,K_i,i}(n) \triangleq \sigma_{j,i}(n) \} \), and ii) the data symbols, channel elements, and noises are independent of one another.

#### 3.3. Constraint for System Performance

Since the allocation and the relay processing affect not only the network power but also the system performance, the optimization problem should include a constraint for the reliable communication; otherwise, a trivial solution that every node becomes silent to minimize network power is obviously obtained. As a metric for the reliable communications, an average SINR, termed as \( \text{SNIR}_m(n) \) for the \( n \)th two-hop user using the \( n \)th subchannel in the \( i \)th cell, can be derived from (4) and used in the performance constraint as (7) at the bottom of next page, where \( C_{n,m}^i(n) = \text{diag}(g_{n_2,i}^j(n_2)) \) and \( C_{n,2,m}^i(n) = \text{diag}(\{ \sigma_{j,1,i}(n) \}^2 \ldots \{ \sigma_{j,K_i,i}(n) \}^2)^T \).

### 3.4. Optimization Formulation

Network power of the \( n \)th subchannel is derived as \( P(n) = C P_B + (P_B \sigma_f^2(n) + \sigma_n^2) \sum_{m=1}^{C} w_m^*(n) w_m(n) \). Hence, the network power for all subchannel can be defined as \( P_{\text{tot}} \triangleq \sum_{n=1}^{N} P(n) \). Denote a multi-cell-multiuser indicating vector by \( u = [u_1^T \ldots u_C^T]^T \in \mathbb{R}^{(C^{A_i \times 1})} \), and a multi-cell-multiuser relay weight vector by \( w = [w_1^T \ldots w_C^T]^T \), where \( w_1 \) is a multiuser (multiple subchannels) expression of the relay processing vector as \( w_i = [w_1^T(1) \ldots w_1^T(A_i)]^T \in \mathbb{C}^{(A_i K_i \times 1)} \). With the constraints in (5)–(7), the optimization minimizing network power is then formulated as

\[
P_{\text{tot}} : \{ u, w \} = \arg \min_{u \in \mathcal{U}_{\text{tot}}, w \in \mathbb{C}^{C \times A_i \times K_i \times 1}} P_{\text{tot}}, \quad \text{s.t. (5), (6), and (7)}
\]

where \( \mathcal{U} \) is a set of the vector \( u \). Noting that the optimization for \( u \) is an assignment problem and its optimal solution depends on the relay weight \( w \), the optimal solution \( \{ u, w \} \) can be found.
from all assignment candidates \( u \in U \) with an optimized \( w \) for each assignment. However, searching all assignment candidates is intractable due to a prodigious number of combinations for the candidates. For a given \( i \), the number of combinations of the sub-channel allocation \( \delta_{m,i}(n) \) for \( A_i \) users is \( \prod_{m=1}^{A_i} (A_i - (m-1)) \), and \( 2^{2n} \) combinations of communication modes are possible for each allocated sub-channel set due to two communication modes \( \xi_{m,i}(n) \). Therefore, for \( C \) cells, the cardinality of set \( U \) is derived as \( |U| = \prod_{m=1}^{C} (\prod_{m=1}^{A_i} (A_i - (m-1))2^{2n}) \). Since the optimization on \( w \) should be performed for \( |U| \) combinations, solving \( P_0 \) is a formidable task. As an example, if there are 20 users and 20 subchannels for each cell and three cells are considered, the number of candidates for the assignment is \( (20!2^{20})^3 \geq 1.66 \times 10^{75} \). Therefore, modifying the optimization problem is inevitable.

\[ \begin{align*}
\text{4. PROBLEM MODIFICATION AND SOLUTION} \\
\text{To simplify the original problem} \ P_0 \text{in (8), it is divided into an assignment problem with a given} \ w \text{and a relay processing design problem with a given} \ u \text{as}, \text{respectively,} \\
\begin{align*}
\text{P}_1: & \quad u = \arg \min_{u \in U} \ P_{net}|_{w}, \text{ s.t., (5)}, \\
\text{and} \\
\text{P}_2: & \quad w = \arg \min_{w_1,2} \ P_{net}|_{u} \text{, s.t., (6) and (7)}.
\end{align*}
\end{align*} \]

Two-step approach, in which \( \text{P}_1 \) and \( \text{P}_2 \) are successively solved, is now available.

\[ \begin{align*}
\text{4.1. Subchannel Assignment Problem} \\
\text{Though the assignment problem is separated from the original problem, it is still difficult to solve due to the coupled relationship among} \ u_i \text{'s. To circumvent the coupled assignment problem and reduce the number of candidates, the assignment in (9) is performed for each cell, i.e., for a given} \ i, \text{as} \\
\begin{align*}
\text{P}'_1: & \quad u_i = \arg \min_{u_i \in U_{A_i}} \ P_{net}|_{w}, \text{ s.t., (5)}, \\
\text{where} \ U_{A_i} \text{is a set of a} \ A_i^2 \text{-by-1 vector} \ u_i. \text{After we get} \ u_i, \text{for all} \ i \text{from (11), we can apply the solution} \ \{u_i\} \text{to (10). However, unfortunately, it is difficult to directly solve (11) because of the following reasons: BS in the} i \text{th cell does not know} \ w, \text{and furthermore,} \ P_{net} \text{is a nonlinear function of} \ \delta_{m,i}(n). \text{Thus, further modification of (11) is required.} \\
\text{Based on the observation that network power decreases as an effective second-hop channel gain increases} \ [1], \text{we further modify (11), so that sum of the effective channel gains can be maximized. This strategy is heuristic, yet we can expect network power reduction. Before the modification, to further reduce the number of candidates, we determine the communication mode} \ \xi_{m,i}(n), \text{for a given} \ i, \text{as} \\
\begin{align*}
\xi_{m,i}(n) = \left\{ \begin{array}{ll}
1, & \text{if} \ |h_{m,i}(n)|^2 \geq \max_k \ \min \left\{ |f_{k,i}(n)|^2, |\delta_{k,i}(n)|^2 \right\} \\
2, & \text{otherwise},
\end{array} \right.
\end{align*}
\end{align*} \]

where \( \delta_{k,i}(n) = \max \{\cdot, \cdot \} \) selects the smaller value and \( \max \{\cdot, \cdot \} \) selects the maximum value over \( \alpha \), respectively. In (12), we define an effective one-hop channel gain by an instantaneous channel gain between BS and UE. On the other hand, we use the largest two-hop link gain to represent the effective two-hop channel gain under the assumption that \( w_{k,i}(n) = 1 \). This is reasonable because the more power is allocated to the BS having the largest two-hop link gain through the power allocation procedure [1]. Here, a minimum channel gain between the first- and second-hop is chosen as the two-hop link gain because it is critical to the system performance of two-hop communications [5]. According to the communication modes in (12), we define an effective channel gains, \( \lambda_{m,i}(n) \in \mathbb{R}^+ \), for given sub-channel \( n \) and cell \( i \) as

\[ \begin{align*}
\lambda_{m,i}(n) = \left\{ \begin{array}{ll}
|h_{m,i}(n)|^2, & \text{if} \ \xi_{m,i}(n) = 1, \\
\max_k \ \min \left\{ |f_{k,i}(n)|^2, |\delta_{k,i}(n)|^2 \right\}, & \text{otherwise}.
\end{array} \right.
\end{align*} \]

Using \( \lambda_{m,i}(n) \) in (13), we can now modify \( \text{P}'_1 \) in (11) to a traditional linear assignment problem as

\[ \begin{align*}
\text{P}'_2: & \quad u_i = \arg \min_{u_i \in U_{A_i}} \ \sum_{n=1}^{N} \sum_{m=1}^{M_i} \delta_{m,i}(n) \left( \lambda_{max} - \lambda_{m,i}(n) \right), \\
\text{s.t., (5)},
\end{align*} \]

where \( \lambda_{max} = \max_{\lambda_{m,i}(n)} \) is a maximum effective channel gain in the \( i \)th cell. The optimal solution of \( \text{P}'_2 \) in (14) can be then easily found by using a simple assignment algorithm. There are already various efficient optimal algorithms for solving the assignment problems, and one of such algorithms, which is called Hungarian (or Munkres) algorithm [4], is applied to our simulation. Through the assignment procedure, if \( N \geq M_i \), there are \( (M_i - N) \)-unassigned subchannels. Otherwise, there are \( (N - M_i) \)-unassigned users. In such cases, additional procedures including scheduling users and composing subchannels are required to further achieve multiuser and frequency diversities, and they are remained as further work. In our simulation, we set \( N = M_i \), yet the algorithm works in any cases of \( N \) and \( M_i \).

\[ \begin{align*}
\text{4.2. Design Problem for Relay Processing} \\
\text{The coupled problem} \ P_2 \text{in (10) with respect to} \ \{w_i\} \text{can be decoupled for a given cell, i.e., given} \ i. \text{For a subchannel} \ n, \text{which is allocated to two-hop user through} \ P'_2, \text{the relay processing can be designed by following the same optimization procedure in [1] as}
\end{align*} \]

\[ \begin{align*}
\text{SINR}_{m,i}(n) = \frac{P_0 \sigma^2(n)w_i(n)g^*_{m,i}(n)w_i(n)}{\left( P_0 \sigma^2(n) + \sum_{j \neq i} C_j w^*_j(n)g_{m,i}(n)w_j(n) + \sigma^2(n)w_i(n)g^*_{m,i}(n)w_i(n) + \sigma^2_0 \right)} \geq Q_i(n), \forall m, i, \text{and} \ n
\end{align*} \]

\( \text{SINR}_{m,i}(n) \)
The relay processing in (15) can be interpreted as a relay power allocation. Specific derivation of (15) is omitted in this paper due to the limited pages.

5. NUMERICAL RESULTS AND DISCUSSION

In this section, we evaluate system bit-error-rate (BER) and network power for one- and two-hop systems with or without subchannel allocation (SA) and relay power allocation (PA). If there is no SA, subchannels are randomly allocated, and the communication mode is then determined by (12). For the sake of comparison, the performance of direct communication system without relays, in which all users perform one-hop communications, is also shown. Binary phase-shift-keying (BPSK) modulation is used for the UE’s in direct communications, while quadrature PSK (QPSK) modulation is used for the UE’s in one- and two-hop communications to compensate spectral efficiency loss arisen from the two-phase communications. Three cells ($C = 3$) are modeled as a hexagonal array with 1 Km radius, where three BS’s are located in same distance among one another. The relays are located at 0.7 Km apart from their BS’s.

We set the transmit power of BS and RS by 43 dBm (20 Watt) and 40 dBm (10 Watt), respectively. The noise standard deviations (STD) are set by $-131.5$ dBm and $-134.5$ dBm at UE and RS, respectively. Large-scale path loss with shadowing is generated from a log-normal model with the path loss exponent 3.76 and the shadowing STD 8.9 dB. The relay processing in [1] is used. Frequency reuse factor is one. There exists a direct interference from inter-cell BS’s to one-hop UE’s due to the omni-directional transmit antennas of BS’s and RS’s. As mentioned in Section II, however, the receive antennas of RS’s are directional, which is set to yield $20$ dB gain in our simulation, and the first-hop interference from inter BS’s to intra RS is then negligible. Fading is modeled as Rayleigh. One OFDMA frame consist of 20 subchannels and 25 OFDM symbols. We assume that the channel is static within one OFDMA frame. 20 users ($M = 20$) are generated $10^3$ times uniformly in each cell. For each user realization, i.e., for one fixed user location, we generate independent Rayleigh fading channels for 100 OFDMA frames of each user.

Figure 1 shows the results over the number of relays, $K_i$. As $K_i$ increases, the performance of the one- and two-hop systems with PA improves with almost constant network power, while that without PA deteriorates though network power increases above the direct communication system’s network power. This result is reasonable because the second-hop interference also increases as $K_i$ increases without PA. Note that every relay uses its own maximum available power if there is no PA. Strange shape of BER curves is observed for the one- and two-hop system with SA due to the following reason: as $K_i$ increases, the average subchannel gain increases due to the frequency diversity gain, yet the second-hop interference also increases.

6. CONCLUSION

Resource allocation method with relay processing design is proposed for OFDMA cellular networks to minimize network power. Sequential method is proposed to design a simple resource allocation. From numerical results, it is verified that multiple half-duplex AF relays can improve the performance of interference-limited cellular networks if we carefully allocate the subchannel and design relay processing.

7. REFERENCES