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AN ENERGY-EFFICIENT MAXIMIZATION BASED PATH SELECTION AND RESOURCE ALLOCATION SCHEME IN OFDMA-BASED TWO-HOP RELAY CELLULAR NETWORKS

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ABSTRACT

In this paper, we investigate the energy efficiency problem in downlink transmission of the OFDMA-based two-hop relay cellular networks. Most of the researches on energy efficiency focus on the transmission in traditional cellular system, especially for the uplink transmission. Our objective is to maximize the system energy efficiency for the downlink transmission of the two-hop relay cellular system. We consider both the circuit power and transmission power consumption, and propose a two-step suboptimal path selection and subchannel allocation scheme to maximize the system energy efficiency. The simulation results show that our proposed scheme have good performance in energy efficiency.

Keywords: *OFDMA, Multi-hop Relay Network, Path Selection, Resource Allocation, Scheduling*

1. INTRODUCTION

In the recent year, as the relaying technology has many advantages, such as network coverage extension, shadowing combat, network capacity enhancement, deployment cost reduction, it has become one of the key technologies in the standards of the next generation wireless communication, such as I long term evolution-advanced (LTE-A) [1], IEEE 802.16m [2]. Moreover, orthogonal frequency division multiple access (OFDMA) is already adopted as the basic multiple access scheme in B3G/4G since it provides flexible degree of freedom of resource allocation and can efficiently combat fading of frequency selective channels. However, the radio resource allocation problems in OFMDA-based multi-hop relay cellular system, such as path selection, wireless resource allocation, scheduling, etc., becomes more crucial and challenging task, which becomes a hot topic in recent years. Nevertheless, path selection and resource allocations algorithm are not mentioned at all in the IEEE 802.16j/m standards or LTE-A standard [3].

As path selection can be used to assist in determining proper relay path in multi-hop wireless networks, the problem of path selection has been widely studied in a variety of wireless networks, such as mobile ad hoc networks, wireless sensor networks. However, these proposed path selection algorithms are unable to be directly exploited in multi-hop cellular systems, such as 802.16j MR networks [3]. In the recent years, many studies concentrate on the path selection problem in multi-hop cellular system [3-5], such as the minimum distance based path selection (Min-DPS), minimum large scale fading (including pathloss and shadowing) based path selection (Min-LSFPS), maximum signal-to-interference-plus-noise ratio (SINR) based path selection (Max-SPS) schemes. However, they mainly focus on the system throughput enhancement and the quality of service (QoS) requirements, and seldom researchers consider the energy consumption problem of the path selection.

In this paper, we propose an energy-efficient based path selection algorithm, based on which, we further provide an energy-efficient maximization based joint path selection, subchannel allocation and scheduling scheme in the downlink of the OFDMA-based two-hop relay cellular networks.

The rest of this paper is organized as follows: system model and problem formulating are given in section 2. Then, section 3 provides the path selection scheme, and further addresses the energy-efficient maximization based joint path selection and resource allocation scheme.

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2. SYSTEM MODEL AND PROBLEM FORMULATION

A. System Model

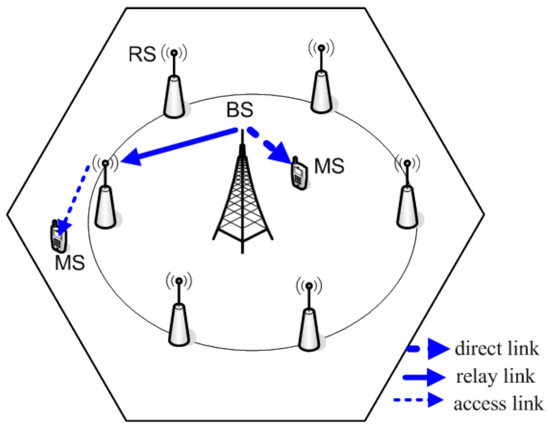

Figure 1. The Two-Hop Relay Wireless Cellular Network Topology

We consider a two-hop relay OFDMA downlink system which is widely used in studies [4]. A BS with an index of 0 is located at the cell center and the fixed RSs with indexes of $\{1,2,\cdots,K\}$ (K=6 in this paper) are symmetrically deployed around the BS. Users are randomly distributed in the cell. It is assumed that an MS can establish a direct link (from BS to MS) to communicate directly with BS, or two hop links via an RS, including BS-RS link (relay link) and RS-MS link (access link), and the BS operates in a time-division duplexing (TDD) mode and all RSs are in the decode-and-forward (DF) mode.

The overall bandwidth W is divided into N subchannels for OFDMA downlink transmission. Each subchannel is consisted by multiple subcarriers. If the subcarriers in each subchannel are continuous, it is considered as a continuous subchannel permutation mode, otherwise a distributive subchannel permutation mode.

The minimum resource allocation unit is a slot which is constituted by one subchannel by one time slot. A time slot contains one or more continuous OFDMA symbols. Each time-slot is further divided by two sub-time-slots with equal duration. For the relaying downlink transmission, each RS receives and decodes the data transmitted from BS in the first sub-time-slot, and then forwards the data to the relevant MSs in the second sub-time-slot. For simplicity, we assume that the RS forwards the received data to the MS on the same subchannel. It is further assumed that the channels are slowly-varying, thus the channel state information of all links can be estimated and fed back to the BS.

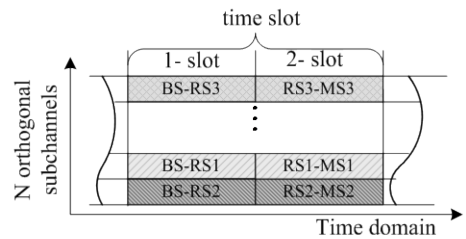

Figure 2. Frame Structure

B. Problem Formulation

For convenience, some notations used in this paper are listed Table I.

Table I: Some Notations Used In This Paper

Notations	Meaning
M	number of users
N	number of subchannels
K	Number of relays
P_c	total transmission associated circuit power
P^{BS}_c/P^{RS}_c	transmission associated circuit power of BS/RS
N_0	noise power density
W	subchannel bandwidth
T	time duration of a time slot
R^n_{km}	achievable rate for user *m* on subchannel *n* (k=0 denotes the direct path *BS-MSm*, otherwise the relay path *BS-RSk-MSm*)
$P_T(R^n_{km})$	minimum required transmission power of user *m*(*k*=0 denotes the transmit power of direct path, otherwise the total transmission power of the relay path)
G^n_{km}	power gain in nth subchannel for mth *MS* (*k=0* denotes the power gain of the direct path, otherwise the equivalent power gain of the relay path)

Let p^n_{ij} and g^n_{ij} denote the transmission power of node *i* and channel power gain from node *i* to node j on subchannel n. It is assumed that the continuous adaptive modulation and coding (ACM) is adopted [6], then the achievable transmission rate can be given by

$$r_{ij} = W\log_2\left(1+\frac{p_{ij}g_{ij}}{\Gamma W N_0}\right), \qquad (1)$$

where, $\Gamma = -\ln(5BER)/1.5$ is the signal to noise ratio (SNR) gap related to a target bit error rate (BER).

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The achievable data rate of direct path *BS-MSm* on subchannel n can be written as:

$$R_{0m}^{n} = W\log_2\left(1+\frac{p_{T,km}^{n} g_{T,km}^{n}}{\Gamma W N_0}\right). \quad (2)$$

As the relay path needs two sub-time-slot to forward data to the users, the achievable data rate can be written as:

$$R_{km}^{n} = \frac{1}{2}\min\left\{r_{sk}^{n}, r_{km}^{n}\right\}, \quad (3)$$

where, r_{sk}^{n} and r_{km}^{n} separately denote the achievable data rates of both first-hop link and the second-hop link of the relay path *BS-RSk-MSm* on subchannel n. The maximum transmission data rate of the relay path is achieved on subchannel n while $r_{sk}^{n} = r_{km}^{n}$ [7], and then the transmission powers for both *BS-RSk* link and *RSk-MSm* link should satisfy the condition as follows:

$$p_{km}^{n} = p_{sk}^{n}\frac{g_{sk}^{n}}{g_{km}^{n}} \quad (4)$$

When the achievable data rate is equal to R_{km}^{n} in Eq. (3) on subchannel n of the relay path *BS-RSk-MSm*, the total transmission power can be given by

$$p_{T,km}^{n} = p_{sk}^{n} + p_{km}^{n} \quad (5)$$

The Eq. (3) can be simplified as follows:

$$R_{km}^{n} = \frac{1}{2}W\log_2\left(1+\frac{p_{T,km}^{n} g_{km}^{n}}{\Gamma W N_0}\right), \quad k \neq 0 \quad (6)$$

where

$$g_{km}^{n} = g_{sk}^{n} g_{km}^{n} / (g_{sk}^{n} + g_{km}^{n}) \quad (7)$$

For a relay-enhanced cellular network, its power consumptions are composed by two parts: 1) the circuit power consumptions of the electronic equipments of both BS and RSs, which are independent from the transmission data and can be assumed to be constants [8-10]; 2) transmission power of BS or RS, which are the minimum required transmission power to guarantee the achievable data rate.

Let the average consuming circuit power on one subchannel is $P_C = (P_C^{BS} + \alpha P_C^{RS})/N$, where $\alpha = 0$ denotes the direct path, otherwise, the relay path. The consuming energy for a direct path *BS-MSm* on subchannel n can be written as:

$$E_{km}^{n} = T(P_C + p_{T,km}^{n}). \quad (8)$$

Similarly, the consuming energy of relay path BS-*RSk-MSm* on subchannel n is given by

$$E_{km}^{n} = T(P_C + p_{T,km}^{n})/2, \quad (9)$$

where, $p_{T,km}^{n}$ is the total transmission power of both BS and RSk on subchannel n. We assume the circuit power is averagely allocated to each subchannel, based on which, we obtain the energy efficiency definition for a path (direct of relay path) on any subchannel.

Definition 1. For a given achievable data rate r_{km}^{n} on a subchannel n, the minimum transmission power is $p_T(r_{km}^{n})$Watts, the energy efficiency can be defined as

$$U(r_{km}^{n}) = \frac{r_{km}^{n}}{(2-\alpha)\left(P_C + p_T(r_{km}^{n})\right)/2} \quad (10)$$

where, Eq. (10) is a unify expression of the energy efficiency for any subchannel

Lemma 1. *The transmission power* $p_T(r_{km}^{n})$ *is monotonically increasing and strictly convex in* $r_{km}^{n} \in [0, +\infty)$.

Proof: Based on the expression $p_T(r_{km}^{n}) = \Gamma W N_0\left(2^{r_{km}^{n}/W} - 1\right)/g_{km}^{n}$ obtained from Eq. (1), is prone to deduce that the $p_T(r_{km}^{n})$ is two order differentiable, then $p_T'(r_{km}^{n}) = \Gamma N_0 2^{r_{km}^{n}/W}/g_{km}^{n} > 0$, $p_T''(r_{km}^{n}) = \Gamma N_0 2^{r_{km}^{n}/W}/W g_{km}^{n} > 0$, and $p_T(r_{km}^{n}) = 0$ when $r_{km}^{n} = 0$. According to the definition of the convex function, we have the conclusion in *Lemma 1*.

Theorem 1. *If the transmission power* $p_T(r_{km}^{n})$ *is monotonically increasing and strictly convex in* $r_{km}^{n} \in [0, +\infty)$, *there exits a unique globally optimal transmission data rate to maximize the energy efficiency in Eq. (10), and given by*

$$r_{km}^{n\,*} = \frac{P_C + p_T(r_{km}^{n\,*})}{p_T'(r_{km}^{n\,*})} \quad (11)$$

Proof:

1) For the direct path, the expression of the energy efficiency is given by

$$U(r_{km}^{n}) = \frac{r_{km}^{n}}{P_C + p_T(r_{km}^{n})}. \quad (12)$$

According to the Theorem 1 in [9], the proof for the direct path scenario is easily obtained.

For the relay path, the expression of the energy efficiency is given by

$$U(r_{km}^{n}) = \frac{r_{km}^{n}}{\left(P_C + p_T(r_{km}^{n})\right)/2}. \quad (12)$$

The proof for the relay path scenario is the same as that for the direct path scenario.

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In this paper, the optimal energy efficiency is easily obtained by using the binary search assisted ascent algorithm proposed in [10], which is a gradient ascent method.

Property 1. *For the flat fading channel, the average energy efficiency of total bandwidth has no relation to the number of subchannels.*

Proof: According to our definition of the energy efficiency of the subchannels, the average circuit power on each subchannel is P_c/N. As the channel is flat fading, the flat fading values on each subchannel are equal. Denote r^n to be the achievable data rate on subchannel n. As the pathlosses and shadowings on all subchannels are the same, for one given link, the optimal data rates and the required powers on all subchannels are equal. When one user takes p subchannels, the energy efficiency is given by $U(nr) = pr/(pP_C/N + pP_T(r)) = p/(P_C/N + P_T(r)) = U(r)$. Hence, property 1 follows immediately.

3. ENERGY-EFFICIENT MAXIMIZATION BASED PATH SELECTION AND RESOURCE ALLOCATION SCHEME

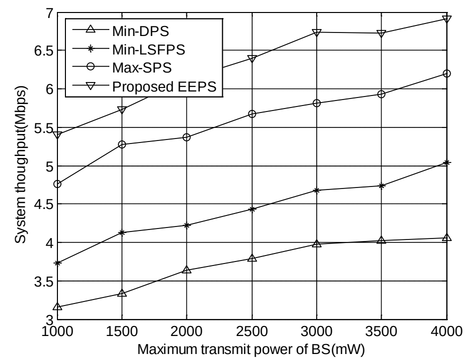
Our proposed energy-efficient maximization based path selection and resource allocation scheme has two steps: first the path selection is performed for each user that requires accessing the network or executes the hand-offs, and the subchannel allocation process sequentially follows.

A. Energy-efficient based Path Selection (EEPS)

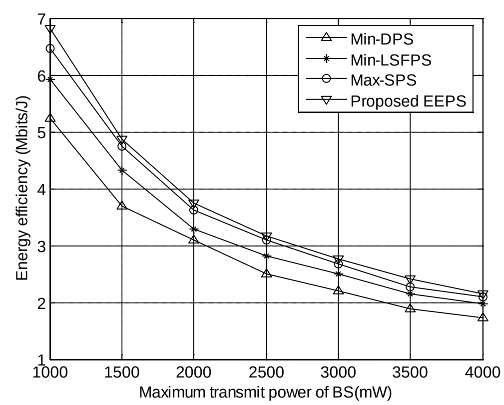
As it would be impractical to perform inter-relaying node and inter-relaying channel hand-offs based on multi-hop conditions [12], it omits the small-scale multi-hop fading effects in our proposed path selection scheme, and just considers the large scale fading (pathloss plus shadowing).

BS performs the path selection for users according to the large-scale fading, where we assume that the large-scale fading values on each subchannel for one link are the same. According to property 1, the energy-efficient value with the total bandwidth for one link is equivalent to that with one subchannel bandwidth. Therefore, the accessing path is determined by the maximum energy-efficient value of one path according to Eq. (10) and Eq. (11) with one subchannel bandwidth.

In order to evaluate the performance of the EEPS algorithm, we present the EEPS scheme by simulations as in Fig. 3. The traditional path selection algorithms, including Min-DPS, Min-LSFPS and Max-SPS, are used for comparisons, where, Min-DPS and Min-LSFPS algorithms are based on the minimum distance and minimum large scale fading value of the access link (BS-MS link or RS-MS link), respectively. Max-SPS algorithm is based on minimum SINR value of the BS-RS link and RS-MS link on relay path. The system parameters are listed in Table II. Here, we assume that there are 10 subchannels and10 users, and each user occupies one subchannel. For one user, the performance metrics, such as the achievable data rate, are obtained based on the large scale fading, and computerized by using equivalent power allocation to each subchannel.



(A) Relation Between System Throughput And Transmission Power



(B) Relation Between Energy Efficiency And Transmission Power

Figure 3. Comparison Of The Path Selection Algorithm In The Two-Hop Relay Cellular System

Fig.3 compares the proposed EEPS algorithm with the existing typical path selection algorithms in the two-hop relay cellular system. In Fig.3, the x label denotes the maximum transmission power of BS. As the maximum transmission power of the RS is set acquiescently to be 1/10 of the BS's maximum transmission power, therefore, the values of x label are equivalent to the system transmission

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power. Once the path is determined, the performance metrics are computed with the equivalent power allocation to all subchannels. As the proposed EEPS algorithm considers the effects of the channel gains of the two-hop links, the throughputs of the proposed EEPS algorithm outperform the existing algorithms. In addition, as the proposed EEPS algorithm considers the effects of the energy efficiency, the proposed path selection scheme have good performance of the energy efficiency compared with the exiting algorithms.

B. Subchannel allocation and scheduling

After the path selection is performed, the effects of multi-path fading are included in the subchannel allocation and scheduling process.

Based on the proposed EEPS algorithm, we proposed a joint energy-efficient path selection and resource allocation scheme (EEPSRA).

For the proposed subchannel allocation and scheduling scheme, each subchannel is allocated to the user with the maximum energy-efficient value.

4. PERFORMACE COMPARISONS

According to the discussion in Fig.3, the Max-SPS algorithm outperforms the Min-DPS and Min-LSFPS algorithm. In order to evaluate the performance of the proposed EEPSRA algorithm, we compare our proposed scheme with Max-SPS scheme, where the Max-SPS scheme allocates equally the total transmission power to subchannels and considers three types of typical scheduling algorithms: joint maximum SINR based path selection and MAX C/I algorithm(Max-SPS+MAX C/I), joint maximum SINR-based path selection and round robin algorithm (Max-SPS+RR), and joint maximum SINR-based path selection and proportional fair scheduling algorithm (Max-SPS+PF).

In this paper, single hexagonal cell is considered. The cell is extended by 6 RSs surrounding the BS symmetrically, each of which is positioned at 3/8 of BS-to-BS distance between RS and BS. The circuit power consumptions per subchannel of BS and RS are 100 and 50 mW, respectively. The maximum transmission powers of BS and RS are set to be 36 and 26 dBm, respectively.

BS-RS links are assumed to be line-of-sight (LOS) above the rooftops (ART) to ART links, where both BS and RS's antennas are mounted ART and they have a LOS between them. The pathloss model of BS-RS links is IEEE802.16j EVM Type D model [12], and defined by

$$PL[dB]=\begin{cases}20\log_{10}\left(\frac{4\pi d[m]}{\lambda[m]}\right) & d\le d_0^{'}\\ A+10\gamma\log_{10}\left(\frac{d[m]}{d_0[m]}\right)+\Delta PL_f+\Delta PL_h & d>d_0^{'}\end{cases},(13)$$

where, $A=20\log_{10}(4\pi d_0^{'}[m]/\lambda)$, $d_0=100m$, $d_0^{'}=d_0[m]10^{-(\Delta PL_f+\Delta PL_h)/10\gamma}$, $\gamma=a-bh_{BS}[m]+c/h_{BS}[m]$ with parameters $a=3.6, b=0.005, c=20$, $\Delta PL_f=6\log_{10}(f_c[MHz]/2000)$, and

$$\Delta PL_h=\begin{cases}-10\log_{10}(h_{RS}[m]/3) & h_{RS}\le 3m\\ -20\log_{10}(h_{RS}[m]/3) & h_{RS}>3m\end{cases}.$$

The pathloss model of BS-MS and RS-MS links is modeled as a non-line-of-sight (NLOS) model, which is the mandatory baseline channel model used for the BS-MS and RS-MS link simulations in [12], and given by

$$PL(dB)=40(1-4\times10^{-3}h[m])\log_{10}(d[km]) -18\log_{10}(h[m])+21\log_{10}(f_c[MHz])+80, \quad (14)$$

where, $d[km]$ is the distance between BS/RS and MS, $f_c[MHz]$ is the central frequency and $h[m]$ is the BS or RS antenna height above the average rooftop. If applied for operation at 2.5 GHz, a frequency correction factor 21log(2.5/2) should be added,

It is assumed that each subchannel of BS-MS and RS-MS links is independent and follows Rayleigh fading model, and each subchannel of BS-RS links is also independent and follows Rician fading model. Other simulation parameters are given in Table II.

TABLE II: System Parameters

Parameter name	Value
BS-to-BS distance	*1500 m*
Total bandwidth	*1MHz*
Central frequency	*2500 MHz*
Subchannel bandwidth	*100kHz*
Subchannels	*10*
BER	*10^{-6}*
Duration of one time slot	*1ms*
Maximum transmit power(BS/RS)	*36/26dBm*
BS/RS/MS Antenna height	*25/15/1.5m*
BS/RS Antenna type	*Omni-antenna*
Thermal noise spectral density	*-174dBm/Hz*
LOS/NLOS shadowing SD	*3.4/8dB*

Figure 4 compares the system throughput and energy efficiency, respectively. Fig. 4(a) shows that the throughput of the proposed EEPSRA algorithm is lower than the Max-SPS+MAX C/I algorithm, but higher than the Max-SPS+RR algorithm, and a little bit higher than Max-SPS+PF algorithm with

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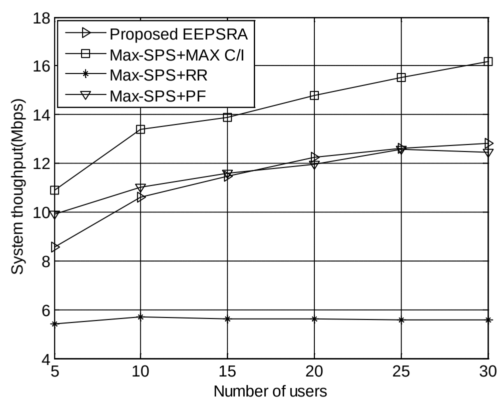
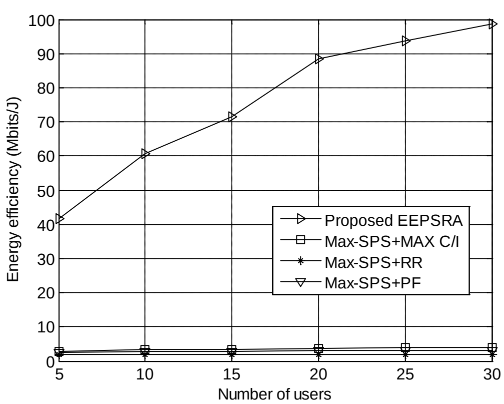
increasing numbers of users in system. The reason is that the Max-SPS+MAX C/I algorithm always allocates the subchannels to the user with the best end to end SINR, the Max-SPS+RR algorithm is totally omits the channel conditions but provide the equal probability opportunities to users to be scheduled. The Max-SPS+PF algorithm considers both the channel conditions and the fairness of users and achieves a trade-off performance in system throughput and users' fairness. According to the definition of the energy efficiency in Eq. (10), the proposed EEPSRA algorithm considers both the end-to-end channel conditions and the power consumption in the two phases, including path selection phase and resource allocation phase, therefore, the throughput performance is lower than Max-SPS+MAX C/I algorithm, but higher than Max-SPS+RR algorithm and Max-SPS+RR algorithm algorithms. Fig. 4(b) illustrates that our proposed EEPSRA algorithm has the best energy efficiency performance, which means that comparing with the traditional path selection and resource allocation algorithms, our proposed MSPSRA algorithm can largely improve the energy efficiency of the system.



(A) System Throughput Comparison



(B) System Energy Efficiency Comparison
Figure 4 Comparisons Of Different Algorithms

5. CONCLUSION

In this paper, we have developed an energy-efficient maximization based joint path selection and resource allocation scheme for the downlink transmission in the OFDMA-based two-hop relay cellular networks. The proposed algorithm aims at improving the system energy efficiency. The simulation results show that the proposed algorithm has good energy efficiency performance. In the future, it could be interesting research topic to consider the quality of service (QoS) of users, such as minimum data rate requirements, and the trade-off between the energy efficiency and the spectrum efficiency to further enhance the overall system performance.

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