Energy Efficient Uplink Resource Allocation in LTE-A Relay Networks

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***Abstract*—The Relay Node (RN) in Long-Term Evolution-Advanced (LTE-A) networks is used to enhance the coverage of high data rate and solve the coverage hole problem. However, for User Equipments (UEs), using a higher transmission rate means more energy consumption; especially they are operated by batteries. In this paper, we consider an uplink resource and power allocation problem for energy conservation in LTE-A networks. The objective is to minimize the total energy consumption of UEs while guarantee the quality of service (QoS) of UEs. This problem is NP-complete and we develop an algorithm to solve the problem. Simulation results show that our algorithm can effectively reduce the energy consumption while guarantee users' service quality.**

Keywords—LTE-A; energy efficiency; resource allocation; relay networks; green communications.

I. INTRODUCTION

In recent years, the 3rd Generation Partnership Project (3GPP) has proposed the Long-Term Evolution (LTE) [1] [2] and LTE-Advanced (LTE-A) [3] to support mobile and broadband wireless access in cellular systems. In LTE/LTE-A, the Orthogonal Frequency Division Multiple Access (OFDMA) has been selected as the downlink access technology, which provides high spectrum efficiency, while in the uplink, LTE employs the Single-Carrier Frequency Division Multiple Access (SC-FDMA) technique to reduce the Peak-to-Average Power Ratio (PAPR) [4].

Relay is one of the key features in LTE-A [3], where relays can enhance the coverage of high data rates, increase the throughput of cell-edge users, and solve the coverage hole problems. Two types of relays are introduced in the LTE-A [5]. Type 1 relays act like Evolved Node-Bs (eNBs) to the attached User Equipments (UEs) and have their own physical identities. On the contrary, Type 2 relays are transparent to the UEs and don't have physical identities. Like most wireless networks, energy saving is always an important issue for UEs due to the limited battery capacity. Deploying relays, cell-edge UEs are able to save more power by connecting to the eNB via relays.

In this paper we study the fundamental problem of energy conservation in LTE-A uplink with Type 1 relays. We consider a resource allocation and power control problem. The objective is to minimize the total energy consumption of UEs, while guarantee their quality of service (QoS). Low power consumption is particularly important for UEs' batteries which can effectively extend their lifetime.

In the literature, much work has been done for the uplink resource allocation both in LTE and WiMAX. Reference [6] presents a set of resource allocation schemes for LTE uplink to achieve the proportional fairness of users while maintain good system throughput. However, the authors do not take relays into consideration in work. For Type 1 relay networks, [7] and [8] show how to achieve a good trade-off between system throughput and proportional fairness over in-band and out-band relay networks, respectively. But, both of them focus on the downlink resource allocation and energy conservation is not the main concern in their work. In IEEE 802.16, reference [9] defines an energy-conserved uplink resource allocation problem which aims at the minimization of energy consumption of UEs. The authors discuss the relationship between the modulation and coding schemes (MCSs) and the energy consumption of a UE and show that the UE can decrease (resp., increase) its power consumption by choosing a lower (resp., higher) level of MCS but spend more (resp., less) physical resource. Reference [10] continues and extends the energy-conserved uplink resource allocation problem in IEEE 802.16j. However, both studies [9] [10] are not valid for LTE.

So far, there is no existing work addressing the energy conservation issue in LTE-A relay networks. Unlike IEEE 802.16j multi-hop relays, LTE-A allows at most two-hop relay networks. A resource block (RB) is the smallest physical resource allocation unit in LTE-A. In this paper, we discuss the uplink energy and resource allocation problem in LTE-A relay networks with minimizing the total UEs' energy consumption as the objective while guaranteeing each UE's QoS as the constraint. Today's wireless networks are characterized by a fixed spectrum assignment policy. Reference [11] shows that the average around 60% of the spectrum remains unutilized. Thus, we can the idle spectrum to decrease the total power consumption of UEs while guarantee the QoS of streams and increase the spectrum utilization. To reduce the consumed power of UEs, we first select low level of MCS and proper uplink paths for UEs. Note that this usually leads eNB and relays allocating much more total RBs to UEs than the free resource in order to guarantee the QoS. To alleviate this problem, we then jointly adopt the spatial reuse (or concurrent transmission) and higher level of MCS to deliver more data bits with limited physical resource so as to fit the demands of UEs to the frame resource. The spatial reuse allows multiple UEs to concurrently transmit their data with less physical RBs in total and higher level of MCS effectively reduces the physical RBs of one UE. Our simulation result shows that our scheme effectively reduces the power consumption of UEs and guarantees their QoS.

The rest of this paper is organized as follows. Section II gives the preliminaries. Section III presents our proposed energy-conserved uplink resource allocation algorithm. Simulation results are shown in Section IV. Section V concludes this paper.

II. PRELIMINARIES

In this section, we first define the system model of LTE-A relay networks in our problem. Then, the energy cost model used in this paper is described. Finally, we define the energy-conserved uplink resource allocation problem in LTE-A relay networks.

A. System Model

In an LTE-A relay network, there is one base station (BS) with M fixed relay nodes (RNs) and N UEs, as shown in Fig. 1. RNs are deployed to help relay data between cell-edge UEs and BS to improve the signal quality. There is no direct communication between UEs or RNs. All UEs roam in the BS's coverage. We called the UEs transmitting data by BS "MUE" and the UE transmitting data by RN "RUE". The *backhaul links*, *access links*, and *direct links* are the links between the BS and RNs, between the RUEs and the RNs, and between the BS and MUEs, respectively. In LTE-A relay networks, the resource allocation unit is 2 consecutive RBs in time domain, called one Transmission Time Interval (TTI). One RB is a two-dimensional array (12 sub-carriers × 7 symbols), as shown in Fig. 2. There are two types of radio frame structures: *Time Division Duplex (TDD)* mode and *Frequency division duplex* (*FDD)* mode [12][13]. To simplify our problem, we focus only on the non-backhaul link uplink sub-frames. Given eNB-MUE and RN-RUE uplink requests in each non-backhaul link uplink sub-frame, this work considers how to allocate resource for the requested UEs in an energy-conserved way while guarantee their QoS.

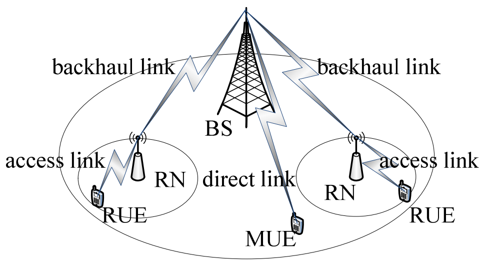

Fig. 1. The architecture of the LTE-A relay network.

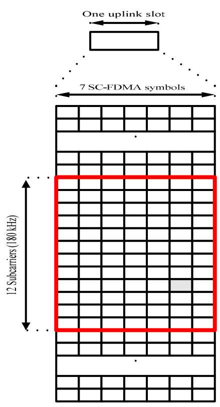

Fig. 2. A resource block..

B. Energy Cost Model

Total energy cost, E_{total}, of UE can be calculated by

$$E_{total} = \sum_{i=1}^{N} E_i \,, \tag{1}$$

where E_i is the energy cost of UE_i. The energy cost of each UE_i, i=1..N, is

$$E_i = P_i \times T_i \,, \tag{2}$$

where P_i is the required transmission power (in W) of UE_i and T_i is the amount of allocated resource (in symbol time, slot or subframe) to UE_i. The required physical resource that has to be allocated to UE_i depend on the modulation and coding rate of UE_i (MCS$_i$), and can be derived by

$$T_i = \left\lceil \frac{\delta_i}{rate(MCS_i)} \right\rceil \,, \tag{3}$$

where δ_i is the number of bits to be transmitted by UE_i and MCS_i is UE_i's MCS. Table I shows the available channel quality indicators (CQIs) in LTE-A and their rates [14]. The CQI value reports the current channel condition and the allowed best level of MCS. We use the open LTE uplink link level simulator provided in [15] to generate the uplink Bits Error Ratio (BER) and throughput performance for different CQIs and SINRs (Signal to Interference plus Noise Ratios) as shown in Fig. 3. According to the result, we can get the required SINRs for each CQI to guarantee different levels of BER. For the communication pair (i, j) (i and j are the transmitter and receiver, respectively), the perceived SINR (in dB) of receiver j can be written as

$$SINR_{i,j} = 10 \times \log_{10} \frac{P_{i,j}}{B \times N_0 + I_{i,j}} , \tag{4}$$

where $P_{i,j}$ is the received power at j, B is the effective bandwidth (in Hz), N_0 is the thermal noise level and $I_{i,j}$ is the interference from transmitters other than i which is evaluated by $I_{i,j} = \sum_{i \neq j} P_{i,j}$. Ignoring shadow and fading effect, with the power P_i for pair (i, j), the received power $P_{i,j}$ is given by

$$P_{i.j} = \frac{G_i \times G_j \times P_i}{L_{i,j}} , \tag{5}$$

where G_i and G_j are the antenna gains at UE_i and RN_j, respectively, and $L_{i,j}$ is the path loss from transmitter i (UE_i) to receiver j (RN_j or the BS). Since each CQI can uniquely identify one MCS, in the following, we use MCS (CQI=k), SINR (CQI=k) and rate (CQI=k), $k = 1,2,\cdots,15$, to represent the MCS which CQI=k identified, the required SINR of CQI=k and the rate that CQI=k can support, respectively. To save UEs' energy, we can minimize their transmission power subject to the required minimum SINR. Using MCS (CQI=k), UEs' data can be correctly decoded by receiver j only when

$$SINR_{i,j} \geq SINR(CQI = k) \,. \tag{6}$$

By integrating Eq. (4), (5) and (6), the required minimum transmission power of UE_i to reach receiver j by employing MCS (CQI=k) is

$$P_i \geq \frac{10^{\frac{SINR(CQI=k)}{10}} \times (B \times N_0 + I_{i,j}) \times L_{i,j}}{G_i \times G_j} \tag{7}$$

TABLE I. 4-BIT CQI TABLE

CQI index	*modulation*	*code rate × 1024*	*efficiency*
0	out of range		
1	QPSK	78	0.1523
2	QPSK	120	0.2344
3	QPSK	193	0.3770
4	QPSK	308	0.6016
5	QPSK	449	0.8770
6	QPSK	602	1.1758
7	16QAM	378	1.4766
8	16QAM	490	1.9141
9	16QAM	616	2.4063
10	64QAM	466	2.7305
11	64QAM	567	3.3223
12	64QAM	666	3.9023
13	64QAM	772	4.5234
14	64QAM	873	5.1152
15	64QAM	948	5.5547

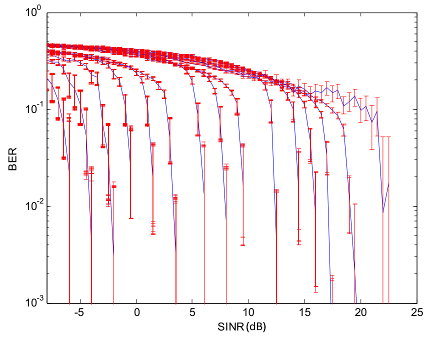

Fig. 3. Error ratio for different CQIs (the 99% confidence intervals are depicted in red.)

C. Problem Definition

Our problem is defined as follows: we assume that in the LTE-A relay network, there is one eNB, M fixed RNs and N UEs. For each UE_i, i=1..N, it has an uplink traffic demand δ_i bits per uplink subframe granted by the resource management of the BS. We assume that the relative distances between BS/RNs and UEs can be estimated through existing techniques. The objective is to minimize the total energy consumption of UEs while guarantee their traffic demands being able to be all delivered to the BS or RNs subject to the total amount of physical resource, F TTI, per non-backhaul uplink subframe. To solve the problem, we have to determine the uplink path, the resource allocation, uplink transmission power P_i and the used MCS of each UE_i.

Theorem 1 The problem is NP-complete.

Due to the space limit, we omit the proof of Theorem 1.

III. PROPOSED METHOD

Our proposed method is suitable for both TDD and FDD modes. Our heuristic consists of two phases. The first phase is that each UE tries to transmit at the minimum power by using the lowest MCS, i.e., MCS (CQI=1). If the amount of required resource of UEs exceeds F, then the second phase is executed. The second phase fits the total required RBs of UEs to the subframe space F and satisfies UE's requests by tuning the transmission power of UEs and concurrent transmission.

A. Phase I

1) There are $M+1$ candidate uplink paths for UEs, i.e., paths connect to networks via RN_j, $j=0...M$. Note that RN_0 is a special RN, which is used to represent the BS. For UE, select the RN with the best channel quality with it as the uplink path.

2) To minimize the total energy consumption $\sum_{i=1}^{N} E_i$, each UE is assigned to use the lowest MCS level of MCS, MCS (CQI=1). This leads to BS/RNs must allocate more RBs to each UE. The required amount of RBs for UE_i, $i=1...N$, can be derived by

$$T_i = \left\lceil \frac{\delta_i}{rate(CQI=1)} \right\rceil \quad , \tag{9}$$

Subsequently, the total amount of required TTIs is

$$\Omega = \sum_{i=1}^{N} \left\lceil \frac{T_i}{2} \right\rceil \quad , \tag{10}$$

3) Checking whether $\Omega \le F$ or not. If yes, terminate the algorithm and return the resource, MCS and power assignments of UEs. Otherwise, go to *Phase II*.

B. Phase II

1) To satisfy each UE's request, we first exploit the spatial reuse (or concurrent transmission) to decrease the required physical resource of UEs without changing their MCSs. UEs in the same concurrent transmission group all connect to different RNs and use the same RBs to transmit data, thus reducing the total required RBs, i.e., $\max\{T_i | \forall i \in g_k\}$, where g_k is the concurrent transmission group. Considering the UEs in the same group will interfere each other. Then each UE in g_k has to increase its transmission power to guarantee the target BER. This will rise the energy consumption of UEs. To alleviate this problem, we define a weight function to select UEs with the least degree of inter-interference to form concurrent transmission group.

2) For each UE_i (with RN_j as its uplink path), calculate its weight (W_i), $i=1..N$, which can be expressed by

$$W_i = \alpha \times \frac{(d_{i,j})^{-\omega}}{(\min\{d_{l,j} | I_{l,j} \ne 0\}, l=1...N)^{-\omega}} + \beta \times \frac{\delta_i}{\max_{l=1...N}\{\delta_l | I_{l,j} \ne 0\}}$$
$$+(-\gamma) \times \sum \frac{(d_{i,v})^{-\omega}}{(\min\{d_{l,v} | I_{l,v} \ne 0\}, l=1...N)^{-\omega}} \forall v, v \ne j, \tag{11}$$

where α, β and γ are the normalized coefficients, and α+β-γ=1. $d_{i,j}$ is the distance between UE_i and RN_j, ω is the spreading factor and indicator $I_{l,j}$=1 if RN_j is UE_l's uplink path; otherwise, $I_{l,j}$=0. W_i involves three factors with different important ratios, α, β, and γ. A relatively shorter distance to the uplink RN_j gives UE_i a larger weight. Then, a relatively larger request under the same RN_j gives UE_i a larger weight, thus reducing more required physical resource. The last factor gets a larger value when UE_i seriously interferes other RNs expect RN_j. So it is a negative factor to the weight W_i.

3) For each RN_j, $j=1..M$, choose one ungrouped UE with the maximum weight in all UEs connecting to RN_j to join the concurrent transmission group to do spatial reuse. Then, calculate the required transmission power P_i of each UE_i in the concurrent transmission group which has to guarantee the original BER. Check whether $\Omega \le F$ or not. If yes, terminate the algorithm and return the resource allocation results; otherwise, go to next step.

4) Check whether there is only one UE in the above derived concurrent transmission group; otherwise, go back to Step 3).

5) For the remaining UEs who are ungrouped in any concurrent transmission group, form a concurrent transmission group for each of them. That is, in these groups, there is only one UE.

6) To fit Ω to the subframe space F, we consider to increase the level of some groups' MCS such that the total required physical resource can be decreased. For each group k, $k=1...K$ (we assume there are totally K groups), calculate the energy consumption and the number of required RBs using different level of MCSs, MCS(CQI=1)…MCS(CQI=15). Define a reward function $f_R(k, x, y)$ to calculate the reward of group k tuning its MCS from a low level MCS(CQI=x) to a high level MCS(CQI=y). We define the reward function as

$$f_R(k,x,y) = \frac{\Delta E_{x,y}^k}{\Delta A_{x,y}^k} = \frac{E_y^k - E_x^k}{A_x^k - A_y^k}, \quad (12)$$

where E_y^k and E_x^k are the total amount of energy consumption of group k using MCS(CQI=y) and MCS(CQI=x), respectively. A_x^k and A_y^k are the number of required RBs of group k adopting MCS(CQI=x) and MCS(CQI=y), respectively. For all groups, we calculate the rewards for all possible MCS level increment. For example, if group k's current MCS level MCS(CQI=x), we'll compute the rewards from MCS(CQI=x) to MCS(CQI=y), y=(x+1)..15.

7) For all derived rewards, select the minimum $f_R(k^*,x^*,y^*)$ to change the group k^*'s MCS from MCS(CQI=x^*) to MCS(CQI=y^*) and then update the required physical resource of group k^*. Check whether the new $\Omega \le F$ or not. If yes, stop the algorithm and return the results. Otherwise, reculcate the rewards of group k^* for all possible MCS level increment, i.e., $f_R(k^*,y^*,z)$, z=(y^*+1)..15, and repeat Step 7).

IV. Simulation Results

In this section, we develop a simulator in Matlab to verify the effectiveness of our heuristics. The system parameters in our simulation are listed in Table II [16]. We consider three types of traffic: Audio, Video and Data [17]. The network contains one BS and several RNs and UEs. RNs are uniformly deployed inside the 2/3 coverage range of the BS to get the best performance gain.

TABLE II. The parameters in our simulation

parameter	Value
Channel bandwidth	10MHz
Inter-site distance (ISD)	500m (case1)
eNB maximum antenna gain	14 dBi
RN maximum antenna gain	5 dBi
UE maximum transmit power	23 dBm
UE maximum antenna gain	0 dBi
thermal noise	-174 dBm
Traffic	Audio: 4-25 kb/s Video: 32-384 kb/s Data:60-384 kb/s
Channel model	**eNB-UE** $L_{LOS}(R)$= *103.4+24.2log10(R)* $L_{NLOS}(R)$= *131.1+42.8log10(R)* *Prob(R)=min(0.018/R,1)* × *(1-exp(-R/0.063))+exp(-R/0.063)* **eNB-RN** $L_{LOS}(R)$=*100.7+23.5log10(R)* $L_{NLOS}(R)$= *125.2+36.3log10(R)* *Prob(R)=min(0.018/R,1)* × *(1-exp(-R/0.072))+exp(-R/0.072)* **RN-UE** $L_{LOS}(R)$=*103.8+20.9log10(R)* $L_{NLOS}(R)$=*145.4+37.5log10(R)* *Prob(R)=0.5-min(0.5,5exp(-0.156/R))+min(0.5, 5exp(-R/0.03))* ***L(R)= L_{LOS}(R)* × *Prob(R)+(1-Prob(R))* × *L_{NLOS}(R)*** *R* : distance in kilometers

We first evaluate the total energy consumption of UEs under different number of UEs as shown in Fig. 4. We compare the three algorithms: our proposed method, our proposed method without spatial reuse and connecting only BS method. We can see that the number of UEs increases, the total energy consumption of our algorithm does not obviously increased compared to other schemes and our method performs the best in all schemes. Fig. 5 shows the total energy consumption of UEs under different number of RNs. We can see that as the number of RNs increases, the total energy consumption for our algorithm with/without spatial reuse both decrease. It shows that deploying more RNs helps energy conservation. In all three methods, our scheme performs the best.

Then, we evaluate the total energy consumption of UEs under different ratio (β/α) as shown in Fig. 6. Fig. 6 presents that as the ratio β/α increases, the total energy consumption is decreased. It means that factor 1($[d_{l,j}/(min\{d_{l,j}|I_{l,j}\neq 0\},l=1..N)]^{-\omega}$) and factor 2 (δ_i / $(max\ \{\delta_l \mid I_{i,j} \neq 0\},\ l=1..N)$) have equal importance for weight w_i. Distance to connected RN and the size of request are significant factors for energy conservation when choosing reuse group.

Finally, we evaluate the total energy consumption of UEs under different data request distribution of UEs per frame as shown in Fig. 7. When the data request distribution of UEs more concentrating, the total energy consumption is small. This is because of spatial reuse increases when the request size of UEs in the same group increases, i.e., reducing the most required physical resource when all UEs in the same group have the same data request.

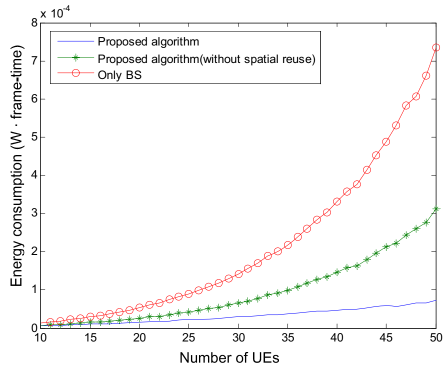

Fig. 4. The impact of number of UEs on the total energy consumption.

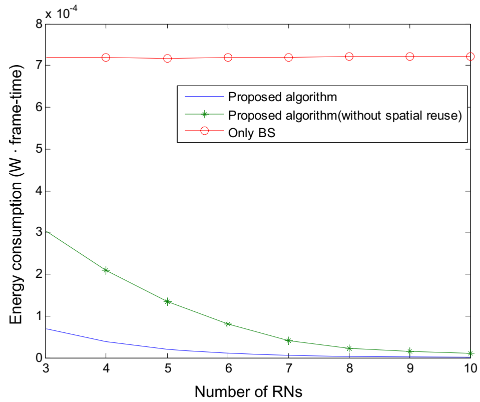

Fig. 5. The impact of number of RNs on the total energy consumption.

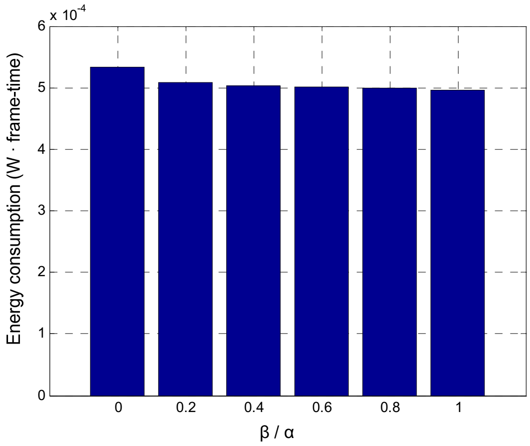

Fig. 6. The impact of (β/α) on the total energy consumption.

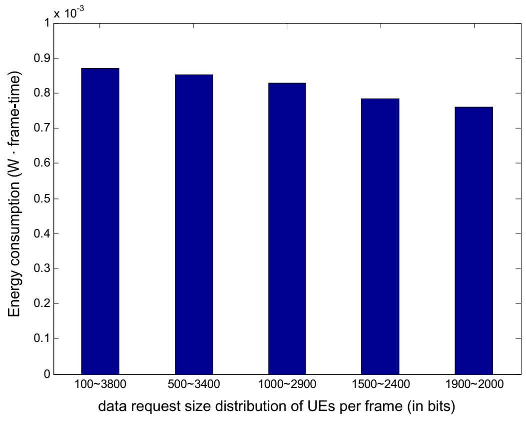

Fig. 7. The impact of the data request distribution of each UE on the total energy consumption.

V. Conclusion

In this paper, we investigate the energy conservation issue of the uplink resource and power allocation in LET-A relay networks. We have proposed heuristics to conserve UEs' energy by lowering down their MCS level and using spatial reuse. To save energy, the key factors are how to determine the best MCSs of UEs and how to select UEs form spatial reuse. To find the best settings of the two factors, we have defined the reward and the weight calculation functions for evaluation. Simulation results show that our proposed scheme significantly reduced the total energy consumption of UEs compared to other schemes.

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