Design a Cross-layer Uplink Green Resource and Power Allocation Method over LTE-A Relay Network

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摘要

在 LTE-A 的架構中，中繼式節點被提出來可以增強基地台的覆蓋率、節省行動裝置的耗電量、提供高速的資料傳輸並解決通訊空洞問題。然而，對使用者來說，LTE-A 使用高的傳輸資料速率將產生更多的能源損耗，尤其行動裝置是由電池供電的，續航力對裝置而言非常重要。在本文中，我們考慮如何在 LTE-A 中繼式網路架構中妥善分配上行資源和安排手機傳輸功率。我們的目標是在保證服務品質的情形下，使得所有的使用者裝置(User Equipments, UEs)所消耗的總能量最少。我們證明這是一個 NP-complete 問題，所以我們提出一個有效率的方法來解決這個問題。模擬結果顯示我們的方法能有效減少使用者裝置的電量消耗並保證他們的服務品質。

關鍵詞：進階長期演進技術、能源效率、資源分配、中繼式網路、綠能通訊。

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 relay networks. The objective is to minimize the total energy consumption of UEs while guarantee their quality of services (QoSs). We prove that this uplink resource and power allocation problem to be NP-complete and we develop a method to solve the problem. Simulation results show that our algorithm can effectively reduce the energy consumption and guarant ee users' service quality.

Keywords: LTE-A, energy efficiency, resource allocation, relay networks, green communications.

Introduction

In recent several years, the third 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 (SC-FDMA) technique to reduce the Peak-to-Average Power Ratio (PARR) [4].

Relay is one of the key features in LTE-A, where relays can enhance the coverage of high data rates, increase the throughput of cell-edge users and solve the coverage hole problem. Two types of relays are introduced in the LTE-A [5]. Type I relays act like Evolved Node Bs (eNBs) to the attached User Equipments (UEs) and have their own physical identities. On the contrary, Type II 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 battery capacity restriction. 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 energy

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conservation problem in LTE-A uplink with Type I 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/LTE-A and WiMAX. Reference [6] proposes the optimal SC-FDMA resource allocation algorithm based on a pure binary-integer program called the set partitioning problem to maximize the total user-weighted system capacity. Reference [7] presents a set of resource allocation schemes for LTE uplink to achieve the proportional fairness of users while maintain good system throughput. However, both works [6] [7] do not take relays into consideration. For Type I relay networks, [8] and [9] show how to achieve a good trade-off between system throughput and global proportional fairness over in-band and out-band relay networks, respectively. But, both of them focus on the downlink resource allocation and the energy conservation is not the concern of the studies. Considering relay backhaul subframe allocation for TDD-LTE networks, reference [10] shows how to design and enhance existing TDD systems to support TDD-LTE relay system for all seven downlink-uplink configurations and balance the backward compatibility, performance, and system complexity. In IEEE 802.16, reference [11] defines a 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. The study shows 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 [12] continues and extends the energy-conserved resource allocation problem in IEEE 802.16j. However, both studies [11] [12] are not valid for LTE/LTE-A. Reference [13] examines the effect of Physical Resource Block (PRB) allocation on LTE UE 's uplink transmission power and energy consumption. Simulation results show that, for each subframe, to allocate as many PRBs as possible to a single user is more energy efficient than sharing PRBs among several users. In reference [14], to improve the energy efficiency, user terminals cooperate with each other in transmitting their data packets to the base station (BS) by exploiting multi-types of wireless interfaces. To be specific, when two UEs are close to each other, they first exchange their data with short range communication interfaces. Once the negotiation is done, they share the antennas to transmit their data to BS by employing distributed space-time coding. Reference [15] proposes a framework for power efficient resource allocation in multi-user, multiservice, LTE uplink systems. A low complexity iterative approach to solve the problem subject to rate, delay, contiguous allocation, and maximum transmitted power constraints is presented. Reference [16] proposes an energy efficient Medium Access Control (MAC) scheme for multiuser LTE downlink transmission, which utilizes the multiuser gain of the MIMO channel and the multiplexing gain of the multibeam opportunistic beamforming technique.

So far, there is no existing work addressing the uplink energy conservation issue in LTE-A relay networks. Unlike IEEE 802.16j multi-hop relays, LTE-A allows at most two-hop relay networks. In this paper we discuss the uplink energy and resource allocation problem in LTE-A relay networks with minimizing the total UE's 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 [17] shows that the average around 60% of the spectrum remains unutilized. This motivates us to exploit the idle spectrum to decrease the power consumption of UEs and thus increase the spectrum utilization and UEs' battery life time. To reduce the consumed energy of UEs, our proposed scheme first selects low level of MCS and proper uplink paths for UEs. Note that this usually leads eNB and relays allocating much more physical resource 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 the same quantity of data with limited physical free 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 Resource Blocks (RBs) in total and higher level of MCS effectively reduces the required physical RBs of one UE. Note that in order to be compliant to the standard, the resource allocation of eNB-UE, RN-UE, eNB-RN links must follow the LTE-A subframe configuration. Simulation results show that our scheme effectively reduces the power consumption of UEs while guarantees their QoS.

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 and prove it to be NP-complete.

A. System Model

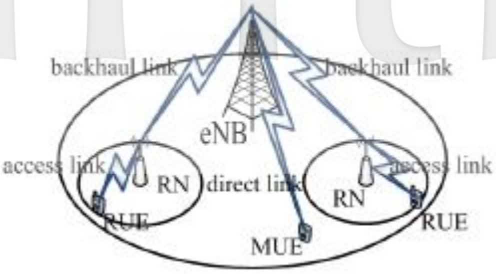

Fig. 1 The architecture of the LTE-A relay network.

In a LTE-A relay network, there is one eNB 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 eNB to improve the signal quality. There is no direct communication between UEs or RNs. All UEs roam in the eNB's coverage. We call the UEs transmitting data by eNB "MUE" and the UE transmitting data by RN "RUE". The *backhaul links*, *access links* and *direct links* are the links between the eNB and RNs, between the RUEs and the RNs and between the eNB and MUEs, respectively.

B. Energy Cost Model

Total energy cost, E_{total}, of UEs 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

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

where P_i is the transmission power (in mW) 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 scheme UE_i (denoted by $\mathrm{MCS_i}$) 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. LTE-A uses Channel Quality Indicators (CQIs) to report the current channel condition and each *CQI=k*, *k=1..15*, has its corresponding MCS (denoted by *MCS(CQI=k)*) and rate (denoted by *rate(CQI=k)*) as shown in Table V [21].

To derive the required Signal to Interference plus Noise Ratios (SINR) of each CQI, we use the open LTE uplink link level simulator provided in [22] to observe the effect of SINR on the uplink Bits Error Ratio (BER) for different CQIs as shown in Fig. 4. 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

$$\mathrm{SINR_{i,j}} = 10 \times log_{10} \frac{\mathrm{P_{i,j}}}{\mathrm{B} \times \mathrm{N}_0 + \mathrm{I_{i,j}}} \,, \tag{4}$$

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 can be evaluated by $\mathrm{I_{i,j}} = \sum_{\mathrm{i \neq j}} \mathrm{P_{i,j}}$. Ignoring shadow and fading effect, with the transmission 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 eNB). 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..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

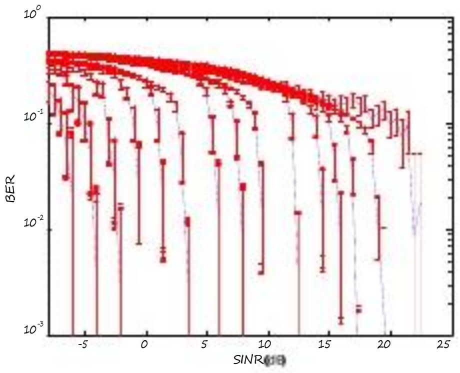

Fig. 2. Error ratio for different CQIs (the 99% confidence intervals are depicted in red).

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, which is to 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 employing concurrent transmission.

A. Phase I

Step 1) There are *M*+1 candidate uplink paths for UEs, i.e., paths connect to networks via RN_j, $j=0\ldots M$. 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.

Step 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, $i=1\ldots N$, can be derived by

$$T_i = \left\lceil \frac{\delta_i}{rate(CQI=1)} \right\rceil \tag{8}$$

Subsequently, the total amount of required TTIs is

$$\Omega = \sum_{i=1}^{N} \left\lceil \frac{T_i}{2} \right\rceil \tag{9}$$

Step 3) Checking whether $\Omega \leq F$ 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

Step 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,

current 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.

Step 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

$$W_i=\alpha\times\frac{(d_{i,j})^{-\omega}}{(\min_{l=1..N}\{d_{l,j}\,|\,I_{l,j}\neq 0\})^{-\omega}}+\beta\times\frac{\delta_i}{\max_{l=1...N}\{\delta_l\,|\,I_{l,j}\neq 0\}}+(-\gamma)\times(1+\Delta\times t_i)\times\sum_{\forall v,v\neq j}\frac{(d_{i,v})^{-\omega}}{(\min_{l=1..N}\{d_{l,v}\,|\,I_{l,v}\neq 0\})^{-\omega}},\qquad(10)$$

where α, β and γ are the normalized coefficients and $\alpha+\beta-\gamma=1$, $d_{i,j}$ 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 demand request under the same RN_j also gives UE_i a larger weight, thus reducing more required physical resource. The last factor gets a larger value when UE_i seriously interferes with other RNs except RN_j. So it is a negative factor to the weight W_i. t_i denotes the amount of times that UE_i has been excluded from concurrent transmission groups (the exclusion operation will be described in the next step) and $\triangle$ is the normalized coefficient. When the value of t_i gets larger, it means that UE_i is unsuitable for concurrent transmission with other UEs due to the serious interference.

Step 3) For each RN_j, j=1..M, choose one ungrouped UE with the maximum weight in all UEs connecting to RN_j to form the concurrent transmission group g_k to do spatial reuse. Next, calculate the required transmission power P_i' of each UE_i in g_k which has to guarantee the original BER. Then, check if the summation of the transmission power of all UEs in g_k, i.e., $\sum_{UE_i\in g_k}P_i'$, is greater than the power threshold $P_{kthreshold}$. Note that we set $P_{kthreshold}$ to the summation of the required transmission power of all UEs in g_k when concurrent transmission is not used and the same number of TTIs is consumed as the case of concurrent transmission. If yes, mean that some communication pairs suffer great interference from other UEs. In this case, the *Exclusion operation* will execute to repeatedly remove the most interfered UEs from g_k until the above condition is relieved. Then check whether $\Omega\leq F$ or not. If yes, terminate the algorithm and return the resource allocation results; otherwise, go to next step.

Step 4) Check whether there is only one UE in the above derived concurrent transmission group. If yes, stop grouping UEs into groups and go to Step 5); otherwise, go back to Step 3).

Step 5) For the remaining UEs who are not in any concurrent transmission group, form a concurrent transmission group for each of them. That is, in these groups, there is only one UE.

Step 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 g_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 for each UE in group k (for each UE, there are totally 15 different level of MCSs, i.e., *MCS*(*CQI*=1)..*MCS*(*CQI*=15), it can use). Define a reward function $f_R(k, x, y)$ to calculate the reward of group k tuning its CQI from a low level x to a high level y, where x and y are vectors of CQIs which represent the CQIs that the UEs in group k use. We define the reward function as

$$f_R(k,x,y)=\frac{\Delta E^k_{x,y}}{\Delta A^k_{x,y}}=\frac{E^k_y-E^k_x}{A^k_x-A^k_y},\qquad(11)$$

where E^k_y and E^k_x are the total amount of energy consumption of group g_k using *MCS*(*CQI*=*y*) and *MCS*(*CQI*=*x*), respectively, A^k_x and A^k_y 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 there are 3 UEs in group k and group g_k's current MCS level is *MCS*(*CQI*=*x*), where x=(1,3,2), we'll compute the rewards from *MCS*(*CQI*=*x*) to *MCS*(*CQI*=*y*), y=(2..15, 4..15, 3..15).

Step 7) For all derived rewards, select the minimum $f_R\left(k^{*},x^{*},y^{*}\right)$ to change the group g_{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 $\Omega\leq F$ or not. If yes, stop the algorithm and return the results; otherwise, reculcate the rewards of group k^* for all possible MCS level increment. For example, if there are s UEs in group k^*, reward $f_R\left(k^*,y^*,z\right)$ is calculated, where z is a vector of CQIs and z=((y_1+1)..15, (y_2+1)..15, ..., (y_s+1)..15). Then, repeat Step 7).

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 [20]. We consider three types of traffic:

Audio, Video and Data [21]. The traffic case applied in the simulation is mixed traffic, where each UE executes an audio, video, or data flow with equal probability. The network contains one eNB and several RNs and UEs. RNs are uniformly deployed inside the 2/3 coverage range of the eNB to get the best performance gain. In default, we set the factor α, β, and γ to 1 and adopt TDD mode uplink-downlink configuration 1, i.e., there are 4 uplink subframes per frame. The ratio of uplink backhaul subframe and uplink non-backhaul subframe is 3:1, unless otherwise stated. We compare the performance of five mehods (including ours): (1) *BS(no ps)*, UEs directly connect with the central eNB and no power-saving algorithm is executed; (2) *BS+relays(no ps)*, UEs select to connect with the eNB or RNs according to the SINR and no power-saving algorithm is executed; (3) *BS(with ps)*, UEs directly connect with the eNB and execute our power-saving algorithm without spatial reuse; (4) *one-time reuse(with ps)*, this is our proposed method, but the 2nd time concurrent transmission group grouping algorithm is not executed; (5) *two-time reuse(with ps)*, this is our proposed method including the 2nd time concurrent transmission group grouping algorithm.

Table II The parameters in our simulation

parameter	***value***
Channel bandwidth	10MHz
Inter-site distance (ISD)	500m (case1)
Channel model	$L(R) = PL_{LOS}(R) \times Prob(R) + (1- Prob(R)) \times PL_{NLOS}(R)$ *R : distance in kilometers* *eNB-UE* $PL_{LOS}(R) = 103.4 + 24.2\log10(R)$ $PL_{NLOS}(R) = 131.1 + 42.8\log10(R)$ $Prob(R) = \min(0.018/R,1) \times (1-\exp(-R/0.063)) + \exp(-R/0.063)$ *RN-UE* $PL_{LOS}(R) = 103.8 + 20.9\log10(R)$ $PL_{NLOS}(R) = 145.4 + 37.5\log10(R)$ $Prob(R) = 0.5 - \min(0.5, 5\exp(-0.156/R)) + \min(0.5,5\exp(-R/0.03))$
eNB maximum transmit power	30 dBm
eNB maximum antenna gain	14 dBi
RN maximum transmit power	30 dBm
RN maximum antenna gain	5 dBi
UE maximum transmit power	23 dBm
UE maximum antenna gain	0 dBi
thermal noise	-174dBm
Traffic	Audio: 4-25 k bits/s Video: 32-384 k bits/s Data: 60-384 k bits/s

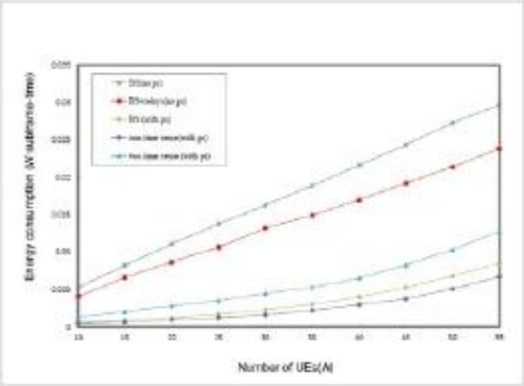

Fig. 3. The impact of N on the total energy consumption (M = 6).

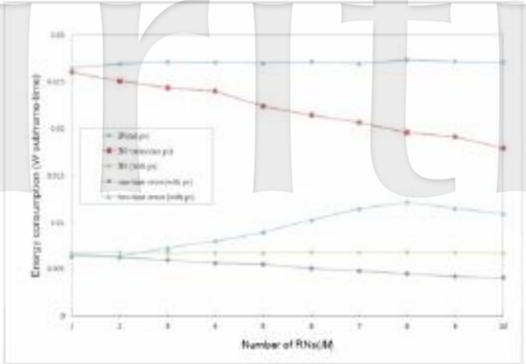

Fig. 4. The impact of *M* on the total energy consumption (*N* = 50).

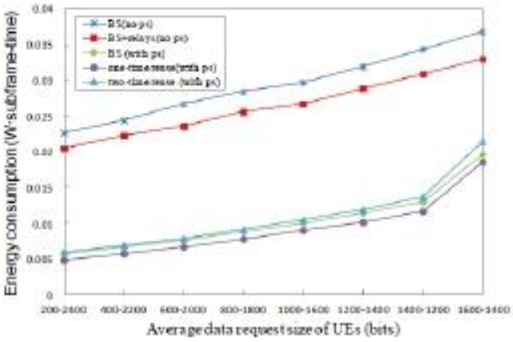

Fig. 5. The impact of average data request size of UEs on the total energy consumption (*N* = 50 and *M* = 3).

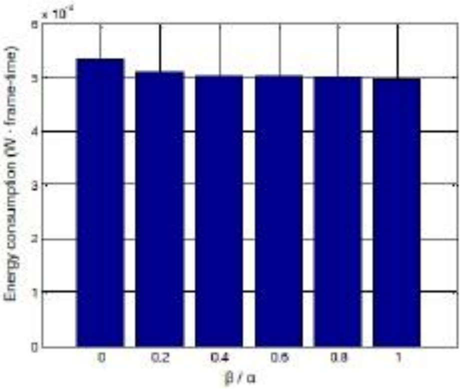

Fig. 6. The impact of β/α on the total energy consumption (*N* = 40 and *M* = 3).

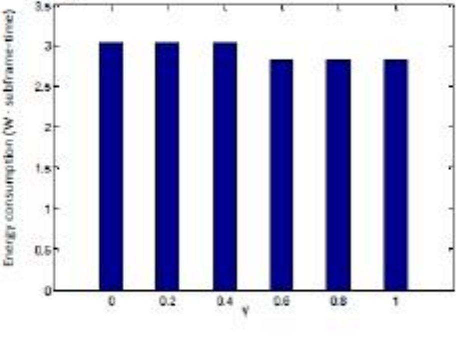

Fig. 7. The impact of γ on the total energy consumption where β=α=1 (*N* = 50 and *M* = 3).

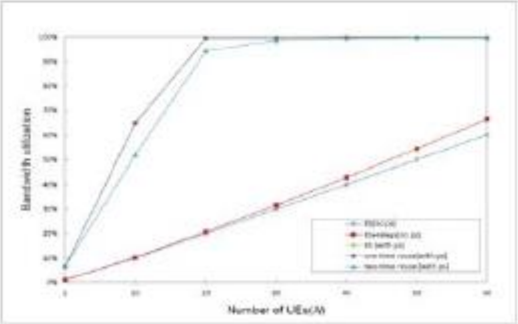

Fig. 8. The impact of *N* on the bandwidth utilization (*M* = 6).

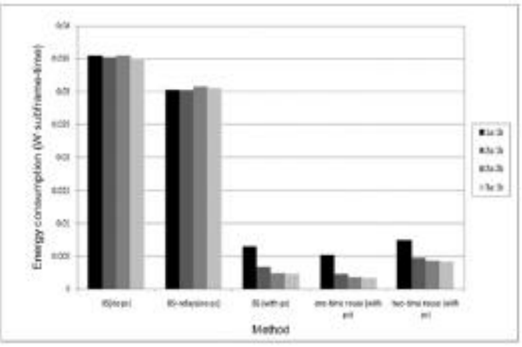

Fig. 9. The impact of subframe configurations on the total energy consumption (*N* = 35 and *M* = 6).

Conclusions

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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