Energy-Efficient Uplink Radio Resource Management in LTE-Advanced Relay Networks for Internet of Things

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***Abstract*—For M2M (Machine-to-Machine) machines in cellular networks, employing high transmission rates or transmitting in large power actually cost them much energy. This is harmful to the machines, especially they are operated by batteries. 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. Considering the limited energy nature of machines, connecting to the RN instead of the BS is a better choice for cell-edge machines. 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 machines while guarantee their quality of service (QoS). We prove this uplink resource and power allocation problem to be NP-complete and develop an energy-conserved resource and power allocation method to solve the problem. Simulation results show that our algorithm can effectively reduce the energy consumption of machines and guarantee their required service qualities.**

Keywords—LTE-A; machine-to-machine (M2M); Internet of Things (IoT); energy efficiency; resource allocation; relay networks.

I. INTRODUCTION

Internet of Things (IoT) is an idea to integrate numerous devices and machines with the Internet. For IoT applications, such as video surveillance [1] and smart meters [2], devices need to report various events and streaming data to a central server over a long period of time in an efficient and robust way. Thus, the 3rd Generation Partnership Project (3GPP) Long-Term Evolution-Advanced (LTE-A) is the most promising technology for IoT applications.

In recent years, 3GPP proposes LTE [3][4] and LTE-A [5] 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) [6].

Since machines are with limited energy and powered by batteries, connecting to the BS through a direct link and delivering data with full power are not a good choice, especially for the cell-edge machines. Relay is one of the key features in LTE-A [5], where relays can enhance the coverage of high data rates, increase the throughput of cell-edge devices and solve the coverage hole problems. Two types of relays are introduced in the LTE-A [7]. 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 do not have physical identities. Energy saving is always an important issue for machines due to the limited battery capacity. Deploying relays, cell-edge machines are able to save more power by connecting to the eNB via relays.

In this paper we study the energy conservation problem 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 machines, while guarantee their quality of service (QoS). Low power consumption is particularly important for machines' 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 [8]. Reference [9] presents a set of resource allocation schemes for LTE uplink to achieve proportional fairness of devices while maintain good system throughput. However, the authors do not take relays into consideration. For Type 1 relay networks, [10] and [11] 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 IEEE 802.16, reference [12] defines an energy-conserved uplink resource allocation problem which aims at the minimization of energy consumption of devices. The authors discuss the relationship between the modulation and coding schemes (MCSs) and the energy consumption of a device and show that the device can decrease (resp., increase) its power consumption by choosing a lower (resp., higher) level of MCS but spend more (resp., less) physical resource. Reference [13] continues and extends the energy-conserved uplink resource allocation problem in [12] for IEEE 802.16j relay networks [14]. However, both studies [12][13] 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. Moreover, LTE-A employs SC-FDMA in the uplink direction. In this paper, we discuss the uplink energy and resource allocation problem in LTE-A relay networks with minimizing the total devices' energy consumption as the objective while guaranteeing each machine's QoS as the constraint. Today's wireless networks are characterized by a fixed spectrum assignment policy. Reference [15] 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 machines and thus increase the spectrum utilization. To reduce the consumed energy of machines, we first select low level of MCS and proper uplink paths for machines. Note that this usually leads eNB and relays allocating much more RBs to machines 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 machines to the frame resource. The spatial reuse allows multiple machines to concurrently transmit their data with less physical RBs in total and higher level of MCS effectively reduces the required physical RBs of one machine. Simulation results show that our scheme effectively reduces the power consumption of machines while guarantees the required QoS of IoT applications.

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 introduce the system model of LTE-A relay networks; then, describe the energy cost model used in this paper. Finally, a formal definition of the energy-conserved uplink resource allocation problem in LTE-A relay networks is given and we will show that the problem is NP-complete.

A. System Model of the LTE-A Relay Network

In an LTE-A relay network, we assume that each base station (BS) is with M fixed relay nodes (RNs) and N machines, as shown in Fig. 1. RNs are deployed to help relay data between cell-edge machines and BS to improve the signal quality. There is no direct communication between machines or RNs. We call the machines transmitting data by BS "MME" and the machine transmitting data by RN "RME". The backhaul links, access links and direct links are the links between the BS and RNs, between the RMEs and the RNs and between the BS and MMEs, respectively. In LTE-A relay networks, the carrier resource is divided into frames in the time domain, each of which is 10 ms in length. A frame consists of 10 subframes and each subframe is further divided into 2 equal slots, each of which is 0.5 ms in length. In the frequency domain, the carrier resource is partitioned into sub-carriers, each sub-carrier is 15KHz in bandwidth. In LTE-A, the resource allocation unit is 2 consecutive RBs in time domain, called one Transmission Time Interval (TTI). One RB

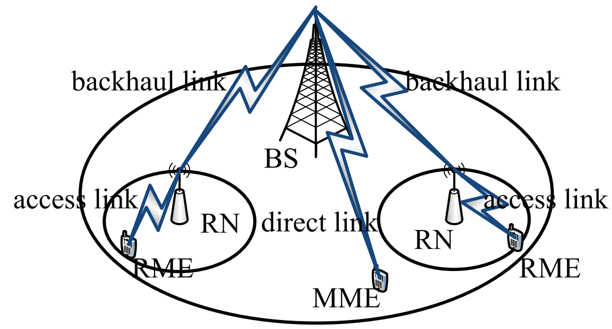

Fig. 1. The architecture of the LTE-A relay network.

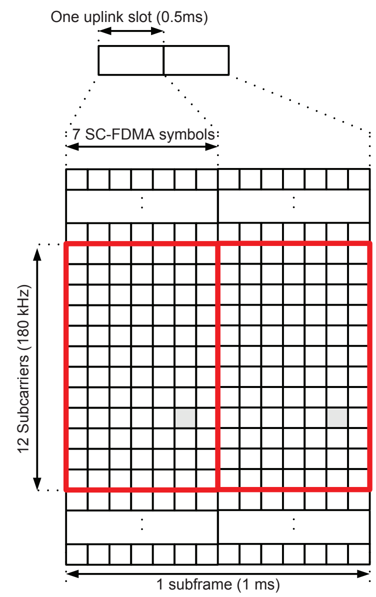

Fig. 2. A resource block.

is a two-dimensional array (12 sub-carriers 7 symbols), as shown in Fig. 2. There are two types of radio frame structures: Frequency division duplex (FDD) mode and Time Division Duplex (TDD) mode [16][17]. In FDD mode, downlink and uplink directions operate at different carrier frequencies; while in TDD mode, the two directions share single carrier frequency but use different subframes.

To simplify our problem, we focus only on the non-backhaul link uplink sub-frames. Given eNB-MME and RN-RME uplink requests in each non-backhaul link uplink sub-frame, this work consider how to energy-conserved allocate resource for the requested MEs and guarantee their QoS.

B. Energy Cost Model

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

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

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

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

where P_i is the transmission power (in mW) of ME_i and T_i is the amount of allocated resource (in symbol time, slot or subframe) to ME_i. The required physical resource that has to be allocated to ME_i depend on the modulation and coding scheme ME_i used (denoted by MCS_i) and can be derived by

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

where δ_i is the number of bits to be transmitted by ME_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 $rate(CQI = k)$) [18]. 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 [19] to observe the effect of SINR on the uplink Bits Error Ratio (BER) for different CQIs. 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

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

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 $I_{i,j} = \sum_{i \neq j} P_{i,j}$. Ignoring shadow and fading effect, with the transmission power P_i for pair (i, j), the received power $P_{i,j}$ is given by

$$P_{i,j} = \frac{G_i \times G_j \times P_i}{L_{i,j}}, \quad (5)$$

where G_i and G_j are the antenna gains at ME_i and RN_j, respectively, and $L_{i,j}$ is the path loss from transmitter i (ME_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 $rate(CQI = k)$, $k = 1..15$, 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 MEs' energy, we can minimize their transmission power subject to the required minimum SINR. Using $MCS(CQI = k)$, MEs' data can be correctly decoded by receiver j only when

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

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

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

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 MEs. For each ME_i, $i = 1..N$, it has an average uplink traffic demand δ_i bits per uplink non-backhaul link subframe granted by the resource management of the BS. We assume that the relative distances between BS/RNs and MEs can be estimated through existing techniques. The objective is to minimize the total energy consumption of MEs while guarantee their traffic demands being all delivered to the BS or RNs subject to the total amount of physical resource, F TTI, per non-backhaul link 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 ME_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 ME tries to transmit at the minimum power by using the lowest MCS, i.e., $MCS(CQI = 1)$. If the amount of required resource of MEs exceeds the total amount of radio resource F, then the second phase is executed. The second phase is to fits the total required TTIs of MEs to the subframe space F and satisfies ME's requests by tuning the transmission power of MEs and employing concurrent transmission. The details of phase I and II are illustrated in the following subsecions.

A. Phase I

1) There are $M + 1$ candidate uplink paths for MEs, 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 each ME, we select the RN with the best channel quality with it as the uplink path.

2) To minimize the total energy consumption , each ME is assigned to use the lowest MCS level, i.e., $MCS(CQI = 1)$. This leads to the BS/RNs allocate large amount of RBs to each ME. The required amount of RBs for ME_i, $i = 1..N$, can be derived by

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

Subsequently, the total amount of required TTIs is

$$\Omega = \Sigma_{i=1}^{N} \left\lceil \frac{T_i}{2} \right\rceil. \quad (9)$$

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

B. Phase II

1) To satisfy each ME's request, we first exploit the spatial reuse (or concurrent transmission) to decrease the required physical resource of MEs without changing their MCSs. MEs 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., $\max \{T_i \mid \forall i \in g_k\}$, where g_k represents the k_th concurrent transmission group. Considering the MEs in the same concurrent transmission group will interfere each other, each ME in g_k has to increase its transmission power to guarantee the target BER. However, this will rise the energy consumption of MEs. To alleviate this problem, we define a weight function and form a concurrent transmission group by selecting MEs accordingly. For each

ME_i (with RN_j as its uplink path), the weight (W_i), $i = 1..N$, can be expressed by

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

where α, β and γ are the normalized coefficients, and $\alpha + \beta - \gamma = 1$. $d_{i,j}$ is the distance between ME_i and RN_j, ω is the spreading factor and indicator $I_{l,j} = 1$ if RN_j is ME_l's uplink path; otherwise, $I_{l,j} = 0$. W_i involves three factors with different important ratios, α, β and γ. The first factor gives the ME_i with relatively shorter distance to its uplink RN_j a larger weight. Then, the second factor allocates a larger weight to the ME_i which is of a larger request compared to the MEs served by the same uplink RN_j, thus increasing the radio resource utilization. The last factor gets a larger value when ME_i seriously interferes other RNs except RN_j. So it is a negative factor to the weight W_i.

2) For each RN_j, $j = 0..M$, choose one ungrouped ME with the maximum weight from all MEs connecting to RN_j. Then, these $M+1$ MEs form a concurrent transmission group g_k. To guarantee the original BER, recalculate the transmission power P_i of each $ME_i \in g_k$. Update Ω accordingly and check whether $\Omega \leq F$ or not. If yes, terminate the algorithm and return the resource allocation results; otherwise, go to next step.

3) If $|g_k| \leq 1$, go to next step; otherwise, go back to Step 2).

4) For the remaining MEs 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 ME.

5) To fit Ω to the subframe space F, we consider to increase some concurrent transmission groups' MCS levels 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 employing different level of MCSs, $MCS(CQI = 1)..MCS(CQI = 15)$. We define a reward function $f_R(k, x, y)$ to calculate the reward of group k by tuning its MCS from a low level $MCS(CQI = x)$ to a high level $MCS(CQI = y)$, i.e., $y > x$. The reward function is defined as

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

where E^k_y and E^k_x are the total amount of energy consumption of group k applying $MCS(CQI = y)$ 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 group k's current MCS level is $MCS(CQI = x)$, we'll compute the rewards $f_R(k, x, y)$, y=(x+1)..15.

TABLE I. THE PARAMETERS IN OUR SIMULATION

Parameter	Value
Channel bandwidth	10 MHz
eNB maximum antenna gain	14 dBi
RN maximum antenna gain	5 dBi
ME maximum transmit power	23 dBm
ME 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	$L(R) = L_{LOS}(R) \times Prob(R) +$ $(1 - Prob(R)) \times L_{NLOS}(R)$ **eNB-ME** $L_{LOS}(R) = 103.4 + 24.2\log(R)$ $L_{NLOS}(R) = 131.1 + 42.8\log(R)$ $Prob(R) = \min\{0.018/R, 1\} \times$ $(1 - \exp(-R/0.063)) + \exp(-R/0.063)$ **eNB-RN** $L_{LOS}(R) = 100.7 + 23.5\log(R)$ $L_{NLOS}(R) = 125.2 + 36.3\log(R)$ $Prob(R) = \min\{0.018/R, 1\} \times$ $(1 - \exp(-R/0.072)) + \exp(-R/0.072)$ **RN-ME** $L_{LOS}(R) = 103.8 + 20.9\log(R)$ $L_{NLOS}(R) = 145.4 + 37.5\log(R)$ $Prob(R) = 0.5 - \min\{0.5, 5\exp(-0.156/R)\}$ $+ \min\{0.5, 5\exp(-R/0.03)\}$ R: distance in kilometers

6) For all derived rewards, select the minimum $f_R(k^*, x^*, y^*)$ to upgrade the group k^*'s MCS from $MCS(CQI = x^*)$ to $MCS(CQI = y^*)$. Then, update the required physical resource and transmission power of group k^*, accordingly. 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, i.e., compute $f_R(k^*, y^*, z)$, $z = (y^* + 1)..15$, and repeat Step 6).

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 I [7]. We consider three types of traffic: Audio, Video and Data [20]. The network contains one BS and several RNs and MEs. RNs are uniformly deployed inside the $2/3$ coverage range of the BS to get the best performance gain.

We first evaluate the total energy consumption of MEs under different ratio of β/α as shown in Fig. 3. Fig. 3 presents that as the ratio β/α increases, the total energy consumption is decreased. It means that factor 1, i.e., $\left(\frac{d_{i,j}}{\min_{l=1..N}\{d_{l,j}|I_{l,j} \neq 0\}}\right)^{-\omega}$, and factor 2, i.e., $\frac{\delta_i}{\max_{l=1..N}\{\delta_l|I_{l,j} \neq 0\}}$, have equal importance for weight W_i. The distance to the connected RN and the data request size are both

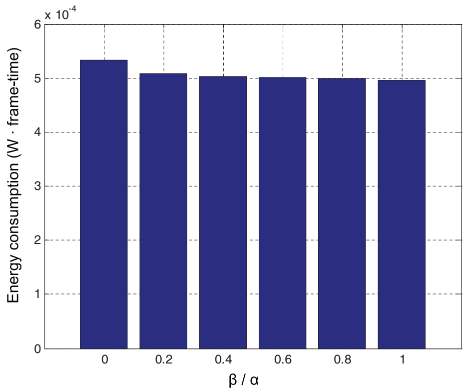

Fig. 3. The impact of β/α on the total energy consumption.

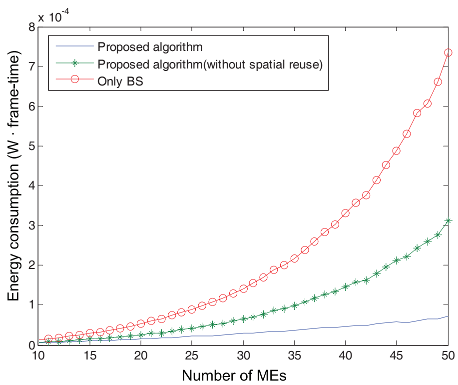

Fig. 4. The impact of number of MEs on the total energy consumption.

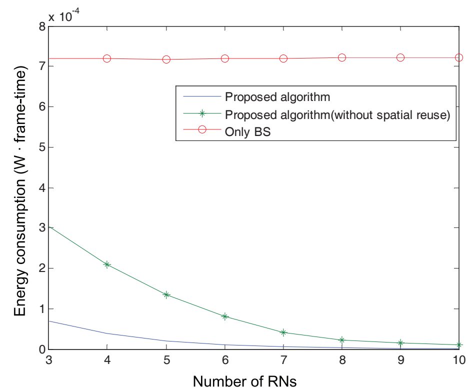

Fig. 5. The impact of number of RNs on the total energy consumption.

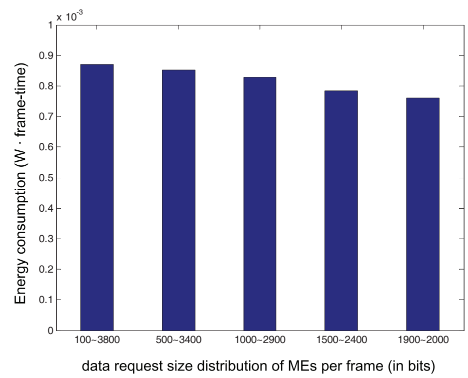

Fig. 6. The impact of the data request distribution of each ME on the total energy consumption.

significant factors for energy conservation when selecting MEs to form reuse group.

Next, we evaluate the total energy consumption of MEs under different number of MEs 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 as the number of MEs 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 MEs 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.

Finally, we evaluate the total energy consumption of MEs under different data request distribution of MEs per frame as shown in Fig. 6. When the data request distribution of MEs more concentrating, the total energy consumption is small. This is because of degree of spatial reuse increases when the request size of MEs in the same group increases, i.e., reducing the most required physical resource when all MEs in the same group have the same data request size.

V. Conclusion

In this paper, we investigate the energy conservation issue of the uplink resource and power allocation in LET-A relay networks for IoT applications. We have proposed heuristics to conserve MEs' 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 MEs and how to select MEs 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 MEs compared to other schemes.

Acknowledgment

This research is co-sponsored by NSC grants 100-2218-E-024-001-MY3 and 102-2218-E-009-014-MY3.

References

[1] L. Atzori, A. Iera, and G. Morabito, "The internet of things: A survey," *Computer Networks*, vol. 54, no. 4, pp. 2787–2805, 2010.

[2] D. Guinard, V. Trifa, S. Karnouskos, P. Spiess, and D. Savio, "Interacting with the SOA-based Internet of Things: Discovery, query, selection, and on-demand provisioning of web services," *IEEE Trans. Services Comput.*, vol. 3, no. 3, pp. 223–235, Jul./Sep. 2010.

[3] E. Dahlman, S. Parkvall, and J. Skold, *4G: LTE/LTE-Advanced for Mobile Broadband*, 2nd ed. Academic Press, 2013.

[4] D. Astely, E. Dahlman, A. Furuskar, Y. Jading, M. Lindstrom, and A. Parkvall, "LTE: the evolution of mobile broadband," *IEEE Communications Magazine*, vol. 47, no. 4, pp. 44–51, 2009.

[5] 3GPP TR 36.913 v8.0.0, "Requirements for Further Advancements for EUTRA (LTE-Advanced)".

[6] H. Holma and A. Toskala, *LTE for UMTS, OFDMA and SC-FDMA Based Radio Access*, John Wiley & Sons, Ltd., 2009.

[7] 3GPP TR 36.814 v9.0.0, "Further advancements for E-UTRA physical layer aspects," Mar. 2010.

[8] IEEE Std 802.16-2012, "IEEE Standard for Air Interface for Broadband Wireless Access Systems," Aug. 2012.

[9] S.-B. Lee, I. Pefkianakis, A. Meyerson, S. Xu, and S. Lu, "Proportional Fair Frequency-Domain Packet Scheduling for 3GPP LTE Uplink," in *Proc. IEEE INFOCOM*, pp. 2611–2615, Apr. 2009.

[10] Z. Ma, W. Xiang, H. Long, and W. Wang, "Proportional fair resource partition for LTE-advanced networks with Type I relay nodes," in *Proc. IEEE ICC*, pp.1–5, Jun. 2011.

[11] G. Liebl, T. M. de Moraes, A. Soysal, and E. Seidel, "Fair Resource Allocation for the Relay Backhaul Link in LTE-Advanced," in *Proc. IEEE WCNC*, pp.1196–1201, Apr. 2012.

[12] J. P. Yoon, W. J. Kim, J. Y. Baek, and Y. J. Suh, "Efficient uplink resource allocation for power saving in IEEE 802.16 OFDMA systems," in *Proc. IEEE VTC, Spring*, pp. 2167–2171, 2008.

[13] J.-M. Liang, Y.-C. Wang, J.-J. Chen, J.-H. Liu, and Y.-C. Tseng, "Energy-Efficient Uplink Resource Allocation for IEEE 802.16j Transparent-Relay Networks," *Computer Networks*, vol. 55, no. 16, pp. 3705–3720, Nov. 2011.

[14] IEEE Std 802.16j-2009 (Amendment to IEEE Std 802.16-2009), "IEEE Standard for Local and metropolitan area networks Part 16: Air Interface for Broadband Wireless Access Systems Amendment 1: Multihop Relay Specification," Jun. 2009.

[15] P. K. Dalela, A. Nayak, V. Tyagi, and K. Sridhara, "Analysis of spectrum utilization for existing cellular technologies in context to cognitive radio," in *Proc. Int'l Conf. on Computer and Communication Technology (ICCCT'11)*, pp. 585–588, Sept. 2011.

[16] 3GPP TR 36.211 v11.0.0, "Physical Channels and Modulation," Sep. 2012.

[17] 3GPP TR 36.216 v10.3.1, "Physical layer for relaying operation," Sep. 2011.

[18] 3GPP Tech. Rep. 36.213 v11.0.0, "E-UTRA; physical layer procedures," Sep. 2012.

[19] J. Blumenstein, J. Ikuno, J. Prokopec, and M. Rupp, "Simulating the long term evolution uplink physical layer," in *Proc. ELMAR*, pp. 141-144, Sep. 2011.

[20] , 3GPP TS 22.105 v10.0.0, "Services and service capabilities," Mar. 2011.