Towards Energy-Aware 5G Heterogeneous Networks

Hafiz Yasar Lateef, Mischa Dohler, Amr Mohammed, Mohsen Mokhtar Guizani and Carla Fabiana Chiasserini

Abstract Over the past decade, the telecommunication industry has witnessed excessive growth in the number of mobile users. Market forecasts envision that there will be nearly 8.6 billion mobile devices worldwide by 2017. This tremendous increase in the number of cellular users demands an expansion in the wireless Base Stations (BSs) for improved coverage and capacity. However, this hike in the deployment of base stations will lead to immense energy consumption, because in mobile networks 70–80 % of the power is consumed by BSs. This upsurge in the energy consumption of telecommunication networks implies an increase in CO_2 emissions in the environment. In addition, energy bills also represent a major chunk of wireless network operators' expenditures. These ecological and economical challenges have provoked the curiosity of telecommunication standardization bodies and researchers in an emerging research area termed 'energy-aware Heterogeneous Networks (HetNets)'. HetNets are a mix of various cell shapes and sizes, including high power macro cells and low power nodes such as micro cells, pico cells and relays. The large macro cells are responsible for the basic coverage of the cell users, and the small cells are effective in providing higher data rates to their nearby users in dense areas with reduced power consumption. The combination of various BSs with different cell sizes and a wide range of power levels can lead to substantial gains in network energy consumption by creating hotspots and enabling dense spatial reuse. It is envisioned that a dense deployment of low power BSs will take place in the near future. HetNets in particular are considered as a promising solution for Fifth Generation (5G) in order to meet the exponentially growing demand for multimedia traffic. The main focus of this chapter is to investigate optimal energy efficient deployment strategies

H.Y. Lateef (✉) · A. Mohammed · M.M. Guizani
Department of Computer Science, Qatar University, Doha, Qatar
e-mail: yasar.lateef@qu.edu.qa

M. Dohler
Wireless Communications, King's College London, London, UK
e-mail: mischa.dohler@kcl.ac.uk

C.F. Chiasserini
Telecommunication Networks Group, Politecnico di Torino, Turin, Italy
e-mail: chiasserini@polito.it

M.Z. Shakir et al. (eds.), *Energy Management in Wireless Cellular and Ad-hoc Networks*, Studies in Systems, Decision and Control 50,
DOI 10.1007/978-3-319-27568-0_2

for low power nodes such as relays and small cells in 5G HetNets. In this chapter, a comprehensive overview of remarkable small cell deployment schemes is presented in order to facilitate the debate on technical challenges in deploying HetNets. It goes on to discuss some useful techniques to mitigate the severe interference in 5G dense HetNets. Finally, a novel Long Term Evolution (LTE)-Advanced relay deployment scheme is introduced using graph theory, not only to address some of the identified deficiencies of existing solutions, but also to optimize the energy efficiency of 5G cellular networks.

1 Introduction

Over the past decade, the cellular industry has witnessed an unprecedented growth in the number of subscribers and traffic, particularly, video and multimedia. This tremendous increase in mobile subscribers calls for major investments in additional wireless infrastructure, namely base stations for enhanced coverage and capacity. However, such hike in the deployment of BSs will result in huge energy consumption. It is estimated that wireless networks currently consume approximately 60 billion kWh per year globally and these statistics are predicted to double by 2020 [1–3].

The economical challenges and high power consumption of conventional macro BSs have led standardization bodies and researchers to seek alternative, cost-effective and energy-efficient solutions. This has, in turn, shifted the focus on energy efficient Fifth Generation (5G) wireless networks in the research community. In this regard, some recent projects such as GreenTouch, Greenet, Towards Green 5G Mobile Networks (5GrEEn), Green Radio Excellence in Architecture and Technology (GREAT), Communicate Green (ComGreen), Energy Aware Radio and neTwork tecHnology (EARTH) and Towards Real and Energy Efficient Network Design (TREND) have started to realize the vision of, both eco-friendly and green 5G cellular networks [4–10].

The challenges associated with the deployment of traditional macro base stations can be overcome through the utilization of BSs with lower transmit power. Specifically, HetNets are the potential solution to achieve energy efficiency in future wireless networks. In a HetNet, macro BSs are deployed in a planned way to achieve required coverage (large area), while Low Power Nodes (LPNs) serve the purpose of coverage extension, throughput enhancement, and achieving overall lower energy consumption for the network [11].

The introduction of dense HetNets and Massive Multiple Input Multiple Output (MIMO) techniques are the key ideas for 5G technology in order to achieve both capacity gains and energy efficiency in future wireless networks [12, 13]. Typically, network operators place low power BSs at strategic areas to enhance the network performance while keeping the infrastructure deployment cost low [14]. However, the dense and random deployment of low power BSs raises fundamental challenges for the energy consumption of dense HetNets. Therefore, dense deployment of small BSs should be carefully designed in order to avoid undesired network behaviour

[15]. Key challenges for dense HetNets from the energy perspective include finding the optimal densities of small BSs and determining which infrastructure network nodes should be switched on/off depending on the user traffic patterns. Thus, optimal switch on/off policies for dense HetNets can play a key role in enhancing the energy efficiency and data rate towards 2020.

2 Energy Efficient Resource Allocation Schemes for 5G HetNets

This section presents a comprehensive survey of state-of-the-art work on energy efficient resource allocation and load balancing schemes for 5G HetNets. Several works have addressed energy-efficient sleep mode protocols and traffic offloading schemes for HetNets, e.g., [16–21]. In particular, the performance of a macro-pico network is studied in [16]. Specifically, the work highlights that the number of pico BSs, the user distribution and the fact that pico BSs can enter a sleep mode can lead to significantly high energy savings. The work in [17] has proposed an analytical framework for the performance evaluation of the energy saving that can be obtained by applying sleep mode to the network devices. Specifically, the authors formulated a theoretical model which allows to estimate that how much energy can be saved for different network topologies. The performance evaluation results reveal that highly connected networks, with high randomness tend to make the use of sleep modes more energy efficient.

The authors in [18] proposed an analytical model to determine the optimal set of BSs that can be switched off based on the daily traffic pattern. Specifically, the authors derived analytical expressions for the energy saving by first assuming that only a single BS can switch off per day and then considering that multiple BSs can switch off per day. The performance evaluation results indicate that substantial energy saving can be realized by switching off a single BS per day, while the advantage of switching off multiple BSs is minor. In [19], the authors have utilized stochastic geometry theory to analyze the optimal macro/micro BS density for energy efficient HetNets under Quality of Service (QoS) constraints. The authors have addressed the two important issues: capacity extension and energy saving, and they have proposed a rule to determine which type of BSs should be deployed or slept with higher priority. Yong et al. have investigated the impact of random sleeping and strategic sleeping on the power consumption and energy efficiency of HetNets [20]. On the other hand, energy minimization in macro-relay networks has been studied in [21] and [22], where minimum user data rate requirements are accounted for. In particular, the authors formulated an integer optimization problem and proposed a heuristic solution for energy minimization.

The effect of coverage area on energy efficiency of macro-pico HetNets has been studied in [23]. System-level simulation results reveal that the area energy efficiency of macro-pico networks can be substantially improved with interference reduction and adaptive power control. The authors in [24] have investigated the energy efficiency of pico nodes in HetNets by taking into account the effect of pico cell size on the overall energy efficiency of the network. The performance evaluation results reveal that energy efficiency of pico BS can improve substantially by applying efficient resource allocation and cross-tier interference mitigation scheme. The work in [25] has proposed a dynamic on/off switching algorithm for BSs based on the concept of network impact which is defined as how much can switching on/off a BS affect the whole network. Moreover, the authors proposed various heuristic algorithms for determining the on/off state of a BS with partial feedback or even no feedback. Shengrong et al. considered the role of smart grid in designing energy efficient cellular networks by taking into consideration, both real-time traffic conditions and the associated carbon emissions [26]. The authors proposed a scheme in which some of the base stations can be switched off to save energy while Coordinated Multi-Point (CoMP) scheme is used to increase the coverage of the active base stations.

3 System Model

In this section, we present a system model for the performance evaluation of an energy efficient macro-relay network consisting of macro eNBs, low power Relay Nodes (RNs) and User Equipment (UEs). An overview of a multi-cell macro-relay network is shown in Fig. 1. The eNBs, RNs and UEs are equipped with single antenna. We consider in-band Type 1 LTE-Advanced RNs, which use the same frequency resources for both backhaul (eNB to relay) and access (relay to UE) links. Moreover, the backhaul and access links are time division multiplexed in order to avoid interference between these links. The RNs must connect to a donor macro eNB either through a backhaul link, or, in a multi-hop fashion, to another RN as shown in Fig. 1. The users can connect to the network through macro eNB, either directly or through RNs using decode and forward technique. The UEs are uniformly distributed in the macro-relay network under consideration. The energy consumption of UEs varies depending on the distance and path loss from macro eNBs or RNs. We adopt the large-scale path loss propagation model that is endorsed by 3GPP [27–29].

The EARTH project [9] introduced a linear power model for different types of base stations, which details the relation between base station power consumption P_{in} and Radio Frequency (RF) output power P_{out}. According to the EARTH power model, we have;

$$P_{in} = P_o + \nabla_p \times P_{out} \qquad 0 \leq P_{out} \leq P_{max} \tag{1}$$

where P_{max} represents the maximum RF output power at full load, P_o is the minimum power consumption when the node is in idle mode and ∇_p denotes the power amplifier efficiency. The power consumption parameters for different types of base stations and relays, based on the EARTH project state-of-the art estimation, are presented in Table 1.

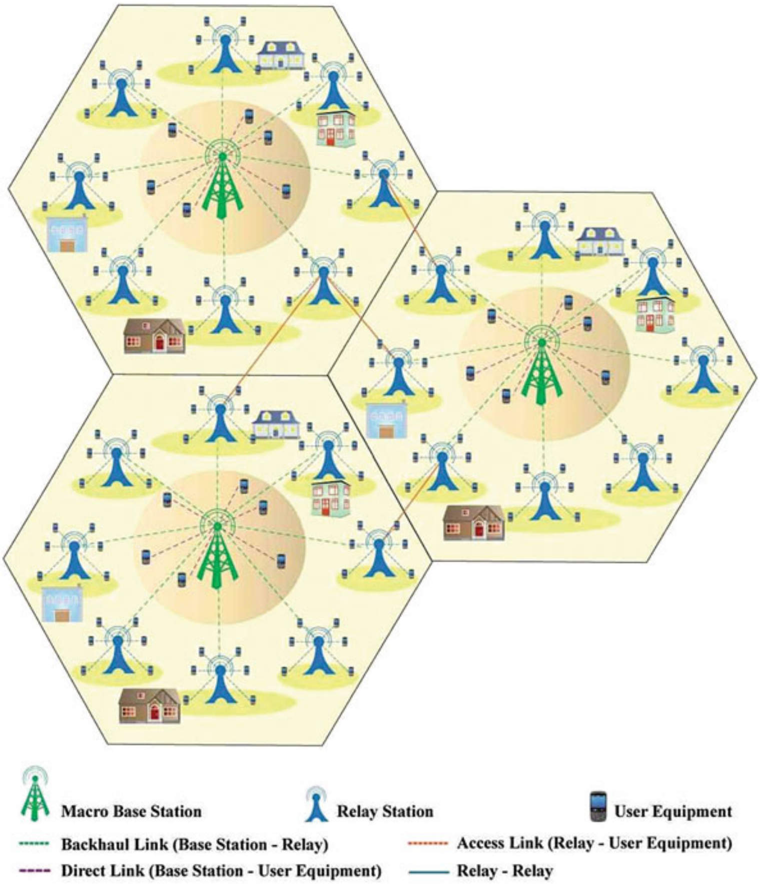

Fig. 1 An illustration of a macro-relay network with relay-to-relay communication

4 Optimization of Energy Efficient Relay Placement and Load Balancing

With the aim to minimize energy consumption, we now present an analytical model for optimizing relay placement and load balancing in a macro-relay heterogeneous network. We divide the network service area into a set τ of non-overlapping tiles. These tiles in general cannot be bigger than a cell and may differ in size and shape as shown in Fig. 2.

We define τ_t to be the amount of traffic or data (e.g., Megabits) requested by each user, for each tile t. We assume that an estimate of τ_t is already known. The set β represents macro eNBs and the set $\mathcal{L}$ represents candidate locations where RNs can be deployed. The eNBs, relay candidate locations and tiles constitute the vertices of a graph, representing our network. The edges of the graph represent the

Table 1 Performance evaluation parameters

Earth parameters for different base stations			
LTE base station type	$P_{max}(W)$	$P_o(W)$	∇_p
Macro	40	712	14.5
Relay urban 2014	1	19.91	5.6
Relay advanced	5 or 1	13.91	20.4

Performance evaluation parameters	
Carrier frequency	2 GHz
Bandwidth	20 MHz
Thermal noise PSD	−174 dbm/Hz
eNB transmit power	43 dbm
Relay transmit power	30 dbm
User transmit power	23 dbm
Antenna configuration (eNB, relay and User)	Tx-1, Rx-1
User distribution	Hotspot + Uniform
Distance and path loss	R (km) & PL (dB)
3GPP Case 1 urban scenario	Inter Site Distance (ISD) = 500 m

Direct link (Macro-UE)
$PL_{LOS} = 103.4 + 24.2log10(R)$
$PL_{NLOS} = 131.1 + 42.8log10(R)$
$P(LOS) = \min\left(\frac{0.018}{R}, 1\right) * \left(1 - \exp\left(-\frac{R}{0.063}\right)\right) + \exp(-\frac{R}{0.063})$
Access link (Relay-UE)
$PL_{LOS} = 103.8 + 20.9log10(R)$
$PL_{NLOS} = 145.4 + 37.5log10(R)$
$P_{(LOS)} =$
$P(LOS) = 0.5 - \min\left(0.5, 5\exp\left(\frac{-0.156}{R}\right)\right) + \min\left(0.5, 5\exp\left(\frac{-R}{0.03}\right)\right)$
Backhaul link (Donor eNB-Relay and Relay-Relay)
$PL_{LOS} = 100.7 + 23.5log10(R)$
$PL_{NLOS} = 125.2 + 36.3log10(R) - b$
$P_{(LOS)} = 1 - \left(1 - \min\left(\frac{0.18}{R}, 1\right) * \left(1 - \exp\left(-\frac{R}{0.072}\right)\right) + \exp\left(-\frac{R}{0.072}\right)\right)^{c}$ b = 5, c = 3

connectivity opportunities among the vertices. It is assumed that each macro base station provides single cell coverage. All the direct link connections from each macro eNB to its neighboring cells are considered redundant and therefore we neglect these connections.

For each edge connecting a pair of nodes (e_1, e_2), there is a corresponding weight $w(e_1, e_2)$, representing how much data we can transfer from e_1 (representing an eNB or a RN) to e_2 (representing a RN or a tile).

For all the edge points (e_1, e_2), representing any of the following pairs (relay candidate location, tile), (eNB, tile), (eNB, relay candidate location), (relay candidate location, relay candidate location) we know the associated transmit power $P(e_1, e_2)$,

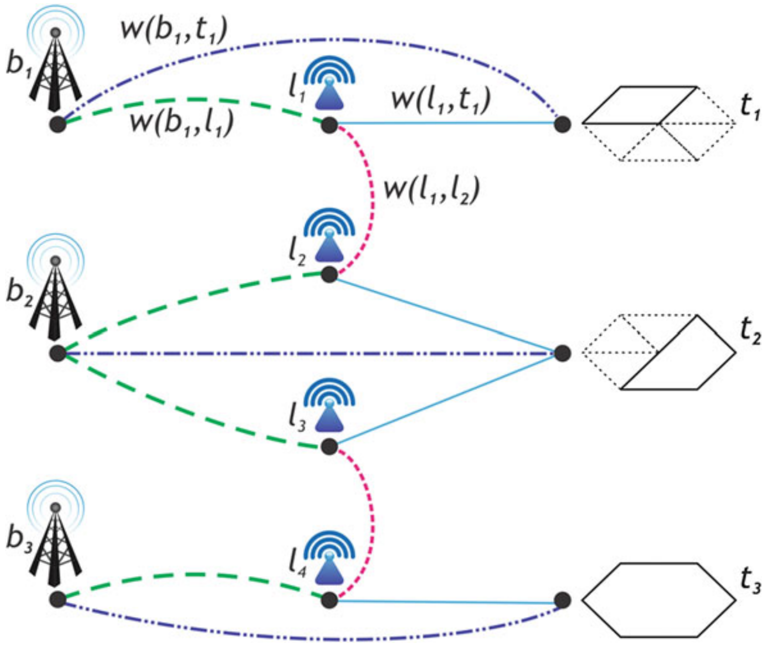

Fig. 2 A graph based representation of a LTE-Advanced macro-relay network

Furthermore, active eNBs and RNs consume $P_o(b)$ and $P_o(l)$ amount of power, respectively, which depend on the transceiver electronics, cooling, etc., i.e., they are independent of the node traffic load. Finally, due to operator's budget constraints, we have a maximum number R of RNs that can be deployed.

The energy efficient relay placement optimization algorithm is formulated as a MILP problem. First, we introduce a set of binary variables y_l, $y_b \epsilon \{0, 1\}$, representing, respectively, whether we place a RN in a candidate location $l \epsilon \mathcal{L}$, and whether eNB is $b \epsilon \beta$ ON or OFF. Furthermore, we need to denote how much traffic we transmit between UEs, RNs and eNBs. We do so through real variables $x(e_1, e_2)$. At last, we introduce a set of binary variables $z(b, l)$, each expressing whether $b \epsilon \beta$ is a donor eNB for RN in location $l \epsilon \mathcal{L}$. To rationalize the notation, we also denote the donor eNB for RN in l as $D_l \epsilon \beta$.

Constraints: The first constraint corresponds to the capacity. For each pair of nodes (UEs, RNs and eNBs) that can communicate with each other, the total amount of transmitted data x must not exceed the capacity (w) of the edge:

$$x(e_1, e_2) \leq w(e_1, e_2) \tag{2}$$

The exact value of the weight w can be calculated using the channel capacity formulas. Next, a flow conservation equation holds for RNs. These are purely relay nodes, so the amount of data receiving and transmitting each of them must be the same:

$$\sum_{e_1 \epsilon \beta U \mathcal{L}} x(e_1, l) = \sum_{e_2 \epsilon \mathcal{L} U \tau} x(l, e_2) \qquad \forall l \epsilon \mathcal{L} \tag{3}$$

The association between the RN and their respective donors (these can be eNB or any other RN) should be in such a way that each active RN is association with only one donor at a particular time.

$$\sum_{e \epsilon \beta U \mathcal{L}} z(e, l) = y_1 \quad \forall l \epsilon \mathcal{L} \tag{4}$$

The constraint in (5) defines that an inactive node (eNB or RN) can't be a donor to any RN.

$$\sum_{e \epsilon \beta U \mathcal{L}} + \sum_{l \in \mathcal{L}} z(e, l) \leq \sum_{e \epsilon \beta U \mathcal{L}} y_e \quad \forall e \in \beta U \mathcal{L} \tag{5}$$

Obviously no date can flow between inactive nodes. Therefore we modify the capacity constraint as follows:

$$x(e_1, e_2) \leq y_{e_1}.w(e_1, e_2). \quad \forall e_1 \in \beta U \mathcal{L} \tag{6}$$

When y_{e_1} is zero, i.e. the source node (eNB or RN) is not active, the right side of the equation becomes zero and no data can be transmitted.

The association variables $z(b, l)$ will also make sure that there is no data flow between an eNB and RN, if they are not associated with each other. This can be represented as;

$$x(e_1, e_2) \leq z(b, l).w(e_1, e_2) \quad \forall b \in \beta, l \in \mathcal{L} \tag{7}$$

As described earlier, each tile must receive the adequate traffic τ_t, in order to meet the minimum data rate requirements. This translates into the following constraint:

$$\sum_{b \in \beta} x(b, t) + \sum_{l \in \mathcal{L}} x(l, t) \geq \tau_t \tag{8}$$

Finally, the following constraint represents the limit on the maximum number of RNs that can be deployed in the network, due to budget constraints

$$\sum_{l \in \mathcal{L}} y_l \leq R \forall l \in \mathcal{L} \tag{9}$$

Objective: Our objective is to minimize the total power consumption of the network. This includes;

- The static or fixed power consumed by active source nodes (eNB and RN)
- The dynamic or traffic dependent power $P(e_1, e_2)$ based on communication end points.

$$\min \sum_{b\in\beta}\left(y_b P_0(b) + \sum_{l\in\mathcal{L}} P(b,l)x(b,l) + \sum_{t\in\tau} P(b,t)x(b,t)\right) + \sum_{l\epsilon\mathcal{L}}\left(y_1 P_0(l) + \sum_{t\in\tau} P(l,t)x(l,t)\right) \quad (10)$$

Clearly, the objective function and all the constraints are linear and the complexity stems from the binary variables y_b and y_l.

5 Performance Evaluation Parameters

In this section, we evaluate the performance of our proposed energy efficient algorithm. The parameter values we use in our analysis are reported in Table 1. The scenario we consider consists of 7 cells macro-relay network with hotspot and uniformly distributed users as shown in Fig. 3. In this scenario, we utilize the relay urban 2014 power model for performance evaluation.

Figure 4 depicts the effect of the density of RNs on the number of active macro base stations in operation. Specifically, from the plot, it can be seen that our proposed load balancing algorithm for a dense macro-relay network can offload traffic from macro BSs and switch off most of the lightly loaded macro BSs. Moreover, it is evident from Fig. 4 that more macro BSs are switched off by increasing the density of RNs in the network.

The effect of the density of RNs on the Area Energy Efficiency (AEE) of a macro-relay network is shown in Fig. 5. The bar labeled "Optimal macro-relay network" in Fig. 5 represents the scenario where we take into account transmission and circuit energy of both macro base stations and RNs in active mode which are obtained by solving the problem in (10) using CPLEX.

Similarly, the bar labeled "macro relay network without sleep mode" represents the scenario where we consider transmission and circuit energy of all macro base stations and RNs in the network. Finally, the bar "Macro only" refers to the scenario where we only deploy macro base stations and all macro base stations are in the active mode. From Fig. 5, we note that our proposed algorithm has the best AEE as compared to other cases. The rationale behind this fact is that most of the macro

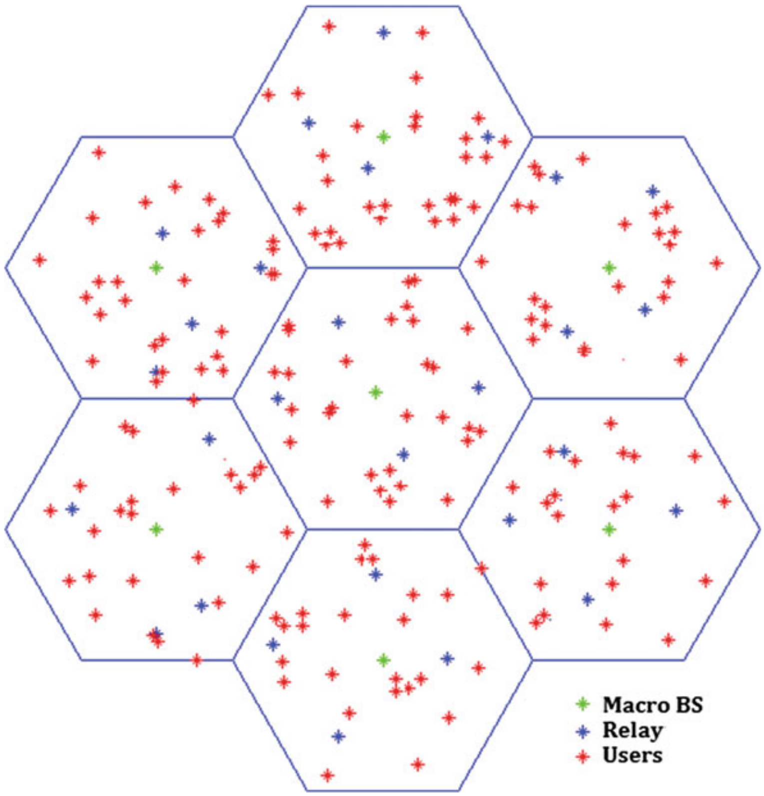

Fig. 3 An illustration of a 7 cell LTE-Advanced macro-relay network with uniformly distributed users

BSs are operating in “off” state in the optimal macro-relay configuration, as shown in Fig. 4. Moreover, it can be seen from Fig. 5 that the AEE of macro-relay network increases with an increase in the density of RNs.

Figure 6 depicts the effect of the density of RNs on the user association for a macro-relay network. It is evident from Fig. 6 that our proposed energy efficient load balancing scheme connects more users to RNs than macro base stations with an increase in the density of RNs in the network. As a result, it relaxes traffic load of some macro eNBs in order to allow them to switch into inactive mode and reduce the overall power consumption of the network.

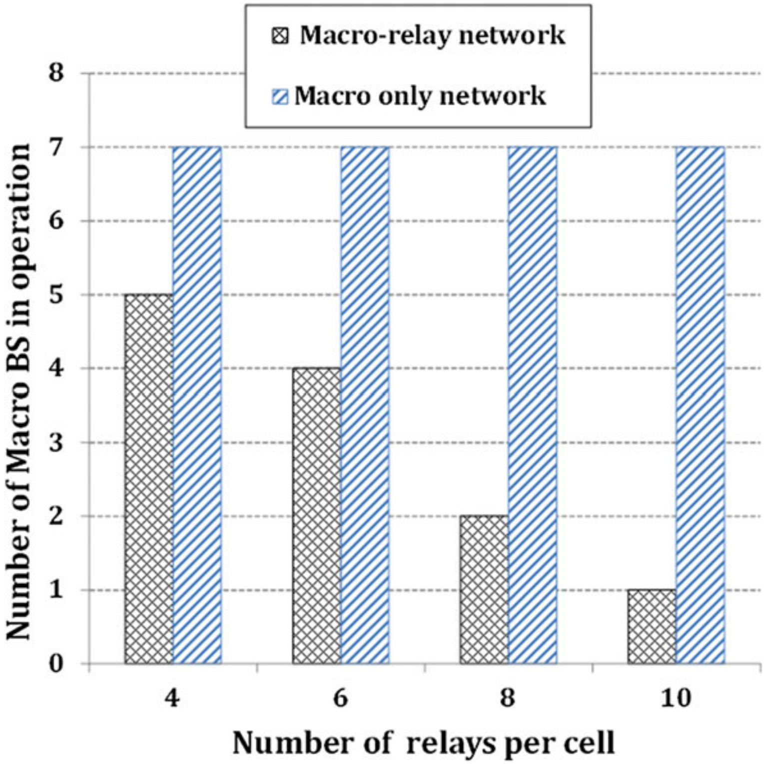

Fig. 4 An illustration of the number of active macro base stations versus relay density for a 7 cell LTE-Advanced macro-relay network

6 Conclusion

In this chapter, we present energy efficient and quality of service aware load balancing and sleep policy for Fifth Generation (5G) dense macro-relay networks. We formulate an energy minimization problem for dense macro-relay HetNets as a Mixed Integer Linear Programming (MILP) problem. Specifically, our proposed algorithm not only optimally connects users to macro BSs and RNs, but also enables lightly loaded macro BSs to switch into off state. Our extensive performance evaluation results reveal that our proposed algorithm for dense macro-relay network can switch off most of the macro BSs with an increase in the density of RNs. It is worth mentioning that our unique approach of relay-to-relay communication forms the basis for relays to act as donors for neighboring relays instead of macro BSs thus allowing the latter to enter the off state. As a result, our proposed energy efficient load balancing and sleep algorithm power consumption is significantly lower than a macro network

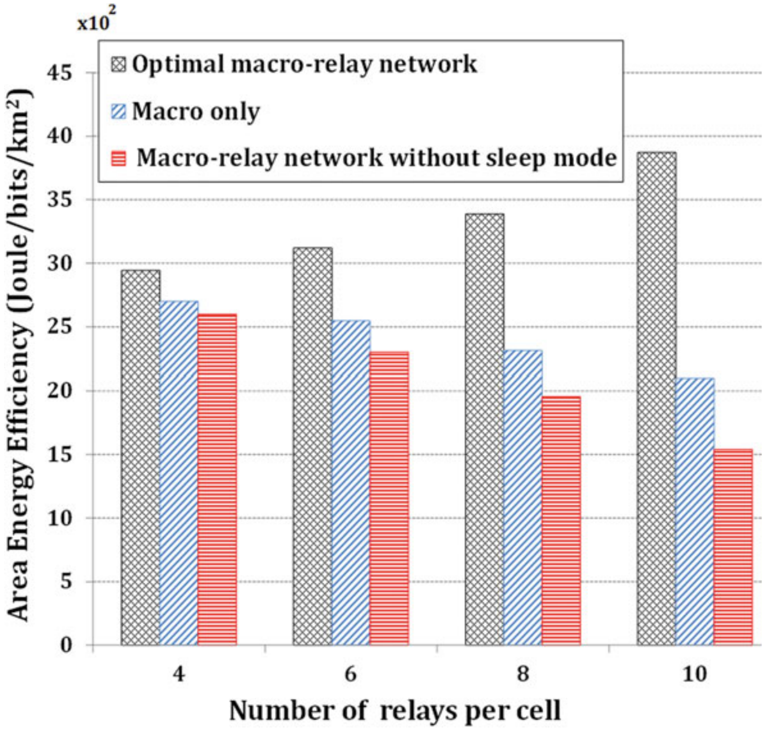

Fig. 5 A comparison of Area Energy Efficiency (AEE) for a 7 cell LTE-Advanced macro-relay network

without relays. Moreover, we have shown that the power consumption of the proposed optimal solution is also lower than a macro-relay network without inactive mode. Our performance evaluation results depict that most of the users connect to RNs with an increase in the density of RNs in the network. It is worth noting that optimally deploying relay nodes should yield communication over short ranges and, hence, lower-power transmissions, as well as enabling switching off some macro BSs. We demonstrated that our proposed algorithm has the best AEE as compared to other load balancing and sleep policies. In summary, we have shown that the proposed algorithm for 5G dense macro-relay networks can significantly reduce system energy consumption while guaranteeing the minimum required data rate in 5G wireless networks. In this chapter, we also present a comprehensive survey of state-of-the-art work on energy efficient resource allocation, load balancing and energy harvesting schemes. However, a number of open challenges suggest a variety of future research directions that can be pursued in order to design QoS aware energy efficient user association techniques for Fifth Generation (5G) cellular networks. One such direction would be to investigate optimal user association between Wi-Fi and LTE coexisted networks

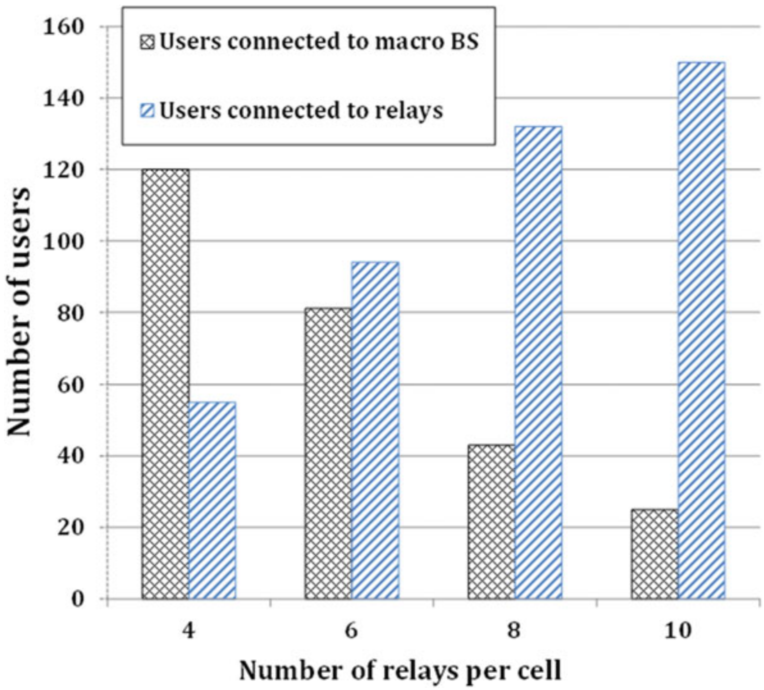

Fig. 6 An illustration of the user association for a LTE-Advanced Macro-pico-relay network

powered by renewable energy sources. Another dimension would be to determine that how much renewable energy should be utilized to power a base station during a specific period of the day based upon real-time weather forecasts.

References

1. Hu, R.Q., Qian, Y.: An energy efficient and spectrum efficient wireless heterogeneous network framework for 5G systems. IEEE Commun. Mag. **52**(5), 94–101 (2014)
2. Chin, W.H., Fan, Z., Haines, R.: Emerging technologies and research challenges for 5G wireless networks. IEEE Wireless Commun. **21**(2), 106–112 (2014)
3. Feng, D., et al.: A survey of energy-efficient wireless communications. IEEE Communic. Surveys Tutorials **15**(1), 167–178 (2013)
4. Andrews, J.G., Buzzi, S., Choi, W., Hanly, S.V., Lozano, A., Soong, A.C.K., Zhang, J.C.: What will 5G be? IEEE J. Sel. Areas Commun. **32**(6), 1065–1082 (2014)
5. http://www.greentouch.org
6. http://www.eitictlabs.eu/innovation-areas/future-networking-solutions/5green-towards-green-5g-mobile-networks/
7. http://www.fp7-greenet.eu
8. http://www.communicate-green.de/
9. Energy Aware Radio and NeTwork TecHnologies (EARTH). https://www.ict-earth.eu/

10. http://www.fp7-trend.eu
11. Leem, H., Baek, S.Y., Sung, D.K.: The effects of cell size on energy saving, system capacity, and per-energy capacity. In: Proceedings of IEEE WCNC, pp. 1–6 (2010)
12. Talwar, S., Choudhury, D., Dimou, K., Aryafar, E., Bangerter, B., Stewart, K.: Enabling technologies and architectures for 5G wireless. In: IEEE MTT-S International Microwave Symposium (IMS), pp. 1–4 (2014)
13. Olsson, M., Cavdar, C., Frenger, P., Tombaz, S., Sabella, D., Jantti, R.: 5GrEEn: towards green 5G mobile networks. In: IEEE International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob), pp. 212–216 (2013)
14. Ling, B.J., Chizhik, D.: Capacity scaling of indoor pico-cellular networks via reuse. IEEE Commun. Lett. **16**(2), 231–233 (2012)
15. Fu, Y., Fei, Z., Wang, N., Xing, C., Wan, L.: An energy-efficient dense pico station deployment and power control strategy for heterogeneous networks. Smart Comput. Rev. **3**(1), 24–32 (2013)
16. Arshad, M.W., Vastberg, A., Edler, T.: Energy efficiency gains through traffic offloading and traffic expansion in joint macro pico deployment. In: Proceedings of IEEE Wireless Communications and Network Conference (WCNC 2012), pp. 2230–2235 (2012)
17. Chiaraviglio, L., Ciullo, D., Mellia, M., Meo, M.: Modeling sleep mode gains in energy-aware networks. Comput. Netw. **57**, 3051–3066 (2013)
18. Marsan, M.A., Chiaraviglio, L., Ciullo, D., Meo, M.: Multiple daily base station switch-offs in cellular networks. In: Proceedings of IEEE International Conference on Communications and Electronics (ICCE 2012), pp. 245–250 (2012)
19. Cao, D., Zhou, S., Niu, Z.: Optimal base station density for energy-efficient heterogeneous cellular networks. In: IEEE International Conference on Communications, pp. 4379–4383 (2012)
20. Soh, Y.S., Quek, T.Q.S., Kountouris, M., Shin, H.: Energy efficient heterogeneous cellular networks. IEEE J. Sel. Areas Commun. **31**, 840–850 (2013)
21. Li, X., Wang, H., Liu, N., You, X.: Dynamic user association for energy minimization in macro-relay network. In: Proceedings of IEEE Wireless Communications and Signal Processing (WCSP), pp. 1–5 (2012)
22. Li, X., Wang, H., Meng, C., Wang, X., Liu, N.: Total energy minimization through dynamic station-user connection in macro-relay network. In: Proceedings of IEEE Wireless Communications and Networking Conference (WCNC), pp. 697–702 (2013)
23. Wang, W., Shen, G.: Energy efficiency of heterogeneous cellular network. In: Proceedings of IEEE Vehicular Technology Conference (VTC Fall), pp. 1–5 (2010)
24. Jiang, J., Peng, M., Zhang, K., Li, L.: Energy-efficient resource allocation in heterogeneous network with cross-tier interference constraint. In: IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC Workshops), pp. 168–172 (2013)
25. Oh, E., Son, K., Krishnamachari, B.: Dynamic base station switching-on/off strategies for green cellular networks. IEEE Trans. Wirel. Commun. **12**(5), 2126–2136 (2013)
26. Bu, S., Yu, F.R., Cai, Y., Liu, X.P.: When the smart grid meets energy-efficient communications: green wireless cellular networks powered by the smart grid. IEEE Trans. Wirel. Commun. **11**(8), 3014–3024 (2012)
27. EARTH Project, Ed.: D2.3 V2—Energy efficiency analysis of the reference systems, areas of improvements and target breakdown. https://www.ictearth.eu/publications/publications.html
28. 3GPP TR 36.814 V9.0.0: Technical specification group radio access network; evolved universal terrestrial radio access (e-utra); further advancements for e-utra physical layer aspects (release 9), Mar 2009
29. Saleh, A.B., Bulakci, O., Redana, S., Raaf, B., Hamalainen, J.: Evaluating the energy efficiency of LTE-advanced relay and picocell deployments. In: Proceedings of IEEE Wireless Communications and Networking Conference (WCNC), pp. 2335–2340, France, 2012

Springer

http://www.springer.com/978-3-319-27566-6

Energy Management in Wireless Cellular and Ad-hoc Networks
Shakir, M.Z.; Imran, M.A.; Qaraqe, K.A.; Alouini, M.-S.; Vasilakos, A.V. (Eds.)
2016, VIII, 450 p. 184 illus., 50 illus. in color., Hardcover
ISBN: 978-3-319-27566-6