A Review on Intelligent Base Stations Cooperation Management Techniques for Greener LTE Cellular Networks

Mohammed H. Alsharif, Rosdiadee Nordin, and Mahamod Ismail
Department of Electrical, Electronics and Systems Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia
Email: moh859@gmail.com; {adee, mahamod}@eng.ukm.my

Abstract —Energy efficiency in wireless networks has become the most compelling challenge for researchers, equipment vendors, and mobile operators not only to reduce operational costs but also to reduce the environmental effects and to make cellular networks more environmentally friendly. There have been many attempts to achieve appropriate solutions to this issue. In this paper, we provide an extensive overview of the intelligent cooperation management techniques (switching cell, cell zooming, heterogeneous networks, and mobile operator cooperation) that have been considered to save energy and we highlight the principles of the operation, energy savings, advantages, and shortcomings of each technique. We conclude this review with several open issues and potential research topics in this field.

Index Terms—Energy efficiency, green networks, cellular base station cooperation, mobile operators cooperative, switch-off cells.

I. INTRODUCTION

The unexpected increase in subscribers and demand for high-speed data has led to tremendous growth in cellular networks. In 2013, the number of global mobile subscribers reached 6.8 billion. The International Telecommunication Union (ITU) expects that number to grow to 7.5 billion by the end of 2014 and to 8.5 billion by the end of 2016 [1]. In Malaysia, the number of mobile subscribers reached 41.9 million people in 2013 [2]. As a result, there will be a significant increase in mobile data traffic; this will prompt cellular operators to increase the number of base stations (BSs) to support this traffic load increment and fulfil the needs of mobile subscribers. According to [3], BSs are considered the primary source of energy consumption in cellular networks, accounting for 57% of the total energy used. Energy efficiency in cellular networks is a growing concern for cellular operators - not only to maintain profitability but also to reduce the overall environment effects. According to [4], the amount of CO2 emitted due to Information and Communications Technology (ICT) was 151 $MtCO_2$ during 2002, with 43% due to the mobile sector; this is forecast to rise to 349 $MtCO_2$ by 2020, with 51% originating from the mobile sector. This puts mobile operators under immense pressure to meet the demands of both environmental conservation and cost reduction.

There have been many attempts to solve this issue by creating ‘greener’ cellular networks that are less expensive to operate. Overall, these improvements can be achieved through two approaches. The first approach is to reduce the power consumption of BSs using power-efficient hardware. The second approach is to adopt intelligent management of network elements based on traffic load variations, which is the focus of our work.

In this paper, we provide an extensive overview of the intelligent cooperation management techniques, such as cell switching, cell zooming, heterogeneous networks, and the cooperation of mobile operators, with highlights on the principles of operation, energy savings, advantages, and shortcomings of each technique. The motivations behind this work can be summarized in the following points:

- Energy efficiency improvement is a key issue in the next generation of networks (5G networks).
- Cooperative management technique is regarded as one of the most promising solutions to reduce the energy consumption of a wireless cellular network.
- For researchers, this survey provides a number of new references relevant to the intelligent BS management techniques in the area of green communication networks.

The rest of this paper is organised as follows. In Section II, the BS power consumption model is described. Section III presents BS cooperative techniques for energy-efficient cellular wireless communication. Section IV includes the techniques of cooperation management among BSs in the network. The mobile operators cooperative is presented in Section V, and Section VI discusses open issues and concludes the paper.

II. BASE STATION POWER CONSUMPTION MODEL

A BS is a centrally located set of equipment used to communicate with mobile units and the backhaul network.

It consists of multiple transceivers (TRXs), which in turn consist of a power amplifier (PA) that amplifies the input power, a radio-frequency (RF) small-signal

Manuscript received May 30, 2014; revised December, 2014.
This work was supported by the Universiti Kebangsaan Malaysia under Grant No. ETP-2013-072.
Corresponding author email: moh859@gmail.com.
doi:10.12720/jcm.9.12.937-945

transceiver section, a baseband (BB) for system processing and coding, a DC-DC power supply, a cooling system, and an AC-DC unit for connection to the electrical power grid. More details on the BS internal components are available in [5]. Table I displays a summary of the energy consumption of the internal BS components at their maximum load, based on an LTE system with a 2×2 multiple-input and multiple-output (MIMO) configuration.

TABLE I: A COMPARISON OF THE POWER CONSUMPTION OF THE HARDWARE ELEMENTS IN LTE BSS FOR DIFFERENT BS TYPES [5].

Item	Notation	Unit	Macro	Micro	Pico	Femto
PA	Max transmit (rms) power	W	39.8	6.3	0.13	0.05
	Max transmit (rms) power	dBm	46.0	38.0	21.0	17.0
	PAPR	dB	8.0	8.0	12.0	12.0
	Peak Output Power	dBm	54.0	46.0	33.0	29.0
	PA efficiency, μ	%	38.8	28.5	8.0	5.2
	Feeder loss, σ	dB	3.0	0	0	0
	Total PA (P_{PA})= $P_{\max}/\left[\mu(1-\sigma)\right]$	W	102.6	22.1	1.6	1.0
TRX	P_{TX}	W	5.7	2.9	0.4	0.2
	P_{RX}	W	5.2	2.6	0.4	0.3
	Total RF (P_{RF})	W	10.9	5.5	0.8	0.4
BB	Radio(inner Rx/Tx)	W	5.4	4.6	0.6	0.5
	Turbo code (outer Rx/Tx)	W	4.4	4.1	0.7	0.6
	Processor	W	5.0	5.0	0.2	0.1
	Total BB (P_{BB})	W	14.8	13.6	1.5	1.2
DC-DC loss, σ_{DC}		%	6.0	6.4	8.0	8.0
Cooling loss, σ_{cool}		%	9.0	0.0	0.0	0.0
AC-DC (main supply) loss, σ_{MS}		%	7.0	7.2	10	10
Total per TRX = $\frac{P_{PA}+P_{RF}+P_{BB}}{(1-\sigma_{DC})(1-\sigma_{cool})(1-\sigma_{MS})}$		W	160.8	47.0	4.5	3.1
Number of sectors		#	3.0	1.0	1.0	1.0
Number of antennas		#	2.0	2.0	2.0	2.0
Number of carriers		#	1.0	1.0	1.0	1.0
Total transceivers (N_{TRX})		#	6.0	2.0	2.0	2.0
Total N_{TRX} chains, $P_{in=}$ N_{TRX} × Total per TRX		W	964.9	94.0	9.0	6.2

From Table I, two conclusions can be drawn based on the following points:

First, the PA consumes the most energy. Consequently, highly efficient power amplifiers are essential for operating expense (OPEX) cost reduction for the mobile network operators. However, the efficiency can be improved in a PA by using a specially designed power amplifier (such as Doherty) or special materials for power amplifier transistors (like high-frequency materials such as Si, GaAs or GaN). Table II summarizes methods that have been used to improve the power amplifier efficiency. Interested readers can find more details on the classifications and descriptions of high efficiency power amplifier techniques in [6].

TABLE II: TECHNIQUES TO IMPROVE THE EFFICIENCY OF POWER AMPLIFIERS [6].

Techniques	Enhancements
Digital pre-distorted Doherty-architectures and GaN	Up to 50%
Class-AB with digital pre-distortion	50%
Class J amplifier	70% to 90%
Inverse Class F	74%
Envelope tracking designs	Up to 60%
Switched mode power amplifier (SMPA)	80-90%

Second, a high-order MIMO in BSs leads to less energy efficiency in cellular networks because it requires more RF transceivers and baseband processing units. For instance, if the branches of the antennas are reduced from 2 to 1, the energy consumption of the transceivers is reduced by 50%, as the PAs associated with those branches can be switched off [3].

However, a new generation of BSs has been designed by Alcatel-Lucent in 2012, called “Light Radio Cubes’’, which can reduce the mobile networks’ energy consumption by up to 50% over the current radio access network equipment [7].

III. BASE STATIONS COOPERATIVE TECHNIQUES FOR ENERGY-EFFICIENT CELLULAR COMMUNICATION

The graph shown in Fig. 1 classifies the different cooperative techniques that will be discussed in the following sections.

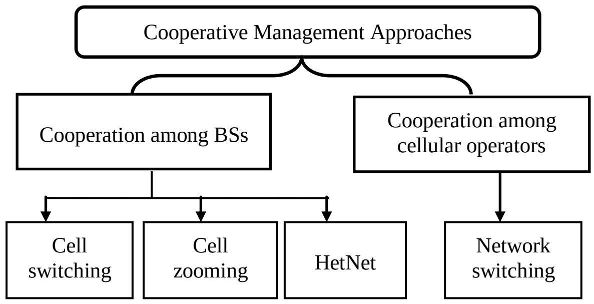

Fig. 1. Classifications of different cooperative techniques.

A. *Switching on/off Cells*

Switching off unused wireless resources and devices has become the most popular approach to reduce power consumption in cellular networks because it can save large amounts of energy. The power consumption grows proportionally with the number of cells, N_{cell}, hence, the total power consumption (in Watt), is calculated as [5],

$$P_{tot} = N_{cell} N_{TRX} \left(\frac{\frac{P_{out}}{\eta_{PA}\left(1-\sigma_{feed}\right)} + P_{RF} + P_{BB}}{\left(1-\sigma_{DC}\right)\left(1-\sigma_{MS}\right)\left(1-\sigma_{Cool}\right)} \right) \quad (1)$$

where $\sigma_{feed}, \sigma_{DC}, \sigma_{MS}$, and σ_{Cool} denote losses incurred by the feeder, DC-DC power supply, main supply, and cooling, respectively. P_{tx}, P_{RF}, and P_{BB} are the output power per transmit antenna, radio frequency, and baseband power, respectively. η_{PA} denotes the PA power efficiency, and N_{TRX} is the number of transceivers.

Cell switching is based on the traffic load condition: if the traffic is low in a given area, some cells will be switched off, and the radio coverage and service will be provided by the remaining active cells. Therefore, the active cells will increase their transmission power to cover the area of the inactive cells. This may lead to a lack of coverage because the BS maximum power is limited and also falls rapidly with the increased radius of the cell. It can be written in a closed form for a cell coverage area (in %) as [8],

$$C = Q\left(\frac{P_{\min} - P_{rx}(r)}{\sigma}\right) + \exp\left(\frac{2-2ab}{b^2}\right) Q\left(\frac{2-ab}{b}\right) \quad (2)$$

where,

$$a = \left(\frac{P_{\min} - P_{rx}(r)}{\sigma}\right), \qquad b = \left(\frac{10\alpha \log_{10}(\exp)}{\sigma}\right)$$

According to Eq. (2), the coverage area of a cell is a function of the minimum received power at the cell boundary, P_{min}; the received power, P_{rx}; the path loss exponent, α; and the shadowing standard deviation, σ. P_{min} (in dBm) can be expressed as [9],

$$P_{\min} = N_o B.w + N_f + SINR + IM - G_d \quad (3)$$

where $N_oB.w$ represents the thermal noise level in a specified noise bandwidth, N_f is the noise figure for the receiver, *SINR* is the minimum signal to interference noise value required for the communication link to be maintained the, *IM* is the implementation margin, and G_d represents the diversity gain. Then, P_{rx} (in dBm) can be expressed as [9],

$$P_{rx}(r) = P_{tx} - 10\ \log_{10} K - 10\alpha \log_{10}\left(\frac{r}{r_o}\right) - 10\ \log_{10} X_\sigma \quad (4)$$

where P_{tx}, and r denote the transmit power, and propagation distance, respectively. The value of K is free-space path loss up to a distance r_o. The term r_o is a reference distance. X_σ is a slow fading effect.

Several studies have investigated the switch-off approach. In [10]-[12], different approaches for switching off a specific number of BSs in Universal Mobile Telecommunications System (UMTS) cellular networks during low traffic periods are presented. In [10], Chiaraviglio *et al.* switched off a randomly chosen number of BSs, and the energy reduction was computed by simulating UMTS cellular networks. In [11], the same authors presented an improvement of their former work. They proposed a dynamic network planning for switching BSs on and off and considered an uniform and a hierarchical scenario. In another work [12], Marsan *et al.* showed how to optimise energy savings by assuming that any fraction of cells can be switched off according to a deterministic traffic variation pattern over time. In addition, in [13], two approaches that achieve energy savings were proposed: (i) a greedy centralised algorithm, where each BS is examined according to its traffic load to determine whether the BS will be switched off, and (ii) a decentralised algorithm, where each BS locally estimates its traffic load and decides independently whether it is going to be switched off. Gong *et al.* [14] proposed a dynamic switch on/off algorithm based on blocking probabilities. The BSs are switched off according to the traffic variation with respect to the blocking probability constraint. Reference [15] studied the optimal number of active BSs that will be deployed based on the trade-off between fixed power and dynamic power. A recent finding published in [16] presented a novel optimisation model that can be used for energy-saving purposes at the level of a UMTS cellular access network. Bousia *et al.* [17] proposed a switch-off decision based on the average distance between BSs and UEs, where the BS that is at a maximum average distance will be switched off. Fig. 2 provides a summary of related works that have investigated the possibility of reducing energy consumption via the switch-off approach.

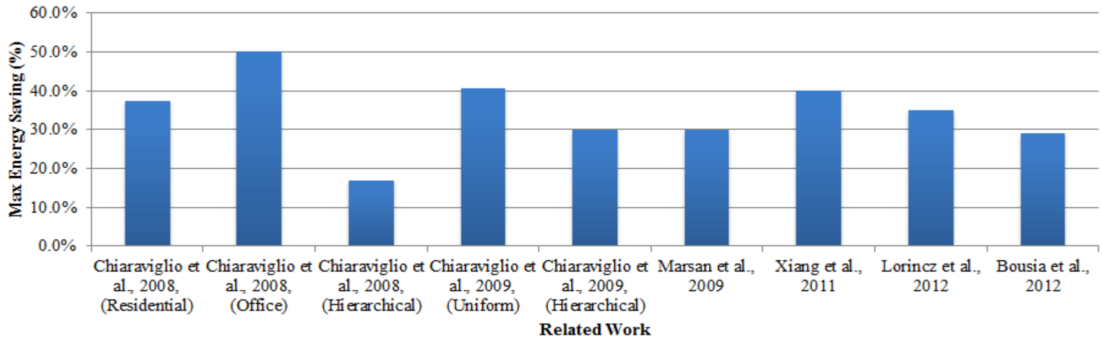

Fig. 2. Studies that have investigated the possibility of reducing energy consumption via the switch-off approach.

Advantages: The energy savings in this approach depend on the number cells that will turn off. However, Switching BSs off is considered an effective way to improve energy efficiency due to the switch-off power amplifier (PA), which consumes the largest portion of energy in a BS (approximately 65% of the total energy consumption) [18]. A trade-off between the number of cells that will be turned off and the QoS should be considered.

Shortcomings: First, the BS maximum power is limited; accordingly, there will be some areas without coverage, which can contribute to the deterioration in the quality of service. Second, the increase in power of the active cells reduces the energy savings. Finally, this approach reduces battery life for users because they require higher receiver power to connect with the other cells, which can be located at long distances away from them.

B. Cell Zooming

The principle of this technique depends on the ability to allow for the adjustment of the size of the cell according to the traffic load. When congestion occurs at a cell due to an increase in the number of UEs, the congested cell could “zoom-in,” while neighboring cells with a smaller amount of traffic could “zoom-out” to provide coverage for the UEs that cannot be served by the congested cell.

If the neighboring cells can provide coverage while the congested cell does not require zooming-in, then the congested cell directly enters into sleep mode to reduce energy consumption. The major component in this design is a cell-zooming server (CS). A CS performs many important processes in this approach, such as collecting network information (e.g., traffic load, channel conditions), data analysis, and deciding whether to zoom [19]. However, if the cells that must zoom-out to provide coverage to the neighboring cells have switched off and cannot provide this coverage due to the limited maximum transmission power of the BS, then an increase in energy consumption occurs because the neighboring cells are unable to switch off, resulting in areas without coverage. To solve this problem, [20] proposed deploying more small cells to further improve energy consumption, i.e., more cells can be switched off compared to the traditional scheme. Reference [21] highlights a small cell deployment, which designed to serve a limited coverage area—approximately 100 times smaller than a traditional macro cell. Where that the small cells target a coverage radius of 50−150 m and radiate at low power (0.1-10 W), thereby increasing energy efficiency and reducing the path loss. Interested readers can find more details in [22]. However, the cell zooming approach reduces the energy consumption of BSs by up to 40% [23].

This technique can improve the throughput and lengthen the UE’s battery. However, the major challenge in these approaches is 'inter-cell interference.' Inter-cell interference in cellular networks is influenced by two major factors—path loss and cell size. Shrinking the cell size decreases the distance between the neighboring BSs and therefore increases inter-cell interference. Designing energy-efficient networks that balance energy savings and inter-cell interference is still an ongoing issue. Based on the traffic load, some cells are zoom-in and others are zoom-out; therefore, when the zoom-out cells increase their transmission power to address areas covered by the zoom-in cells, two problems will emerge. First, the BS maximum power is limited; accordingly, there will be some areas without coverage, which can contribute to the deterioration in the quality of service. Second, this approach reduces the battery life for the users because they require higher transmitting power to connect with the other cells, which can be located at long distances away from them.

C. Heterogeneous Network Deployment

In [24], the authors presented a comprehensive overview on heterogeneous networks. These networks are intended to improve both the throughput and energy consumption through the deployment of small size cell networks, such as micro, pico, and femto. The mechanism of these networks is further discussed in [25]. In the following sections, we will discuss the energy efficiency of downlink two-tier heterogeneous networks.

C.1. Macrocell-Microcell Deployment

The power consumption is accumulative. Therefore, the overall power consumption P_C (in Watt) can be expressed as follows,

$$P_C = P_{Macro} + N_{micro} P_{Micro} \tag{5}$$

where P_{Macro} and P_{Micro} denote to macrocell power consumption and microcell power consumption, respectively. N_{micro} refer to the number of microcells within macrocell.

However, in green cellular radio networks, a trade-off between the power consumption and the coverage is an important factor. The overall coverage (in %) can be expressed as follows [26],

$$C_{tot} = \left(N_{micro} \frac{A_{micro}}{A_{macro}} C_{micro} + (1 - N_{micro} \frac{A_{micro}}{A_{macro}})\ C_{macro} \right) \tag{6}$$

where A_{macro} is the area of macrocell and A_{micro} is the area of microcell; C_{macro} and C_{micro} are the coverage of macrocell and microcell.

References [27], [28] investigated the impact of both homogeneous (pure micro and macro) and heterogeneous networks, consisting of a varying number of micro sites based on the traffic load conditions and on energy efficiency. The result of the study indicated that the homogeneous micro deployment offers improved energy efficiency compared to a heterogeneous network. With an increase in both the throughput and number of users in the network, the best method to improve the energy efficiency is by deploying more micro sites. The energy efficiency of heterogeneous networks in LTE-A has been investigated in [29] for both homogenous and heterogeneous networks, by reducing the number and size of active macro-cells following traffic load conditions. In [26], a joint deployment strategy was investigated utilizing micro-cells within the macro-cell network, and the impact on energy consumption was determined. In addition, the authors considered the power consumption area as a performance metric. The results showed, a moderate energy savings can be achieved for full-load scenarios. The same authors, in [30], investigated the same issue in more detail. They evaluated and optimized the average number of micro sites per macro cell. Reference [31] investigated on the impact of random micro site deployment with varying density on the energy efficiency. In addition, they further introduced a traffic model that allows for taking into account the co-channel interference and non-full load scenarios.

C.2. Macrocell-Picocell Deployment

The power consumption is determined by Eq. (7) in Watt, and the coverage in Eq. (8) in %,

$$P_C = P_{Macro} + N_{pico} P_{pico} \tag{7}$$

$$C_{tot} = \left(N_{pico} \frac{A_{pico}}{A_{macro}} C_{pico} + (1 - N_{pico} \frac{A_{pico}}{A_{macro}})\ C_{macro} \right) \tag{8}$$

where P_{pico}, N_{pico}, A_{pico}, and C_{pico} denote to picocell the power consumption, the number of picocells within macrocell, the area of picocell, and the coverage of picocell.

Reference [32] examined the impact on energy efficiency of the deployment of different pico-cell sizes in the macro-cell. Simulations indicated that this approach can reduce the energy consumption by 60% when used by 20% of customers within the pico-cells' coverage area. The numerical results in [33] confirmed that there exists an optimal pico-macro density ratio that maximizes the overall energy efficiency. Reference [34] demonstrated that both the cell energy efficiency and area energy efficiency can be improved by deploying low power pico stations combined with a reduction of macro transmission power. The authors in [35] proposed an energy saving strategy for an LTE heterogeneous network with overlapping picos that uses the remaining resources of the neighboring pico-cells and macro-cell to accept the users of pico-cells that are to be switched off. Simulations showed that the proposed approach has an improved performance in increasing the energy efficiency of the system. A recent study in reference [36] evaluated the Energy Efficiency of 3GPP LTE-A relay and pico-cell Deployments. The results showed that the relay nodes and pico-cells achieve a significant gain in the throughput power consumption in the uplink. Similar gains are achieved by pico-cells in the downlink as well, whereas relay nodes provide similar throughput power consumption in the downlink as macro-cell deployments.

C.3. Macrocell-Femtocell Deployment

Femto-cells are the closest to the users in terms of the network size, i.e., the distances are shorter, which leads to a decrease in the power transmission, thereby increasing the energy efficiency and reducing the path loss [37]. Femto-cell deployment has a 7:1 operational energy advantage ratio over the expansion of the macro-cell network to provide approximately similar indoor coverage [38]. Reference [39] provided an overview of a joint femto-macro deployment. Zheng *et al.*, in [40], corroborated that femto-cell technology is an energy-efficient solution for indoor coverage in LTE-A cellular networks. Reference [41] described how femto-cells impact the capacity and the energy efficiency of LTE-A networks.

A recent study in reference [42] offered analytical models of the power consumption in macro-cells, micro-cells, pico-cells and femto-cells. This paper discussed the five classes of networks. In Class A, they have considered a femto based network where, instead of macro, an area is fully covered by femto. The results show a reduction in energy consumption by 82.72–88.37%. Class B network divides the whole area into three parts: urban area, suburban area and rural area, which are covered by femto, macro and portable femto, respectively. Simulation results show a reduction in the total transmitted power between 78.53–80.19%. In Class C, femto, pico, micro and portable femto are allocated in densely populated urban area, sparsely populated urban areas, suburban areas and rural areas, respectively, which leads to a reduction in the total transmitted power between 9.19–9.79%. In Class D, micro, pico and femto are allocated to border regions and macro in the rest of the region of an area. Simulation results demonstrate a reduction in total transmitted power between 5.52–5.98%. In Class E network, femto-cells are allocated at the boundary region of the macro and turned on in that region when the received signal from the macro BS is too low to successfully receive or generate a call. When all the femto-cells are kept on, the macro shrinks in coverage area. Simulation results present 1.94–2.66% reduction in power consumption.

However, recent research [43], [44] are mostly focused on the main challenge of inter-cell interference coordination, which is still an open issue that needs to be addressed.

Advantages: Lower transmission power, higher SINR, higher spectral efficiency, lower loss paths, prolonged handset lifetime, and smaller cells that have lower costs.

Shortcomings: The major challenge is the interference management between the heterogeneous environments, which may lead to dead zone problems. However, reference [45], presented an overview on Inter-cell Interference Coordination for Heterogeneous Networks. Additionally, the network capital expenses increase due to an increased number of sites; moreover, the operation and maintenance becomes more complex.

IV. Principle of Cooperation Management Technique to an Energy Saving Solution

The philosophy behind the all approaches of reducing energy consumption based on traffic load is that if traffic is low in a given area, several cells can be switched off, and the radio coverage and service can be provided by the remaining active cells, according to the operator's deployment policy. The cells switch off can be applied in both single layer network and multi-layer network such as a heterogeneous network (HetNet). In HetNet, not all the cells scattered in the network have the capability to execute switch off/on operations. Accordingly, the network has classified into coverage sites and capacity sites. Capacity booster cells have the capability to execute switch off/on operations, while the coverage will be guaranteed by coverage cells.

Both BS and operation, administration, and maintenance (OAM) system can initiate cell switch off/on operations based on different trigger mechanisms. The BS depends on the real-time traffic load of its cells, while OAM system depends on the historical statistics to the traffic load of a wide range of cells.

TABLE III: TECHNIQUES OF COOPERATION MANAGEMENT AMONG BSS IN THE NETWORK.

Features	BS trigger	OAM trigger
Trigger mechanism	Local real-time traffic load monitoring of the eNB's cells	Historical statistics to the traffic load.
Switch-off	Enhancement to the current X2 interface signalling message of eNB configuration update or X2 setup	Explicit OAM command of cell deactivation shall be transmitted via Itf-N, cell status notification to the neighbouring eNBs via X2 interface is necessary.
Switch-on	Explicit X2 signalling message of cell activation is expected to request for the eNB in cell deactivation state	Explicit OAM command of cell activation shall be transmitted via Itf-N, cell status notification to the neighbouring eNBs via X2 interface is necessary.

1) Cell switching-off:

During the operation time, the BS is monitoring the traffic load and is able to switch off when the traffic load drops below a certain threshold and stays below the threshold for a certain period. At this time, the BS will notify its neighbouring BSs by X2 signalling to inform that this cell will be switched off. Neighbouring BSs will care about the coverage for this area, and resident UEs in the cell that switched-off will inter-handover to neighbouring cells based on a stronger UE-BS path.

For OAM, cell deactivation is initiated by explicit OAM command of cell deactivation shall be transmitted via Itf-N and then set down to the BS. When the BS successfully or unsuccessfully switches off the cell, it will return a response signal to the OAM system.

2) Cell switching-on:

Cell activation is initiated by the neighbouring BS's trigger mechanism which are still monitoring the traffic load in the same area. If the traffic load increased above a certain threshold and stayed for a certain period, an explicit X2 signaling message of cell activation is expected to request for the BS which in the cell deactivation state to switch on to the original state again, i.e. active. Therefore, the neighbouring BSs will allow its resident UEs to handover to this recovered cell again, based on a stronger UE-BS path.

For OAM, cell activation is similar to that of cell deactivation which is initiated by the OAM's trigger mechanism. When the BS successfully or unsuccessfully switches on the cell, it will return a response signal to the OAM system.

Table III summarizes the differences between both of the principles of the BS and OAM.

V. MOBILE OPERATION COOPERATION FOR ENERGY EFFICIENCY CELLULAR WIRELESS COMMUNICATION

Recent studies [46], [47] have proposed the cooperation between different operators (particularly in dense urban centers), which leads to substantially improved energy efficiency of cellular systems. Most of the previous studies focused on the energy-aware management of individual cellular access networks, estimating the amount of energy that can be saved by an operator by reducing the number of active cells in a network during decreased traffic.

Cooperation between mobile network providers in the same geographical area can be an effective way of reducing operating expenditures, as stated in [47]. The basic idea of cooperation among mobile operators is to switch off one or more BSs when the traffic load is low, managing coverage with a subset of the remaining active BSs through either the same operator network or another operator, with both networks covering the same geographical area. The idea was inspired by roaming.

The amount of energy that can be saved by using two cellular access networks in high-traffic conditions has been investigated in [48]. One of the two networks can be switched off during low traffic, and service can be supplied with just one network. This has achieved energy savings of 15-25%. The same authors, in [46], improved their idea by introducing more than two operators in a metropolitan area (a typical case) and assuming that their networks were designed with different QoS targets. The results showed that it was possible to save between 20-40% in energy costs. The fairness and stability between cooperating providers, with the objective of minimizing overall energy consumption/monetary costs, has been investigated in [47], based on the concepts of game theory. Evaluating cross-operator cooperation using a game theoretic approach is an interesting area of research that is beneficial in designing energy-efficient operation policies. For interested readers, [46] has presented a mathematical analysis of this approach.

Advantages: This approach can save a huge amount of energy with an energy-aware cooperative management of networks and suggests that, to reduce energy consumption and thus the cost to operate the networks, new cooperative attitudes of the operators should be encouraged with appropriate incentives or enforced by regulatory authorities.

Shortcomings: Many practical challenges remain that must be addressed through additional research to realize the potential benefits of cooperation between mobile operators. Some of these challenges include the complex network operation due to the roaming traffic from other operators' users, the high bandwidth backhaul to support increased traffic, the handover process, the switch-off transients due to the transfer of users from a network that is switched off to a network that remains on, and the type of services that are provided by the network that remains on. In addition, if there is ongoing VoIP calls or video streaming, there must be compatibility among the channel capacity with signaling loads. Finally, there will be cross operator authentication and billing concerns.

VI. Conclusion and Open Research Issues

This article provides an overview of the energy efficiency of cellular communication systems, which is becoming a major concern for network operators to not only reduce the operational costs, but also to reduce their environmental effects. However, research on energy efficient or "green" cellular network is quite broad; this paper highlighted on the cooperative techniques among cells and network operators as effective ways to improve the energy efficiency. We began our discussion with energy-aware cooperative BSs power management, where certain BSs can be turned off depending on the load which called 'switching cells'. Minimizing the number of BSs with a better network design and bringing minor architectural changes can be beneficial in achieving energy efficiency, which is a concept of "Cell zooming". Another way to significantly reduce the power consumption is a heterogeneous network deployment based on smaller cells such as micro, pico and femtocells is another significant technique. We also discussed cooperative mobile operator's power management. Table IV shows summarize the energy savings that can be obtained through of the techniques that discussed in this paper.

TABLE IV: Energy Saving Obtained by the Discussed Techniques.

Energy efficient solutions	Technique	Energy Savings (%)
Cell Switching	Energy-aware by cell switching	12-50 %
HetNet	Macrocell-microcell deployment	44%
	Macrocell-picocell deployment	60%
	Macrocell-femtocell deployment	78-88%
Cell Zooming	Zooming in/out of cell size	up to 40%
Cooperation among cellular operators		
Cooperative Mobile Operators	Switch off of the network according to a deterministic traffic	15%-40% Depends on the number of operators.

Lastly, we briefly introduce some of the open research issues related to BS cooperation

- In the switching cell and cell zooming techniques, issues, such as coverage, inter-cell interference, compatibility between signaling load and channel capacity, and impact on the battery life of users, are still open for investigation in future studies.
- In heterogeneous networks, the energy efficient resource management, the inter-cell interference as well as the coverage, and the impact of high frequency reuse on the network are all issues that need to be further studied and must be thoroughly analyzed.
- In the collaboration between mobile operators, there are issues that need additional investigation in future studies, such as resource management; increasing the load on the host network (due to its own customers plus the roaming customers) and the ability to provide good service as well as handling traffic data, for example, VoIP calls or video streaming with no delay; compatibility between the signaling load and channel capacity; and communication overhead due to handovers. Other important issues are the coverage of mobile operators being different from one area to another and the types of services being different.
- In cooperation between mobile operators, the issue that should be further studied is complexity and communication overhead. The trade-off analysis of the computational complexity versus savings in the transmit power requirement is an important issue. The complexity increases with an increase in the number of networks. Emphasis should be given to designing low complexity schemes, resulting in easy, viable implementations as well as gain in the overall network level energy efficiency.

Acknowledgment

The authors would like to thank the Universiti Kebangsaan Malaysia for the financial support of this work, under the Grant Ref: ETP-2013-072.

References

[1] International Telecommunication Union (ITU) Statistics Database. [Online]. Available: http://www.itu.int/en/ITU-D/Statistics/Pages/stat/default.aspx

[2] Malaysia Telecommunications Statistics Database. (2013). [Online]. Available: http://www.forest-interactive.com/malaysia-statistics-2013/

[3] T. Chen, Y. Yang, H. Zhang, H. Kim, and K. Horneman, "Network energy saving technologies for green wireless access networks," *IEEE Wireless Communications*, vol. 18, no. 5, pp. 30-38, October 2011.

[4] M. H. Alsharif, R. Nordin, and M. Ismail, "Survey of green radio communications networks: Techniques and recent advances," *Journal of Computer Networks and Communications*, vol. 2013, December 2013.

[5] G. Auer, O. Blume, V. Giannini, I. Godor, A. M. Imran, Y. Jading, *et al*., "Energy efficiency analysis of the reference systems, areas of improvements and target breakdown," EARTH Project Report, Deliverable D2.3, pp. 1-68, January 2012.

[6] B. Berglund, J. Johansson, and T. Lejon, "High efficiency power amplifiers," *Ericsson Review*, vol. 3, pp. 92-96, 2006.

[7] Alcatel-Lucent: Annual Report on Form 20-F, Sep. 2014.

[8] A. Goldsmith, *Wireless Communication*, 2nd ed., U.K.: Cambridge University Press, 2005, ch. 2, pp. 47-50.

[9] S. Sesia, I. Toufik, and M. Baker, *LTE - The UMTS Long Term Evolution: From Theory to Practice*, 2nd ed., USA: Wiley, 2011, ch. 21, pp. 478-479.

[10] L. Chiaraviglio, D. Ciullo, M. Meo, and M. A. Marsan, "Energy-aware UMTS access networks," in *Proc. 11th International Symposium on Wireless Personal Multimedia Communications*, 2008, pp. 1-5.

[11] L. Chiaraviglio, D. Ciullo, M. Meo, and M. A. Marsan, "Energy-efficient management of UMTS access networks," in *Proc. 21st International Teletraffic Congress*, 2009, pp. 1-8.

[12] M. A. Marsan, L. Chiaraviglio, D. Ciullo, and M. Meo, "Optimal energy savings in cellular access networks," in *Proc. IEEE International Conference on Communications Workshops*, 2009, pp. 1-5.

[13] S. Zhou, J. Gong, Z. Yang, Z. Niu, and P. Yang, "Green mobile access network with dynamic base station energy saving," in *Proc. ACM MobiCom*, 2009, pp. 1-5.

[14] J. Gong, S. Zhou, Z. Niu, and P. Yang, "Traffic-aware base station sleeping in dense cellular networks," in *Proc. 18th International Workshop on Quality of Service*, 2010, pp. 1-2.

[15] L. Xiang, F. Pantisano, R. Verdone, X. Ge, and M. Chen, "Adaptive traffic load-balancing for green cellular networks," in *Proc. 22nd IEEE International Symposium on Personal Indoor and Mobile Radio Communications*, 2011, pp. 41-45.

[16] J. Lorincz, A. Capone, and D. Begusic, "Impact of service rates and base station switching granularity on energy consumption of cellular networks," *EURASIP Journal on Wireless Communications and Networking,* vol. 2012, November 2012.

[17] A. Bousia, A. Antonopoulos, L. Alonso, and C. Verikoukis, ""Green" distance aware base station sleeping algorithm in LTE-advanced," in *Proc. IEEE International Conference on Communications*, 2012, pp. 1347-1351.

[18] Z. Hasan, H. Boostanimehr, and V. K. Bhargava, "Green cellular networks: A survey, some research issues and challenges," *IEEE Communications Surveys & Tutorials*, vol. 13, no. 4, pp. 524 - 540, November 2011.

[19] Z. Niu, Y. Wu, J. Gong, and Z. Yang, "Cell zooming for cost-efficient green cellular networks," *IEEE Communications Magazine*, vol. 48, no. 11, pp. 74-79, November 2010.

[20] X. Weng, D. Cao, and Z. Niu, "Energy-efficient cellular network planning under insufficient cell zooming," in *Proc. 73rd International Conference on Vehicular Technology Conference (VTC Spring)*, China, May 2011, pp. 1-5.

[21] J. Hoydis and M. Debbah, "Green, cost-effective, flexible, small cell networks," *IEEE Communications Society MMTC*, vol. 5, no. 5, pp. 23-26, September 2010.

[22] J. Hoydis, M. Kobayashi, and M. Debbah, "A cost-and energy-efficient way of meeting the future traffic demands," *IEEE Vehicular Technology Magazine*, vol. 6, pp. 37-43, March 2011.

[23] R. Balasubramaniam, "Cell zooming techniques for power efficient base station operation," Master dissertation, Dept. Elect. Eng., San Diego State Univ., USA, 2012.

[24] H. Hamdoun, P. Loskot, T. O'Farrell, and J. He, "Survey and applications of standardized energy metrics to mobile networks," *Ann. Telecommun*., vol. 67, no 3, pp. 113-123, April 2012.

[25] 3GPP R3-100162. Overview to LTE energy saving solutions to cell switch off/on. (January 2010). [Online]. Available: http://www.3gpp.org/ftp/tsg_ran/WG3_Iu/TSGR3_66bis/docs/R3-100162.zip

[26] A. Damnjanovic, J. Montojo, Y. Wei, T. Ji, T. Luo, *et al.*, "A survey on 3GPP heterogeneous networks," *IEEE Wireless Communications*, vol. 18, no. 3, pp. 10-21, June 2011.

[27] F. Richter, A. J. Fehske, and G. P. Fettweis, "Energy efficiency aspects of base station deployment strategies for cellular networks," in *Proc. 70th International Conference on Vehicular Technology Conference Fall*, Germany, September 2009, pp. 1-5.

[28] F. Richter and G. P. Fettweis, "Cellular mobile network densification utilizing micro base stations," in *Proc. IEEE International Conference on Communications*, May 2010, pp. 1-6.

[29] C. Khirallah, J. S. Thompson, and D. Vukobratovic, "Energy efficiency of heterogeneous networks in LTE-Advanced," in *Proc. Wireless Communications and Networking Conference Workshops*, Paris, April 2012, pp. 53 – 58.

[30] F. Richter, A. J. Fehske, P. Marsch, and G. P. Fettweis, "Traffic demand and energy efficiency in heterogeneous cellular mobile radio networks," in *Proc. 71st IEEE Vehicular Technology Conference (VTC 2010-Spring)*, Taiwan, May 2010, pp. 1-6.

[31] A. J. Fehske, F. Richter, and G. P. Fettweis, "Energy efficiency improvements through micro sites in cellular mobile radio networks," in *Proc. IEEE GLOBECOM Workshops*, December 2009, pp. 1-5.

[32] H. Klessig, A. J. Fehske, and G. P. Fettweis, "Energy efficiency gains in interference-limited heterogeneous cellular mobile radio networks with random micro site deployment," in *Proc. 34th IEEE Sarnoff Symposium,* Princeton, NJ, May 2011, pp. 1-6.

[33] H. Claussen, L. T. Ho, and F. Pivit, "Effects of joint macrocell and residential picocell deployment on the network energy efficiency," in *Proc. 19th International Symposium on Personal, Indoor and Mobile Radio Communications,* Swindon, September 2008, pp. 1-6.

[34] Q. S. Quek Tony, C. W. Chi, and K. Marios, "Energy efficiency analysis of two-tier heterogeneous networks," in *Proc. 11th European Conference on Sustainable Wireless Technologies*, Vienna, April 2011, pp. 1-5.

[35] W. Wang and G. Shen, "Energy efficiency of heterogeneous cellular network," in *Proc. 72nd IEEE Vehicular Technology Conference Fall*, Ottawa, September 2010, pp. 1-5.

[36] A. B. Saleh, O. Bulakci, S. Redana, B. Raaf, and J. Hamalainen, "Evaluating the energy efficiency of LTE-Advanced relay and picocell deployments," in *Proc. IEEE International Conference on Wireless Communications and Networking Conference,* China, April 2012, pp. 2335 – 2340.

[37] C. Liu, Z. Pan, N. Liu, and X. You, "A novel energy saving strategy for LTE HetNet," in *Proc. IEEE International Conference on Wireless Communications and Signal Processing*, Nanjing, November 2011, pp. 1-4.

[38] J. G. Andrews, H. Claussen, M. Dohler, S. Rangan, and M. C. Reed, "Femtocells: Past, present, and future," *IEEE Journal on Selected Areas in Communications*, vol. 30, no. 3, pp. 497-508, April 2012.

[39] C. Forster, I. Dickie, G. Maile, H. Smith, and M. Crisp, "Understanding the environmental impact of communication systems," Final Report, Sep. 2014.

[40] D. Calin, H. Claussen, and H. Uzunalioglu, "On femto deployment architectures and macrocell offloading benefits in joint macro-femto deployments," *IEEE Communications Magazine,* vol. 48, no. 1, pp. 26-32, January 2010.

[41] K. Zheng, Y. Wang,W. Wang, M. Dohler, and J. Q. Wang, "Energy-efficient wireless in-home: The need for interference-controlled femtocells," *IEEE Wireless Communications*, vol. 18, no. 6, pp. 36-44, December 2011.

[42] L. Saker, S. E. Elayoubi, and T. Chahed, "How femtocells impact the capacity and the energy efficiency of LTE-Advanced networks," in *Proc. 22nd IEEE International Symposium on Personal Indoor and Mobile Radio Communications*, Toronto, September 2011, pp. 177 – 181.

[43] A. Mukherjee, S. Bhattacherjee, S. Pal, and D. De, "Femtocell based green power consumption methods for mobile network," *Computer Networks*, vol. 57, no. 1, pp. 162–178, January 2013.

[44] S. Xu, J. Han, and T. Chen, "Enhanced inter-cell interference coordination in heterogeneous networks for LTE-advanced," in *Proc. 75th IEEE International Conference on Vehicular Technology Conference*, Yokohama, May 2012, pp. 1-5.

[45] L. Lindbom, R. Love, S. Krishnamurthy, C. Yao, N. Miki, and V. Chandrasekhar. (2011). Enhanced inter-cell interference coordination for heterogeneous networks in LTE-Advanced: A survey. [Online]. Available: http://arxiv.org/abs/1112.1344
[46] M. A. Marsan and M. Meo, "Energy efficient wireless internet access with cooperative cellular networks," *Computer Networks*, vol. 55, no. 2, pp. 386-398, February 2011.
[47] L. Militano, A. Molinaro, A. Iera, and Á Petkovics, "Introducing fairness in cooperation among green mobile network operators," in *Proc. 20th International Conference on Software, Telecommunications and Computer Networks*, Italy, September 2012, pp. 1-5.
[48] M. A. Marsan and M. Meo, "Energy efficient management of two cellular access networks," *ACM SIGMETRICS Performance Evaluation Review*, vol. 37, no. 4, pp. 69-73, March 2010.

Mohammed H. Alsharif received his engineering degree in Communication and Control from the Electrical and Computer Engineering Department at the Islamic University of Gaza (IUG), Palestine, in 2008 and an M.S. degree in Computer and Communication Engineering from Universiti Kebangsaan Malaysia (UKM), Malaysia, in 2012. Alsharif is currently pursuing a Ph.D. degree in Electrical and Electronic Engineering at the Universiti Kebangsaan Malaysia. His research interests include wireless communications, green communication, cooperative communication, and multiple radio access technologies.

Rosdiadee Nordin received his B.Eng. from Universiti Kebangsaan Malaysia in 2001 and Ph.D. from University of Bristol, United Kingdom in 2011. He is currently a senior lecturer in Department of Electrical, Electronics and System Engineering in Universiti Kebangsaan Malaysia teaching different subjects related to wireless networks, mobile and satellite communications. His research interests include resource allocation, green radio, Multipl-Input Multiple-Output (MIMO), Orthogonal Frequency-Division Multiple Access (OFDMA), carrier aggregation (CA), cognitive radio and indoor wireless localization.

Mahamod Ismail joined the Department of Electrical, Electronics and System Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia (UKM) in 1985, and currently, he is a Professor in Communication Engineering. He received the B.Sc. degree in Electrical and Electronics from University of Strathclyde, U.K. in 1985, the M.Sc. degree in Communication Engineering and Digital Electronics from University of Manchester Institute of Science and Technology (UMIST), Manchester U.K. in 1987, and the Ph.D. from University of Bradford, U.K. in 1996. He was with the first Malaysia Microsatellite TiungSat Team Engineers in Surrey Satellite Technology Ltd. U.K. for 9 months started in June 1997. His research interests include mobile, wireless networking and radio resource management for the next generation wireless communication.

