A Survey in Green Cellular Networks

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Abstract—Energy efficiency in cellular networks is a growing concern for cellular operators to not only maintain profitability, but also to reduce the overall environment effects. This emerging trend of achieving energy efficiency in cellular networks is motivating the standardization authorities and network operators to continuously explore future technologies in order to bring improvements in the entire network infrastructure. In this paper, we present a brief survey of methods to improve the power efficiency of cellular networks, explore some research issues and challenges and suggest some techniques to enable an energy efficient or "green" cellular network. Since base stations consume a maximum portion of the total energy used in a cellular system, we will first provide a comprehensive survey on techniques to obtain energy savings in base stations. Next, we discuss how heterogenous network deployment based on micro, pico and femtocells can be used to achieve this goal.

Index Terms—Green communication, energy efficient networks, efficiency metrics, microcells, picocells, femtocells.

I. Introduction

Tremendous growth in cellular data traffic due to Android and iPhone devices, iPad and Kindle and success of social networking giants like Facebook. Number of pages viewed on the Opera mobile browser grew from 1.8 billion pages in January 2008 to 109 billion pages in April 2012. Since April 2011, page views increased by 88%. In fig.1 ,we shown that BSs take around 57% of energy of cellular network. There are currently more than 4-million base station (BSs) serving mobile users. Each consuming an average of 25 MWH per year. The numbers of BSs in developing regions are expected to almost double by 2012 as shown in fig. 2.W hile the BSs connected to electrical grid may cost approximately 3000$ per year to operate, the off-grid BSs in remote areas generally run on diesel power generators and may cost ten times more. So , The rising energy costs and carbon footprint of operating cellular networks have led to new research area called "green cellular networks".

II. MEASURING GREENNESS: THE METRICS

Metrics can be Facility-level metrics: relates to high-level systems where equipment is deployed, equipment level metrics: evaluate performance of individual equipment, network level metrics: related to capacity and coverage of the network.
Energy Efficiency Metrics are used to: Compare and assess the energy consumption of various components and the overall network. Set long term research goals of reducing energy consumption.
So, defining metrics at component level is easy .while ,it is more challenging to define metrics at system on network level . To asses true "Greenness" metrics must also consider Deployment costs: site construction, QOS requirements: transmission delay, Spectral efficiency, and … Due to the variety of network types and objectives defining one single metric is doubtful. In tab.1 there are many type to measure greenness.

III. III. ARCHITECTURE: ENERGY SAVINGS IN BASE STATIONS

Number of cellular BSs has increased many millions within last couple of year .power consumption for each BS can increase up to 1400 watt and energy cost per BS can reach to 3200 $ per annum with carbon footprint of 11 tons of CO_2. Cellular network consist of :Core network: take care of switching, BSs: providing radio frequency interface. Mobile terminals: to make voice and data connection. BSs consist of radio, base band and feeder.BSs consumption around 60% of wireless cellular network, radio consumes more than 80% of BS energy requirements; Power amplifier (PA) consumes almost 50%.

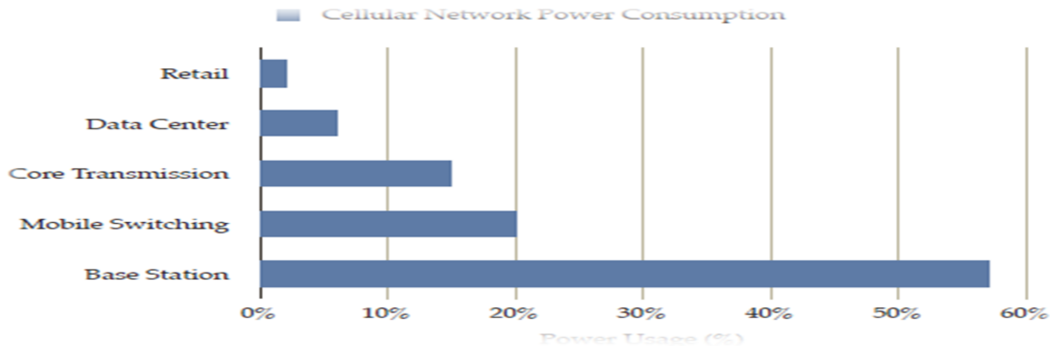

Fig. 1.Power consumption of a typical wireless cellular network

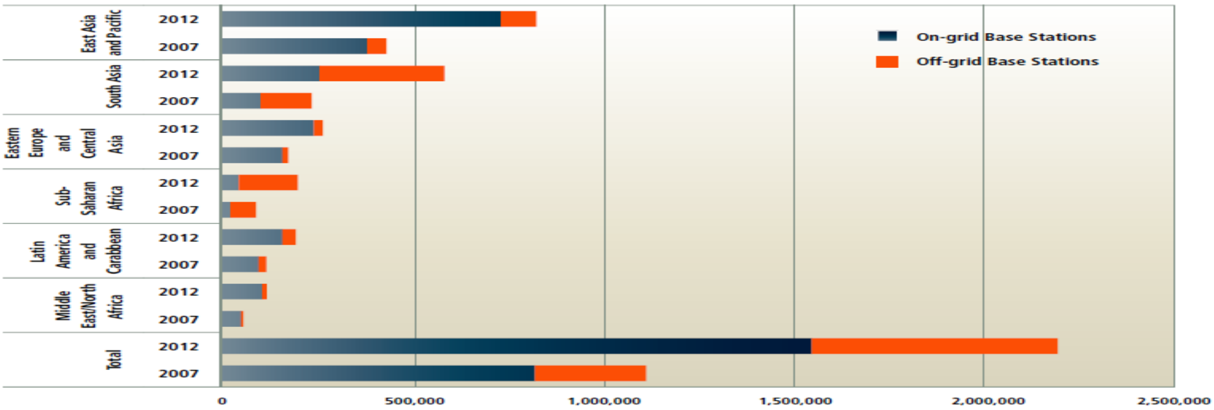

Fig. 2. Growth in base stations in developing regions 2007-2012 (GSMA Research)

TABLE I
SOME ENERGY EFFICIENCY METRICS

Metric	Type	Units	Description
PUE (Power Usage Efficiency)	Facility-Level	Ratio ($\geq$1)	Defined as ratio of total facility power consumption to total equipment power consumption.
DCE (Data Center Efficiency)	Facility-Level	Percentage	Defined as reciprocal of PUE.
Telecommunications Energy Efficiency Ratio (TEER)	Equipment-Level	Gbps/Watt	Ratio of useful work to power consumption
Telecommunications Equipment Energy Efficiency Rating (TEEER)	Equipment-Level	$-\log\left(\frac{\text{Gbps}}{\text{Watt}}\right)$	$-\log\left(\frac{P_{\text{total}}}{\text{Throughput}}\right)$, where P_{total} is given by equation (1)
Energy Consumption Rating (ECR)	Equipment-Level	Watt/Gbps	Ratio of energy consumption over effective system capacity
ECR-Weighted (ECRW)	Equipment-Level	Watt/Gbps	Calculated the same way as ECR except energy consumption is now calculated as $0.35E_f + 0.4E_h + 0.25E_i$, where each term corresponds to energy consumption in full load, half load and idle modes.
ECR-variable-load metric (ECR-VL)	Equipment-Level	Watt/Gbps	Average energy rating in a reference network described by an array of utilization weights [16].
ECR-extended-idle metric (ECR-EX)	Equipment-Level	Watt/Gbps	Average energy rating in a reference network, where extended energy savings capabilities are enabled [16].
Performance Indicator in rural areas (PI_{rural})	Network-Level	km^2/Watt	Ratio of total coverage area to power consumed at site as given by eq. (3)
Performance Indicator in urban areas (PI_{urban})	Network-Level	users/Watt	Ratio of number of subscribers to power consumed at the site as given by eq. (4)

a) improvement in power amplifier: 80-90% of power wasted as heat in PA. So, we need to air cooling that add more energy cost. Modern BSs are inefficient because of their need for PA linearity and leak to average power ratio (PARR). Since these technologies have reached their limits by using Gallium nitride {GaN}based amplifier seem to be more promising by pushing power efficiency levels to over 50%.GaN structure can under higher temperature and high voltage in switch mode . Type of modulation affects on PA efficiency by non

constant envelope of signal causing different in linearity.

b) Power saving protocols: In the current cellular network architecture based on WCDMA/HSPA, BSs and mobile terminals are required to continuously transmit pilot signals. Newer standards such as LTE, LTE-Advanced and WiMAX have evolved to cater ever-growing high speed data traffic requirements. With such high data requirements, although BSs and mobile units (MU) employing newer hardware (such as 6 multiple-input and multiple-output (MIMO) antennas) increase spectral efficiency allowing to transmit more data with the same power, power consumption is still a significant issue for future Computer Science & Information Technology (CS & IT) 345 high speed data networks and they require energy conservation both in the hardware circuitry and protocols.. Energy consumption in base stations can be minimized without affecting the quality of service by developingenergy-efficient, radio resource management schemes. Sleep mode mechanisms for base station operations is one of the promising approaches to reduce energy consumption. The authors in [15] propose two sleep mechanisms for 2G and HSPA base station to shut down a number of systemresources in light traffic scenarios: dynamic way and semistatic way. In dynamic way resources areactivated/deactivated in real-time as a function of the instantaneous load of the system. In a semi-static way resources are kept unchanged during longer time intervals, in the order of one hour. The authors show that the dynamic one achieves larger energy reductions while the semi-static one has an acceptable performance with low complexity. The authors in [16] discuss a sleep mode mechanism for base stations in Orthogonal Frequency-Division Multiple Access (OFDMA) cellular networks where the lightly loaded base stations are turned off randomly achieving explicit expressions for the impact of switching off base stations on the total expected power consumption, on the coverage, and on the amount of radiation to the human's body. The authors assume base station distribution to form a homogeneous Poisson point process and the radio interference to be negligibl

IV. NETWORK PLANNING

Traffic load in cellular networks have significant fluctuations in space and time due to a number of factors such as user mobility and behavior. SO, static cell size deployment is not optimal with change traffic conditions. According to low or heavy traffic , Self-organizing networks (SON) is one of the promising areas of the latest 3rd Generation Partnership Project technology- Long Term Evolution (LTE) for nextgeneration radio access networks that save operational expenditures. The SON can be applied to achieve objectives like self configuration for load balancing, self optimization and self healing, cell outage management, and management of relays and repeaters, etc. The authors in [18] discuss dynamic operations to switch off the redundant base stations during periods of low traffic such as at night to provide significant energy savings. The authors quantitatively estimate the percentage of power savings through a first-order analysis based on real cellular traffic traces and found promising potential savings. They also have identified a number of open issues pertinent to implementation of energy- efficient dynamic base station operation schemes, such as various approaches to ensure coverage, and inter-operator coordination. The authors in [19] discuss the base station handover optimization in self organized networks. The role of selforganized handover optimization in the overall radio network performance is significant. From the results obtained by simulations of handover optimization procedure characterized by heterogeneous radio conditions between neighboring cells, the authors show that their procedure is stable and efficient from initial suboptimal parameter settings towards optimum values of the handover key performance indicators. The authors in [20] introduce algorithms for partitioning energy in coordination with network elements to power on and power off base stations and save energy with the objective of matching offered capacity with the traffic demand in a flexible manner. These algorithms achieve network-level energy saving and are based on shared knowledge of load and coverage information to enable an appropriate cell reconfiguration. The authors analyze the performance of centralized and distributed algorithms under different network topologies and traffic conditions through simulation evaluation. Cell zooming is a technique to adaptively adjusts the cell size according to traffic conditions. It has the potential to balance the traffic load and reduce the energy consumption. When a cell is congested, the cell can zoom in to reduce the cell size and therefore release from the congestion and the neighboring cell zooms out to avoid anypossible coverage hole. Cell zooming can be implemented by adjusting the physical parameters such as the transmit power of base stations, or by base station cooperation and relaying. The authors in [21] discuss cell zooming to balance the traffic load, while reducing the energy consumption. The authors have implemented two cell zooming algorithms centralized and distributed algorithm. In the centralized algorithm resource allocation and cell zooming operations are performed in a centralized way depending on all the channel conditions and user requirements in the networkcollected by the central system. In the distributed algorithm each mobile unit itself selects the base station to beassociated with, based on the broadcasted information by the base stations. The simulation results show that with cell zooming the energy consumption can be greatly reduced.

V. Other ways to reduce energy consumption

In several remote locations of the world such as Africa and Northern Canada, electrical grids are not available or are unreliable. Cellular network operators in these off-grid sites constantly rely on diesel powered generators to run BSs which is not only expensive, but also generates CO2 emissions. One such generator consumes an average of 1500 litres of diesel per month, resulting in a cost of approximately $30,000 per year to the network operator. Moreover, this fuel has tobe physically brought to the site and sometimes it is eventransported by helicopter in remote places, which adds further to this cost. In such places, renewable energy resources such as sustainable biofuels, solar and wind energy seem to be more viable options to reduce the overall network expenditure. Hence, adopting renewable energy resources could save cellular companies such recurrent costs, since they are capital intensive and cheaper to maintain. Also, since renewable energy is derived from resources that are regenerative, renewable energy resources do not generate greenhouse gases such as CO2.

Recently, a program called “Green Power for Mobile” to use renewable energy resources for BSs has been started by 25 leading telecoms including MTN Uganda and Zain, united under the Global Systems for Mobile communications Association (GSMA) [39]. This program is meant to aid the mobile industry to deploy solar, wind, or sustainable biofuels technologies to power 118,000 new and existing off-grid BSs in developing countries by 2012. Powering that many BSs on renewable energy would save up to 2.5 billion litres of diesel per annum (0.35% of global diesel consumption of 700 billion litres per annum) and cut annual carbon emissions by up to 6.8 million tonnes. Such BSs operating on renewable energy resources are expensive and network operators have been reluctant to adopt them because of fear of little commercial viability and lack of equipment expertise. However, according to a bi-annual recent report by GSMA, the implementation of green power technology represents a technically feasible and financially attractive solution with a payback period of less than three years at many sites

VI. CONCLUSION

This paper addresses 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. We began our discussion with green metrics or energy efficiency metrics. Here, we presented a brief survey of current efforts for the standardization of the metrics and the challenges that lay ahead. Regarding architecture, since BSs represent a major chunk of energy consumed in a cellular network, we then presented an exhaustive survey of methods that have been currently adopted or will be adopted in future in order to obtain energy savings from BSs. In particular, we discussed the recent improvements in power amplifier technology that can be used to bring energy savings in BSs. Improvements in the power amplifier will not only decrease the power consumption of the hardware system, but will also make the BS less dependant on air-conditioning. We also discussed the power saving protocols such as sleep modes, that have been suggested for next generation wireless standards. Such power saving protocols at the BS side still need to be explored in future wireless systems. Next, we discussed energy-aware cooperative BS power management, where certain BSs can be turned off depending on the load. A recent concept called “Cell zooming” appears to be a promising solution in this regard. Another way to significantly reduce the power consumption of BSs, in particular, those at the off-grid sites, is by using renewable energy resources such as solar and wind energy in place of diesel generators. Lastly, we

discussed how minimizing the number of BSs with a better network design and bringing minor architectural changes can be beneficial in achieving energy efficiency. Heterogeneous network deployment based on smaller cells such as micro, pico and femtocells is another significant technique that can possibly reduce the power consumption of a cellular network. However, as some of the recent research suggests, careful network design is required as deploying too many smaller cells may in fact reduce the power efficiency of the central BS. Also, when a large number of BSs with small cell sizes are deployed, the embodied energy consumption will dominate and lead to an increase in total energy consumption

In summary, research on energy efficient or "green" cellular network is quite broad and a number of research issues and challenges lay ahead. Nevertheless, it is in favor of both the network operators and the society to swiftly address these challenges to minimize the environmental and financial impact of such a fast growing and widely adopted technology. This article attempts to briefly explore the current technology with respect to some aspects related to green communications and we discuss future research that may prove beneficial in pursuing this vision.

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