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Energy Efficient Cellular Networks: A Survey

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Abstract

In recent years, the cellular network market has shown a rapid growth and with the advent of new technologies, the cellular data traffic has increased significantly which has led to excessive power consumption of the network devices. In this paper, we present a brief survey on techniques to enhance the power efficiency of the cellular network. On the basis of recent study it seems that base stations consume a major part of the energy in the cellular system. We put forward a few techniques to minimize the energy consumption with the energy efficient hardware design like power saving via sleep mode and network self organizing methods that involve cell zooming, and multi layered cellular architecture. Lastly, this paper also includes a brief survey of the enabling technologies such as- cognitive radio, MIMO, Femtocells and cooperative relaying.

Keywords: Cellular networks, cell zooming, self organizing networks, cognitive radio, Femtocells, MIMO, cooperative relaying.

1. Introduction

The rapid growth in cellular networks and network devices has led to severe impact on the environment. The number of subscribers and the demand for cellular traffic has grown exponentially. With the advent of technologies such as iPhone, Android, 3G Networks more number of people use Cellular network for data transmission.

According to Technology analyst [1], fraction of the worldwide energy, ranging between 2%-10% is consumed by the ICT industry in manufacturing, using and disposal of ICT equipments.

The technical drawbacks of current cellular network which can be illustrated as:

1. Most of the cellular network techniques tend to maximize throughput, bandwidth, QOS without paying any attention on energy consumption by network devices.
2. Most of the network devices are not utilized at their full capacity except the peak hours due to which the power consumed by these devices is wasted.

Green Communication [1] is a new era of communication where we can greatly improve energy –efficiency and resource efficiency of the cellular network without compromising the quality of services for the users. India is the second largest and fastest growing market in the world [2]. The ever growing India Telecom Industry is concerned about the energy cost which is the largest operating expenses and cost to several million dollars annually to telecom operators and energy consumption from telecom networks is an increasing contributor to global Green house gas emission.

The objective of this paper is to provide the brief survey of the techniques that have been proposed for green cellular network. We have divided the paper into four sections. In section (1) we introduce the topic cellular network, drawing attention to the drawbacks of the current cellular networks. In section (2) we have presented techniques for reducing the base station power consumption. This section is subdivided into four parts where first part gives the general idea of how to improve the hardware design of the base station to make it energy efficient, second part provides the view of Power saving Protocol for sleep mode, third part describes the techniques for self organizing network and the fourth part describes the Multi Layer Cellular Architecture. Few of the enabling technologies such as Cognitive Radio, MIMO, femtocells and cooperative relaying are presented in section (3).

2. Reducing Base Station Power Consumption

Energy efficiency in terms of Base station should be taken care of in all the stages of cellular network. Green Base stations can be derived in various ways-

2.1. Improving Hardware Design of Base station-

The next Generation Base stations are designed to be more energy-efficient. To reduce Power demands of base stations the base station equipment manufacturers have started to offer a few eco friendly and affordable solutions.

2.1.1. The Flexi base station.

This industry leading, energy-efficient and economic multi-radio base station for single Radio Access Network (Ran) advanced mobile broadband network is a showcase of efficient site design and management by Nokia Siemens Network [8]. The benefits are as follows: (1) reduced site energy cost up to almost 70% ; (2) reduced weight and size of network equipments by up to 80% ; (3) allows flexible locations (indoor or outdoor) with no need for air conditioning ; (4) makes new sites for future radio technologies.

The Flexi base station GHG footprint is further diminished by its software-based capacity and capability upgrade.

2.1.2. The Tower Tube.

This award winning solution by Ericson with latest technology and innovation design to reduce construction cost, decrease carbon emission, energy optimization and for pleasant look[1]. Tower tube has its radio base station positioned at height for increased network's coverage, capacity and low feeder loss. The slim designed equipments encapsulated in the tower make it space-efficient. The Tower tube lowers the amount of carbon dioxide in the manufacturing process.

2.2. Power saving Protocols for Sleep mode.

Energy-efficient, radio resource management schemes are developed to reduce energy consumption in base stations without affecting the quality of service. One of the promising approaches for this cause is the Sleep mode mechanism. When a base station is in sleep mode the air-conditioner and other energy consuming equipments can be switched off and thus can largely reduce the energy consumption.

In [9] the authors have proposed two sleep mechanisms for base stations that include shutting down a number of system resources during light traffic: dynamic way and semi-static way. In dynamic way resources are activated or deactivated in real-time as a function of instantaneous load of the system. In a semi-static way, resources are kept unchanged during longer time intervals. Authors show that the former technique achieves larger energy reductions while the latter has an acceptable performance with low complexity.

Another technique discussed in [11] shows a method to switch off base stations based on store-carry and forward-relaying paradigm. The authors have shown with their mathematical investigation that significant energy gains are obtained by using this technique that formulates a joint routing and scheduling problems and uses the mobility of relay nodes to migrate traffic from base stations of low utilization to neighbor base station, allowing in this case these sites to be switched off.

2.3. Network self-organizing Technique.

One of the promising areas of third generation partnership project technology- Long Term Evolution (LTE) for next Generation radio access networks to minimize operational expenditures is Self-organizing networks (SON). This can be used to achieve goals like self-configuration for balancing load and cell management.

A new concept of cell zooming is introduced in [12]. The authors define cell zooming as the ability of the cell to adaptively adjust the cell size according to the traffic conditions. This technique can balance the traffic load and hence reduce energy consumption. Cell zoom-in and zoom-out are used to manage conditions of congestion and low traffic. The cell with high traffic zooms in to relieve congestion so that those

mobile users may be covered by the neighboring cells. Similarly the cells with low traffic zoom out to provide signals to the left out mobile users.

The author in [12] has discussed two cell zooming algorithms: centralized and distributed algorithm .In the centralized algorithm resource allocation and cell zooming operations are performed by the centralized server known as Cell Zooming server depending on all the channel conditions and user requirements in the network.In the distributed algorithm each mobile unit itself selects the base station to be associated with, based on the broadcasted information by base stations. Cell zooming helps in the base station sleeping mode as when a base station is working in sleep mode, the neighboring cells zoom out accordingly to provide coverage.

2.4. Multi-Layer Cellular Architecture.

As shown in [3], for optimizing the overall energy consumption of a cellular network, there is no fixed cell size. Although smaller cells efficiently support high capacity but they tend to become less energy efficient when the demand is low due to the fixed power consumption. We need a cellular architecture whose cell size is adaptive to current demand, to optimize energy consumption during traffic load variation. For instance, in the figure-1 there are 7 base stations named A, B, C, D, E, F, G. Assuming that there are 1400 active users in the area, in the peak hour. The cell sizes have been designed to support this peak load. Now assume that during the off-peak time, there are only 700 users in the area and only 50 users under base station A. Now these 50 users can either be served by base station A itself or by the central base station D. This decision is taken on the basis of the energy consumption. If the extra energy consumption of BS D for serving these extra users is less than the energy consumption of the BS A for serving its users, then these users are served by the central BS D rather than BS A, which is switched off to save energy. Here, in figure-1b the cells under the base station D are known as Umbrella cells while the other cells are known as Subsidiary cells. Hence the base stations corresponding to these cells are known as Umbrella BS and subsidiary BS respectively. Noting that an umbrella BS can turn off its transmit power in a sector if a subsidiary BS is ON in that particular sector, thereby reducing the coverage in that direction. Here in the figures 1c and 1d, cell D is the subsidiary cell with all other umbrella cells.

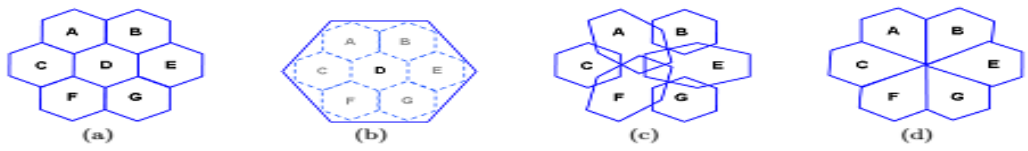

Fig. 1: (a) Original ,high traffic cell configuration; (b) Cell D covers for its subsidiary neighbor; (c) Cell D is subsidiary; (d) All of the neighbor take over the coverage of D.

3. Enabling technologies

Recent research on technologies like cognitive radio, MIMO, Femtocells, and cooperative relaying has been brought to significant attention for both academics as well as industry. Enabling the utilization of radio spectrum in a more efficient manner, cognitive radio seems an adaptive and intelligent wireless communication, while significant improvements can be provided in coverage and throughput for next generation wireless networks by using cooperative relaying, MIMO and Femtocells —

3.1. Cognitive Radio.

Bandwidth efficient systems are the result of efforts of the wireless communication engineers led by a serious concern for the Bandwidth efficiency. Trying to access the unused frequency bands in an intelligent way by collecting the information on the spectrum usage, to compensate for the spectrum underutilization is the main purpose of cognitive radio. As given by the author in [1], the definition of cognitive radio is "to meet a certain objective, most likely power saving, every possible parameter which is measurable by a wireless node or network is taken into account i.e. cognition, for the network to intelligently modify its reconfigurability i.e. functionalities. Basically cognitive radio refers to wireless architectures in which, rather than operating in a fixed band, the system searches and finds an appropriate band to operate. The main functions [7] of cognitive radio include-

3.1.1. Spectrum sensing.

Involves detecting the unused spectrum and sharing it while preventing interference to the other users. Detecting an empty spectrum is the primary requirement of the cognitive radio network, which may be done by detecting the primary users. Spectrum-sensing may be grouped into two categories: Transmitter detection, where the presence of the signal from a primary transmitter must be detected and Cooperative detection is a spectrum-sensing method in which the information from multiple cognitive-radio users is used for primary user detection.

3.1.2. Spectrum management.

To meet the user communication requirements without creating interference to other primary users, the best available spectrum must be captured. Hence, cognitive radio must select the best spectrum band to meet the quality of service requirements. Hence spectrum management functions involve spectrum analysis and spectrum decision. The practical implementation of spectrum-management functions is a complex issue, since it must address significant number of technical and legal requirements.

3.2. MIMO: Multiple-Input-Multiple-Output.

In [13] author has described MIMO as technique where multiple antennas are used at both transmitter and receiver to improve communication performance.

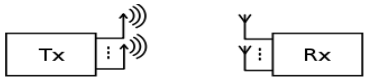

Fig. 2: MIMO.

As we can see in the diagram above there are two antennas at transmitter side and two antennas at the sender side which forms the basic structure of MIMO.

In recent years, there is a dramatic boost in wireless communication with the introduction of latest technologies such as i-Phones, Tablets, Android Phones which have integrated cameras, emailing capability and GPS. To use such features and applications we require high speed data transfers which traditional antennas i.e. single antennas are not capable of delivering due to channel interference and multipath fading. Apart from high data rates users require high Quality of Service which includes low error rate and high capacity. The author in [14] gave an alternative approach of multiple antennas that can be used to improve the error rate as well as the capacity and quality of wireless transmission. All multiple antennas are equipped with several antennas at both sender and receiver side.

MIMO technique can be broken down into two categories: Spatial Diversity and Spatial Multiplexing. Spatial Diversity is a technique where multiple antennas are used to improve the reliability and quality of the wireless link. In Spatial diversity technique multiple antennas are located such that if one signal experiences a fade, another antenna having line of sight with the receiver's antenna can be used to transmit the signal. The same signal is fed through single antenna or multiple antennas, and the same signal is captured by single antenna or multiple antennas. Spatial Multiplexing [14]is a technique where multiple antenna system are capable of establishing parallel data streams through different antennas .So , the bit rate increases dramatically without increasing the transmission power .

3.3. Femtocell

Femtocell as described by author in [16] also called home base stations are short-range low cost low power base stations installed by the consumer for better indoor voice and data reception and are connected to their own wired backhaul connection . Femtocell is not only characterized by short communication range and high throughput , but also its ability to seamlessly interact with the traditional cellular network at all layers of the network stack , performing task such as Handoffs, interference management , billing, and authentication [15]. Femtocells [16] can greatly lower transmit power, prolong handset battery life, and achieve a higher signal-to-interference-plus-noise ratio (SINR).

3.4. Cooperative relaying.

Cooperative Relaying or relay assisted communication is a technique [17] where several distributed terminals cooperate to transmit or receive their intended receiver. In this approach, the source wishes to transmit the message to the destination, but

obstacles degrade the source-destination link quality. The message is also received by the relay terminals, which can retransmit it to desired destination.

Cooperative Relaying technique [5] involves two techniques for delivering energy efficient cellular system. The first approach is to install fixed relays within the network coverage area in order to provide to more users using less power. Second approach is to exploit the users to act as relays. Based on the existing literature, first approach is considered more attractive as it provides a flexible way to improve the spatial reuse and relay reduce the power in the in the system compared to system based on direct transmission.

Table I: Comparison of Various Techniques for Energy-Efficient Network.

S. No.	Techniques	Reference	Parameters	Benefits
1.	Flexi Base Station	Muthy C et.al., April 2012	Location of base station	Up to 70% reduction in site power Consumption
2	Tower Tube	Muthy C et.al., April 2012	Height of base station	Increases the network coverage, capacity, low feeder loss
3	Sleep Mode Mechanism	Muthy C et.al., April 2012	Activation and deactivation of the resources in real time .	Large energy reductions.
4	Cell Zooming	Niu Z et. al., Nov 2011	Cell size	Load-balancing, reduce energy consumption
5	Multi-Layer Cellular Architecture	Bhaumik S et. al. , August 30,2010	Cell Size and dynamic power consumption of base station	Optimize energy consumption during traffic load variation
6.	Store-carry and Forward Relaying	Kolios et. al., 2010	Routing and scheduling of data traffic	Significant energy gain
7.	Cognitive Radio	Hasan Z et. al., Sep 24,2011	Access unused frequency band intelligently	Bandwidth efficient cellular system
8.	MIMO	Muhammad Razin Ibn Azad, May 29, 2012	Multiple antennas at sender and receiver side	Improve error rate, channel capacity and quality of wireless transmission

9.	Femtocell	Chandrasekhar V et. al., September 2008	Low power home base stations	Low cost, high throughput
10.	Cooperative Relaying	Hossain E , et. al.	Relay stations are used to transmit signals to destination	Coverage enlarging , Capacity enhancement

4. Conclusion

We began our discussion by highlighting the known drawbacks of the cellular networks further drawing attention towards the Green cellular network. Main agenda of this survey was to acknowledge the solutions for the reduction in the energy consumption of the cellular network, and since base stations consume the maximum energy, so our paper present a survey on the methods that have been adopted to increase the energy saving in the future. To be precise, we first discussed the improvements that can be brought in the hardware designs of the base stations including the changes in the Power amplifier which are expected to not only reduce the energy consumption but also reduces the need for air conditioning and hence saving power. We have also surveyed power saving protocols for sleep mode which still need to be explored in future systems. Next, we discussed the network self organizing technique that focuses on a new technique called cell zooming. Another way of saving power in the base station is the multi layered cellular architecture which introduces a new concept of umbrella cells and subsidiary cells. Lastly, we discussed how emerging technologies like cognitive radio, MIMO, Femtocell and cooperative relaying contribute in the Green cellular network. Although the research on the discussed topic involves a deep discussion but we have tried to introduce the methods and bring them to attention.

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