Femtocell - Energy Efficient Cellular Networks

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Abstract— Vast advances in the field of Information Communication and Technologies (ICT) has significantly increased the energy requirement. CO_2 emissions adversely affected the atmosphere causing unanticipated changes. It is a major issue because we have very limited energy resources and environmental degradation is unacceptable. This can't be compromised for the facilities that people are getting through the improvements in science and technology which are indirectly affecting the environment. Various energy efficient technologies aka green technologies mainly targeting femtocell networks. Femtocell facilitates better in-door mobile call coverage.

Most of mobile handset initiated calls and the data service requests are generated from home premises. Hence the huge resource consumption by indoor users encourages operators to provide adequate indoor coverage and a higher peak data rate for data services to home subscribers. Femtocells offer a different approach to these problems. Femtocells are cellular access points that connect to a mobile operator's network using residential DSL or cable broadband connections. This paper proposes the architecture of femtocell networks along with its advantages.

Keywords - Energy Efficiency; Green Technology; Femtocell; Femto Gateway; Femto Access Point; Mobile agent;

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I. Introduction

Rapid growth of energy consumption has made global environment issues more severe. As per a survey, 57% of energy consumption of ICT industry attributes to uses and network devices in mobile and wireless networks the scale of which is still growing exponentially [1]. According to a survey, the global mobile traffic is expected to reach 6.3 Exabyte's per month by 2015 which is more than 26 times as much as traffic load per month in 2010. So, energy efficiency has become a critical issue for the government and industries. Current mobile network technologies didn't focus on these issues due to one or the other reason leading to following drawbacks:

1. Most of mobile communication technologies gave no attention to energy efficiency while focusing on achieving better performance metrics.
2. Networking loads differ at different times on a day but the power consumption is same as there wasn't any technique discussed or thought of so as to dynamically adjust power consumption with respect to the current load (network) so as to consume power efficiently.

II. GREEN TECHNIQUES-A NEW THING FOR MOBILE NETWORK

Green technology is a new technology which focuses on utilizing the available energy in any given form more efficiently [3]. Nearly half of the operators' expenditure of a typical mobile system is for the consumed energy and hence effective green techniques are important to lessen the energy consumption of the mobile systems. Novel design of whole green cells is challenging and hence a lot of research is being carried out in the field.

The following are the major constituents of the mobile networks where the green techniques can be utilized for effective utilization of the available energy resources:

A. Data Centers in Backhaul
B. Macrocell
C. Femtocell
D. End-host
E. Applications and Services

A. Data Centers in Backhaul

At present, the data centers used in mobile networks are increasing at a much faster speed due to the high demands of online storage and computation. Data centers are also consuming huge amount of energy for computing, storing, transmitting and computing. Green technologies are developed to reduce all these using ON/OFF research allocation and virtualization techniques.

B. Macrocells

It is observed that nearly 60% energy consumption of a cellular networks is for operating the macrocell base station (BS) [6].Hence, the research work related greenness of macrocell base station has recently gained momentums in these aspects :

a. Dynamic scheduling of Base-Stations(BS)
b. Cells zooming and power saving of Power Amplifier (PA)

Again, it is practically observed that 50% of the energy consumption in BS is attributed to the PA. Therefore a method is needed that dynamically adjusts the supply voltage margin and the power losses in linear PA are reduced.

C. Femtocells

Femtocells is a recent research area .For the mobile operators, femtocell major features are to improve both coverage and capacity in the in-doors while optimizing the energy consumption and make BS deployment cost effective. Mobile users get better signal quality and longer battery life using femtocells. Green techniques for femtocell fall into two categories [6]:

Coverage Optimization

Control and Interference Avoidance

The femtocell is discussed in detail in third section.

D. End-Host

As mobile end-host devices have evolved very fast from simple phones to high-end computing and communication devices. This is driving researchers to consider power saving areas of the end-host devices as a new research direction.

Green techniques for end-users fall into 3 main categories

1. Energy Profiling
2. Utilization of Multiple Radios and
3. Effective Transmission

These are summarized as under:

Energy profiling is needed to accurately know about the energy demands, local resources traffic patterns and user behaviors' of mobile end-host systems.

Most of the current end-host devices utilize multiple radios e.g. Bluetooth, Wi-Fi and 3G with different magnitudes of energy consumption. Targeting multiple radios' energy consumption effectively may lead to effective utilization of the available energy sources.

Transmission is the most energy-consuming and hence the most important factor we need to focus while finding out ways to effectively utilize energy sources on demand.

Hence, we conclude that we need to focus not only on Quality of Service (QoS) but also the Quality of Experience (QoE) to get what is the need of the hour.

E. Applications and Services

There are many trivial and advanced applications that have originated out of mobile smart phones. Hence the need of the hour is to use green techniques for mobile applications and services to introduce specific power-saving designs. The proposed methods may fail but they provide experience to move forward to better approaches later where the "Experience" leads to "Quality".

III. FEMTOCELL AND FEMTO GATEWAY

A. Architecture Evolution

In order to maintain higher data rates, 3G systems require a good receiver signal level to increase system performance. However, various research results suggest that the majority of mobile users suffer from inadequate indoor signal penetration which actually leads to poor coverage provided to consumers and they do not enjoy the full data capacity marketed by the operators. 3G systems will facilitate high speed data services, but poor indoor coverage and interference will definitely diminish the quality of real-time applications and will significantly slow down high speed data services.

In the traditional macro cell network, it is very difficult for operators to provide high quality services and cell coverage to indoor users. Because in order to improve indoor coverage operators need to install a huge number of outdoor base stations sites and this is nearly impossible in those areas that are densely populated. Even if operators manage to install more base stations then network planning and optimization become a challenging task for them, because frequency planning and handover management need more care in dense network deployment. 3GPP is continuously working towards the evolution of new communication models for the next generation mobile communication system. Recent attempts from 3GPP towards improved cell coverage and capacity have brought a new network element, the Home NodeB (HNB), into existing cellular network architecture. The name HNB is proposed by 3GPP in release 8 specifications [5]. The HNB is used especially in home and office environments and its introduction in the existing communication paradigm has already opened new opportunities for operators and service providers.

A femtocell is as small private cell which operates on a 3GPP air interface. A femtocell produces a coverage range up to 30-50 meters with a low output power level typically less than 50mW [12].

In the present era, the HNB is usually called as a Femtocell or a Femto Access Point (FAP). Typically HNBs operate over the licensed spectrum and connect to the operator's core network by using a residential Internet connection. A residential Internet connection can be based on a DSL, cable broadband connection, optical fiber or wireless last-mile technologies. Like a Wireless Local Area Network (WLAN) Access Point (AP), the HNB is a small device and it is installed by the user.

B. Femto cell

Femtocell or home base station is a low-power access point which is basically used to enhance the traditional mobile communication system's coverage and capacity in home and office environments. The femtocell enables users to access voice and broadband services over their own standard broadband Internet connection. A single femtocell supports usually at most four to eight simultaneous voice connections (concurrent maximum voice connection support in femtocell is implementation specific i.e. different products support different amount of simultaneous voice connections) in any indoor environment, permitting many authorized users to be able to connect to the femtocell to utilize services other than voice, such as text or real time multimedia streaming etc. the user's subscription model (service and charging) for femtocell services may vary according to user needs and depends upon operators. There are various factors that affect peak data rates such as the air interface technology used, the user subscription and broadband link capacity. Fig below shows the basic Femto cell network.

For supporting femtocells operations it requires a network element called Femto Gateway which acts as an RNC towards the core network.

Figure 1 illustrates a basic femtocell deployment model in a real world environment. In order to utilize femtocell services, a user will buy a femtocell and will connect to it through its own fixed broadband access. Upon being connected to the broadband access, the HNB will further connect to the operator's gateway; thereafter the HNB will be authenticated and configured according to the user's subscription policy. Femtocell access is usually available to a restricted number of authorized users. Thus ensures that the coverage area which is provided by femtocell is only accessible by femtocell owner or by a trusted group of people.

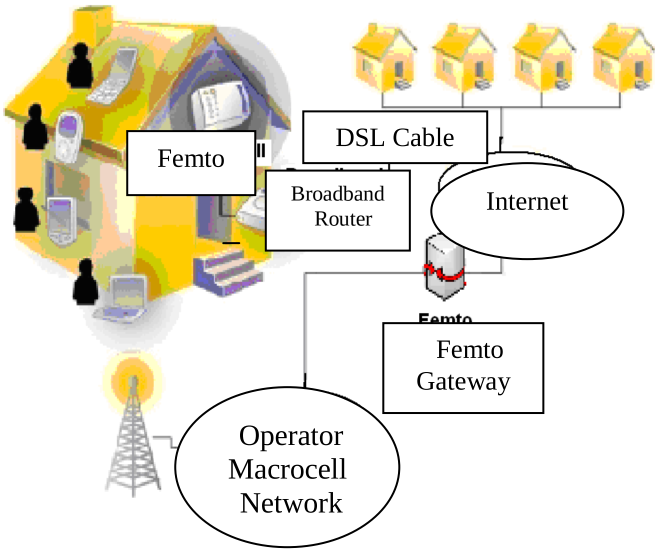

Figure 1. Basic femtocell network [12]

C. *Femto Gateway overview*

The Femtocell or Femto Access Point (FAP) functions as the BTS and the RNC. It is located at the End User's Premises. The Femto Gateway (FGW) concentrates the different FAPs towards the Core Network and is located at the Mobile Network Operator's premises.

The FGW's main responsibility is to function as a single RNC towards the Core Network and hide the details of the different FAPs connected to it. The FGW functions as the core network towards each FAP. Apart from this, the FGW also functions as the element manager for all the connected FAPs [13].

As seen in the Figure 2, the Femto Gateway shall implement the Iu interface (over ATM) towards the CN and the Iu over IP interface towards each FAP. Since the interface between the FAP and the FGW is over the internet, all traffic is encrypted using an IPSec tunnel between the two entities. The FGW implements the BTS OAM interface towards OMS. All OAM operations with the FAP are done over TR-069.

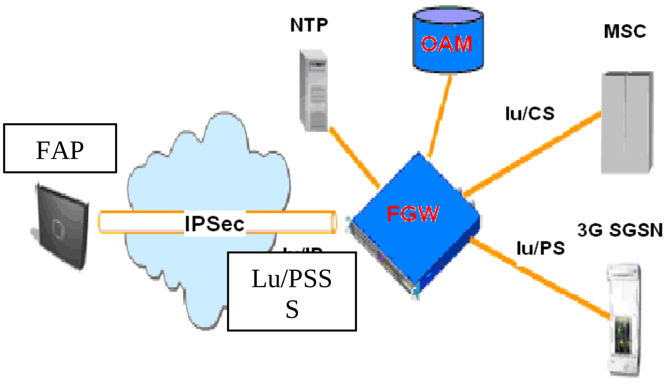

Figure 2. FGW Interface [13]

The FAP is a single plug and play box that integrates a DSL modem and the 3G Access parts. Additionally, it may also provide WiFi, Ethernet and USB functionalities depending on the model of the FAP. The DSL modem is controlled by the ISP who provides the broadband connection to the end user, while the FGW is responsible to configure and maintain the 3G Access part of the FAP

The UE connects to the FAP via the air interface (Uu). The FAP functions as the RNC and the BTS and is responsible for controlling the dynamic updates of the operating parameters for the air interface. All the required algorithms are implemented on the FAP itself. The FGW only acts as a repository of FAP parameters.

In Idle mode, access control is implemented by the FGW. Access control involves deciding whether a particular UE is allowed to access services via a particular FAP or not.

The Femto Gateway entity provides the following functionality [13]:

i. Aggregate several Femto Access Points (FAPs) towards the Core Network (CN) as shown in Figure 2
ii. Function as a single RNC towards to the Core Network and hide details of the FAPs connected to the FGW from the CN
iii. Convert between the ATM/IP based interface towards CN and IP based interface towards the Femto Access Point
iv. Authenticate and administer the FAPs that connects to the Femto network.

D. *System architecture*

a. UMTS Architecture[14],[15]

The UMTS architecture comprises three parts (or domains):

i. Core network
ii. Access network
iii. User equipment

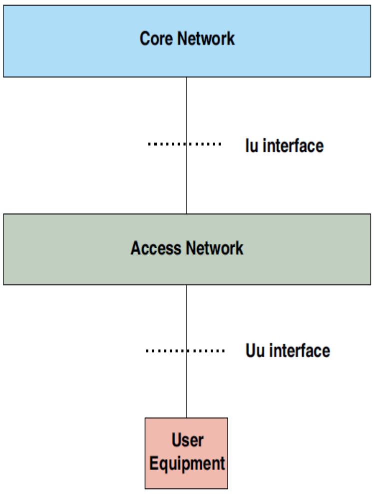

Figure 3. High-level illustration of the UMTS architecture

i. Core Network

The core network provides the central switching, transmission and service provisioning functions required to provide UMTS services.

ii. Access Network

The access network provides the radio access between the mobile user and the core network. A UMTS network may consist of one or more access networks (using different radio access systems) linked to the same core network. Together they form a single UMTS network.

iii. User Equipment

User Equipment refers to the mobile devices used to access UMTS services. The User Equipment has a radio interface (Uu interface) to the access network.

b. Network architecture

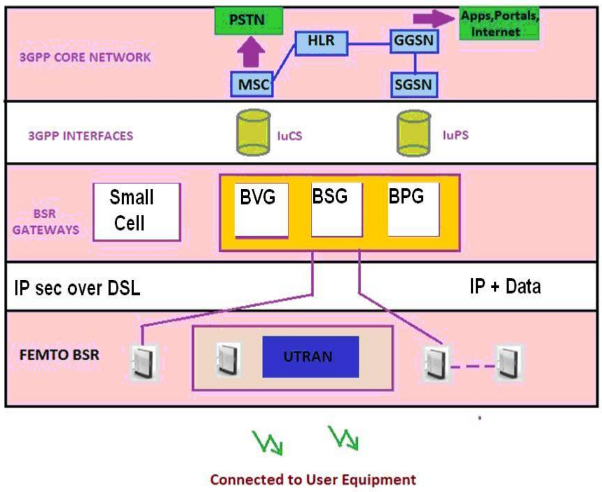

Figure 4. Femtocell Network architecture

The Small Cell Solution is fully compliant to 3GPP standards and uses 3GPP interfaces to connect to the existing UMTS core network nodes. It supports legacy Circuit Switched Voice, Packet Switched Data and HSPA (High Speed Packet Access). The Small Cell Solution uses a "flat" architecture, meaning the consolidation of all of the UTRAN (Universal Terrestrial Random Access Network that consists of Node-B and Radio Network Controller) into a single node. This methodology decentralizes the network, reduces latency and allows for a highly-scalable solution for future network expansion. The use of IP on the backhaul reduces infrastructure costs and allows the Small Cell to connect to the existing home broadband connection or corporate network. The major elements of the small cell (Femtocell) network are explained in brief as follows: [16]

i. Small Cell (Femto) Home Network

The Small Cell is located in the home network and uses services of the home network (e.g. DHCP service, DNS relay service, WAN connectivity provided by a DSL router). The small cell also allows direct access from a The Small Cell also allows direct access from a UE to nodes on the home network.

ii. BSR

The Base Station Router provides the air interface for the UEs to connect to the Small Cell Core Network, and from there to the MNO's Core Network.

iii. BSG

The BSR Signaling Gateway provides a single point node for all the Small Cells in the cluster, and interworks the signaling messages from the Core Network to the individual Small Cells.

iv. BPG

The BSR Packet Gateway acts as a concentrator for packet-switched user plane paths, so that the packet core is not overwhelmed by the number of nodes in the cluster.

v. BVG

The BSR Voice Gateway acts as a concentrator for circuit-switched user plane paths, so that the circuit core is not overwhelmed by the number of nodes in the cluster.

vi. SeGW

The Security Gateway terminates the IP Sec tunnels from the Small Cells in the cluster and provides firewall protection to the Small Cell Core Network.

vii. WMS

This is responsible for SNMP-based management of all network elements in the Small Cell network, with the exception of the Small Cells themselves; these are managed in conjunction with the HDM.

viii. HDM

This is responsible for management of the Small Cells in conjunction with the WMS; the HDM manages dynamic aspects of the Small Cells (notifications, operator intervention, etc.) whereas the WMS manages static and semi-static aspects (configuration) and periodic upload of Small Cell information (FM logs, PM files).

ix. WPS

This optional network element assists with configuration management by the WMS.

x. File Server

This logical element is a central repository for the software and configuration files for the Small Cells.

xi. SGSN

This terminates the IuPS interface on the UMTS core network side. It provides support for IP transport option and support for Direct Tunnel Feature.2 GGSN.

xii. GGSN

If the Direct Tunnel feature is active, the IuPS user plane tunnel can be established directly between the Small Cell and the GGSN via the BPG.

xiii. MSC

This terminates the IuCS interface on the UMTS core network side. It provides support for IP transport option.

Need for Femtocells

Capacity demands of modern mobile telecommunication networks are increasing year by year. People all over the world are using not only more voice call services but also a growing amount of data services with their cell phones. Many of these services, including Web surfing, downloading emails, video streaming and video calls require high speed connections and generate large amounts of data traffic to the network. The customer expectations are rising and soon the mobile terminals will have to achieve the same bitrates as the current fixed internet connections.

Coverage has always been an important issue in mobile telecom networks. It has traditionally been a problem in rural areas due to the long distance between.

The vendors have to constantly come up with solutions to make the best of the limited radio resources: space and spectrum. Smaller cell sizes such as microcells and nanocells have been used to gain more capacity in urban hotspots like shopping centers and office buildings. Microcells and nanocells as well as distributed antenna systems (DAS) have also been used to improve coverage inside buildings, basements and subway tunnels. These solutions are effective but also expensive.

Femtocells offer a different approach to these problems. Femto is a factor denoting one thousandth of nano. Femtocells are very small, low cost base stations and their maximum allowed transmit power level is low. Femtocells are even smaller than nanocells but the biggest difference is not the size of the cell. The devices are integrated to small plastic desktop or wall mount cases and are installed to the customers' premises by the customers themselves. The customers' existing internet connections are used as backhaul connections and the devices are powered from the customers' electricity sockets.

Femtocells provide following key benefits [12]:

1. Better Efficiency: As femtocells localize the mobile networks, it lowers the transmission power and prolongs the handset battery life to achieve a higher Signal Interference and Noise (SNIR) ratio. These translate into the so-called 5 bar coverage.
2. Improved Reliability and Subscriber Turn-Over: Femtocells provide a virtual way to make mobile phones available on the roof of a house where there is a better signal strength which improves reliability and increases customer satisfaction which in turn leads to decreased subscriber turn-over as customer satisfaction is increased and hence he doesn't think of changing over to another mobile network.
3. Cost Benefits: The femtocell provides cost benefits as the femtocell infrastructure is minimal as compared to installing a new tower which incurs additional costs such as site lease and additional back haul and electricity overheads.

Technical Aspect

Shannon's law verifies the potential of femtocell. Shannon's law relates wireless link capacity (in bps) in a bandwidth of W Hz to the SINR. The SINR is a function of the transmission power of a desired and interfering transmitter, path losses and other unwanted (Noise) effects. Path losses cause the transmitted signal to decay as Adα, where A is the fixed loss, d is the distance between the transmitter and receiver and α is the path loss exponent.

Femtocells enable a reduced transit power maintaining good in-door coverage which implies that the penetration losses are overcome. Assuming a fixed receive power target with a path-loss propagation model (no fading) and denoting α (resp. β) as out-door (resp. In-door) path loss exponent, overlaying an area A_2 with N femtocells results in a transmit power reduction of the order of $[10(\alpha- \beta)\mathrm{Log}_{10}A + 5\beta \mathrm{Log}_{10}N]$ dB. To conclude, the capacity benefits of femtocells are achieved out of following features [7]:

a. Reduced distance between femtocell and user leading to better signal strength.
b. Penetration effects are overcome which leads to lower transit power requirement.

One femtocell covers only 1-4 users, hence, they can devote larger portion of their resources to the subscribers. This provides better QOS in return.

IV. TECHNICAL CHALLENEGES

There are many challenges which are the current research topics. The key technical challenges facing the femtocell networks depend on their application domains such as [12]:

a. Broadband Femtocells: Resource Allocation Timing, Synchronization and backhaul.
b. Voice Femtocells: Interference Management .
c. Network Infrastructure Femtocells: Security.

Experiments and results

From experiment and testing it has been proved that femtocell technology leads following achievements.

a. Better coverage and Capacity
b. Lower transmit power
c. Prolonged battery life
d. Higher SINR
e. Higher spectral efficiency
f. The traffic originating indoors can be absorbed into femtocell networks over IP backbone
g. Reduced Subscriber Turn-Over

V. CONCLUSION

Thus, Femtocells utilize green techniques to efficiently utilize the energy resources in a mobile network. These are the most recent trend of the market causing "buzz" in the respective fields of applications. The vision for the future mobile communication system is now shifting towards `information at any time, at any place but only in packet switched format'. UMTS architecture evolution has changed both the service delivery and business models for operators and users.

The advent of the femtocell in UMTS architecture evolution has changed the expectation for broadband customer experience dramatically. Nobody could even have thought of receiving excellent broadband performance with excellent wireless coverage especially in homes during the past few years. Femtocell is used to provide high quality packet switched services at low cost simultaneously reduce the burden from the operator's core as well as offload traffic from the macrocell access network.

VI. FUTURE ENHANCEMENT

During recent years the concepts of LTE is gaining momentum in the field of mobile communication systems and the future scope of the project can be using femtocell architectures as a building blocks for the further study and development of LTE femtocell architecture.

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REFERENCES

[1] Fettweis G, Zimmermann E (2008) ICT energy consumption-trends and challenges. In: Proceedings of the 11th international symposium on Wireless Personal Multimedia Communications (WPMC).

[2] Hansen J, Sato M, Kharecha P, Russell G, Lea DW, Siddal M (2007) Climate change and trace gases. Philos Trans R Soc 365(1856):1925–1954.

[3] Williams F (2008) Green wireless communications.Mobility, Tech. Rep.

[4] Karl H (2003) An overview of energy efficient techniques for mobile communication systems. Technische University Berlin, Tech. Rep.

[5] V. Chandrasekhar and J. Andrews, Femtocell; A Survey, IEEE Communications Magazine, pp. 59 - 67, September 2008.

[6] Chetana R Murthy, Dr. C Kavitha : A Survey of Green Base Stations in Cellular Networks -IJCNWC, ISSN: 2250-3501 Vol.2, No.2, April 2012.

[7] Analysys, “Picocells and Femtocells: Will indoor base-stations transform the telecoms industry?,” [Online]. Available: http://research.analysys.com

[8] Picochip, “The Case For Home Base Stations,” White Paper, April 2007.

[9] Lester T.W. Ho and Holger Claussen, “Effects of User-Deployed, Co-Channel Femtocells on the Call Drop Probability in a Residential Scenario,” The 18th Annual IEEE International Symposium on Personal, Indoor and Mobile Communications, pp.1 – 5, Sep 2007.

[10] 3rd Generation Partnership Project [Online]. http://www.3gpp.org/

[11] Simon R. Saunders et al.; "FEMTOCELLS Opportunities And Challenges for Business And Technology", John Wiley & Sons Ltd 2009

[12] FemtoForum[Online] http://www.femtoforum.org/femto/

[13] ALU 9365 BSR Gateway based on ATCA v2 Release BCR 3.0

[14] http://www.airwalkcom.com

[15] 3GPP TR R3.020 V0.9.0, "Home (e) Node B: Network Aspects," September 2008.

[16] 3GPP Femtocells Architecture and Protocols by Gavin Horn.