IEEE Access
Multidisciplinary ⋮ Rapid Review ⋮ Open Access Journal

SPECIAL SECTION ON RECENT ADVANCES ON RADIO ACCESS AND SECURITY METHODS IN 5G NETWORKS

Received October 6, 2017, accepted October 31, 2017, date of publication November 15, 2017, date of current version December 22, 2017.

Digital Object Identifier 10.1109/ACCESS.2017.2773834

Energy Efficiency Perspectives of Femtocells in Internet of Things: Recent Advances and Challenges

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This work was supported by the Deanship of Scientific Research at King Saud University Research Group under Project RG#1435-051.

ABSTRACT Energy efficiency is a growing concern in every aspect of the technology. Apart from maintaining profitability, energy efficiency means a decrease in the overall environmental effects, which is a serious concern in today's world. Using a femtocell in Internet of Things (IoT) can boost energy efficiency. To illustrate, femtocells can be used in smart homes, which is a subpart of the smart grid, as a communication mechanism in order to manage energy efficiency. Moreover, femtocells can be used in many IoT applications in order to provide communication. However, it is important to evaluate the energy efficiency of femtocells. This paper investigates recent advances and challenges in the energy efficiency of the femtocell in IoT. First, we introduce the idea of femtocells in the context of IoT and their role in IoT applications. Next, we describe prominent performance metrics in order to understand how the energy efficiency is evaluated. Then, we elucidate how energy can be modeled in terms of femtocell and provide some models from the literature. Since femtocells are used in heterogeneous networks to manage energy efficiency, we also express some energy efficiency schemes for deployment. The factors that affect the energy usage of a femtocell base station are discussed and then the power consumption of user equipment under femtocell coverage is mentioned. Finally, we highlight prominent open research issues and challenges.

INDEX TERMS Femtocell, energy efficiency, Internet of Things, smart grid.

I. INTRODUCTION

The Internet of Things (IoT) is a novel paradigm where objects become part of the Internet. It paves the way for connecting actuators, sensors, mobile phones, Radio Frequency Identification (RFID) tags and other objects to the Internet and these objects are uniquely defined, its status and position were known, accessible to the network, permitting the perception of the world [1], [2]. Moreover, IoT promotes lots of new applications in various domains such as healthcare, environmental monitoring, automotive and energy management in smart homes where it provides economic benefits [3]. Indeed, IoT is considered as ''one of the six disruptive civil technologies with potential impact on US national power'' by the US National Intelligence Council [4].

Fig. 1 depicts some beneficiaries of a smart grid, which is one of the main IoT applications and one of the leading technological advancement today, it can monitor the energy supply and demand and efficiently adjusts power consumption in the network [5]. It can be used with smart meters, it provides real-time information to suppliers and consumers. Smart houses can communicate with a grid using these smart meters and enables consumers to manage their electricity usage [6]. In a smart home, the consumer can access and operate appliances through energy management, using the network between appliances. In order to manage energy as mentioned, there is a need for a communication network in this layer such as ''home area network (HAN)'' and ''neighborhood area network (NAN)''. HANs have three basic components; it analyzes, measures, and collects energy usage of smart devices. On the contrary, multiple HANs are connected with NAN through local access points where data are carried to the utility. An infrastructure is needed for HANs to connect these elements. Femtocell can be used as a HAN communication mechanism like wireless LAN and Zigbee [7]. In addition, in [8] femtocell is used as an indoor or an outdoor network in smart grid wireless

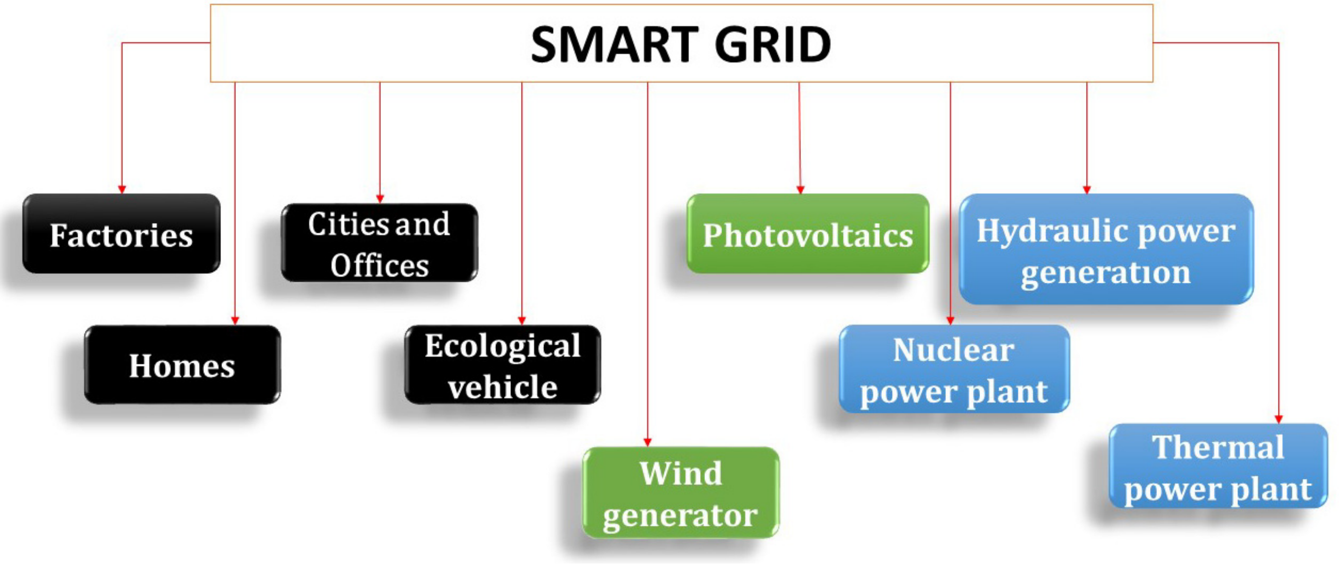

FIGURE 1. Some beneficiaries of a smart grid.

communications network which is based on radio-over-fiber (ROF) and cooperative relaying.

Energy consumption and carbon emission are some of the key challenges that need to be addressed, mobile networks are used in smart grids in order to provide energy efficiency. However, it is a fact that they consume energy and its amount cannot be regarded as too little. Moreover, carbon emission is the result of energy usage and as mentioned in [9], information and communication technologies (ICT) are responsible for between 2% and 2.5% of total carbon emission, which is almost equivalent to global aviation industry [10]. It is expected that this rate will be doubled over the next decade. The 10% of ICT carbon emission is produced by mobile networks and energy usage of radio access network (RAN) is about 55% to 60%. To illustrate, each macro base station use between 2.5 kW to 4 kW [8]. The number of these stations in each nation is about tens of thousands so this means lots of energy consumption and carbon emission.

Femtocell can be defined as a small cell, looking at its energy efficiency, a femtocell consumes 8mW and 120mW of energy, it is analyzed that it consumes less energy compared to a Wi-Fi access point [11]. Therefore, it is an efficient communication solution in HANs from the consumer's perspective. They can track their energy usage and this can enable consumers to manage their electricity bills. Moreover, with the help of home area network, appliances can be automated and reduce electricity demand on the grid and also consumer energy bill [6].

Briefly comparing Femtocell and Macrocell, Macrocell base stations work with high energy consumption and most of this energy is used by driving high power radio frequency signal. However, it is estimated that only between 5% and 10% of this energy is used to create a useful signal. The reason behind that issue is that macrocells provide high area coverage and most of the space is unoccupied (i.e., without people that need radiated signals in these areas). Moreover, RF sections of base stations need high power, without efficiency. In other words, energy is used for just in case. Unlike macrocells, a femtocell is a solution to prevent these energy losses and it only provides local area coverage [12]. In other words, femtocell delivers power where there is a need and hence it requires less RF power to proffer high bandwidth since they are closer to the user. An average femtocell consumes a total of 2W while it is very high in the macrocell. The other advantage is that user equipment consumes less energy when it is connected to a femtocell since it is closer [13]. Thus, a femtocell is an efficient solution, which provides large coverage, longer battery, and better quality of service (QoS).

Accordingly, the main contributions in this article can be summarized as follows. A comprehensive background about the femtocells and their IoT-specific applications are outlined while emphasizing energy consumption and system capacity effects. Energy metrics and models for IoT-based femtocells have been investigated as well, and accurate ones are recommended. Furthermore, the femtocell base-station performance is inspected while discussing different deployment strategies in the literature. Key parameters that affect the femtocell power consumption under IoT setups have been reported. Moreover, femtocells' challenges and open research issues in the IoT era have been highlighted to open the door for further improvements in next generation networks such as the 5G cellular network.

This paper is organized as follows. Section 2 provides a preliminary background of a femtocell and its role in IoT applications. Energy efficiency metrics are introduced in Section 3 and Section 4 includes how energy can be modeled. Section 5 gives some about energy efficiency schemes for deployment including the criteria and examples in the literature. In Section 6, we mentioned the factors that affect the energy consumption of femtocell base station and in Section 7 we discuss some challenges facing small cell networks. In section 8, we mentioned energy efficiency of user equipment when it is used under femtocell coverage. Open research issues are mentioned in Section 9 and concluding remarks are given in Section 10.

II. BACKGROUND

A. WHAT IS A FEMTOCELL?

Femtocell connects mobile devices to the network through different wired and wireless technologies [14]. It is a low-cost macrocellular base station (MBS), which provides radio access interface to a user equipment (UE) [5]. It is a solution to offload from overloaded macrocells and increase the coverage area. They are specifically designed and used for increasing indoor coverage (e.g. home or small business), where there is a lack of cellular network or improving the QoS is desirable. It has advantages for both cellular operators and users. For the cellular operator, the advantage is to increase coverage and capacity. The coverage area is widened because the loss of signal is eliminated through buildings and capacity is increased by a reduction in the total number of UEs that uses the main cellular network. They use the Internet instead of using a cellular operator network. For customers, they have better service, improved coverage, and signal strength since they are closer to the base station. Moreover, using femtocells leads to increase UE battery life because of being close to femtocell [14].

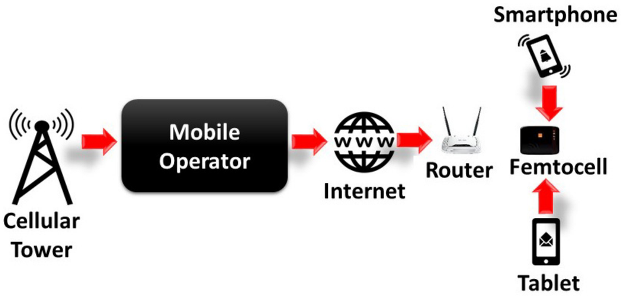

FIGURE 2. A typical femtocell network structure.

A typical femtocell structure consists of five parts: DSL or cable router, femtocell device, cellular tower (macrocell), mobile operator network, and ISP Internet link [14] as shown in Fig. 2. Femtocell does not require a cellular core network since it contains RNC (Radio Network Controller) and all other network elements. It acts as a Wi-Fi access point and it needs a data connection to the DSL or Internet connected to cellular operator core network [14]. Although it does not need to be under macrocell coverage area, there are lots of examples for deployment in macrocell coverage area in order to increase capacity and QoS where there is huge user demand or there is a less coverage in buildings. Apart from this, it can be used in rural areas in order to provide cellular coverage where there is no macro coverage.

Although femtocell technology was first designed to use indoor, however, there are lots of outdoor applications of this technology as well. To illustrate, it can be deployed in transit systems such as bus, train. In this application, mobile users connect to femtocell instead of macrocells or satellite. There is a transceiver connected to femtocell access point (FAP) through wired connection and to macrocell or satellite through wireless link [15]. Moreover, femtocells can be a good solution to increase coverage and capacity in public outdoor areas, especially in crowded areas.

The main idea behind femtocell is to bring cellular network closer to the user and it is a low-power and low-cost technology [15]. It is usually difficult for a macrocell to provide indoor service since there is a signal loss. The author in [16] says that macrocell is not efficient in delivering data indoors due to high penetration losses. Moreover, 50% of voice calls and 70% of data calls comes from indoor [15]. There is an estimation that 10% of active femtocell household deployment can offload 50% of the overall macrocellular tier load [17]. Thus, it increases revenues of cellular operators and it is expected that there will be about 28 million units of femtocell by 2017 [18].

B. FEMTOCELL IN IoT APPLICATIONS

Internet of Things touches every facet of our lives and it has potential to cover a wide range of applications (e.g., Transportation and logistics, healthcare, smart environment, personal and social, and futuristic) that can positively impact the quality of life at different places e.g., home, travelling, sick, and at work). Femtocell is a preferred for operator networks as well as for industrial wireless sensor networks [1], [19]. It describes communication capabilities of various objects with each other and to elaborate information perceived. Most of these applications can be categorized and classified as shown in Fig. 3.

Femtocell can be used as a communication mechanism of IoT, especially in the smart grid. For example, the authors in [7] introduced a femtocell based communication mechanism in HAN and argued the security issues about using femtocell in the smart grid. Moreover, using femtocell in home area network as a cost-effective technology was also proposed in [20], [22]. Healthcare IoT applications are another example for using a femtocell in IoT applications. In [23], they proposed an Internet of Things oriented healthcare monitoring system where sensors gather the data from the android application and then used LTE based femtocell network in order to send the data with new scheduling technique.

In [24], they underline that femtocell is susceptible to Man-in-the-middle attacks when it is used to fix shadow area problem. Moreover, they propose the interlock protocol to protect the confidential information. In [25], the benefits of using 56 femtocells for supporting indoor generated

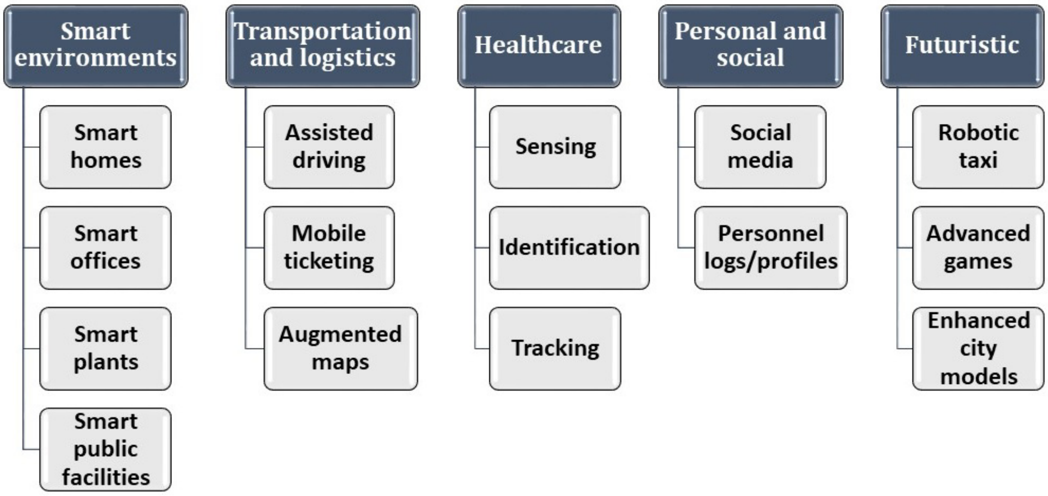

FIGURE 3. Application domains of IoT.

IoT traffic and they underline the fact that supporting the traffic produced from IoT is a major challenge for 5G and an important percentage of the traffic is generated indoor. Thus, it can be said that femtocells can be used in most of the IoT applications since there is a need for evolutionary telecommunication mechanisms. Indeed, it is expected that small cells such as femtocell will be central to 5G network architectures, both for human users and for IoT. Moreover, authors in [26] talk about a new method called network slicing for boosting up the performance of 5G so that it will be able to handle the high demand for information exchange with minimum energy.

1) IoT IN TRANSPORTATION AND LOGISTICS

As shown in figure 3, there are many IoT applications in the field of transportation and logistics. Some of the listed areas include logistics, mobile ticketing, driving, monitoring environment, and improved maps. The authors in [16] concur with this statement by saying that IoT plays an important role in transport and logistics. They go on to point out some of the main areas where its application has made major strides, such as the ability of transportation and logistics companies to track their goods from origin to destination and have a real time location of their property, using the bar codes and sensors planted on the goods. The recent technological advancement in vehicles increasing sensing, communication, and data processing capabilities, have opened up IoT to a new range of possibilities, where we can now track the exact location of the vehicle, track its path and predict its next location. Moreover, the authors highlight an intelligent system called iDrive system which monitors the conditions to enable better driving conditions. Additionally, the authors in [27] talks about the advancement of vehicular networks which are able to make decision on their own and has autonomous control to cloud-assisted context-aware vehicular cyberphysical systems (CVCs).

2) IoT IN HEALTHCARE

Figure 3 also shows some of the areas where IoT has been applied in healthcare. Some of these areas include sensing, tracking data collection identification and authentication. The authors in [16] say that IoT uncovers new opportunities in healthcare. The ability of IoT to sense, identify and communicate has enabled the healthcare department to track and monitor all its objects such as people, equipment, and medicine among others. Moreover, due to the immense global connectivity of IoT, health care-related information such as logistics, therapy, diagnosis, medication and the likes, can be managed, collected and shared easily. The authors also note that by using personal computers and mobile phones, the healthcare system can be personalized. Moreover, the author in [28] talks about a synthesis of wireless body area networks (WBANs) which are largely adopted in the passive healthcare data collection, has limited storage capacity among a few other challenges, with Mobile cloud computing (MCC) which provides flexibility in massive computing and large storage spaces to allow for storage of data in the healthcare department.

3) IoT IN SMART ENVIRONMENT

Figure 3 also features some of the areas in a smart environment where IoT is applied, these areas include relaxed homes, offices, and commercial places. The authors in [29], propose a flexible low-cost home controlling and monitoring system where they use an android based smart phone app to remotely control and monitor appliances in a smart home. The authors in [30] proposed a system for a smart factory aimed at improving safety in plants using an IoT-based WSN and RFID integrated solution. Moreover, the authors in [31] note that wireless sensor network plays a major role in industrial monitoring and control, therefore, they proposed a new algorithm to assist the conventional orthogonal frequency division multiple access (OFDMA) to maximize the subcarrier pairing, subcarrier allocation, and power allocation.

4) IoT IN PERSONAL AND SOCIAL

Personal and social areas are some other fields where IoT has been employed and has made some improvements in these areas. Under this section, IoT has impacted fields such as social networking where the vast connection of smart devices has enabled users to connect and interact without worrying about the distance between them. Historical queries is another field where anyone can retrieve or store information about anything from anywhere without distressing about losing that information. Moreover, IoT has made an impact in the security sector where the installation of smart security systems is used to guard property and prevent theft.

5) FUTURISTIC IoT

The future of IoT is one that is very exciting because of the countless possibilities that it holds. Figure 3 highlights only a few of these possibilities i.e. robot taxi, city information model and enhanced game rooms. In their conclusion, the authors in [32] talk about the web squared, which they say, is an evolution of the Web 2.0. In their paper, they argue that this future model of the internet will help integrate the Web and sensing technologies by taking into consideration the information about the environment of the user, collected by sensors such as cameras and microphones and using the information to better the content provided to the user.

III. ENERGY EFFICIENCY METRICS

There are three different energy-efficient (EE) metrics proposed at three different levels in literature: network, component, and a base station (BS). In the component level, millions of instructions per second can be calculated. Of course, the speed of communication has always been a critical issue that needs to be optimized at all cost, the author in [33] propose a handover system based on cell ID information which is able to effectively operate in a fast moving environment such as LTE (Long Term Evolution) -Advanced. Processor related energy consumption, whose formula is given in Eqn.1, and the ratio of power amplifier (PA) output power to input power (ROI) can be used to calculate energy efficiency of power amplifier component. In base station level, EE metrics can be evaluated under two main categories. Bits per second per hertz per watt represent a trade-off between energy consumption and spectral efficiency (SE). Spectral efficiency and the transmission range of the base station are taken into consideration. In network level, obtained service relative to the consumed energy is evaluated by energy-efficient metrics which is power per area unit (watts per square meter) in order to evaluate the coverage energy efficiency. Table 1 gives the summary of the energy efficient metrics.

$$P_{cpu} = P_{dyn} + P_{sc} + P_{leak} \tag{1}$$

TABLE 1. Energy efficiency metrics.

Energy Efficiency Metrics	Levels	Descriptions
ROI	Component level	Indicate energy savings of power amplifiers
MIPS/W or MFLOPS/W	Component level	Guages energy consumed during processing
bits/s/Hz/W	BS level	Represent trade-off between energy dissipation and spectral efficiency
(b*m)/s/Hz/W	BS level	Account for energy consumption, SE, and the transmission range of base stations
W/m2	Network level	Assess energy efficiency with respect to coverage

where P_{cpu} represents the CPU power consumption, P_{dyn} is the dynamic power consumption that varies based on the environment conditions, P_{sc} is the short-circuit power consumption, and P_{leak} denotes the power loss due to transistor current leakage.

Since femtocells structure is similar to macrocell, component level energy efficiency metrics are also suitable for a femtocell. However, for BS and network level, service difference between femtocell-supported and macrocell provided services and the interference between both of them should also be considered. In [34] an interference-aware pricing-based metric has been discussed, and energy factors had the dominant effect they proposed an energy efficient metric for femtocell and macrocell heterogeneous network that considers the service rate and power consumption in both femto-base station and macro-base station. In [17], uplink power control allocation is investigated through the circuit and transmit power to reduce energy consumption. The author in [35] states that there is an exponential increase in wireless data traffic due to the massive increase in wireless terminal equipment and wide usage of bandwidth-hungry applications of mobile Internet. Therefore, the conventional method of macrocell base stations (MBS) deployment is no longer effective. It has low quality but preferred in 5G [36]. Smaller cells are used to curb this problem, because, as noted in [35], smaller cells have low-power, low-cost and small access points (e.g., microcell, picocell, and femtocell).

IV. HOW CAN ENERGY BE MODELED?

Generally, wireless network energy consumption is evaluated at two different levels (Table 2). The first one, embodied energy consumption of a femtocell calculates the total primary energy that is consumed for making the product. It is assumed as 162 MJ, same as a mobile terminal and the average lifetime of a femtocell can also be assumed as 5 years.

TABLE 2. Energy consumption of a femtocell BS at different levels.

Energy Consumption Level	Definition	Average Power
Embodied Energy	The total primary energy that is consumed for making the product.	162 MJ (1 W/s)
Operational Energy	The aggregate energy consumed in a system's lifespan	6 W/s

In other words, embodied the energy of femtocell per second is calculated as 1W [37]. The second level is operational energy consumption, which is consumed during a system's lifetime and it changes depending on different configurations such as the age of the facility and load of the femtocell. The average operational energy consumption of a femtocell was considered 6W in [37]. Femtocell power consumption mainly depends on radio frequency power amplifier and the power amplifier of the power supply.

In the literature, there are few models about power consumption of femtocells. On-off model is the most basic one which can be used for theoretical analysis where femtocell base station consumes unit and zero power in active and off mode respectively. In reality, power consumption is different. In [38], they proposed a linear power model that considers traffic load, which is better than on-off model since traffic load is defined. In [39], they proposed a more detailed model, where the authors made an argument that the impact of traffic load on power consumption is insignificant so it can be omitted.

In [40], they proposed a simple analytic model to predict the femtocell base station power consumption based on offered load and datagram size. The authors tried to fit the model to real experiment, the power consumption of a femtocell base station is measured in idle and varied load. In the experiment, one femtocell is used, which supported up to four simultaneous end-user devices and it is connected to the campus network. The energy consumption of voice and FTP was also predicted. In the experiment, radio energy is neglected. Since in a voice call, the downlink is active for a small period, while it remains most of the time during FTP download. It was expected that radio power consumption should be higher than voice calls.

In [41], the authors proposed power consumption model, it is based on a femtocell that consists of three interacting blocks: a microprocessor, FPGA, radio frequency transmitter, and power amplifier. They used energy efficiency, which is defined as power consumption needed to cover a certain area, in order to compare different technologies. They used ITU-R P.1238 propagation model and office scenario is assumed. They considered frequency, the floor penetration loss factor, the number of floors between the base station and terminal and the distance power loss coefficient to calculate the range. Based on this model, they compared the energy consumption for different bit rates and different technologies. Moreover, they used this model in a deployment tool that allows designing energy efficient femtocell networks by using a genetic algorithm. Table 3 summarizes the mentioned energy consumption models.

TABLE 3. Comparison of different energy consumption models.

Reference	Model Type	Input
[38]	Practical	Static power consumption (idle mode power consumption of power amplifier, base band transceiver units, feeder network and cooling system) and dynamic power consumption (load on the base station and backhaul power consumption of base station)
[39]	Analytical (Log-normal distribution)	Radio frequency output power at maximum load, minimum load and in sleep mode and the dependency of the required input power on the traffic load
[40]	Analytical	Datagram size (byte), offered load (Mbps), baseline power consumption when the femtocell is idle (Watts)
[41]	Practical	Power consumption (Watts) of the microprocessor, the FPGA and the power amplifier (input power of antenna and the efficiency of the power amplifier which is the ratio of radio frequency output power to electrical input power)

V. ENERGY EFFICIENCY SCHEMES FOR DEPLOYMENT

Femtocells can be deployed in a heterogeneous network with different combinations of macrocells, microcells, picocells and femtocells and reduction in total power consumption can be obtained from these schemes. The amount of energy efficiency depends on different variables. However, how to create the combination is also a challenging issue and there are some criteria to choose which cell to deploy. Although energy efficiency is not the first goal in some of the combinations modeled, energy efficiency is achieved. In general, cell deployment takes into account density of mobile users, traffic volume, and coverage in the network models. It is also important to provide same or better QoS when energy efficiency is subjected. Although femtocells have potential to improve coverage, it degrades the performance due to cross-tier interference. The network criteria mainly depend on the mobile user density, traffic, and coverage, in most of the previous studies. Mobile user density and traffic are considered to choose the correct cell size. Urban and rural areas are also important criteria in order to choose the cell. In the areas that have very low signal can be deployed with smaller cells, such as femtocell so that coverage can be increased and there will be a reduction in total power consumption.

There are different models in the literature to analyse energy efficiency using heterogeneous network includes femtocell and macrocell. The authors [25] considered a different size of cells depending on mobile user density, the authors try to reduce power consumption without effacing coverage and QoS. An analytical model is developed for five different schemes and it is concluded that it consumes less power compared to macrocell network. In the first schema, the femtocell based network is used instead of macrocells and it is observed that power consumption is reduced by 82.72% and 88.37%. In the second schema, the area is divided into three parts as urban, suburban and rural. The mobile user density is considered, mobile user traffic and required coverage and they covered urban areas by femtocells, suburban areas with macrocells and rural areas with portable femtocells. As a result of this simulation, they succeed between 78.53% and 80.19% reduction in power consumption. In the third schema, the femtocells are allocated to the congested urban area, picocells to less congested urban areas, the power consumption is reduced between 9.19% and 9.79% [42], [36]. In the fourth schema, they allocated microcells, picocells, and femtocells to the border region and macrocell to remaining region. The reduction in power consumption is between 5.52% and 5.98% for this combination. The last one, femtocells are allocated between the boundaries of the macrocell, where the signal is not enough for a call. The result of the last model was 1.94% - 2.66% reduction in power consumption and shrunk macrocell coverage.

Bell Labs recommended a hybrid network, both femtocell, and macrocell, with open access femtocell, where all subscribers can connect to these femtocells like any base station [8]. The implementation area was 10 km by 10 km urban area of New Zealand and the population was about 200,000 people that means 65,000 homes and the 95% of the population uses the mobile equipment. The authors deployed a different number of femtocells that can serve up to 8 users in 100 x 100 m2 with 15 W energy consumption. It consumes higher energy due to an open access model. In this technique, macrocells are permanently used with 2.7 kW energy and femtocells are randomly deployed. Energy consumption depends on the use of the network: voice call and data connections. It is analyzed femtocells can reduce energy consumption up to 60 for data connections, while it has no impact for a voice call. The authors used femtocell to offload capacity and macrocells to enhance coverage.

Another one was from Ofcom (the UK telecoms company) and Plextek as a consultant [43], [44]. They analyzed two approaches; first, the femtocells are deployed to 8 million households which are almost 25% of the UK population. It is analyzed that each femtocell daily consumed 7W and annual energy consumption was 490 GWh. In the second approach, they modelled macrocell network in order to provide indoor coverage, same with the first approach and they would need 30,000 base stations in order to provide coverage. It was concluded that macrocells take 40 times more energy compared to femtocell for indoor signals. To provide same coverage macrocell annual energy consumption was 700GWh for each operator. For indoor coverage in the UK, energy consumption ratio was 7:1 over using macrocells.

VI. WHAT AFFECTS THE POWER CONSUMPTION OF A FEMTOCELL BS?

Access type for the femtocell plays a key role in the amount of a femtocell energy consumption. Femtocell access type sets the rules about who can connect to a femtocell base station (BS). It can be categorized in three type: open, closed and hybrid [45]. In the literature, most of the studies about access type examine interference, QoS, and handover issues. On the other hand, although there is no work directly compares the energy efficiency related the access type, energy consumption can be compared with examining different models in the literature.

In open access, sources are shared among the users and all users can connect the network in public places without any restriction. On the other hand, closed access, only authorized users to connect the network. There are different service levels among users and they are mainly used in small buildings. A Hybrid access is a combination of both the techniques where outside users can access a femtocell. However, the outside user group must register with the system and the system provides limited services depending on the management policies. The comparison of the access types is given in Table 4.

TABLE 4. **Comparative performance analysis of access types.**

	Open	**Closed**	**Hybrid**
Deployment	Public spaces	Residential area	Enterprise
High user densities	No	Yes	Yes
Owner preference	No	Yes	Yes
Number of handovers	High	Small	Medium
QoS	Low	High	High
Interference between femtocell and macrocell	Increase	Decrease	Decrease

Although there is no work that compares the power consumption based on different access mode, it can result as open access consumes more energy. In [8], the power consumption of a femtocell is assumed as 15W although it is assumed as 6W in [37]. The reason for the high power consumption is open access. Bit rate is another important factor that affects the energy consumption of a femtocell. It can be defined as a number of bits that are conveyed or processed per unit of time.

As it reaches higher rates, the speed of connection becomes better since it is speed based measurement. Cellular operators try to increase the bitrates since it is important in the market. On the other hand, bit rate has an impact on energy consumption. In general, as bit rate increases, energy consumption also increases. Moreover, energy consumption for different bit rates is not same on different wireless technologies.

As mentioned, energy consumption of femtocell is not stable for different wireless technology standards such as WiMAX, HSPA, and LTE which are rivals in the sector. WiMAX (Worldwide Interoperability for Microwave Access) can be used for transferring data across an ISP (Internet service provider) network, as a fixed wireless broadband Internet access, replacing satellite Internet service or as a mobile Internet access [46]. HSPA (High Speed Packet Access) is another wireless technology standard, which is enhanced version of 3G [47]. LTE (Long Term Evolution) is considered as 4G and provides better capacity and speed [48]. They provide different bitrates and energy consumption of a femtocell is different for these technology standards. On the other hand, it is hard to say which one provides better energy efficiency since it changes with different bitrate ranges. The authors [41] compared the energy efficiency of a femtocell base station with different wireless technologies, i.e. WiMAX, LTE, and HSPA. Based on this model, it is found that femtocell consumes nearly 10 W for a range between 9 to 130 m, WiMAX is the most energy efficient technology for bit rates more than 5 Mbps. LTE consumed the least energy for bit rates between 2.8 and 5 Mbps. They used this model in a deployment tool that allows designing energy efficient femtocell networks by using a genetic algorithm and they concluded WiMAX is the most energy efficient one in this scenario.

Network type also affects the energy consumption of femtocell. To illustrate, its power consumption is different for voice call and data transfer. Moreover, there are different data transfer protocols such as FTP and UDP. Datagram size and offered load have also impacts on the consumption. In [40], they studied the effects of network type, datagram size and offered load. The result of the analysis conducted by Bell Labs [8], the network efficiency depending on the type of data connections (voice and data). When femtocells mainly used for a voice call, there was no big saving on total energy consumption. On the other hand, when femtocells used for data connections, femtocells were able to reduce total energy consumption up to 60%.

The last factor that has an impact on femtocell power consumption is sleep mode. Since femtocell provides very small coverage compared to the macrocell and very few users are connected to it which makes it idle often times particularly in the case of indoor deployment. However, it consumes energy even if it serves no user. In this case, it is better to switch off the base station so this can be implemented with sleep mode. Sleep mode is energy efficient and feasible, but the decision is also important [49]. There are few works in the literature that analyze the impact of sleep mode. In [41], they examined the sleep mode to reduce power consumption and it reduces the power consumption supporting up to 8 users and it led to 24% of power consumption in the network. Table 5 gives the summary of the section.

TABLE 5. Factors that affect power consumption of a femtocell BS.

Factor	Energy Consumption
Access mode	Higher in open access, less in close access
Bit rate	Increases with higher bit rate
Wireless technology standards	Depends on bit rate range
Network type	Higher in data transfer
Sleep mode	Less energy consumed if sleep mode is an option

VII. USER EQUIPMENT POWER CONSUMPTION

One of the main ideas of the femtocell is to become closer to the user equipment which is an approach to enhance capacity and decrease energy depletion of both cellular network and user equipment [15]. However, since the coverage area of the femtocell is not wide, the number of handovers is very high in a femtocell network. Moreover, user equipment uses most of its energy for the handover process [50]. Another issue about handovers is that they decrease QoS and network capacity. Thus, the handover decision algorithm is an important issue in femtocells. Although there are lots of studies about handover decision, only a few of them depends on energy efficiency.

In [50], they studied about the energy efficiency of femtocell on user equipment battery. They worked on the fact that there is a reduction in power consumption of user equipment under femtocell coverage, compared to macrocell connection and they proposed a handover decision algorithm that aims to reduce user equipment power consumption while maintaining QoS. The suggested algorithm enhances the strongest cell handout policy using an adaptive handout hysteresis margin. Although there is a need for increased LTE network signaling in the proposed algorithm, they derived power consumption and also interference. The result is compared with different algorithms in the literature and a strongest cell based handout decision algorithm. It was analyzed that the proposed algorithm reduced 85% user equipment energy consumption compared to femtocell deployment in LTE network.

VIII. CHALLENGES

Even though small cell cognitive network such as Femtocell is a promising technique, there are still many challenges that must be addressed, for instance: interference mitigation, spectrum access, and QoS provisioning [51]. Providing reliable services for applications which demand low-energy consumption and latency within the Internet of things context is a challenging issue. It is well known that some wireless network applications require deterministic systems with a reliable and low latency aggregation service guarantees. Since the IEEE 802.15.4e standard is considered as the backbone of the IoT using WSNs, the existing low latency deterministic network (LLDN) mode used to fulfill the major requirements these applications require further contributions. In turn, research groups for this standard have studies on improvement of quality of service related concerns including energy efficiency [52]. Test-beds, simulation studies and analytical modelling approaches are being employed for this purpose effectively.

Moreover, the authors in [13] poses some questions on a few of the challenges faced by femtocell, for instance, they ask how will femtocell provide timing and synchronization?, given that femtocell require synchronization to align incoming signals, and hence minimizing multiple access interference and guarantee a tolerable carrier off-set. Another challenge discussed by the authors is how backhaul will provide acceptable QoS, IP based backhaul need to provide QoS for traffic that is sensitive to delays, additionally, microcells systems provide a latency guarantee of 15ms. However, current backhaul networks do not have such protection against unnecessary delays. Another key challenge is how a femtocell will adjust to its surroundings and assign spectrum with the existence of intra- and cross-tier interference. The authors in [53] talk about an existing problem in small cell cognitive networks of power control and sensing time optimization, this problem has been evaded by many researchers yet it has real effects in the operation of the network. Moreover, the author in [54] says that fairness and spectrum sensing errors were ignored in most research. The author in [55] defines Heterogeneous cloud small cell network (HCSNet) using small cells and cloud computing, while the author in [19] defines Ultra dense cloud small cell network (UDCSNet) as a combination of cloud computing and massive deployment of small cells. They will play a major role in a 5G mobile communication network in the quest of trying to satisfy the massive data traffic generated by the ever growing number of users. However, problems such as co-channel interference and handover management that came about due to massive deployment of small cells must be considered [55].

The author in [56] outlines a problem that arises in small cell networks when trying to achieve capacity growth through network densification, this attempt will be faced with the challenge of severe inter-cell interference. This problem arises due to the limited licensed spectrum for cellular networks. Therefore researchers are looking at using unlicensed spectrum bands, including the 2.4 GHz and 5 GHz to curb this problem.

IX. OPEN RESEARCH ISSUES

Recently, popular technology solutions for various cellular network applications have emerged as a significant advancement for Internet and mobile networks. Internet of Things (IoT) is a novel paradigm where connected entities become part of these infrastructures, and the advancements in IoT make it quite popular where the traditional telecommunication systems facilitate basic communications between these entities. IoT has converged technologies in terms of sensing, computing, information processing, networking and controlling intelligent technologies. Among the key technologies converged is the femtocell due to its low-energy wireless communications and cost effectiveness. Femtocells are composed of base-stations and numerous low cost resources, in terms of communication, storage and computation facilities. Wealth of various approaches have been proposed and designed for considering the collaborative nature of femtocells in the existing literature. However, there are key open research problems still to be solved in the IoT era.

Since in general enabling technologies have restricted authentication privileges for mobile users, different strategies are introduced for the extension of user authentication over IoT based environments. Commercialization of remote applications, security issues in femtocells have gained much attention of the researchers to satisfy the security properties of authentication and key agreement protocols. In general, the development of security protocols is more challenging and should also consider mitigation of the computation and communication cost. Moreover, considering the femtocell and the macrocell energy consumption for heterogeneous networks is another key challenge. Where energy consumption models, considering the aforementioned IoT setups are mandatory for more accurate estimations while considering different access types. Furthermore, covering a large area with the optimized deployment of macrocell and many overlapping femtocells needs a careful consideration in order to realize the femtocells in the IoT era.

X. CONCLUDING REMARKS

Energy efficiency of femtocell networks becomes indispensable with the growing deployment of femtocells. Moreover, it can be used in order to manage energy efficiency when it is used in smart grids. In this survey, we mentioned energy efficiency of femtocell networks in IoT, considering energy metrics, energy consumption models, energy efficiency schemes for deployment, factors that affect the energy consumption of femtocell networks and energy efficiency of user equipment under femtocell coverage. The energy efficiency of the femtocell in IoT still needs to be investigated.

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