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Why Femtocell Networks?

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Why Femtocell Networks?

Padmapriya Sambanthan [α] & Tamilarasi Muthu [σ]

Abstract- Cellular communication has witnessed tremendous growth during the past couple of decades. It plays an inevitable role in day-today life and in modernizing the human society. Throughout the evolution of cellular networks, many standards have come into existence, in order to meet the growing demand of ubiquitous, high quality voice, data and multimedia services. Besides, next generation cellular networks are in the necessity to offer seamless services even at the cell-edges and indoor provinces where the requirement for the cellular services is never the less. Though there is a growing demand for higher data rate services every day, the conventional macro cell (MC) is unable to provide better coverage extension to cell-edge users. To handle indoor and outdoor traffic growth, the recent heterogeneous network has emerged with an answer in the form of small cell technology. A study on fem to cell (FC) network along with its challenges is elaborated in this paper. We concentrate on revealing the importance of fem to cells and its evolution phases. As well, the technical challenges faced in fem to cell network are detailed to this end.

Keywords: long term evolution, small cells, fem to cell networks.

I. Introduction

Telecommunication has come a long way from Grahambell's wired telephone to the Long Term Evolution's (LTE) multimedia services. Conventional wired network has left the long-lasting footprints in terms of radiation-free communication, despite it cannot extend its limited service to longer distances. To span communication networks globally, wireless communication evolved in the year 1960. Compared with wired communication, wireless communication has led to lesser hardware and signal processing complexities.

The cellular network, an integral part of our society, has subjected the wireless communication to many generations, in order to guarantee ubiquitous voice, data and multimedia services to each and every network users. The First Generation (1G) cellular network has evolved during 1980's provided voice-only analog communication. In addition to voice, the Second Generation (2G) has offered data, fax and message services to the network users. The 2G's digital phone equipment has ushered in the cellular networks to multimedia computing and entertainment services through Third Generation (3G) technology. The high-capacity systems have turned the 3G network as an all-inclusive network.

The requirement for anytime, anywhere services has shifted the paradigm of 3G towards the Fourth Generation (4G). The goal of 4G is to increase the capacity and the speed of wireless data networks by using Digital Signal Processing (DSP) and Orthogonal Frequency Division Multiplexing (OFDM) techniques, which exist around the turn of the millennium. With the application of Internet Protocol (IP) based architecture, the 4G networks attain lesser data transfer latency compared with the 3G networks. The succeeding Fifth Generation (5G) networks are another high speed IP based networks, aiming to deliver multimedia services at the rates of Terabytes.

In the recent years, cellular network has witnessed a huge network user growth and hence, the network operator finds it harder to accommodate more number of users over the limited amount of spectrum. A recent study of Cisco has forecasted that the demand for wireless data traffic is drastically increasing and the monthly demand is expected to reach 6.3 Exabyte by 2016, that is, a 26-fold increase in data traffic demand when compared with the year 2010 [1]. In addition, specific studies show that more than 50% of voice traffic and 70% of mobile data traffic originate from indoor and enterprise environments [2]. On the other hand, poor indoor coverage is experienced by 30% of business and 45% of household network users [3]. Therefore, to increase the revenue of network operator and to satisfy all type of network users, a special emphasis must be given to handle astonishing network user growth, spectral demand and indoor coverage necessity. It is remarkable that all the wireless network generations (1G to 4G) are highly motivated to handle growing network traffics over the costly spectrum.

On the contrary, the Macro-base Station (MBS) provides limited coverage to indoor and cell-edge subscribers. As the MBS operates at high frequency, the ability of short-wave signal to penetrate walls gets reduced. Network operators would need 30,000 base-stations to offer good geographic coverage in a densely populated urban area and the power used by each MBS are set to achieve "marginal" indoor coverage at the cell-edges [4]. Some research has found that MBSs are responsible for 10% of global carbon-di-oxide emission and this percentage is expected to double over the next decade [5]. Moreover, jumbo MBSs consume 2.5kW to 4kW of power for connecting the mobile devices to the core network. Out of this huge power, only 5% to 10% of

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the energy would emerge out as a useful radiated signal and the remaining input power is dissipated as heat.

In addition, the simultaneous traffic originating from dense network users overload the MBS, which creates higher service blocking probability over busy hours. To handle this circumstance, the cellular network is reformulated into LTE based heterogeneous networks.

As the name implies, the co-existence of many small-radius cells in the same geographical area and over the same set of frequency has given rise to the heterogeneous networks. The idea of overlaying small cells on the existing macro cell network's frequency not only overcomes the spectral demand, but also provides enhanced indoor coverage to the network users.

II. Smallcell Technology

One MBS per Macro cell (MC) is not sufficient to satisfy the service requirements of widely distributed outdoor as well as indoor users. Hence, to serve all users efficiently, the large MC coverage is divided into many tiny cells, called small cells, which bring the base station closer to the users. Small cells not only lend excellent radio signal reception inside buildings, but also guarantee high quality multi-media services to the users in shadow, edge and coverage holes of a network [6]. Frequency reuse between MC and small cell enhances network capacity and revenue of the operator as well.

The overall spectral efficiency on overlaying small cells on the existing MC network is much greater than that is achievable by MC alone.

The small cell deployment process is customer-friendly as the small cell owners do not require on-site technical assistance. Small cell subscribers enjoy good signal quality from the closely located plug-and-play base stations and hence, the user equipments require minimal battery power. Thus, small cell technology is the solution to handle prevailing network challenges like network user density, spectral demand, poor indoor and cell-edge coverage, non-guaranteed service quality, huge power consumption and green-vegetation hazard.

In general, cells define the coverage boundary or footprint, till which they can provide service to the associated users. Based on the cell radii and transmit power, cells are classified into four major types. Table 1 lists the cell types with respect to the decreasing cell radii and decreasing transmit power level [7]. Among them, fem to cell, pico cell and microcell are called as small cells, which are overlaid on conventional MC network.

Table 1: Various cell types and their radius and transmission power

Cell types	Typical Cell Radius	Transmission power values
Macrocell	1Km-2Km	40W
Microcell	250m-1Km	5W
Picocell	100m-300m	2W
Femtocell	10m-50m	200mW

It can be observed from the Table 1 that the Fem to cell (FC) is the smallest cell and the pico cell is the second smallest cell. Macro cells and microcells cover wider geographical area and they bring-in the disadvantages like tall antennas, huge operating power, greater path loss and fading effects. On the other hand, pico- and fem to-base stations are closely associated with their registered users, where the chance of signal attenuation and other propagation loss are very less. Hence, the service quality of pico cell and fem to cell is comparatively higher than that of macro cell and microcell.

Fig. 1 indicates that FCs are preferred for residential based network users, pico cells are suggested for indoor enterprise users, whereas microcells and macro cell are preferred for large organizations and huge geographical areas respectively. All these cells are deployed over the same licensed band and controlled by a single network operator. Vodafone, a globally known service provider, launched small cells in the name of "Full Signal" in July 2010 [8] and it has deployed 25,000 pico cell units and 100,000 FC units, as on 2013 [9].

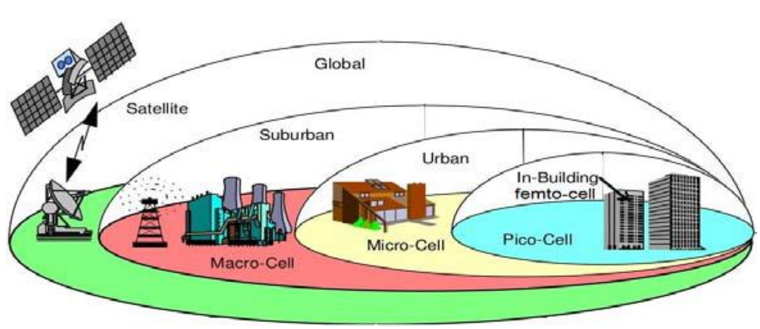

Fig. 1: Illustration of various types of cells

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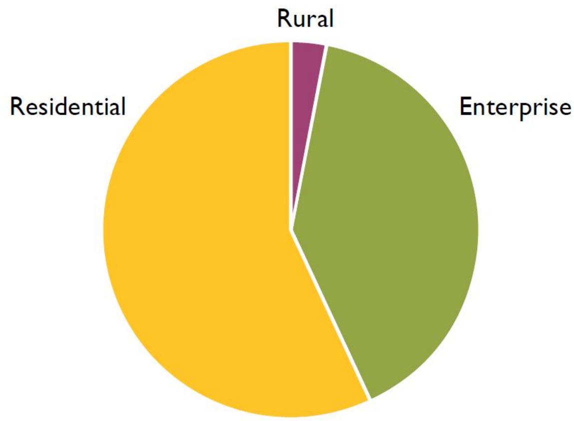
With the help of such small cells, the network operators are able to extend high quality coverage inside the subscriber house without the need for expensive high powered cellular towers. Small cells contribute in the growth of 4G standards and yield backward compatibility to 3G, 2G and 1G technologies as well. Hence, small cells are designed to offer superior indoor coverage at lower operating power with lesser path loss and fading effects.



Source: Informa Telecoms & Media

Fig. 2: Illustration of small cell deployment in the areas like residential, rural and enterprise environment

Major residential deployment, as shown in Fig. 2, highlights the takeover of FC technology (residential) compared with pico cell (enterprise) and microcell (rural) technologies. Thus, FCs are preferred by network users, who desire high quality indoor services.

III. The Best Candidate – Fem to cell

The theoretical concept of FC dates back to the year 1999, where Bell Research Labs first studied the small cell in the name of "home base station". The Alcatel brought a GSM-based home base station in the market in the year 2000. Later, in 2002, Motorola announced its 3G home base station, but the concept was yet found to be new. The FC concept became more famous in 2005 and the actual term FC was coined in 2006 [10]. Right then, a number of companies started trials and demonstrations on deploying FC technology.

A not-for-profit organization was formed by different vendors, operators and research organizations in July 2007 and was named as Fem to Forum [11].

FCs are subscriber deployed base stations, which provide guaranteed high quality voice, data and multimedia services to indoor communication devices, thereby offloading the MC traffic. FCs create small wireless coverage area and connect the registered network users to the cellular core network through subscriber's broadband Internet access. The low power Fem to-base Station (FBS) visually looks like an ordinary wireless router. FCs can concurrently serve 1 to 4 registered network users and can travel with the owners.

FCs operate at 20mW power with a coverage area of 10 to 15meters [12]. These low power nodes operate over licensed frequency band and hence provide backward compatibility to conventional cellular standards and forward compatibility to future cellular networks. They are cost effective solutions as they yield same performance as MBS, yet play a supplementary role to the power consuming MBS.

It is predicted that the future LTE-A networks would include FCs as one of the important member for the indoor cellular coverage. Deployment of FCs can enhance the total network capacity of more than three orders of magnitude [13]. The whole 4G FC market value is predicted to surpass \$600 million in 2014. More than 5 million small cells have already been deployed and it is expected to reach 90 million units by 2016. ARC chart estimates that by 2017, a total of 5 million small cells would be deployed annually [14].

Worldwide, more than 47 leading operators have already deployed FCs in their existing network - encompassing public, enterprise and residential sectors [15]. In comparison with the existing MBS, the FBS consumes 40 times less power to deliver a signal to the indoor. This implies that FCs can increase the site density at the cell edges and at the indoor by 6.3 fold than that of an MC network [16].

a) *Necessity of Fem to cell Networks*

The pursuit of FC network is due to the following fact: the capacity of a cell depends on the cell radius. From inverse square law, the total cell capacity is inversely proportional to the square of the cell radius.

$$\text{Capacity of a cell } \alpha \ \frac{1}{(\text{Cell radius})^2} \qquad (1)$$

If the cell radius is halved, the cell capacity is quadrupled. On correlating Table 1 and Equation (1), it is understood that the FC is the smallest cell among the prevailing cellular family and hence, FC is the best candidate to offer higher cell capacity.

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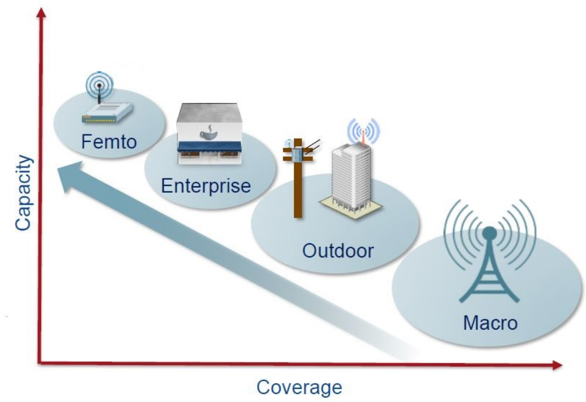
Smaller the cell radius, closer the base station to its users. The signal degradation is negligible in such a scenario which improves received signal quality. Also, the registered users inside FC coverage may possess less mobility and the effect of fading is less and the aggregate throughput is more when compared to MC network. Hence, among various cell types, the short range FCs are preferred to as the best candidate for achieving higher cell capacity as shown in Fig. 3.



Source: Radisys Trillium

Fig. 3: Relation between coverage and cell capacity for various cell types

From the aspect of spectral efficiency, FCs play an important role in advancing the cellular networks. The conventional cellular network concept, called cell splitting [17] was invoked by LTE standard to enjoy the benefit of more users over limited spectrum. Donald postulates that the big MC coverage can be equally divided into multiple N subcells and each of them can have same set of frequency as of MC, with an extra care on efficient frequency planning. This concept enhances the cell capacity N times at the cost of careful network configuration and management procedures.

Out of contention, FCs offer numerous advantages like offloading MC traffic, guaranteed high quality indoor services, spectral efficiency, network capacity, multiuser diversity, non-emission of greenhouse gas and ubiquitous services to all users.

Due to its wide application, industry people call FCs as network in box, in-building coverage nodes, private network, plug-and-play base stations and low power access points. The FBSs are designed to support Global System for Mobile (GSM)/Code Division Multiple Access 2000 (CDMA2000) standards and are equipped with Global Positioning System (GPS) to sense the environment. Features such as frequency planning, sleep mode activation, synchronous operations with the under-laid MC network are attained through GPS enabled FBSs. In addition, self-configuring and self-organizing features in FC network greatly reduce the supervision task of the network operator. FC acts as a stand-alone, network integrating node that facilitates the co-existence of cross-tier users in FC proximity through proper access mode selection.

b) Fem to cell Network Model

The general FC network model is depicted in Fig. 4.The Fem to users (FUs) are connected to the operator core network through FBS and Fem to cell Management System (FMS). An FMS is a centralized FC coordinator, through which FC admission and management take place. It is an integral part of network operator cloud. Each FC or FBS can serve 3 to 4 FUs concurrently. The FBS aids the registered FUs in transmitting and receiving the intended signal to and from the operator core network. Cognitive enabled FBSs can sense and adapt to the environment.

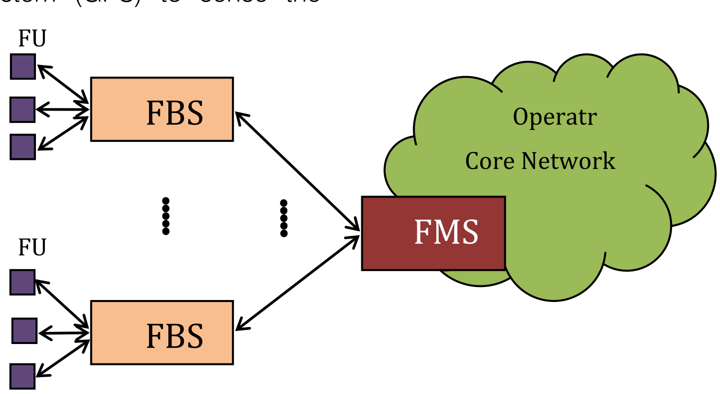


Fig.4: Fem to cell network model

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The FCs are owned by FUs and hence, the FBSs posses plug-and-play nature on use's mobility. FMS organizes the FC clusters and provides service to the registered FUs in the cluster. Due to random FC deployment, the coverage area of neighboring FCs residing under an FMS may overlap. At any given point of time, each FMS is defined to take care of fixed number of FCs. With an increase in the number of FCs, new FMSs are deployed to handle the traffics originating from newly formed FCs.

It is noticeable from Fig. 5 that the spatially apart Macro users (MUs) and FUs are assigned with same set of frequency. Such type of frequency planning enhances the overall spectral efficiency and network capacity. The FC configuration procedure is as simple as configuring an IP modem. When FBS is powered on, it scans the network for a nearby-associated FMS. On tracking the existence of FMS's signal over the radio environment, FBS forwards its unique Fem to cell Identity (FC_ID) to FMS and gets registered to it. Upon FC_ID authentication, the FMS assigns the radio parameters to the FC.

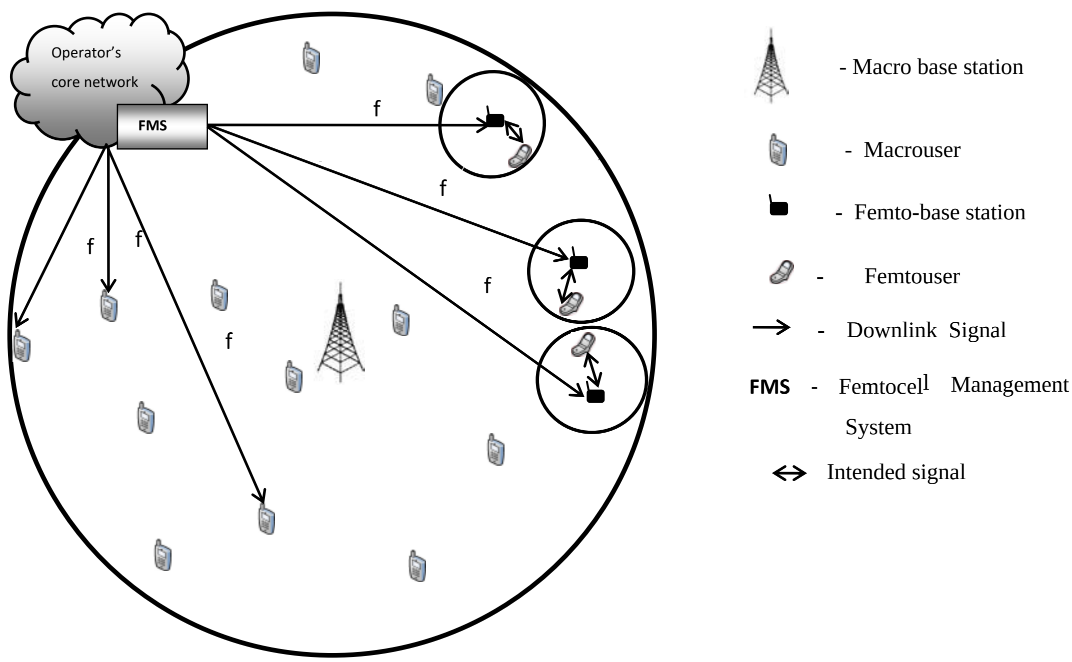

Fig. 5: Macro-fem to cell heterogeneous network model

Once configured, FCs periodically broadcast the FC_ID to intimate their presence to the FMS and neighboring FCs. Moreover, the self-configuring feature enables the FC to scan the environment and acquire knowledge about the neighbors on its own. The MC and FCs operate under the same network operator and therefore they can read and exchange common sets of information.

c) *Comparison between FC and Wi-Fi Networks*

Wireless Fidelity (Wi-Fi), the most popular wireless local area network, has evolved in the year 2005 [18], [19]. The standard of Wi-Fi is IEEE 802.11n and it is otherwise called as hotspot. Wi-Fi technology has brought the high speed data services closer to business organizations and enterprise environment. The growing pervasiveness of Wi-Fi has helped the 3G data network to extend beyond the personal computers. In comparison with Wi-Fi standard, the importance of FC technology is highlighted in Table 2.

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Table 2: Comparisons between FC and Wi-Fi networks

Femtocell (FC)	Wireless Fidelity (Wi-Fi)
FC operates over a licensed frequency band (800MHz, 2.5GHz)	Wi-Fi operates over an unlicensed band(2.4GHz or 5GHz)
Coverage area spans 10 to 15meters and operating power is 20mW	Coverage area spans till 100meters and its operating power is 1W
Careful frequency planning is required as the FC utilizes the frequency bands of MC.	Wi-Fi does not require frequency planning as it is deployed over unlicensed band.
FC network provides superior quality *voice and data* services at the rate of 1Gbps	Wi-Fi offers *only data* service at the rate of 100Mbps.
Existing handsets can be utilized to access FC network	Wi-Fi technique demands Wi-Fi enabled device.
Same radio link is utilized by FU and MU. Hence, battery draining in FU handset is less.	Unlicensed radio is powered by the handset to activate the Wi-Fi service. It leads to faster battery draining.
No privacy or security issues	Has privacy and security issues due to unlicensed band operation
Supports power control through sleep Mode	There is no default sleep mode setting in Wi-Fi standard
Provides inter-tier and intra-tier Mobility	Provides mobility only within the legal Wi-Fi coverage area

IV. Conclusion

Fem to cell has carved a niche for itself among small cell family and most of the industry and research people view FC as the promising candidate in the next generation cellular networks. On recognizing the benefits of FC, most of the industry and business people celebrate FC as a prominent candidate in small cell family. However, a flip side investigation on FC technology reveals that the technology has also got some challenges to be addressed. In practice, improper access mode selection, dense FC deployment and seamless mobility of MU has lead to serious challenges like interference, backhaul bottleneck and handoff mechanisms respectively. Hence, to meet with the requirements of FC owners without affecting the network operator's revenue, more emphasis must be given in handling aforementioned challenges.

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