 ISSN: 2250–3676

[IJESAT] INTERNATIONAL JOURNAL OF ENGINEERING SCIENCE & ADVANCED TECHNOLOGY Volume-2, Issue-6, 1596 – 1602

3GPP LTE FEMTOCELL – PROS & CONS

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Abstract

This paper highlights brief on FEMTOCELL implementation. The Femtocell is the latest evolution of the mobile network base station. It is aimed at providing dedicated indoor coverage, bringing benefits of enhanced coverage and improved call quality and data rates. Femtocells have been extensively discussed in the telecommunication industry over the last few years, and a high level of interest is ongoing. The femtocell concept is applicable to all standards, including GSM, CDMA2000, TD-SCDMA, WiMAX and LTE solutions. In this paper need, positive/ negative aspects, technical issues and market scenario for the femtocells is explored.

Index Terms: *Femtocell, 3GPP HSPA LTE, Improved macrocell reliability, Backhaul via broadband, interference, QoS, Cell Association and Biasing, Mobility and Soft Handover, Self organising networks*

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1. INTRODUCTION

The exploding growth of the mobile internet and related services in the past few years has fuelled the need for more and more bandwidth. The demand for higher data rates in wireless has triggered the design and development of new data minded cellular standards such as WiMAX, 3GPP's High Speed Packet Access (HSPA) and LTE standards. A femto cell is currently the smallest implementation of a cellular network. It is designed to be placed in each home and enable ordinary mobile handsets to communicate with the mobile network through broadband connections, including cable or xDSL. Besides number of benefits to end users (consumers) and MNO's(Mobile Network Operators), femtocells are a complicated technology and there have been a number of issues and concerns, although as deployments have increased these have largely been addressed.

1.1 Origin

The name Femtocell has the prefix 'Femto', meaning a very small cell (area of network coverage). In English, it is one divided by a figure with fifteen zeros. Well, close to infinitely small. The first interest in femto cells started around 2002 when a group of engineers at Motorola were investigating possible new applications and methodologies that could be used with mobile communications. In addition to developing a mobile television scheme, they also put together a very small UMTS base station. A couple of years later in 2004, the idea was beginning to gain some momentum and a variety of companies were looking into the idea. In particular two new companies, Ubiquisys and 3WayNetworks were formed in the UK to address the area of femtocells. With the idea gaining momentum, and many more companies investigating femto cell technology, the Femto Forum was set up in July 2007. Its aim was to promote the wide-scale adoption of femtocells. With mounting industry pressure to be able to deploy femto cell technology, the Femto Forum also played a coordinating role in ensuring that the standards were agreed and released as fast as possible.

1.2 Why Femtocell

Studies on wireless usage show that more than 50% of all voice calls and more than 70% of data traffic originates indoors. Voice networks are engineered to tolerate low signal quality, since the required data rate for voice signals is very low, on the order of 10 kbps or less. Data networks, on the other hand, require much higher signal quality in order to provide the multi-Mbps data rates users have come to expect. For indoor devices, particularly at the higher carrier frequencies likely to be deployed in many wireless broadband systems, attenuation losses will make high signal quality and hence high data rates very difficult to achieve. This raises the obvious question: why not encourage the end-user to install a short range low-power link in these locations? This is the essence of the win-win of the femtocell approach. The subscriber is happy with the higher data rates and reliability; the operator reduces the amount on traffic on their expensive macrocell network, and can focus its resources on truly mobile users. Many mobile users enjoy decent cell phone reception

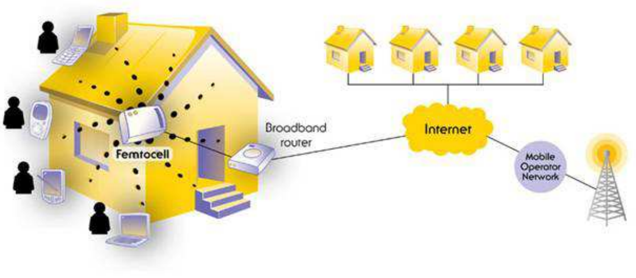

Figure 1 : Femtocell Network Structure

when they are out but can't get a signal inside. Indoor signals have long been a weak point of cellular coverage. Femtocell offers the possibility of using a device like a broadband router to boost cellular reception indoors.

The most efficient way to increase network capacity in a cellular network is to shrink the cell size.

Macrocells: A Macrocell provides the largest area of coverage within a mobile network. Its antennas can be mounted on ground-based masts, rooftops or other structures and must be high enough to avoid obstruction. Macrocells provide radio coverage over varying distances, depending on the frequency used, the number of calls and the physical terrain. Typically they have a power output in tens of watt. Macrocells are conventional base stations with power about 20W, that use dedicated backhaul, are open to public access and range is about 1 km to 20 km.

Table-1: Comparison of Small Cells

Cell type	Typical cell size	Data rate limitation
Macro	1-30km	Propagation
Micro	200m-2km	Capacity and propagation
Pico	4-200m	Capacity and propagation
Femto	10m	Broadband connection and handset

Microcells: Microcells provide additional coverage and capacity in areas where there are high numbers of users, for Example, urban and suburban areas. Microcells cover around 10% of the area of a Macrocell. The antennas for microcells are mounted at street level, are smaller than Macrocell antennas and can often be disguised as building features so that they are less visually intrusive. Microcells have lower output powers than marocells, usually a few watts. Microcells are base stations with power between 1 to 5W, that use dedicated backhaul, are open to public access and range is about 500 m to 2 km.

Picocells: Picocells provide more localised coverage. These are generally found inside buildings where coverage is poor or where there is a dense population of users such as in airport terminals, train stations and shopping centres. Picocells are low power base stations with power ranges from 50 mW to 1 W, that use dedicated backhaul connections , open to public access and range is about 200 m or less .

Femtocells: Femtocell base stations allow mobile phone users to make calls inside their homes via their Internet broadband connection. Femtocells provide small area coverage solutions operating at low transmit powers. Femtocells are consumer-deployable base stations that utilize consumer's broadband connection as backhaul, may have restricted association and power is less than 100 mW.

1.3 3GPP LTE Femtocell

3GPP is now focused on Long Term Evolution (i.e. LTE, formally 3GPP Release 8 onwards) and LTE-Advanced technologies (LTE-A, Release 10 onwards). WiMAX marches on, including femtocell standardization activities, but its impact in developed markets figures to be small. The physical and MAC layer impact of femtocells on LTE and WiMAX are quite similar, due to their comparable physical and MAC layer designs, which are based on orthogonal frequency division multiple access (OFDMA). Since LTE is likely to be the dominant cellular data platform for the foreseeable future, the smooth integration of femtocells into LTE is particularly important. A key difference in OFDMA (both LTE and WiMAX) is the large quantity of dynamically allocated time and frequency slots. This considerable increase in the flexibility of resource allocation is both a blessing and a curse. Because femtocells can be allocated orthogonal resources to nearby pico and macrocells, the possibility for fine-tuned interference management exists, whereas it did not in GSM or CDMA. That is, in theory, a complex network-wide optimization could be done whereby femtocells claim just as much resources as they "need", with the macrocells then avoiding using those time and frequency slots. And therein lies the curse: potentially a large amount of coordination is necessary. A popular compromise is fractional frequency reuse, whereby frequency (or time) resources can be semi-statically allocated to interior, edge, or small cell users, with power control on top to lower the throughput disparities experienced in each of these scenarios.

Alternatively, a semi-static partition could simply be made between femtocells and macrocells. The results indicate that even with dense femtocell deployments, most resources should go to the macrocell, since each femtocell only needs a small number of resource blocks to provide comparably high throughput to their user(s).

Figure 2 shows, adaption of consumers for Data services over voice and data services are mainly used in indoors.

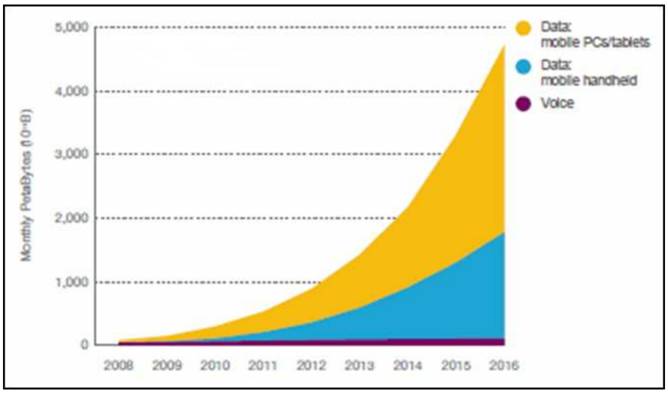

Figure 2: Expected Exponential Wireless Data Growth

2.1 PROS- in favour of Femtocell

There are many advantages for the deployment of femtocells to both the user and the mobile network operator. For the user, the use of a femto cell within the home enables far better coverage to be enjoyed along with the possible provision of additional services, possible cost benefits, and the use of a single number for both home and mobile applications. For the network operator, the use of femtocells provides a very cost effective means of improving coverage, along with linking users to their network, and providing additional revenue from the provision of additional services.

The key arguments in favor of femtocells are the following.

Better Coverage and Capacity

The relentless advance of smart phones, broadband-enabled laptops, and other data-hungry devices has mobile data traffic doubling from one year to the next. Much of it originates at home and in the office, and devices outdoors are hard-pressed to meet indoor bandwidth demand. It will take a lot more macrocells to deliver deep indoor coverage and sophisticated services. But most service providers want to reuse legacy sites, and adding new sites is not always feasible.

Lightening the macro network’s traffic load frees up capacity. One very efficient and cost-effective way of doing this is to deploy femtocells. As a fringe benefit, the femtocell improves radio performance, treating users to a more gratifying experience.

Due to their short transmit-receive distance, femtocells can greatly lower transmit power, prolong handset battery life, and achieve a higher signal-to-interference- plus-noise ratio (SINR). These translate into improved reception—the so-called five-bar coverage—and higher capacity. Because of the reduced interference, more users can be packed into a given area in the same region of spectrum, thus increasing the area spectral efficiency, or equivalently, the total number of active users per Hz per unit area.

Femtocells are aimed at delivering dedicated 3G coverage to a household and in doing so can provide a very good end-user experience within the home environment. As a result, femtocells have a design “capacity” of up to 6 end-users.

The capacity potential of femtocells can be verified rapidly from Shannon’s law, which relates the wireless link capacity (in bits/second) in a bandwidth W Hz to the Signal-to-Interference plus Noise ratio (SINR). The SINR is a function of the transmission powers of the desired and interfering transmitters, path losses and shadowing during terrestrial propagation. Path losses cause the transmitted signal to decay as Ad-α, where A is a fixed loss, d is the distance between the transmitter and receiver, and α is the path-loss exponent. The key to increasing capacity is to enhance reception between intended transmitter-receiver pairs by minimizing d and α.

Penetration losses insulate the femtocell from surrounding femtocell transmissions. Assuming a fixed receive power target with a path-loss propagation model (no fading), and denoting α (resp. β) as the outdoor (resp. indoor) path-loss exponent, overlaying an area L2 with N femtocells results in a transmit power reduction of the order of

$$[10(\alpha-\beta) \log10 L + 5 \beta \log10 N] \text{ dB.}$$

For example, choosing a cell dimension of L=1000 meters and N=50 femtocells, with equal path-loss exponents $\alpha=\beta=4$, femtocells give a transmit power saving of nearly 34 dB. When the indoor path-loss exponent is smaller, say choosing $\beta=2$, the transmit power savings increase to nearly 77dB.

The capacity benefits of femtocells are attributed to:
1. Reduced distance between the femtocell and the user, which leads to a higher received signal strength.
2. Lowered transmit power, and mitigation of interference from neighbouring macrocell and femtocell users due to outdoor propagation and penetration losses.
3. As femtocells serve only around 1-4 users, they can devote a larger portion of their resources (transmit power & bandwidth) to each subscriber. A macrocell, on the other hand, has a larger coverage area (500m-1 km radius), and a larger

number of users; providing Quality of Service (QoS) for data users is more difficult.

Reduced subscriber turnover

Poor in-building coverage causes customer dissatisfaction, encouraging them to either switch operators or maintain a separate wired line whenever indoors. The enhanced home coverage provided by femtocells will reduce motivation for home users to switch carriers.

Improved macrocell reliability

If the traffic originating indoors can be absorbed into the femtocell networks over the IP backbone, the macrocell BS can redirect its resources towards providing better reception for mobile users.

Cost Benefits

Femtocell deployments will reduce the operating and capital expenditure costs for operators. A typical urban macrocell costs upwards of $1K per month in site lease, and additional costs for electricity and backhaul. The macrocell network will be stressed by the operating expenses, especially when the subscriber growth does not match the increased demand for data traffic. The deployment of femtocells will reduce the need for adding macro-BS towers. A recent study shows that the operating expenses scale from $60K per year per macrocell to just $200 per year per femtocell.

There is significant competition for access solutions in the home space. Wi-Fi is commonplace, easy to install/configure, provide a very good benchmark in terms of performance, and are highly cost effective. Femtocells will be offered for purchase via their Operators. This may be direct or through resellers.

Low-impact

Space may be limited for some households. As a result femtocells must be physically small, ideally aesthetically pleasing and easy to position. Furthermore, they should also be silent in operation, generate low levels of heat output and inexpensive to run in terms of on-going [electricity] costs.

Low RF power

The transmit RF power output of femtocells is low; between 10 and 100 milli-watts. Put in perspective, this is a lower power level than many Wi-Fi access points, which can be specified up to 1 Watt of output power. Additionally, by being close to the femtocell the 3G handset is itself able to transmit at lower power levels than it might otherwise have to when on the macro network.

Energy offset - Low-power consumption

Clearly if the end-user is to foot the bill for the electrical energy consumed by the femtocell base-station then this figure must be low enough not to raise concerns as to its impact on the fuel bill. That said, from an Operator’s perspective, this OPEX is effectively offloaded, which makes the business case for femtocells even more attractive.

Easy end-user installation

Like cable modems and DSL routers, femtocells will be installed by consumers and activated through service providers. This means that the Operator no longer has to employ installation teams or have a truck-roll every time a new femtocell is “deployed”. From the end-user perspective the unit must be a simple “plug and play” installation with a minimal amount of intervention required.

Backhaul via broadband

Femtocells utilize Internet protocol (IP) and flat base-station architectures. Backhaul connection to Operator networks will be through wired broadband Internet service existing in the home such as DSL, cable, or fiber optics as available. There are no connections required to the wider cellular network other than through the IP core. This will benefit Operators by effectively offloading traffic that would otherwise be on the macro-layer directly onto the internet from the femtocell; this not only reduces the load on the core network but also lowers the cost of delivering wireless traffic when compared to the macro network.

Worldwide cellular network standards support

Understandably femtocell products are likely to appeal to many end-users around the world. As a result differing models will be developed and offered to satisfy the various needs from the different regions. Products will offer support for their respective and existing (3GPP) UMTS and (3GPP2) CDMA standards, as well as emerging standards such as WiMAX, UMB and LTE.

Support for existing 3G handsets and devices

Support for existing handsets and devices is a very important consideration for the end-user and Operator alike, not least because of the cost of changing devices if that were necessary. In each technology market, femtocells will support existing handsets and devices further helping to drive uptake of 3G services and femtocells in particular.

Due to numerous advantages, femtocells represent a tremendous market opportunity for telecommunications service providers and a great boost in cellular network performance for consumers. Many operators have launched Femtocell service including Vodafone, AT&T, Sprint Nextel, Verizon and Mobile TeleSystems. Figure 2 shows worldwide adaptations for deployment of Femtocell.

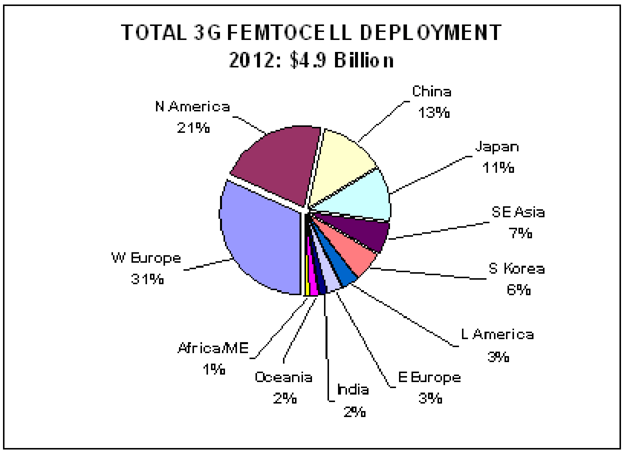

Figure 2 : Femtocell deployment

2.2. CONS- Femtocell de-merits

Femtocells are a complicated technology and there have been a number of issues and concerns, although as deployments have increased these have largely been addressed.

Interference

Interference is a key issue associated with femtocell development. There are a number of issues associated with interference all of which have needed to be investigated and solutions found to ensure that the deployment of any femtocells will take place successfully.

The issue arises from the fact that femtocells will utilize the spectrum already allocated for cellular telecommunications. The femtocells will be deployed in what may be termed an ad-hoc fashion, without the network planning that is normally undertaken for the deployment of cellular telecommunications base stations. As a result there is very real the possibility that interference will arise. This could cause problems to the main network resulting in poor levels of performance being achieved, not only by those using the femtocell, but other users who may be communicating via the main cellular network.

As a result a considerable amount of work has been undertaken to ensure that femtocell interference issues do not arise and prevent their widespread deployment. There are a number of methods that have been developed to ensure the easy minimization of interference so that femtocells can be installed by users without the need to worry about any technical issues. Few are Adaptive Pilot Power Control, Dynamic femtocell receiver gain management, Mobile phone uplink power capping, Extended femtocell receiver dynamic range

Synchronization

Femtocell synchronization is an important aspect of their design. Many aspects of their operation require reasonable levels of femtocell synchronization. 3GPP specifies that base station frequencies need to be very accurate, and there needs to be close synchronization with precise clock signals. Although Release 6 of the 3GPP standard relaxed the requirements for femtocell synchronization, and further relaxation may be possible in the future, methods of providing sufficient femtocell synchronization provide a challenge at the design stages.

Quality of Service (QoS)

As femtocells serve only around 1-4 users, they can devote a larger portion of their resources (transmit power & bandwidth) to each subscriber. A macrocell, on the other hand, has a larger coverage area (500m-1 km radius), and a larger number of users; providing Quality of Service (QoS) for data users is more difficult.

Cell Association and Biasing

A key challenge in a heterogeneous network with a wide variety of cell sizes is to assign users to appropriate base stations. The most obvious way, which does in fact maximize the SINR of each user, is to simply assign each user to the strongest base station signal it receives. However, simulations and field trials have shown that such an approach does not increase the overall throughput as much as hoped, because many of the small cells. This motivates biasing, whereby users are actively pushed onto small cells. Despite a potentially significant SINR hit for that mobile station, this has the potential for a win-win because the mobile gains access to much larger fraction of the small cell time and frequency slots. Furthermore, the macrocell reclaims the time and frequency slots that user would have occupied. Biasing is particularly attractive in OFDMA networks since the biased user can be assigned orthogonal resources to the macrocell, so the interference is tolerable.

An immediate practical challenge introduced by biasing include the use of overhead channels, which are typically common to all BSs in time and frequency and so a biased user would not be able to even hear its channel assignment, for example. This can be solved by introducing time-slotting for the control channels or interference cancellation.

Mobility and Soft Handover

Since the coverage area of an individual femtocell is small, it is essential to support seamless handovers to and from femtocells to provide continuous connectivity within any wide-area network. Handover scenarios include femto-to-macro (outbound mobility), macro-to-femto (inbound mobility) and possibly femto-to-femto; the latter occurring in enterprise deployments or dense femtocell coverage in larger public areas.

In principle, femtocells act as other base stations and can therefore utilize existing mobility procedures. However, femtocell mobility presents a number of unique challenges that require special consideration. Standards bodies such as 3GPP have devoted considerable attention to these mobility issues. Procedures are also being developed for vertical handovers between femtocells and non-cellular access technologies such as WiFi, for example, under the Generic Access Network framework

Self-Organizing Networks

Femtocell networks are unique in that they are largely installed by customers or private enterprises often in an ad hoc manner without traditional RF planning, site selection, deployment and maintenance by the operator. Moreover, as the number of femtocells is expected to be orders of magnitude greater than macrocells, manual network deployment and maintenance is simply not scalable in a cost-effective manner for large femtocell deployments.

Femtocells must therefore support an essentially plug-and play operation, with automatic configuration and network adaptation. Due to these features, femtocells are sometimes referred to as a self-organizing network (SON). The 3GPP standards body has placed considerable attention on SON features defining procedures for automatic registration and authentication of femtocells, management and provisioning, neighbour discovery, synchronization, cell ID selection and network optimization. One aspect of SON that has attracted considerable research attention is automatic channel selection, power adjustment and frequency assignment for autonomous interference coordination and coverage optimization. Such problems are often formulated as mathematical optimization problems for which a number of algorithms have been considered.

CONCLUSION

Femtocells provide a one-box solution: a small, low-cost, low power unit that can be self- installed to provide mobile 3G coverage to the home. For the end-user femtocell solutions Femtocells are not simple standalone devices. They must be integrated into the mobile operator's network to enable seamless service and to ensure optimal performance across both femtocell and macrocell networks. The architectures for the UMTS and CDMA solutions have been defined by their respective standards bodies (3GPP and 3GPP2). Both architectures enable a better experience, with service parity for users, while ensuring security and scalable solutions for operators. Considering that the majority of ―mobile calls originate in the home and end-users prefer to use a single handset – their mobile, Operators now have focused solutions available to them that overcome the issues of poor in-building coverage.

The next logical step for Femtocells in Future is to get your household devices to interact with one another. In Future, Femtocell application could be to use them in aircrafts, trains or in passenger ferries. This type of femtocell deployment can use satellite as a backhaul. However, several challenges are yet to be solved. The Potential challenges to the deployment of Femtocells are the reliance on the consumer to support of backhaul capabilities and the possibility of interference caused by the close placement of multiple Femtocell devices. Some other Problems faced are the security, femtocell spectrum and regulatory issues.

Whether or not they live up to the hype and help move the data avalanche to being a backhaul problem is as yet unclear; but it seems to the authors that there is nothing fundamental preventing very dense femtocell deployments, and that the economic and capacity benefits femtocells provide appear to justify the optimistic sales forecasts.

ACKNOWLEDGEMENT

A large number of people generously contributed to this paper including, including reviewers, and IJESAT editorial staff. We are thankful to Dr.Udhav Bhosale, Principal, RGIT, Mumbai for valuable suggestions.

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