

# ANALYSIS OF FEMTOCELL FOR BETTER RELIABILITY AND HIGH THROUGHPUT

## ABSTRACT

An unrelenting need for mobile broadband data has become the norm for end users. Mobile operators are faced with a challenge to deliver higher data rates and this has prompted the development of new innovative mobile technologies to satisfy this data hungry generation. Poor indoor building penetration is a major stumbling block in achieving higher data rates as good signal strength of better quality influences higher data rates. Methods to solve indoor penetration issues such as cranking up power on existing base stations can be alternate but this can potentially introduce interference to the system and effectively decrease system capacity. Like in any other wireless communication environment, having a transmitter and receiver closer to each other will potentially increase signal strength thus effectively increasing signal quality and potentially higher data rates. This inevitably means more Base stations need to be installed to improve coverage. The idea is not feasible in practice based on financial constraints if we using traditional Macro and Micro sites thus the emergence of FemtoCell seems to be a feasible endeavour. A FemtoCell is a self-installed low powered Base station connected to the mobile operator via backhaul using IP connection. These devices bring a lot of benefits such as Opex savings, increased spectral efficiency, improved battery life and higher data rates for customers resulting from increased signal strength. In this paper an overview of advancement of cellular network from Legacy standards 2G to 4G-LTE/LTE-A and benefits/challenges of FemtoCell are analysed.

## KEY WORDS

LTE/LTE-Advanced, FemtoCell BS and MIMO

## 1. Introduction

Mobile communication has seen a quick transition from focusing mainly on voice with low data rate circuit switches (data as Value Added Service) to it being more focused on delivering mobile wireless broadband. With the introduction of GPRS by adding GGSN and SGSN on 2G, access network opened up opportunities and raised need of higher data rates. With exponential rise of demand for higher rates, an obvious need to improve system performance was evident [3]. An Enhanced-GPRS was introduced through software upgrades of 2G to 2.75 G EDGE. This upgrade proposed to achieved a remarkable 240 kbps (theoretical speed) with 4 timeslots. This system was still based on a TDMA frame as the access type remained the same. 2.75G introduced advanced

modulation techniques and 8 coding scheme, but it was 3 times sensitive to Interference. As per any wireless communication system interference or low Signal to interference has a negative impact on data throughput [1] as we require a good signal quality. The emergence of 3G(UMTS) and its later releases was no surprise. 3G (HSDPA, HSUPA etc.) and its other enhancements changed the access type to WCDMA. 3G shifted its mindset and focused its primary requirement to cater more for data services while digital voice was also being enhanced. Capacity (no of simultaneous users) was not more of an issue in relations to voice. But 3G also reaching its limits (peak data rates) on the downlink, advancement of LTE was adopted and changed access type to OFDMA and the system migrated to an all IP based flat architecture [2].

LTE and LTE-Advanced is aiming/promising to provide data rates beyond 100Mbps. The fundamental problem is that we currently/have limited amount of spectrum and there is a high demand for data. Thus far the only way we can increase capacity (data rates) without increasing interference and decreasing capacity (spectral efficiency) is to reduce cell radius. Reducing cell radius requires installation of new other cells to achieve umbrella coverage with good indoor coverage. This affect recent technology such as UMTS and LTE even more as compared to the legacy 2G. This means more expenditure for operators with deployment/installation of Macro base station, distributed antenna systems etc. It is known that macro base stations are expensive to build plus their maintenance are high. Aforementioned factors have negative impact on OPEX and CAPEX for operators. FemtoCell Base station (FBS) brings a low cost solution for small home or office and eliminates installation costs, backhauling, site maintenance cost etc. FBS and FemtoCell are used interchangeably in this paper.

Surveys have been conducted and showed that more than 50 % of voice traffic and 70 % of data traffic originated within indoors [4]. This evidently shows that there is an obvious need to have better indoor environment's signal quality. We will need to improve Signal to interference ratio indoors by either reducing penetration losses or by compensating losses to improve system performance. For data traffic it is critical to have a good signal quality as higher modulation schemes are more sensitive to noise and we need to use them to achieve higher data rates but doesn't affect more on voice channel. To improve indoor penetration, we can increase power to existing macro sites as an alternative, but this solution will introduce interference to the other sites and possibly create dead zones. The method used to solve in building penetration

will be to introduce indoor solutions to improve overall system performance and this will help achieving higher data rates [5]. FBS are more useful and valuable for home-small office environment in providing good signal quality with higher data penetration. FBS is user deployed and allows ad hoc fashion distribution. FBS provides good flexibility for users to locate them on their areas of interest. They typically have a cell radius between 10-15 m and operates in licensed bands with low operating transmission power (max 20 dBm). They do not have the same resemblance as a traditional macro site, but they still comprise of all macro cell/site functionalities by providing mobility and hand-offs plus all macro site functionalities [6]. The other great thing about this solution is that it makes use of existing fixed line broadband links such as Fibre to home, DSL etc. Assuming a good backhaul of low latency and good quality, the user experience will be greatly improved with the only limitation being interference related on the RF component of the system namely cross tier interference between macro-Femto (cross tier) and femto-femto (co-tier) [5]. FemtoCell comprises of 3 different types of configuration namely:

- closed group, allowing only predefined group of users,
- open subscriber, allowing anyone within close vicinity and lastly,
- hybrid mode, of which some resources are reserved and some open for other users to roam [7].

In this paper the configuration will be based on closed group unless stated otherwise.

This paper is organized in the following manner:

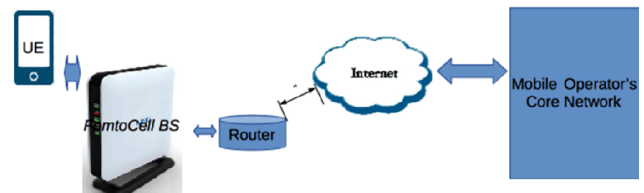
- Showcasing FemtoCell Benefits and Techniques to improve overall system performance.
- Energy savings when deploying FemtoCell BS on OFDM technologies such as LTE and LTE-Advance(LTE-A) including trade-off between performance and energy efficiency.
- Challenges of FemtoCell BS installation and its Architecture.
- FemtoCell as a SON (Self Optimized network.)
- Benefits using MIMO on FemtoCell BS.

## 2. Benefits of Femto Cell and Techniques to improve overall system performance

Capacity and coverage issues are well knowing problems in mobile communication. However, the forever growing demands for high data rates presents operators with huge challenges. While deploying more macro cells provides a significant coverage blanket with improved capacity, operators are faced with a huge task in filling coverage holes especially for LTE and UMTS Technologies. LTE and UMTS cell radius cannot be too large, this is due to the fact that a smaller radius provides better Capacity. This relation of coverage and capacity is also termed or known

as a breathing effect. Trade-off between coverage and capacity opened door for on-going research to find ways to improve both Capacity and coverage without sacrificing the other. Emergence of Pico Cell and FemtoCell, which are smaller radius cells, promises to improve indoor environment coverage, which will in turn also reduce number of interference and provides higher capacity (data rates).

In [8] it has been shown, that using the smallest radius provides highest or close to maximum capacity. This is what makes small cells more attractive. In comparison to a traditional macro site a small cell capacity is about 89 % higher [24]. Whilst mentioned that all small radius base station promises to bring better coverage and higher data rates, they also offload traffic from traditional macro sites. Operators' preferred choice should be FemtoCell BS. This is due to the nature of Pico cells being more complex and expensive to deploy than FBS. The fact that FBS has easy backhauling proves less costly for operators. Small cells



provide rise to mobile broadband delivering higher data rates at low cost for mobile operators. An architecture for FemtoCell has been shown in figure 1 as a block diagram.

Figure 1: Standard Architecture for FemtoCell connected to Mobile Operator

As showed by figure 1, a user will need to purchase a FBS and plug it to his/her own DSL line. The connection basically connects to the Mobile core network via internet. 3G and 4G FemtoCell are of preferred choice because the main aim is to improve data rates as a primary priority. maintaining good coverage and obtaining higher signal quality will allow the system to transmit more bits at the same time through the use of techniques such as reducing cell size, beam forming etc. Voice traffic (circuit switched) is currently well catered for by operators as it doesn't require as much bit rates more focus is on data-networks namely 3G and 4G.

FBS typically support between 5-8 users simultaneously and up to 32 Active users can be configured on enterprise 3G FemtoCell chipsets [10]. This is deemed as a better option to offload and optimize traffic from macro sites while maintaining good Quality of Service and high data rates.

Mobile operators can leverage benefits of FemtoCell and deliver better network coverage when deploying technologies such as UMTS, HSPA, LTE, LTE-A etc. Offloading traffic from tradition macro sites and freeing up resources will provide better capacity for outdoor mobile

users too. Other benefits such as saving on backhauling with low maintenance on site makes it ideal for operators.

For end users, benefits include experiencing a fixed line like mobile-broadband connection on their mobile phones even when they in their indoor vicinity [9]. This also includes experiencing low delays for their services, effectiveness decreased latency for uplink and downlink [22].

### 3. Energy Efficiency in FemtoCell

New technologies are faced by coverage gaps problems. For operators to achieve the same coverage for LTE as for legacy 2G networks operators will need to spend 60 times more energy compared to the legacy 2G standard [23]. This leads to newer technologies such as UMTS, HSPA, LTE etc. susceptible to being energy inefficient mobile technology advances. Fengming Cao [12] showed that there are certainly energy efficiency benefits by deploying FemtoCell Base stations. Through models showed by [12], deployment], deployment of FemtoCell Base station showed how it can conserve energy and simulations were based using LTE system parameters. Fengming Cao [12] Used Energy consumptions ratio to model (ECR) energy consumptions of one transmission information bit:

$$ECR = \frac{P}{D} \quad \frac{Watt/bit}{s} \quad (1)$$

in (1) P is power in Watt and  $D = \frac{M}{T}$  equates to Mbits over time T (Data rate). Approach used by [12], is a straight forward approach which did not include peak times, off peak times and other variations on the network, but rather simply normalize the energy consumption with an assumption that highest throughput is obtained through max transmit power in full load.

First, ECR of a FemtoCell base station is calculated and then for Macro Base station using the formula then an efficiency model is calculated using the following formula.

To compare energy efficiency, Energy consumption, gain formula is used:

$$ECG = \frac{ECR1}{ECR2} \quad (2)$$

The results of the quotient of 2 separate systems indicates the gain.

Furthermore, energy reduction gain was used to compare energy efficiency with and without FemtoCell has been used

$$ERG = \frac{ECR1 - ECR2}{ECR1} \times 100\% \quad (3)$$

It is worth mentioning that only the energy efficiency of the maximum transmit power was used to conduct the comparison study. With other factors not included such as cooling and backhauling power. But up to 80% of the network originates from the BS itself [26].

UE benefit by having its energy saved as the transmitter and receiver will not be far from each other thus reduces the need for UE to transmit with high power.

Sleep modes techniques are also proposed in [14] to prolong UE battery life and reduce consumption of Electricity and whilst also known techniques such as power saving modes can be applied. This can be achieved by switching off MS's radio interfaces and periodically checking incoming data. These techniques are already implemented in wireless technologies such as WLAN, UMTS and WiMAX [16].

To save energy, consumptions techniques proposed in [17] includes completely switching off Femto Base stations if the traffic in the location is low and neighbouring sites extend their coverages (cell breathe). The downfall of this strategy is the turnaround time to power up the base station after a complete shutdown [16], also the fact that we cannot guarantee same coverage from neighbouring cells to cover up the coverage.

Another technique proposed was to temporarily shut down base stations, this is achieved by turning off only pilot transmission whilst keeping connectivity alive between the Femto Base station and network up to avoid bigger delays in booting up the Femto Base station [18].

### 4. Challenges of FemtoCell and architecture

#### Architecture in LTE

With the introduction of FemtoCell on wireless mobile network, an introduction of Home eNodeB Gateway and Home eNodeB management were introduced to support operation of FemtoCell. A Home eNodeB operates as a concentrator for FemtoCell traffic and placed at the operator's premises. Home eNodeB Home Management system maintains that services are running secured and of high quality [15].

It is important to note that [15] indicated that several configurations can be possible for 4G FemtoCell. Those variations can be as follows in Figure 2 (a) - (c).

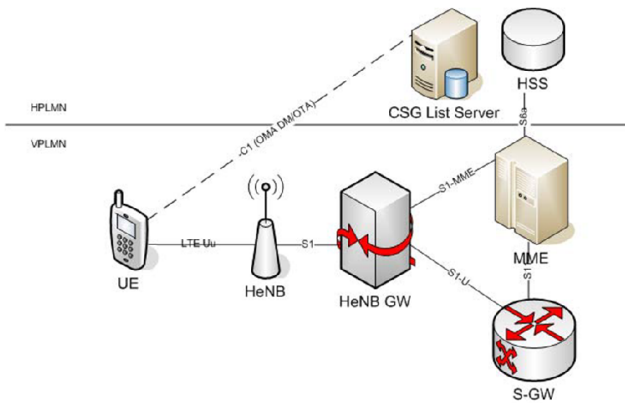


Figure 2 (a): First 4G Femtocell architecture configuration [15]

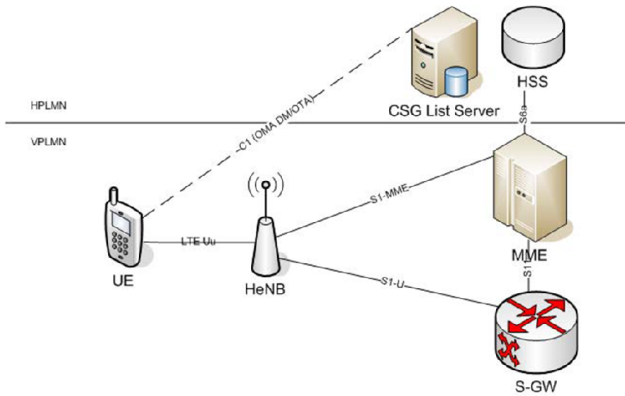


Figure 2 (b): Second 4G Femtocell architecture variation [15]

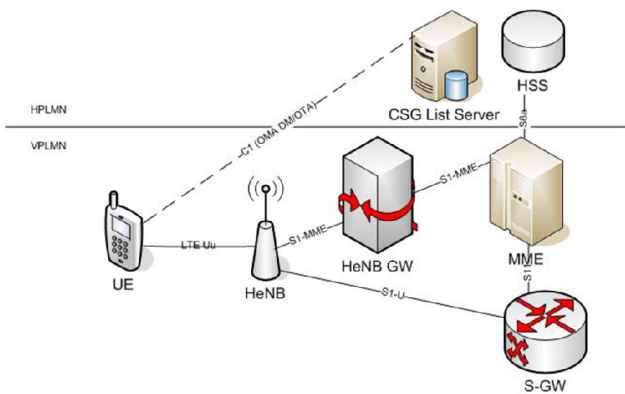


Figure 2 (c): Third 4G Femtocell architecture variation [15]

With all the various configurations released by 3GPP an operator will have to choose the one that best fits their needs and requirements.

In all this figure is should be noted that an evolved packed core (EPC) has been used to showcase the various configs based on LTE. As can be seen in Figure 2a-c a HeNB GW sits the operator's premises. HeNB and HeNB GW are

responsible for all RAN functionalities, as per 3GPP release [27].

FemtoCell HeNB GW core functions are mainly, providing link security, control plus aggregation .

Figure 2(b) shows that an architecture where HeNB GW physical hardware is not placed anywhere. This is done so by integrating functionality of HeNB GW in between HeNB and MME thus reduces cost and decreased latency. This configuration also assist in Self Optimized Network (SON) as no post configuration is required as compared to the other configurations [15].

It is worth knowing that [12] showed that too much deployment of FemtoCell also has negative impact on the performance of throughput on macro cell.

### Interference management in FemtoCell and SON

Introduction of FemtoCell also has its challenges to Operators. Now that network coverage comprises of 2 layered structure in which the blanket will be covered by the macro site and hotspots/indoor will mostly be served by FemtoCell base station. Ad hoc distribution of FemtoCell Base station is a threat and a challenge when in comes to interference alignment as FemtoCell base station uses a decentralized configuration approach [7], whilst known methods such as power control have been used for CDMA interference cancellations, methods for MIMO has been proposed such as interference alignment for two tier network [7]. Most of the interference related problems rise on densely populated areas such as cities where there are more active users and more cells are deployed.

For OFDM systems in this case an HSPA/LTE FBS UE will most likely to experience interference in a case when non-orthogonal frequencies have been assigned to a Macro BS and FBS [12].

Operators can split frequencies and assign different band to FemtoCell and Traditional macro, this solution is ideal but with band limitation this option will not be received well by operators mainly due to the inefficiency of spectrum reuse. This effectively calls for a strong interference management to be in place.

While other methods such as automated small cell deployment are proposed (Self Optimization Network), they provide interference management using sophisticated methods such for interference and saturation-aware deployment algorithms. This can potentially enable FemtoCell BS to be used (deployment) whilst minimizing inter-cell interference and maximizing spectral efficiency for the whole network .

for example:

Two FemtoCell base stations are deployed in neighboring houses, they will automatically adjust power in so as to achieve less interference [11].

Advance antenna can also be used to mitigate interference in a smart way. Using transmit beam at the transmitter to minimize/reduce interference to zero or use other interference cancelation methods by the receiver [12].

**MIMO benefits**

FemtoCell can benefit with recent advancement on MIMO communication. This technique which will ensure that communication links are reliable (robust) and provides higher data rates. This is achieved by leveraging advancement of using multiple streams of data coming through via multipath reflections of one can be able to afford better link with higher data rates and robust. The advancement of MIMO is exciting and will complement implementation of FemtoCell using LTE. Benefits of using FemtoCell MIMO includes having to separate co-channel interference in the uplink. For example: neighbouring FemtoCell and macro users produce interfering signal to the FemtoCell base station, this essentially creates interfering signals as interfering users in the surrounding FemtoCell base station [21], then we leverage spatial diversity offered by MIMO by means of e.g. Optimum combining method [22].

Capacity of SISO can be modelled as follows:

C represents capacity of the system, B represents Bandwidth, S/N represents the signal to interference ratio, and M is the Number of streams and is always less or the same as TX/RX antenna used.

Shannon theorem:  

$$C = B \log_2(1 + S/N) \tag{4}$$

While Capacity on Multiple Input Multiple Output:

$$C = M B \log_2 (1 + S/N) \tag{5}$$

The above formula how's how Capacity C increases linearly with the number of streams M theoretically

$$y = Hx + n \tag{6}$$

The above (6) shows the transmission formula for a MIMO system:

y represents the receive vector x is a transmit vector and n is noise and H is the channel matrix.

H can be represented by a matrix

$$H = \begin{bmatrix} h_{11} & h_{12} & \dots & h_{1m} \\ h_{21} & h_{22} & \dots & h_{2m} \\ \dots & \dots & \dots & \dots \\ h_{n1} & h_{n2} & \dots & h_{nm} \end{bmatrix}$$

General MIMO System:

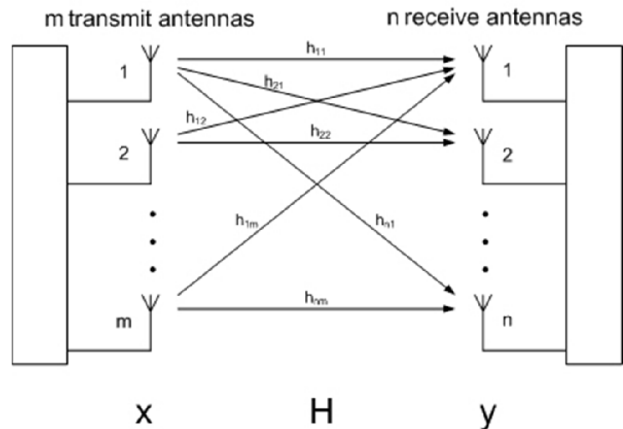


Figure 3: Standard Architecture for MIMO

For Single user MIMO configuration (SU-MIMO):  
 Data rates are increased for single user and multiuser MIMO (MU-MIMO)

When operating in Multiuser mode, more benefits are seen on the uplink side as the mobile phone's side complexity can be kept reduced through using one transmit antenna [25].

The configuration thus useful to increase system capacity as separate data are sent to different UE with each of the UE being regarded as multiple Receive Antennas.

**Spatial Diversity**

This method sends information through different paths and multiple independently faded replicates of the data symbol can be obtained at the receiver thus improving reliability of the system. The system focuses on improving Quality of service by Using redundant data on different paths.

**Spatial Multiplexing**

Spatial Multiplexing improves system performance by sending different information through multiple streams and thus increasing transmission rate. This form does not make system transmission more robust. Although multiple data streams are sent, the total power remains the same throughout. In LTE different data can be sent through different antennas and each layer would contain the same data as compared to one transmission link as SISO system. This of course would best be achieved under ideal condition in which high SNR has been achieved.

This is why MIMO can linearly increase system capacity by the number of antennas used, theoretically.

For LTE to make use of this advancement, three conditions must be fulfilled:

- Maximum rich scattering within a cell
- Real world conditions must properly match MIMO configurations on eNodeB (Home eNodeB for FemtoCell)
- Having the UE taking full advantage of multipath conditions which are present.

Disadvantage

Currently MIMO femtocell can either be designed to fulfil either of those or little of both, so it can either be providing data rate at a cost of robust transmission or the other way round. Also cellphone battery life is compromised a bit on MIMO as it consumes more battery power than SISO.

## CONCLUSION

The concept of small cells is quite an interesting route for Operators to make use of, especially with high growing demands for data rates. It also promises to improve spectral efficiency and provide to deliver fixed line broadband like experience to end users, it significantly has more benefits to both service providers and end users (customers). researches coming up with methods to mitigate problems such as interference. They also have added benefits such as longer battery life, good indoor coverage and high throughputs.

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