CHAPTER 2

In this chapter the literature review and the extensive background and overview of LTE-femtocell is presented. Firstly the literature review of the related work is being presented.

2.1 LITERATURE REVIEW

1. **Vizzarri A.** in October 2015 gave an Investigation of VoLTE end-to-end quality of service by means of OPNET. The purpose of work was to analyze end-to-end QoS of VoLTE focusing on impact of voice codec. Different voice codecs were considered and used in diverse scenarios. An efficient analysis of end-to-end QoS KPIs was presented. The investigation was based on MOS, end-to-delay, voice traffic sent and received, voice packet delay variation, LTE downlink/uplink delay [2.1].

2. **Raheem, R., Lasebae, A. and Loo, J.** in May 2014 gave a Performance Evaluation of LTE network using Fixed/Mobile. The research inspects the conception of Mobile Femtocells to be the revolution of the cutting-edge cellular networks. Mobile Femtocells can be installed in public transport automobiles such as trains, buses or private cars that form its own cell inside vehicles to support vehicular and mobile User Equipments. The aim of the study was to help cell-edge users to have improved signal strength. Consequently, an analysis into Long Term Evolution cell-edge users’ performance was being conducted by examining the implementation of Mobile Femtocells in LTE system, and was found that the throughput for cell-edge users can be enhanced by deploying Fixed/Mobile Femtocells [2.2].

3. **Tabany MR, Guy CG** in June 2014 performed a Performance Assessment of End-to-End QoS for VoLTE in 4G E-UTRAN-based Wireless Networks. In the research, a practical Voice over LTE (VoLTE) wireless network was simulated and its performance in terms of Quality of Service (QoS) was assessed and authenticated using OPNET modeler wireless suite 17.5. The work has confirmed that the simulation results have matched the ITU-R and 3GPP standard requirements related to the VoLTE over 4G LTE. The simulation results are important in three different QoS respects; end-to-end delay, jitter and packet loss rate. It has been found that the overall VoLTE end-to-end delay was about 0.12 ms, and its packet loss rate was about 0.005%, while jitter was almost 0. Furthermore, another different simulation scenario was designed to examine the effects of different LTE bandwidths on the VoLTE service quality. Three different LTE bandwidths
(1.4, 5 and 20 MHz) were realized and their effects on the VoLTE end-to-end QoS and LTE DL and UL delays were also calculated. The results show that LTE can achieve better performance with a 20 MHz bandwidth [2.3].

4. Joseph M, Akindeji AO. in October 2014 gave a Review of Femtocell. The paper has given the concept of femtocell technology and its significant improvement in network performance in the indoor environment. Furthermore, it provided advantage to mobile operators, in terms of increased revenue and better quality of service. Based on various research works from literatures, the femtocell technology is a promising substitute for next generation wireless communication networks. However, Interference has being one of the main problems in femtocell network. The interference comprises, between neighbouring femtocells and between macro cells and femtocells, due to the allocation of the similar licensed frequency spectrum with an existing macro cells. Researchers have proposed different types of techniques, such as interference cancellation and interference avoidance, to cope with interference problem in femtocell networks [2.4].

5. Silva KC, Silva CP, Donza AC, Frances CR, Vijaykumar NL in January 2014 gave an approach for analysing the impact of LTE based femtocell network. The research work explains virtual deployment of femtocells in a scenario to attain Quality of Service (QoS) and handover. The work also argues restrictions of incorporating LTE with femtocells. Based on the primary investigates, one can note that incorporating LTE and femtocells was not a good option as anticipated. For the considered parameters and scenarios, inclusion of femtocells would improve QoS. The outcomes stress the requirement of self-configuration for appropriate working of femtocells. It is also important to mitigate the degradation of the performance due to the interference between macrocell and femtocell as well as among femtocells, especially when installations are conducted without proper planning [2.5].

6. Sreenivas T.H. in April 2014 gave a Survey on Implementation and Design of Femtocell Device. The research work has presented the Femtocells structure and application for installation in consumer home. The work includes a significant attention on design and implementation of femtocell device and the fundamental hardware architecture [2.6].

7. Babkin A, Pylenok A, Ryzhkov A, Trofimov A. in June 2013 proposed an analysis on LTE Network Throughput Estimation. In his work he considered LTE networks throughput optimization as one of the key problems. For macro and femto LTE networks,
two virtual LTE network models were analyzed to give approximation of the possible throughput for downlink. Bearing in mind macro networks four frequency distribution scenarios were evaluated and their throughputs were compared. In femtocell design the scenarios with two femtocells were discussed [2.7].

8. Yusof AL, Salihin SS, Ya'acob N, Ali MT. in November 2013 investigated the performance of handover strategy in Femtocells network under Hybrid Access Mode to decrease the needless handover. Bearing in mind the velocity of user equipment (UE) in the mobility the handover strategy for three different threshold stay time was examined. The simulation outcomes revealed that the projected algorithm reduced the number of handover and decreased the needless handover probability. Simulation outcomes indicate that the suggested algorithm has a superior performance as compare with the outdated approach [2.8].

9. Kritikou Y, Paradia M, Demestichas P. in June 2013 presented a Survey on Femtocells. Numerous characteristics of femtocell networks in a diverse field were presented. A comprehensive examination of the previous methodologies was given to highlight their pros and the cons. It has also presented some technical issues and their proposed solutions [2.9].

10. Saad SA, Ismail M, Nordin R. in December 2013 presented a Survey on Power Control Techniques in Femtocell Networks. In the research work, different power control techniques in femtocell networks were discussed and compared. The investigation has concentrated on distributed power control techniques due to the distributed nature of femtocell networks. The conclusion drawn from this evaluation was that the distributed power control techniques using pilot power control schemes are modest and effective in enhancing the coverage of femtocells as well as reducing power consumption of the femtocell base stations (FBS) [2.10].

11. Zahir T, Zahir T, Arshad K and Nakata A in March 2013 presented a theoretical review on the interference management in femtocell networks. The work summarises the key conceptions of femtocells that are covered in collected works and the major complications encountered in its large scale installations. The main difficulties of interference management were examined in depth with its varieties in femtocells and the resolutions suggested over the years to manage interference have been accounted. In
addition an explanation of the present femtocell standardization and the future research scope of femtocells were presented [2.11].

12. **Tom Priebe** in 2012 has given the Current Development and Innovations in the Area of Femtocells. The paper has given an overview about current techniques and research ensuring high receptability with femtocells. The first part had described an interference management method that has become most important when high density femtocell grids, i.e., multi-story apartments and company buildings, establishes. The second part, handovers, had its use for passing a connection of a mobile device on from e.g. a Wi-Fi network to a macrocell or vice versa but will become more important when especially public femtocells starting to have an influential part in the field of mobile network coverage. The research concentrated on either making smart handover decisions in order to accelerate a handover and keeps a bandwidth contraction to a minimum or avoiding handovers in general [2.12].

13. **Andrews JG, Claussen H, Dohler M, Rangan S and Reed MC.** in April 2012 proposed a study on the Femtocells. The tutorial article gave a summary of the history of femtocells, understands their key aspects. The article presented a preview of the next few years, which will see a prompt stepping up towards small cell technology. The work and special issues debate, although uncertainties about femtocells negative effects are overblown [2.13].

14. **Barbieri A, Damnjanovic A, Ji T, Montijo J, Wei Y, Malladi D, Song O and Horn G.** in April 2012 presented an analysis of LTE Femtocells. The investigation has considered a heterogeneous LTE network where femtocells are arbitrarily installed in a macro network. Femtocells are demonstrated as closed cells i.e. only group member UEs can be connected with the femtocells. It explains the inter-cell interference can restrict reliable operations for non-member UEs that are in vicinity of a closed cell, which thus experience refusal of services. It displays how certain of the original features presented in the Rel-10 specifications of the LTE standard can be influenced by a proper intercellular interference coordination scheme (ICIC), which depend on upon resource allocation between different nodes to decrease the intercellular interference concern [2.14].

15. **Salman EH, Noordin NK, Hashim SJ, Hashim F and Ng CK.** in June 2012 presented an investigation on precise simulations of LTE femtocells. The research work explained about LTE, Long-term evolution (LTE) femtocells represent a very encouraging solution
to the ever increasing bandwidth demand of mobile applications. They can be effortlessly installed deprived of a centralized planning, to deliver high data rate connectivity with a narrow coverage area. In this way, the entire capacity of the cellular network can be significantly enhanced. At the same time, the clumsy arrangement of femtocells creates new concerns that need a deep and thorough investigation before distributing this technology globally [2.15].

16. Elleithy KM and Rao V in 2011 presented a survey on Femto Cells. The survey was on the recently developed and rapidly evolving field of femtocells. When the cellular consumers were inside a building office/home, it was observed that cell-phone signals were tremendously reduced, causing to call drops or poor call quality. Femtocells are small base stations that are installed in user houses so that the user can directly link to the cellular network over the femtocell network instead of the outside macrocell, thus increasing call quality. The promising femtocell is being tested meticulously by mobile operators everywhere globally. There were still some problems that required to be worked on for femtocells to be deployed as fault-free devices [2.16].

17. Cheng SM, Lien SY, Chu FS and Chen KC. in June 2011 proposed the solution of Network Synchronization among Femtocells. The research paper gave solution for the most vital issue on the network synchronization of femtocells to accomplish the critical hypothesis of autonomous interference mitigation solution in proceedings. Yielding a very narrow computational complication and enforces no effects on the system architecture of the present femtocell architecture in 3GPP, the suggested network synchronization algorithm permits every femtocells to accomplish a successful synchronization between all femtocells with or without the existence of the Macrocell [2.17].

18. Xia P, Chandrasekhar V and Andrews JG. in December 2010 presented a study on Open vs. Closed Access of Femtocells. The research work examines the effect of large-scale random channel effects in the subcategory by integrating lognormal shadowing with standard deviation in the channel model. Simulation outcomes displayed that shadowing has an impact on the performance of open and closed access, but it does not change the main conclusions about the optimal access policy.

Bearing in mind the home user’s statistical rate in TDMA. It was realized that shadowing pull down the rates by approximately 5% ∼ 10%, but the crucial inclinations of the curves
are well-kept: open access in TDMA still has a fading rate gain for the home user as cellular user density grow into enormous. Thus, in the existence of shadowing, open access in TDMA is chosen by the femtocell consumer in small user density [2.18].

19. **Haddad Y and Porrat D.** in 2009 presented a study on Femtocell Opportunities and Challenges of the Home Cellular Base Station for the 3G. The paper has first presented the background history that led to this new conception and then describes the femtocell technology in the context of 3G-based cellular networks. Then it has presented the left over challenges and debates the probable answers. Finally it has dealt with the opportunities for users and operators and present further works. Also it has explained the advantages for both end-users and operators in the context of a 3G network based on the CDMA scheme [2.19].

20. **Vikram Chandrasekhar and Jeffrey G. Andrews** in 2008 presented a survey on Femtocell Networks. The research article has demonstrated that Femtocells have the capability to deliver high quality network access to indoor users at low cost, while concurrently decreasing the liability on the entire structure. The article has identified the key benefits of femtocells, the technological and business challenges, and research opportunities. From a technical perspective, operators face difficulty in providing a low cost solution, while modifying RF interference, providing quality of service (QoS) over the IP backhaul, and sustaining scalability. From a business perspective, generating long-term revenue growth and overcoming initial end user subsidies are key challenges [2.20].

### 2.2 FEMTOCELLS

In this section, an extensive introduction is given to the femtocells background and overview with definitions, challenges and the alignment towards LTE-Femtocells.

#### 2.2.1 Femtocells Overview

The femtocell has been characterized as one of the measures to improve the concerns of capacity and coverage for consumers. There has been significant effort to increase the system capacity, under the 3GPP releases, by using enhanced antenna configurations, microcells, even nanocells and the use of relays. But the use of the above mentioned has significant restrictions. For example, indoors capacity enhancement or better coverage cannot be increased by the use of the relays; also, the CAPEX and OPEX is the major target for cost reduction but for the microcells and nanocells it cannot be considered.
Therefore, the 3GPP Release 8 specifications have proposed the use of indoor home base station in the existing network architecture and future networks, in order to have an enhanced system capacity and better coverage for indoors. The femtocell for 3G is called as the Home NodeB and for the LTE and LTE-Advanced it is termed as the Home enhanced NodeB (HeNB) [2.21].

### 2.2.1.1 Basic definition of Femtocell

Femto Base Station (FBS) or femtocells are small, low-power cellular access points or base station that are installed by the user which adequately improve the traditional mobile communication for improved capacity and extended coverage area in cellular networks [2.22], [2.23]. The advancement of the femtocell network is an important step taken to support network density in macrocells. Femtocell supports to decrease the cell dimension for amplified QoS (quality of service). Considerable stress is on the reduction in the highest transmitted signal strength in femtocells as compared to the broader macrocells. Figure 2.1 gives a significant comparison between the coverage and the radius of the different networks.

![Small cell comparison in terms of range](image)

**Figure 2.1:** Small cell comparison in terms of range.

### 2.2.1.2 Benefits of Femtocell

Femtocell network brings several noteworthy benefits [2.24], [2.25] as mentioned:

1. **Coverage and Capacity:** As the femtocell works inside a small coverage area, that helps to have a reasonable low transmitted signal strength and aid to have greater SINR. This results in higher capacity and excellent signal reception for coverage.
2. *Macrocell Reliability:* The femtocell absorbs some of the indoor traffic; thus traffic load on the macrocells is reduced reasonably with its help.

3. *Cost:* To decrease the CAPEX and OPEX for the service providers the implementation of femtocells has been examined, this leads in overall cost reduction. Cost of power and backhaul is decreased and the cost of installing additional macrocells is skipped as a result of the femtocells implementation, it has remarkable advantage on the broader macrocell network.

4. *Subscriber Turnover:* Consumers switch their operators more frequently, because consumers are not satisfied with indoors signal strength. So the usage of the femtocell will benefit in building a better consumers perspective in this regards. In summary, the femtocells are principally advantageous to the operator and the consumers equally:

   (a) There is the data offload from macrocell for the mobile operators, increase in operator’s income, lesser cost on backhaul and improved or possibly stable number of consumers.

   (b) For the users, they enjoy better indoor coverage, exceptional data speed in an all universal setting and enhanced terminal power consumption.

2.2.2 Femtocells Technologies

As part of the key benefits involved to the use of femtocells is the use over the authorized spectrum and the use of the operators’ network combined with the use of the internet connections at home or office. The femtocell requires technology schemes that could fix into the cautiously planned cellular networks [2.26] of service providers. The capability of the femtocells to relieve of data and video traffics will depend on how effective and dependable the technology is [2.27]. In a broad perspective, the femtocell is not just a small range device or perhaps, a high capacity device but it is significantly a device that has been designed from generation of technologies (or anticipated) to be able to interact easily with existing cellular networks conveniently at all the network layer. It does perform the tasks like handoffs, interference management, authentication and billing functions. Some of these functions have necessitated the quest for standardization, research and development coupled with compliance with growing radio access technologies. The figure 2.2 shows a simple illustration of the basic femtocell network.
Figure 2.2: Femtocell basic network [2.28].

According to the Small Cell Forum, some of the essential issues to be considered in the development of the femtocell technologies worldwide are primarily focused on:

(a) Standardization, regulation and interoperability; and

(b) Marketing and promotion of femtocell solutions. From this perspective, the most popular technologies of femtocells are the UMTS/CDMA2000 femtocells and the LTE/LTE-Advanced femtocells.

The femtocell architecture will be discussed based on the 3GPP standard releases subsequently in this chapter.

2.2.3 Challenges of Femtocells

Though, there has been an essential paradigm swing in the use of femtocells, there have been few challenges [2.29] that the femtocells deployment has to combat. In a short form, some of these challenges have been based on [2.30]:

(a) User-installation;

(b) Unplanned deployment;

(c) Inter-operability with present infrastructure: and

(d) Restricted access.
In a dissimilar perception as assembled by [2.31], the femtocell difficulties are based on the following:

(i) Voice femtocells;

(ii) Broadband femtocells; and

(iii) Network infrastructure; this is illustrated in figure 2.3.

<table>
<thead>
<tr>
<th>BROADBAND FEMTOCELLS</th>
<th>VOICE FEMTOCELLS</th>
<th>NETWORK INFRASTRUCTURE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resource Allocation</td>
<td>Interface Management</td>
<td>Secured Bridge between Operator over Internet Protocol</td>
</tr>
<tr>
<td>Timing/Synchronization</td>
<td>Femtocell Access</td>
<td>Handoffs and Mobility</td>
</tr>
<tr>
<td>Backhauling</td>
<td>Emergency Services</td>
<td></td>
</tr>
</tbody>
</table>

Table 2.1: Perspective challenges on Femtocells.

In a broader perspective, the key technical challenges [2.24], [2.26], [2.30] of femtocells would be discussed for all categories of femtocells, these are:

1. Interferences;
2. Mobility and Handover;
3. Backhaul;
4. Self-configuration and Network Interoperability;
5. Restricted Access and Selection; and
6. Synchronization and Location.

2.2.3.1 Interferences

The issue of interference is perhaps the most significant and widely known challenge to the deployment of femtocells. The introduction of femtocell into a cellular network
fundamentally modifies the network configuration. The issue of interferences could arise from interferences related to:

1. Macrocell to Femtocell;

2. Femtocell to Femtocell; and

3. Femtocell to Macrocell.

The interferences of Macrocell to/from femtocell are due to the near-far effect of receiving power not uniformly distributed. The interferences among femtocells are at a low end as this is due to apparent low transmit power and (indoor) penetration losses. The figure 2.3 shows a cross tier interference [2.26] illustration.

![Cross tier interference illustration](image)

**Figure 2.3:** Cross tier interference illustration [2.26].

### 2.2.3.2 Mobility and Handover

In a perfectly located position within the macrocell, there is always an excellent capacity and service experience; in the vein, when users are within the femtocell region, they expect to have the same service. It is important that there is a seamless handover between femtocells and macrocells or rather between femtocells for excellent service experience within the femtocell region since there are increasing numbers of femtocells and they are becoming densely deployed. Although, it is quite possible for UE to search and transition outside of the femtocell region, a big threat to the femtocell technology is the issue of having efficient and seamless transition from femtocell to femtocell or
femtocell to macrocell. As a matter of fact, the state of the UE is also dependent on the transition. In other words, this transition creates a bigger problem especially during call handover idle or active.

i. **Idle Mode:** During idle mode, it is important for UE to transition smoothly from outside the femtocell into the femtocell range; this is very important for efficient paging for registration. But since the femtocell and the macrocell are deployed essentially on different frequency band, there is a need for an efficient mechanism of handover for the UE from the macrocell frequency into the femtocell. A big problem in this case is that the issue of frequency registration affects the level of battery life consumption. Therefore, if there is regular transition from the femtocell to the macrocell, regular frequency searching and registration will steadily affect the battery life.

ii. **Active Mode:** In the active mode, identifying the target femtocell is the major problem. For macrocells, the source macrocell easily identifies the target macrocell because of its unique identity and the combination sequence used in transmission. But in the femtocells, the numbers of pilot sequences comparatively in the femtocells are less and they are not unique. As a result of these challenges, a solution has been developed to combat the problem of active mode handover called femto-aware [2.30]. There are femto-aware user equipments and infrastructure, but the cost and complexity of the modification of already deployed network infrastructure has hindered significantly the growth of the femto-aware user device. Additionally, the issue of mobility problems as a result of handover is still an ongoing process as the standard organizations are looking for ways to create procedures for perpendicular handovers among femtocells and non-cellular access technologies in the case of femto-to-femto movement.

### 2.2.3.3 Backhaul

The concern of security and quality of service over the third party backhaul is a major issue in the installation of femtocell. Subsequently the femtocells are backhauled over municipal infrastructure like the internet (which supports as the backhaul for the femtocell front door and the service provider core network), there are main worries concerning to safety of the femtocell, deceased level of QoS and bandwidth inadequacy.
Compared to the backhaul that is centrally controlled in a macro-cellular system, the femtocell backhaul is a third party entity out of the control of the user or the operator, and such managing the QoS and the security becomes extremely difficult in a femto-cellular scenario.

### 2.2.3.4 Self-configuration and Network Interoperability

It is essential that femtocells are able to self-interface with the rest of the network, especially in terms of management and control. In the macro-cellular network, network planning is necessary to have better coverage, good capacity and efficient interference management, which are very important for network optimization.

To follow this system of network planning in femto-cellular will not be cost effective; and more also, femtocells are used by voluntarily by subscribers without the real permission of the service provider at any instance.

Therefore, full standardizations are able to have self-organization and proper remote authentication and integration of femtocells. In other words, the femtocells must be able to function as a plug-and-play device with automatic self-configuration and adaptation. That is why the femto-cellular network is sometimes refers to the Self-Organizing Network (SON).

### 2.2.4 Typical Femto-cellular Network

In the 3GPP descriptions, in the femtocell architecture some of the femtocell operational elements are the Home Node B Gateway (HNB-GW) and Home Node B Management System (HMS). These two network elements have been released as part of the release 8 which focuses mainly on the 3G UMTS network architecture [2.32]. In addition to the two main essential network elements, there is the logical element called the Security Gateway (SeGW) and the introduction of the Iuh interface which connects the HNB and the HNB-GW.

A detail illustration is given in figure 2.4; where the Closed Subscriber Group (CSG) is used to identify subscribers of a Service Provider that are given permission to access the cells of the PLMN; although they still have secure access. Also, as indicated in the figure, the HNB Subsystem (a combination of the HNB and HNBGW), (HNS) serves as an RNS to CN and with connection via Iu-CS interface straight to the MSC using the Iu-PS interface to the SGSN.1
Figure 2.4: UTRAN Network Architecture (with CSG provisioning and Access Control) [2.32].

1. Iuh Interface;
2. HNB Management System, HMS;
3. Security Gateway, SeGW;
4. Home Node B Gateway, HNB-GW;
5. Home Node B, HNB;

2.2.4.1 Iuh Interface

The figure 2.5 shows the Iuh reference model extract from the figure 2.5 has described by [2.31], [2.33], [2.34]. The Iuh interfaces the HNB and the HNB-GW. It serves as the transport line for the messages for the C-plane and the U-plane. It should be noted that the Iuh is the only the interface used by the SeGW and the Authentication, Authorization and Accounting (AAA) from the HNB-GW to provide the needed data integrity in the tunnelling of the IPSec.

Figure 2.5: Iuh Interface as shown in the 3G Femtocell logical architecture [2.31], [2.34].
2.2.4.2 HNB Management System, HMS

The HMS procedure is based on the operational depiction in the TR-069 [2.35] family of standards. The HMS functions by sending configured data through to the HNB, coupled with functioning as an aid to the HNB-GW and SeGW discovery. In other words, it performs the function of a Location Verification for HNB, and then assigns the necessary elements. With the help of the HMS, the operator is empowered to control and do HNB configuration.

2.2.4.3 Security Gateway, SeGW

The SeGW serves as a terminating point for secured tunnelling for the TR-069 family of standards described in [2.35] and likewise the Iuh. In addition, it provides secured link for communication between the CN and HNB. Also, the SeGW provides authentication service for the HNB; most importantly provides access the HMS and the HNB-GW.

2.2.4.4 Home Node B Gateway, HNB-GW

The HNB-GW is the central device that links the HNB to the core UMTS network. Its functions are mainly as described in the 3GPP release under [B2] [2.21]. The HNB-GW is provides many functions in the femto-cellular network, typically link control and security. The HNB-GW serves as the RNC and maintains the CN connectivity. As mentioned luh, the HNB-GW (may) provide the AAA functions to improve the security level of the femtocell [2.36].

2.2.4.5 Home Node B, HNB

The HNB is typically the Femto Access Point installed at the user’s residence or in the office. It is the main femtocell device. It is used as a plug-and-play device. The HNB offers the same service as though the UE is within the NodeB range. It is everything one can define literally as the femtocell. The HNB uses the subscribers’ broadband connection to connect to the Service Provider’s core network. Also, the HNB uses the Uu interface to interact with the UE.

2.2.5 Architecture Model of an HNB Access Network

The figure 2.6 shows the high-level logical architecture of an HNB access network as presented in [2.37].
2.2.6 LTE Femtocells

Tremendous effort has been made to find a way to integrate the HNB into the LTE systems. It has been planned that the HNBs are to be integrated into the EPC of the LTE infrastructure using the same defined interfaces as used in the macro-cellular network. The objective is to make the HNB and the macrocell use the EPC; with the EPC having the flat architecture offered by the LTE architecture. In the real sense, the LTE femtocells is planned to have a flat architecture. A point of note is that the interfaces between the LTE femtocells and the main EPC elements are redundant.

The overall architecture of the LTE femtocell architecture is illustrated in figure 2.7.

**Figure 2.6:** Logical Architecture of an HNB Access Network [2.37].

**Figure 2.7:** A basic diagram of LTE Femtocell network architecture [2.38].
The figure 2.8 gives an outline a characteristic E-UTRAN network architecture that includes a CSG provisioning and access control; and numerous elements involved. As shown, the HeNB Subsystem (HeNBS) is a combination of the HeNB and may have the HeNB-GW. The HeNBS is linked to the EPC via the S1 interface; and since the EPC has the MME and S-GW interface points, the HeNBS links to the MME via the S1-MME interface and to the S-GW via the S1-U.

Figure 2. 8: The E-UTRAN network architecture for CSG provisioning and access control [2.32]

The LTE femtocell architecture (or HeNB system) [2.25], [2.37] has been proposed in three different variations of implementation by the 3GPP. The three variants depend on how the Femtocell gateway is placed, particularly how the HeNB is connected to the CN. The three different variants are presented accordingly.

2.2.6.1 Variant 1 of LTE Femto-Cellular Architecture

The figure 2.9 shows the architectural model for the Variant 1 of the LTE femtocell. This variant is with dedicated HeNB-GW. This is about the most familiar architecture because of its simplicity of deployment. The presence of the HeNB-GW makes its availability and operational convenience. The HeNB and the HeNB-GW communicate via a secured mandatory Se-GW; also the Se-GW implementation may be done separately as a physical entity or part of the HeNB-GW 18.
Some of the benefits [2.25] of using this variant option are highlighted: In this variant, there is only a single Stream Control Transmission Protocol (SCTP) involved in between the HeNB-GW and MME. Similarly, among HeNB and HeNB-GW, there is merely single SCTP. It is important to note that, if the HeNBs is increased in a network, the SCTP association with the MME remains the same; The HeNB does not necessarily need to support the S1-Flex to reduce the total number of S1 interfaces; Of much security importance, this variant can hide the IP addresses of the MME and S-GW from the HeNB, thereby creating a better secured system by not revealing the CN IP addresses to the subscribers. Another safety and security importance is that, the HeNB-GW has the possibility to implement a Denial of Service (DoS) which protects the MME and the S-GW. It can apparently detect, filter and shield from traffic attacks and at the same time maintains the desired QoS; SIPTO implementation is possible under this variant; and the implementation of the local S-GW and the P-GW in the HeNB-GW can help reduce the need for additional network elements within the existing architecture; and so on.

On the low side, this variant offers a processing load which affects the traffic proportionately; and since HeNB connects to just a single HeNB-GW concurrently, redundancy is reduced.

Application scenario of this variant 1 to service providers is that for those who already have a 3G HNB solution, it will be easier to redeploy to an LTE HeNB, due to their similarity in architectural terminations for the C-plane and the U-plane in the GW.
2.2.6.2 Variant 2 of LTE Femto-Cellular Architecture

This type of variant does not have any HeNB-GW physical presence. In this case, the HeNB-GW functionalities are integrated in between the HeNB and the MME so as to reduce the network cost and latency level. The variant 2 architecture supports the possibility for the HeNB to be able to self-configured, apparently serving as a plug-and-play [2.39]. Of greater advantage is that, it can be deployed without any prior network planning. The HeNB and the MME/SGW communicate via a secured mandatory Se-GW. The variant architecture is shown in the figure 2.10. Some of the advantages in this variant are discussed below:

![Diagram of LTE Femto-cellular Architecture: Variant 2](image)

**Figure 2.10:** LTE Femto-cellular Architecture: Variant 2 without Dedicated HeNBGW [2.25], [2.37].

In this second variant architecture, there is always an isolated failure in the system, that is, when there is a failure below the MME/S-GW in one of the HeNB network elements, all other HeNBs are not affected; by having a simple flat architecture of the second variant, there are less number of network elements. A major short-coming of this variant is that it does not create any connection concentration for SCTP/GTP-U as in variant 1; and of much concern is that if support for the S1-Flex is made, additional system complexity is introduced. The application deployment scenario benefit for this second variant is that, there is considerable reduction in cost, especially when there are not much HeNBs or less density of the HeNB.

2.2.6.3 Variant 3 of LTE Femto-Cellular Architecture

The figure 2.11 shows the third variant of the LTE femto-cellular architecture. In this alternative, there is a committed HeNB-GW in C-plane and the S1-U interface of the HeNB
is terminated at the S-GW. In other words, the HeNB-GW is used for the C-plane accumulated signalling and the U-plane is terminated at the S-GW.

Some of the advantages associated with using this type of variants are:

- The HeNB does not have to support the S1-Flex on the C-plane;

- The use of this kind of variant will allow for paging optimization mechanism implementation within the broader HeNB-GW.

- Also, in this variant, the HeNB-GW is allowed to implement an overflooding of MME mechanism when there are unexpected HeNBs failures, for example due to power supply disruption or emergency.

On the negative side, this variant 3 does not support GTP-U connection; if there is desired increase in the number of HeNBs within the system, an overload situation might occur as a result of the UDP/IP. More also, in this variant, in the C-plane, the HeNBs connect to every single HeNB-GW at a time.

![Diagram](image)

**Figure 2.11:** LTE Femto-cellular Architecture: Variant 3 with Dedicated HeNB-GW in C-plane only [2.25], [2.37].

As a summary of the variants for the LTE femto-cellular architecture, the figure 2.12 shows the combined possibilities in the architecture as presented in [2.38].
2.2.6.4 Other Possibilities

Although the three variants discussed above could become implementation options for vendors and service providers alike, the LTE Femtocell architecture are not limited to the three variants. More future developments have been considered with respect to the operational needs of the service providers. Moreover, with the Local IP Access (LIPA) and Selected IP Traffic Offload (SIPTO) concepts [2.40], [2.41], the introduction of new possibilities with different functional variation is possible for the development, deployment and future of femtocells.

2.3 Future of Femtocells

2.3.1 General perspective on the femtocells future

According to Fierce Wireless, Europe, over 95% of service providers believe that small cells are essential for the future [2.42]. It is a known that the resurgence witnessed in the enhancement of the mobile wireless network has been significantly improved by the use of the small cells (and most importantly by the femtocells). In the case of The Mobile Network, two thirds of operators claim 2014 will be ‘year of deployment’ [2.43].

Obviously, the future of femtocells is dependent on several factors that would either see the prospects of the development or mar its desired use by subscribers over the coming years, thereby reducing the confidence level. In examining the future of the femtocells with respect to this thesis, a close look has been given into examining most of the vital challenges faced by the femtocells in general. An evolving LTE roadmap with specific issues of advance...
interference management and enhanced self organising network techniques are very critical to the success of reducing the operating cost of HetNets in general. The issue of cost reduction is a particular point of concern for the network operators.

In addition, it is noteworthy to say that the use of femtocell has come with recent attacks from some security experts who view the femtocells has been vulnerable to hacking. With the recent releases of clarified documents of the National Security Agency (NSA) [2.44] and raw intelligence of citizens alike; allegations abound that a larger percentage of the snooping has been done due to the security lapses with some femtocells. CNN Money and the iSEC Partners, made recognized the level of vulnerability in the present femtocells operating under Verizon Network [2.45]. This security flaws has potentially caused a rethink by users. Tom Ritter, a Senior Security Consultant with iSEC Partners made a claim, we see everything that your phone would send to a cell phone tower: phone calls, text messages, picture messages, mobile web surfing.

Also, the use of femtocells for emergency services like (911, 112 and the likes) has been faced with a couple of challenges. To ensure a public safety solution, it is important that the future of femtocells get proper standardization in terms of its use for emergency services. At the moment, lack of properly defined standards poses some challenges especially when it comes to its use. Some of these (as discussed in [2.46]) are:

(a) Provision of subscriber information;

(b) Data delivery to the Public-Safety Answering Point (PSAP); and

(c) Verification of the Radio Frequency Coverage.

Although, a considerable effort has been made in solving some of these problems, much needs to be done in terms of standardization.

2.3.2 Technical Challenges for the future

In solving some of the problems associated with the current deployments of femtocells, listed below are some of the most technically challenging areas of concerns:

1. Security and backhaul

2. Self-Organizing Network

3. Enhanced MIMO

4. Interferences
2.3.2.1 Security and Backhaul

One of the factors that will have tremendous impact on the global success of the femtocells will be the issue of security. As examined in [2.47], security is a critical point in the femto-cellular network, particularly in all aspects of its operation or use. For a device placed in the customer’s own premises, the level of attack or vulnerability will be higher as compared to under the operator’s jurisdiction. Therefore, it is important that Femtocells are designed to avoid security attacks either physically or remotely via hacking.

To further make emphasis on the vulnerability of the present situation of femtocells, an example of an attack on a femtocell network was by the Hacker’s choice on the Vodafone Access Gateway; with supposed claims that more attacks will be published as a follow-up which shows the extent of insecurity involved [2.48]. As presented in [2.47], certain level of operational requirements must be set to combat the issue of security breach in future femtocells. Some of these are highlighted below as specific requirements operators or service providers need to strictly adhere to and strongly regulated by respective regulatory bodies.

- Higher level of cryptographic algorithm needed that will protect the confidentiality and integrity, coupled with excellent authentication;
- The use or modification of the Hosting Party information must be allowed only with strict permission obtained by the Service Providers from the hosting party;
- The International Mobile Subscriber Identity (IMSI) data of users who are connected to the femtocell network with not be displaced or released to the Hosting party.

Worthy of note is that the femtocell is still legally the property of the operator but placed in custody of the Hosting party.

Furthermore, to enhance the security of the femtocells, set requirements should be created relative to the overall femtocell, the Se-GW, and the HMS. Also, since the femtocell relies on the backhaul for connection; and the backhaul connection requires the public internet; a very high level of attack is very much possible.
The Backhaul is a major tool by anti- femtocell guilds [2.49], but it could be overcome. Since the backhaul is used in Wi-Fi and even LTE macrocell, it can be said that the issue of backhaul does not have only femtocell peculiarity.

Therefore, there are essential needs to have a well secured backhaul link encryption as presented in [2.50]. Of great importance is that a better secured backhaul will provide high level of integrity protection for data transmission and may ensure dependable confidential level. More also, creating a backhaul security solution based on Internet Protocol Security (IPSec) [2.51] Encapsulating Security Payload (ESP) tunnel mode will be an excellent security solution.

The figure 2.13 shows a simple illustration of the three level vulnerability attacks in a femto-cellular network as depicted by [2.52].

![Diagram of Backhaul Security Solution](image)

**Figure 2.13:** A three-target malicious attacks on a femto-cellular network as shown indicated by the red arrow [2.52].

### 2.3.2.2 Self-Organising Networks (SON)

The future of femtocells (and particularly, the future networks) depends on SON’s capabilities. Although, some of the concepts of SON have been used in some regards, a
number of key 3GPP principles still need to be addressed in the future. The ones highlighted in the figure 2.14 are based on the Ubiquisys System. To have a self-organizing network that caters for the femtocells without the assistance of human control, the following concept of SON [2.53] are needed and are presented as follows:

- Efficient self-configuration system;
- Spectrum selection;
- Power tuning;
- Resource block assignment; and
- Access control policy.

![Diagram](image.png)

**Figure 2.14:** Key 3GPP outline principles for SON [2.54].

Some of the previous releases of the 3GPP towards a better standardization of the SON concepts [2.55] have been SON Release 8, which focuses on Automatic Inventory, Automatic Software download, Automatic Neighbour relations, Automatic Physical Cell Identification (PCI) assignment and subsequently the release 9 which caters for the functionality introduction for the developing networks: Coverage and Capacity Optimization, Mobility Optimization [2.56], Random-Access Channel, RACH and Load Balancing
optimization. Some of the original ideas of the SON were main focus on the femtocell originally.

It is therefore important to improve this sophisticated technology to be able to meet up with the future demands of the femtocell development. Due to insufficient materials on the Femtocells SON, future works should focus on how to efficiently develop femtocells to be better self-configured and self-optimized; and inclusively, self-healing by being able to detect failures in the network and to be able to correct or reduce their occurrence [2.57].

2.3.2.3 Interferences

The issue of interference is a vital concern for the future of femtocell. To efficiently have an excellent link quality and efficient spectral re-use, the issue of interference needs to be addressed squarely. In [2.58], a cognitive radio enabled (CR-Enabled) femtocell has been proposed as a solution to the many problems of interference in femtocells deployment. Of much importance is the ability of the CR-Enabled femtocell to reduce or eliminate the very complicated interferences. The CR-Enabled techniques offer a new paradigm that includes opportunistic interference avoidance, interference cancellation and interference alignment.

2.3.2 Small Cells today and the future

As the small cells network (SCN) becomes more prosperous with the help of femtocells deployment, it is important to note that the future of small cells generally cannot be limited to femtocells but all other cells alike need their potentials harnessed critically.

As presented in [2.59], as much as some of the major challenges of the SCN abound; issues like suboptimal spectrum utilization, dense deployment interference, mobility in SCN, energy consumption and so on, the future of the SCN is dependent on the solution provision to combat most of these problems [2.59]. As presented in the Alcatel-Lucent Strategic White Paper [2.60], if operators will plan to turn small cells into big profits, they must be ready to use the SCN to solve target challenges the deployment of femtocells.
Reference

[2.1]. Vizzarri A. Analysis of VoLTE end-to-end quality of service using OPNET. In Modelling Symposium (EMS), 2014 European 2014 Oct 21 (pp. 452-457) IEEE.


[2.6]. Sreenivas TH. A Survey on Implementation and Design of Femtocell Device.


[2.19]. Haddad Y, Porrat D. Femtocell: opportunities and challenges of the home cellular base station for the 3g. In IADIS international conference wireless applications and computing (WAC) 2009.


[2.29]. Haddad, Y. and Porrat, D., Femtocell: Opportunities and Challenges of the Home Cellular Base Station for the 3G.


[2.42]. Rasmussen, P., FierceWireless Europe, Analyst: 98% of operators say small cells are essential for the future, 7th December, 2012.


[2.54]. Campbell-Black, L., Well Done 'SON’ - Femtocell Self Organising Networks; The Ubiquisys.com, 10th March, 2011.

[2.55]. SON Technology, Self Organizing Networks (SON) http://www.sonlte.com/technology/


