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REVIEW ARTICLE

A Review on Femtocell and its 3G and 4G Architectures

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Abstract— A femtocell is small private cell which acts as a base station and provides increased coverage and capacity in indoor area such as offices, home environment. Femtocell Network uses femtocell access point (FAP) and existing network for backhaul connectivity which fulfils the upcoming demand of higher data rate for wireless communication system as well as increases the coverage strength. Therefore deployment of femtocell in the existing macrocell networks, 3G and 4G networks will significantly increase. The objective of this paper is to explain the need of femtocell and its basic architecture. It also gives a depth view of 3G and LTE (Long Term Evolution) Femtocell architecture. This paper also provides some other scenarios related to handover and interference in femtocell.

Keywords— femtocell, femtocell access point, 3G, 4G

I. INTRODUCTION

Over the past two decades, the demand of high data rate for wireless communication was increased tremendously. Wireless communication system faces a lot of problems for high data rate access. A survey in mobile communication is conducted which says that more than twenty three percent of calls and ninety percent of data services are used indoor [1]. And people are experiencing poor coverage because of which operators loses their clients. To overcome this issue concept of femtocell arise. Development of femtocell provides good opportunity to solve this problem. Femtocell is a small private cell that can set up by both mobile users as well as mobile operators. It helps in extending the network coverage and enhancing the quality as well. . For mobile users, it provides good signal strength, enhances capacity, provides reliability and also save battery. For mobile operators, it reduces the load of macrocells, solve the shortage of radio resources and BS building cost is also reduce [2].

What is Femtocell?

The name femtocell has the prefix ‘femto’ which means a very small cell. Femtocell is a small private cell or we can say it is a small low power base station which help in extending the coverage strength and help in provide quality of data service at high data speed, typically designed for home and office environment [3,4]. A femtocell networks uses Femtocell Access Point (FAP) and existing network as a connectivity to fulfil the high transfer data rate and improve the range for wireless communication.

1.1 Characteristics of femtocell [1]

- It provides indoor coverage in places where macrocell cannot provide coverage.
- It is a good solution for Fixed Mobile Coverage (FMC).
- It reuses radio spectrum indoors which enhances the total network capacity.
- It offers power saving features.
- It offloads the traffic form macrocell and improves overall macrocell capacity.
- I solve the shortage of radio resources.
- It provides reliable transmission because of better coverage.

II. INTERFERENCE SCENARIOS

Interference is any form of disruption occurs while transmitting and receiving. In femtocell network, interference is divided into the two categories:

- Co-layer
- Cross-layer.

Co-layer occurs when one femtocell interfere with another femtocell. Co-layer interference occurs within the two closest femtocells due to the low isolation between houses and apartments. This co-layer interference is independent of the disruption to the macrocell layer. These are described as the unwanted signals which are received at a femtocell and sent from another femtocell which degrade the quality of its communication.

Cross-layer occurs when femtocell and macrocell interfere with each other. This problem occurs mainly in CDMA co-channel deployed two layer network this is due to the fact that both femtocell user (F –user) and macrocell user (M-user) use the same frequency band. It is possible that coverage area of isolated femtocell interfere with neighbour due to high power level than the macrocell. This interference often occurs for M-user in F-user service area and causes uplink and downlink interference. Figure 1 and 2 shows interference for downlink and uplink transmission.

A. *Interference for downlink transmission*

When the femtocell user are located at the edge of macrocell coverage area, nearby m-user may request for increasing the macrocell transmission power(as far away from mobile base station) , in this case if there is no proper subchannels are used then it causes uplink interference with FAP. Uplink interference with FAP also occurs when femtocells are located to close to mobile base stations, shown in figure 1 [2, 10].

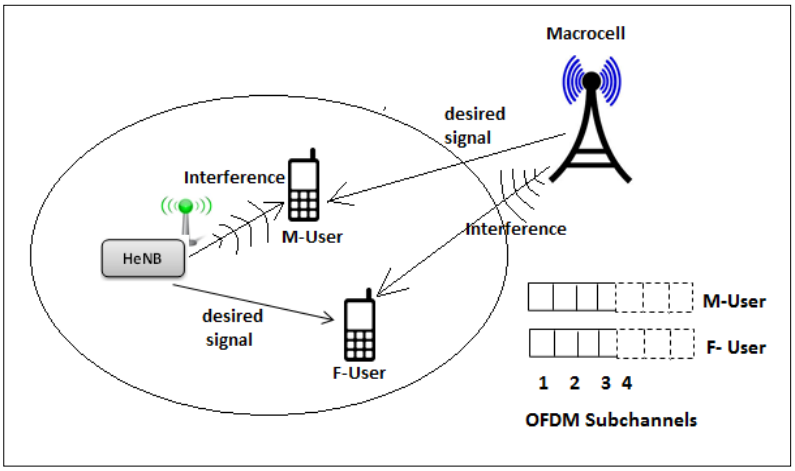

Fig. 1 Interference for downlink transmission

B. *Interference for uplink transmission*

When the femtocell user are located at the edge of macrocell coverage area, nearby m-user may request for increasing the macrocell transmission power(as far away from mobile base station) , in this case if there is no proper subchannels are used then

it causes uplink interference with FAP. Uplink interference with FAP also occurs when femtocells are located to close to mobile base stations, shown in figure 2 [2, 10].

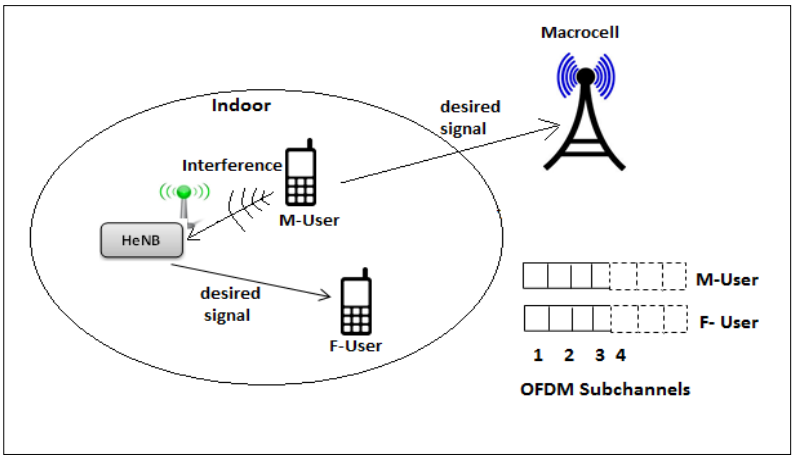

Fig. 2 Interference for uplink transmission

III. 3G AND 4G FEMTOCELL ARCHITECTURES

A) Basic Architecture of Femtocell:

1) Elements of basic architecture

- Femtocell Access Point (FAP): This is the fundamental unit of femtocell. It is basically an access point through which role of femtocell is accomplished. It is the basic node of femtocell which place in user site such as offices and home. It functions as a base station controller which controls and connects with mobile operator and provides a secure connection.

- Security Gateway: It is a node that provides a security during the establishment of connection between femtocell user and mobile operator core network. It also provides security when data is exposed to public network. Security gateway uses secure internet protocols i.e. IPv4 and IPv6 to provide authentication and also provide encryption to the data to maintain its confidentiality.

- Femtocell Mobile Management System: It is a node which may locate at operator network and is used to monitor and manage the control flow of connection, activation and operational functions of femtocell using standard TR-069. It also ensures user for the quality of data received. It is responsible for reliable connection between femtocell user and mobile operator core network. It is responsible for low cost and easy setup for users.

- Mobile Operator Network (MON): This node is responsible for providing authentication about the user services. MON helps in knowing and managing the policy subscribe by user and formulate this information to FAP during the connection of femtocell user to core network.

2) Basic architecture

In the basic architecture of femtocell, all the elements were combining to provide good coverage and capacity to mobile node. Firstly any user who wants to access femtocell services should install the femtocell access point in their home premises. After installing it, register all the mobile devices which you need to provide the services of femtocell. Whenever mobile devices come under the range of the femtocell whom they are registered can able to access its services. This FAP can use FMS (femtocell management system) to provide activation and operational function to the registered FAP. It authenticate for their subscribed policy. FAP uses plug and play services to build connection for providing good coverage and strength. FAP uses security gateway to know the authentication of user policy and to securely connect user with core network. After establishing the connection of user with core network, Femtocell routes the user data trough

broadband router and provides secure and reliable transmission. In between establishing the connection and providing services it uses MON for authentication of services. Basic architecture of femtocell is shown in figure 3.

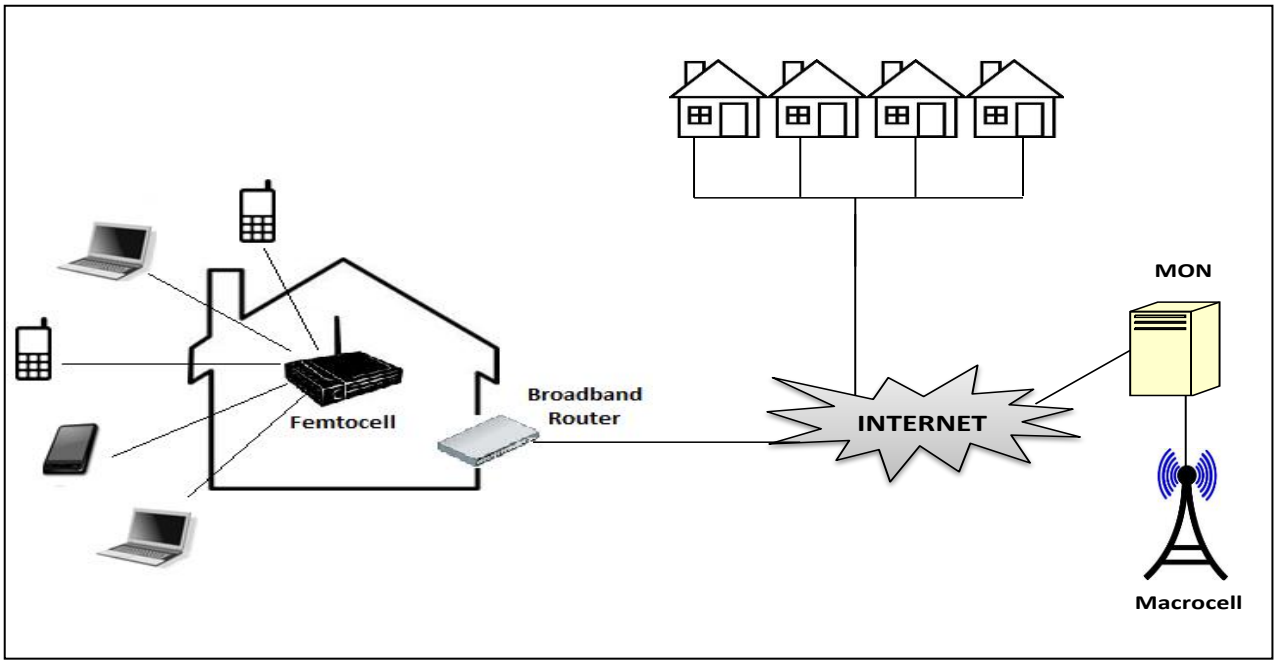

Fig 3 Basic architecture of Femtocell

B) 3G Femtocell Architecture:

3G femtocell architecture relies on UMTS (universal mobile telecommunication system) on which some architectural enhancement is done which supports femtocell functionality by adding UTRAN (UMTS terrestrial radio access network). It added HNB in spite of node-B and HNB-GW in spite of and RNC (radio network controller).

TABLE 1
FEMTOCELL TERMINOLOGY FOR 3G

General Terminology	3GPP Terminology
Femtocell or Femtocell Access Point (**FAP)**	Home NodeB (**HNB**)
FAP Gateway (**FAP-GW)**	Home NodeB Gateway (**HNB-GW**)
Auto Configuration Sever (**ACS)**	Home NodeB Management System (H**MS**)

1) Elements added to 3G femtocell architecture

Element added to 3G femtocell architecture are to the existing architecture are listed below:

- HNB (Home NodeB): HNB is an essential node of the operator network. It provides a dedicated mobile coverage and capacity in the home environment.

- HNB-GW (Home NodeB Gateway): HNB-GW is used as intensifier for whole traffic coming from the HNB. It offers improved mobility and operation administration and maintenance (OAM) functions for user's equipment (UE's). It acts as intensifier function for better control and user plane. It is designed in such a manner that it can concentrate on both or either one of it (control or user functionalities) [3, 6].

- HMS (Home NodeB Management System: Role of HMS is to ensure that user is uses services of high quality and securely. Its functionality is on the standards of TR-069 group [3, 7]. HMS functionalities include discovery of HNB gateway, location verification of HNB.

- SeGW (Security Gateway): The Security gateway (SeGW) in 3G works as a separate entity. It also gives security opposed to various harmful network attacks and security threats that can occur when traffic is open to public network.

- **Iuh Interface:** It is a kind of interface which is use to connect HNB and HNB-GW. The Iuh interface provides control plane and user plane functionalities. User plane functionalities: Radio resource management, mobility management, radio access bearer management, security etc. Control plane functionalities: HNB registrations, UE registrations to HNB and error handling.

This Iu interface functionality is split into two i.e. Iu-Packet Switching and Iu-Circuit Switching.

2) 3G femtocell logical architecture

To utilize femtocell service, user has to purchase femtocell and connect it to their internet service and then after connecting to internet HNB will first link to operator gateway. The role of HNB is to provide authorization and configure it on the basis of user's subscription. Femtocell service depends on mode of FAP.
User Equipment connects (UE) to HNB through Uu interface, HNB gives continuous mobile range capacity inside the building. This HNB is then link with HNB-GW by using the Iuh interface. The Iuh interface provides control plane and user plane functionalities.
There are many HNB's which are connected to a single HNB-GW (many-two-one relationship). HNB-GW combines a lot of HNB's together by using Iu interface to the main network. In between HNB and HNB-GW there are HMS and SeGW which plays their respective roles. HMS responsible for providing quality services to user so it maintain the quality. SeGW provides security while we sending data from HNB to HNB-GW over public network from external attacks and threats. Figure 4 shows 3G Femtocell logical architecture [3].

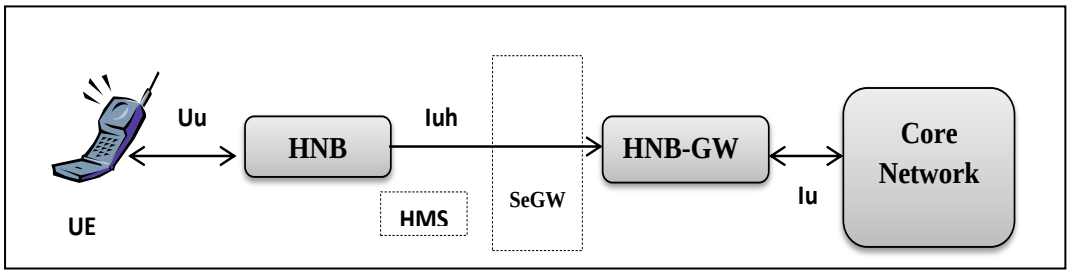

Fig. 4 3G Femtocell logical architecture

3) High-level functional architecture of 3G femtocell :

The high level functional architecture of 3G femtocell shows the working of whole 3G femtocell architecture. In this, firstly UE (user equipment) is verified in CSG list server for providing authentication. When it verifies UE connects with HNB through Uu interface. For providing dedicated coverage after connecting with HNB, HNB route it to the HNB-GW using Iuh interface which provides user plane and control plane functionality. During this establishment of connection SeGW provides security from outside attacks and threats when exposed to public network. HMS is responsible for managing the quality of services. HNB-GW concurrently works using circuit switch signalling to MSC or VLR and packet switch signalling to a SGSN by using Iu-PacketSwitching and Iu-CircuitSwitching interface respectively. The Iu-CS interface is responsible for circuit switching signalling to MSC or VLR and Iu-PS interface is responsible for packet switching signalling to SGSN. The Iu-CS interface is responsible for circuit switching signalling to MSC or VLR and Iu-PS interface is responsible for packet switching signalling to SGSN. Fig. 5 shows High-level functional architecture of 3G femtocell [3].

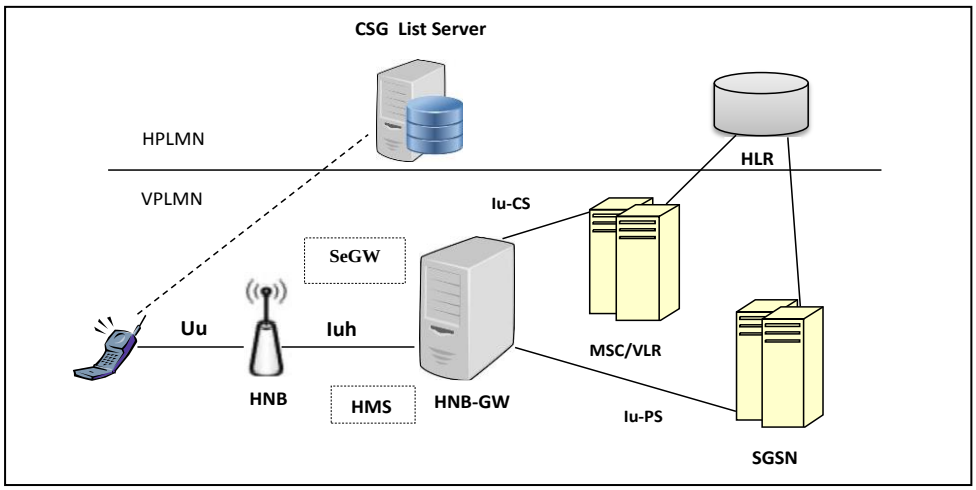

Fig. 5 High-level functional architecture of 3G femtocell

C) 4G Femtocell Architecture:

Long term evolution (LTE) or 4G provide high speed data services, HD streaming and quality of services but it requires good coverage strength. As we discussed earlier twenty third of calls and more than ninety percent of data services were accessed indoors and majority of the user suffer from bad indoor signal, this degraded the quality of real-time application and weakens the fast access to data services of 4G (LTE). Traditionally, macrocell network are not able to provide good coverage as well as quality services indoor to overcome this problem macrocell network operator (MNO) need to install a large number of base station. Practically placing large number of mobile base station is not possible in densely populated area [3].

3GPP is continuously working to improve the cell coverage and capacity, it also work on improving broadband user experience in cost effective manner. 3GPP finds a solution for this problem by introducing femtocell concept in 4G architecture. The concept of femtocell has seemed as a very good solution for providing high capacity and coverage indoors. This introduces several new elements in the existing architecture. HeNB is proposed by 3GPP in release 8 specifications [3, 6, 12]. HeNB is used in home and office environment and is generally called as femtocell or FAP.

TABLE 2
FEMTOCELL TERMINOLOGY FOR 4G

General Terminology	3GPP Terminology
Femtocell or Femtocell Access Point **(FAP)**	Home eNodeB (**HeNB**)
FAP Gateway (**FAP-GW)**	Home eNodeB Gateway (**HeNB-GW**)
Auto Configuration Sever (**ACS)**	Home eNodeB Management System (**HeMS**)

1) Elements added to 4G femtocell architecture

Element added to LTE (4G) femtocell architecture are to the existing architecture are listed below:

- HeNB (Home eNodeB)/ Femtocell Access point (FAP): It is consider as a plug and play consumer device. FAP can seamlessly be access by the users in office and home environment It uses subscriber's policy of broadband to connect to the operator's core network. For users basically it provides dedicated coverage and capacity over the licensed spectrum, due to which it enhances the quality of services provided by their respective operators. HeNB supports the radio management function.

- HeNB-GW (Home eNodeB Gateway): HeNB-GW functions such as aggregation, security and control. It also maintains the core network functions. It also has AAA (Authentication, Authorization and Accounting) functions [6, 13]. It aid authorisation and authentication for HeNB. This AA is needed for registration process.

- HeMS (Home eNodeB Management System): This belongs to TR-069 group. It permits operators to control and guide configuration of HeNBs. It also provides OAMP functions to the HeNB. With the HeMS, an operators permits access to HeNBs with additional services and apply service usage policies [6].

- SeGW (Security Gateway): It is used to provide security during the connection of HNB and core networks. SeGW enables HeNBs to establish a secure connection using IPSec (Internet Protocol security) tunnels. GTP (GPRS tunnelling Protocol) over the S1 interface help in accessing the data securely, this protocol works in the IPSec connection. In between HeNB and MME (mobile Management Entity) generally GTP forms.

- S1 Interface: This interface is used between Home enodeB and Home enodeB-gateway to transport all the data and procedure over IPv4 and IPv6. S1 is a multifunctional interface. It uses the SCTP (Stream Control transmission Protocol) to relaying the control and signalling data in between Home enodeB and Home enodeB-gateway.

2) 4G femtocell logical architecture

This 4G Femtocell logical-architecture was proposed by 3GPP. This architecture is very much similar to LTE's EPS architecture but some new elements are added to it which is discussed in previously. It is a combination of 3G architecture model and LTE operational functionality. In 4G femtocell architecture the position of HeMS and SeGW is not fixed. Functionality of SeGW either be merged in HeNB-GW or can be used as a separate entity.

4G logical architecture works similar to the 3G logical architecture. In this UE first establish the connection with HeNB using LTE operational functionality and Uu interface. Then HeNB make connection with HeNB-GW through S1 interface, HeMS and SeGW plays their respective role in establishing the connection between them. After making connection with HeNB-GW this, He-NB-GW combines a lot of HeNB using S1-MME and S1-U interface to the main network. Fig 6 shows 4G Femtocell logical architecture [3].

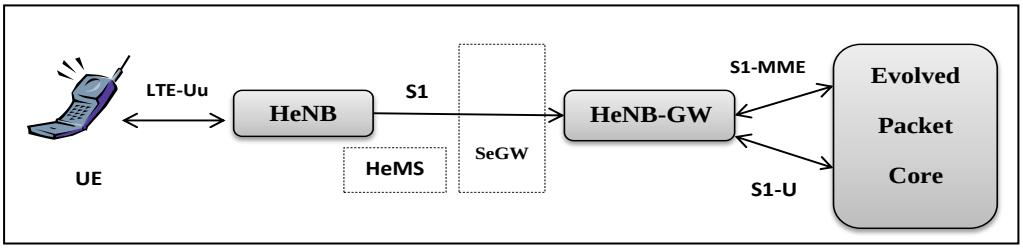

Fig. 6 4G Femtocell logical architecture

3) High-level functional architecture of 4G femtocell :

The high level functional architecture of 4G femtocell shows the working of whole 4G femtocell architecture. In this, firstly UE (user equipment) is verified in CSG list server for providing authentication. When it verifies UE connects with HeNB through LTE-Uu interface i.e. LTE operational functionalities with Uu interface. HeNB uses S1 interface to link between HeNB and HeNB-GW to provide dedicated coverage. During this establishment of connection SeGW provides security from outside attacks and threats when exposed to public network. With the HeMS, an operators permits access to HeNB for some extra services and give access to service policies. In HeNB-GW AAA (Authentication, Authorization and Accounting) functions enables authentication services such as EAP-SIM (Extensible Authentication Protocol- Subscriber Identity Module) and EAP-AKA (Extensible Authentication Protocol-Authentication and Key Agreement) between HeNB and MME (mobile management entity). HeNB-GW communicates with MME and S-GW (Serving Gateway) through S1-MME and S1-U interface respectively. Fig 7 shows High-level functional architecture of 4G femtocell [3].

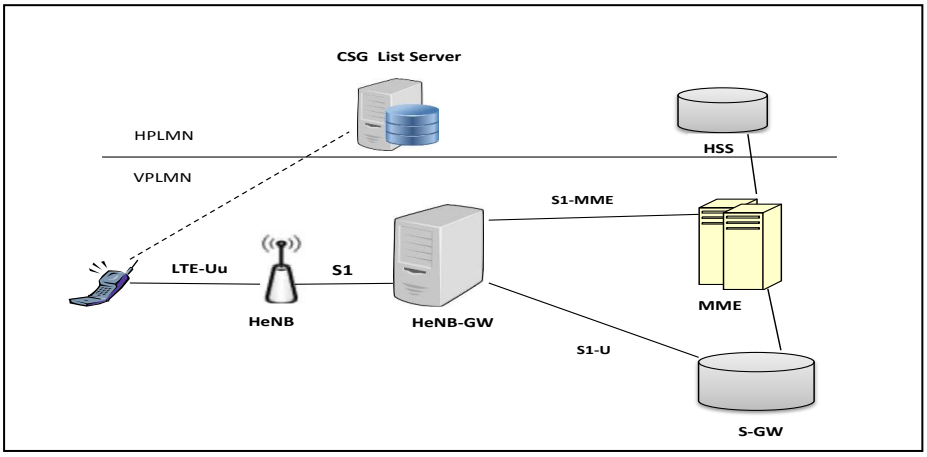

Fig. 7 High-level functional architecture of 4G femtocell

4) Variants of 4G (LTE)

These variations are on the assessment of HeNB-GW functions and its physical presence of arrangements. These variation need to be done to increase the system performance and efficiency, for this functional operation of different networks are integrated in one device.

a) Variant 1: With dedicated HeNB- GW

In this there are HeNB-GW which illustrate the EPS based architecture. This In first variation of 4G femtocell architecture there HeNB-GW which illustrate the EPS based architecture. This variant is a very equitable and works by finding the scope of serving HeNB-GW [6, 5]. Architecture is shown in figure 8 [13].

Characteristics of this variant:

- There is dedicated HeNB-GW present.
- HeNB-GW serves as a concentrator for the C-Plane and also terminates the user plane towards the HeNB and towards the Serving Gateway [13].
- There is one-to-one mapping.
- HeNB-GW does not establish concurrent connection with the mobile management entities.
- All UEs have to maintain a file of name of CSG identities. This will help in authorization for accessing services.

There are two advantages in this variation, one is there is no deployment concern and drawbacks and other is that this architecture does not require any up gradation [6].

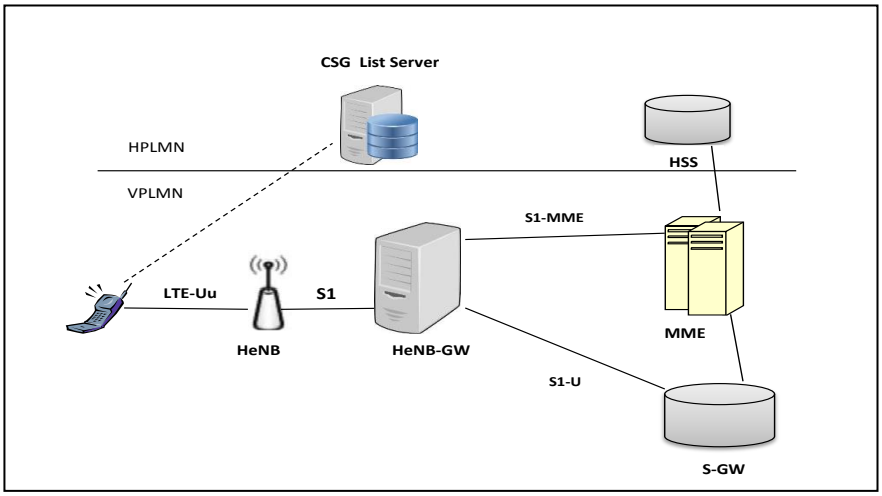

Fig. 8 Variant 1

b) Variant 2: Without HeNB- GW

In this variation here is no HeNB-GW present i.e. in this architecture there is no presence of HeNB-GW shown in figure 3.7 [13]. Functionality of HeNB gateway is integrated with HENB and MME. This combination lowers the cost and latency.

Characteristics of this variant [6, 5]:

- HeNB-GW is not present.
- It used as plug and play device.
- As there is no HeNB-GW, so the user can freely move towards any position and access HeNB regardless of its geographical location, for accessing femtocell services, there is a need of HeNB to just connect with internet according to its new location.
- In this S1 C-plane is directly connected from HeNBs to MME and U-plane are directly connected from the HeNBs to S-GW. It results in reducing the latency.
- As there is no physical presence of HeNB-GW so there are less upgrade and compatibility issues.

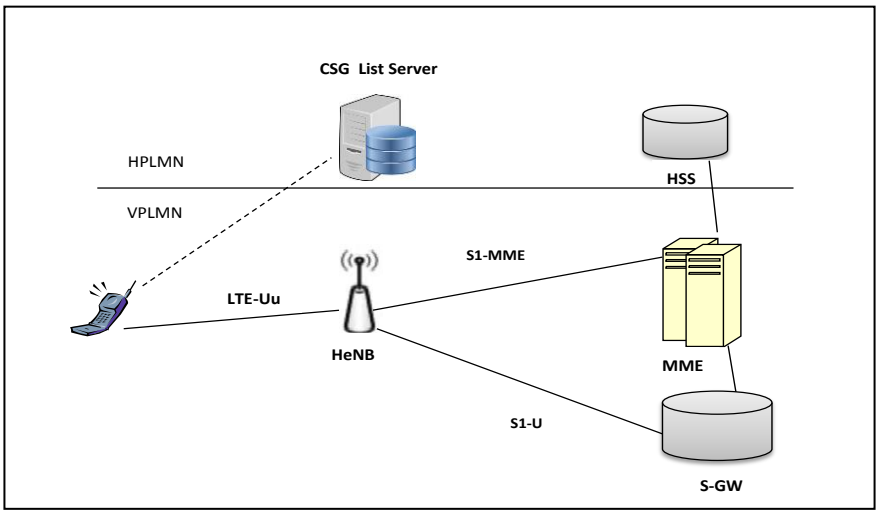

Fig. 9 Variant 2

c) Variant 3: With dedicated HeNB- GW in C-plane only

As we know that HeNB-GW serves as a concentrating device for C-plane ad U-plane signalling and S1-U interface which transports user plane signalling can also be terminated in the S-GW (Serving Gateway) by these facts another variant for 4G femtocell architecture is build shown in Figure 10 [13]. In this variation they separate the U-plane and C-plane functionality [6, 5].

Characteristics of this variant [6, 5]:

- It has dedicated HeNB-GW in C-plane only.
- Implementation of paging optimisation mechanism can be done in HeNB-GE.
- In comparisons with other there is less point of failures in the network.
- S1 User-plane are straight linked from the HeNBs to S-GW and there is no need of protocol termination at HeNB-GW which in turn reduces the latency in User-plane
- There is many to one mapping between HeNB and CSG.

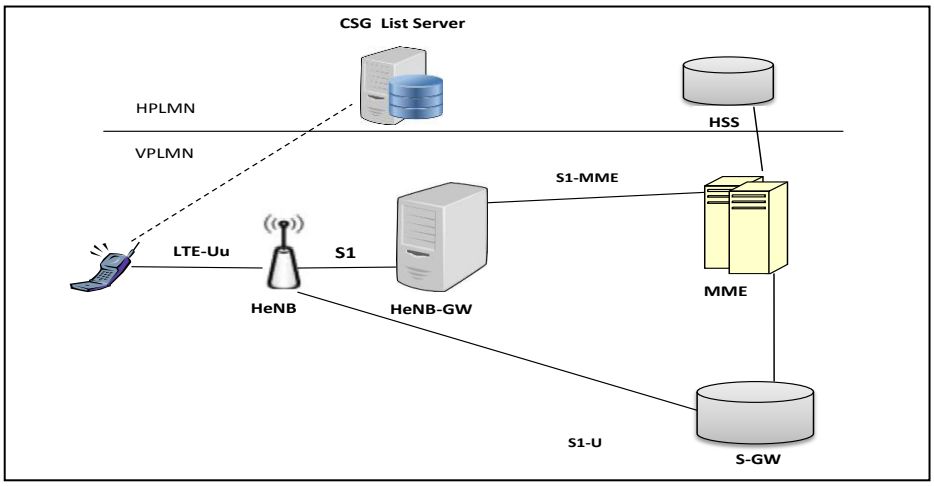

Fig. 10 Variant 3

IV. ISSUES AND CHALLENGES

Issues and challenges of femtocell:

1) *Interference Issues*: Interference is a key issue associated with femtocell development. When deployed femtocell uses same frequency band as of macrocell (co-channel deployment) this result in interference and reduce the levels of performance. Some of them are:

- Interference of femtocells with base stations on the same frequency: If femtocells are operating with the same channel frequency that is of macro base station then there is chance interference may be caused by the femtocells. This reduces the performance of the whole network.
- Interference of base stations with femtocells having same frequency**:** If macro base station is operating with the same channel frequency that is of femtocells then there is chance interference between the two.
- Femtocells are very closely spaced causes interference with each other: If distances between various femtocells installed are very small i.e. femtocells are closely spaced then there will have a level of background noise that will reduce the sensitivity of each femtocell.

2) *Security issues***:** Security is also big challenge. Some of the security risks are listed below:

- User privacy**:** Since a variety of data including the voice calls and data themselves pass over the Internet. As a result it is necessary to provide security for these IP communications and prevent any monitoring of the data.
- Denial of service and general service availability: Data is send or communicated over public network, so there is a chance of denial of service attacks which overload the network and degrade the service or even totally prevent legitimate users accessing the cellular network.
- This form of femtocell security addresses the scenarios where unauthorized users connect to the femtocell and use it in an unauthorized fashion.

3) *Femtocell handover management:* Whenever the signal strength decreases there is a need of femtocell handover. An appropriate selection mechanism for the efficient handover is significant. For smooth and seemly handover there is a need of better mechanism in femtocell to femtocell, femtocell to macrocell and macrocell to femtocell handovers. There is a need of handover mechanism which can reduce the failure rate of handover and provide efficient services. There are various factors which need to consider during femtocell handover management. Some of them are hidden FAP (Femtocell access point) problem, RSSI (Received Signal strength indicator) and different modes in femtocell etc.

V. CONCLUSION

In this paper the basic need and working of femtocell architecture is given. It provides an understanding about the femtocell interference scenario, logical and high level functioning architectures of 3G and LTE. This also gives some variation in LTE (4G) femtocell architecture and highlights important issues related to femtocell. As for future work the various issues related to femtocell, those summarize in paper need to be taken care of. Femtocell handover is an important research area for reducing the handover failure rate which further enhances the femtocell's capability.

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