e-ISSN 2805-4356
p-ISSN 2805-4364

Check for updates

Gph-International Journal Applied Science www.gphjournal.org

10.5281/zenodo.12792817 Vol. 07 Issue 05 May - 2024 Manuscript ID: #01481

FEMTOCELLS TECHNOLOGY DEPLOYMENT FOR IMPROVED QUALITY OF SERVICE IN MOBILE COMMUNICATION SYSTEM

USIADE, Rex Ehiedum
ADEOYE, Olayode Semiu
DEPARTMENT OF COMPUTER ENGINEERING, DELTA STATE POLYTECHNIC
OTEFE-OGHARA, DELTA STATE

Corresponding author: E-mail: rexiadeu@gmail.com

Abstract:

Mobile technology has evolved exponentially interms of contents and subscriber growth within the past few decades. This evolution has come with its numerous valueadded services that are delivered to customers via legacy mobile communications networks that have little or no service within confined areas, homes and offices. This limitation together with high demands for services within indoor environment, have thrown a challenge to mobile operators and manufacturers to come up with solutions for addressing the poor Quality of Service (QoS). The concept offemtocells has been considered to be one of the available techniques for improving the degraded QoS within indoor environment. Femtocell is a compact portable low power home base station that can be connected via home internet access such as home digital subscriber line (DSL), fiber opticbroad band connection or any other available broadband connectivity to extend and improve mobile signal reception and also provide other wireless applications such as data,movies and pictures transfer. This paper provides an overview of femtocell technology applications and deployment scenarios for indoor environment that arecharacterized by multipath and attenuation which affects the performance of received signal hence degrading the QoS available to customers. Security and handover with in femtocell are also addressed.

Keywords:

Femtocells, Base Station, Quality of Service, Mobile Technology, Handover.

Introduction

Past decades have witnessed the evolution and rapidgrowth in mobile cellular technologies. The demands formore content applications and services by consumers especially within indoor environment present a challenge to operators and stakeholders in the mobile world. This has triggered the need to lookfor an efficient and cost effective ways of delivering these contents with guaranteed Quality of Service (QoS)irrespective of location and time. For instance, "*As Smartphone Penetration Climbs, Current Networks can barely Handle Incremental Data Traffic in Peak Times"* (www.morganstanley.com). Studies conducted in the past in Nigeria have shown aphenomenal growth pattern in mobile traffic usage with high percentage of mobile phone usage time occurring at home orwork (Saunders S.R., Carlaw S., Giustina S.A. and Bhat R.R., 2009). A global survey conducted for femto forum by Parks Associates 2011 in the US, UK, Germany, Spain,China and Japan have shown a statistical variance interms of poor voice and data service quality while athome amongst consumers within the surveyed countries (www.smallcellforum.org).

According to Odadzic B., Lukic N.M. and Jankovic M. (2012), Femtocells are gaining an important position in mobile telecommunications industry, mostly because they seem to have overcome the existing problems that are common to macro cells, as well as the fact that these cells provide high quality coverage of inner premises (small amount of transmitting power that is up to 20mV in the range of up to 50 metres). Similarly as in Chandrasekhar V., Andrews J. and Gatherer A. (2008), it was shown that more than 50%and 70% of voice and data respectively originate within indoor environments. A femtocell is an inexpensive lowpower access point that provides voice and broadband services extension to homes and office environments operating in a licensed spectrum with operator's consent (Boccuzzi J. and Ruggiero M., 2010). Femtocells provide connection via residential Digital Subscriber Line (DSL), Cable Broadband or other access techniques to mobile operator's networks (Zhang J. and Roche G., 2010; Sungoh K. and Neung-Hyung L., 2011).

As in Saunders S.R., Carlaw S., Giustina S.A. and Bhat R.R., (2009), the attributes of femtocells include; mobiletechnology accessibility, operating in a licensed spectrum, improved coverage and capacity. Otherattributes of femtocell are; internet-grade backhaul, price affordability, ownership by the licensed operators andeasy management and organization.

Propagation loss due to multipath and reflections within the indoor environment have contributed to low wireless access coverage and this becomes worst when base station is located far away from the mobile station. Tocarter for subscriber growth, as in BoccuzziJ. and Ruggiero M. (2010), the mobile operatorneed to; analyses BTS deployment options, BTS rangeand provide micro and pico cells. Deploying traditional cellular BTS to serve both outdoor and indoor environments is quite an expensive task and challenging. The primary aim design for mobile networks was formobility purposes only and are not designed to providerobust home services but the pattern has significantly changed with high demands for services with mobile devices while stationary either at home or in the office (Saunders S.R., Carlaw S., Giustina S.A. and Bhat R.R., 2009).Therefore the concept of femtocell has to be adopted which did not only provide coverage and capacity to thecustomer, but leverages outdoor public BTS's trafficloads. A mobile device recognizing the presence of afemtocell will register and informed the public BTS thatits communication will henceforth be via the home ISP connection while freeing the resources it occupied on the public BTS (BoccuzziJ. and Ruggiero M., 2010).

The remaining part of this paper focuses on femtocells standardization, architecture, deployment scenarios and handover. Other aspects that are also addressed includesecurity, interference, QoS and health and femtocell challenges.

Femtocell Standardization

To have its way into the general market, femtocell mustcomply with the existing standards that defined interfaces to mobile and network devices and must also supportmulti-vendor platforms to allow interoperability (www.airvana.com). The prominent standard deployment organizations (SDO) that defined femtocell technology according to Knisely D., Yoshizawa T. and Favichia F. (2009) are 3GPP and Broadband Forum. The Small Cell Forum has further categorized the bodies into standards as hereby described .

- **3GPP-Femtocell Standardization**

In a publication by Knisely D.N., Yoshizawa T. and Favichia F. (2009), they came to conclusion that 3GPP has undertaken a large effort on an aggressive schedule to define industry standards for all of the essential aspects of UMTS/ UTRAN-based femtocells. The commitment by system operators and vendors to complete this critical work as part of UMTS Release 8 has provided the basis for the robust commercialization of open interoperable femtocell products and femtocell core network components. Looking forward, these efforts will expand to address new capabilities (such as "local breakout" of IP traffic at the femtocell device) and new radio technologies such as LTE.

- **Broadband Forum**

Broadband Forum released two versions of standards forthe femtocells technology specifications which are theTR-196 (Femto access Point Service Data Model) andTR-262 (Femto Components Objects) in April, 2009 andNovember, 2011 respectively (www.smallcellforum.org).

- **The WiMAX Forum**

Femtocell Standardization was released in 2010 incollaboration with femto forum (Small Cell Forum) that incorporates support for larger access points, SON forauto configuration. Residential, indoors and outdoors arealso supported (www.smallcellforum.org).

There are some non-standard deployment organizations which include the Femtoforum and Next Generation Mobile Network (Sungoh K. and Neung-Hyung L., 2011).

Femtocell Architecture

Small Cell Forum (formally the Femto Forum) is atelecommunication body responsible for promoting theadoption of femtocells, picocells, metrocells andmicrocells otherwise known as small cells to enhanced service and contents delivery by mobile networks (www.smallcellforum.org).Figure 1depicts a simplified femtocells reference points based on Small Cell Forum specifications. The femtocell architecture supports some key requirements such as; service parity, call continuity, security and self-installation, simple operational management andscalability (www.airvana.com)

The main components of femtocells architecture asindicated in fig.1 are:

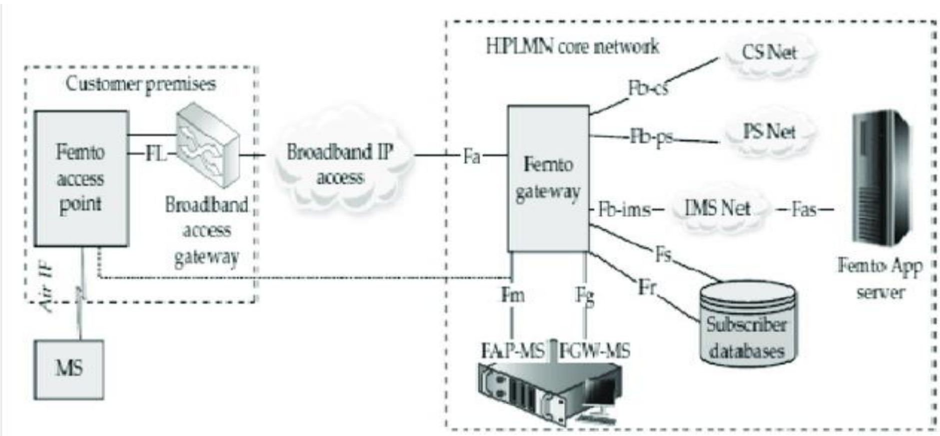

Fig.1 Femto Forum Reference Points (Boccuzzi J. and Ruggiero M., 2010)

a) Femto Access Point (FAP)

The FAP is a primary node domicile within user premises SungohK. and Neung-Hyung L. (2011). It is a hardware device emitting low power,and is responsible for air interface connectivity to mobile devices it also connects to the mobile core networks over a secure tunnel via residential broadband access techniques as stated earlier (BoccuzziJ. and Ruggiero M., 2010).The FAPs are designed to support a number of mobile devices. Depending on the types and applications and could be four (4) or eight (8) for residential and small businesses respectively (BoccuzziJ. and Ruggiero M., 2010).

b) Femto Gateway (FGW)

The FGW interfaces the FAP via broadband IP access network and it is responsible for; signalling protocol conversion and bearer channel conversion. The FGW also serves as a security gateway protecting the mobile networks from attacks. It interfaces the broadband network via Fa reference and to core network via Fb-csreference (BoccuzziJ. and Ruggiero M., 2010). Other reference points defined are; Fb-psfor packet switched networks, Fb-ims for IMS network, Fs and Fr for subscriber databases and Fm, Fg for FAPMS and FGW-MS respectively (BoccuzziJ. and Ruggiero M., 2010).

c) The Subscriber Database

The DB is responsible for storing customer’s identity which could be used for identity set ups and provides access to FAPs (BoccuzziJ. and Ruggiero M., 2010).

d) The Management System

The MS provides two reference points for the management of FAPs and FGWs, the Fm serves as a reference point providing management capabilities to FAPs and Fgfor the management of FGWs (BoccuzziJ. and Ruggiero M., 2010).

e) Femto Application Server (FAS)

FAS connectsto the IMS network via FAS reference point and is used for authentication and billing management.

Femtocell Deployment Scenarios

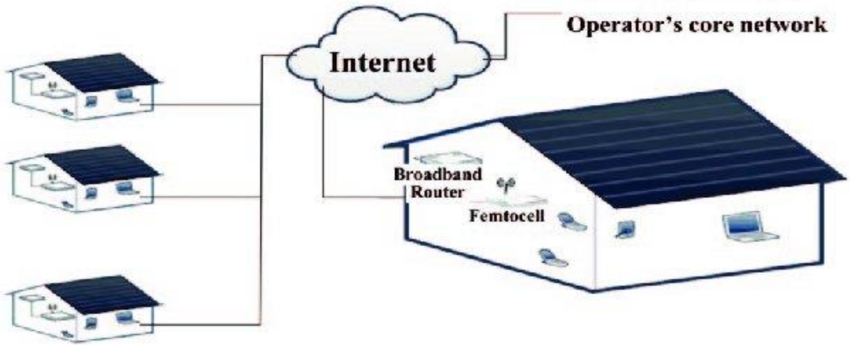

Fig. 2a An example Femto Deployment Scenario (Nasrin W. and Xie J., 2015)

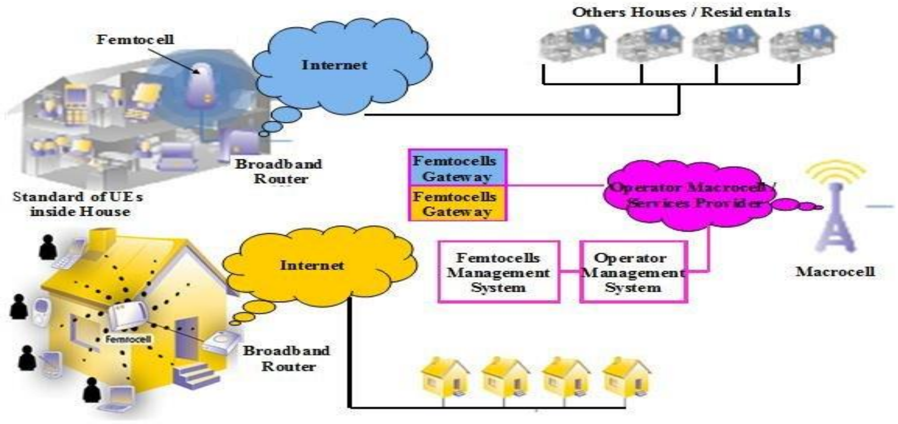

Fig. 2b.Typical Femtocells Deployment Scenario (Yusof A.L., Salihin S.S., Ya'acob N. and Ali M.T., 2013)

Fig. 2a and 2b shows an example of femtocell deployment scenario; the femtocell is connected to digital subscriber line (DSL) via home router (Calin D, Claussen H, and Uzunalioglu H., 2010).Other network devices in the home are also connected to the router via either wireless fidelity (WiFi) or Ethernet (Knisely D., Yoshizawa T. and Favichia F., 2009).

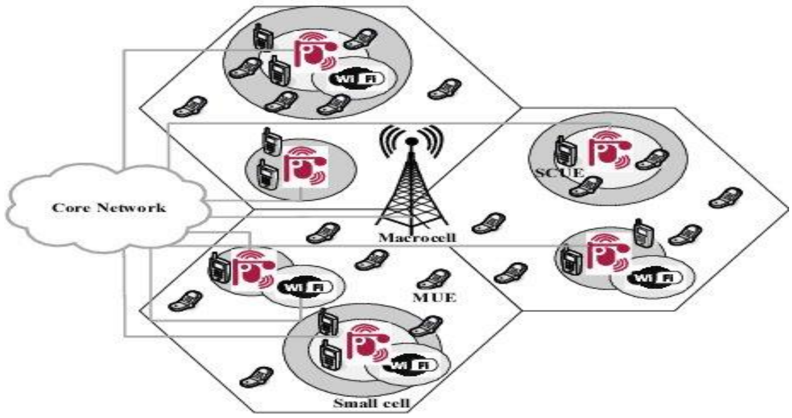

Fig. 3a) Traditional Macrocellular Deployment(Bennis M., Simsek M., Saad W and Czylwik A., 2013)

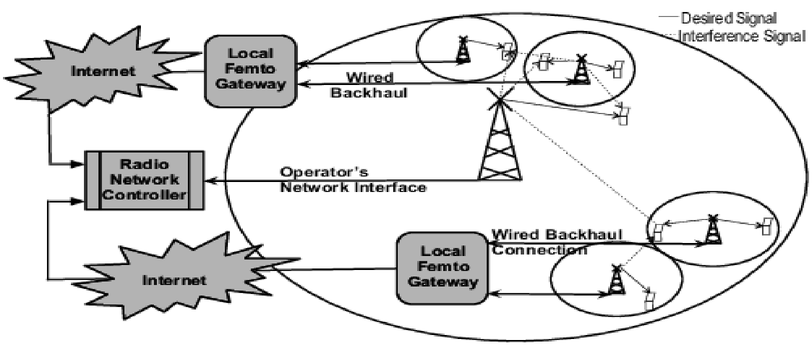

Fig. 3b) Joint Macro-Femtocell Deployment (Tariq F., Dooley L. D. and Poulton A.S., 2013)

Figure 3a depicts a scenario where both indoor and outdoor user are connected via a macrocell base station while Fig. 3b shows a joint macro-femtocell deployment scenario, the femtocells serves the indoor user and the outdoor users are served by the macrocell thereby reducing traffic offloads on the outdoor base station and enhances capacity of the cellular network (Calin D, Claussen H, and Uzunalioglu H., 2010).

Femtocells Classes and Applications

There are three classes of femtocells which include; class1, class 2 and class 3. Class 1 was the first generation of femtocells, it radiates about 20dBm of power and is similar to WiFi access points and could be used either for residential or enterprise applications offering 4-8 voice channels together with data access for residential and enterprise respectively. This class also supports both close and open access. Class 2 has higher power than class 1, typically 24dBm and may support 8- 16 users simultaneously, and finally class 3 which offer higher power than both class 1 and class 2 and could accommodate more users (Saunders S.R., Carlaw S., Giustina S.A. and Bhat R.R., 2009).

The original idea for femtocells was to offer profound solutions for mobile capacity and coverage enhancement within residential entities, however, though this remains the primary core objective of femtocells other applications deployments could be anticipated in the near future. As in Saunders S.R., Carlaw S., Giustina S.A. and Bhat R.R., (2009), femtocells applications are categorized into the following four (4) classes.

1. **Residential**

Here femtocells are installed within home environment by the end user giving him increased service delivery and capacity coverage, the device in this category falls in class 1 femtocells types. The residential femtocells are normally close access and restricted to close users only (Saunders S.R., Carlaw S., Giustina S.A. and Bhat R.R., 2009).

2. **Enterprise**

Femtocells also find its way into enterprise application offering small offices and business environments with an improved voice and data access. Femtocells within this category fall into class 1 and class 2 and offer additional functionalities such as handover between femtocells and integration with PBX and local call routing. The access could either be close or open and can be installed and managed by the operator or the company’s IT experts (Saunders S.R., Carlaw S., Giustina S.A. and Bhat R.R., 2009)..

3. Operator

Apart from residential and enterprise applications, as stated by Saunders S.R., Carlaw S., Giustina S.A. and Bhat R.R(2009), the operator also uses the femtocell to improve services andcoverage issues within outdoor and indoor environments. This category uses all classes of femtocells and could be installed by the operator or an approved third party agent as directed by the operator.

4. Others

The last category has not been defined but could use all classes and support customer needs, operator and regulatory requirements.

Handover in Femtocell

As with other mobile technologies, handover in femtocells is a necessity and a must for seamless connectivity and mobility within the network (Knisely D., Yoshizawa T. and Favichia F., 2009). Three categories of handovers exist in femtocells as described in Saunders S.R., Carlaw S., Giustina S.A. and Bhat R.R(2009); 5, 11, 12] hand in, hand out and inter FAP hand overs.

The hand in, macro-to-femto or in-band handover is a process where a transfer of services occurs between macro base station and FAPs as the user equipment (UE) enters the femto zone or environment (Saunders S.R., Carlaw S., Giustina S.A. and Bhat R.R., 2009); Ulvan A., R. Bestak R. and Ulvan M., 2010). Hand out or out-band handover happens when a service access is transferred to the macro base station as the UE leaves the femto zone while the femto to femto or inter femto handover occurs when one FAP transferred or handover services to one another (Ulvan A., R. Bestak R. and Ulvan M., 2010).Figure.4 depicts simple femtocells handover scenarios.

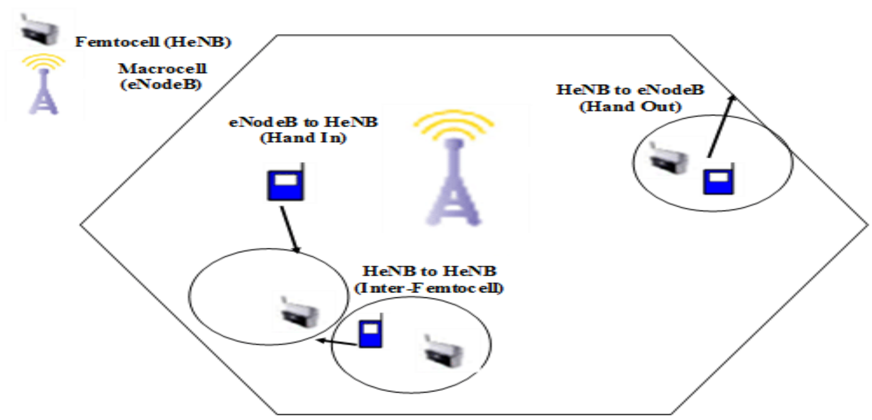

Fig. 4 Handover Scenario in Femtocell Network Yusof A.L., Salihin S.S., Ya'acob N. and Ali M.T. (2013)

Femtocell Security

One of the concern of any new technology for gaining acceptance is how secured is the system, the security importance in femtocells could be viewed from two perspectives as in Saunders S.R., Carlaw S., Giustina S.A. and Bhat R.R(2009), that is from continuity and contained change. The privacy of communication and the integrity of data transferred have to be protected against eaves dropping and message contents modifications (Saunders S.R., Carlaw S., Giustina S.A. and Bhat R.R., 2009).

Looking from the continuity angle, the trust between customers and mobile operators due to uncompromising level of security has to always be maintained while technology evolved without exposing them to treats or attacks (Saunders S.R., Carlaw S., Giustina S.A. and Bhat R.R., 2009).The contained change of the new model within the network architecture must ensure that the end customers are protected against any kind of treats associated with the new technology such as the femtocell concept and the overall network security must not be compromised (Saunders S.R., Carlaw S., Giustina S.A. and Bhat R.R., 2009). Customer must also be protected against spoofing or service theft and that service availability has to be guaranteed (BoccuzziJ. and Ruggiero M., 2010).

The security issues as discussed above could be mitigatedvia the following as in (VanekT. and M. Rohlik M., 2011).

IPsec: The use of IPsec or IP security which was standardized by Internet Engineering Task Force (IETF) as a means of providing security across internet has been adopted for the femtocell concept. Figure.5 shows architecture of IPsec tunneling protocol (VanekT. and M. Rohlik M., 2011)

Femtocell Secure Authentication: This ensures that only registered femtocells are allowed within the femto zone. The security authentication is achieved via SIM card or X.509.

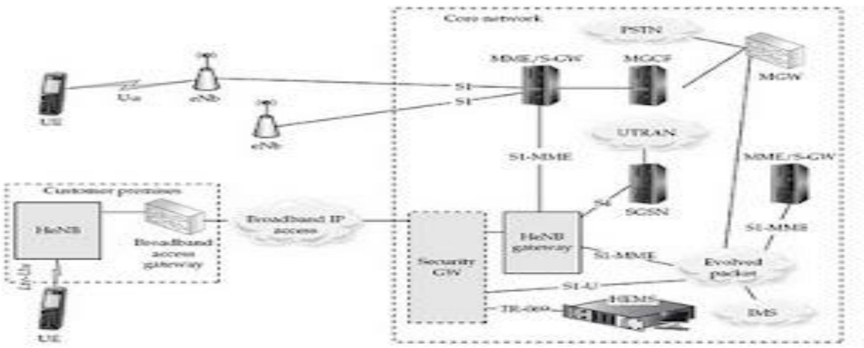

Fig..5 Security Architecture of a Femtocell(www.trends-in-telecoms.blogspot.com)

Wireless link security: The wireless link area is protected against unauthorized access by making sure that the coverage area is within the femtocell usage area.

Extensible Authentication Protocol: Another femtocell security measure is to use the EAP which stands for Extensible Authentication Protocol where IP protocol is not available. Details on EAP can be found in RFC 5247 as defined by IETF.

Interference in Femtocells Network

The coexistence of femtocells with other femtocells and macrocell lead to interference within the femtozone due to type of femtocell architecture, location and density (MostafaZaman C., J. Yeong Min J. and Haas Z.J., 2010). Different scenarios have been discussed in (MostafaZaman C., J. Yeong Min J. and Haas Z.J., 2010; El-Din N.D., Sourour E.A., Ghaleb I.A. and Seddik K.G., 2011).

A. Scenario1

Single femtocell without overlaid macrocell. Normally found in remote area and no interference from other cells.

B. Scenario2

Single stand-alone femtocells overlaid by macrocell. In this scenario there is no inter-femtocells interference since only the discrete femtocells are overlaid by macrocell.

C. Scenario3

Multi-femtocells overlaid by macrocell. Here receivers of microcells, macro UE, FAP and femto UE are affected.

D. Scenario4

Dense femtocells overlaid by macrocell. This type ofdeployment scenario is the worth case because itcontained many femtocells within a small area. Similarly as with scenario C, the receivers of microcells, macro UE, FAP and femto UE are also affected.

Quality of Service in Femtocell

Signal quality within femtocells network has to be guaranteed to appeal customers and ensure end-to-end network performance, some of the performance metrics for measuring quality of service as described in BoccuzziJ. and Ruggiero M. (2010) are highlighted below.

A. Delay: The delay is measured in milliseconds and indicates average duration of packet across the network. Large delay can lead to poor QoS especially for interactive services such as voice and video.

B. Packet Jitter: Too much packet jitter across the network leads to delay streaming and packet drops which could affect user experience.

C. Packet Loss: Sometime users can experience packet loss due to network congestion.

D. Sequential Packet Order: Packet arrives at destination through different routes due to network congestion and leads to packets arriving out of order.

Some mechanisms are introduced to improve performance of network and QoS such as resource reservation, Diffserv and Integrated Service.

Femto Health Issues

The fundamental concern of public and regulatory bodies for any new mobile technology is the health issues associated with the intending technology due to radio frequency radiation. The International Commissionon Non-Ionizing Radiation Protection (ICNIRP) ischarged with the responsibility of defining the maximumallowed safety limits on non-ionized radiation (NIR) andhas set a power density of 10 W/m2 as a limit forfrequency range between 2 to 300 GHz (www.ofta.gov.hk).The powerdensity of 1.3 W/m2 has been recorded by FAP for a10cm distance from direction of maximum radiation fromusers; in actuality the user is located beyond 10 cm which means that the radiation level is even lower than the 1.3W/m^2 (www.ofta.gov.hk)

Femtocells Challenges

Although femtocell deployment has started, there still exist some challenges that need addressing. These challenges as in (Zahir T., Arshad K., Nakata A, and Moessner K., 2012) include:

- **Access Modes**

Only registered mobile devices are allowed access within femtozone, the presence of unregistered mobile devices could interfere with the performance of femtocells. To overcome this challenge, a hybrid access mode is applied and carefully selected the number of allowed mobile devices.

- **Mobility Management and Handovers**

Indoor femtocell need no mobility management, but femtocells deployed in a dense manner need to have mobility management and handover capabilities in order to keep track of neighbouring femtocells and make a handover decision.

- **Self-Organization**

Since femtocells are turn off and on at random, it needs to able to support and handle self-configuration, self-optimization and self-healing.

- **Timing and Synchronization**

Timing and synchronization present another class of femtocell challenge that must be addressed to prevent packet misalignment due to clock error and inter symbol interference (ISI) due to synchronization error. Timing error could be addressed by using an accurate crystal oscillator clock, while the synch error could be mitigated by using the backhaul Asymmetric Digital Subscriber Line (ADSL).

Conclusion

Femtocell is a potentialand dominant cellular mobile technology for improving the network and capacity coverage at low price especially within the non-line-of sight (NLOS) environments such as homes and small offices as earlier mentioned. This paper has identified and discusses various technology aspects of the femtocell technology ranging from standards, network architecture to health issues. The challenge is still there for convincing consumers to go for additional expenses upon their existing commitments on mobile broadband services. The key players within the femtocells ecosystems have to ensure amongst other things, affordability, security and privacy protection of millions of anticipated customers.

References

1. Bennis M., Simsek M., Saad W and Czylwik A., (2013). When Cellular meets WiFi in Wireless Small Cell Networks. IEEE Communications Magazine 51(6):44-50.
2. Boccuzzi J. and Ruggiero M. (2010). Femtocells: Design and Application: McGraw-Hill.
3. Chandrasekhar V., Andrews J. and Gatherer A. (2008). FemtocellNetworks: A Survey. Communications Magazine, IEEE, Vol.46, Pp. 59-67.
4. Calin D, Claussen H, and Uzunalioglu H. (2010). Femto Deployment Architectures and Macrocell Offloading benefits in Joint Macro-Femto Deployments. CommunicationsMagazine, IEEE Vol. 48, Pp. 26-32.
5. El-Din N.D., Sourour E.A., Ghaleb I.A. and Seddik K.G (2011). Femtocells interference avoidance using Femtocell Identification. National Radio Science Conference(NRSC), Pp. 1-9.
6. Knisely D., Yoshizawa T. and Favichia F. (2009). Standardization of Femtocells in 3GPP," Communications Magazine, IEEE, Vol. 47, Pp. 68-75.
7. MostafaZaman C., J. Yeong Min J. and Haas Z.J. (2010). Interference Mitigation using Dynamic Frequency Re-use for Dense Femtocell Network Architectures in Ubiquitous andFuture Networks (ICUFN), 2nd InternationalConference, 2010, Pp. 256-261.

8. Nasrin W. and Xie J. (2015). A self-adaptive Handoff Decision Algorithm for densely deployed closed-group Femtocell Networks. 12th Annual IEEE International Conference on Sensing, Communication and Networking (SECON).
9. Odadzic B., Lukic N.M. and Jankovic M. (2012). The Application of Femtocells as a Technical Solution for a Telecommunication Provider - Analysis of Benefit and Utility. TEM Journal Vol. 1, No. 1, Pp. 1-8.
1. Saunders S.R., Carlaw S., Giustina S.A. and Bhat R.R (2009). Femtocells: Opportunities and Challenges for Business andTechnology. Wiley Publishers.
2. Sungoh K. and Neung-Hyung L. (2011). Virtual Extension of Cell IDs in a Femtocell Environment.WirelessCommunications and Networking Conference (WCNC), IEEE 2011, Pp. 428-433.
3. Tariq F., Dooley L. D. and Poulton A.S., (2013). Resource Constraint Impact Analysis in Closed Access Femtocell Networks. 2nd Conference on Applied Radio Systems Research and Smart Wireless Communications, 2013. Available at www.researchgate.net/publication/239492452. Accessed 16th June, 2021.
4. Ulvan A., R. Bestak R. and Ulvan M., (2010). A Study of Handover Procedure in LTE-Based Femtocell Network. Wireless andMobile Networking Conference (WMNC), Third JointIFIP, 2010, Pp. 1-6.
5. VanekT. and M. Rohlik M. (2011). Perspective Security Procedures for Femtocell Backbone. Ultra-Modern Telecommunicationsand Control Systems and Workshops (ICUMT), 3rdInternational Congress, 2011, Pp. 1-4.
6. Yusof A.L., Salihin S.S., Ya'acob N. and Ali M.T., (2013). Performance Analysis of Handover Strategy in Femtocell Network. Journal of Communications. Vol. 8, No. 11.
7. Zhang J. and Roche G. (2010). Femtocells: Technologies and Deployment. John Wiley and Son.
8. Zahir T., Arshad K., Nakata A, and Moessner K. (2012). Interference Management in Femtocells.CommunicationsSurveys and Tutorials, IEEE, Vol. 01, Pp. 1-19.
9. www.argela.com/solutions.php?cid=femtocell [Accessed: 22nd January 2023]
10. www.morganstanley.com/institutional/techresearch/pdfs/Theme_6_Data_Growth.pdf [Accessed: 1st March 2021]
11. www.ofta.gov.hk/en/report-paperguide/ report/rp20071012. pdf [Accessed: 20th March 2021]

12. www.radio-electronics.com/info/cellulartelecomms/femtocells/femto-cells-handover-andoff.php [Accessed: 22nd March 2023]
13. www.smallcellforum.org/smallcellforum/resources-whitepapers [Accessed: 2nd March 2022]