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A Review on 3GPP Femtocell Networks and its Technical Challenges

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Abstract

Background/Objective: The demand for the data traffic is exponentially increasing day to day because of the proliferation of smart phones, tablets and internet-connected devices. To meet this requirements network operators has to dramatically increase their network capacities. **Methods:** One of the possible ways to increase the system capacity is bringing the transmitter and receiver nearer to each other. It gives dual benefits higher quality and spectrum efficiency. **Findings:** The cost effective solution is installing the low power nodes instead of traditional high power macro base stations. Examples of these low power nodes are microcells, picocells, femtocells and distributed antenna systems. The network, which consists of different power nodes, architectures, and protocols is called Heterogeneous network. To overcome the indoor coverage problem and to increase the system capacity femtocells also called low power base stations are selected by the researchers as the suitable solution. In this paper we overview the femtocell deployment scenarios, access modes, and technical challenges briefly. **Improvements:** This paper gives the details about solutions available in the literature and gives future research directions to solve the technical challenges faced by femtocells.

Keywords: Femtocell, Heterogeneous Network, 3GPP, Interference Management, Smallcell

1. Introduction

With the increase in the use of electronic gadgets like smart phones, tablets and laptops, the demand for data is increasing in the today's world. To satisfy this demand we have to select higher data minded cellular technologies such as WiMAX, LTE, and LTE-A etc. or wireless technologies such as Wi-Fi[1]. But the Wi-Fi networks are operating in the unlicensed band, so security will be less and these networks are not suitable for high mobility environments; it is competitive with cellular standards in the case of home and office applications.

The demand for cellular networks are increasing at an exponential rate in the today's world. Cisco reveals 39 fold increase in the data traffic increases from 2009 to 2014[2]. To satisfy this demand and increasing spectral efficiency, we have to densify the network[3]. It can be done by deploying the smallcells such as Microcell, picocell, femtocell, Distributed Antenna Systems (DAS) and relays in the network. The comparison of macrocell, microcell, picocell and femtocell are given in the Table 1. The network which consists of different nodes with different power levels, access modes and protocols is called as a heterogeneous network[4]. Heterogeneous network are expected to be one of the major performance enhancement enablers of LTE-Advanced and WiMAX[5,6]. With the use higher data rate cellular standards the operating frequency range also increasing, simultaneously propagation losses also increases. This lead to the poor indoor coverage. ABI research report describes more than 50% of the voice and more than 70% of the data traffic is expected to be originating from indoor users. Out of which 30% of business and 45% of household users are suffering with poor indoor coverage problem[7]. By installing the low power nodes or Femtocell Access Points (FAPs), the Quality of Service (QoS) of the indoor users can be increased.

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FAPs also known as Home base stations or plug-and-play devices. Informa Telecoms and Media report gives that 98 percent of the mobile operators are interested in installing the small cells[8].

The definition of a femtocell can be given as, it is a low-power base station working in a licensed spectrum, giving improved indoor coverage with greater performance; functioning with the operator's approval; providing improved voice and data services in a low-cost[10]. These are installed by the customers to improve their indoor voice and data coverage. The backhaul for the FAPs is provided though optical fiber, cable modem, Digital Subscriber Line (DSL) or a separate RF channel. Since, operator give a certain level of QoS guarantee to the associated user, who are involved in occupying the private band[10]. The connection from the user equipment to the mobile core network though FAP is as shown in Figure 1. A normal indoor femtocell is shown in Figure 2. FAPs are like as Wi-Fi routers, customer has to purchase and install in the indoor area to provide improved coverage. According to ARC chart, it is estimating that by 2017, 5 million small cells will be deployed annually[8].

Femtocells usage will give benefits for both users and operators. Operator gets benefits from large network capacity and spectral efficiency. The traffic load on the traditional macrocell network will decrease which is to be used to provide good QoS for high mobility users. In addition to that capital expenditure (CAPEX), operational expenditure (OPEX) on the macrocell also will reduce[8]. Users will benefit from higher data rates, QoS due to the smaller distance between the transmitter and receiver, SINR will increase, which results in larger reliabilities and throughputs. Furthermore, this leads to so called five-bar coverage which increases battery life, reduced electromagnetic interference, energy consumption and system capacity. This leads step towards the green communication.

The expenditure on the macrocell is more because of the capital expenses and operating expenses, mainly when the subscriber growth is not matching with the demand of data traffic[9]. The assumption that here we considered is the wired backhaul provides sufficient QoS, otherwise it reduces the indoor capacity gains provided by the femtocells[10].

In these paper different aspects of femtocell such as access modes, standardizations, deployment scenarios, technical aspects, air interface technologies, technical challenges, some of the solutions and future research directions are discussed. The paper is organized as follows: Section 2 focuses on the history, standardizations of femtocells and deployment scenarios. Section 3 discusses about technical challenges and its possible solutions and Section 4 gives the future research directions and conclusion.

2. Standardizations and Deployment Scenarios

2.1 A Brief History

The 'Home base station' concept was first introduced by Bell Labs in 1999. Motorola first launched the home base station product based on 3G technology in 2002. Until 2005, there is no much acceptance for this home base station concept. The term femtocell was first coined in 2006. In 2007, in the 3GSM world congress, number of operators and companies demonstrated the femtocell

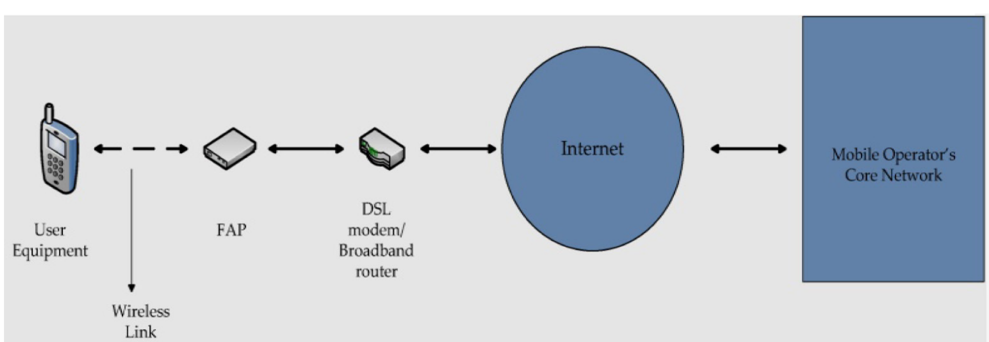

Figure 1. Connecting UE to mobile core network through FAP.

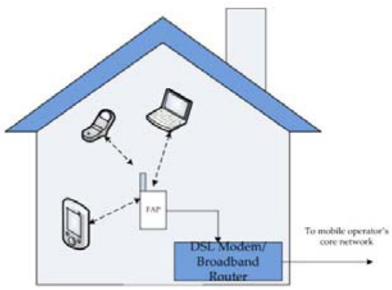

Figure 2. A Normal Indoor Femtocell.

concept and about their trails. To promote femtocells a Femtoforum[11] is started in 2007 for standardization and deployment across the world. By the end of 2008, nearly 100 telecom hardware and software companies and operators are became members in the forum. In LTE, along with macrocells, indoor femtocells have been considered in each level of deployment and architecture. Femtoells can also be deployed in outdoors to satisfy enterprise applications[2].

Based on the number of users connected to the FAP, it can be classified as either Home FAP, having a capacity of 3-5 users and enterprise FAP, having a capacity of 8-16 users[12].

2.2 Standardizations

The physical layer technology used by femtocells is same as that of the cellular networks. According to 3GPP release 8, femtoells are standardized and is been known as Home Node B (HNB) in WCDMA, and Home e Node B (HeNB) in LTE based systems[13]. The documents like IMS, service requirements, mobility procedures, radio frequency requirements, architectural aspects, Self Organizing Networks (SON) issues, Operation, Administration, Maintenance and Provisioning (OAM&P) for HeNB are described[13]. In 3GPP release 8 femtocells are operated in only closed access mode, called Closed Subscriber Group (CSG). In release 9 along with CSG, open access and hybrid access mode controls are enhanced. More details about these access modes are explained in the fore coming sections.

In spite of having lot of advantages like reduction in CAPEX and OPEX, operator has to incur strategic investments. To cope up all this technical and business issues, a Femto-forum has been formed in 2007 along with operators, vendors. The main motive of this forum is to develop the open standards for product interoperability. Later in 2009, the femto forum is changed into smallcell forum[11].

2.3 Deployment Scenarios

There are different types of deployment scenarios based on different parameters.

- Depending upon Access mode:

Femtocell supports only a limited number of users; it maintains the list of users registered to that particular femtocell. Based on the type of access, three access modes are defined in the literature; those are closed access, open access and hybrid access.

Open Access mode: Any user in the coverage area of a femtocell can access the femtocell and get benefits from it.

Closed Access mode: Registered users only can get the access to connect and get the benefits from the femtocell. The owner will decide which UEs can get this benefits; 3GPP describes it as CSG (Closed subscriber group).

Hybrid Access mode: In this access mode along with registered users, limited number of outside users also can access the femtocell services. The terms and policies to access these services is operator dependent and the new user has to request the owner to get the access.

According to survey home users prefers closed access mode, because of the limited access for the registered users dead zone will form, the macrocell users near to the femtocell will be in outage area. Open access mode is preferred in the enterprise applications like airports, shopping malls, stadiums, etc. Access mode plays a major role in the interference analysis of the system. Therefore, much care is needed while selecting the access mode. One of the possible solutions is to use of hybrid access mode. In this mode some macro users can be able to access the femtocell services. The access is decided by the service provider and owner.

- Depending on the channel assignment:

There are two types of channel assignment strategies discussed in the literature.

Dedicated channel assignment: Assigning a different set of frequencies to macrocell and femtocell users.

Co-channel assignment: Assigning a same set of frequencies to the macrocell and femtocell users.

Because of the cost and scarcity of the spectrum operators are interested in co-channel assignment compared to dedicated channel assignment. Because of the using same set of frequencies between macro and femtocell users interference will occur. This interference may be co-tier

Table 1. Comparison of Smallcells with Macrocell

LICENSED SMALL CELLS				
	Femto	**Pico**	**Micro**	**Macro**
Indoor/Outdoor	Indoor	Indoor/Outdoor	Outdoor	Outdoor
No. of users	4 -16	32 - 100	200	200 - 1000+
Max. Output power	20-100mW	250 mW	2 to 10W	40 – 100 W
Max. Cell radius	10-50 m	200 m	2 km	10 – 40 km
Bandwidth	10 MHz	20 MHz	20,40 MHz	60 -75 MHz
Backhaul	DSL, Cable, fiber	Microwave	Microwave, fiber	Microwave, fiber

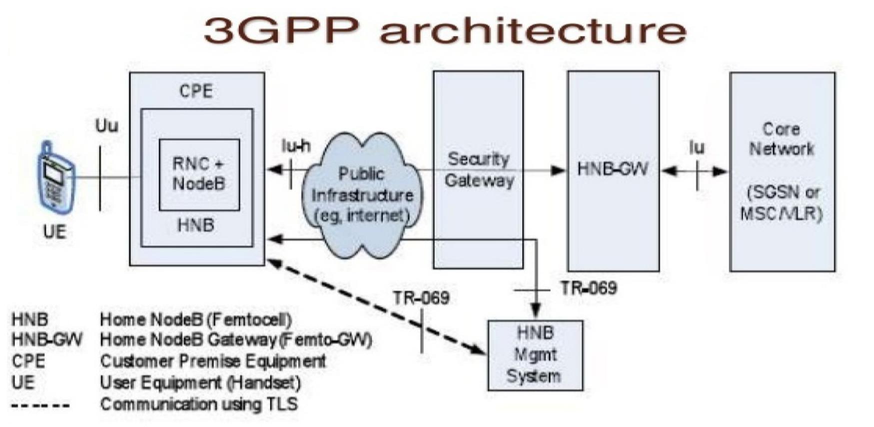

Figure 3. 3GPP Femtocell Architecture.

(Femto-Femto) interference, or cross-tier (Macro-Femto) interference. In a dedicated channel assignment, cross-tier interference doesn't come, only co-tier interference exists[14].

- Depending upon the transmitted power

It may be either fixed or Adaptive downlink power. In the case of adaptive downlink power the transmit power of the femtocell may be varied depends on the interference levels, etc. In the case of fixed power the femtocell transmits power is fixed, because of the advantages adaptive power is preferred in the literature[15].

- Depending upon the air interface technology

It may be either CDMA based or OFDMA based femtocells i.e either 3G or 4G femtocells. Different interference management techniques are addressed in the literature for both the techniques. Because of the orthogonality between the sub carriers in OFDMA we can eliminate the interference partially, by assigning orthogonal sub carriers to both macro and femtocells. OFDMA has advantages compared to CDMA, so 4G femtocells are more preferred by the operators[16]. The 3GPP femtocell architecture is shown in Figure 3. Femto user equipment (UE) is connected to core network through a FAP and security gateway and home node gateway (HNB-GW)[13]. All the FAP are connected to HNB-GW. Different interfaces used between these devices are also given in the architecture.

3. Technical Challenges

There are many challenges that are being encountered in femtocell networks. Although the femtocells are being randomly deployed, the challenges faced by these networks are more significant, particularly when the deployment of femtocells becomes denser in an urban environment.

3.1 Mobility Management and Handover

In general indoor users make use of femtocells, so there is no specific mobility management is required. However, it is mandatory to have mobility management and handover procedures with the dense deployment of femtocells[17]. In the case of dense deployment, this is one of the main challenges, it would not be possible for a femto to keep track of its neighbors for handover. It is difficult to keep track of all the neighboring femtocells due to the fact that the neighbors of femtocell are varied on an ad hoc basis. It is very difficult to maintain handover with the finite radio resources. In the literature[17], a mobility management scheme is proposed. The access mode being used determines the handover in femtocells. In femtocell, handovers are higher in open access mode and are lesser in case of closed and hybrid access modes[17]. Mobility management is done by maintaining a neighboring cell list at each femtocell, it should be updated whenever handoff is performed.

3.2 Access Modes

A closed access femtocell has a fixed limited number of subscribers for privacy and security, whereas the open access femtocell provides service to the macrocell users if they pass nearby. Interference and handover are due to the access modes. Open access mode reduces the cross-tier interference, but results in the hike of handoffs. The Open access mode is suitable for business and enterprise applications. In the closed access mode because of the restricted access, dead zones are formed. So cross-tier interference is more and the number of handoffs should be less. CSG is preferred by the home subscribers. For these reasons operators are looking at hybrid models[10].

3.3 Timing and Synchronization

Timing and synchronization is very important in wireless systems. Normally crystal oscillator is used as the internal clock. The internal clock plays a role in maintaining synchronization and specific frequency alignment between the transmitter and receiver. In OFDM systems, Inter Symbol Interference (ISI) is caused by the error in synchronization and timing. The design of these good quality oscillators in FAP increases the femtocell cost.

Security breaches, network usage monitoring, event mapping, session establishment and termination are being tracked with the help of timing and synchronization. As the network becomes denser, the number of femtocells and the location of each femtocell cannot be determined. Moreover, the service provider does not have full control over the location and placement of femtocells. Time Synchronization cannot be attained in such cases[18].

Synchronization of femtocells can be attained by the use of backhaul DSL. However, there can be undetermined delays on the internet connection due to the unpredictable traffic. With a potential timing accuracy of 100 ns, the IEEE 1588 precision timing protocol over IP, and adaptive timing recovery protocols (e.g. The G.8261 standards) are promising[18]. Another option is equipping femtocell with GPS for synchronization. However, maintenance of stable satellite indoor connection is also difficult. The neighboring femtocells can aid a femtocell in order to synchronize with the remaining part of the network.

3.4 Self Organisation

Femtocells are plug-and-play stations, installed by the customers. It can be turned on and off at any time, hence it is randomly deployed. In a macrocell, the number and location of each femtocells can be varied continuously. This makes the classic network planning and designing very difficult to implement. The femtocell needs to be intelligent enough to independently integrate in a radio access network[19]. This self organizing capability of femtocell increases the capacity, better QoS and reduced interference. The self organization mainly comprises of self configuration, self optimization and self healing.

- Self configuration: The addition or removal of network features and addition of new cell sites creates self configuration in wireless networks occurs. In the case of femtocell, it needs to configure itself whenever location is changed, rebooted, switch on or off. Prior to operation and optimization, the femtocell needs to configure many parameters like neighbor list and pilot power.
- Self Optimization: In this section femtocell needs to check all the network parameters such as access modes, transmit power, physical resources, admission control, the handover control etc., are tuned to an acceptable threshold. This phase progress continuously which keeps on updating the parameters for an optimized performance of the femtocell network.

- Self Healing: At any incident, this phase used to resolve the problem occurred. When the problem causing the failure is detected and resolved, it should get back to normal settings.

In the case of dense deployments of femtocells, efficient self organizing capabilities are required. So many techniques are addressed in the literature. Research is still needed to improve these capabilities.

3.5 Security

Enabling security to the femtocell networks is one of the major key challenges. Security of femtocell networks depends on the access mode also. In the case of open access mode, users belongs to outer region also can access the femtocell, protection of users private information is of much importance. The femtocell network is subjected to many security hazards. For example, the private information of subscriber which transmits over the backhaul through internet connection. These data can be hacked by others, which would crack privacy and confidentiality[20].

Femtocells are also disposed to Denial of Service (DoS) attacks. A third person or hacker can overload the link between FAP and mobile core network. In such cases femtocell user cannot get the services[21]. Security is also required to prevent unwanted users to access the network and resources. Mainly IP security is used to provide security between the FAP and operator's core network. So in 3GPP architecture they use a security tunnel between the FAP and core network. It is connected to a security Gateway. With increase in femtocell deployment the security problem would become more severe and therefore it is important to do extensive research in this area.

3.6 Interference Management

One of the most technical challenge facing by the femtocell network is the Interference management. Spectrum is limited and costliest one, so the operators are not interested to allocate separate frequencies for femtocell networks. So they are preferring co-channel deployment, femtocell share the same frequencies which are using by the traditional macrocell network[22]. Because of the dense deployment of smallcells, it causes severe interference in the network. So the conventional one-tier architecture consisting of only macrocells is changed into two-tier architecture[23] consist of macrocells in one tier and femtocells in the other tier.

Because of this two-tier network mainly there are two types of interferences occur:

1. Cross-tier interference
2. Co-tier interference

Cross-tier interference[24] will occur between the different layers, i.e. in between the femto and macro layers.

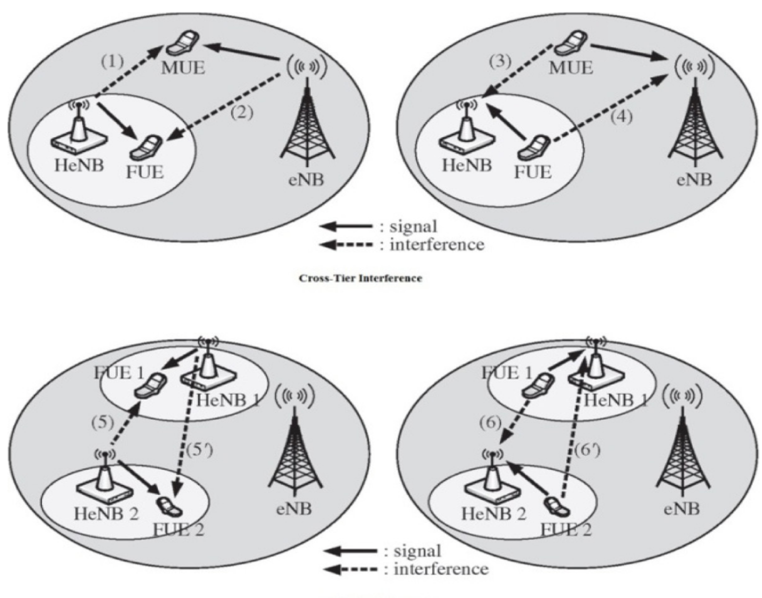

Figure 4. Different Possible Interference Scenarios.

Table 1. Summary of different interference scenarios.

Index	Aggressor	Victim	Interference type	Transmission Mode	Symbol
1	Macrocell CE	Femtocell BS	Cross-tier	Uplink	3
2	Macrocell BS	Femtocell UE	Cross-tier	Downlink	2
3	Femtocell UE	Macrocell BS	Cross-tier	Uplink	4
4	Femtocell BS	Macrocell CE	Cross-tier	Downlink	1
5	Femtocell UE	Femtocell BS	Co-tier	Uplink	6
6	Femtocell BS	Femtocell UE	Co-tier	Downlink	5

Further, it can be either down link interference or uplink interference. Co-tier interference occurs within the layer, i.e. in between the femto and femto. This can also be either uplink or downlink. There are six different possibilities to occur interference between these layers, as shown in the Figure 4. And their description is given in the Table 2. Because of higher frequencies, penetration losses are more, so the effect of co-tier interference is less compared to cross-tier interference.

Interference management techniques are mainly categorized into three types.

- Interference Cancellation
- Interference Avoidance
- Distributed Interference Management

Interference cancellation is the technique in which interference is removed after receiving the signal by using threshold level[25]. The basic techniques available in the literature for interference cancellation are Successive Interference Cancellation (SIC), Parallel Interference Cancellation (PIC) etc[26]. For implementing cancellation techniques, antenna arrays are required. So, it is difficult to implement these techniques in the user equipment. These techniques are suitable for base stations[27]. So these techniques are used in uplink interference management.

Interference avoidance techniques are either based on CDMA or OFDMA. In OFDMA based techniques by assigning orthogonal channels between the Femto User Equipment (FUE) and Macro User Equipment (MUE), we can avoid the interference. Because of the advantages of the OFDMA most of the researchers are interested in implementing LTE femtocells[28,29]. Because of the easy implementation interference avoidance algorithms are of more important in interference management, extensive work is needed in this area. Power control techniques has a greater importance in the interference avoidance; different power control techniques are discussed in[22], distributed power control with active link protection is implemented in[30] to reduce the interference. Energy efficient power control[31] is proposed to increase the energy efficiency and reduce the interference. Centralized power control with clustering of femtocells and their predicted SINR of the users are proposed in[32] to reduce the interference between the macro and femto base stations.

Power control techniques are used to improve the user experience and reducing the outage probability. Even though power control is implemented, the interference generated by the FAP still be large, which degrading the performance, throughput and create outage or dead zones to the macro UEs. By properly assigning the available resources between the femtocell and macrocell in frequency domain we can reduce the interference. Inter cell interference coordination (ICIC) techniques plays a major role in LTE Rel-10 to reduce interference among the Co-channel cells. Time domain resource partitioning with power control techniques plays major role to reduce the interference[27]. Still adaptive techniques are required to reuse the channels[33].

Cognitive radio is used as a one of the prominent approaches to mitigate the interference[34]. The femtocell which is having Cognitive Radio (CR) capabilities is called cognitive femtocell. Cognitive radio has the capability of sensing the spectrum and identify the available frequencies and access it opportunistically. In case of Cognitive femtocell, we consider the Primary User (PU) as Macrocell User and the femtocell user as a Secondary User (SU). Cognitive femtocell senses the spectrum holes with the help of spectrum sensing technique, and allocates it to the SU; whenever PU returns back it will retain the resources and searches for another white space. Sensing period and accuracy are the major important parameters. Different spectrum sensing techniques is addressed in the literature[35]. More work is needed to maintain fairness and reduce sensing errors. Interference alignment is proposed in uplink interference management for co-existing

MIMO femtocells and macrocells networks[36]. The analysis of energy and spectral efficiencies for the uplink of smallcells locating at the cell edge of a heterogeneous network are described in[37]. To improve spectral and energy efficiency of heterogeneous networks novel algorithms are needed.

Because of the random deployment and ad hoc nature of femtocell, centralized controlling becomes complex issue, so distributed techniques are needed to give intelligence to FAP and to avoid the interference. Self-organization is needed to give intelligence to FAP, to configure themselves in the network and to cope up with the interference issues. Distributed interference avoidance techniques play a major role.

4. Conclusion and Future Directions

The need for high speed data cellular networks and the higher path losses in the advanced technologies, femtocell concept becomes more popular in the next generation networks. Femtocells reduces the load on the traditional macrocell networks and providing good indoor coverage at a lower cost. The coverage of femtocell is limited, it is installed by the customer in a random manner, because of this several business and technical challenges will comes into picture. This paper focuses on the basics of the femtocell technology, standardizations technical aspects, business aspects, technical challenges involved in the network and their solutions discussed in the literature. If these issues are addressed with advanced novel techniques, femtocells give the improved coverage, spectral efficiency, energy efficiencies, higher QoS, and larger capacities.

Because of the dense deployment of femtocells in the future there will be a need of still advanced interference management, resource allocation; mobility management techniques and security techniques are needed. Cognitive radio, graph theory, game theory based approaches are more suitable for future femtocell networks. MIMO is one of the most research areas by suing femtocells. To implement femtocells in realistic scenarios novel algorithms are still needed to cope up all the issues.

5. References

1. Chandrasekhar V, Andrews J. Femtocell networks: A survey. IEEE Communication Magzine. 2008 Sep; 46(9):59-67.
2. Reardon M. Cisco predicts wireless data explosion. Press release, online available. 2010 Feb 9.
3. sson, Mobile data traffic surpasses voice. 2010 March; Available from: www.ericsson.com/thecompany/press/releases/2010/03/1396928.
4. Ghosh A, Mangalvedhe N, Ratsuk R, Mondal B, Cudak M, Visostsky E, Timothy A, Jeffrey GT, Andrews, Xia P, Jo HS, Dhilon HS. Heterogenous Cellular Networks: From Theory to Practice. IEEE Communication Magazine. 2012 June; 50(6):54-64.
5. Aleksander D, Juan M, Wei Y, Ji T, Luo T, Madhavan V, Yoo T, Osok S, Durga M. A Survey on 3GPP Heterogeneous Networks. IEEE Wireless Communication. 2011 June; 18(3):10-21.
6. Perez DL, Valcarce A, G Roche G, Liu E, Zhang J. Access methods to WiMAX femtocells: A downlink system-level case study. Proceedings of 11th IEEE International Conference on Communication Systems, Singapore. 2008 Nov 19-21; 1657-62.
7. Shetty N, Parekh S, Walrand J. Economics of femtocells. Honolulu: Proceedings of IEEE Global Telecommunications Conference. 2009 Nov 30; p. 1-6.
8. Analysis, Picocells and Femtocells: Will Indoor Base Stations Transform the Telecoms Industry? 2007. Available from: http://research.analysis.com,.
9. Presentations by ABI Research, Picochip, Airvana, IP.access, Gartner, Telefonica Espana. 2nd International Conference Home Access Points and Femtocells. Available from: http://www.Avrenevants.com/dallas-femto2007/purchase_presentations.html.
10. Boccuzzi J, Ruggiero M. Femtocells: Design & Application, ISBN: 978-0-07-163359-8, McGraw Hill publications, 2011.
11. Small Cell Forum, Small cells - what's the big idea? 2012 Feb. Online Availability: www.smallcellforum.org/Files/File/SCF_Small_Cells_White_Paper.pdf.
12. Zhang J, Roche GDL. John Wiley and Sons, Ltd., Publication: Femtocells: Technologies and Deployment. 2010.
13. From Macro to Small Cells. 2013 June. Available from: http://www.3gpp.org/news-events/conferences/1506.
14. Zhang H, Chu X, Wen X. Springer: 4G Femtocells: Resource Allocation and Interference Management. 2013; ISBN 978-1-4614-9079-1.
15. Chandrasekhar V, Andrews JG, Muharemovic T, Shen Z, Gatherer A. Power control in two-tier femtocell networks. IEEE Transactions on Wireless Communication. 2009 Aug 8; (8):4316-28.
16. Ip.access collaborates on next generation radio access. 2016 Feb. Available from: http://www.ipaccess.com/eng/news/press-latest.php.
17. Wang L, Yongsheng Z, Zhenrong W. Mobility management schemes at radio network layer for LTE femtocells.

Proceedings of IEEE 69th Vehicular Technology Conference, VTC Spring. 2009 April 26-29; p. 1-5.

18. Hwang I, Kang Y, Kim H, Kim S. Synchronization issue for mobile WiMAX femtocell. Jeju: Proceedings of International Conference on Information and Communication Technology Convergence. 2010 Nov 17-19; 65:563-64.
19. Young JS, Hae GH, K Wang KS. A self organized femtocell for IEEE 802.16e system. Honolulu: Proceedings of IEEE Global Telecommunications Conference. 2009 Nov 30; p. 1-5.
20. Chan H, Kee CH, Hwan I. Building femtocell more secure with improved proxy signature. Honolulu: Proceedings of IEEE Global Telecommunications Conference. 2009 Nov 30; p. 1-6.
21. Marc V, Manikandan, Sriram VSS. Securing the Femtocells: Anonymity and Location Privacy. Indian Journal of Science and Technology. 2014; 7(S4):46-51.
22. Saad SA, Ismail M Nordin R. A Survey on Power Control Techniques in Femtocell Networks. Journal of Communications. 2013 December; 8(12):845-54.
23. Ahmed AU, Islam MT, Ismail M. New York: Springer Science Business Media: A Review on Femtocell and its Diverse Interference Mitigation Techniques in Heterogeneous Network. 2014.
24. Motea Al, Rahman AR, Sail A, Raja SA. A Femtocell Cross-Tier Interference Mitigation Technique in OFDMA-LTE System: A Cuckoo Search based Approach. Indian Journal of Science and Technology. 2016 January; 9(2).
25. Andrews JG. Interference cancellation for cellular systems: A contemporary overview, IEEE Wireless Communication. 2005 April; 2(3):19-29.
26. Trichard LGF, Evans JS, Collings IB. Large system analysis of linear parallel interference cancellation. Helsinki: Proceedings of IEEE International Conference on Communications. 2001 Jun 11-14; 1:26-30.
27. Karlsson RS. Radio resource sharing and capacity of some multiple access methods in hierarchical cell structures. Proceedings of Vehicular Technology Conference, Amsterdam, 1999 Sep.; 5, 2825–29.
28. Perez D L, Valcarce A, Roche G D L, Zhang J. OFDMA Femtocells: A Roadmap on Interference Avoidance. IEEE Communications Magazine, 2009 Sept; 47(9), 41-48.
29. Valizadeh SR, Abouei J. An adaptive distributed coverage optimization scheme in LTE enterprise femtocells. Iran: IEEE, 22nd Iranian Conference on Electrical Engineering (ICEE). 2014; p. 1723-8.
30. Sreevardhan Ch, Venkata Ratnam D, Sivaganga Prasad M , Vyshanvi B, Sai Nitin A. Implementation of Distributed Power Control/Active Link Protection for Femto Cell Networks. Indian Journal of Science and Technology. 2016 January; 8(34):1-5.
31. Mao T, Feng G, Liang L, Qin S and Wu B. Distributed Energy-Efficient Power Control for Macro–Femto Networks. IEEE Transactions on Vehicular Technology. 2016 Feb; 65(2):718-31.
32. Lotfollahzadeh T, Kabiri S, Kalbkhani H and Shayesteh MG. Femtocell base station clustering and logistic smooth transition autoregressive-based predicted signal-to-interference-plus-noise ratio for performance improvement of two-tier macro/femtocell networks. IET Signal Processing. 2016 Jan; 10(1):1-11.
33. Huang G, Li J. Interference Mitigation for Femtocell Networks via Adaptive Frequency Reuse. IEEE Transactions on Vehicular Technology. 2015 April; (99):1.
34. Haykin S. Cognitive Radio: Brain-Empowered Wireless Communications. IEEE Journal on Selected Areas in Communications. 2005 February; 23(2):201-20.
35. Harold O, Ghazanfar AK, Safdar. Interference Mitigation in Cognitive Radio based Femtocells. IEEE Communications Surveys & Tutorials. 2014 Oct; 17(3):1511-34.
36. Basak G, Aylin Y. Uplink Interference Management for Coexisting MIMO Femtocell and Macrocell Networks: An Interference Alignment Approach. IEEE Transactions on Wireless Communication. 2014 April; 2246-57.
37. Shakir MZ, Hina T, Khalid AQ, Serpedin E, Alouni MS. Spectral and energy efficiency analysis of uplink heterogeneous networks with small cells on edge. Elseiver Physical Communications. 2014 May; 13:27-41.