

Enhancement of Geometry and Throughput in LTE Femtocells Cognitive Radio Networks

Mohamed Shalaby · Mona Shokair · Yaser S. E. Abdo

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Abstract The mutual electromagnetic interference among macro users and femto users is a challenge, when femtocells are deployed in LTE and LTE advanced systems. When the used femtocells have a closed access, the macro users, who are indoors or near to the femtocells, are prone to a severe interference from the femto access points especially, in the case of the universal frequency reuse deployment. A power control is an effective way to improve the macro users' geometry at the expense of a drop in the femto users' geometry and capacity. The concept of a cognitive radio is proposed, as a novel approach, to mitigate the interference and improve the macro and femto users' geometry. The system is designed, mathematically analyzed, and simulated considering that the femto users are secondary users for the macro users. The macro users and the femto users' throughputs of the proposed system are estimated. Comparisons among the universal frequency reuse, the power control, and the suggested approach are held. The simulation results validate the efficiency of the proposed system. The average of femto users' throughput in the proposed system is better than the corresponding one employing the universal frequency reuse or the power control, even if only 20% of the subcarriers are available to be accessed by the femto users. Moreover, the macro users' throughput in the proposed system is better than the corresponding one applying the universal frequency reuse or the power control, even if only 40% of the subcarriers are available to be accessed by the macro users.

Keywords LTE · LTE Advanced · Femtocells · Universal frequency reuse · Power control · Cognitive radio

M. Shalaby · Y. S. E. Abdo
National Institute for Standards, Tersa Street, Haram, Gizah, Egypt
e-mail: Mhmd_Shlp@yaho.com

Y. S. E. Abdo
e-mail: yaserabdo76@gmail.com

M. Shokair (✉)
Faculty of Electronic Engineering, Menoufia University, Menouf, Egypt
e-mail: shokair_1999@hotmail.com

1 Introduction

In the age of information revolution, the multimedia communication becomes a requirement. There is a need to transmit and receive large data files in short time periods. To overcome the challenges of data communication, the 3GPP developed the LTE and the LTE Advanced systems. The LTE and LTE Advanced systems can be considered as the beginning of the fourth generation mobile system. They can provide a high data rate in the uplink and downlink. Therefore, they can achieve a multimedia communication between a transmitter and a receiver. Moreover, they can fit in a lot of applications such as; video conferencing, wireless data networks, last mile data delivery, andetc [1,2].

LTE and LTE Advanced Systems may have dead zones. These zones represent a weak point in the performance of the LTE and the LTE Advanced system. These zones include indoor zones, zones in tunnels, zones in the underground, zones at the edges of the cell, and any not properly covered zones inside the mobile cells. There is a challenge to cover these zones properly and provide wireless network connectivity with the users, who are inside these zones. Therefore, these zones are called dead zones. There are a lot of solutions, which can be used to connect these zones with the LTE system [3]. It was noticed that, the deployment of the femtocells is the best solution to cover these dead zones [3].

Femtocells (HeNBs) are mobile cells, which can cover a small range. Their base stations can emit low power. Femtocell is the smallest size cell up till now. These base stations can be used to extend the LTE network coverage to include indoors and any dead zone within the coverage area [3]. Since the femtocells become an important technology, it was supported by the standards of 3GPP1 and 3GPP2 [4,5].

When the LTE or the advanced LTE systems are used to support a multimedia mobile communication system, their base stations can cover a large range. The mobile cell, which has a large range, is called a macrocell. On the other hand, femtocells, which can cover a small range, can be deployed in indoors and dead zones to provide connectivity to the users, who are trapped in these dead zones.

Femto users, who are served from the femtocells, usually share the spectrum with the existing macrocells. In other words, each femtocell operates at the spectrum bands, which are accessed by a macrocell. This type of spectrum assignment is called a co-channel deployment or a universal frequency reuse. Operating at the same spectrum bands results in a mutual electromagnetic interference among the macro cells and the existing femtocells. For more clarification, a femto user can be interfered from any existing macro cell inside the mobile system. By the same way, a macro user can be interfered from any existing femtocell inside the mobile system. This interference has the ability to reduce the macro and femto users' geometry, signal to interference and noise ratio (SINR), and throughput.

In Ref [6–8], the power control algorithms were proposed to reduce this mutual electromagnetic interference. The idea of power control is the reduction of the HeNBs transmission power. It is an effective way to improve the macro users' geometry and throughput. Unfortunately, the reduction of HeNBs transmission power results in a degradation of the femto users' geometry and throughput.

In this paper, a cognitive radio is proposed to improve the geometry of the macro users and the femto users. The cognitive radio concept is not new but introducing it as an interference mitigation tool among the macrocells and femtocells in a LTE Femtocells system is a novel approach, which is not clarified until now. Cognitive radio was proposed to increase the spectrum utilization of a fixed policy wireless network [9,10]. The cognitive radio network consists of two subsystems. The first subsystem is the primary subsystem, which contains the primary base station and the primary users. The second subsystem is the secondary

subsystem, which contains the secondary base station and the secondary users. Femto users are considered as secondary users for the macro users (primary). The spectrum subcarriers are available to be accessed by the macro users at any time. On the other hand, the femto users have to investigate about the free subcarriers in order to operate at them. Moreover, the macro users have the priority to occupy more subcarriers. In this case, the femto users have to vacate subcarriers in order to be available to the macro users in order to satisfy their requirements. Femto users have to sense the wide band spectrum around 2 GHz and allocate the free subcarriers. Moreover, they have to cooperate with each other to determine these free subcarriers. As soon as the information about the free subcarriers reach a spectrum server by each femto user, it can manage (reuse) them among the femtocells. Therefore, the interference between the macro users and the femto users can be completely avoided. The interference becomes limited to the interference among the macro users themselves or the femto users themselves, and hence the geometry of the macro users and the femto users is greatly improved. The throughput of the femto users is proportional to the available subcarriers for them. Therefore, it is a function of the free subcarriers, which are not occupied by any macro user.

The LTE and Advanced LTE Cognitive Femtocells system is designed and the mathematical derivations are carried out through this paper. In Sect. 2, the mathematical model that describes the LTE system, which has femtocells, is stated. A discussion of the power control algorithms is held in Sect. 3, while in Sect. 4, the proposed cognitive radio approach is illustrated. Finally, the system simulation model and the analysis of the simulation results are handled in Sect. 5.

2 Mathematical Analysis of LTE Femtocells

The performance of the system is evaluated by estimating the geometry (SINR) of the macro users and the femto users, and their throughput [11]. This analysis goes through three steps; a path loss models calculation, a SINR estimation, and a throughput evaluation.

2.1 Path Loss Models

Path loss maps are used to express the attenuation of power, when the signals travel from a base station to a user equipment. These models are provided by 3GPP standard release [1]. In fact, the path loss value (PL) is a function of the distance between the user equipment and the base station. Moreover, it depends on the position of the user equipment. The user may be outdoor, or indoor. Assuming urban deployment, these maps can be formed as;

- *Macro base station (BS) to user equipment (UE)*
 - UE is outside: Both BS and UE are outdoors.

$$PL(dB) = 15.3 + 37.6 \log_{10} R \tag{1}$$

where R is the distance between the BS and UE expressed in meters.

- UE is inside an apartment: The UE is indoor but, the BS is outdoor.

$$PL(dB) = 15.3 + 37.6 \log_{10} R + W \tag{2}$$

where W is the wall attenuation loss.

• *HeNB to UE*

- UE is inside the same apartment with the HeNB.

$$PL(dB) = 38.46 + 20 \log_{10} R + W \tag{3}$$

- UE is outside the apartment.

$$PL(dB) = \max ([15.3 + 37.6 \log_{10} R], [38.46 + 20 \log_{10} R]) + W \tag{4}$$

- UE is inside a different apartment.

$$PL(dB) = \max ([15.3 + 37.6 \log_{10} R], [38.46 + 20 \log_{10} R]) + W \tag{5}$$

To estimate W , the following models can be used;

- UE is inside the same apartment with the HeNB.

$$W = q^* L_{iw} + 18.3n \left(\frac{n+2}{n+1} - 0.46 \right) + .7d_{2D,indoor} \tag{6}$$

- UE is outside the apartment.

$$W = q^* L_{iw} + L_{ow} + 18.3n \left(\frac{n+2}{n+1} - 0.46 \right) + .7d_{2D,indoor} \tag{7}$$

- UE is inside a different apartment.

$$W = q^* L_{iw} + L_{ow1} + L_{ow2} + 18.3n \left(\frac{n+2}{n+1} - 0.46 \right) + .7d_{2D,indoor} \tag{8}$$

where q is the number of walls separating between the UE and HeNB, n is the number of penetrated floors, R and $d_{2D,indoor}$ (indoor distance) are in meters, L_{ow} is the penetration loss of the outer walls, and L_{iw} is the penetration loss of the inner walls.

2.2 SINR Estimation

The macro user can be interfered by the neighboring macrocells and all adjacent femtocells. In this case, the *SINR* of the received signal of a macro user m , which is loaded on a subcarrier k , is given by [11];

$$SINR_{m,k} = \frac{P_{M,k} G_{m,M,k}}{N_o \Delta f + \sum_{M'} P_{M',k} G_{m,M',k} + \sum_F P_{F,k} G_{m,F,k}} \tag{9}$$

where $P_{M,k}$ and $P_{M',k}$ are the transmitted power of the serving macrocell M and the neighboring macrocell M' on a subcarrier k , respectively. $G_{m,M,k}$ is the absolute channel gain between the macro user m and the serving macrocell M on a subcarrier k . The absolute channel gain from the neighboring macrocell M' is denoted by $G_{m,M',k}$. $P_{F,k}$ is the transmitted power of the neighboring femtocell F on a subcarrier k , and $G_{m,F,k}$ is the absolute channel gain between the macro user m and the neighboring femtocell F on a subcarrier k . N_o is the additive noise power spectral density, and Δf is the subcarriers spacing.

The same analysis is used for the HeNBs, the *SINR* can be expressed as;

$$SINR_{f,k} = \frac{P_{F,k} G_{f,F,k}}{N_o \Delta f + \sum_M P_{M,k} G_{f,M,k} + \sum_{F'} P_{F',k} G_{f,F',k}} \tag{10}$$

The absolute channel gain can be expressed as a function of the path loss (dB);

$$G = 10^{-PL/10} \tag{11}$$

2.3 Throughput Evaluation

The throughput of a macro user m on a subcarrier k , $C_{m,k}$, can be evaluated by [11];

$$C_{m,k} = \Delta f \cdot \log_2 (1 + \alpha \cdot SINR_{m,k}) \tag{12}$$

where α is a constant factor, which depends on the target bit error rate (BER); $\alpha = -1.5 / \ln(5 \cdot BER)$. Finally, the overall throughput of the serving macrocell M can be estimated by [11];

$$T_M = \sum_m \sum_k \beta_{m,k} C_{m,k} \tag{13}$$

where $\beta_{m,k}$ is the subcarrier assignment for a macro user. When $\beta_{m,k} = 1$ means that the subcarrier k is assigned to a macro user m . Otherwise, it becomes zero. In a macro cell, each subcarrier is allocated to only one macro user at any time slot. From the characteristics of OFDMA, it can be observed that;

$$\sum_{m=1}^{N_m} \beta_{m,k} = 1 \tag{14}$$

where N_m is the number of macro users in a macrocell.

3 Interference Reduction Using Power Control

Reduction of the HeNB transmission power is the main concept of power control algorithms. These algorithms are exploited to reduce the interference, which affects the macro users. The HeNB transmission power can be reduced according to different strategies [8] and they are;

- The first strategy is based on assigning a fixed value of power to every HeNB. This value is less than the maximum allowed power for any HeNB (P_{max}), which is 20dBm [1] ($P_f < 20dBm$). where P_f is the HeNB transmission power after employing power control.
- The second strategy depends on varying the HeNB transmission power in order to cover a certain range. The power of the HeNB is;

$$P_f = \min ([P_M + G_\theta - PL_M(d) + PL_f(r)], [P_{max}]) \tag{15}$$

where r is the femtocell radius, P_M is the macro base station transmission power, G_θ is the antenna gain, $PL_M(d)$ is the macrocell path loss at distance d , and $PL_f(r)$ is the path loss at distance r .

- The third strategy is to vary the HeNB transmission power in order to guarantee a target $SINR$ for a user specified range. Suppose that, $SINR_t$ and $SINR_c$ are the target and the current $SINR$ respectively. The algorithm can be implemented as;

$$P(k + 1) = \frac{SINR_t}{SINR_c} P(k) \tag{16}$$

where $P(k)$ is the power level of HeNB at k th iteration.

4 Proposed Cognitive Radio Approach

In this section, applying the proposed cognitive radio concept is explained. Moreover the pseudo code, which illustrates the mechanism, and the mathematical analyses are clarified. Figure 1 displays the pseudo code, which explains the process of applying the cognitive radio concept in a LTE femtocells system.

- 1) At beginning, the places of macro cells, femtocells, macro users, and femto users are determined. In other words, the network is plotted. Moreover, the network should have a random deployment.
- 2) The specifications of the system have to chosen according to the LTE standards, which are the 3GPP releases.
- 3) According to the applied bandwidth and the used subcarrier spacing (subcarrier bandwidth), the number of subcarriers, K , is determined. This number affects the obtained throughput.
- 4) The macro cells manage all the subcarriers for their users to satisfy their requirements.
- 5) For a subcarrier k , each femto user senses the spectrum at this subcarrier band to check the operation of any macro user at this subcarrier. After the sensing process, each femto user analyses the obtained sensing information. Then, it decides if it is empty (free) or occupied by a macro user (not free).
- 6) The femto user sends a positive response to the spectrum server, if the checked subcarrier is not occupied by any macro user. This positive response indicates that this subcarrier can be used in the femtocells. Otherwise, the femto user sends a negative response to the spectrum server.
- 7) For a subcarrier k , the spectrum server receives the decision of each femto user in the network. The subcarriers, which have a positive response from all femto users, are determined by the spectrum server. Then, they can be used in the femtocells.
- 8) By using the system specifications and the network topology, the macro and femto users' geometry and throughput (channel capacity) can be calculated.

```

Create_network ( ) % defines macro and femto cells and users
Enter_Specifications ( ) % defines system parameters according to the 3GPP Specifications
For k=1:K % all subcarriers within the used bandwidth
Allocate the frequency subcarriers for macrocells
End
For k=1:K
Femto user (f) senses a subcarrier k
If k == empty
Send a positive response to the spectrum server
Else
Send a negative response to the spectrum server
End if
End
Spectrum server manages the free subcarriers among the femtocells
for i = 1 : I % all users in the system (macro and femto users)
sinr = calculate_sinr(i)
capacity = calculate_capacity(i)
End
Plot CDF

```

Fig. 1 The mechanism of applying the cognitive radio concept in a LTE femtocells system

- 9) The CDF of the macro and femto users' geometry and throughput can be plotted to obtain the proposed system performance.

The previous steps explain applying the cognitive radio mechanism in a LTE femtocells system. From the previous steps, it is clear that the femto users cannot access any subcarrier, which is occupied by a macro user. Therefore, the interference among the macro users and the femto users is completely eliminated. The *SINR* of the received signal at a macro user *m* on a subcarrier *k*, can be derived from Eq. 9 by neglecting the term, which represents the interference due to the femtocells, as shown in Eq. 17.;

$$SINR_{m,k} = \frac{P_{M,k}G_{m,M,k}}{N_o\Delta f + \sum_{M'} P_{M',k}G_{m,M',k}} \tag{17}$$

The same analysis is carried out for the HeNBs, the *SINR* of the received signal at a femto user *f* on a subcarrier *k*, can be deduced from Eq. 10 after neglecting the term, which represents the interference due to the macrocells, as illustrated in Eq. 18.;

$$SINR_{f,k} = \frac{P_{F,k}G_{f,F,k}}{N_o\Delta f + \sum_{F'} P_{F',k}G_{f,F',k}} \tag{18}$$

The *SINR* of the femto users and the macro users is greatly improved. However, the available subcarriers for the femto users are less than the corresponding ones applying the universal frequency reuse as they can access the free subcarriers only.

5 Simulation Results

The proposed system is simulated considering a single macrocell, which serves eight macro users and four HeNBs. Each HeNB serves two femto users. The simulation parameters, which are stated in Table 1, are chosen to satisfy the requirements of 3GPP 36.814 [1]. The macro users' and the femto users' geometry and throughput are estimated for the LTE Femtocells system after applying the universal frequency reuse, the first power control algorithm, and the proposed cognitive radio approach. The geometry is an important factor to be examined. If the user geometry becomes below a certain value, it cannot transmit or receive, regardless the available subcarriers for this user.

The Cumulative Distribution Function (CDF) is the probability of a user geometry becomes below a certain value. Figure 2a displays CDF of macro users' geometry applying the co-channel deployment (C.D), power control (P.C), when HeNB transmission power is 17 dBm, and 14 dBm, respectively, and the cognitive radio (C.R). It is observed that, the power control can improve the macro users' geometry, and this improvement is a function of the HeNB transmission power. When the HeNB transmission power is reduced, the macro users' geometry becomes better. This result is due to the reduction of the HeNB transmission power, which lowers the interference that affects the macro users. It is obvious that, the implementation of a cognitive radio concept can greatly improve the macro users' geometry as the interference from the HeNBs is completely eliminated.

Figure 2b shows the CDF of femto users' geometry using the co-channel deployment, power control (when HeNB transmission power is 17 dBm, and 14 dBm respectively), and the proposed cognitive radio. It is clear that, power control can degrade the femto users' geometry. On the other hand, the proposed cognitive radio can greatly improve the femto users' geometry as the interference from the macro base stations is completely cancelled.

Table 1 The simulation parameters

Simulation parameters	
Value	Parameter
Number of macrocells	1
Number of femtocells	4
Number of macro users per macrocell	8
Number of femto users per femtocell	2
Femtocell radius	20 m
User distribution	Random
Deployment	Urban
Macrocell base station power	46 dBm
Femtocell base station power	20 dBm
Bit error rate	10^{-6}
Noise power spectral density	-174 dBm/Hz
Subcarriers spacing	15 kHz
Modulation type	QAM-64
Bandwidth	20 MHz
Subcarriers number	1,200
Indoor wall loss	10 dB
Outer wall loss	10 dB
Number of penetrated floors	0
Indoor walls number	0
Indoor distance	0

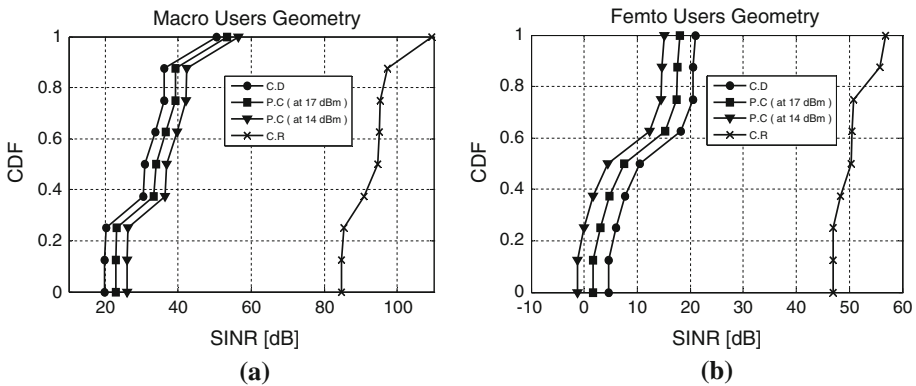


Fig. 2 The CDF plots of the macro users’ geometry and the femto users’ geometry at different deployments

The CDF of the macro users’ throughput is examined at different deployments, as shown in Fig. 3. It is observed that the power control can improve the macro users’ throughput. The throughput, using the cognitive radio, depends on the available subcarriers for the macro users. Moreover, it is better than the corresponding one employing co-channel deployment or power control algorithm, when 40% of subcarriers are available to be accessed by the macro users. Supposing that the macro users are the primary users, they have the priority to occupy the subcarriers at any time.

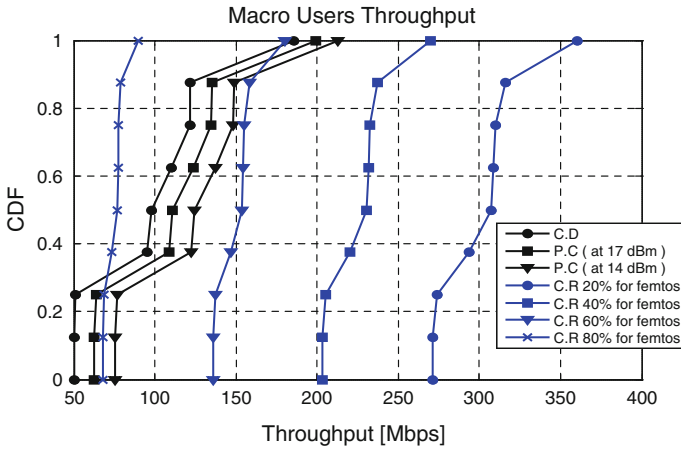


Fig. 3 The CDF plots of the macro users' throughput at different deployments

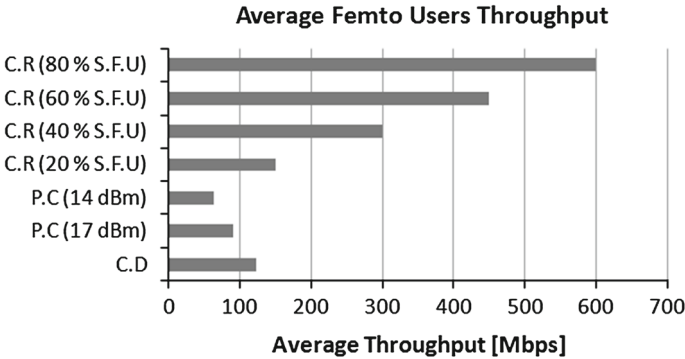


Fig. 4 The average of femto users' throughput at different deployments

Figure 4 discusses the average of femto users' throughput at different deployments. It is clear that, the power control can degrade the femto users' average throughput. On the other hand, employing the proposed cognitive radio has a great effect on the average throughput, even when there are a small number of subcarriers, which are available to the femto users. Moreover, the average femto users' throughput in the proposed system is better than the corresponding one utilizing the universal frequency reuse or the power control, even if 20% subcarriers only are available to be accessed by the femto users (20% S.F.U).

The LTE advanced cognitive femtocells system is compared to the LTE cognitive femtocells system in terms of the macro users' throughput and femto users' throughput. The motivation to the LTE advanced system is achieved by a carrier aggregation technique in such a way that five bands are used [2]. Each band has a bandwidth of 20 MHz. Figure 5 displays the CDF of the macro users' throughput and the femto users' throughput in the LTE cognitive femtocells system and the LTE advanced cognitive femtocells system, respectively. It can be concluded that the proposed cognitive LTE advanced system has a better performance than the proposed LTE cognitive system, as shown in Fig. 5.

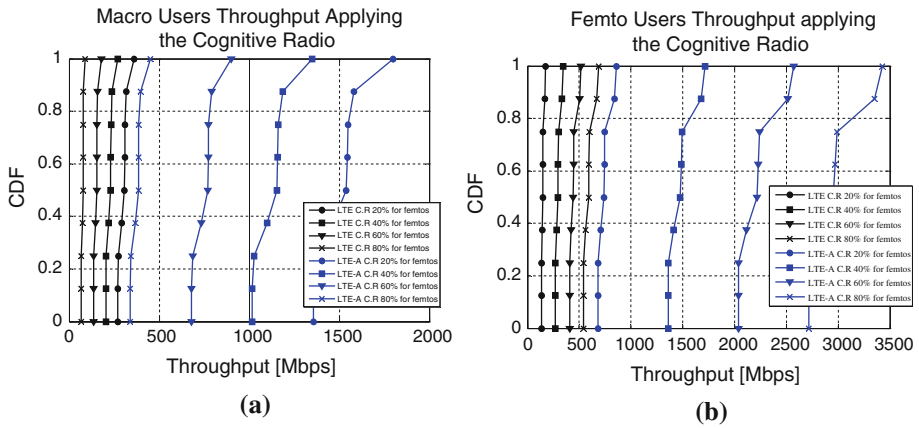


Fig. 5 The CDF plots of macro users' and the femto users' throughput in LTE cognitive femtocells system and LTE advanced cognitive femtocells system

6 Conclusions

The performance of LTE femtocells system was estimated. It was observed that, employing the proposed cognitive radio can increase the macro users' geometry and femto users' geometry, when it is compared to the corresponding one, which implements the universal frequency reuse and the power control algorithms. Moreover, the femto users' average throughput in the proposed system is better than the corresponding one utilizing the other two deployments, even if only 20% of subcarriers are free for femto users. It is also noticed that, the macro users' throughput in the proposed system is better than the corresponding one applying the universal frequency reuse or the power control, even if only 40% of the subcarriers are available to be accessed by the macro users. Moreover, the LTE advanced cognitive femtocells system has higher macro users' and femto users' throughputs than the LTE cognitive femtocells system, as the available subcarriers are higher due to the higher bandwidth.

References

- 3GPP TR 36.814 V9.0.0 (2010). Evolved Universal Terrestrial Radio Access (E-UTRA); further advancements for E-UTRA physical layer aspects (Release 9) Technical Report, 3rd Generation Partnership Project.
- Parkvall, S., Dahlman, E., Furuskar, A., Jading, Y., Olsson, M., Wanstedt, S., et al. (September 2008). LTE-advanced-evolving LTE towards IMT-advanced. *IEEE Vehicular Technology Conference* pp. 1–5.
- Chandrasekhar, V., & Andrews, J. G. (2008). Femtocell networks: A survey. *IEEE Communications Magazine*, 46, 59–67.
- Knisely, D. N., Yoshizawa, T., & Favichia, F. (2009). Standardization of femtocells in 3GPP. *IEEE Communications Magazine*, 47, 68–75.
- Knisely, D. N., & Favichia, F. (2009). Standardization of femtocells in 3GPP2. *IEEE Communications Magazine*, 47, 76–82.
- Barbieri, A., Damnjanovic, A., Ji, T., Montojo, J., Wei, Y., & Malladi, D. (May 2011). LTE femtocells: System design and performance analysis. *IEEE Vehicular Technology Conference*, pp. 1–5.
- Barbieri, A., Damnjanovic, A., Ji, T., Montojo, J., Wei, Y., Malladi, D., et al. (April 2012). LTE femtocells: System design and performance analysis. *IEEE Journal on Selected Areas in Communications*, 30(3), 586–594.
- Bouras, C., Diles, G., Kokkinos, V., & Papazois, A. (2012). Power management over co-channel femtocells in LTE-a systems (pp. 1–3), Wireless Days (WD).

9. Akyildiz, I. F., Lee, W. Y., Vuran, M. C., & Mohanty, S. (2006). Next generation/dynamic spectrum access/cognitive radio wireless networks: A survey. *Computer Networks*, 50, 2127–2159.
10. Wang, B., & Ray Liu, K. J. (2011). Advances in cognitive radio networks: A survey. *IEEE Journal of Selected Topics in Signal Processing*, 5(1), 5–23.
11. Bouras, C., Kokkinos, V., Kontodimas, K., & Papazois, A. (2012). A simulation framework for LTE-a systems with femtocell overlays. In *15th ACM international conference on modeling, analysis and simulation of wireless and mobile systems*.

Author Biographies



Mohamed Shalaby was born in Menoufia, Egypt, in 1986. He received the B.Sc. degree in electronics, and electrical communication engineering from Menoufia University, Menoufia, Egypt, in 2008. Presently, he is an Assistant Researcher at the National Institute for Standards, Cairo, Egypt. His research interests include wireless communications, broadband technologies, mobile communications, and next generation networks.



Mona Shokair received the B.Sc., and M.Sc. degrees in electronics engineering from Menoufia University, Menoufia, Egypt, in 1993, and 1997, respectively. She received the Ph.D. degree from Kyushu University, Japan, in 2005. She received VTS chapter IEEE award from Japan, in 2003. She published about 40 papers until 2011. She received the Associated Professor degree in 2011. Presently, she is an Associated Professor at Menoufia University. Her research interests include adaptive array antennas, CDMA system, WIMAX system, OFDM system, and next generation networks.



Yaser S. E. Abdo was born in Mansoura, Egypt, in 1976. He received the B.Sc., and M.Sc. degrees from Mansoura University, Mansoura, Egypt, in 1998, and 2004, respectively, and the Ph.D. degree in electrical engineering from Royal Military College, Kingston, Canada, in 2012. From 1999 to 2005, he worked as an Assistant Researcher at the National Institute for Standards, Cairo, Egypt. From 2006 to 2012, he was a Research Assistant at the Royal Military College, Kingston, Canada. Presently, he is a Researcher at the National Institute for Standards, Cairo, Egypt. His research interests include microwave measurements, EBG structures, leaky-wave antennas, near-field measurements, wireless communications, and electromagnetic compatibility.