Simulated Annealing Based Femtocell Power Control in Heterogeneous LTE Networks

Aykut Kalaycıoğlu, Ahmet Akbulut

***Abstract*—**In two-layer heterogeneous femtocell LTE networks co-channel interference is a limiting factor for the overall system performance. Since both femtocell and macrocell users share the same frequency spectrum, there exists a co-channel interference in the downlink direction. In this study, a power management scheme for macrocells and femtocells in a heterogeneous network, based on simulated annealing optimization algorithm, is employed to adjust the transmission power of the femtocell base stations to mitigate the co-channel interference. The algorithm tries to maximize the signal-to-interference plus noise ratio of the users while minimizing the transmission power of the femtocell base stations. The simulation results show that any noticeable signal-to-interference plus noise ratio doesn't occur for femtocell users while reducing the femtocell average power consumption dramatically. Besides, the signal-to-interference plus noise ratio for macrocell users is improved though. Thus, simulated annealing based power management is an effective solution to mitigate the co-channel interference for both the femtocell users and macrocell users in a heterogeneous Long Term Evolution network.

***Keywords*—**femtocell, heterogeneous, interference, LTE, power control, optimization, simulated annealing.

I. INTRODUCTION

LONG Term Evolution (LTE), also commercially known as 4G for marketing reasons, is one of the latest standards specified by the Third Generation Partnership Project (3GPP) in order to satisfy the requirements of mobile broadband users. LTE network provides very high data rates and better coverage. However, there are some technical challenges due to the increased number of users and different type of base stations, such as micro, pico and femtocell base stations in addition to macrocell base stations.

In a traditional LTE cellular network, a single macrocell base station, which is also called as eNB, is employed to serve both indoor and outdoor users. However, to satisfy the requirements of various users, unlike from the homogeneous networks in which only macrocells exist, a new paradigm, heterogeneous cellular networks are formed by deploying the micro, pico and femtocells, which have lower power base stations than does the macrocell base station. These base stations also have a smaller coverage area and are generally deployed into the large coverage area of macro cellular networks. Among these low power serving nodes, especially the femtocells are one of the most attractive solutions due to the improved indoor coverage, reduced power consumption and improved quality of service satisfaction, which also reduces the traffic congestion in the macrocell [1, 2].

Femtocell base station, which is also known as HeNB, has a transmitting power of less than 20 dBm whereas a macrocell base station has a typical transmitter power of 40 dBm. A femtocell base station's coverage radius is generally less than 30 meters [3]. The femtocell base stations have to occupy the service provider's frequency spectrum and need to employ the user's cable broadband connection to connect to the core LTE network [4].

To satisfy the increasing demand for the higher data rates and to solve the coverage problem that exists in the indoor environment, the deployment of femtocells is crucial and nowadays the heterogeneous networks tend to become denser which causes some technical challenges, mainly the severe interference that occurs among the different types of base stations and between the indoor and the outdoor users. Since there are many base stations with different transmission powers, the interference management in heterogeneous networks is much more complex and crucial than that of the homogeneous deployment of macrocells. Moreover, the unplanned deployment of the femtocells and the usage of the same frequency spectrum among the femtocells and macrocells make the solution more complex [5, 6]. Closed access mode of the femtocells also degrade the system performance of the heterogeneous networks compared to the open access mode femtocells because only the registered users can connect to the closed access femtocells. In that case, a nearby user to a transmitting closed access femtocell base station will suffer from the interference of that femtocell base station.

In a two-layer femtocell heterogeneous network, femtocells constitute the femto layer whereas macrocells form the macro layer. The interference between the same layers and the interference among the different layers can be called as co-layer and cross-layer interference, respectively [7]. When both these two layers share the same frequency spectrum of the service provider, there are mainly two interference sources for the outdoor macrocell users and the indoor femtocell users in the downlink direction. For outdoor users the neighboring macrocell base stations have a negligible impact due to the

---

A. Kalaycıoğlu is with Ankara University, Department of Electrical and Electronics Engineering, Ankara, Turkey (e-mail: kalaycioglu@ankara.edu.tr).

A. Akbulut is with Ankara University, Department of Electrical and Electronics Engineering, Ankara, Turkey (e-mail: aakbulut@ankara.edu.tr).

large distance between the outdoor macrocell users and the other transmitting macrocell base stations unless the outdoor users are close to the edge of the macrocell area. On the contrary, the transmitting femtocell base stations in a macrocell area will have a more degrading effect on the outdoor macrocell users. Furthermore, the neighboring femtocell base stations that share the same spectrum with the serving femtocell base station will severely degrade the signal-to-interference plus noise ratio (SINR) of the other indoor femtocell users which are not the registered users of that femtocell. Moreover, the transmitting macrocell base station in the coverage area that also shares the same frequency spectrum with the femtocell base station may also interfere the indoor femtocell users [8]. In a typical heterogeneous LTE environment, there are many femtocell base stations with various number of users in addition to large number of outdoor macrocell users, who may not have the permission to the femtocell base station. Since the main interference source is the transmitting femtocell base station with the excessive power level for both outdoor and indoor users, to mitigate the degrading effects of the interference for both the macrocell and femtocell users is a crucial requirement to improve the overall performance of the heterogeneous LTE network [9-11].

Although assigning different parts of the frequency spectrum to different users is accepted as a solution to mitigate the degrading effects of interference in a heterogeneous femtocell network, this is not an effective way to use the scarce spectrum. On the other hand, in a two-layer heterogeneous femtocell network adjusting the femtocell base station's transmission power to improve the performance of the overall network is much more preferable both in terms of effective usage of the spectrum and the mitigation performance of the interference. Since power management is a promising solution to mitigate the degrading effects of the interference, the signal-to-interference plus noise ratio (SINR) of both the femtocell user and the macrocell user may be improved by adjusting the transmission power of the femtocell base stations [9].

The mitigation of the co-channel interference by adjusting the transmission power of the femtocell base stations is an attractive study area in the literature. For instance, very basic downlink power control techniques in addition to frequency domain techniques are given in [12]. A self-organized resource allocation with power control which provides a desired throughput level for femtocell users is proposed in [5] only for co-layer interference case. Besides, an autonomous downlink power control based on channel quality indicators for femtocell users is studied in [13] and the results show that the decentralized solution provides better throughput performance for the users. Authors in [14] propose a simple downlink power control scheme for the femtocell base stations to reduce the interference for the nearby macrocell users. The study shows that overall interference in the system is reduced and the algorithm does not reduce femtocell base station power unless the base station is an interference source for the macrocell users. In [15], a two level power management technique is proposed to reduce the interference among the femtocells. A power minimization problem is solved to decide the power level of the femtocells. Simulation results shows to maximize the sum capacity, the ratio of the transmission powers of the adjacent femtocells should be kept in a specific value. Authors in [16] propose a power optimization technique in a dense femtocell network based on the exact potential game theory. Their simulation results show that total transmit power of the femtocell base stations is reduced while improving the throughput performance. Another power control scheme based on Hungarian algorithm for co-channel interference is also studied in [17]. The simulation results show that the proposed centralized scheme improves the performance of the heterogeneous network while increasing the complexity. Another power management technique, using particle swarm optimization scheme, to improve the outage performance of macro users in a two-layer heterogeneous network is studied in [18]. The proposed solution improves the performance of the macrocell users while doesn't make a noticeable effect on the performance of the femtocell users. In [19], authors propose two different algorithms based on reducing the transmission power of the cell. System level simulations show that reducing the downlink transmission power per resource block individually will allow reduced interference and improvement in network capacity. Authors in [20] proposed a power management technique for femtocell base stations in a cellular network. Simulation results show that their decentralized algorithm increase the system capacity of the network. Another downlink power control algorithm for LTE networks is proposed in [21]. Simulation results show that downlink power consumption is decreased by employing the proposed heuristic power adjustment method while improving the performance of the cell edge users.

In this paper, simulated annealing optimization algorithm [22] is used to adjust the femtocell base station transmission power in the downlink direction to reduce co-channel the interference for both indoor femtocell users and outdoor macrocell users. Although the power management scheme is a centralized technique, it requires a few number of iterations that does not increase the complexity of the network. Simulation results show that the consumed power at the femtocell base stations is reduced in almost all trials. The performance degradation due to low transmission powers at the femtocell base stations for femtocell users is negligible. Furthermore, since transmission power of the femtocell base stations is reduced, the SINR performance of the outdoor macrocell users is improved.

The remainder of this paper is organized as follows. System model is given in Section II. Simulated annealing optimization algorithm is briefly discussed in Section III. Simulation parameters and the obtained results are given in Section IV. Finally, Section V gives the conclusion.

II. SYSTEM MODEL

M macrocells overlaid with *F* femtocells exist in a two-layer heterogeneous femtocell LTE network. Each macrocell has three sectors, where a dual strip model of *n*-floor building is randomly deployed in one of these sectors, as shown in Fig. 1. Macrocell users and femtocell users are assumed to be outdoor users and indoor users, respectively. The dual strip model is used to characterize the suburban indoor femtocell environment. In dual strip model, there are 20 apartments, with a dimension of 10x10 m, in each strip. The distance between the first and the second strip is 10 m [23].

Outdoor macrocell users are randomly deployed in the two-layer environment. Both the macrocells and the femtocells share the same frequency spectrum with the same number of resource blocks. We also assume that all femtocells are employing closed access mode, in which unregistered users can't access to the resource blocks of a femtocell unless they are the authorized users for that femtocell.

Heterogeneous LTE femtocell network is based on an orthogonal frequency division multiple access, in which each resource block has a bandwidth of 180 kHz and a time duration of 1 ms. The number of resource blocks depends on the transmission bandwidth of the network, e.g., there are 50 resource blocks available for a bandwidth of 10 MHz [24].

For our heterogeneous network, we use the indoor femtocell channel models for a suburban deployment, given in the 3GPP standard to measure the SINR values. Suburban path loss for indoor channel users are given in (1) and (2), when the femtocell base station and the femtocell user are inside the same apartment and when the femtocell is inside a different apartment, respectively [23].

$$PL_1 = 38.46 + 20\log R + 0.7d + 18.3n^{((n+2/n+1)\text{-}0.46)} \tag{1}$$

$$\begin{aligned} PL_2 &= \max\left(2.7 + 42.8\log R, 38.46 + 20\log R\right) \\ &+ 0.7d + 18.3n^{((n+2/n+1)\text{-}0.46)} + L_{ow,1} + L_{ow,2} \end{aligned} \tag{2}$$

In these equations, R is the distance between the serving base station and the user and d is the distance inside the apartment, both in meters, n is the number of floors in the building and $L_{ow,1}, L_{ow,2}$ are the penetration loss values of the different apartment's outdoor walls.

Besides, there are macrocell users in the heterogeneous network environment. For macrocell users, we use the outdoor path loss models given in [23]. Since we assume that all the macrocell users are outside the apartments, the path loss model for the macrocell user from the macrocell base station is given in (3), in which R is in meters.

$$PL_3 = 15.3 + 37.6\log R \tag{3}$$

Due to the interfering femtocell base stations and the macrocell base station in the neighborhood, the SINR value of an indoor femtocell user allocated in the resource block r of the femtocell base station i is given in (4) [20].

$$SINR_r^{i,F} = \frac{P_r^{i,F}\, PL_{ii,r}^{FF}}{\sum_{j=1}^{M} P_r^{j,M}\, PL_{ji,r}^{MF} + \sum_{k=1,k\neq i}^{F} P_r^{k,F}\, PL_{ki,r}^{FF} + N_0} \tag{4}$$

In (4), $PL_{ii,r}^{FF}$ indicates the path loss between the serving femtocell base station and its corresponding femtocell user where as $PL_{ki,r}^{FF}$ is the path loss between the other transmitting femtocell base station in the neighborhood and the femtocell user. Besides, $PL_{ji,r}^{MF}$ is the path loss between the transmitting macrocell base stations and the femtocell user. In addition, $P_r^{i,F}$, $P_r^{k,F}$ and $P_r^{j,M}$ are the power of the serving femtocell base station, transmitting other femtocell base stations and transmitting macrocell base stations, respectively.

In addition, similar to (4), the SINR value of an outside macrocell user allocated in the resource block r of the macrocell base station i is given in (5).

$$SINR_r^{i,M} = \frac{P_r^{i,M}\, PL_{ii,r}^{MM}}{\sum_{i=1}^{F} P_r^{i,F}\, PL_{ji,r}^{FM} + \sum_{k=1,k\neq i}^{M} P_r^{k,M}\, PL_{ki,r}^{MM} + N_0} \tag{5}$$

In (5), $PL_{ii,r}^{MM}$ indicates the path loss between the serving macrocell base station and its corresponding macrocell users whereas $PL_{ji,r}^{FM}$ is the path loss between the transmitting femtocell base station and the macrocell user whereas $PL_{ki,r}^{MM}$ is the path loss between the transmitting other macrocell base stations and the macrocell user. In addition, $P_r^{i,M}$, $P_r^{k,M}$ and $P_r^{i,F}$ are the power of the serving macrocell base station, transmitting other macrocell base stations and transmitting femtocell base stations, respectively.

Furthermore, both in (4) and (5), N_0 is the thermal noise power. The maximum transmit power for a macrocell base station and femtocell base station are defined as, $P_{\max}^{M}$ and $P_{\max}^{F}$, respectively.

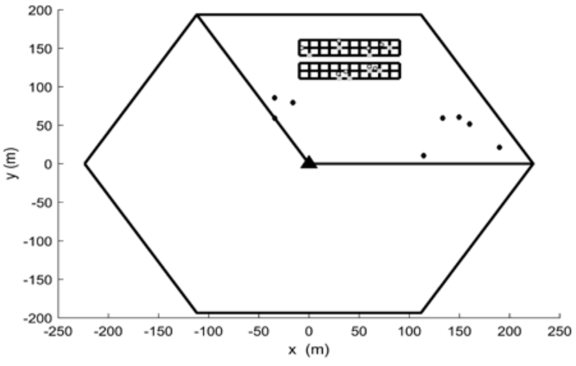

Fig. 1. Simplified simulation environment for heterogeneous network.

III. SIMULATED ANNEALING OPTIMIZATION ALGORITHM

In this study, simulated annealing (SA) is used as an optimization algorithm for power management. The SA was proposed by Kirkpatric, Gelett and Vecchi in 1983 [22]. The algorithm is based mainly on ideas coming from statistical mechanics and simulates the behavior of physical systems in a heat bath. If a solid heated to the melting point is cooled, the structural properties of the solid material depend on the cooling rate. If the molten solid is cooled slowly, large crystals form. However, if the molten solid is rapidly cooled, the crystals will contain defects. The algorithm imitates the cooling process, which gradually reduces the temperature of the system until it becomes stable. This process ensures that the initial solution is improved by making small local changes until a better solution cannot be achieved. Simulated annealing randomly performs this operation to provide uphill movements from time to time to avoid weak but locally optimal solution. The SA algorithm initially starts at high temperature and with a random solution. The temperature is reduced at each iteration of the algorithm. The temperature also determines the frequency of acceptance of weak solutions. When the temperature is high, the search space is kept wider. On the other hand, while the temperature is decreasing, neighboring solutions are selected from closer regions. A new random solution is created at each iteration. The distance between the new solution and the previous solution is calculated and used in the temperature-based distribution function. Fig. 2 shows flow chart of the simulated annealing algorithm.

IV. SIMULATION RESULTS

Simulation parameters, to evaluate the performance of our proposed simulated annealing based femtocell power control algorithm in LTE heterogeneous networks, are given in Table I.

TABLE I. SIMULATION PARAMETERS

Macro cell coverage radius, meter	250
Femtocell coverage area, meter	10x10
Transmission Bandwidth, MHz	10
Number of Resource Blocks	50
Number of blocks per sector	1
Number of femtocells in each apartment	1
Number of total femtocell users	8, 40
Number of macrocell users	8
Activation Ratio	1
Deployment Ratios	0.2, 1.0
Penetration loss values of the walls, dB	10
Maximum power of the macrocell base station, dBm	40
Maximum power of the femtocell base station, dBm	20

We assume that there is only one floor for each strip, activation ratio is one and deployment ratio is chosen as 0.2 and 1.0 and all the femtocells employ closed access mode. Besides, 8 outdoor macrocell users are randomly deployed in the simulation environment and none of these users are inside the apartments. Position of the dual strip, femtocell users and macrocell users are randomly changed over 1000 simulation trials to obtain statistically meaningful results. For the SA optimization algorithm, the number of iterations for the optimization process and the number of neighboring solutions in each iteration is selected as 10 and 100, respectively.

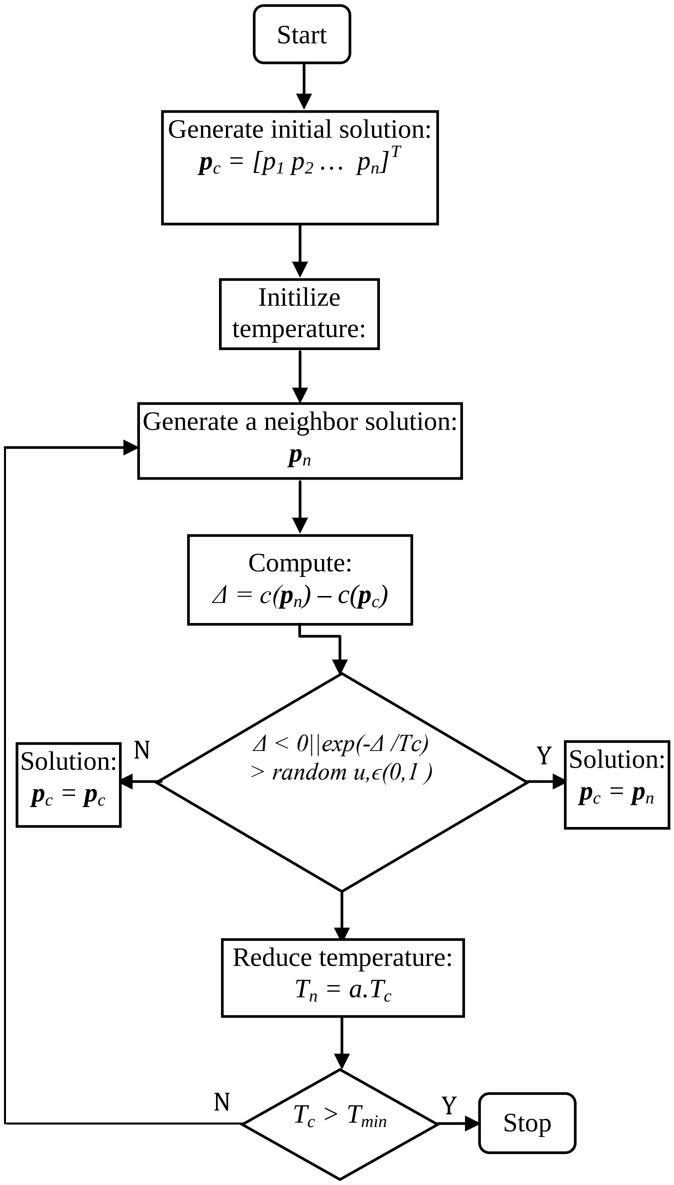

Fig. 2. Flow chart of the simulated annealing algorithm

The cost function, CF for the optimization algorithm subject to femtocell base station power and threshold SINR value is given in (6), in which λ and η are the tuning parameters to adjust the impact of SINR and the transmission power values of the femtocells, respectively. Furthermore, $SINR_{th}^{i,F}$ is the SINR threshold value that should be exceeded by the user of the femtocell *i* to satisfy the transmission requirements.

$$CF = \sum_{i=1}^{F} e^{-\lambda\left(SINR_r^{i,F} - SINR_{th}^{i,F}\right)} + \eta P_r^{i,F} \tag{6}$$

Fig. 3 simply shows that femtocell base stations have to transmit at the maximum transmission power for less than 6% of the overall 1000 simulation trials. On the other hand, in almost 25% of the simulation trials the femtocell base stations need to transmit at the minimum transmission power, which is chosen as 5 mW. Therefore, it is straightforward that the simulated annealing based power control scheme saves a huge amount of power wastage for the femtocell base stations.

In Fig. 4, histograms of the SINR values are given to compare the performance of the fixed power scheme (FPS) and that of the simulated annealing based power control scheme (SAPS) for femtocell users.

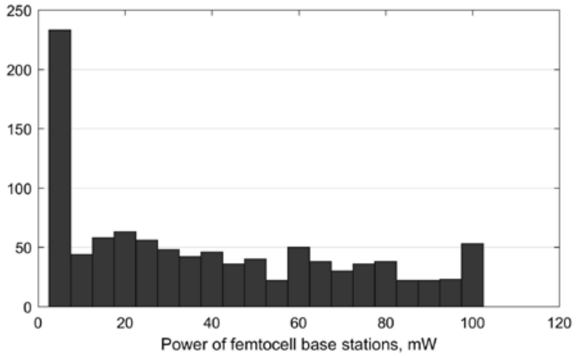

Fig. 3. Histogram of the power of femtocell base stations with SAPS (deployment ratio = 0.2).

As shown in Fig. 4, the number of high SINR values for the femtocell users is decreased whereas the number of low SINR values is increased when the simulated annealing based power control scheme is employed. However, it is clear that the SINR performance degradation due to reducing the femtocell base station power with SAPS is negligible in almost all cases.

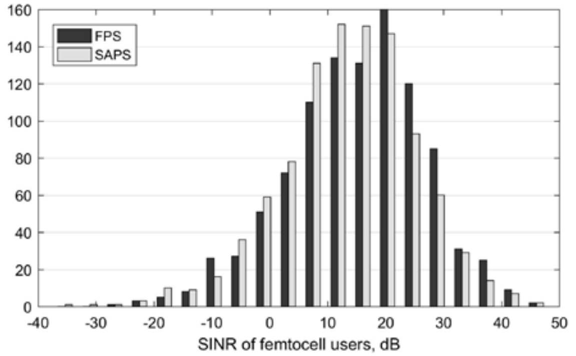

Fig. 4. Histograms of the SINR values with FPS and SAPS for the femtocell users (deployment ratio = 0.2).

Cumulative distribution function (CDF) of the SINR values with FPS and SAPS for femtocell users is given in Fig. 5 to show the negligible performance degradation when the femtocell base station power is decreased dramatically.

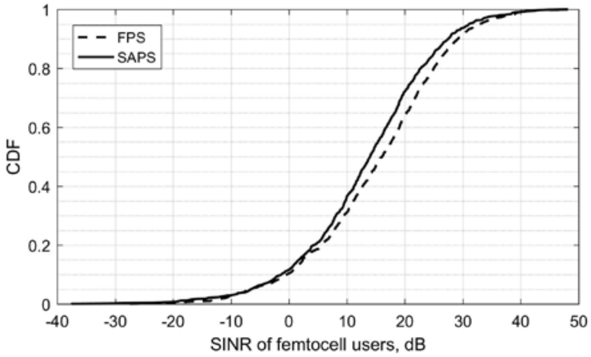

Fig. 5. Cumulative distribution functions of the SINR values with FPS and SAPS for femtocell users (deployment ratio = 0.2).

It is clear that there is a negligible SINR degradation for the femtocell users while reducing the femtocell base station power dramatically with SAPS scheme, especially for low and high SINR values.

Fig. 6 now shows the histograms of the SINR values to compare the performance of the FPS and that of the SAPS for macrocell users.

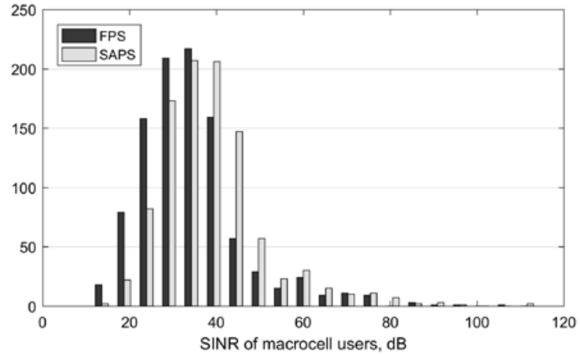

Fig. 6 Histograms of the SINR values with FPS and SAPS for macrocell users (deployment ratio = 0.2).

According to Fig. 6, there is a noticeable performance improvement in terms of the SINR values of the macrocell users when the SAPS is used. The number of macrocell users with low SINR values is decreased and the number of macrocell is users with high SINR values is increased by reducing the transmission power of the femtocell base stations.

Fig. 7 is given to compare the CDF performance of the FPS and SAPS for the macrocell users.

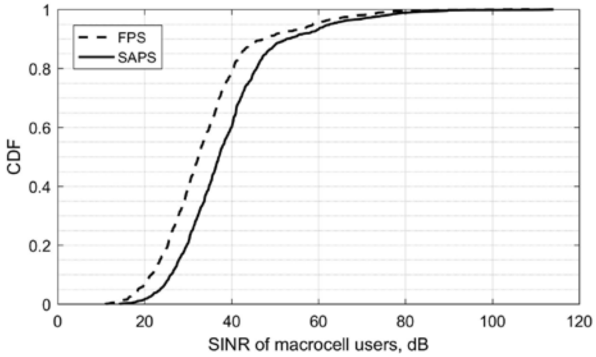

Fig. 7. Cumulative distribution functions of the SINR values with FPS and SAPS for macrocell users (deployment ratio = 0.2).

By reducing the transmission power of the femtocell base station powers, the interference for the macrocell users is decreased. Thus, the CDF performance of the SAPS for the macrocell users is improved in all SINR values.

Fig. 8 and Fig. 9 are given to compare the CDF performance of the FPS and SAPS for the femtocell users and that of the macrocell users, respectively, in a dense femtocell network. In this case, the deployment ratio is set to 1.0 to increase the number of active femtocell users, which becomes 40, in the simulation environment.

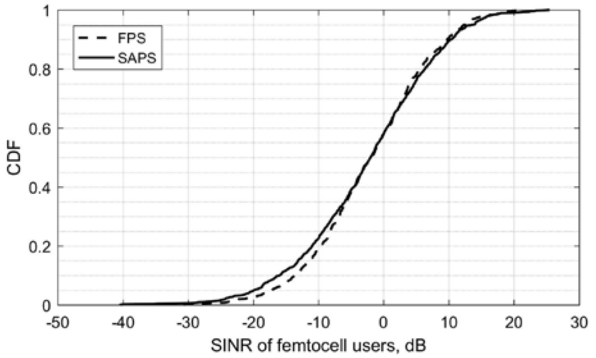

Fig. 8. Cumulative distribution functions of the SINR values with FPS and SAPS for femtocell users (deployment ratio = 1.0).

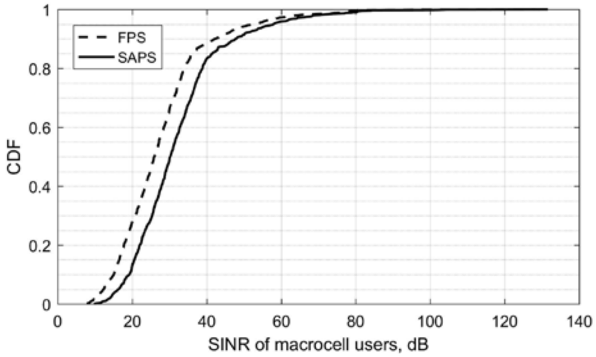

Fig. 9. Cumulative distribution functions of the SINR values with FPS and SAPS for macrocell users (deployment ratio = 1.0).

When the number of femtocell users is increased, as shown in Fig 8, both FPS and SAPS yield similar performance for femtocell users. On the other hand, the SINR performance of macrocell users is not degraded for the high deployment ratio.

V. CONCLUSION

In this study, a power management scheme for outdoor macrocell and indoor femtocell users in a heterogeneous network, based on the well-known simulated annealing optimization algorithm, is employed to adjust the transmission power of the femtocell base stations to mitigate the co-channel interference among both the neighboring femtocell users and the macrocell users.

The power control algorithm relies on reducing the transmission power of the femtocell base stations while maintaining a minimum threshold value of the signal-to-interference plus noise ratio by defining a cost function for the simulated annealing optimization algorithm.

The simulation results show that simulated annealing based power control for femtocell base stations in a heterogeneous LTE network decreased the excessive power usage for the femtocell base stations. On the other hand, although the femtocell base stations requires less transmission power, the SINR performance degradation for the femtocell users is negligible in almost all SINR values. Furthermore, the performance of the macrocell users in terms of SINR values is improved by reducing the transmission power of the femtocell base stations for both low and high deployment ratios.

In this study, number of iterations for the simulated annealing algorithm is set very few to avoid additional communication overhead among femtocell base stations to perform the iterative process. Thus, it is clear that simulated annealing based power management can be a much more effective way when the number of iterations is increased to mitigate the co-channel interference in a heterogeneous network while decreasing power consumption for the femtocell base stations.

REFERENCES

[1] V. Chandrasekhar, J.G. Andrews, “Femtocell networks: a survey”, IEEE Communications Magazine, vol. 46, issue.9, September 2008.

[2] A. Kalaycıoğlu, A. Akbulut, “A heuristic method for power control of femtocells in LTE networks”, International Conference on Control, Artificial Intelligence, Robotics and Optimization, ICCAIRO 2017, May 2017.

[3] J Y.L. Lee, T.C. Chuah, J. Loo, A. Vinel, “Recent advances in radio resource management for heterogeneous LTE/LTE-A networks”, IEEE Communications Surveys&Tutorials, Vol.16, No.4, Fourth Quarter 2014.

[4] T. Zahir, K. Arshad, A. Nakata, K. Moessner, “Interference management in femtocells”, IEEE Communications Surveys&Tutorials, Vol. 15, No.1, First Quarter 2013.

[5] M. Mehta, N. Rane, A. Karandikar, M. A. Imran, B.G. Evans, “A self-organized resource allocation scheme for heterogeneous macro-femto networks”, Wireless Communications and Mobile Computing, vol. 16, issue 3, 2016, p.330-342.

[6] C. Bouras, G. Diles, V. Kokkinos, K. Kontodimas, A. Papazois, “A simulation framework for evaluating interference mitigation techniques in heterogeneous cellular environment”, Wireless Personal Communications, vol.77, issue 2, p.1213-1237.

[7] F. Mhiri, K. Sethom, R. Bouallegue, “A survey on interference management techniques in femtocell self organizing networks”, Journal of Network and Computer Applications, vol. 36, p. 58-65, 2013.

[8] N. Saquib, E. Hossain, L. B. Le, D. I. Kim, “Interference management in OFDMA femtocell networks: Issues and approaches”, IEEE Wireless Communications, vol. 19, issue 3, June 2012.

[9] M. Yassin, M. A. AboulHassan, S. Lahoud, M. Ibrahim, D. Mezher, B. Cousin, E. A. Sourour, “Survey of ICIC techniques in LTE networks under various mobile environment parameters”, Wireless Networks, vol. 23, issue 2, February 2017, p.403-418.

[10] V. Chandrasekhar, J.G. Andrews, T. Muharemovic, Z. Shen, A. Gatherer, “Power control in two-tier femtocell networks”, IEEE Transactions on Wireless Communications, Vol.8, issue 8, August 2009.

[11] Y.S. Lianng, W.H. Chung, G.K. Ni, I.Y. Chen, H. Zhang, S.Y. Kuo, “Resource allocation with interference avoidance in OFDM femtocell networks”, IEEE Transactions on Vehicular Technology, vol. 61, no. 5, June 2012.

[12] D.L. Perez, İ. Güvenç, G.Roche, M. Kountouris, T.Q.S. Quek, J. Zhang, “Enhanced intercell interference coordination challenges in heterogeneous networks”, IEEE Wireless Communications, vol. 18, issue 3, June 2011.

[13] X. Xu, G. Kutrolli, R. Mathar, “Autonomous downlink power control for LTE femtocells based on channel quality indicator”, 2013 IEEE 24th International Symposium on Personal, Indoor and Mobile Radio Communications: Mobile and Wireless Networks, September 2013, p. 3050-3055.

[14] T. Zahir, K. Arshadi Y. Ko, K. Moessner, “A Downlink power control schemes for interference avoidance in femtocells”, 2011 7th International Wireless Communications and Mobile Computing (IWCMC), 2011, p.1222-1226.

[15] G. Zhang, X. Ao, P. Yang, M. Li, “Power management in adjacent cognitive femtocells with distance-dependent interference in full coverage area”, EURASIP Journal on Wireless Communications and Networking, 2016.

[16] X. Wang, W. Zheng, Z. Lu, X. Wen, W. Li, “Dense femtocell network power self-optimization: an exact potential game approach”, International Journal of Communication Systems, vol.19, 2016, p.16-32.

[17] G. Cao, D. Yang, X. Ye, X. Zhang, “A downlink joint power control and resource allocation scheme for co-channel macrocell-femtocell networks”, 2011 IEEE Wireless Communications and Networking Conference (WCNC), 2011, p.281-286.

[18] Z. Huang, Z. Zeng, H. Xia, J. Shi, “Power control in two-tier OFDMA femtocell networks with particle swarm optimization”, 2011 IEEE 73rd Vehicular Technology Confrence (VTC Spring), 2011.

[19] D. L. Perez, X. Chu, A. V. Vasilakos, H. Claussen, “Power minimization based resource allocation for interference mitigation in OFDMA femtocell networks”, IEEE Journal on Selected Areas in Communications, vol. 32, no. 2, February 2014, p.333-334.

[20] A. Galindo-Serrano, L. Giupponi, “Distributed q-learning for interference control in OFDMA-based femtocell networks”, 2010 IEEE 71st Vehicular Technology Conference (VTC 2010-Spring), May 2010.

[21] M. Yassin, S. Lahoud, M. Ibrahim, K. Khavam, “A downlink power control heuristic algorithm for LTE networks”, 2014 21st International Conference on Telecommunications (ICT), 2014.

[22] S. Kirkpatrick, C.D. Gelett, M.P. Vecchi, “Optimization by simulated annealing”, Science, vol. 220, issue 4598, 1983, p. 671-680.

[23] 3GPP, “Further advancements for E-UTRA physical layer aspects (Release 9)”, Technical Report 36.814v 9.0.0, March 2010.

[24] E. Dahlman, S. Parkvall, J. Sköld, “4G:LTE/LTE-Advanced for mobile broadband”, 2nd Edition, Elsevier Academic Press, 2014.