Design and Simulation of Optimal Number of Small Cells Deployment in Fourth-Generation Cellular Networks

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Abstract —In next-generation of wireless communication systems, Fifth-Generation (5G), small cells deployment is one of the most important issues that must be taking in the account. This paper discusses this issue in three aspects. First, it aims to derive the Critical Handover Location (CHL) point for neighbouring wireless stations which in turn is considered an entrance to the second aspect of this work that decides the small cell placement in one network. Finally, the work proposed a new approach to evaluating the Number of Small Cells (NRS) deployment mathematically. The proposed approach provides the balance in resources allocation in the network in terms of transmitted power of each small cell and their placement in order to provide maximum capacity and coverage area with a lower level of interference between nearest wireless stations thus decreasing the total cost of network insulation**.**

Index Terms**—**Cellular networks, CHL, handover, NRS, small cells deployment

I. Introduction

A small cell is a miniature eNB that breaks up a cell site into smaller segments, these small cells include picocells, microcells, and femtocells can be installed indoor/outdoor [1], [2]. In LTE-A small cell deployment introduced as one of the keys and effective solution to address poor coverage area with low cost and easy installations. Small cells deployment considers a favourable solution to achieve large coverage area and high capacity in next-generation cellular systems [3], [4]. The 5G systems are aimed towards the investigation of various technologies that provide higher capacity and throughput, best coverage area, and compelling wireless services for the user. Furthermore, in order to make the small cell aware of the surrounding radio environment, several spectrum awareness technologies such as spectrum sensing and the signal-to-noise ratio can be utilized for this purpose [5]-[7].

Several methods of small cells deployment have been reported recently. Maveddat [8] showed the necessity of small cell deployment. Chen [9] studied the deployment of small cells nested with macro cells, and improves overall network performance. Ranaweera [10] discussed the backhaul of small cells. The automated deployment of a small cell in networks of heterogeneous cellular is addressed in [11].

The main contributions of this paper are determined an optimal number of small cells should be deployed to provide maximum capacity and coverage area with eliminating the interference between the cells which consider major challenges facing cell deployment in 5G cellular networks.

The remainder of this paper includes: Section 2 explains CHL in the cellular network of two contiguous channels. Section 3 provides an optimal number of small cells to achieve maximum coverage area with evading the overlaying in between cell while Section 4 discusses numerical results of the proposed model. Subsequently, Section 5 present the paper concludes.

II. Critical Handover Location

The cellular network defines the status in which the two channels are available, and then the network decides to choose the operation frequency from them, this process called hand over process. CHL in the multi-hop system is difficult compared to the cellular network system because it is implements reliably without interruption in wireless links. Received Signal Strength (RSS) from Remote Station (RS) along with RSS from eNB must be known to evaluate the CHL in multi-hop system. Thus, MS chooses the higher signal in terms of RSS for accessing as shown in Fig. 1.

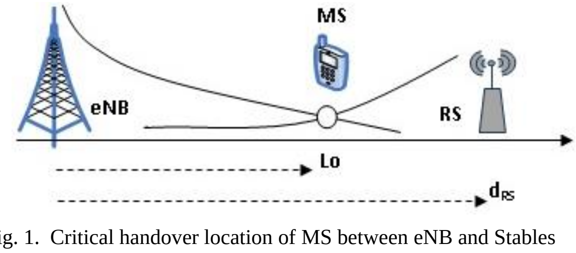


Fig. 1. Critical handover location of MS between eNB and Stables

In multi-hop system, RS and eNB are placed at a distance (dRS). CHL appears when the RSS from the RS is equal to the RSS from eNB at MS. Here, the distance from

Manuscript received July 15, 2021; revised November 12, 2021.
doi:10.12720/jcm.16.12.583-588

the eNB to CHL is indicated by Lo, as shown in Fig. 1. To determine the Lo, the received signals from eNB to MS and from RS to MS in handover location can be mathematically calculated as:

$$Y_{MS,eNB} = \sqrt{P_{eNB}} H_{eNB} X_{eNB} + \sigma_{MS} \tag{1}$$

$$Y_{MS,RS} = \sqrt{P_{RS}} H_{RS} X_{RS} + \sigma_{MS} \tag{2}$$

where PeNB is the transmit power of the donor eNB, while PRS is the transmit power of the RS, HeNB and HRS are the channels between the eNB and RS respectively. XeNB and XRS are signals from eNB and RS respectively and σMS is Additive White Gaussian Noise (AWGN) for mobile station.

At the CHL point, the received signals from both stations eNB and RS are equal

$$Y_{MS,RS} = Y_{MS,eNB} \tag{3}$$

$$\sqrt{P_{eNB}} H_{eNB} X_{eNB} + \sigma_{MS} = \sqrt{P_{RS}} H_{RS} X_{RS} + \sigma_{MS} \tag{4}$$

$$P_{eNB} \left|H_{eNB}\right|^2 = P_{RS} \left|H_{RS}\right|^2 \tag{5}$$

For simplicity, H can be given by [12], [13],

$$\left|H\right| = d^{-\alpha} \tag{6}$$

$$\left|H_{eNB}\right|^2 = L_o^{-\alpha}, \quad \left|H_{RS}\right|^2 = (d_{RS} - L_o)^{-\alpha} \tag{7}$$

where the d is the distances between stations, and α represents the path loss exponent for free space and urban area, α typically $\in (2-5)$. Therefore, Eq. (5) can be written as:

$$P_{eNB} L_o^{-\alpha} = P_{RS} (d_{RS} - L_o)^{-\alpha} \tag{8}$$

$$P_{eNB}^{(\frac{-1}{\alpha})} L_o = P_{RS}^{(\frac{-1}{\alpha})} (d_{RS} - L_o) \tag{9}$$

$$L_o = \frac{d_{RS}}{\left(\left(\frac{P_{RS}}{P_{eNB}}\right)^{\frac{1}{\alpha}} + 1\right)} \tag{10}$$

III. Number of Small Cell Stations

To provide the maximum coverage area with evading the overlaying in circular coverage of RSs and providing best coverage with less cost through using of small cell stations lower number RSs. The optimal number of small cell stations should be computed to assure distribution with fair capacity and above conditions.

By proposing that a MS exists in the middle between two RSs, and that (l) is the distance from RS to MS as demonstrated in Fig. 2.

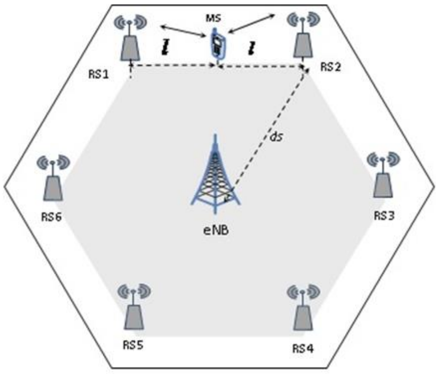


Fig. 2. The deployment dimensions of small cells (RSs) within the cell.

In network cell, increasing the number of small cells deployed can improve coverage area but in other side causes other problems such as increased cost and interference between all stations [14]. In order to avoid the interference, this paper presents the balance method between all above constraints by derivation of NRS with respect of the path loss and neighboring RSs and donor eNB [15], [16].

The received signal for a MS, as shown in Fig. 2. can be mathematically expressed as:

$$Y_{MS,1} = \sqrt{P_{RS1}} H_{RS1} X_{RS1} + \sigma_{MS} \tag{11}$$

$$Y_{MS,2} = \sqrt{P_{RS2}} H_{RS2} X_{RS2} + \sigma_{MS} \tag{12}$$

Mathematically, the received signal from the donor can be expressed as:

$$Y_{MS,eNB} = \sqrt{P_{eNB}} H_{eNB} X_{eNB} + \sigma_{MS} \tag{13}$$

At location of MS, the total of received signal from two neighbouring RSs is equal or exceeds the received signal from donor eNB. Therefore, Eqs. (11), (12), and (13) can be written as:

$$Y_{MS,1} + Y_{MS,2} \geq Y_{MS,eNB} \tag{14}$$

$$P_{RS1}(l)^{-\alpha} + P_{RS2}(l)^{-\alpha} > P_{eNB}(d_S)^{-\alpha} \tag{15}$$

$$2P_{RS}(l)^{-\alpha} > P_{eNB}(d_S)^{-\alpha} \tag{16}$$

As shown in Fig. 2, deployed of RSs on the circumference of a circle around the eNB with radius dS, thus the distances between neighbouring RSs calculates by:

$$2l = \frac{2\pi d_S}{N_{RS}} \tag{17}$$

By substituting Eq. (17) into Eq. (16) yields:

$$\frac{2P_{RS}}{P_{eNB}}\left(\frac{\pi d_S}{N_{RS}}\right)^{-\alpha} > (d_S)^{-\alpha} \tag{18}$$

Thus, the number of small cell stations which should be deployed in one cell (NRS) is:

$$N_{RS} < \pi\left(\frac{2P_{RS}}{P_{eNB}}\right)^{\frac{-1}{\alpha}} \tag{19}$$

Equation (19) shows that NRS is depend on the power transmitted by both RS and eNB as well as α. Consequently, higher transmit power of RS implies fewer RSs should be deployed in the cell to reduce interference between deployed RSs and between RS and eNB on another hand.

IV. Numerical Results and Discussions

In this section, we investigate three aspects of distribution of small cell station which called here RS.

First, we begin by deriving the CHL. Then, we investigate the optimal placement of RS which provide the maximum coverage with mitigation the interference between wireless stations. Finally, we derive NRS equation which should be deployed in the one wireless cell.

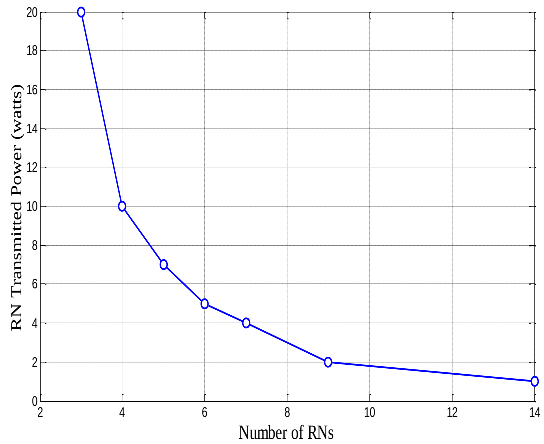


Fig. 3. PRS versus NRS per Cell.

NRS is determined as well-matched with proposed PRS which allocated for each station RSs depends on Eq. (19). This means an increase in the level of allocated power transmission for RS Leads to reduce the number of RS required to deploying per cell in order to reduce the interference between them as shown in Fig. 3.

Fig. 4. demonstrated the relationship of determination of transmission power of RSs with their placement within the cell in order to provide maximum capacity by choosing the appropriate power of RSs with their placement.

NRS is close to this optimization by balancing the NRS with optimal relay placement. At the result, NRS increase when the RS lie far from donor eNB as shown in Fig. 5.

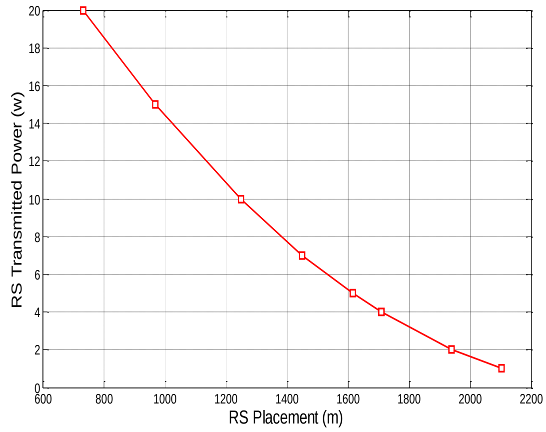


Fig. 4. PRS against RS placement per Cell.

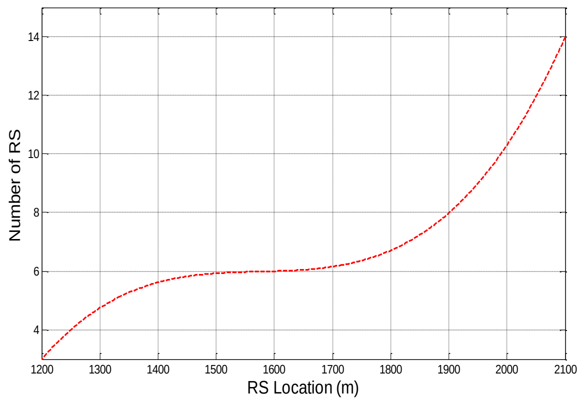


Fig. 5. RS placement versus NRS per Cell

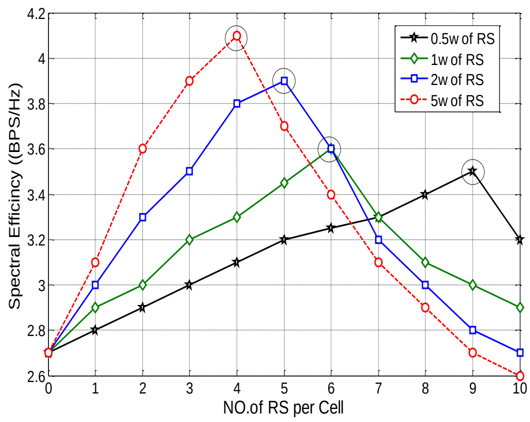
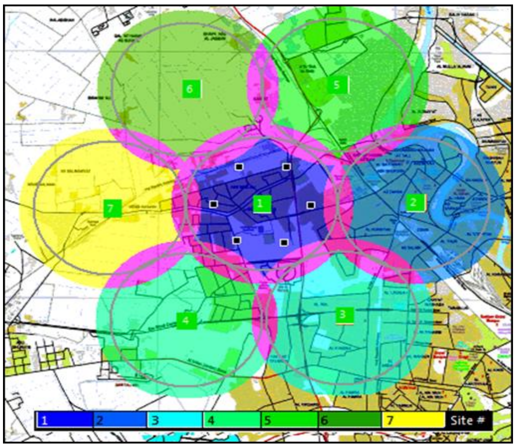
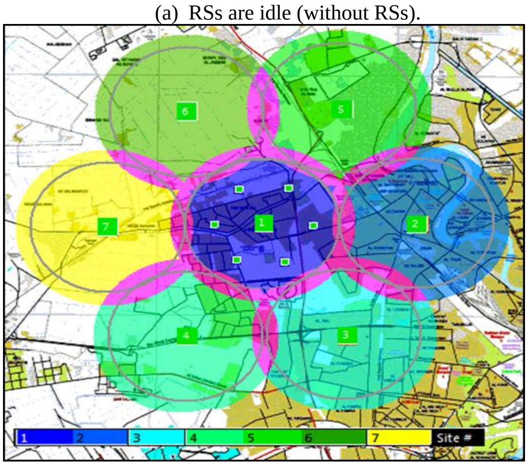


Fig. 6. Spectral efficiency as a function of the NRS per Cell.

For examination the mathematical analysis, Fig. 6. illustrates the maximum capacity which provides by proposed NRS as well as chooses suitable transmission power for each RS. For example, when choosing 1 watt as transmission power, the optimal NRS that achieve maximum capacity is six and vice versa. When the level of received signals from the neighbouring cells is exceeded or equal to the signal from a donor station, the bad interference happens.



(a) RSs are idle (without RSs).



(b) RSs are active (with RSs).

Fig. 7. Interference mitigation with deploying small cells within first tier of cellular networks

ICS telecom EV simulator (radio network planning software) from ATDI company has been used to validate the results of proposed model, i.e. Fig. 7, the simulator has certified by most of communications companies [17].

In Fig. 7 the pink colour represents interference level either from eNBs or from deployed RSs near cell edge region, Fig. 7 (a) depicts the in case of Idle RSs, while Fig. 7 (b) shows in case of activated RSs. The improvement in the model not just increasing the coverage area and capacity but also decrease the level of interference resulted from small cells deployment in central eNB as illustrated in Fig. 7 (a) with a comparison on Fig. 7 (b).

$$E = \sum_{p=1}^{P} \sum_{k=1}^{K} (\delta^{o}_{pk})^2 \tag{20}$$

V. Conclusion

With the rapid growth in cellular networks, small cell deployment becomes one of the keys to increase the capacity and coverage area in next generation of mobile communication, capacity small cell distribution is a crucial issue in next-generation cellular networks. Increasing the number of small cells improves the network capacity. However, it is also aggravating interference between cells, and therefore the optimal number of small cell has been decided in this paper. This work derived and provided formulas for CHL, ds and NRS help the radio planning operators to design the high capacity without the need for high cost of licensed simulators

Nomenclatures

d	Distance between stations
dRS	Distance between Donor and Remote Station
eNB	Donor
HeN	Channels between the Donor and RS
B	Channels between the eNB and RS
HRS	Distance from RS to MS
l	Distance from the eNB to CHL
Lo	Transmit Power of Donor
PeN	
B	
PRS	Transmit Power of Remote Station
XeN	Signals from eNB and RS
B	
XRS	Signals from eNB and RS

Greek Symbols

α	Path loss exponent for free space
σMS	Additive white gaussian noise

Abbreviations

5G	Fifth Generation
AW	Additive White Gaussian Noise
GN	Critical Handover Location
CHL	Path Loss Effect
H	Long-Term Evaluation – Advanced
LTE	mobile station
-A	
MS	
NRS	Number of Relay Stations
RS	Remote Station
RSS	Received Signal Strength

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

All authors cooperated in work conducting, from the idea of the work, gathering the references and data, design the a implementing it and analysis the results.

References

[1] S. A. Asakipaam, J. J. Kponyo, J. O. Agyemang, and F. Appiah-Twum, "Design of a minimal overhead control traffic topology discovery and data forwarding protocol for software-defined wireless sensor networks," *International*

Journal of Communication Networks and Information Security, vol. 12, no. 3, pp. 450-458, 2020.
[2] S. Ravindra and G. K. Siddesh, "Distance based power control for D2D communication in LTE-Advanced networks," *International Journal of Communication Networks and Information Security*, vol. 11, no. 2, pp. 278-282, 2019.
[3] S. Wei, L. Qi, L. Yiqun, B. Meng, C. Guoli, and Z. Hongke, "Small cell deployment and smart cooperation scheme in dual-layer wireless networks," *International Journal of Distributed Sensor Networks*, vol. 10, no. 3, 2014.
[4] M. K. Al-Azzawi, H. S. Hatem, and M. I. Shujaa, "Multiple parameters optimization for cognitive radio environment employing cuckoo search algorithm," in *Proc. Al-Mansour International Conference on New Trends in Computing, Communication, and Information Technology*, 2018, pp. 42-46.
[5] M. Ajamgard and H. S. Shahraki, "Improved phantom cell deployment for capacity enhancement," *The Journal of Mobile Communication, Computation and Information*, vol. 25, no. 1, pp. 157–166, January 2019.
[6] M. Patwary, S. K. Sharma, S. Chatzinotas, Y. Chen, M. Abdel-Maguid, R. Abd-Alhameed, and B. Ottersten, "Universal Intelligent Small Cell (UnISCell) for next generation cellular networks," *Digital Communications and Networks*, vol. 2, no. 4, pp. 167-174, 2016.
[7] P. Muñoz, O. Sallent, and J. Pérez-Romero, "Capacity self-planning in small cell multi-tenant 5G networks," presented at the 2017 IFIP/IEEE Symposium on Integrated Network and Service Management (IM), 2017.
[8] J. Hoadley and P. Maveddat, "Enabling small cell deployment with HetNet," *IEEE Wireless Communications*, vol. 19, no. 2, pp. 4-5, 2012.
[9] C. S. Chen, V. M. Nguyen, and L. Thomas, "On small cell network deployment: A comparative study of random and grid topologies," in *Proc. IEEE 76th Vehicular Technology Conference*, 2012
[10] C. Ranaweera, P. Iannone, K. Oikonomou, K. C. Reichmann, and R. Sinha, "Cost optimization of fiber deployment for small cell backhaul," presented at the National Fiber Optic Engineers Conference, 2013.
[11] W. Guo, S. Wang, X. Chu, J. Zhang, J. Chen, and H. Song, "Automated small-cell deployment for heterogeneous cellular networks," *IEEE Communications Magazine*, vol. 51, no. 5, pp. 46-53, 2013.
[12] J. A. Aldhaibani, A. Yahya, R. Ahmad, R. A. Fayadh, and A. H. Abbas, "Reducing transmitted power of moving relay node in long-term evolution-advanced cellular networks," *Journal of Computer Science*, vol. 10, no. 6, pp. 1051-1061, 2014.
[13] A. Taufique, M. Jaber, A. Imran, Z. Dawy, and E. Yaacoub, "Planning wireless cellular networks of future: Outlook, challenges and opportunities," *IEEE Access*, vol. 5, pp. 4821-4845, 2017.
[14] M. H. Qutqut, H. Abou-zeid, H. S. Hassanein, A. M. Rashwan, and F. M. Al-Turjman, "Dynamic small cell placement strategies for LTE heterogeneous networks," in *Proc. IEEE Symposium on Computers and Communication*, 2014.
[15] B. J. Lee, J. P. Cho, I. H. Ra, and K. S. Kim, "Propagation characterization based on geographic location variation for 5G small cells," *Mobile Information Systems*, pp. 1-8, 2017.
[16] X. X. Nguyen and D. T. Do, "Optimal power allocation and throughput performance of full-duplex DF relaying networks with wireless power transfer-aware channel," *EURASIP Journal on Wireless Communications and Networking*, vol. 152, December 2017.
[17] O. Fratu, A. Martian, R. Craciunescu, A. Vulpe, S. Halunga, Z. Zaharis, and S. Kasampalis, "Comparative study of Radio Mobile and ICS Telecom propagation prediction models for DVB-T," in *Proc. IEEE International Symposium on Broadband Multimedia Systems and Broadcasting*, 2015.

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