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A novel optimal small cells deployment for next-generation cellular networks

Nael A. Al-Shareefi, Ammar AbdRaba Sakran
Faculty of Medical Informatics, University of Information Technology and Communications (UOITC), Baghdad, Iraq

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ABSTRACT

Small-cell-deployments have pulled cellular operators to boost coverage and capacity in high-demand areas (for example, downtown hot spots). The location of these small cells (SCs) should be determined in order to achieve successful deployments. In this paper, we propose a new approach that optimizes small cells deployment in cellular networks to achieve three objectives: reduce the total cost of network installation, balancing the allocation of resources, i.e. placement of each SC and their transmitted power, and providing optimal coverage area with a lower amount of interference between adjacent stations. An accurate formula was obtained to determine the optimum number of SC deployment (NSC). Finally, we derive a mathematical expression to calculate the critical-handoff-point (CHP) for neighboring wireless stations.

Corresponding Author:

Nael A. Al-Shareefi
Faculty of Medical Informatics
University of Information Technology and Communications (UOITC)
Baghdad, Iraq
Email: dr.nael.al_shareefi@uoitc.edu.iq

1. INTRODUCTION

Outage in wireless services in the urban areas due to the poor coverage and the long geographical distance from the donor base station (D_{eNB}) and mobile stations (MS), is critical design challenge that radio planning engineers need to think about. Radio engineers have chosen to deploy more D_{eNBs} with a small radius to solve this issue. However, this solution is impractical science it increases total cost of network and resources allocation [1]. SCs are miniature D_{eNB} that divides a cell into smaller geographical area. SCs have been appeared to save the energy consumption and raise the throughput in cellular scenarios [2]. The most common form of SCs is microcells, picocells and femtocells which can be installed indoor/outdoor [3], [4]. Because of its easy deployment, low power and low cost, SCs provide a feasible and cost-effective way to boost cellular coverage, capacity and quality of service. Since wireless carriers seek to "condense" existing wireless networks to provide data capacity requirements for "5G", SCs are currently seen as a solution to allow the same frequency reuse and as an important means of raising mobile network throughput and quality with increased focus with 4G long term evolution advanced (LTE-A) [5], [6].

Some initial studies involved with CSs deployment were explored in [7]-[19]. Hoadley and Maveddat [12] showed the necessity of CS deployment. Chen *et al.* [13] studied how to deploy small cells nested with macro cells, and improves overall network performance. Ranaweera *et al.* [14] discussed the backhaul of small cells. The automated deployment of a small cell for heterogeneous cellular networks is addressed in [15]. However, the researchers did not identify the optimum SC deployment. In this paper, we propose a new approach that can optimizes SC deployment and enhances coverage area by mitigate the amount of the interference between stations. An accurate and simple mathematical formula was obtained to determine the optimum number of SC deployment (N_{SC}).

2. THEORITCAL ANALYSIS

2.1. Critical-handoff-point

Cellular telecommunications define the handoff as a situation where two frequency channels are available, thereafter the cellular network selects one them [20]. It is activated either by crossing the cell boundaries or by degrading the signal quality. The cellular network searchs for the available channels and chooses which channel and cell to perform this operation [21]. Multiple Hops have been considered as supplementary technology in next generation cellular networks. To assess the CHP in multi-hop cellular networks, received signal strength (RSS) from SC and D_{eNB} need to be known. Consequently, MS selects the strongest in terms of RSS as depicted in Figure 1.

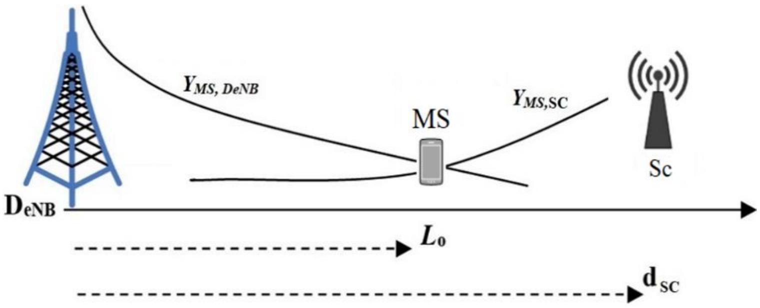


Figure 1. Critical-handover-point

In Figure 1, the distance between the D_{eNB} and SC is indicated by (d_{sc}). The distance from the D_{eNB} to MS is indicated by L_o. The distance from the SC to MS is indicated by (d_{sc}-L_o). Critical-handoff becomes clear when the RSS from the D_{eNB} to MS, ($Y_{DeNB, MS}$), is equal to the RSS from SC to MS ($Y_{SC, MS}$). Based on this relation the value of L_o can be evaluated and ($Y_{DeNB, MS}$) and ($Y_{SC, MS}$) can be mathematically written as:

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

$$Y_{SC,MS} = \sqrt{P_{SC}} H_{SC} X_{SC} \tag{2}$$

where P_{SC} and P_{DeNB} are the transmit power of the SC and D_{eNB}, respectively. H_{SC} is the channel gain from SC location to MS and H_{DeNB} is the channel gain form D_{eNB} to MS. X_{DeNB} and X_{SC} are RSSs from D_{eNB} and SC, respectively. At CHP, the received signal from D_{eNB} to MS equals to the received signal from SC to MS. This situation can be written as

$$Y_{SC,MS} = Y_{D_{eNB},MS} \tag{3}$$

$$\sqrt{P_{D_{eNB}}} H_{D_{eNB}} X_{D_{eNB}} = \sqrt{P_{SC}} H_{SC} X_{SC} \tag{4}$$

$$P_{D_{eNB}} \left| H_{DeNB} \right|^2 = P_{SC} \left| H_{SC} \right|^2 \tag{5}$$

For simplicity, H can be given by [22]

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

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

where α is the path–loss, typical values range between 1.5 and 5. Therefore, In (5) can be written as:

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

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

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

2.2. Optimum number of SCs deployment (N_{SC})

To to reduce the number of the deployed SCs and enhancing the coverage area with minimizing the interference between SC stations, N_{SC} should be computed. To compute N_{SC}, **s**uppose that a MS exists in the middle between two SCs, and that *Lo* is the distance from SC to MS as demonstrated in Figure 2.

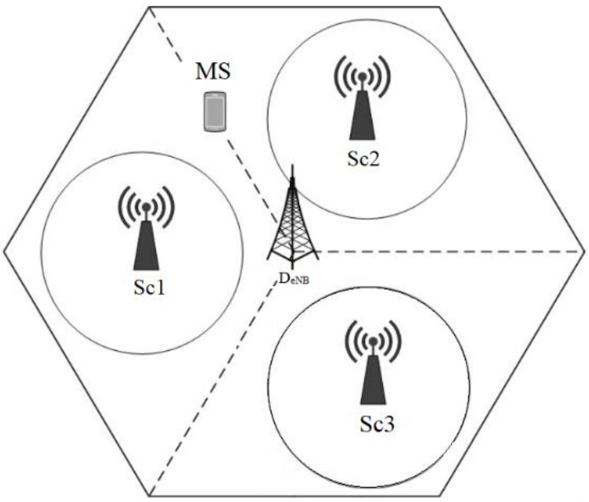


Figure 2. SCs deployment

In Figure 2, increasing the number of SCs can enhance coverage area. But at the same time, it is increasing interference between SCs [23]. This paper presents a solution to balance between increasing number of SCs, increasing interference between SCs and increasing resource allocation by derivation of N_{SC} based on (α) from adjacent D_{eNB} and SCs [24], [25]. In Figure 2, really simple syndication (RSS) from two neighbouring SCs can mathematically expressed as:

$$Y_{MS1} = \sqrt{P_{SC1}} H_{SC1} X_{SC1} + \sigma_{MS} \tag{11}$$

$$Y_{MS2} = \sqrt{P_{SC2}} H_{SC2} X_{SC2} + \sigma_{MS} \tag{12}$$

σ_{MS} is additive white Gaussian noise for mobile station. The RSS from the D_{eNB} can be mathematically expressed as:

$$Y_{D_{eNB},MS} = \sqrt{P_{D_{eNB}}} H_{D_{eNB}} X_{D_{eNB}} + \sigma_{MS} \quad (13)$$

At MS, the interference power among adjacent SCs to MS is greater than or equal to that from D_{eN}B to MS. Therefore, in (11)-(13) can be written as:

$$Y_{D_{eNB},MS} \le Y_{MS1} + Y_{MS2} \quad (14)$$

$$P_{D_{eNB},MS} .(d_S)^{-\alpha} < P_{SC1}(L_o)^{-\alpha} + P_{SC2}(L_o)^{-\alpha} \quad (15)$$

$$P_{D_{eNB},MS} .(d_S)^{-\alpha} < 2P_{SC}(L_o)^{-\alpha} \quad (16)$$

As depicted in Figure 2, SCs deployed at cell boundaries around the D_{eNB} with radius d_S. Consequently, the distance between neighboring SCs is:

$$2L_o = \frac{2\pi d_S}{N_{SC}} \quad (17)$$

Substitution of (17) into (16) produces:

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

Thus, the optimum number of SCs (N_{SC}) is:

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

Based on (19), the optimum number of SCs (N_{SC}) depend on three factors: the distributed transmitted power of each SC (P_{SC}), D_{eNB} and α. These factors provide the maximum enhancement in capacity and coverage area and mitigate the interference between nodes (SCs, D_{eNB}).

3. NUMERICAL RESULTS AND DISCUSSION

The numerical results based on the above theoretical derivation coupled with simulation results using MATLAB R2019a and industrial control system (ICS) telecom simulator, are presented in this section. Figure 3, shows the effect of optimum SC location on the N_{SC}. The highest N_{SC} can be obtained when the placement of SC from D_{eNB} is increased. The N_{SC} value degrades slowly with the decrement of the placement of SC from $D_{eNB.}$ This enhancement in N_{SC} is obtained by balancing the N_{SC} with optimal SC location.

Figure 4, shows the relationship between power allocation of each SC and N_{SC}. The power allocation for each SC increases as N_{SC} decreases based on (19) to avoid interference between neighboring SCs as well as balance the total power consumption for SCs with the N_{SC}. Figure 5, shows the relationship between transmitted power allocation of each SC and their placement within the cell. This relation ensures the enhancement of spectral efficiency by balancing the power allocated for SCs with their locations. The power assigned for each SC is reduced whenever the location of SC from D_{eNB} is increased as shown in Figure 5.

Figure 6 depicts interference alleviation for the optimum SCs deployment based on our approach assuming the number of SCs (N_{SC}=3) and using ICS telecom simulator. Figure 6(a) shows the interference when SCs inside cell boundaries of the D_{eNB} are deactivated (SCs idle), while Figure 6(b) depicts the interference in case of activated SCs. Compared with Figure 6(a), Figure 6(b) shows an interference alleviation and an enhancement in the coverage area.

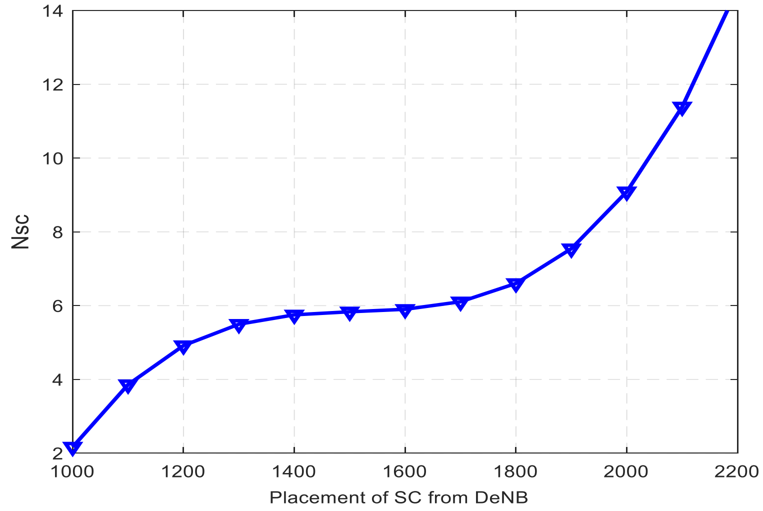


Figure 3. N_{SC} Vs. placement of SC from D_{eNB}

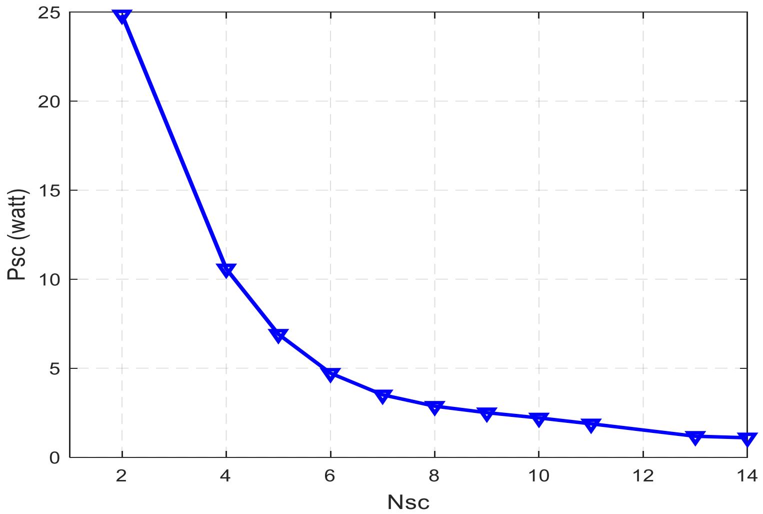


Figure 4. P_{SC} Vs. N_{SC}

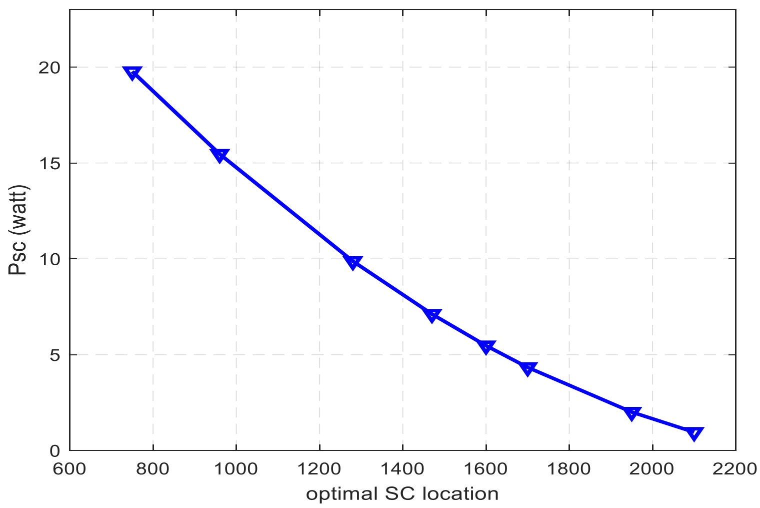
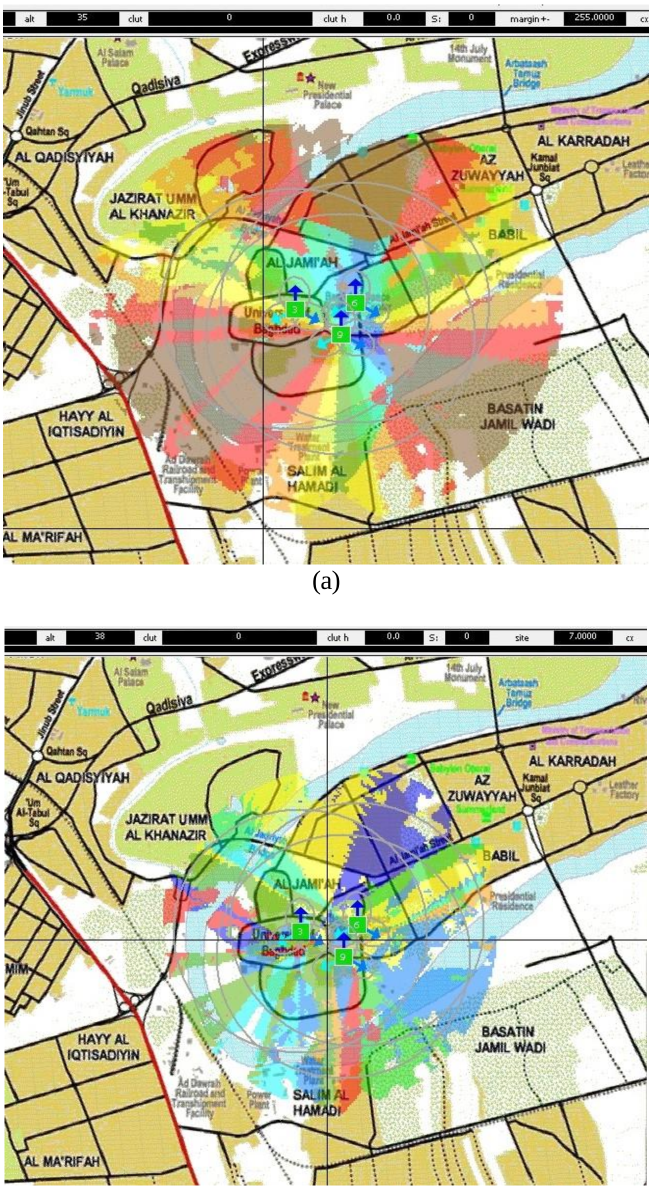


Figure 5. P_{SC} Vs. optimal SC location



(a)

(b)

Figure 6. Interference alleviation with deploying SCs, (a) the interference when SCs inside cell boundaries of the D_{eNB} are deactivated (SCs idle), (b) the interference in case of activated SCs

4. CONCLUSION

This paper investigates a new optimal small cells deployment technique that is developed to mitigate the interference level between adjacent SCs and the D_{eNB}, reduce the total cost of network installation, and providing maximize coverage area. The proposed technique involves more than one phase. These phases aim, firstly, to get accurate equations for critical-handoff-point and optimum number of small cell stations (N_{SC}). The deduced equations showed good accuracy with numerical simulation which represent the second phase. The paper assists radio planning engineers in determination N_{SC} and CHP without using licensed and expensive simulators to achieve maximum coverage area with a minimum amount of interference between adjacent stations for next generation cellular networks.

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