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Optimal Placement of Heterogeneous Wireless Nodes in LTE/WiFi Integrated Networks

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Abstract—Small cell deployment is considered one of solutions to increase capacity and improve the coverage to meet the growing of mobile data traffic. LTE–Wi-Fi Aggregation (LWA) is Heterogeneous based which enables an aggregation between LTE small cells and Wi-Fi Access Points (AP) at radio network level. In this work, we investigate the problems of determining the optimal placement of different types of Heterogeneous wireless small nodes that will be deployed to cover a hotspot zone. The placement is optimized with the objective of (i) Maximizing the total system capacity while considering the minimum Signal-to-Interference-plus-Noise Ratio (SINR) constrain (ii) choosing the optimal number of wireless nodes which guarantee the coverage. The objective function are formulated as Mixed Integer Non-Linear Programming (MINLP) problem and solved using the genetic algorithm. The proposed optimal deployment is compared to uniform distribution placement and showed a significant increase in system throughput.

Keywords: Small cell deployment, HetNets, LWA, Genetic Algorithms

I. INTRODUCTION

In recent years, cellular enabled devices such as smartphones and laptops with cellular modem are using mobile broadband to download content anywhere, any time with data-hungry applications, which increases the mobile data traffic usage at an exponential rate [1]. Even though the performance and capacity of mobile networks are highly

improved in the recent mobile generations, it's still not sufficient to meet the expected huge amount of mobile data traffic demand especially in the hotspot zones. The mobile network operators need an effective way for offloading the mobile data traffic and hence improving the users' quality of experience (QoE).

The small cells can be considered as one of solution as they offered short range coverage to cover a hotspot area and it can be deployed as a supplement to base stations to relief congested traffic. Adopting small cells architecture in a massive IOT network that connect a large number of devices and smart sensors which support huge number of applications can also offer better coverage, less power consumption and high data rates. Small cells-based heterogeneous networks forms an efficient architecture to offload mobile data traffic through a deployment of heterogeneous wireless small nodes (LTE Femto-Base Station "LTE-FBS" and Wi-Fi Access Point "WAP") overlaid on the macro Base Station (MBS).

The use of Wi-Fi unlicensed spectrum provides an attractive opportunity for operators to support their subscribers in a cost-effective way and exploit the unlicensed band. On the other hand, using small LTE-FBS can improve the network capacity if the intra-tier and inter-tier interferences are efficiently managed. Consequently, 3GPP standardized LTE-WLAN Aggregation (LWA) in release 13, where the user's data flow can be sent on both radios simultaneously [2], similar to the idea of LTE Dual

Connectivity (DC). In LWA, the data aggregation is performed at the radio access network (RAN), where the evolved NodeB (eNB) controls all the traffic on both LTE and Wi-Fi radio links. Aggregating the data transparently to the core network is one of the LWA advantages. In LWA, the LTE small node can be connected to the WLAN access point in a collocated deployment via internal backhaul or in a non-collocated deployment via an Xw interface. In release 13, the LWA aggregation is performed in the downlink and characterized by two types of bearer: the split bearer and switched bearer to identify if the user's data will be steering over one link or over both links [2]. Since LTE and Wi-Fi operating on two different bands (licensed and unlicensed), the use of heterogeneous wireless small nodes with different technologies (LTE and Wi-Fi) can minimize the interference and improve the total network capacity if these nodes are optimally located within the targeted hotspot zones.

In this paper we investigate the problem of determining the optimal placement of a mixture of wireless small nodes (LTE-FBS, WAP, and LWA nodes) that will be deployed to cover a hotspot zone under the coverage area of LTE MBS. Our proposed architecture can be sufficient for different types of wireless devices, who are seeking different requirement. The placement problem is formulated as an optimization problem with an objective to maximize the total system capacity in terms of the throughput while considering the minimum Signal-to-Interference-plus-Noise Ratio (SINR) requirement to guarantee the coverage of the target area. The objective function are formulated as Mixed Integer Non-Linear Programming (MINLP) problem and solved using the genetic algorithm.

The rest of the paper is organized as follow. Section II represents the related work; our proposed system model and the objective function are formulated in section III. The objective function is then formulated in section IV using genetic algorithm. Section V represents the simulation results including the simulation parameters. Finally the conclusion is mentioned in section VI.

II. RELATED WORK

The interworking between different radio access technologies can be considered as a promising solution to support different types of devices with different requirements as it can offers better coverage, higher capacity with low complexity and low cost. Interworking between LTE and Wi-Fi technologies was introduced in [3-5] in terms of data offloading. Other studies [6-11] focused on the RAT selection in HetNets architecture, as the user association can be considered as a challenging problem.

The aforementioned studies [3-11], consider sending the user traffic either on LTE or Wi-Fi in their proposed architecture but none of them consider the aggregated architecture, where the user's traffic can be send on both LTE and Wi-Fi simultaneously. In [12-13] the authors considered the LWA aggregation in their proposed architecture where the user's data can be send on both LTE and Wi-Fi technologies simultaneously.

The deployment of small cells in a hotspot zones is one of the technical solutions to meet the challenges of data traffic rise [14]. Many cell planning schemes were studied in the literature with different objectives. In [15], the authors formulated a solution for efficient placement of LTE small cells with power control mechanism to ensure all building regions coverage and dynamically the femtocell transmitted power based on the occupancy of Macro users. the authors in [16] proposes a cell planning algorithm to satisfy both cell coverage and capacity tacking into account the inter-cell interference under the assumption that the covered areas have a different user densities. They proposed algorithm run in three steps: 1) in the first step select the locations of macro BSs' to is selected to satisfy global coverage and capacity, 2) the second step the algorithm selects the locations of small BSs' to satisfy capacity in each subarea without considering coverage, and 3) in the third step they remove redundant BSs using the elimination algorithm. [16] focuses on the cost and energy efficiency based optimal deployment strategies for small-cell and fiber backhaul networks. In [18], authors propose a small cell placement model to maximize the coverage, ensure

the required capacity and mitigate the cross-tier interference in the crowded zones. A limitation of works in [15-18] is that the authors have considered the placement only with respect to homogeneous radio access technologies (RATs).

The work in [19] investigates the small base stations (SBS) placement problem in high demand outdoor environments. Authors propose a dynamic placement strategy (DPS) that optimizes SBS deployment for two different network objectives, minimizing data delivery cost and minimizing macro cell utilization. An optimal placement of collocated and non-collocated LWA nodes in hotspot zones with the objective to minimize the number of LWA nodes without coverage hole and maximizing the SINR in every sub-region of a building is proposed in [20]. In this context, the authors considered a small hotspot area covered by only one type of LWA nodes. In this paper we will consider the optimal placement problem of three different types of wireless small nodes (LTE-FBS, WAP, and LWA nodes), in order to overcome the limitation of each technology alone.

III. SYSTEM MODEL AND PROBLEM FORMULATION

In this paper, we consider a heterogenous network that consists of one MBS and N heterogenous wireless small nodes (LTE-FBS, WAP, and LWA nodes) that are deployed on a high demand traffic area (hotspot zone) covered by the MBS. The total number of nodes can be represented by two sets S^{LTE} and S^{WiFi} according to the nodes technology (LTE or Wi-Fi) in which any LWA node is represented by one LTE-FBS belonging to the set S^{LTE} and another WAP belonging to S^{WiFi} . The WAPs are operating on different frequency band from that of MBS and LTE-FBS, while all cellular BSs share the same frequency band even those are working in the aggregated mode. The hotspot zone is divided into K sub-regions, each with a much smaller size compared to the size of the hotspot zone as shown in Fig.1, so we can safely assume that within every sub-region the SINR value is constant.

Given the number of heterogeneous wireless small nodes and the ratio between the number of

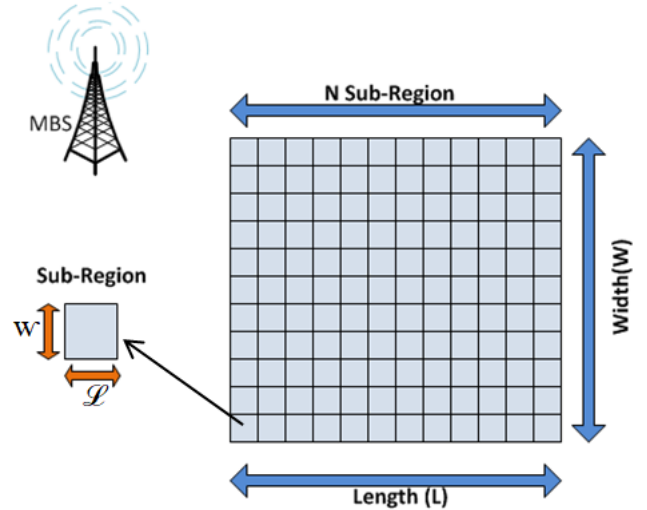


Fig. 1. A Hot Spot Area Considered Proposed System Model

WAPs, LTE-FBS, and LWA nodes, we optimize the placement of these nodes among the hotspot area in order to maximize the system capacity while considering the SINR threshold requirement in each subregion to guarantee coverage. This can be formulated as the following objective function,

$$\max \sum_{j \in N} \sum_{i \in K} \beta R_{ji}^{LTE} + \alpha R_{ji}^{WiFi} \quad (1)$$

S.t

$$SINR_i \geq SINR_{th} \quad \forall i \in K \quad (2)$$

where R_{ji}^{LTE} is the achieved data rate in subregion i covered by LTE node j , R_{ji}^{WiFi} is the achieved data rate in subregion i covered by WAP node j , while β and α are binary indicators which their values can be decided as follows: $\beta = 0$ and $\alpha = 1$ if j represents WAP; $\beta = 1$ and $\alpha = 0$ if j represents LTE-FBS; and $\beta = 1$ and $\alpha = 1$ if j represents LWA node. Constraint (2) represents the minimum SINR requirement ($SINR_{th}$) at each subregion in order to guarantee its coverage by at least one wireless node (WAP, LTE-FBS, or LWA). The threshold value for the SINR depends on the radio access technology of each node (LTE or Wi-Fi). The achieved data rate in the sub-region i covered by LTE or Wi-Fi node j can be calculated as follows,

$$R_{ji}^{LTE} = \frac{B_j^{FBS}}{K} \log_2 \left(\frac{P_j^{FBS} h_{ji}}{P^{MBS} h_i^{MBS} + \sum_{m \in S^{LTE}/\{j\}} P_m^{FBS} h_{mi} + \sigma_j^2} \right) \quad \forall j \in S^{LTE} \quad (3)$$

$$R_{ji}^{WiFi} = \frac{B_j^{WiFi}}{K} \log_2 \left(\frac{P_j^{WiFi} h_{ji}}{\sum_{m \in S^{WiFi}/\{j\}} P_m^{WiFi} h_{mi} + \sigma_j^2} \right) \quad \forall j \in S^{WiFi} \quad (4)$$

where P^{MBS} , P_j^{FBS} , and P_j^{WiFi} indicate the transmit powers of LTE MBS, LTE-FBS j , and WAP j , respectively. h_i^{MBS} represents the channel gain on the link between MBS and subregion i while h_{ji} represents the channel gain between wireless node j and subregion i . B_j^{FBS} and B_j^{WiFi} represent the LTE and Wi-Fi system bandwidth, respectively. σ_j^2 represents the noise power of node j .

IV. GENETIC BASED OPTIMAL PLACEMENT

Genetic Algorithm (GA) is categorized as global search heuristics, which search for exact or approximate solution in both constrained and unconstrained optimization problems. It is based on natural selection, process driven biological evolution. In the proposed GA, Eq. (1) is used as the fitness function which is evaluated in each iteration according to the generated population that consists of N chromosomes representing the positions of the wireless nodes. Constraint (2) is considered as a separate objective within the GA algorithm. GA terminates when the difference between two successive values of the Fitness function reaches a predefined tolerance, or when the maximum number of generations (iterations) is exceeded which those are considered the stopping criteria for the GA as shown as Fig.2.

GA algorithm can be formulated with three main rules to formulate a next generation through current population, which are selection, crossover and mutation. The process of genetic algorithm can be started by an initialization process to indicate the population and randomly selected the chromosomes. The population of chromosomes represent as candidate solution to the initialization

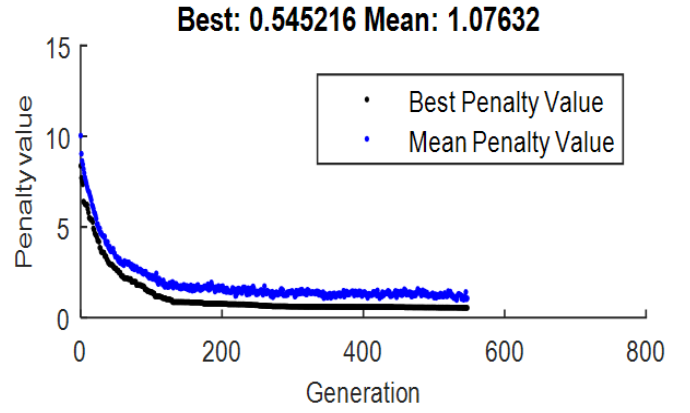


Fig. 2. Genetic Algorithms Convergence

problem. The initialization is then followed by a representation process which can be formulated as chromosomes encoding. A breeding process is then evaluated which include first a fitness function to evaluate the quality of chromosomes and a selection process to guide the fitness function to select the chromosomes for reproduction. Second a cross over process which can be chosen as fixed or random single point with a chosen ratio to create new offspring chromosomes by swapping two subsequence chromosomes.

A mutation process is then applied which also can be classified into a fixed or random single point and can be performed by flipping individual bits in the new offspring chromosomes. The breeding process is continued until the numbers of new offspring become as equal as the number of the initial produced chromosomes.

Algorithm 1: Genetic Algorithm

Generate initial Population P_0

Evaluate Population P_0

While (stopping criteria for the GA.) **Repeat**

{

For 1: N number of Matching Generations

 {

Select N_M chromos

Find Fitter chromosomes validate eq. (1)

Constraint $SINR > SINR_{th}$.

Crossover create new offspring

Mutation New chromosomes

 }

Evaluate (New chromosomes)

}

Table I Simulation Parameters

Simulation Parameters	Value
LTE Parameters	
Transmit power of FBS	20dBm
Path loss between FBS and UE	$140.7+36.7\log_{10} d(km)$
System Bandwidth	20MHz
Channel Bandwidth	180KHz
SINR Threshold	-2 dB
Noise Power Density	-174 dBm/Hz
WLAN Parameters 802.11n	
Transmit Power of WAP	23dBm
Path loss between WAP and UE	$20\log_{10}(2400) + 30\log_{10} d(km) + (13 + 3) - 28$
WLAN Bandwidth	20MHz
Noise Power Density	-174 dBm/Hz
Spatial Streams	4
Minimum Contention Window Size	16
Minimum Number of Re-transmission	6
SINR Threshold	2 dB
SIFS	10 μ s
DIFS	50 μ s
ACK	160 bits
RTS	208 bits
CTS	160 bits

The genetic algorithm process is explained in algorithm 1. The presented algorithm explained the three main genetic rules in generating the new population using a fitness function in each iteration while considering a $SINR_{th}$ as a constraint.

V. SIMULATION RESULTS

We consider an integrated network architecture which consists of heterogeneous wireless small nodes (LTE-FBS, WAP, and LWA nodes) allocated in a hotspot zone of area $100 \times 100 \text{ m}^2$ under the coverage of a MBS. The hotspot zone is divided into 100 sub regions each with $10 \times 10 \text{ m}^2$. The rest of simulation parameters are presented above in Table I. The proposed objective function is evaluated using genetic algorithms to determine the optimal placement for three types of wireless small nodes (LTE-FBS, WAP, and LWA nodes) to cover

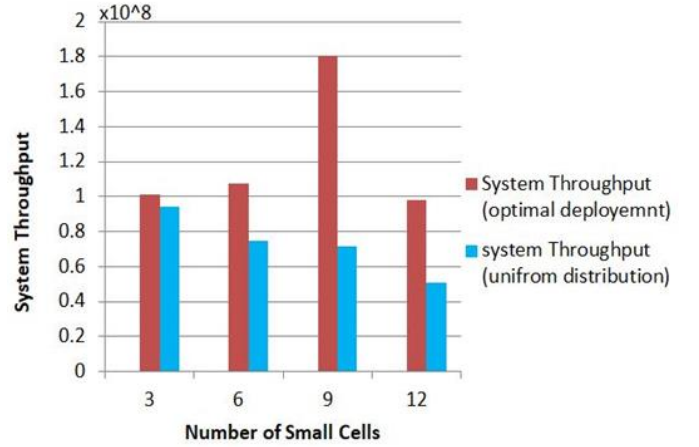


Fig. 3. System Throughput VS Number of Small Cells

a dense area taking into consideration a $SINR_{th}$ as a constraint function.

We also studied the impact of increasing the numbers of wireless small nodes deployment on the coverage, and their reflection on the total system throughput. In order to analyze our framework, our proposed algorithm is compared with placement of wireless nodes at a uniformed distribution as shown in Fig.3 We compared our proposed optimal small nodes deployment to small nodes deployment at a uniform distribution. The numbers of small nodes in Fig.3 reflects the three different types of wireless nodes, for example 3 small cells means one FBS, one WAP and one aggregated node, while 6 means 2 of each types and etc. the number of small cells are changing in both deployments to represent the effect of increasing the number of mall nodes in a dense area on the system throughput.

Fig.3 shows that, starting with a small number of wireless nodes. The $SINR_{th}$ is maintained in both deployment and our proposed algorithm results were close to the uniform distribution deployment. However, the selected number of nodes was lower than the coverage and capacity requirements which results in low system throughput in both deployment algorithms. Through increasing the number of small cells in the dense area the system throughput increase while maintains the required $SINR_{th}$ in our proposed optimal placement algorithm. In contrary, when the wireless small nodes are placed at uniform distribution, a reduction in system throughput has been noticed due to overriding the $SINR_{th}$. the continuous increase in

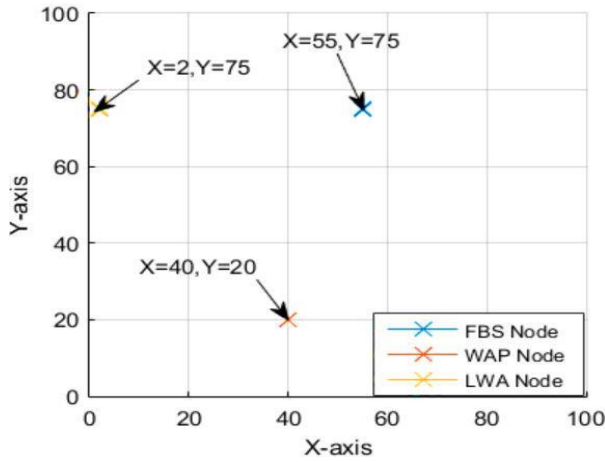


Fig .4. Optimal Cell Deployment of 3 Wireless Nodes.

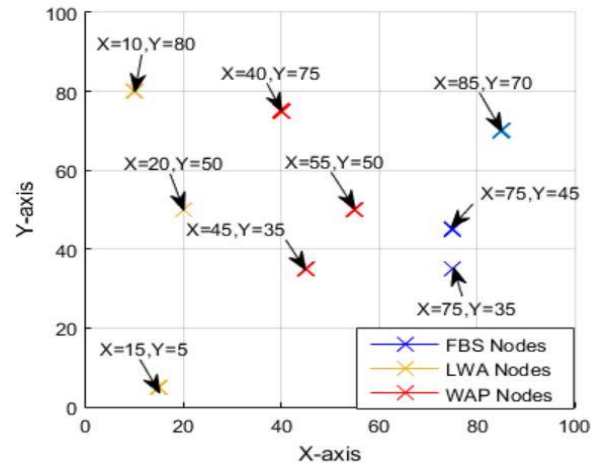


Fig .6. Optimal Cell Deployment of 9 Wireless Nodes.

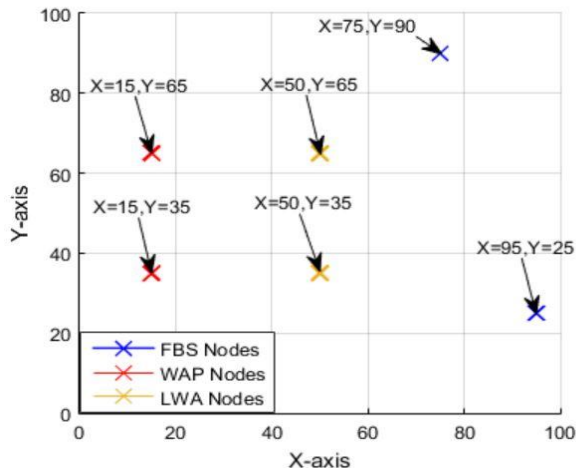


Fig .5. Optimal Cell Deployment of 6 Wireless Nodes.

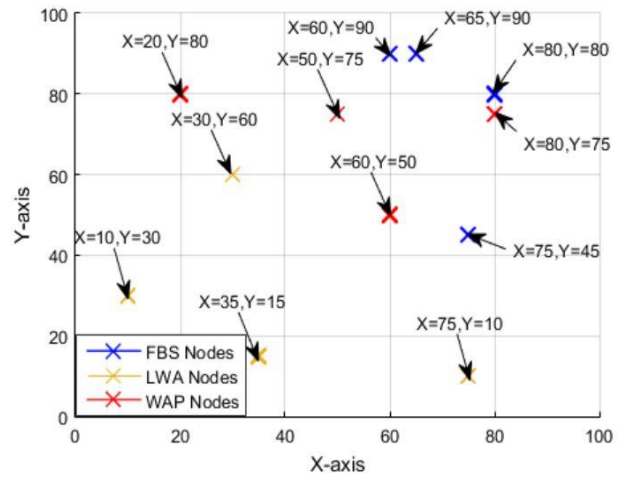


Fig .8. Optimal Cell Deployment of 12 Wireless Nodes.

the number of wireless nodes will result in degradation in system through in both deployment due to the interference between the wireless nodes which make it difficult to maintain the $SINR_{th}$.

In Fig.4 and Fig.5, we represent the cell plotting of the optimal placement of different number of wireless nodes in the hotspot area of size 100m x 100m as illustrated before in the Fig.1. We choose these numbers of nodes to represent the optimal deployment location which results in the system throughput illustrated in Fig.3.

Fig.4 captures the nodes distribution on the hotspot zone, it can be noted that, although the three nodes are deployed at optimal placement, however the selected number of nodes was lower than the required coverage and they can't serve all the sub-regions in the hotspot area. In Fig.5, the number of wireless nodes increase to reach 6 (2 of each type of

wireless nodes), by increasing the number of the wireless nodes, the coverage increase to fulfill approximately 75% of the whole density area. From this, increasing the number of nodes to an optimal number can lead to get a better coverage to maintain the $SINR_{th}$ and increase the system throughput as shown in Fig.6 which captures the distribution of 9 wireless nodes (3 of each type) to cover approximately 90% of the hotspot zone. It can be noted that, covering the hotspot zone with the optimal placement of 9 nodes can result in 45% increase in the system throughput compared to the two other deployments.

In Fig.7, the number of wireless nodes increases to reach 12 nodes (4 of each wireless node type), we can be noted that although the optimal deployment of 12 wireless nodes success to serve all the sub

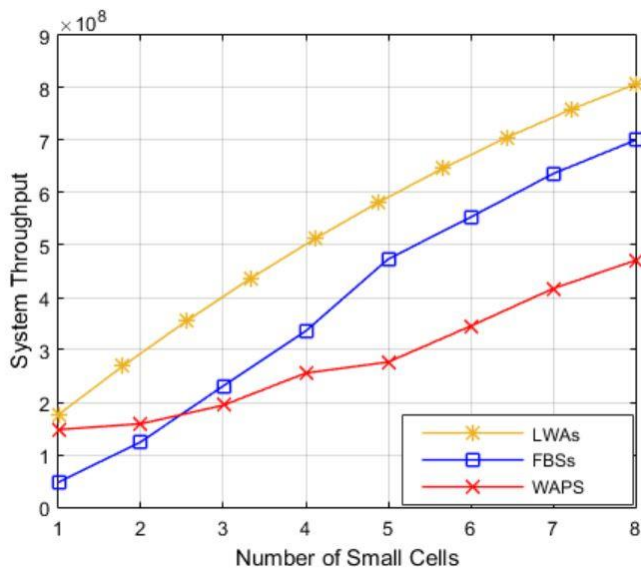


Fig. 5. System Throughput VS Number of Small Cells.

regions in the hotspot zone, however increasing the number of nodes can affect the system throughput due to the interference between the wireless nodes which make it difficult to maintain the $SINR_{th}$.

Fig.8 also shows the comparison between the three types of wireless nodes in terms of system throughput while changing the number of the Wireless nodes in each type. From Fig. 5, we can be noted that covering the Hotspot zone all with optimal placement of LWA node will result in improvement of the system throughput compared to FBS and WAP, however it will increase the network deployment cost and complexity. Regarding the FBS, if all the Hotspot zone was under the coverage of FBSs optimal location, this will result in degradation in the system throughput by a small amount compared to the WAPs, however by covering the hotspot zone all with FBSs exploiting the unlicensed band is missed. From this we can obtain that, mixing different types of wireless nodes will improve the system throughput and overcome the limitation of using each type alone.

VI. CONCLUSION

In this paper, we investigated the optimal deployment of a mixture of different technologies wireless small nodes problem under the coverage area of LTE MBS. We have addressed the placement problem with two major objectives,

which include (i) Maximizing the overall system throughput under a SINR constrain (ii) choosing the optimal number of wireless nodes which guarantee the coverage. The objective function are formulated as Mixed Integer Non-Linear Programming (MINLP) problem and solved using the genetic algorithm.

Solutions obtained for these optimization problems have improved the system performance in terms of coverage and throughput by 50 % while maintains the required $SINR_{th}$ compared to the uniform distributed scenario, and overcome the limitation of using each type alone when employed independently, which fits the requirements of the new trends (M2M, and IoT) applications with billions of connected devices transmitting sensor data that will use these networks.

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