ISSN 2047-3338

Innovative Technique for a Rational Location of Antennas on a Shared Tower in a Multi-Operator Environment

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***Abstract*—Tower sharing provides benefits to both operators and regulators in terms of cost saving and relative ease of deployment. Notwithstanding these benefits, tower sharing or colocation can result in some technical challenges such as non-availability of optimal height. This work proposes an algorithm to find the optimal height based on outage probability and go further to predict other possible positions on the tower with comparable performance for effective tower sharing based on a required isolation distance and spectral efficiency. Mathematical modelling and computer simulations are used in this paper. The results showed that different number of locations which are close to the global optimal height, provide comparable performance. Four different scenarios based on 3 and 7 clustering and 120° and zero sectorization of antennas are used in the testing of the algorithm with the MATLAB simulation environment. It was observed that different scenarios caused the optimal height to vary and hence put a limitation on the possible number of locations with comparable performance for colocation. The findings of this article can motivate more tower sharing in the telecommunication sector.**

***Index Terms*—Tower Sharing, Antenna Co-location, Optimal Height, Outage and Spectral Efficiency**

I. INTRODUCTION

INFRASTRUCTURE sharing among telecommunication network operators is gaining massive popularity due to its profound benefits such as low capital expenditure and relative ease of deployment especially for new entrants. Passive infrastructure sharing that is sharing of space or physical supporting infrastructure such as tower, site, trench, power and other "non-intelligent" portions of the mobile network, which does not require active operational coordination between network operators has profound benefits such as low capital expenditure and relative ease of deployment especially for new entrants [1]. Tower sharing or colocation, which is a form of passive sharing, provides a number of benefits to stakeholders, but also raises a number of technical challenges such as non-global optimal height for new occupiers.

Ineffective colocation can have adverse effects on the throughput, coverage and spectral efficiency of a cell. But opting for tower sharing, which has CAPEX and other benefits may require mounting antennas away from the global optimal height [2]. Choosing an optimal height is crucial in cellular communication planning which indeed relates very keenly to performance indicators or quality of service [2], [4]. Thus, finding an effective way to share a tower or collocate while achieving the required performance can motivate more operators to opt for tower sharing.

With practical LTE assumptions in [6], the decoupling of antenna tilt and height in the optimization of large networks and their impact on performance was examined. The performance consisted basically of a utility function based on the spectral efficiency at cell edge and the average spectral efficiency of the network. It was found that decoupling height and antenna vertical tilt didn't have a significant impact on performance. Moreover, this technique also reduces the search space significantly which further reduces optimization complexity and time. However, it was proved in [6] that the optimization algorithm has positive impact on the performance of the network when height and tilt are separately used [4], [8], [7]. Likewise, [4], proves average sector spectral efficiency can be improved by 10% while the sector edge spectral efficiency can even be improved by 100% by varying only the vertical tilt angle in a simulated LTE like environment.

Subsequently, down-tilting can be used to compensate suboptimal height during deployment, but efficient tilt still depends on the appropriate height because there is a constraint on how much tilt can be achieved, and thus an optimal height is required for the right tilt, to achieve optimum coverage [2], [5], [6], [7].

This paper proposes an algorithm based on outage probability and spectral efficiency to determine the best optimized height that meets an acceptable coverage and predict a set of available heights with comparable performance to the optimal for co-sharing. The proposed algorithm is modelled and simulated with MATLAB (R2015a). The rest of the paper is organised as follows; section 2 provides the proposed algorithm with some mathematical modelling, section 3 deals with the testing of the algorithm in MATLAB and also discusses the results, and finally

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section 4 provides the conclusion.

II. PROPOSED ALGORITHM

A. Algorithm Description

The algorithm for predicting the optimal height and other heights with comparable performance is based on outage probability, spectral efficiency and antenna isolation.

The algorithm is depicted in Fig.1 below. The algorithm typically determines the optimal height by using the outage at the cell edge and the overall outage of the cell. It then goes further to determine other heights which are close to the optimal height based on a required isolation distance and output other heights for colocation based on a required spectral. The heights which meet the spectral efficiency requirement are output as the best heights for colocation.

B. SIR Values for Different Heights

Initially, the Signal to interference ratio (SIR) values for various heights are taken and their outage calculated with (1) below.

$$O(h) = P_{outage}(SIR_o) = P_r(SIR(h) < SIR_o) \quad (1)$$
$$= 1 - Q(\frac{SIR_o - m_{SIR\,(h)}}{\sigma_{SIR}(h)}), \forall\, h$$

Note:

- $O(h)$ designates the outage for the whole population data for a height h
- SIR_o is the threshold,
- $m_{SIR\,(h)}$ is the mean and
- $\sigma_{SIR}(h)$ is the standard deviation.

C. Outage at the Cell Edge

Secondly, the outage at the cell edge is also calculated. The cell edge is described as a distance beyond an assumed value 90% of the cell radius and it is given by

$$d_e = R \times 0.9 \quad (2)$$

Where R is the radius of the cell. With this criteria, the SIR values which are at distance d_e and beyond are sampled and the outage for each height is calculated as follow

$$O_e(h) = P_r(SIR(h, d_e) < SIR_o) \quad (3)$$
$$= 1 - Q(\frac{SIR_o - m_{SIR\,(h,d_e)}}{\sigma_{SIR}(h, d_e)})$$

The value $O_e(h)$ is then inverted and scaled to the range of 0-1 as below

$$O_{e'}(h) = \frac{1}{O_e(h)} \quad (4)$$

$$O_{eS}(h) = (O_{e'}(h) - \min(O_{e'}(h)) / (\max(O_{e'}(h)) - \min(O_{e'}(h)) \quad (5)$$

These values are then weighed down as below

$$U_e(h) = O_{eS}(h) \times \frac{1}{\beta} \quad (6)$$

D. Formulation of Objective Function

The objective function O_{pt} to be optimized can be expressed as follows

$$O_{pt}(h) = \frac{1}{|M|}\sum_{j\in M}(O(h) + U_e(h)) \quad \forall\, M \quad (7)$$

The objective function O_{pt} to be optimized, where $O(h)$ is the outage with respect to a height and $U_e\,(h)$ is the inverted scaled cell edged outage, M is a set of different base stations. Formula below (8) is the gradient which can be followed to get the global optimum.

$$\frac{dO_{pt}(h)}{dh} = \left\{\frac{O_{pt}(h_b - \Delta_b) - O_{pt}(h_b + \Delta_b)}{(h_b + \Delta_b) - (h_b - \Delta_b)}\ , b \in\right\} \forall\, C_i \in M \quad (8)$$

$h_{min} \le h_b \le h_{max}$, with h, the base station height

Thus find $\min (O_{pt}(h))$ in (7) subject to the gradient in (8). *M* is the total number of base stations, *Ci* is the subset of base station which are co-channelled and thus forms a cluster b=1…||Ci || and ||Ci||≤Z, where Z is the number of cells in the cluster. Further proceed to determine the average spectral efficiency for all the data at each height with

$$\Gamma = \frac{C}{W} = \log_{10}(1 + \frac{S}{I + N}) \quad (9)$$

$$SIR \approx \frac{S}{I}, \text{since } I \gg N \quad (10)$$

$$\therefore\ \Gamma = \log_{10}(1 + SIR) \quad (11)$$

Thus

$$\acute{\Gamma} = \frac{\Gamma}{N'}, \quad (12)$$

$\acute{\Gamma}$ is average spectral efficiency and N' is the total number of data values.

Where C is the Shannon limited capacity, B the bandwidth of the system, S the signal power and I and N, the interference and Noise power respectively. The Ratio of C to B gives the ideal spectral efficiency and finally SIR is the signal to interference ratio.

Furthermore, the distance dv is determined to meet the isolation required in order to have minimal interference from the collocated antennas

$$I_v[dB] = 28 + 40 \times \log{(d_v / \lambda)} - (G_{Tx} + G_{Rx}) \quad (13)$$

If $G_{TX}=G_{RX}$ =0dBi then

$$I_v[dB] = 28 + 40 \times \log{(d_v / \lambda)}\ ) \quad (14)$$

$$\therefore\ \ d_v = \lambda \times 10^{-(0.7 - 0.25 I_v)} \quad (15)$$

I_V (dB) is vertical isolation, d_v (m) is separation for required isolation, G_{TX} (dBi) and G_{RX} (dBi) are the gains of the

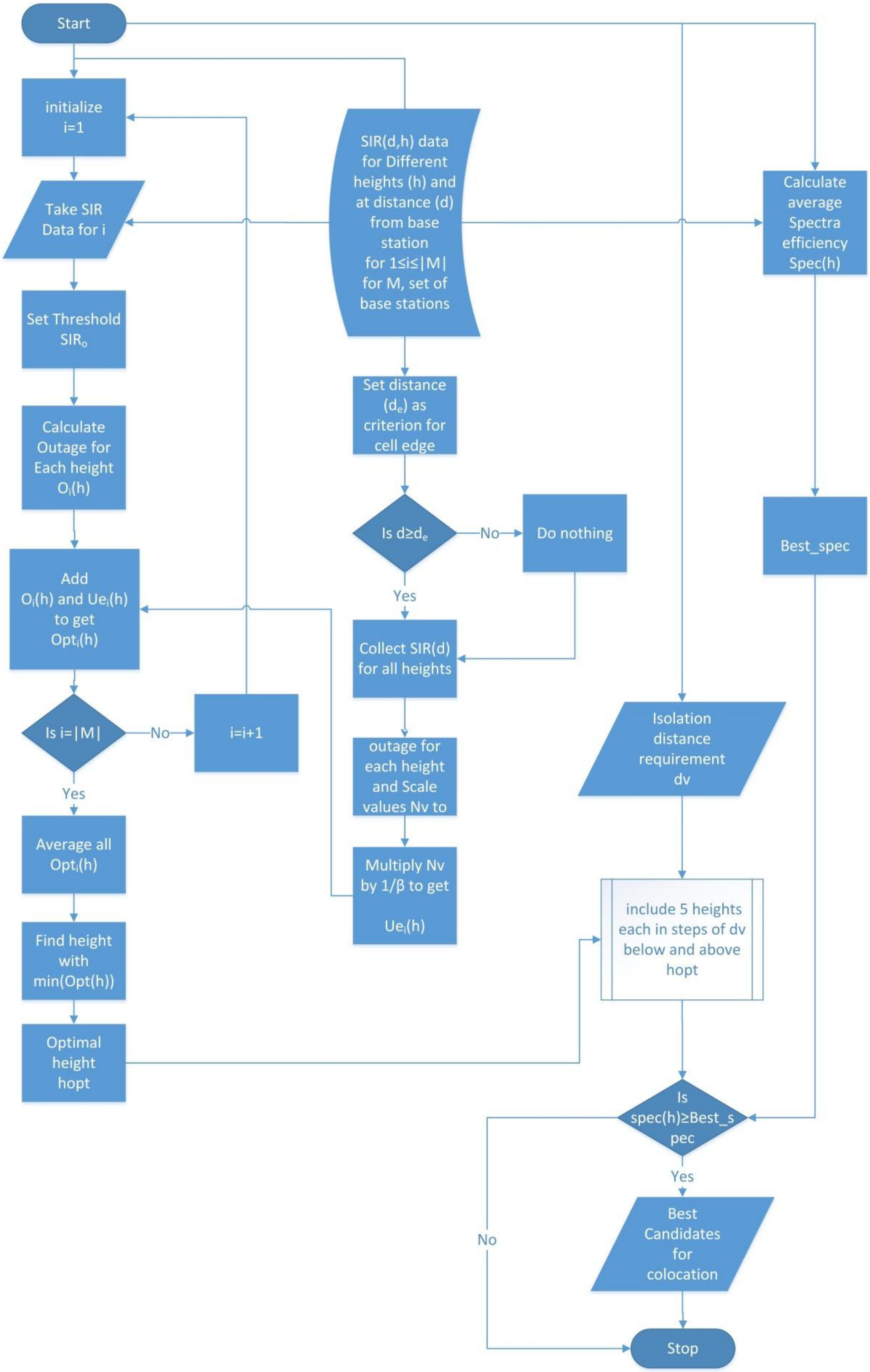

Fig. 1. Flowchart Describing the Proposed Algorithm

interfering and interfered antennas respectively and λ (m) is the wavelength of the interfered system frequency band.

E. Selection of Other Heights Based on the Antenna Isolation Requirement

An isolation of about 70dB has been reported to be achieved with vertical separation of 0.5m in [9]. A separation of 1m has therefore been assumed in this paper to achieve the desired isolation. On this basis, five (5) heights have been added below and above the optimum height. The value five (5) is reasonable since it gives eleven possible locations.

The next stage consists of getting the spectral efficiency of the selected heights and choosing the ones with the best spectral efficiency as the best candidates' locations (heights) for co-sharing.

F. Parameters Adopted for Different Simulation Scenarios

Monte Carlo link level simulation is used to collect the data by taking 10000 snapshots. The first tier of the cellular system with a centre reference cell and six interfering is considered.

TABLE I
SCENARIOS BASED ON CLUSTER SIZE AND ANTENNA SECTORS

Scenario	Cluster size	Sectoring
1	3	120^{o}, 3 sector
2	3	None, omnidirectional
3	7	120^{o}, 3 sector
4	7	None, omnidirectional

The propagation model used in Table II has been described in [10], where Ptx is the transmitter power, Prx is the received power, Gtx and Grx are the transmitter and receiver antenna gains respectively. *L* is the Pathloss, f carrier frequency in MHz, *h* is transmitting station height above average roof height in meters, *d* is the distance between UE and base station in kilometres. The Front to back ratio for 70^{o} at 3dB bandwidth of 25dB is assumed.

The SINR is calculated assuming $I >> N$ thus the noise is ignored, which gives SIR as follow:

$$\mathrm{SIR} = \frac{\mathrm{S}}{\sum \mathrm{I_C}} \tag{16}$$

Where *S* is the value of the desired signal and *Ic* is the interference observed from co-channels. Further SIR calculations are described in [10].

III. PERFORMANCE ANALYSIS

Different simulation scenarios have been considered during the performance analysis. Firstly, an analysis based on outage only have been considered followed by a consideration of the optimization function which was applied to different simulation scenarios explained earlier.

TABLE II
ASSUMED PARAMETERS FOR THE TESTING OF THE ALGORITHM

Parameter	Assumption
Cell radius	1Km
Propagation model	$\mathrm{L = 21log(f) + 18\log(h) + 80 + (40 - 0.16h)log(d)}$ $\mathrm{Prx = Ptx - max(L - Gtx - Grx, MCL)}$
Carrier frequency	2GHz
Co-base station height range	27-30m
Base station transceiver power	46dBm
Outage threshold	-0.5dB
Minimum coupling loss	70dB
Height range for optimal selection	1-50m

A. Analysis of Scenarios Based on Outage Only

Fig. 2 presents the result of the comparison based on outage. It can be observed that for the different scenarios considered, different outage probabilities were obtained. The best category of outage probabilities was recorded with scenario 2, that is, 7 cluster size cell and 120^{o} and the worst was recorded with scenario 3, that is, 3 cluster size cell with Omni directional antenna. These findings agree with theoretically expected results because using 7 cluster size cell, the frequency reuse distance is relatively far apart, which makes interference from co-channels minimal, however, with frequency reuse of 3, base stations are relatively close and the reuse distance is shorter, this increases the co-channel interference and thus result in minimal SIR. However, the benefit of using smaller reuse distance is that, capacity is increased [11]. Using sectorization, further improves the interference characteristics, since sectors focus the beam of the antenna in only specific directions, thus interference with co-channels are reduced as compared to Omni directional antennas where antennas radiate in all directions [12]. Another important finding with the comparison based on outage only, is that, scenario 1 and scenario 4 converge and give relatively equal performances. This implies that higher cluster size can help reduce interference with Omni directional antennas and sectorization can also help reduce interference as observed with scenario 1 over scenario 4. These findings corroborate with several literature as observed in [11], [12], [13], thus confirming the validity of the data used and the effectiveness of the adopted algorithm.

B. Analysis of Scenarios Based on Developed Optimization Function

A comparison of scenarios, based on the optimization function which seeks to minimize the outage in order to achieve the optimal height and eventually use it as a reference for the prediction of the other heights (locations) has been performed. The outcome of the simulation results based on the optimization function depicted earlier is illustrated in Fig. 3.

In general, the optimization results show lower outages in scenario 2 and higher in scenario 3. It is important to observe that the optimal heights for the different scenarios are obtained at the minimum of the function, which indeed show how unbiased, the algorithm is in different scenarios. It can be deduced that the algorithm scales well under different conditions or scenarios. As the height increases above the optimal location, the output of the function begins to increase, which is a reflection of how increasing the height will result in higher interference from co-channels. Obviously, as the height is increased, the optimization function of the different scenarios also increases, which is consistent and thus prove the point that, under different system conditions, different optimal heights will be achieved

C. Analysis of Scenarios Based on Other Scenarios Considered

Fig. 4 and Fig. 5 scenario shows the global optimal height to be 27m and 24m respectively, which is seen at the centre of the heights range, while the other heights are candidate locations of comparable performance to the optimal. The threshold line which is set at 6 b/s/Hz is used for the purposes of comparison for the different scenarios. It is observed that scenarios 1 and 4 are relatively close and that all the predicted heights meet the criteria for optimal locations for co-sharing. The global optimal heights of the two scenarios are close in the range of the assumed heights in the cluster, which ranges from 27-30m. This points to the fact that the algorithm indeed conforms to the assumption of the height made for the co-channels cells. The different colocation spots, as observed in the algorithm implementation were chosen in steps of the distance required for effective isolation, which was, 1 meter for a 70dB isolation. This isolation distance provides a good isolation to prevent interference with antennas which are collocating [9]. The range of predicted heights for colocation is expedient because all the heights fall round the optimal region.

Scenario 2 which was found earlier to be the best scenario in terms of interference reduction, shows a very good performance based on the threshold in Fig. 6. It is also observed in Fig. 6, that, all the predicted heights exceed the spectral efficiency threshold quiet significantly. The interesting observation is that; the global optimal height occurs at 17m. The 17m optimal height and the 12m height as minimum height for colocation, appear very low, but this is not totally out of place, because scenario 2 provides two good interference reduction techniques which are clustering and sectorization, thus interference is highly reduced, hence, at low height a reasonably high SIR can still be achieved.

Scenario 2 seems to be the best option, but this configuration can limit capacity, that is, very limited amount of spectrum will be available for a number of users, which limits the number of traffic users, leading to high blocking or call drop rate in a highly populated area [14].

In contrast scenario 3 output of the algorithm as observed in Fig. 7 seems to provide the worst scenario. The threshold requirement is not met under this scenario. Another insightful observation is that, the global optimal height is located at 38m, which is vastly above the other co-channel base stations height used in the simulation (27—30m). This is due to the fact that, scenario 3 is highly prone to interference. The algorithm tries to increase the height to compensate for the low SIR because co-channels in this configuration are closer and Omni directional antennas are used resulting in high channels interference, thus the reduced spectral efficiency. However, using a 3 cluster size can increase capacity in terms of the number of users who can use the available spectrum. A good number of channels are available here to reduce congestion. But the challenge is interference, which certainly will limit the number of heights with comparable performance, because it will be difficult achieving the required spectral efficiency. Although the configuration is prone to interference problems, if an operator adopts it, there will be several spots available for other operators who intend using one of the less interference prone scenarios. Scenario 3 is not entirely bad when considering colocation, because depending on the scenario (configuration) an operator wants to deploy, several spots may be available

Thus, depending on the type of configuration, an operator will be able to know where to collocate. There are a number of propositions to help mitigate the interference under various circumstances, one is soft frequency reuse which aims at increasing the number of channels and reducing interference from co-channels [15], [16], [17].

The availability of these positions for colocation in all the scenarios will depend on the dimensions of the antenna. For instance, if antennas with dimension 1m are to collocate, and using the centre of the antenna as a mount point, and fulfilling the isolation distance criteria of 1m, then only 5 spots will be available in a set of 11 spots as illustrated in Fig. 4, Fig. 5, Fig. 6 and Fig. 7. Base station antennas can fall in ranges that are below half a meter or above a meter [18]. Another constraint will be the loading capacity of the tower, that is, the total weight of the antennas that the physical structure (tower) can support [19], [20].

IV. CONCLUSION

In this paper an algorithm based on outage, spectral efficiency and isolation distance for the prediction of heights is proposed. It is observed that different scenarios affect the choice of optimal height and thus there is a determined number of potential heights with close performance for colocation of antennas on a single tower. Further works can be carried out by adding more performance criteria for the prediction of the heights.

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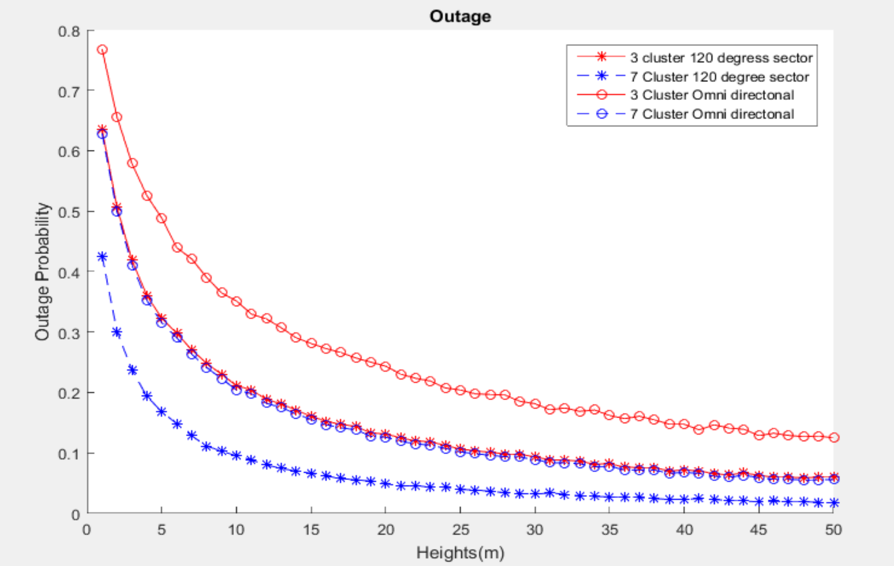

Fig. 2. Scenarios Comparison based on outage probability

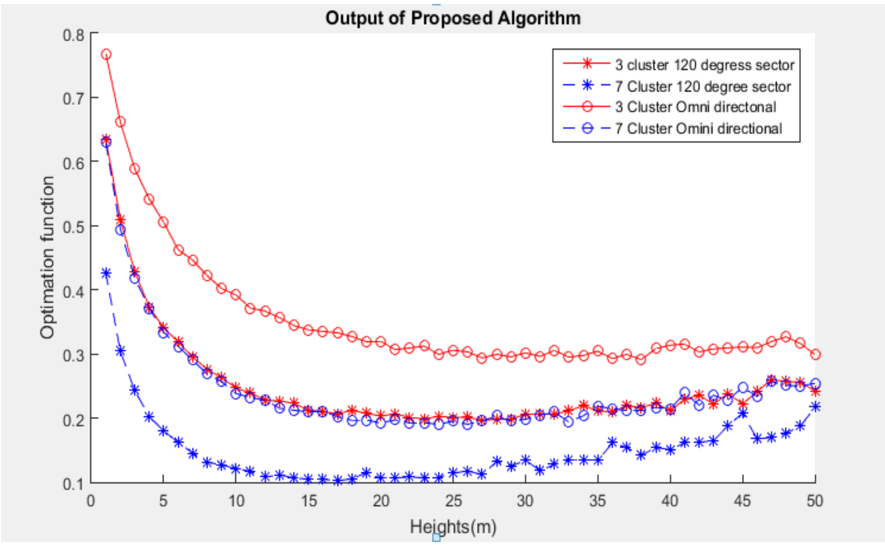

Fig. 3. Scenarios Comparison based on the optimization function

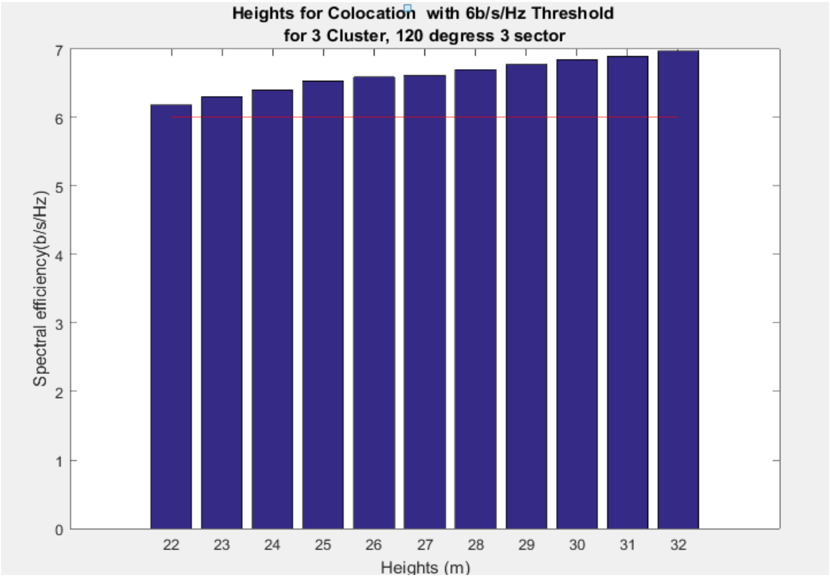

Fig. 4. The output of the algorithm for scenario 1

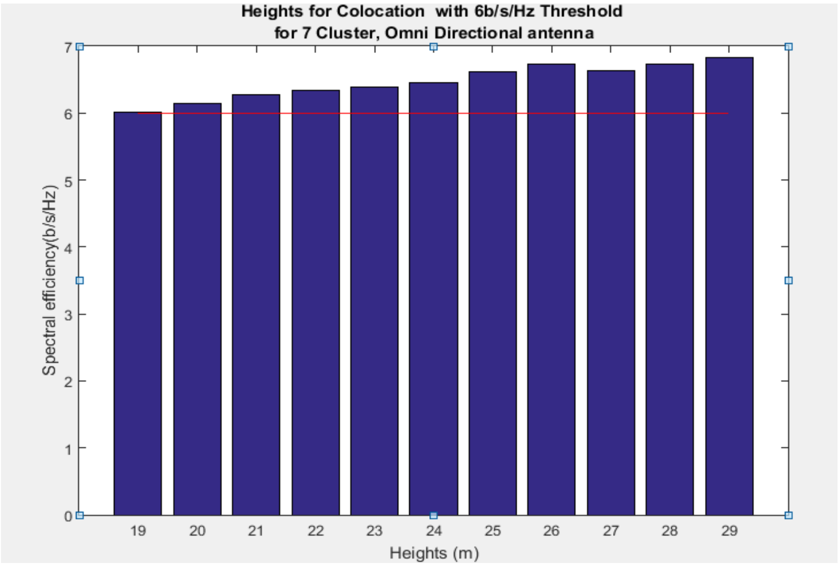

Fig. 5. The output of the algorithm for scenario 4

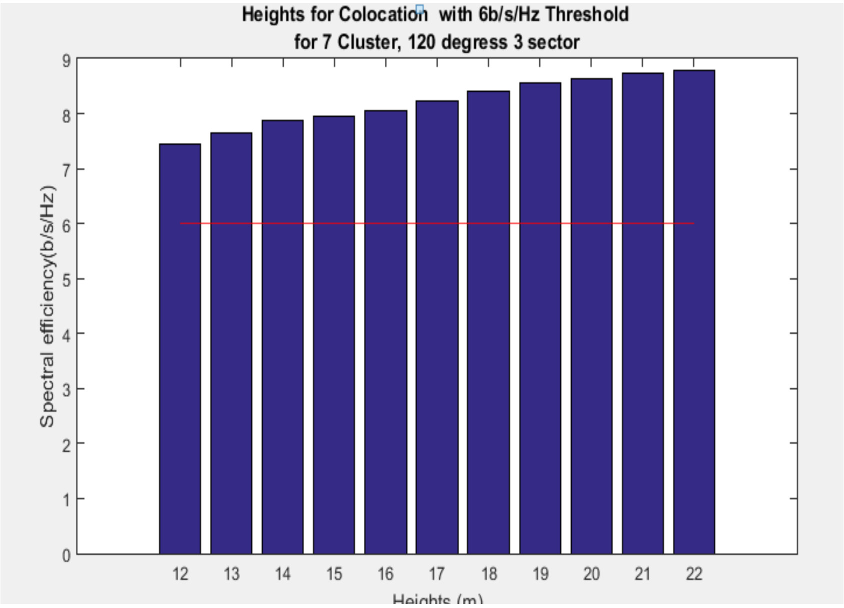

Fig. 6. The output of the algorithm for scenario 2

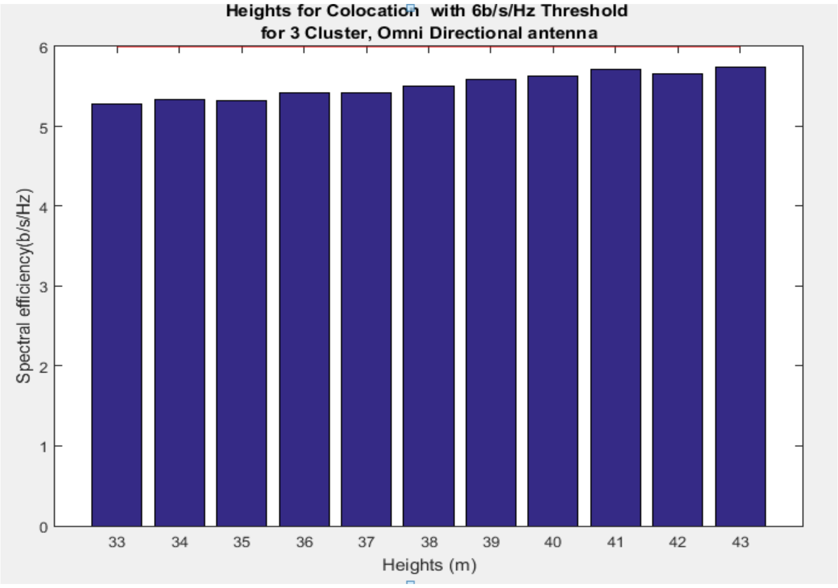

Fig. 7. The output of the algorithm for scenario 3