Cost-effective Policy for Deployment of Dense 5G RAN with Fiber and Wireless Backhaul Link

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***Abstract*— Densification of network with numerous small cells is an important aspect of 5G radio access network (RAN). Planning of backhaul connectivity for these small cells has become crucial for cost effective deployment of the network. Integrated access and backhaul (IAB) node has been envisaged to address this important aspect. In this work, we have considered a scenario where, an existing telecom service provider (TSP) plans to augment its network by deploying additional multiple small base stations (SBSs) at different locations. We consider that the TSP has optical fiber cable (OFC) at few existing locations. Hence, the SBS may be integrated by laying of OFC from nearest OFC available location. Alternatively, self-backhauled SBSs may be employed for the integration. In case of OFC backhaul, involvement of capital expenditure (CAPEX) will be higher. On the other hand, the deployment of self-backhauled SBSs causes higher interference to the users in the network. Hence, optimal deployment policy for the TSPs is required considering usage patterns of the subscribers, CAPEX involvement, deployment hindrance, and resulting interference in the network.**

The problem of cost effective deployment of the 5G RAN has been posed as an optimization problem. Subsequently, novel GA based hybrid backhauling (GAHB) technique has been presented. Our simulation results show that GAHB outperforms All Wired (AW) and All Unwired (AU) approaches as far as total cost of ownership (TCO) of the network is concerned.

Keywords—network densification, hybrid backhaul planning, IBFD, 5G RAN, Genetic Algorithm.

I. INTRODUCTION

To cater to the ever increasing demand for wireless data combined with requirements of diverse use cases such as machine to machine communication, ultra-reliable communication and enhanced mobile broadband in 5G, densification of base stations (BSs) appears to be the only way forward [1]. Naturally, optical fiber cable (OFC) backhaul at each BS has become preferred choice for providing the new-age services like virtual reality, augmented reality, autonomous car etc.

Planning and management of dense networks throw up various technical challenges such as handoff management [2], load sharing with small cells through offloading of traffic from macro cell to micro cells [3] to name a few. In addition to these, telecom service providers (TSPs) face various deployment challenges at the time of network roll out. Incidentally, the infrastructure readiness for 5G is quite different in developing countries such as India compared to that of developed countries for the following reasons:

i. In India, around 20% of the BSs have OFC as backhaul compared to 70%-80% in developed countries [4].

ii. Incidence of damage/cut at optical fiber is considerably higher in India compared to the developed countries due to overhead laying of the cables.

Therefore, the road ahead toward migration to 5G network for the countries such as India is poised to be different compared to that of the developed countries. Hence, it can be presumed that significant number of the BSs would continue to use wireless links as backhaul. In this front, two solutions namely, in-band and out-band solutions have been envisaged in the literature [5-7]. In-band solutions utilize the same spectrum band of the users in the backhaul link whereas, out-band solutions use different spectrum band for transportation of the access data and the backhaul data. In-band technologies have advantages of lower CAPEX involvement at the cost of higher level of interference for the access users compared to the out-band technologies. In spite of the shortcoming, there is a growing interest in the in-band full-duplex (IBFD) technology [5] for the self-backhauled wireless systems [6-7].

It is evident from the above that OFC backhaul at every site may not be commercially viable/practically feasible. Alternatively, deployment of IBFD at each BS may affect the quality of service (QoS) of the access users due to increased interference. Hence, hybrid architecture consisting of either OFC or wireless links as backhaul to the BSs has been envisaged in [8]. Certainly, this approach may emerge as cost-effective approach for the TSPs during their deployment of 5G in price-sensitive markets. In the above context, it is important for the TSPs to plan their RAN in a way such that the expected QoS of the users can be maintained as far as possible considering the CAPEX involvement toward the network roll out. However, to realize this kind of integrated access and backhaul (IAB) network architecture, it is required to develop wireless technology that share same standard for access and backhaul transport. Incidentally, the requirement has been considered during the development of 5G New Radio (NR). Several technical challenges of IAB network such as measurement, management and mitigation of Cross-link interference between trans-receiver points (TRPs) and user equipments (UEs) have been addressed in 3GPP Release 16 through Study Item 38.874 [8].

We have considered a system model in which, TSP serve its service area through combination of macro base station

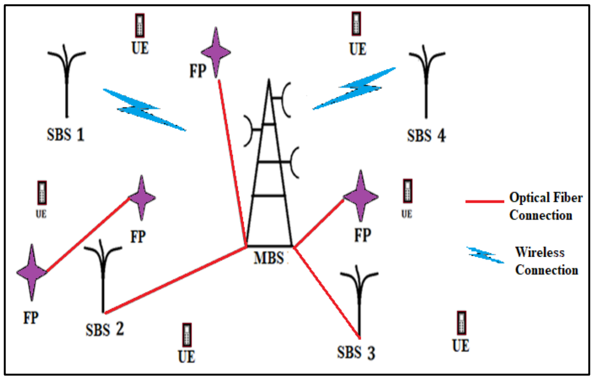

Fig. 1: System Model with wired and wireless backhaul

(MBSs) and small base stations (SBSs). It is presumed that all the MBSs are connected through OFC. The TSPs use two types of SBSs: a) SBSs with OFC backhaul b) SBSs with in-band self-backhaul capability. Moreover, the TSP has existing OFC network in the service area. Hence, a new OFC-backhauled SBS can be integrated by laying new OFC up to its nearest OFC tapping point or fiber point (FP). We have presented the system model in Fig. 1.

In the present work, we have addressed the problem of cost effective deployment of the additional SBSs over existing network of the TSP. We have identified two major cost components namely, the CAPEX involvement in OFC and recurring expenditure because of increased interferences due to wireless backhaul. A policy for the deployment of 5G RAN has been presented by hybrid planning of backhaul either through OFC or through IBFD. The objective of the work is to minimize the summation of the amortized CAPEX cost and the recurring cost in terms of increased interference due to deployment of IBFD. We have posed the deployment planning problem as an optimization problem and proposed genetic algorithm (GA) based hybrid backhauling (GAHB) technique for optimal decision regarding nature of backhaul connectivity of the SBSs. The performance of the GAHB has been compared with the all wired (AW) approach in which, all the SBSs are integrated through OFC and all unwired (AU) approach in which, all the SBSs are connected through IBFD. It can be seen from the simulation results that GAHB outperforms AW and AU method as far as our total cost of ownership (TCO) of the network is concerned.

The paper is organized as follows. A brief literature survey of relevant works is presented in Section II. In Section III, the problem formulation is presented. Section IV is devoted to the solution methodology. The simulation results have been provided in the Section V. Section VI concludes the work.

II. Related Works

Different aspects of IAB architecture have been addressed in various works [9-10]. In [9], architecture of single and multi-hop backhaul deployment has been considered. The authors have presented novel scheduling mechanism for sharing access and backhaul resources. Considering the similar architecture, the the authors in [10] explored joint resource allocation among the backhaul and access links to maximize geometric mean of user throughput. Cooperation in resource sharing among access and backhaul links is envisaged in [11]. Full duplex (FD) mode of communication in wireless backhaul link is proposed in [12-13] in order to enhance the capacity of backhaul link. Through analytical studies, it has been observed that IBFD capability helps to improve the average throughput (nearly 2 times) at the cost of reduced coverage which shrinks to close to half. Hence, it has been inferred that IBFD would be suitable candidate for small cells only [13]. In [12], the problem of optimal access/backhaul spectrum allocation has been addressed considering three different backhaul link designs namely, OBFD, IBFD and hybrid OBFD/IBFD. The authors in [6] have discussed several technical challenges in IBFD self-backhauling for indoor deployment scenarios.

In [15], the authors have proposed deployment of OFC on top of the existing fiber infrastructure of the TSP. Moreover, there is growing interest on the hybrid wired/wireless deployment solution for 5G network roll out. In [16], it has been concluded that deployment of small cells with hybrid wired and wireless backhaul links are cost effective and offers similar level of network coverage of all-wired backhaul link solution. The front-haul of C-RAN has been planned through hybrid OFC and free space optics (FSO) links to minimize the deployment cost while maximizing the flexibility of placement of radio remote heads (RRHs) in [17]. The problem of network planning to determine the number and locations of BSs with both wired and wireless backhauls is addressed in [7]. The authors presented multi-objective optimization problem a) to maximize the coverage of the network and b) to minimize the network deployment cost through wired and wireless backhaul. The authors have proposed Non-Dominated Sorting Genetic Algorithm II (NSGA-II) technique to solve the problem [7]. Here, the authors have considered mm-wave backhauling.

However, none of the above works has considered incremental network deployment scenario or brown-field scenario. Our work deals with practical business problem that is most likely to be faced by the incumbents in deployment of 5G network. Hence, to the best of our knowledge, this work is unique in its kind.

III. Problem Conceived

Let the WSP serves its service area with m number of MBSs, n number of SBSs. Further, the WSP has FPs at o number of locations. Let $\mathcal{M} = \{MBS_1, MBS_2, \dots, MBS_m\}$,$\mathbb{N} = \{SBS_1, SBS_2, \dots, SBS_n\}$ and $\mathcal{F} = \{FP_1, FP_2, \dots, FP_o\}$ be the set of MBSs, SBSs and FPs, respectively. Each $MBS_i \in \mathcal{M}$ is characterized by $< \mathcal{L}^i_{MBS}, P^i_{MBS}, \mathcal{H}^i_{MBS}, \{\ell\} >$ where, $\mathcal{L}^i_{MBS}$ denotes the location (Latitude and Longitude) of MBS_i, P^i_{MBS} signifies the transmited power, $\mathcal{H}^i_{MBS}$ indicates the heights of the antennas and ℓ signifies the set of orientations of the antennas. Similarly, each $SBS_j \in \mathbb{N}$ is characterized by $< \mathcal{L}^j_{SBS}, P^j_{SBS}, h^j_{SBS}, BH^j_{SBS} >$ where, $\mathcal{L}^j_{SBS}$, P^j_{SBS} and h^j_{SBS} denote the location, transmitted power and antenna height of SBS_j, respectively. Further, the SBS may be connected to the core network through OFC or wireless link. The type of backhaul link is denoted by term $BH_{SBS}^{j} = \{1,0\}$. In case of wired connection, notation BH_{SBS}^{j} takes the value of 1, $BH_{SBS}^{j} = 0$ otherwise. $FP_k \in \mathcal{F}$ is identified by their location $\mathcal{L}_{FP}^{k}$. According to our system model, each MBS_ihas Moreover, user UE_l is identified by $< \mathcal{L}_{UE}^{l}, h_{UE}^{l} >$ where, $\mathcal{L}_{UE}^{l}$ and h_{UE}^{l} indicate location and height of UE_l. Further, notations AG_M^i, AG_S^j and AG_{UE}^l denote the antenna gains for MBS_i, SBS_j and user UE_l, respecively.

A. Interference generated by the users

Considering UE_l is associated with SBS_j having wireless backhaul (i.e. $BH_{SBS}^{j} = 0$), the SINR at UE_{l-U} user is expressed as [7]:

$$\mathbb{I}_{l-U} = \frac{P_{SBS}^{j} \times AG_S^j \times AG_{UE}^l \times PL^{-1}(d_{jl}, f_c, h_{SBS}^{j}, h_{UE}^{l}, \alpha_l)}{\sigma_N{}^2 + I_{MU-l} + I_{BU-l}} \quad (1)$$

where,

$$I_{MU-l} = \sum_{i'} P_{MBS}^{i'} \times AG_{MBS}^{i'} \times AG_{UE}^{l} \times PL^{-1}\left(d_{i'l}, f_c, h_{MBS}^{i'}, h_{UE}^{l}, \alpha_l\right)$$
$$\text{MBS}_{i'} \in \mathcal{M}/\text{MBS}_i | \mathcal{D}(\mathcal{L}_{MBS}^{i'}, \mathcal{L}_{UE}^{l}) \leq \mathcal{D}_{th-UE} \quad (2)$$

$$I_{BU-l} = (\tau_{SBS} + \omega_{SI}) \times PL^{-1}(d_{jl}, f_c, h_{SBS}^{j}, h_{UE}^{l}, \alpha_l | \omega_{SI} = \frac{P_{SBS}^{j}}{C_{SI}} \quad (3)$$

In (1), the numerator signifies the received signal strength at SBS_j. In the equation, PL refers to the path loss along with the fading effect. In the path loss model [7], the notation d_{jl}, f_c and α_l denote the distance from UE_l from its associated SBS_j, carrier frequency and shadow fading, respectively. Moreover, the denominator of the equation indicates the noise and interference level. Gaussian noise is denoted by $\sigma_N{}^2$. As the SBS with IBFD would use the same spectrum of MBSs, interference from nearby MBSs and backhaul link are represented by I_{MU-l} and I_{BU-l}, respectively. Notation I_{MU-l}, as illustrated in (2), is computed by multiplying the transmitted power of the interfering MBS ($P_{MBS}^{i'}$) with the antenna gain of the mobile user (AG_{UE}^{l}) after considering the respective path loss $PL^{-1}\left(d_{i'l}, f_c, h_{MBS}^{i'}, h_{UE}^{l}, \alpha_l\right)$. It may be noted that notation $i'$is used to denote the MBSs other than MBS_i. In the equation, function $\mathcal{D}$ calculates the distance between the MBSs and the UE. Interference from the MBS is computed only if its distance from the UE_l is less than pre-defined threshold distance $\mathcal{D}_{th-UE}$, According to our system design, full duplex transmission has been employed by the SBSs toward the backhaul. The interference from the backhaul link to the UE_l is expressed by (3). In the equation, notation τ_{SBS} signifies the noise generated at SBS. Considering C_{SI} be the self-interference cancellation value, the residual self-interference power is indicated by ω_{SI}. Further, the interference from the backhaul link is measured by taking into account the path loss from the SBS to the UE_l.

In case the SBS is connected to the core network through wired connectivity through FP_k, the value of I_{BU-l} becomes zero. Here, we introduce term y_{jk} that denote the connectivity of SBS_j with FP_k. The terms y_{jk} become 1 when, SBS_j is connected to FP_k. Therefore, interference at the user l of the OFC connected/wired SBSs is expressed as:

$$\mathbb{I}_{l-W} = \sum_k y_{jk} \times \frac{P_{SBS}^{j} \times AG_S^j \times AG_{UE}^l \times PL^{-1}(d_{jl}, f_c, h_{SBS}^{j}, h_{UE}^{l}, \alpha_l)}{\sigma_N{}^2 + I_{MU-l}} \quad (4)$$

For sake of simplicity, we use $BH_{SBS}^{j} = \sum_k y_{jk}$ to denote the backhaul type of SBS_j. Naturally, $BH_{SBS}^{j} = 1$ when SBS_j is connected to any FP_k.

Let B_l be the bandwidth allocated to UE_l from the SBS. Let x_{jl} denotes the association between UE and SBS. Value of x_{jl} is equal to 1 when, UE_l is associated with SBS_j and the value of the same is 0, otherwise. Therefore, the maximum achievable data rate of UE_l will be:

$$r_l = \sum_j x_{jl} \times [BH_{SBS}^{j} \times B_l \log_2(1 + \mathbb{I}_{l-W}) + \left(1 - BH_{SBS}^{j}\right) \times B_l \log_2(1 + \mathbb{I}_{l-U})] \quad (5)$$

Let the data rate requirement for UE_l at a particular time be R_l. If sufficient wireless capacity is available to the users i.e. $R_l \leq r_l \, \forall l$, there is no impact on the users. Otherwise, quality of experience (QoE) of the users gets affected.

B. Cost of wired backhaul

Let n_p numbers of site are planned for deployment by the TSP and the planned sites are denoted by $SBS_{j'}$. If the sites are integrated through OFC from FP_k at distance $d_{j'k}$ then, the amortized fixed cost (AFC) of the network deployment is computed as:

$$C_F = \sum_{j'} d_{j'k} \times \vartheta_W \times BH_{SBS}^{j'} + \vartheta_U \times (1 - BH_{SBS}^{j'}) \quad (6)$$

In the above equation, ϑ_W indicates the amortized unit cost of OFC laying. The notation $d_{j'k}$ is the distance from the SBS location $\mathcal{L}_{SBS}^{j'}$ to the FP location $\mathcal{L}_{FP}^{k}$. Further, ϑ_U refers to amortized cost of wireless link including spectrum licensing cost and equipment cost.

C. Cost of wireles bachhaul

Interference received by $SBS_{j'}$ can be denoted by:

$$\mathbb{I}_{j'-B} = \frac{P_{MBS}^{i} \times AG_M^i \times AG_S^{j'} \times PL^{-1}(d_{ij'}, f_c, h_{MBS}^{i}, h_{SBS}^{j}, \alpha_j)}{\sigma_N{}^2 + I_{MS-j'}} \quad (7)$$

In the above equation, the numerator indicates the received signal level at the backhaul link of $SBS_{j'}$ from MBS_i. Further, interference received by $SBS_{j'}$ from MBSs other than MBS_i (i.e. $\text{MBS}_{i'}$) located within pre-defined distance $\mathcal{D}_{th-SB}$ is denoted by $I_{MS-j'}$:

$$I_{MS-j'} = \sum_{i'} P_{MBS}^{i'} \times AG_{MBS}^{i'} \times AG_{SBS}^{j'} \times PL^{-1}\left(d_{i'j'}, f_c, h_{MBS}^{i'}, h_{SBS}^{j'}, \alpha_{j'}\right),$$
$$\text{MBS}_{i'} \in \mathcal{M}_{-\text{MBS}_i} | \mathcal{D}(\mathcal{L}_{MBS}^{i'}, \mathcal{L}_{SBS}^{j}) \leq \mathcal{D}_{th-SB} \quad (8)$$

Considering $B_{ij'}$ amount of spectrum bandwidth is allocated to $SBS_{j'}$, the backhaul capacity of $SBS_{j'}$ would be:

$$Cap_{ij'} = B_{ij'} \log_2(1 + \mathbb{I}_{j'-B}) \quad (9)$$

We have measured the interference cost from the reduced system throughput from the higher interference. For this, the quantum of reduced throughput of the individual users is determined first. In case all the SBSs are connected through OFC (i.e. $y_{jk} = 1$) then, the aggregate interference of the users would be: $\sum \mathbb{I}_{l-W} = \sum \frac{P_{SBS}^{j'} \times AG_S^{j'} \times AG_{UE}^l \times PL^{-1}(d_{j'l}, f_c, h_{SBS}^{j'}, h_{UE}^{l}, \alpha_l)}{\sigma_N{}^2 + I_{MU-l}}$.

If some of the SBSs are connected through wireless links, the higher interference to the users will reduce the throughput of the users. Hence, we have considered the reduction of the throughput as the recurring cost (RC):

$$C_R = \sum_l \sum_{j'} x_{j'l} \times \left(1 - BH_{SBS}^{j'}\right) \times B_l \times [\log_2\{1 + \mathbb{I}_{l-W}\} - \log_2\{1 + \mathbb{I}_{l-U}\}] \quad (10)$$

D. Objective function: Total cost of ownership (TCO)

Objective of the work is to minimize the total cost of ownership (TCO) of the network roll out consisting of weighted sum of AFC and RC where, λ_F and λ_R be the coefficient for AFC and RC, respectively. Therefore, $y_{j'k}$ (the connectivity indicator between $SBS_{j'}$ and FP_k) being the decision variable, the objective of the work is to:

$$\text{Minimize: } (\lambda_F C_F + \lambda_R C_R) = f(\{y_{j'k}\}) \quad (11)$$

Subject to:

$$x_{j'l} \leq 1 \quad (12)$$

$$BH_{SBS}^{j'} = \sum_k y_{j'k} \leq 1 \quad (13)$$

$$\sum_{j'} \sum_l r_l \times x_{j'l} \times \left(1 - BH_{SBS}^{j'}\right) \leq Cap_i \quad (14)$$

$$\sum_l r_l \times x_{j'l} \leq Min(Cap_{j'}, Cap_{ij'}) \quad (15)$$

$$\sum_l x_{j'l} \times B_l \leq B_{j'} \quad (16)$$

$$\sum_k \sum_{j'} d_{j'k} \leq \mathfrak{D}_F \quad (17)$$

As the current work deals with deployment planning of the new SBSs over the existing network, constraint (12) considers the users that are connected with these planned $SBS_{j'}$ only. Constraint (13) signifies that all the planned $SBS_{j'}$ would have wireless (IBFD) or wired (OFC) backhaul connectivity. Constraint (14) implies that the cumulative required data rate of the users directly/indirectly connected to MBS_i would be within than the data handling capacity of MBS_i. Moreover, throughput of the users may be limited due to the wireless backhaul link of the SBS or the capacity of $SBS_{j'}$. This constraint is at reflected at (15). If $B_{j'}$ amount of spectrum is allocated to $SBS_{j'}$ and the same amount of spectrum is deployed in access as well as backhaul link then, the aggregate of spectrum assigned to the users of $SBS_{j'}$ should be limited to the spectrum allocated to $SBS_{j'}$as per constraint (16). In real life deployment scenario, availability of CAPEX is a major constraint for connecting all the SBSs through OFC. Constraint (17) indicates that the length of the OFC deployment must be less that the pre-approved length $\mathfrak{D}_F$.

IV. Solution Methodolgy

We have presented GAHB algorithm to solve the problem.

A. Background

GA belongs to the class of adaptive heuristic search algorithms based on the principles of genetics [18]. These algorithms use the concept of natural selection and survival of the fittest [19]. In GA, multiple genes or parameters form a chromosome, whereas multiple chromosomes form

TABLE I. Mapping of GA To Backhaul Planning Problem

GA	Backhaul Planning
Chromosome	Connectivity Solution
Population	Solution space
Fitness function	Objective function

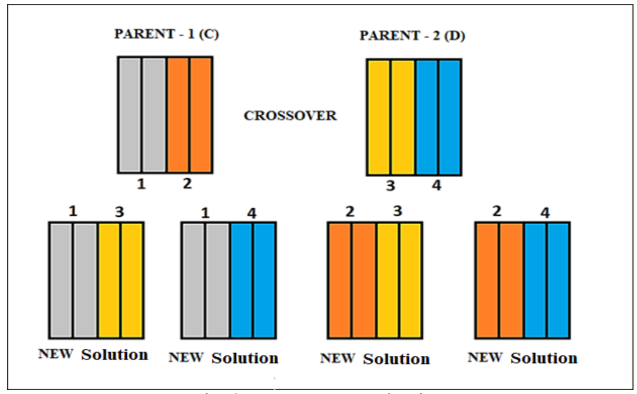

Fig. 2: Crossover Mechanism

population. Further, the concept of fitness function quantifies the suitability of a chromosome in the problem context. Subsequently, children are produced from two parent chromosomes by two processes namely, crossover and mutation. In the process of crossover, children inherit their characteristics from both the parents. This means, a child will have genes from both of parents. In rare case, certain characteristics of a child become complete opposite from that of its parents. This process refers to as mutation. From a population, chromosomes having relatively higher fitness value are selected as parents and are used for production of next generation population. The process of generating the new population continues until an identical population is achieved. Hence, we have mapped the GA for the current problem in Table I. Next, we discuss our proposed GAHB solution:

B. GAHB

1) Formation of Initial Solutions

Initial solution is arrived with the formation of connection matrix having n_p (no. of planned sites) of columns and o (i.e. cumulative nos. of FPs) number of rows. It is assumed that all the MBSs have collocated FPs. Value of element of the connection matrix $\{y_{j'k}\}$ becomes 1 when, planned SBS $SBS_{j'}$ is connected with the FP_k. Otherwise, the value is 0. It may be noted that new SBS is planned to be parented with only one FP.

2) Crossover

For the crossover, parent solution is segmented from a point called crossover point. In other words, columns are identified as segment based on the crossover point. Subsequently, the segments are interchanged to generate different combination of solutions. As an illustration, the process of crossover between two solutions is shown in Fig. 2. Here, we consider 4 new SBSs as a test case. It can be seen from the figure that number of columns (4 nos.) are equally divided for identification of segment. Subsequently, new solutions are prepared by swapping the identified segments of Parent 1 and Parent 2. As a result, 4 nos. new solutions are generated.

3) Selection of Solutions

The selection of the solutions is done based on the value of the objective function (TCO) of the respective solution. The new solutions generated from the crossover are validated against the objective function at (11). A solution is deemed to

Initialization:
Input: *max_iter_count*; n_p=No. of planned SBS; *count*=0;
o= No. of FPs
parent_1= First solution from the population
parent_2= Second solution from the population
min_value_best = Minimum value of the best solution
min_sol_best = Solution with minimum objective function value
Step 0:
parent_1←Random connection solution of $(n_p \times o)$matrix
parent_2←Random connection solution of $(n_p \times o)$ matrix
min_sol_ best ← Solution with lowest objective function value
min_value_ best ← Lowest objective function value
Iterations:
1. While (*count*< *max_iter_count*)
2. Perform crossover between *parent_1* and *parent_2*
3. Compute the objective function value through (11) for each child solution
4. Select the solutions having minimum objective function values.
5. If(*min_value_ best* <lowest objective function value)
 5.1 *min_value_best* ← lowest objective function value
 5.2 *min_sol_best* ←Solution with lowest objective function value
6. *parent_1*←Solution with lowest objective function value
7. *parent_2*← Solution with second lowest objective function value
8. *Count*← *Count*+1
9. Go to Step 1
10. End

Output:
Returns *min_sol_best* and *min_value_best*

Fig. 3: Algorithm of GAHB technique

be fittest if the corresponding TCO value is lower. In our example at Fig. 2, values of the TCO for 4 nos. solutions are computed. Consequently, the solution with minimum value of TCO is chosen as the parent for the next crossover process.

4) Termination Criteria

The GA process is terminated when objective functions values of the generated solutions cannot be improved further.

5) Algorithm of GAHB

GAHB algorithm is presented in Fig. 3. The algorithm is initiated by values of n_p and o . Variables namely, *max_iter_count* and *count* have been introduced to indicate the maximum permissible iteration count and the current iteration count, respectively. Moreover, variables *parent_1* and *parent_2* are employed to represent the parent connectivity solutions.

In the beginning, variables *parent_1* and *parent_2* are initialized by generating the connectivity solution matrices $\{y_{j'k}\}$ in random manner. Among the generated solutions, the solution with minimum objective function value is identified and the same is stored along with the value as *min_sol_best* and *min_value_best*, respecively. Next, we start the iterative process. Here, crossover operation is performed with *parent_1* and *parent_2*. Subsequently, TCOs are computed as per (11) for the child solutions generated out of the crossover. The solutions with the lowest and the second lowest TCO values are identified. If the TCO of any solution is lower than *min_value_best* then, the *min_sol_best* and *min_value_best* is replaced by the current solution and TCO of the current solution, respectively. Moreover, the two best solutions from the current iteration are used as parents for the next phase of crossover. The iteration continues until *max iter count* value. Finally, the algorithm returns the best connectivity solution *min sol best* found so far along with its respective TCO i.e. *min_value_best*.

V. Result Analysis

In order to evaluate the performance of our proposed solution technique, we have implemented the technique in MATLAB release 2014b and run the simulation in a PC environment having Intel Core i3 3.20 GHz processor. As a test case, we have considered 8 nos. of planned SBSs, 16 nos. of MBSs and total 32 nos. of FPs in the simulation setup. Values of few important parameters used in the simulation are indicated at Table II. The performance of GAHB has been compared with two approaches namely, all-wired (AW) solution and all-unwired (AU) solution.

TABLE II. Simulation Setup

Parameters	Descriptions	Values
ϑ_W	Amortized OFC laying cost per meter	\$10
ϑ_U	Amortized cost of IBFD systems	\$100
f_c	Carrier frequency	3.5 GHz
$B_{ij'}/B_l$	Bandwidth allocated to $SBS_{j'}/UE_l$	100/5 MHz
P_{MBS}/P_{SBS}	Power of macro/small base station	20/5 Watt
$\mathcal{D}_{th-SB}$	Threshold distance	1500 Meter
C_{SI}	Self-interference cancellation value	100
λ_F/λ_R	Coefficient for AFC and RC	0.25/0.75

We have observed the variation of TCO by varying the number of planned SBSs keeping the number of users unchanged. The result is shown in Fig. 4, It can be seen that TCO of the network increase with the planned SBSs. In case of AW approach, the increase in TCO is considerably higher. However, GAHB solution offers up to (66%) saving in TCO compared to AW approach. This is because TCO for AW

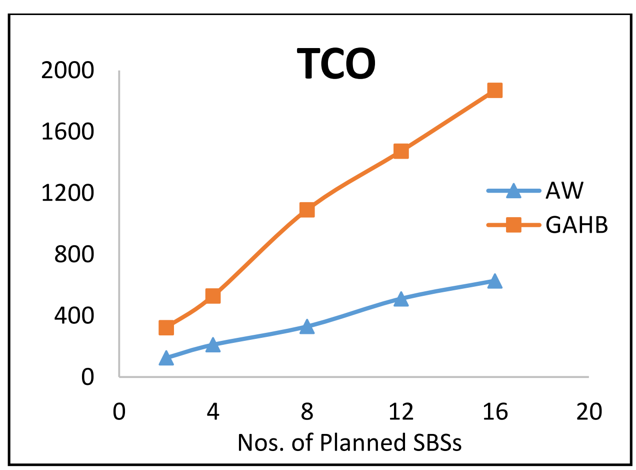

Fig. 4: Performances of different techniques with the variation of the TCO with the nos. of Planned SBSs

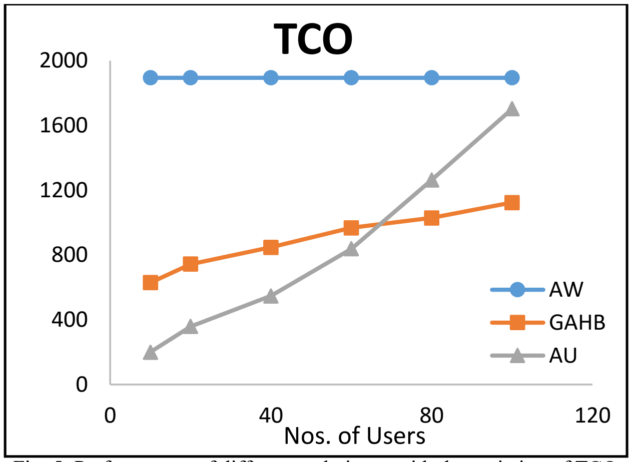

Fig. 5: Performances of different techniques with the variation of TCO with the nos. of users

approach increases due to higher OFC laying cost. On the other hand, our proposed GAHB technique intelligently use hybrid wired and wireless backhaul solution to minimize the TCO.

Further, we have varied the number of users while keeping the planned SBSs unchanged to find its effect on the TCO of the network. The simulation result is shown in Fig. 5. It can be seen from the figure that the TCO with AW approach is not dependent on the number of users. Here, TCO is only dependent on number of planned SBSs. As the same is kept constant in this experiment, the TCO is also remains unchanged. On the other hand, the TCO with AU approach varies with the number of users. It can be seen that the TCO increases with the increase of number of users. Performance of the GAHB is inferior to AU approach when the number of users is low. This is because the interference is low when the number of users is low. On the other hand, the GAHB technique outperforms the AU technique when the number of users is increased. This is due to the fact the GAHB uses hybrid connectivity options and it searches for the optimal solution within the available search space. When the number of users is increased, network interference cost is also increased considerably. In this case, GAHB plans to connect some of the SBSs with wired connectivity. This approach reduces the interference in the network. In addition, the TCO of the network is saved up to 34%.

VI. Conclusion

In this work, the practical problem of backhaul planning of the SBSs deployed in 5G has been addressed and hybrid backhaul connectivity solution using OFC and IBFD links has been presented. It is inferred from the study that the AU approach should be preferred to GAHB technique when the number of users is expected to be low. On the other hand, GAHB technique should be preferred as resulting saving in TCO with this technique is up to 66% compared to AU approach. As telecom networks are planned for large number of users, GAHB technique should be employed by the TSPs for the backhaul planning for their 5G/beyond 5G networks.

References

[1] J. An, K. Yang, J. Wu, N. Ye, S. Guo, and Z. Liao, "Achieve Sustainable Ultra-Dense Heterogeneous Networks for 5G," 2017

[2] A. H. Arani, M. J. Omidi, A. Mehbodniya, F. Adachi, "A Handoff Algorithm Based on Estimated Load for Dense Green 5G Networks," in IEEE GLOBECOM, 2015

[3] C. Yang, J. Xiao, J. Li, X. Shao, A. Anpalagany, Q. Niz, M. Guizani, "DISCO: Interference-Aware Distributed Cooperation with Incentive Mechanism for 5G Heterogeneous Ultra-Dense Networks," IEEE Communications Magazine, vol. 56 , no. 7, July 2018

[4] Deloitte, Indian Tower Industry The Future Is Data, June 2015

[5] D. Bharadia, E. McMilin, and S. Katti, "Full duplex radios," ACM SIGCOMM Computer Communication Review, vol. 43, no. 4, 2013.

[6] R. A. Pitaval et al., "Full-duplex self-backhauling for small-cell 5G networks," IEEE Wireless Communications, vol. 22, Oct. 2015.

[7] A. L. Rezaabad, H. Beyranvand, J. A. Salehi, and M. Maier, "Ultra-Dense 5G Small Cell Deployment for Fiber and Wireless Backhaul-Aware Infrastructures", IEEE Transactions on Vehicular Technology, 2018.

[8] 3GPP TR 38.874, "NR; Study on integrated access and backhaul," Tech. Rep., 2017.

[9] M. Polese, M. Giordani, A. Roy, S. Goyal, D. Castor, and M. Zorzi, "End-to-end simulation of integrated access and backhaul at mmWaves," in IEEE 23rd International Workshop on Computer Aided Modeling and Design of Communication Links and Networks (CAMAD), pp. 1-7, Sep. 2018.

[10] M.N. Islam, N. Abedini, G. Hampel, S. Subramanian, and J. Li, "Investigation of performance in integrated access and backhaul networks," In IEEE INFOCOM 2018-IEEE Conference on Computer Communications Workshops (INFOCOM WKSHPS), pp. 597-602, 2018.

[11] R.I. Rony, E. Lopez-Aguilera, and E. Garcia-Villegas, "Cooperative spectrum sharing in 5G access and backhaul networks," in 14th International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob), pp. 239-246, Oct. 2018,

[12] U. Siddique, H. Tabassum, and E. Hossain, "Downlink spectrum allocation for in-band and out-band wireless backhauling of full-duplex small cells," IEEE Transactions on Communications, vol. 65, no. 8, pp.3538-3554, 2017..

[13] A. Sharma, R.K. Ganti, and J.K. Milleth, "Joint backhaul-access analysis of full duplex self-backhauling heterogeneous networks," IEEE Transactions on Wireless Communications, vol. 16, no. 3, pp.1727-1740, 2017.

[14] ETSI TR 138 901 V14.3.0, "5G; Study on channel model for frequencies from 0.5 to 100 GHz (3GPP TR38.901 version 14.3.0 Release 14),"

[15] C. S. Ranaweera, P. P. Iannone, K. N. Oikonomou, K. C. Reichmann and R. K. Sinha, "Design of cost-optimal passive optical networks for small cell backhaul using installed fibers," IEEE/OSA Journal of Optical Communications and Networking, vol. 5, no. 10, Oct. 2013.

[16] X. Xu, W. Saad, X. Zhang, X. Xu, and S. Zhou. "Joint deployment of small cells and wireless backhaul links in next-generation networks." IEEE Communications Letters, vol. 19, no. 12, pp. 2250-2253, 2015.

[17] T. Federico, C. Raffaelli, L. Wosinska, and P. Monti, "Cost-optimal deployment of a C-RAN with hybrid fiber/FSO fronthaul," Journal of Optical Communications and Networking, vol. 11, no. 7, pp. 397-408, 2019.

[18] B. Dorronsoro and E. Alba, "A Simple Cellular Genetic Algorithm for Continuous Optimization," in IEEE International Conference on Evolutionary Computation, Vancouver, BC, pp. 2838-2844, 2006.

[19] P. Arunasalam, K. N. Seetharamu and I. A. Azid, "Determination of thermal compact model via evolutionary genetic optimization method," IEEE Transactions on Components and Packaging Technologies, vol. 28, no. 2, pp. 345-352, June 2005.