Spectrum Allocation in IAB Networks: A Hierarchical Auction-based Approach

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***Abstract*—To support the data requirements of exponentially increasing number of cellular users, Internet of Things (IoT) devices, and enterprises, wireless cellular networks are undergoing significant architectural enhancements. The heterogeneous network architecture is one such advancement, which can augment the capacity of cellular networks through the addition of femto/pico (small) cells. However, fiber connectivity to each small cell is not feasible. In such scenarios, wireless backhaul enables connectivity between small cells and core network (CN). Integrated Access and Backhaul (IAB) has emerged as a solution in 5G network, where wireless backhauling is supported. In IAB networks, IAB-donors are connected to the CN through fiber connectivity, and the multiple IAB-nodes are associated with IAB-donors through wireless backhaul. IAB Nodes can support small cells and provide last mile connectivity to users and IAB-donors act as wireless backhaul provider. For efficient utilization of the spectrum in wireless backhaul, we design an auction-based mechanism to allocate resources dynamically across IAB-nodes considering the spatial and temporal variation of the network traffic. Moreover, using Monte Carlo simulations, we show that the proposed mechanism achieves optimal social welfare.**

I. Introduction

The amount and the variety of data traffic have been steadily increasing since the inception of the mobile data networks. To support this diverse and burgeoning data traffic, the cellular network has been undergoing significant enhancements.The heterogeneous network (HetNet) architecture, comprising macro cells overlaid with multiple small cells leading to increased network densification, is one of the key advancements in this direction. Furthermore, Fifth Generation (5G) cellular networks are expected to operate in higher frequency bands such as Millimeter Waves, to address spectrum scarcity. Consequently, the cell coverage will reduce further, resulting in ultra-dense deployment. Although ultra-dense deployment has advantages such as better capacity, coverage, and channel conditions to edge User Equipments (UEs), connecting each base station via fiber to the Core Network (CN) may not be an economical and scalable solution. Integrated Access and Backhaul (IAB) has been considered by Third Generation Partnership Project (3GPP) as a cost-efficient solution to wireless backhaul for 5G cellular network [1].

3GPP 5G standard has defined IAB feature to enable wireless backhauling (relaying) in 5G New Radio (NR) based Radio Access Network (RAN). The 5G IAB architecture comprises two different types of network elements (NE), IAB-nodes and IAB-donors. An IAB-node provides last mile connectivity to UEs. It is a gNB-Distributed Unit (gNB-DU) augmented with wireless backhaul capability to connect to an IAB-donor. The IAB-donor, plays the role of a gNB-Centralized Unit (gNB-CU) for IAB-nodes. IAB-donors have additional functionality to support wireless backhaul connectivity to downstream IAB-nodes. An IAB-donor terminates the wireless backhauling towards the CN, it may be connected to CN through fiber or other similar wireline infrastructure.

Multiple IAB-nodes (small cell gNBs) may be connected to a single IAB-donor in a hierarchical tree like structure as shown in Fig. 1. Since more than one IAB-node is connected to a single IAB-donor, there is a need to share the backhaul resource (wireless spectrum) among these IAB-nodes. A simple scheme that can be used for resource allocation (spectrum sharing) in wireless backhaul is static allocation, wherein spectrum is allocated to IAB-nodes for a large duration, which is utilized to serve UEs associated with them.

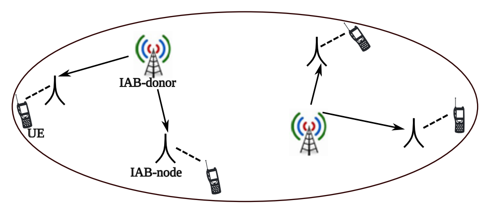

Fig. 1: Illustration of IAB network.

Although the static allocation mechanism is simple and easy to implement, it does not account for the temporal and spatial variations in the network and thereby lead to sub-optimal spectrum utilization [2]. For efficient utilization of spectrum, the dynamic nature of traffic must be considered while performing the allocation. Dynamic Spectrum Allocation (DSA) has been considered a potential solution for improving spectrum utilization [3]. In our work, we devise a strategy-proof auction-based mechanism for DSA that optimally allocates spectrum based on UE demands in IAB networks. Note that in IAB networks, spectrum allocation needs to be done in a hierarchical fashion, i.e., based on UEs' demands the resources need to be allocated not only to UEs' but also to the IAB nodes as backhaul and access share the same spectrum. To address this, we propose a socially optimal strategy-proof hierarchical auction mechanism.

A. Related Work

Most of the auction-based resource allocation works have been focused on the single-stage auction with direct interaction between the resource owner and the base stations (BSs). Moreover, these works consider only one-sided auctions. However, in our work, we consider a multiple-stage hierarchical auction. The authors in [4], have presented the first-ever analyses of resource allocation in hierarchical settings. Nevertheless, the work lacks focus on mechanism design with constraints arising from specific application under consideration. In [5], the authors have investigated the Nash implementation of a combinatorial auction.

The authors in [6], have studied how the transit and customer prices affect Quality of Service (QoS) in 3-Tier settings. The main focus is on pricing equilibrium instead of the mechanism design. The authors in [7], have proposed a scheme for spectrum sharing across multiple operators dynamically using bankruptcy game, which is not applicable in HetNet scenario. Another work [8] has proposed a combinatorial auction for virtualization of the network in hierarchical settings. The authors in [9], [10] have considered DSA across operators with multiple BSs considering single-stage auction between operators and auctioneer. A strategy-proof DSA with fairness in resource allocation across BSs has been proposed by the authors in [11]. The authors in [12], have proposed a three-stage spectrum allocation framework. However, middlemen are restricted to get at most one unit of resource. In contrast, our work considers multiple unit resource demand at every stage with no restriction on the number of units that can be allocated. The key contributions of the paper are as follows:
1) We propose a spectrum allocation framework for hierarchical settings in IAB enabled HetNet. 2) The proposed auction-based mechanism is computationally efficient and achieves optimal social welfare. 3) The proposed mechanism satisfies individual rationality and strategy-proofness.

The paper is organized as follows. We provide a description of the system model and the problem formulation in Section II. We propose the algorithms in Section III. We discuss the simulation results in Section IV and conclude in Section V.

II. System Model

We consider a scenario of downlink transmission in IAB enabled 5G HetNet. The system model comprises IAB-donors and IAB-nodes in HetNet settings to provide connectivity (service) to UEs. In a HetNet setting, IAB-nodes are low power BSs, supporting small coverage area cells. A UE associates itself with one of the BSs over wireless channel. We assume that a UE is associated with the BS (IAB-node) with the best channel condition. Typically, multiple UEs are connected to one BS. These small cell BSs (IAB-nodes) are connected to CN through wireless backhaul provided by IAB-donors. Multiple IAB-nodes (BSs) may be connected to a single IAB-donor. IAB-donors allocate radio resources to downstream IAB-nodes just as an IAB-node does for the associated UEs.

The entities in HetNet architecture exhibit a hierarchical structure as illustrated in Fig. 2. We categorize the network entities into 3 levels, namely Tier 1, Tier 2 and Tier 3, which are IAB-donors, IAB-nodes and UEs, respectively. The UEs requesting a service, report their bid to the respective IAB-node. To avoid the excessive control signaling, IAB-nodes

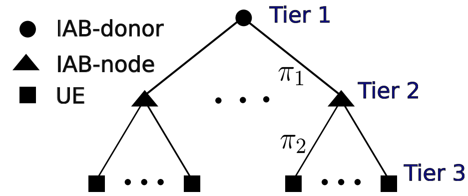

Fig. 2: System model

perform aggregation of bids and report the same to the IAB-donors. The aggregation of bids also serves the purpose of hiding the UE specific information for privacy concerns.IAB-donor distributes the resources among IAB-nodes based on the bids received from them. Subsequently, IAB-nodes allocate the acquired resources to UEs. We assume that IAB-donors and IAB-nodes incur a particular operating cost in the transmission. The operating cost may consist of various facilities such as power consumption, or energy consumed in cooling of apparatus in the network. Therefore, a UE is considered for resource allocation only if the cost of transmission is less than the reported bid. We refer the per Resource Block (RB) cost of transmission to a UE incurred by IAB-node as *reserve price*. Note that the additional resources required for transmission of the information from IAB-node to IAB-donor are also accounted in the reserve price.

Summarizing the setting under consideration: UEs report the number of RBs they desire and valuation per RB to their respective IAB nodes. IAB nodes aggregate the received information and send it to the IAB donor. Based on the received information, IAB-donor distributes the resources to IAB nodes that in turn distributes the received resources to the UEs and charges price for the allocated resources.

By $\pi = (\pi_1, \pi_2)$, we denote the resource allocation mechanism, where π_1 and π_2 are sub-mechanisms implemented in Tier 1 and Tier 2 levels, respectively. We assume that UEs at Tier 3 are non-cooperative, rational, and selfish. Since IAB-nodes are network entities, they cooperate with the IAB-donors in achieving the goal of resource allocation. Although we consider only one hop in the system model, IAB framework supports multiple hops between IAB-donor and UEs. The proposed mechanism can be readily extended for the multiple hop settings. For notational clarity, vectors are in bold lower case (e.g. $\boldsymbol{x}$), and sets are in calligraphic letters (e.g. $\mathcal{N}$).

A. Mechanism Design Framework

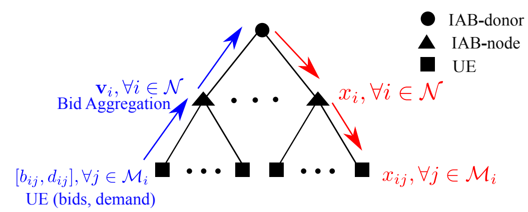

Fig. 3: Illustration of mechanism design framework

Let C be the total number of RBs available at IAB-donor. In general, RB is the smallest unit of radio resource that can be allocated to a UE. Let $\mathscr{N} = \{1, \ldots, N\}$ denote the set of IAB-nodes associated with the IAB-donor. Each IAB-node provides services to multiple UEs associated with it. By $\mathscr{M}_i = \{1, \ldots, M_i\}$, we denote the set of UEs associated with IAB-node i. Note that a UE can be associated with only one IAB-node at any time instance in the network.

Each UE has data rate requirement. Based on the required data rate and Channel Quality Indicator (CQI), the number of RBs are evaluated by UE as per the 3GPP standard [13]. Each UE has a resource valuation and demand (required number of RBs) based on the service requested. Let v_{ij} and d_{ij} denote per RB true valuation and the number of RBs required by UE $j \in \mathscr{M}_i$. We assume that UEs accept RBs less than or equal to their demand and each UE acts rationally. Therefore, if strategically misreporting valuation to the IAB-node has an incentive, UEs may deviate from their true valuation. Let UE $j \in \mathscr{M}_i$ reports bid b_{ij} to IAB-node i, where b_{ij} may or may not be the same as v_{ij}.

As stated earlier, the resource allocation mechanism π comprises π_1 and π_2. Here, π_1 is responsible for resource allocation across the IAB-nodes, based on the aggregated bids reported by them. Subsequently, depending on the acquired resources, IAB-nodes perform resource allocation across UEs using π_2. Let us denote the allocation vector across the UEs associated with IAB-node i as $\boldsymbol{x}_i^\pi = (x_{i1}^\pi, \ldots, x_{iM_i}^\pi)$, where $x_{ij}^\pi \in \mathbb{Z}_+$ is the number of RBs allocated to UE j associated with IAB-node i. The utility of UE $j \in \mathscr{M}_i$ can be given as:

$$U_{ij}^\pi(x_{ij}^\pi) = v_{ij} \cdot \min\{x_{ij}^\pi, d_{ij}\} - p_{ij}^\pi. \tag{1}$$

where, p_{ij}^π denote the price charged to UE $j \in \mathscr{M}_i$ under π. The price can depend upon the bids, demands and reserve prices of all the UEs in the network. Thus, Equation (1) computes the utility of UE $j \in \mathscr{M}_i$ for given demands and reserve prices.

As mentioned in Fig. 3, IAB-nodes act as middlemen between IAB-donor and UEs. Therefore, they do not have any intrinsic valuation for the resource. An IAB-node derives its valuation and demand from the associated UEs. By $d_i = \sum_{j=1}^{m_i} d_{ij}$, we denote the demand at IAB-node i which is aggregate of the demands of the UEs $j \in \mathscr{M}_i$. In addition, IAB-node i reports a $(C+1)$-dimensional vector $[v_i(u)]_{u=1,\ldots,C+1}$ to IAB-donor, where $v_i(u)$ indicates the valuation of IAB-node i when u RBs are allocated. By $\boldsymbol{x}^\pi = (x_1^\pi, \ldots, x_n^\pi)$, we denote allocation vector at Tier 2 entities, where $x_i^\pi \in \mathbb{Z}_+$ is the number of RBs acquired by IAB-node i under Tier 1 sub-mechanism (π_1) in π. Furthermore, each IAB-node $i \in \mathscr{N}$ has a reserve price γ_{ij} per RB for the associated UE $j \in \mathscr{M}_i$ based on the cost incurred while providing the service.

With the aggregation of bids, IAB-nodes report a vector $[v_i(u)]_{u=1,\ldots,C+1}$. Contrary to this, if an IAB-node communicates the information received from UEs transparently, it requires to report $([b_{ij}, d_{ij}])$ for every $j \in \mathscr{M}_i$ to IAB-donors. Thus, the aggregation of bids at IAB-nodes reduces the signaling overhead significantly. Using the above notations, we define the social welfare of the system as follows:

Definition 1. *Social welfare of the resource allocation under mechanism π is defined as*

$$W^\pi = \sum_{i=1}^{N} \sum_{j=1}^{M_i} v_{ij} \cdot \min\{d_{ij}, x_{ij}^\pi\}. \tag{2}$$

where, x_{ij}^π denotes number of RBs allocated to UE $j \in \mathscr{M}_i$ under π. The term on R.H.S of Equation (2) signifies the sum of the true valuations (v_{ij}) of the UEs, where v_{ij} is private information of the UEs in the system.

B. Problem Statement

The aim of resource allocation mechanism is to design a $\pi^\star$ such that

$$W^{\pi^\star} \geq W^\pi, \text{ for any } \pi.$$

As stated above, resource allocation aims to maximize social welfare, which is the sum of true valuations of the UEs. However, true valuation is private information of the UEs, unknown at the IAB-node and IAB-donor. Therefore, to achieve the desired objective, we need to ensure that the mechanism enforces the UEs to reveal their true valuation.

Definition 2. *A mechanism π is said to be strategy-proof if $\forall\ i, j$*

$$U_{ij}^\pi(v_{ij}, \boldsymbol{b}_{-ij}) \geq U_{ij}^\pi(b_{ij}, \boldsymbol{b}_{-ij}),\ \forall \boldsymbol{b}. \tag{3}$$

where, v_{ij}, and $U_{ij}^\pi(.)$ are true valuation, and utility of UE $j \in \mathscr{M}_i$ under mechanism π, respectively. $\boldsymbol{b}_{-ij}$ represents the bid vector of all UEs except $j \in \mathscr{M}_i$.

Next, we aim to design strategy-proof mechanism.

III. Proposed Algorithm

In this section, we propose a computationally efficient strategy-proof mechanism $\pi = (\pi_1, \pi_2)$ for the hierarchical settings in an IAB-enabled HetNet. Each sub-mechanism π_1 and π_2 comprises a resource allocation strategy and a pricing scheme. As illustrated in Fig. 3, IAB-nodes aggregate the bids reported by the associated UEs and report to the IAB-donor. The aggregated bids are reported as a $(C+1)$-dimensional vector $[v_i(u)]_{u=1,\ldots,C+1}$. Without the loss of generality, assume bids are ordered such that $b_{ij} \leq b_{i(j+1)}\ \forall i, j \in \mathscr{M}_i$. The aggregated bid value for a given number of RBs (u) at an IAB-node can be evaluated as follows:

$$j_u^\star = \min\{j : \sum_{\ell=1}^{j} d_{i\ell} \geq u\}, D_{ij_u^\star} = \sum_{j=1}^{j_u^\star} d_{ij}$$

$$v_i(u) = \sum_{j=1}^{j_u^\star} b_{ij} \cdot d_{ij} + (u - D_{ij_u^\star}) \cdot b_{ij_u^\star}.$$

A. Tier 1 Auction Mechanism (π_1)

As an IAB-donor can only communicate with the associated IAB-nodes, IAB-donor aims at maximizing the aggregate valuation reported by the IAB-nodes i.e., $\sum_{i \in \mathscr{N}} v_i(x_i^\pi)$. We propose a sub-mechanism at IAB-donor in Algorithm 1. π_1 computes $\Gamma_i(\boldsymbol{x}^\pi),\ \forall i \in \mathscr{N}$ for each RB. $\Gamma_i(\boldsymbol{x}^\pi)$ is the aggregate bid if the next RB is given to IAB-node i.

Algorithm 1 Sub-mechanism π_1 at IAB-donor

Input: $\mathscr{N}$, $[v_i(u)]_{u=1,\dots,C+1}$, RBs C
Output: allocation $\tilde{x}_i^{\pi}$, $\forall\ i \in \mathscr{N}$, p

Initialize $x_i^{\pi} = 0$, $v_i(0) = 0 \quad \forall\ i \in \mathscr{N}$, $R \leftarrow C+1$
while $(R > 0)$ **do**
  Set $i^{\star} \leftarrow \arg\max_{i \in \mathscr{N}} \Gamma_i(\boldsymbol{x}^{\pi})$ (Using Equation 4)
  Set $x_{i^{\star}}^{\pi} \leftarrow x_{i^{\star}}^{\pi} + 1$
  if $(R = 2)$ **then**
    $j^{\star} \leftarrow i^{\star}$
    $\tilde{x}_i^{\pi} \leftarrow x_i^{\pi}$ for every $i \in \mathscr{N}$
  end if
  Update $R \leftarrow R - 1$
end while
$p \leftarrow \Gamma_{i^{\star}}(\boldsymbol{x}^{\pi}) - \Gamma_{j^{\star}}(\boldsymbol{x}^{\pi})$

$$\Gamma_i(\boldsymbol{x}^{\pi}) = \sum_{j \neq i} v_j(x_j^{\pi}) + v_i(x_i^{\pi} + 1). \tag{4}$$

In each iteration, IAB-node with the highest $\Gamma_i(\boldsymbol{x}^{\pi})$ is allocated an RB. The process is repeated until all RBs are allocated.

B. Tier 2 Auction Mechanism (π_2)

The objective of resource allocation is to maximize the social welfare. However, the bids reported by UEs may or may not be the same as their true value. IAB-node maximizes the aggregate sum of bids reported by UEs subject to the constraint on the number of resources (x_i^{π}) assigned by IAB-donor. We consider that UEs generate elastic traffic and willing to accept any number of RBs in the range of their demand.

We propose sub-mechanism (π_2) in Algorithm 2 which determines the optimal allocation across the set of UEs $j \in \mathscr{M}_i$ based on the reported bids and also enforces the UEs to reveal true value. Note that IAB-nodes distribute the RBs orthogonally across the UEs.

Algorithm 2 Sub-mechanism π_2 at IAB-node i

Input: $\mathscr{M}_i$, $[b_{ij}\ d_{ij}]$, RBs x_i^{π}, γ_{ij} for every $j \in \mathscr{M}_i$
Output: allocation x_{ij}^{π}, price p_{ij}^{r} $\forall\ j \in \mathscr{M}_i$

Initialize $x_{ij}^{\pi} = 0$, $\forall\ j \in \mathscr{M}_i$
Permute b_{ij} in decreasing order in array L
Set $\ell \leftarrow 1$
while $(x_i^{\pi} > 0)$ **do**
  $x_{i\ell}^{\pi} \leftarrow \min\{d_{i\ell}, x_i^{\pi}\}$
  Update $x_i^{\pi} \leftarrow x_i^{\pi} - x_{i\ell}^{\pi}$, $L \leftarrow L \setminus \{L(\ell)\}$
end while
$p_{ij}^{\mathrm{r}} = \gamma_{ij} \cdot \min\{x_{ij}^{\pi}, d_{ij}\}$

We assume that each UE in the system has bid value greater than the reserve price set by IAB-node, i.e., $b_{ij} \geq \gamma_{ij}\ \forall j \in \mathscr{M}_i$. First, arrange UEs in decreasing order of bids in array L. The resources are allocated across the UEs in greedy fashion, that is the highest bidding UE in L will be allocated the RBs first, then second and so on until all the RBs available at an IAB-node are exhausted. Each UE is charged $p_{ij}^{r} = \gamma_{ij}$ per RB. Next, we define optimal allocation in Definition 3.

Definition 3. *An allocation $\boldsymbol{x}_i^{\pi} = (x_{i1}^{\pi}, \dots, x_{ij}^{\pi})$ is said to be optimal if it maximizes the aggregate sum of the bids reported by UEs for a given number of RBs x_i^{π}, i.e.,* $\max\{\sum_{j=1}^{M_i} b_{ij}. \min\{x_{ij}^{\pi}, d_{ij}\} : \sum_{j \in \mathscr{M}_i} x_{ij}^{\pi} \leq x_i^{\pi}\}$.

Lemma 1. *Algorithm 2 performs optimal allocation.*

Proof. The optimality of the allocation can be proved as follows. The algorithm performs the resource allocation greedily based on their bids. Therefore, first UE is selected as $\ell = \arg\max_{j \in \mathscr{M}_i}\{b_{ij}\}$. Thus, if we have to select only one UE from $\mathscr{M}_i$, then optimal allocation is to allocate resources to UE ℓ with the highest bid. Now, update the set of remaining UEs $\mathscr{M}_i' = \mathscr{M}_i \setminus \{\ell\}$. Again determining a single UE with the optimal allocation in $\mathscr{M}_i'$ is the same as in $\mathscr{M}_i$. Thus, the iterative allocation provides optimal allocation at every reduced set. This leads to the optimal allocation of RBs across the UEs associated with IAB-node i. $\square$

Lemma 2. *If UE j is allocated RBs at bid b_{ij}, then it will also be allocated RBs at $\tilde{b}_{ij} > b_{ij}$, provided bid of other UEs ($\{b_{i\ell} : \ell \neq j, \ell \in \mathscr{M}_i\}$) does not change.*

Proof. As stated in Algorithm 2, RBs are allocated greedily across UEs based on per RB bid b_{ij} for every $j \in \mathscr{M}_i$. Suppose UEs are sorted in decreasing order of their bids in an array, wherein UE j lies at k^{th} position. Assuming UE j increases per RB bid to $\tilde{b}_{ij}$, while the bids of other UEs ($b_{i\ell} : \ell \neq j$) remain unchanged. Subsequently, UE j shifts at $\tilde{k}^{\text{th}}$ position in the sorted array such that $\tilde{k} \leq k$. This implies that if UE is allocated RBs being at k^{th} position in the sorted array, then it is also allocated resource at $\tilde{k}^{\text{th}}$ position after increasing per RB bid. This proves the required. $\square$

C. Pricing Scheme for π

The price charged by UEs is given as

$$p_{ij}^{\pi} = \max\{\gamma_{\text{ij}}, p\} \cdot \min\{x_{ij}^{\pi}, d_{ij}\}. \tag{5}$$

where, γ_{ij} is the UE specific reserve price (cost of transmission) set by IAB-node i and p is the minimum price per RB to be charged by a UE, if allocated resource. By p, we denote the price set by IAB-donor for each UE which is allocated resources obtained using Algorithm 1. Intuitively, p is the highest bid among the UEs which are not allocated resources.

Lemma 3. *The resource allocation mechanism $\pi = (\pi_1, \pi_2)$ is individually rational.*

Proof. We are required to show that the price charged by UE is less than or equal to $b_{ij} \cdot \min\{x_{ij}^{\pi}, d_{ij}\}$. UE j is either charged γ_{ij} or p per RB using Equation (5). UE j is served by IAB-node i only if $\gamma_{ij} \leq b_{ij}$.Thus, $p_{ij}^{\pi} \leq b_{ij} \cdot \min\{x_{ij}^{\pi}, d_{ij}\}$. As sub-mechanism π_1 allocates resources greedily based on the valuation reported by IAB-nodes, $\{p \leq b_{ij}, \forall j \in \mathscr{M}_i, i \in \mathscr{N} \ :\ x_{ij}^{\pi} \neq 0\}$. This proves the required. $\square$

Theorem 1. *The proposed mechanism $\pi = (\pi_1, \pi_2)$ is strategy-proof.*

Proof. We are required to show that a UE has no incentive to deviate from its true value. In other words, utility gain is independent of its bid. The utility of UE j is given as

$$\begin{aligned} U_{ij}^{\pi} &= b_{ij} \cdot \min\{x_{ij}^{\pi}, d_{ij}\} - p_{ij}^{\pi}, \\ &= (b_{ij} - \max\{\gamma_{ij}, p\}) \cdot \min\{x_{ij}^{\pi}, d_{ij}\}. \end{aligned}$$

Case 1: $\underline{p = \max\{\gamma_{ij}, p\}}$

$$U_{ij} = (b_{ij} - p) \cdot \min\{x_{ij}^{\pi}, d_{ij}\} \quad (6)$$

In Equation (6), p is independent of the bids of UEs allocated resource. Thus, to maximize the utility UE must report its true value, i.e., $b_{ij} = v_{ij}$.
Case 2: $\underline{\gamma_{ij} = \max\{\gamma_{ij}, p\}}$ Reserve price, γ_{ij} is independent of the bid of UE j and computed by the IAB-node based on the cost of transmission. From the above cases, it is seen that the pricing scheme is independent of the bids of the UEs allocated resource(s). Hence, UEs have no incentive to deviate from their true valuation. □

IV. Simulation Results

In this section, we compare the performance of the proposed mechanism with that of the optimal resource allocation mechanism and another mechanism proposed by the authors in [4], being referred as Tier based Individually Strategy-proof Mechanism (TISM) in this paper. The optimal mechanism achieves the maximum social welfare. Simulation settings comprises one IAB-donor and multiple IAB-nodes. We vary the number of IAB-nodes associated with the IAB-donor. We consider uniform distribution of UEs in the region and 50 RBs are available at the IAB-donor. Each UE associated with an IAB-node generates traffic based on the type of service required resulting in a demand for certain RBs. Furthermore, we consider that UEs have elastic traffic. Therefore, UEs accept any number of RBs within their demand. Each UE reports valuation per RB requirement uniformly distributed in the interval $[5, 20]$. The RB demand across UEs is uniformly distributed in the interval $[1, 5]$. Each IAB-node has a reserve price of 5 per RB. Therefore, UEs only with per RB valuation greater than or equal to 5 are considered. The simulations are performed in MATLAB and results are averaged over 100 iterations.

From Fig. 4, we observe that the social welfare of the proposed mechanism and optimal solution are the same. The optimal solution is obtained by omitting the IAB-nodes in the network. Thus, the resource allocation in such scenario reduces to a single-stage resource allocation problem. Furthermore, the increase in the number of IAB-nodes in the system does not affect the performance of the mechanism. Another important aspect of the proposed mechanism is that it is strategy-proof across all the Tiers considered simultaneously as well as individually at each level (Tier). However, TISM is strategy-proof individually at each level but fails to be strategy-proof when multiple Tiers are considered.

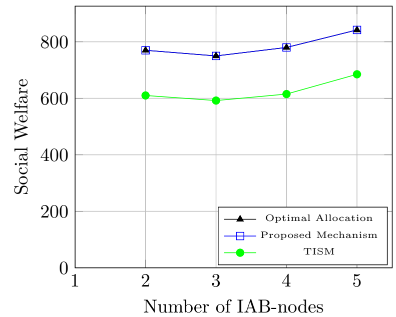

Fig. 4: Comparison of social welfare vs. number of IAB-nodes.

V. Conclusions

In this paper, we investigate the problem of DSA in IAB networks considering the hierarchical arrangement of IAB-donor and IAB-nodes. We devise a strategy-proof computationally efficient spectrum allocation algorithm to maximize the social welfare of the auction. We propose an auction-based mechanism for spectrum allocation at IAB-donor and IAB-nodes. We also prove the optimality, individual rationality, monotonicity, and strategy-proofness of the mechanism. Simulation results corroborate with the analysis.

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