Minimum Span Frequency Allocation Technique for 6G In-Band Full-Duplex IAB Networks

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***Abstract*—We propose a novel centralized minimum span frequency allocation (MS-FA) technique for 6G in-band full-duplex integrated access and backhaul (IBFD-IAB) networks. The objective of the proposed method is to minimize the total bandwidth required in the backhaul network while ensuring each link's quality-of-service (QoS) requirements. Simulation results demonstrate that IBFD operation has remarkable potential for the MS-FA. Furthermore, the low-complexity MS-FA algorithm still achieves performance comparable to the optimal solution regarding the required total bandwidth with feasible polynomial time.**

***Index Terms*—6G, in-band full-duplex, integrated access and backhaul, minimum span frequency allocation, optimization.**

I. INTRODUCTION

Integrated access and backhaul (IAB) has received much attention as a promising network architecture that provides an alternative to fiber backhaul, especially for millimeter-wave (mmWave) communication systems [1], [2]. In a general IAB network, only some base stations (IAB donors) are linked to the core network through wired infrastructures, while the rest (IAB nodes) are connected wirelessly. Conventional IAB standards consider operating under half-duplex (HD) constraints, undermining spectral utilization efficiency and increasing bidirectional communication latency. In other words, the existing HD IAB fails to exploit the full advantage of its potential [3].

In-band full-duplex (IBFD) capabilities, one of the advanced duplex technologies, enable IAB to more than double spectral efficiency and reduce network latency compared to HD IAB scenarios [4]. Applying IBFD functionality to backhaul links is exceptionally reasonable, as interference between access and backhaul links can be suppressed through site configuration and precise pencil-beamforming between fixed nodes. In practice, IBFD IAB networks have been investigated recently in the literature [3], [5]. In this paper, we examine the effectiveness of IBFD operation for wireless backhaul in terms of minimum span frequency allocation (MS-FA).

II. IBFD IAB SYSTEM MODEL

The spatial model, association policy, and channelization we consider are the same as in [1, Section II]; hence, we restate only the propagation model. In [1, (3)], if the receiver (RX) of link j and the transmitter (TX) of link i refer to the same node, this means the received signal strength (RSS) of self-interference (SI). Although the specific SI cancellation (SIC) techniques are beyond the scope of this paper, it is evident that imperfect SIC results in residual SI (RSI) and limits the performance improvement of IBFD networks. To examine the impact of the RSI on the system performance, we utilize a statistical RSI model as in existing studies [6], [7]. Specifically, based on practical measurements, the RSI after applying all SIC techniques in the propagation, analog, and digital domains, denoted by I_{R} in [6, (1)], is modeled as following a complex Gaussian distribution, e.g., $I_{\mathsf{R}} \sim \mathcal{CN}(0, \rho_i P_i^{\mathsf{TX}})$. Using this RSI model, the average RSS of each link after applying SIC techniques is given by

$$r_{j,i}=\begin{cases}P_i^{\mathsf{TX}}G_{j,i}^{\mathsf{TX}}G_{j,i}^{\mathsf{RX}}L_{(1m)}L_{j,i}(\|\mathbf{p}_j-\mathbf{p}_i\|), & \text{if } \|\mathbf{p}_j-\mathbf{p}_i\|>0,\\ \rho_i P_i^{\mathsf{TX}}, & \text{if } \|\mathbf{p}_j-\mathbf{p}_i\|=0,\end{cases}$$

where ρ_i ($\in [0,1]$) represents the SIC capability of link i ($\in \mathcal{L}$) and other parameters are described in [1, Section II-C].

III. MINIMUM SPAN FREQUENCY ALLOCATION

The minimum span frequency allocation problem (MS-FAP) aims to reduce the overall bandwidth required in the network by minimizing the gap (*span*) between the highest and lowest frequencies used while ensuring the quality-of-service (QoS) requirements of each link [8]. By using [1, (4)], formulation [1, (7a)–(7d)] and algorithm [1, **Algorithm 1**] can be simplified into formulation (1a)–(1d) and Algorithm 1, respectively.[1]

$$\min_{z_k} \sum_{k\in\mathcal{K}} 2^{k-1} z_k \tag{1a}$$

$$\text{s.t. } z_k \geq \frac{1}{|\mathcal{L}|}\sum_{j\in\mathcal{L}} z_{j,k}, \qquad \forall k \in \mathcal{K}, \tag{1b}$$

$$\sum_{k\in\mathcal{K}} z_{j,k} = 1, \qquad \forall j \in \mathcal{L}, \tag{1c}$$

$$\alpha_j z_{j,k} + B(1-z_{j,k}) \geq \sum_{i\in\mathcal{L}\setminus j} r_{j,i} z_{i,k}, \quad \forall j\in\mathcal{L}, \forall k\in\mathcal{K}. \tag{1d}$$

Refer to [1, Section III] for detailed descriptions of the formulation and algorithm.

IV. SIMULATION RESULTS

We validate the MS-FA techniques in IBFD IAB networks via computer simulations. The simulation parameters are the same as in [1, Table III]. Furthermore, all base stations (BSs) are assumed to employ the state-of-the-art SIC technique investigated in [3] for mmWave IBFD transceivers; hence, $\rho_i = -115$ dB, $\forall i \in \mathcal{L}$. The noise power is set to -77.9794 dBm, and the average RSI strengths at IAB donors and nodes

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[1] In this paper, we only consider orthogonal frequencies without partially overlapping channels to focus on the effect of FD operation.

Algorithm 1 Low-Complexity MS-FA

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Input: $\mathbf{R} \in \mathbb{R}^{L \times L}$, $\mathcal{K}$.
Output: $\mathbf{f}$.
Initialization: $\mathbf{f} = [f_1, f_2, \ldots, f_L]^{\mathrm{T}} = \mathbf{0}^{L \times 1}$, $k = 1$

while $0 \in \mathbf{f}$ do
    ▷ Step I. Get Candidate Links
    $\mathcal{L}_{\mathsf{A}} = \{j \,|\, f_j = k, \forall j \in \mathcal{L}\}$, $\mathcal{L}_{\mathsf{S}} = \{j \,|\, f_j = 0, \forall j \in \mathcal{L}\}$
    if $\mathcal{L}_{\mathsf{A}} = \varnothing$ then
        Update $f_{j^*} = k$, where $j^* = \arg\max_{j \in \mathcal{L}_{\mathsf{S}}} (r_{j,j})$
        Update $\mathcal{L}_{\mathsf{A}} = \{j^*\}$ and $\mathcal{L}_{\mathsf{S}} \leftarrow \mathcal{L}_{\mathsf{S}} \backslash \{j^*\}$
    end if
    $\mathcal{L}_{\mathsf{C}} = \left\{ j \,\middle|\, \frac{r_{j,j}}{\sum_{i \in \mathcal{L}_{\mathsf{A}}} r_{j,i} + N_0 W_j} \geq \underline{\gamma}_j, \forall j \in \mathcal{L}_{\mathsf{S}} \right\}$
    if $\mathcal{L}_{\mathsf{C}} = \varnothing$ then
        $k \leftarrow k + 1$
        continue
    end if
    ▷ Step II. Frequency Allocation
    $\mu_j = \min_{i \in \mathcal{L}_{\mathsf{A}}} \left( \frac{r_{i,i}}{r_{i,j} + \sum_{l \in \mathcal{L}_{\mathsf{A}} \backslash i} r_{i,l} + N_0 W_j} - \underline{\gamma}_i \right), \forall j \in \mathcal{L}_{\mathsf{C}}$
    if $\mu_j < 0, \forall j \in \mathcal{L}_{\mathsf{C}}$ then
        $k \leftarrow k + 1$
        continue
    else
        Update $f_{j^*} = k$, where $j^* = \arg\max_{j \in \mathcal{L}_{\mathsf{C}}} (\mu_j)$
    end if
end while
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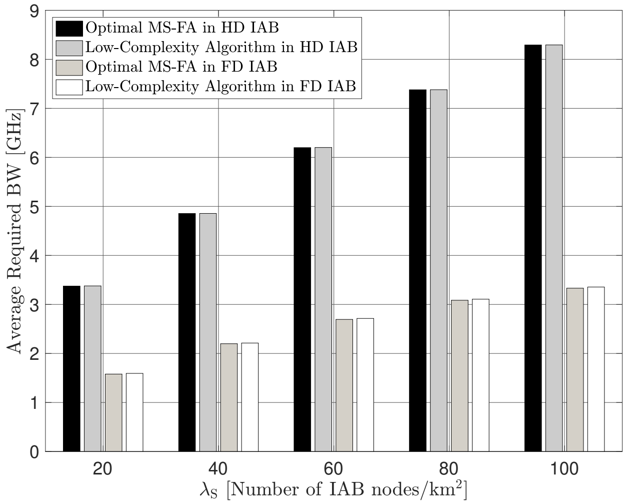

Fig. 1. Average required total bandwidth according to the IAB node density of the optimal MS-FA and low-complexity algorithm in HD/FD IAB networks.

are -75 dBm and -85 dBm, respectively. IAB nodes can suppress their SI below the noise level, while IAB donors still have RSI that is almost 3 dB higher than the noise power. On the other hand, we set $\Delta = 500$ MHz and $K = L$ to eliminate adjacent channel leakage ideally. K represents the worst-case scenario where all links are allocated orthogonal frequencies.

Fig. 1 shows the average required total bandwidth of the optimal MS-FA and low-complexity algorithm according to the IAB node density λ_{S} in HD and IBFD (FD) IAB networks. First, we can observe significantly less bandwidth is exploited in FD IAB networks than in HD ones, especially with bandwidth savings of over 50 %. Specifically, when the IAB node density is equal to 100, the required total bandwidth in the FD IAB network is approximately 40.17% of the HD one.

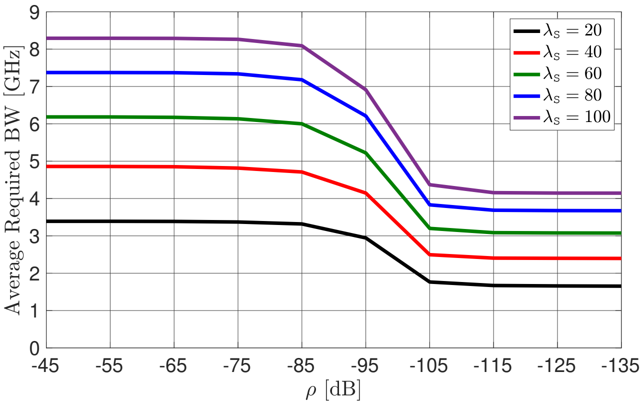

Fig. 2. Average required total bandwidth with respect to SIC capability ρ.

Notably, the low-complexity MS-FA algorithm still achieves performance comparable to the optimal solution while quickly yielding solutions. We found that the low-complexity algorithm can derive a solution within a few milliseconds, even for $\lambda_{\mathsf{S}} = 100$.

Fig. 2 presents the impact of SIC capability ρ on the required total bandwidth. Not surprisingly, it is observed that the required bandwidth decreases monotonically as the SIC capability increases. Interestingly, even though the SI power level for the IAB donor is slightly greater than the noise power, the required bandwidth is almost constant when the SIC capability is above -115 dB, which is what we considered.

V. CONCLUSION

We investigated the IBFD IAB network and verified it regarding the MS-FAP. Applying IBFD capability to backhaul links is exceptionally reasonable since interference between access and backhaul links can be suppressed through precise pencil-beamforming between stationary BSs. Through computer simulations, we have demonstrated that IBFD operation has remarkable potential to save more than 50 % of the required total bandwidth for MS-FA.

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