

Hybrid Coordinated Beamforming for WiFi 8 with Reconfigurable Antennas: A Measurement-Driven Study

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Abstract—To mitigate the interference among transmissions originated from different access points (APs), the next generation of WiFi (WiFi 8) is introducing coordinated multipoint beamforming. We further enhance such a solution by considering APs equipped with reconfigurable antennas that provide additional analog beamforming capabilities. We then evaluate the potential of a hybrid coordinated multi-point beamforming (H-COMP-CBF) framework, where the selection of analog and digital beamforming parameters is jointly optimized to quantify the achievable performance gains in multi-AP scenarios. We use measured channel state information (CSI) as inputs to a standard-compliant IEEE 802.11be PHY-level simulator, which we extend to support multi-AP coordinated beamforming. The reported throughput values are then obtained through simulation, while the propagation channels are experimentally measured. In particular, using measured frequency-domain CSI, reconstructed channel impulse responses, and analog beamforming radiation patterns, we compare H-COMP-CBF with existing solutions for several AP-associated station (STA) pairing configurations. The results show that H-COMP-CBF significantly improves system throughput in interference-limited scenarios and exhibits robustness to non-optimal radiation pattern selection.

Index Terms—WiFi 7, WiFi 8, Coordinated Beamforming, Channel State Information, Hybrid Beamforming.

I. INTRODUCTION

The rapid growth of wireless devices and bandwidth-intensive applications is driving the evolution of wireless local area networks (WLANs) toward increasingly dense deployments. In such environments, the performance of traditional single access point (AP) transmission strategies becomes limited by strong inter-cell interference and inefficient spatial reuse. Although recent standards such as IEEE 802.11be (i.e., WiFi 7) introduce advanced multi-user multiple-input multiple-output (MU-MIMO) and orthogonal frequency-division multiple access (OFDMA) techniques to increase spectral efficiency [1], interference between neighboring APs remains a major performance bottleneck in dense scenarios.

To address this limitation, next-generation WLAN systems, moving toward IEEE 802.11bn (WiFi 8), are exploring coordinated multi-point (CoMP) transmission [2]–[5]. In general, CoMP can be categorized into two main paradigms: CoMP joint processing (CoMP-JP) and CoMP coordinated beamforming (CBF) (CoMP-CBF). Although CoMP-JP offers

significant gains by enabling multiple APs to transmit data to a single user jointly, its implementation in WLAN is hampered by the massive backhaul overhead and tight synchronization required to share user data. In contrast, CoMP-CBF is emerging as a more practical solution for WiFi 8, as it only requires the sharing of channel state information (CSI) among APs to jointly design transmit precoders that mitigate interference without the need for data exchange [6]. This approach has the potential to significantly improve system throughput and reliability in multi-AP deployments and is considered a key enabler for the next generations of WiFi.

In parallel, recent advances in smart antennas and analog beamforming architectures allow WLAN APs to dynamically steer their radiation patterns [7], [8]. When combined with cooperative transmission techniques, these directional capabilities can provide a joint analog-digital beamforming effect. In particular, the analog beamforming shapes the multi-path environment and reduces the visibility of interferers, while the digital beamforming performs fine-grained interference nulling. However, to evaluate the performance of such complex systems in realistic WLAN scenarios we need simulation frameworks that incorporate not only multi-AP coordination algorithms, but also realistic channel measurements and antenna radiation patterns.

In this paper, we consider APs equipped with reconfigurable antennas that provide additional analog beamforming capabilities. We then investigate a hybrid CoMP-CBF (H-COMP-CBF) that exploits both the analog and digital beamforming capabilities. We investigate the choice of optimal analog and digital precoders among different APs in a WLAN scenario representative of a future WiFi 8 system. For performance evaluation, we rely on an experimental CSI dataset collected in a residential test-house environment. The measured channels, obtained for multiple AP positions, STA locations, and antenna radiation states, are used as input to a customized IEEE 802.11be PHY-level simulator [9]. The resulting throughput values are therefore simulation-based, while the underlying propagation channels are obtained from over-the-air measurements.

We evaluate the system aggregate throughput for several AP-STA pairing scenarios. In particular, we compare H-COMP-CBF, where the transmit precoders are jointly optimized by accounting for inter-AP interference, with a conven-

tional uncoordinated beamforming strategy, representative of WiFi 7 operation, where the precoders are designed independently via singular value decomposition (SVD) on the channels for the intended STA. We also assess the impact of the radiation pattern used at the analog antennas. Numerical results show that our proposed H-COMP-CBF solution significantly improves throughput in scenarios limited by interference.

The paper is organized as follows. Section II introduces the system model of WiFi communications. Our H-COMP-CBF solution is introduced in Section III, where the baseline scheme is also introduced. Section IV describes the setting used to simulate the scenario considered and the metrics used to assess the system performance. The results of the experimental validations are presented and discussed in Section V, before the main conclusions are given in Section VI.

II. SYSTEM MODEL

We consider a WLAN system consisting of J APs equipped with N_A smart antennas and J single-antenna STAs distributed within the coverage area. We focus on the downlink transmission from the APs to the STAs, where orthogonal frequency division multiplexing (OFDM) with N_s subcarriers is used. A one-to-one association between APs and STAs is assumed to be such that AP j serves STA j . Each STAs is served by a single AP and a single spatial stream is transmitted per user.

Each AP performs hybrid beamforming, which combines analog and digital processing before transmission. In particular, each AP is equipped with a reconfigurable antenna system capable of selecting one radiation pattern from a finite set of P possible configurations. The AP i selects an antenna pattern index $p_i \in \{1, \dots, P\}$. Each antenna pattern corresponds to a measured channel realization, capturing the overall radiation mode resulting from the specific configuration of each RF chain. Then, the selected pattern modifies the electromagnetic interaction with the propagation environment, resulting in a different effective channel toward the STAs.

Let $\mathbf{h}_{i,j}^{(p_i)}[k] \in \mathbb{C}^{1 \times N_A}$ denote the channel vector between AP i and STA j in the subcarrier k when AP i uses the radiation pattern p_i . Before being sent to the N_A antennas, signals are beamformed in the baseband-equivalent discrete-time domain. Let $\mathbf{w}_i^{(p_i)}[k] \in \mathbb{C}^{N_A \times 1}$ be the unit-norm digital transmit precoding vector in subcarrier k for AP i , when an analog radiation pattern p_i is used. Note that we have highlighted the dependency of the digital precoder on the analog pattern, as it affects the equivalent digital channel $\mathbf{h}_{i,j}^{(p_i)}[k]$, from which $\mathbf{w}_i^{(p_i)}[k]$ is designed.

Upon transmission of symbols $x_j[k]$ with unitary power from APs $j \in \{1, \dots, J\}$ on the subcarrier k , the received signal by the corresponding STA j on the subcarrier k is

$$y_j[k] = \mathbf{h}_{j,j}^{(p_j)}[k] \mathbf{w}_j^{(p_j)}[k] x_j[k] + \sum_{i=1, i \neq j}^J \mathbf{h}_{i,j}^{(p_i)}[k] \mathbf{w}_i^{(p_i)}[k] x_i[k] + n_j[k], \quad (1)$$

where $n_j[k]$ is the additive white Gaussian noise in subcarrier k with zero mean and variance σ^2 . The second term in (1)

represents the inter-AP interference caused by simultaneous transmissions from other APs operating on the same time-frequency resources.

III. H-COMP-CBF AND COMPARED BEAMFORMING STRATEGIES

The proposed H-COMP-CBF framework explores the joint space of analog radiation patterns and digital precoders to quantify the throughput gains achievable by their synergy. Unlike conventional coordinated beamforming, where only digital precoding is considered, the analog configuration is here treated as an additional design variable. Since the selected analog pattern directly affects the effective channel realization, it also influences the resulting interference and, consequently, the design of the digital precoders.

The hybrid beamforming design can be interpreted as a two-stage optimization process. First, each AP selects an analog radiation pattern, which determines the effective propagation environment. Then, for the resulting channel realization, digital precoders are designed to manage interference. Specifically, to determine the optimal hybrid beamforming, an exhaustive search in the available radiation patterns is performed. The goal is to identify J radiation patterns in all APs, denoted as $\mathbf{p}^* = [p_1, p_2, \dots, p_J]$, that maximize the aggregate system throughput, i.e.,

$$\mathbf{p}^* = \arg \max_{\mathbf{p} \in \{1, \dots, P\}^J} \sum_{j=1}^J T_j(\mathbf{p}). \quad (2)$$

Here, $T_j(\mathbf{p})$ denotes the per-user throughput achieved by STA j , which depends on both the selected analog patterns in APs and the corresponding digital precoders. The throughput is calculated taking into account the specific Modulation and Coding schemes (MCSs) available and the resulting packet success rate.

Note that for each pattern set $\mathbf{p} \in \{1, \dots, P\}^J$, the digital precoding vectors $\mathbf{w}_j^{(p_j)}[k]$, for $j = 1, \dots, J$ and $k = 1, \dots, N_s$, are designed to manage spatial interference based on CSI. To actively mitigate inter-AP interference, H-COMP-CBF takes advantage of a *coordinated* digital precoding strategy, representative of WiFi 8.

Remark: In this work, the radiation-pattern selection in (2) is evaluated offline using the measured CSI dataset and the PHY-level simulator. This allows us to quantify the best-case performance achievable over the considered finite set of radiation-patterns. The H-COMP-CBF framework itself is compatible with practical implementations in which the radiation state is selected by the AP controller and updated on a slow timescale. However, the design of a low-overhead online pattern-selection protocol, including its signaling and training cost, is left as future work.

A. Proposed Coordinated Digital Precoding (WiFi 8)

The APs jointly manage interference through a CoMP-CBF strategy to design the digital precoding vectors $\mathbf{w}_j^{(p_j)}[k]$. Unlike CoMP-JP, which requires user data to be exchanged,

CBF only requires CSI to be shared among APs, significantly reducing backhaul overhead [6].

To enable a distributed and scalable implementation, we adopt a criterion based on the signal-to-leakage-plus-noise ratio (SLNR) [6]. For each subcarrier k , AP j designs its digital precoder to maximize the ratio between the power delivered to its intended STA j and the power of the *leaked* signal that interferes with any other STAs $i (\neq j)$, i.e.,

$$\mathbf{w}_j^{(p_j)*}[k] = \arg \max_{\|\mathbf{w}\|^2=1} \frac{\|\mathbf{h}_{j,j}^{(p_j)}[k]\mathbf{w}\|^2}{\sum_{i \neq j} \|\mathbf{h}_{j,i}^{(p_j)}[k]\mathbf{w}\|^2 + \sigma^2}. \quad (3)$$

This formulation allows each AP to locally balance signal enhancement and interference suppression. The resulting optimization problem can be cast as a generalized eigenvalue problem. The optimal digital precoder corresponds to the dominant eigenvector of the matrix

$$\mathbf{M}_j^{(p_j)}[k] = \left(\mathbf{R}_j^{(p_j)}[k] + \sigma^2 \mathbf{I} \right)^{-1} \mathbf{Q}_j^{(p_j)}[k], \quad (4)$$

where $\mathbf{Q}_j^{(p_j)}[k] = (\mathbf{h}_{j,j}^{(p_j)}[k])^H \mathbf{h}_{j,j}^{(p_j)}[k]$ is the signal covariance matrix and $\mathbf{R}_j^{(p_j)}[k] = \sum_{i \neq j} (\mathbf{h}_{j,i}^{(p_j)}[k])^H \mathbf{h}_{j,i}^{(p_j)}[k]$ is the leakage covariance matrix.

It is worth noting that the SLNR criterion is adopted here as a representative coordinated digital precoding strategy for WiFi 8-like multi-AP transmission, rather than being claimed as a novel digital precoder. The contribution of this work lies in combining this coordinated digital precoding mechanism with measured reconfigurable-antenna radiation states and in quantifying, through a measurement-driven PHY-level evaluation, the additional gain provided by considering their synergy.

B. Baseline: Non-coordinated Digital Precoding (WiFi 7)

As a baseline for comparison, we consider a non-coordinated digital precoding strategy representative of WiFi 7 operation. In this case, each AP designs its precoder independently by considering only the intended AP–STA channel, without accounting for the leakage generated toward non-associated STAs. Specifically, on subcarrier k , AP j uses the multiple-input single-output (MISO) channel vector $\mathbf{h}_{j,j}^{(p_j)}[k] \in \mathbb{C}^{1 \times N_A}$ toward its associated STA j .

Since each STA is equipped with a single antenna, the resulting precoder reduces to maximum-ratio transmission (MRT), i.e.,

$$\mathbf{w}_j^{(p_j)*}[k] = \frac{(\mathbf{h}_{j,j}^{(p_j)}[k])^H}{\|\mathbf{h}_{j,j}^{(p_j)}[k]\|}. \quad (5)$$

Equivalently, this vector corresponds to the dominant right singular vector of the intended channel $\mathbf{h}_{j,j}^{(p_j)}[k]$. This strategy maximizes the desired received signal power for the single-user MISO link in isolation, but it does not explicitly suppress the interference caused to neighboring STAs.

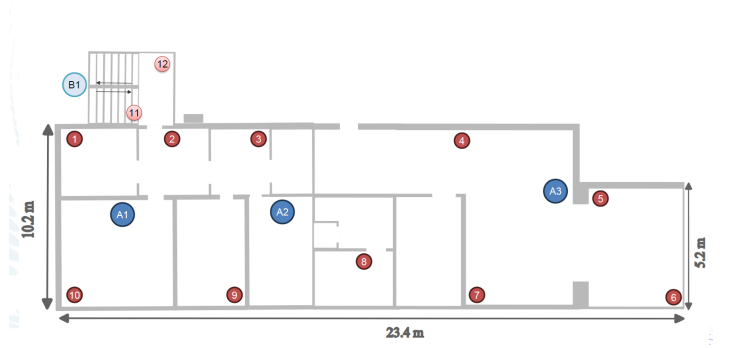


Fig. 1. Considered indoor deployments, where red and blue circles represent STAs and APs positions, respectively.

IV. EXPERIMENTAL AND SIMULATION SETUP

To validate the proposed H-COMP-CBF framework, we rely on an experimental dataset of CSI acquired in a real-world indoor environment.

The measurements campaign is conducted in a residential test-house with dimensions of approximately 23.4×10.2 m. The environment consists of multiple rooms separated by standard internal walls, representing a typical dense indoor deployment, as shown in Fig. 1. The setup includes 3 candidate positions for the APs (identified by A1, A2, and A3 and each with $N_A = 4$ reconfigurable antennas), and 10 WiFi STAs (identified by 1, 2, ..., 10, in blue circles) distributed across different rooms. This allows for the definition of different multi AP-STA scenarios. In particular, we define a *configuration* as a pair of simultaneously active AP–STA links sharing the same time-frequency resources. Therefore, each configuration consists of two APs, each serving one of the two STAs.

Note that the two-AP/two-STA configuration is the smallest non-trivial multi-AP scenario in which inter-AP interference and coordinated beamforming effects arise. This choice allows us to isolate and interpret the impact of coordinated digital precoding and analog radiation pattern selection using measured channels, without confounding effects due to scheduling, clustering, or user association. Extending the evaluation to larger multi-AP topologies is left for future work.

A. Hardware and Antenna System

The acquisition system relies on residential-grade routers integrated with Adant reconfigurable antenna systems. Each AP can select one among 16 distinct radiation states, allowing adaptive modification of the propagation conditions. The internal implementation of the commercial reconfigurable antenna module is based on a proprietary design and is outside the scope of this paper. From the system-level perspective considered here, the antenna is modeled as a controllable finite radiation-pattern codebook composed of 16 measured states. Each radiation state produces a distinct far-field radiation pattern and, consequently, a different effective AP–STA channel realization in the considered indoor environment. During the measurement campaign, CSI was collected for all available radiation states.

In a practical implementation, the radiation state can be selected by the AP controller and kept fixed over several packet transmissions, or updated on a slow timescale based on CSI feedback or long-term link-quality statistics. On the receiver side, the setup employs a variety of commercial WiFi 7-capable smartphones as STAs, including flagship models such as the Samsung Galaxy S24, Google Pixel 8, and OnePlus 11. Measurements are collected at a carrier frequency $f_C = 5$ GHz with a channel bandwidth of 80 MHz.

B. Data Collection

The CSI acquisition captures both spatial and frequency selectivity of the channel across all radiation patterns. A residential-grade IEEE 802.11ax AP is used to extract raw CSI from the Legacy Long Training Field (L-LTF) of received Physical Layer Protocol Data Units (PPDUs).

For an 80 MHz bandwidth, the system employs 256 subcarriers with spacing $\Delta_F = 312.5$ kHz. A frequency-domain decimation is applied by sampling one tone every 4 subcarriers, resulting in 60 active subcarriers.

CSI reports are generated every 50 ms, which yields approximately 600 samples per AP–STA link. In this work, we consider static channels by selecting representative snapshots from the dataset, which are used as the effective channel matrices for performance evaluation.

C. Simulation Setup

We evaluate the proposed framework using a customized IEEE 802.11be physical layer simulator developed in MATLAB. The framework extends an existing MU-MIMO downlink processing chain [9] to support multi-AP coordination based on the H-COMP-CBF strategy and measured CSI. We consider a representative scenario where two APs transmit simultaneously, each serving one STA. Under this assumption, each user experiences a single dominant interferer.

Measured MISO channels are used to reconstruct the corresponding channel impulse responses, which are consistently applied during both channel sounding and data transmission phases.

For each pattern combination $\mathbf{p}$, the simulator follows a standard WiFi downlink transmission procedure. It starts with a sounding phase, where APs transmit Null Data Packets (NDPs). The transmitted signals propagate through the reconstructed channel impulse responses derived from the measured CSI. We assume that sounding transmissions are orthogonal across APs, i.e., there is no interference between AP during channel estimation. At the receiver side, the STAs estimate the channel using Extremely High Throughput Long Training Fields (EHT-LTF), taking into account practical impairments such as synchronization errors.

The estimated CSI is sent back to APs and used to design the digital precoders by SVD (baseline) or by using CoMP-CBF. Data transmission then follows standard steps: encoding, modulation, OFDM mapping, and spatial precoding.

At the receiver, each STA performs channel equalization, demodulation, and decoding to recover the transmitted Physical Layer Service Data Units (PSDUs). This enables the

evaluation of the throughput for each pattern configuration and the identification of the optimal hybrid beamforming.

D. Performance Metric

We evaluate performance in terms of throughput, defined as the successfully delivered data rate accounting for both protocol overhead and transmission errors.

Let $N_{succ,j}(\mathbf{p})$ be the number of packets correctly received, i.e., those where the entire PSDU is recovered without errors. Let L_{bit} denote the number of information bits per packet, N_{tot} be the total number of transmitted packets, while T_{pkt} and T_{idle} represent the packet duration and the idle time between consecutive transmissions, respectively. For a given set of radiation patterns across the APs $\mathbf{p}$ and the corresponding digital precoders, the per user throughput $T_j(\mathbf{p})$ for STA j is computed as

$$T_j(\mathbf{p}) = \frac{N_{succ,j}(\mathbf{p}) \cdot L_{bit}}{N_{tot} \cdot (T_{pkt} + T_{idle})}. \quad (6)$$

Remark: To clarify the role of measurements in the evaluation, the experimental component of this work consists of the over-the-air CSI acquisition campaign performed for all considered AP–STA links and antenna radiation states. The reported packet throughput values are not measured over-the-air, but are obtained through PHY-level simulations using channel impulse responses reconstructed from the measured CSI.

V. NUMERICAL RESULTS

We first show in Fig. 2 representative examples of two antenna patterns. It can be seen that the radiation mode of the AP can significantly reshape the radiation envelope. In particular, Fig. 2 (a) exhibits a directive main lobe, maximizing the gain towards a specific target area. Conversely, a different spatial distribution of energy can be seen in Fig. 2 (b), where deep nulls are introduced in directions where, in (a), we had significant emission. This capability allows the AP to select the most favorable propagation environment, effectively modifying the resulting channel frequency response.

The measured CSI provides a detailed characterization of the considered indoor propagation environment under a specific antenna pattern. Fig. 3 shows the magnitude and phase of the frequency response of the A1-S2 link. The magnitude of the channel frequency response exhibits significant frequency-selectivity, with deep fading dips. These fluctuations are due to the multi-path destructive interference, typical of an indoor environment. However, despite these magnitude drops, the spatial diversity provided by $N_A=4$ antennas ensures that the fading nulls of the single spatial links do not perfectly overlap in frequency. The beamforming strategy can exploit the available degrees of freedom at the AP to properly steer the signal toward the single-antenna STA, mitigating the effect of frequency-selective fading.

To evaluate the effectiveness of the H-COMP-CBF approach (labeled as *WiFi 8*), we compare the aggregate throughput (in Mbps) of different configurations obtained with respect

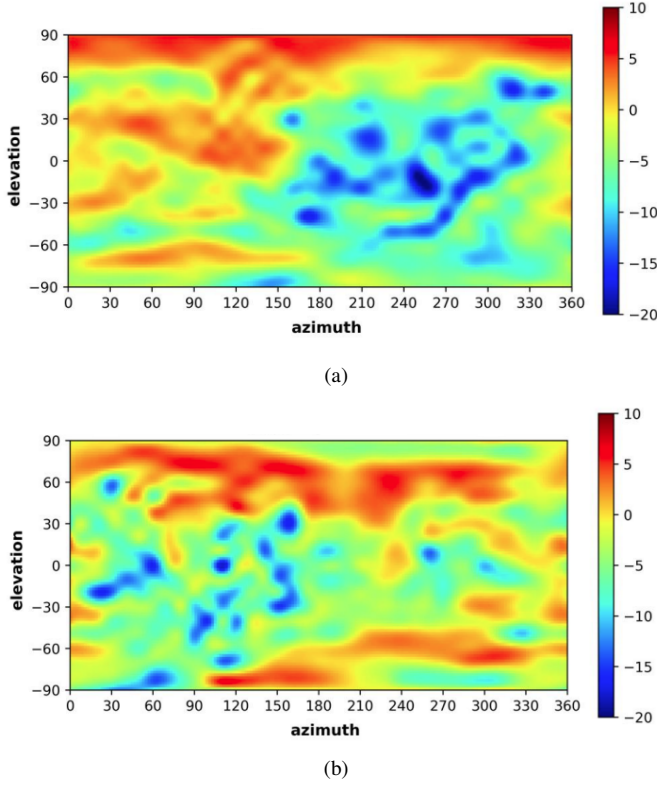


Fig. 2. Example of two antenna patterns (in dB) for the reconfigurable antenna in the elevation-azimuth plane.

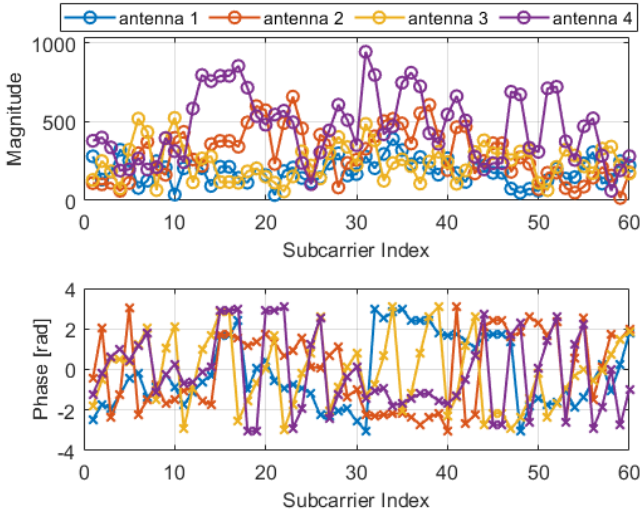


Fig. 3. Magnitude and phase of the frequency response of the A1-S2 link.

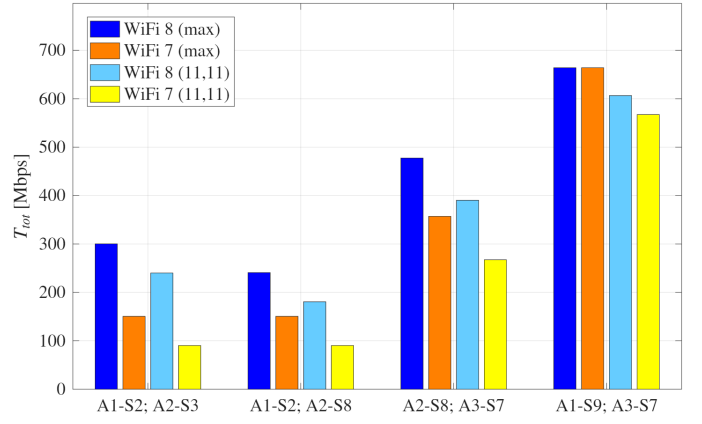


Fig. 4. Aggregate throughput for 4 distinct AP-STA pairing configurations, considering both WiFi 7 and WiFi 8. We evaluate the aggregate throughput obtained with the optimal hybrid beamforming at the APs (labeled as *max*), and the aggregate throughput achieved using the fixed reference radiation pattern at the APs (labeled as *(11,11)*).

to that resulting from the non-coordinated approach (labeled as *WiFi 7*). Fig. 4 shows the aggregate throughput for 4 different pairing configurations AP-STA and WiFi 7 and WiFi 8. Moreover, for each configuration we evaluate the aggregate throughput obtained by optimizing the hybrid beamforming of each AP to maximize the aggregate throughput (labeled as *max*) as discussed in Section III, and the aggregate throughput achieved using a fixed reference radiation pattern in the APs (labeled as *(11,11)* since the reference analog pattern is the number 11).

It can be seen that the WiFi 8 strategy consistently outperforms WiFi 7 in all tested configurations. The performance gap is particularly pronounced in configurations with high interference potential, such as the (A1-S2; A2-S3) configuration (see Fig. 1). When considering the same antenna reference pattern, the gain achieved in WiFi 8 highlights the effectiveness of coordinated beamforming in mitigating inter-AP interference. Furthermore, the joint optimization of antenna radiation patterns and digital precoders provides additional performance improvements. This shows that antenna pattern reconfigurability and coordinated beamforming act as complementary mechanisms: while coordinated precoding mitigates interference, antenna pattern selection shapes the propagation conditions, further enhancing the overall system performance.

Finally, Fig. 5 shows the per-user throughput for the configuration (A1-S2; A2-S3), comparing the ideal interference-free case (i.e., where the transmission from A1 to S2 does not affect the transmission from A2 and S3 and vice versa) with the actual performance achieved using baseline and H-COMP-CBF strategies. For each case, we evaluate the per-user throughput under both the reference antenna pattern and the optimized hybrid beamforming. For WiFi 7, it can be observed that while A2 successfully serves S3, its transmission acts as a dominant interferer for S2. Moreover, with the reference antenna pattern, the S2 throughput reaches zero. Even when optimizing the beamforming capability, the per-

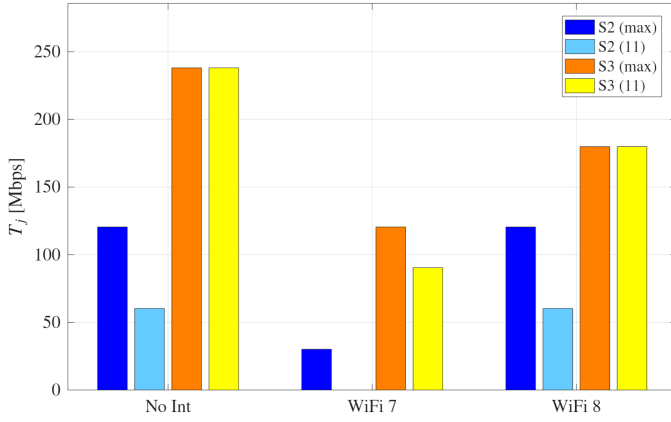


Fig. 5. Per-user throughput for the pair (A1-S2; A2-S3), comparing the interference-free case with the actual performance achieved in WiFi 7 and WiFi 8.

formance improvement remains limited, as the digital precoder does not exploit information about the channels toward neighboring STAs, which is required to actively suppress inter-cell interference. However, WiFi 8 enables more effective interference management through coordinated precoding. In particular, spatial nulls can be generated toward non-intended STAs, leading to a more balanced performance among users and a significant improvement in reliability.

VI. CONCLUSIONS

In this paper, we proposed the H-COMP-CBF framework for WiFi 8, which showcases the performance gains achievable through the synergy of coordinated digital precoding and reconfigurable antenna systems. Experimental results demonstrate that while coordinated beamforming alone significantly

improves throughput over the WiFi 7 baseline, the joint optimization of the antenna radiation patterns and the digital precoders provides a further essential boost in interference-limited scenarios. This hybrid approach ensures maximum spectral efficiency, making it a key enabler for next-generation dense WLAN deployments.

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