Poster: Towards Flexible Frequency-dependent mmWave Multi-Beamforming

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Abstract

We propose a new mmWave radio architecture called delay-phased array (DPA) that improves efficient utilization of large bandwidth and large antenna array at high mmWave frequencies by creating flexible frequency-dependent multi-beams. DPA allows for flexible division of system bandwidth into small bands and independent radiation of each band in different chosen beam directions.

CCS Concepts

• **Hardware** → **Wireless devices**; • **Networks** → **Physical links**; **Wireless access points, base stations and infrastructure**.

Keywords

Millimeter-wave, Analog beamforming, Phased array, Multi-beam, Multi-user, Frequency multiplexing, Spectrum utilization

1 Introduction

The next generation of communication networks, utilizing millimeter-wave and terahertz frequencies, have large bandwidths to support high-throughput applications such as AR/VR. However, conventional millimeter-wave (mmWave) networks experience low effective utilization of the available bandwidth. This is because the traditional phased array creates directional beams which are localized to a specific angular direction but spread across the entire frequency band, as shown in Figure 1(a). This results in underutilization of bandwidth when the demand in that beam direction is lower than the system bandwidth. For instance, the initial access beam scan procedure in 5G NR requires only 7% bandwidth towards a beam direction, but the remaining 93% goes unused if there are no active users in that direction to serve.

■ **Related Work:** One potential solution is to split the beam into multiple directions with phased array, but beam splitting reduces the directivity in each direction, reducing signal strength, range, and data rate [1]. Recently, true-time delay (TTD) array [2] architecture is proposed to achieve frequency-dependent beamforming that spread different frequencies in different directions while maintaining high directivity (Figure 1(b)). However, these beam patterns have limitations in that each user only receives a tiny fraction of the bandwidth in one timeslot, which may not meet their demand in a reasonable time frame. Additionally, these architectures do not provide control over the number of beams, beam directions, and ***beam-bandwidth***[1], resulting in large chunks of frequency resources being wasted in directions where there is no active user.

[1]**Beam-bandwidth** is defined as a fraction of system bandwidth that has high beamforming gain in the desired beam direction and low elsewhere.

HotMobile '23, February 22–23, 2023, Newport Beach, CA, USA

ACM ISBN 979-8-4007-0017-0/23/02.
https://doi.org/10.1145/3572864.3581579

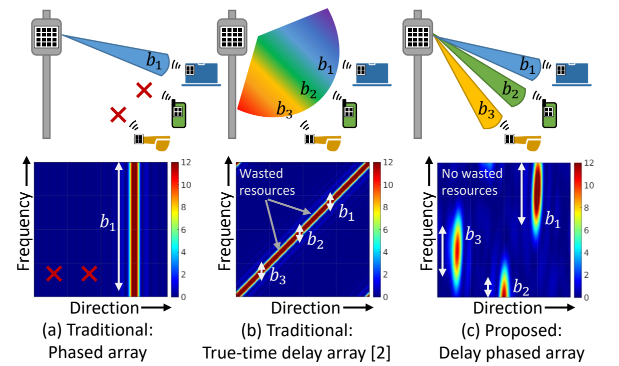

Figure 1: Beamforming strategies for mmWave systems: Traditional phased array creates beam over the entire bandwidth, while TTD array is limited to a tiny fixed beam-bandwidth (shown by arrows). our proposed DPA offers flexibility over the number of beams, beam-bandwidth, and beam directions.

2 Proposed Delay Phased Array Design

In this poster, we present a new analog antenna array architecture called delay-phased array (DPA) that creates an arbitrary number of beams with flexible beam direction and beam-bandwidth. Each beam carries a separate frequency band for users in that beam direction, while other beams serve in other directions with different frequency bands. A key advantage of DPA is that it preserves beamforming gain across all beams while re-distributing power to only desired frequency-direction pairs with minimal leakage in other directions and frequency bands as shown in Figure 1(c).

■ **Contribution:** We made novel contributions to both the hardware design and software programming of DPA. On the hardware side, DPA consists of a single RF-chain connected to an antenna array that includes variable phase and variable delay elements for each antenna. The phase element provides beam steerability, while the additional delay element enables frequency selectivity. Our design significantly reduces the range of delay values required in comparison to traditional true-time delay array designs, making it more practical and easy to manufacture. Additionally, the delay range is not dependent on the number of antenna elements, making it scalable for large arrays. On the software side, we provide a closed-form expression for the delay and phase values to create any arbitrary frequency-direction response[2].

■ **Simulation Results:** Figure 1 (bottom) shows that the phased array baseline serves only one direction with the entire bandwidth, while the TTD baseline serves three users but with a tiny fixed beam-bandwidth. In contrast, DPA is able to create the desired 3-beam response with flexible beam-bandwidth and beam directions.

References

[1] Ish Kumar Jain, Raghav Subbaraman, and Dinesh Bharadia. Two beams are better than one: towards reliable and high throughput mmwave links. In *Proceedings of ACM SIGCOMM*, pages 488–502, 2021.

[2] Ruifu Li, Han Yan, and Danijela Cabric. Rainbow-link: Beam-alignment-free and grant-free mmw multiple access using true-time-delay array. *IEEE Journal on Selected Areas in Communications*, 2022.

[2]For more details and artifacts on DPA, please visit https://wcsng.ucsd.edu/dpa