Many-Antenna Full-Duplex with Fully Digital and Hybrid Beamforming Radios

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Next generation wireless systems are expected to use a very large number of antennas at base stations (BSs). For example, the 3GPP has already included support for up to 128 antenna BSs for sub-6 GHz cellular systems in its standard specifications. The traditional approach to build many-antenna BSs is to connect each antenna element to a separate Tx-Rx RF chain (an architecture referred to as *fully digital*). However, it is possible to reduce the cost and power consumption of the BS by connecting each RF chain to an array of antennas by using phased arrays or switched beam antennas (an architecture referred to as *hybrid beamforming*).

Our goal in this paper is to study the potential for full-duplex (FD) in sub-6 GHz many-antenna systems with hybrid beamforming radios. In particular, we **propose to design transmit analog (e.g., phased array) beams that not only provide high beamforming gains in the desired directions but also reduce self-interference (SI)**. We quantify the relationships between these two objectives (i.e., Tx beam gain and SI reduction) and experimentally evaluate them through over-the-air experiments on high quality software-defined radios (SDRs).

Our work in this paper builds on our recent work [1] where we presented an iterative algorithm for FD beam design with phased array antennas. However, our algorithm in [1] was designed for linear arrays and its performance was evaluated through WARP SDRs, which have up to -80 dBm of noise power. In addition, the algorithm incurred a large computational complexity, which limited its use case to very slowly varying channel conditions. This paper builds on our prior work by (i) extending the algorithm to support planar arrays, (ii) reducing the computational complexity through extra convexification steps, (iii) evaluating its performance on our recently acquired Iris SDRs (Fig. 1), which have a much lower noise level (-95 dBm at 20 MHz bandwidth) and much improved synchronization across the radios, and (iv) comparing its performance against SoftNull [2], the state-of-the-art many-antenna FD design that assumes a fully digital BS architecture. In particular, we show that hybrid beamforming systems can achieve SI reduction and beamforming gains that are close to fully digital systems. The gap between the two designs reduces as we use phased arrays with higher weight resolutions.

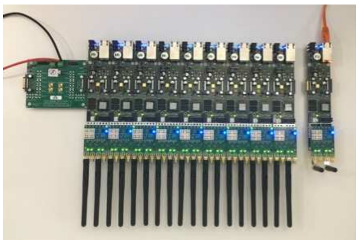

Figure 1. A fully digital BS architecture based on our Iris radios with 20 antennas and 20 Tx-Rx RF chains

We present the results of experiments on our new many-antenna platform, which uses Skylark Wireless Iris SDRs. This testbed is designed for exceptional flexibility in antenna configuration. The example setup shown in Fig. 1 is fully digital, but can be easily extended to support phased arrays. We use self-interference channel measurements with 20-40 antennas to quantify the SI reduction and beamforming gains in indoor, outdoor, and anechoic chamber environments, with varying antenna configurations, and across two frequency bands (2.4 and 5 GHz). Our measurements, code, and detailed methodology will be made publicly available online. We compare the results of our algorithm against SoftNull using our own measured dataset and additional channel estimates from the SoftNull public dataset (which uses WARP SDRs) [2].

1. E. Aryafar and A. Keshavarz-Haddad, “PAFD: Phased Array Full-Duplex”, in Proceedings of *IEEE INFOCOM 2018,* Honolulu, HI, April 2018.

2. E. Everett, C. Shepard, L. Zhong, and A. Sabharwal, “SoftNull: Many-Antenna Full-Duplex Wireless via Digital Beamforming”, *IEEE Transactions on Wireless Communications*, vol. 15, no. 12, 2016, pp. 8077-8092.