STEER+: Robust Beam Refinement for Full-Duplex Millimeter-Wave Systems

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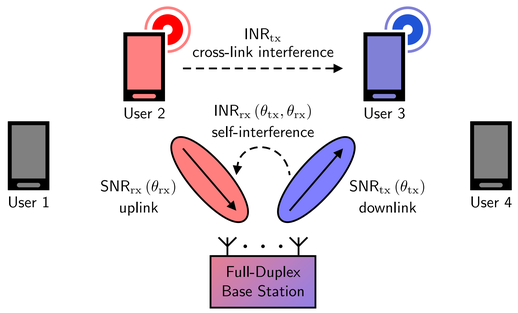
Why Full-Duplex mmWave Systems?



- Higher spectral efficiency and network throughput.
- Lower latency, especially in multi-hop networks.
- Unlocks scheduling opportunities.
- Efficient medium access control.
- Applications in wireless backhauling, sensing, security, spectrum sharing, feedback, and more.

How to unlock full-duplex capability at mmWave?

Key Metrics of a Full-Duplex System

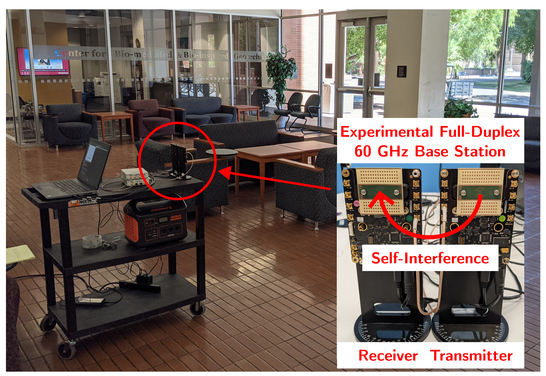
$$\mathsf{SINR}_{tx}(\theta_{tx}) = \frac{\mathsf{SNR}_{tx}(\theta_{tx})}{1+\mathsf{INR}_{tx}}$$

$$\mathsf{SINR}_{rx}(\theta_{tx},\theta_{rx}) = \frac{\mathsf{SNR}_{rx}(\theta_{rx})}{1+\mathsf{INR}_{rx}(\theta_{tx},\theta_{rx})}$$

$$R_{sum} = \underbrace{\log_2(1+\mathsf{SINR}_{tx}(\theta_{tx}))}_{\text{downlink rate}} + \underbrace{\log_2(1+\mathsf{SINR}_{rx}(\theta_{tx},\theta_{rx}))}_{\text{uplink rate}}$$

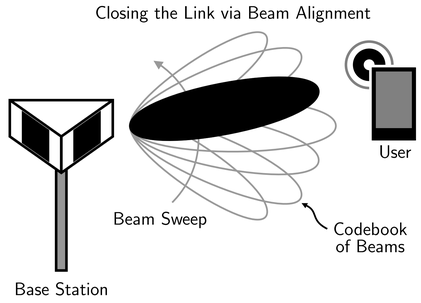
How to choose beam steering directions $(\theta_{tx}, \theta_{rx})$?

Experiments with 60 GHz Phased Arrays

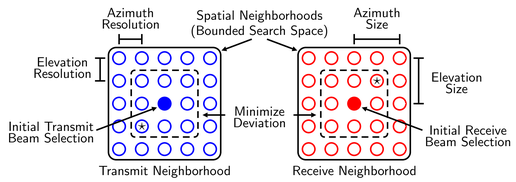


STEER+: How Can Beamforming Enable Full-Duplex in Practical mmWave Systems?

Beam Alignment is Critical



Spatial Neighborhood



Our Approach: STEER [1] robustify STEER+ [2]

1. Conduct beam alignment as usual for an initial beam selection.

$$\theta_{tx}^{init} = \underset{\theta_{tx}\in\mathcal{C}_{tx}}{\operatorname{argmax}}\ \mathsf{SNR}_{tx}(\theta_{tx})$$

$$\theta_{rx}^{init} = \underbrace{\underset{\theta_{rx}\in\mathcal{C}_{rx}}{\operatorname{argmax}}\ \mathsf{SNR}_{rx}(\theta_{rx})}_{\text{search across coarse codebooks}}$$

2. Slightly shift transmit and receive beams to reduce self-interference to below a threshold INR_{rx}^{tgt} while meeting a desired sum rate.

$$\underbrace{(\theta_{tx}^\star, \theta_{rx}^\star)}_{\text{beam selections}} = \underset{\theta_{tx},\theta_{rx}}{\operatorname{argmin}}\ \min_{\Delta\vartheta_{tx},\Delta\vartheta_{rx}} \underbrace{\Delta\vartheta_{tx}^2 + \Delta\vartheta_{rx}^2}_{\text{shifting distance}}$$

$$\text{s.t. } \underbrace{\mathsf{INR}_{rx}(\theta_{tx},\theta_{rx}) \le \mathsf{INR}_{rx}^{tgt}}_{\text{self-interference below a threshold}}$$

$$\underbrace{R_{sum}(\theta_{tx},\theta_{rx}) \ge \min\left(R_{sum}^{tgt}, R_{sum}^{max}\right)}_{\text{sum rate above a (feasible) threshold}}$$

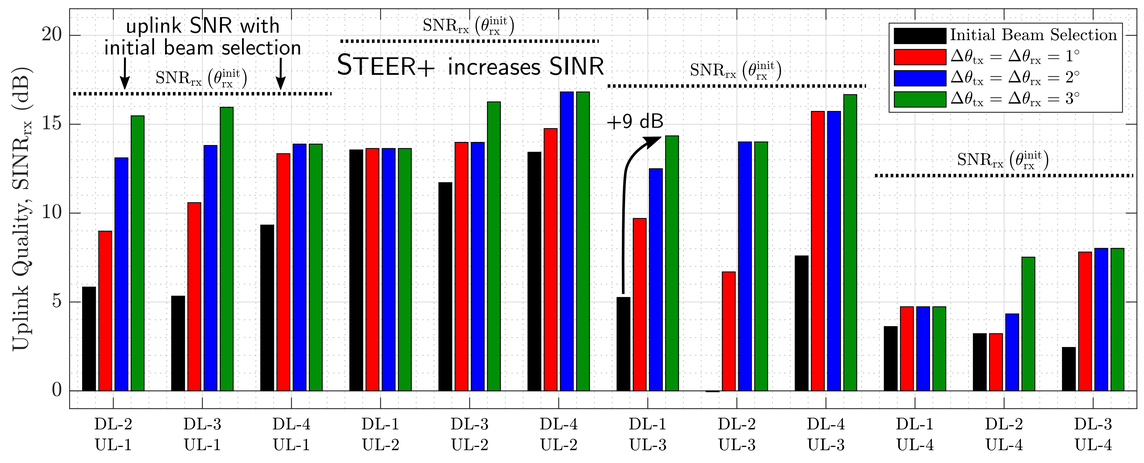
$$\theta_{tx} \in \theta_{tx}^{init} + \mathcal{N}(\Delta\vartheta_{tx}, \delta\theta_{tx})$$

$$\underbrace{\theta_{rx} \in \theta_{rx}^{init} + \mathcal{N}(\Delta\vartheta_{rx}, \delta\theta_{rx})}_{\text{within neighborhood of initial selections}}$$

$$\underbrace{0 \le \Delta\vartheta_{tx} \le \Delta\theta_{tx},\ 0 \le \Delta\vartheta_{rx} \le \Delta\theta_{rx}}_{\text{upper-bound beam shifting distance}}$$

- Design parameter #1: Self-interference target INR_{rx}^{tgt} → Increasing triggers more measurements of DL/UL SNR.
- Design parameter #2: Sum rate target R_{sum}^{tgt} → Increasing consumes more overhead overall but increases sum rate.
- Design parameter #3: Neighborhood size $(\Delta\theta_{tx}, \Delta\theta_{rx})$ → Increasing will consume more overhead but widen search space.

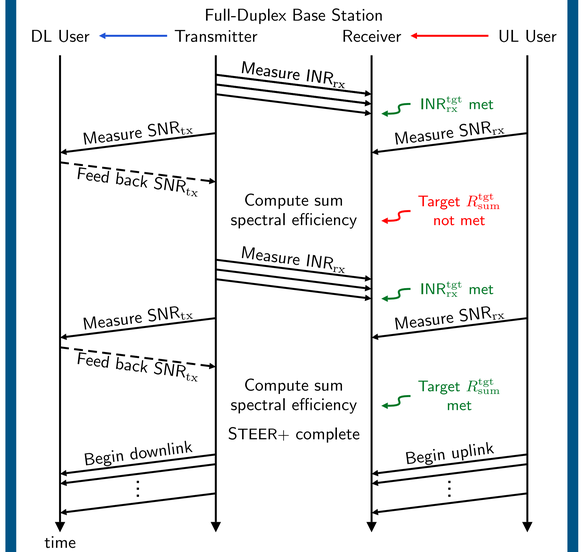
Uplink SINR Improvement with STEER+ from Real-World Implementation



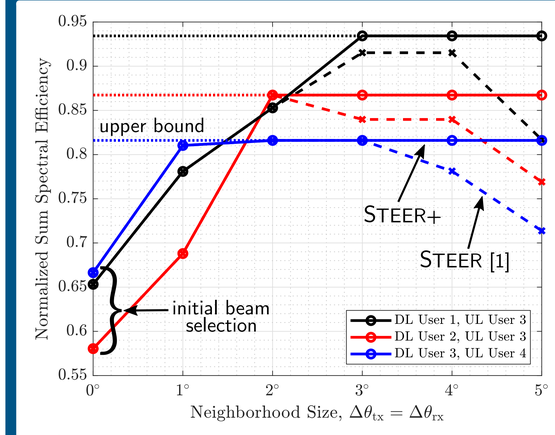
⟵ 12 different downlink-uplink user pairs from our experiments ⟶

STEER+ can greatly improve uplink SINR by slightly shifting its transmit and receive beams from their initial selections.

Efficiently Implementing STEER+



Comparing STEER [1] vs. STEER+ [2]



STEER+ improves when widening search space ⟶

Relevant References

[1] I. P. Roberts et al., "STEER: Beam Selection for Full-Duplex Millimeter Wave Communication Systems," *IEEE Trans. Commun.*, Oct. 2022.
[2] I. P. Roberts et al., "STEER+: Robust Beam Refinement for Full-Duplex Millimeter Wave Communication Systems," *Asilomar*, Oct. 2023.