# STEER: Beam Selection for Full-Duplex Millimeter Wave Systems

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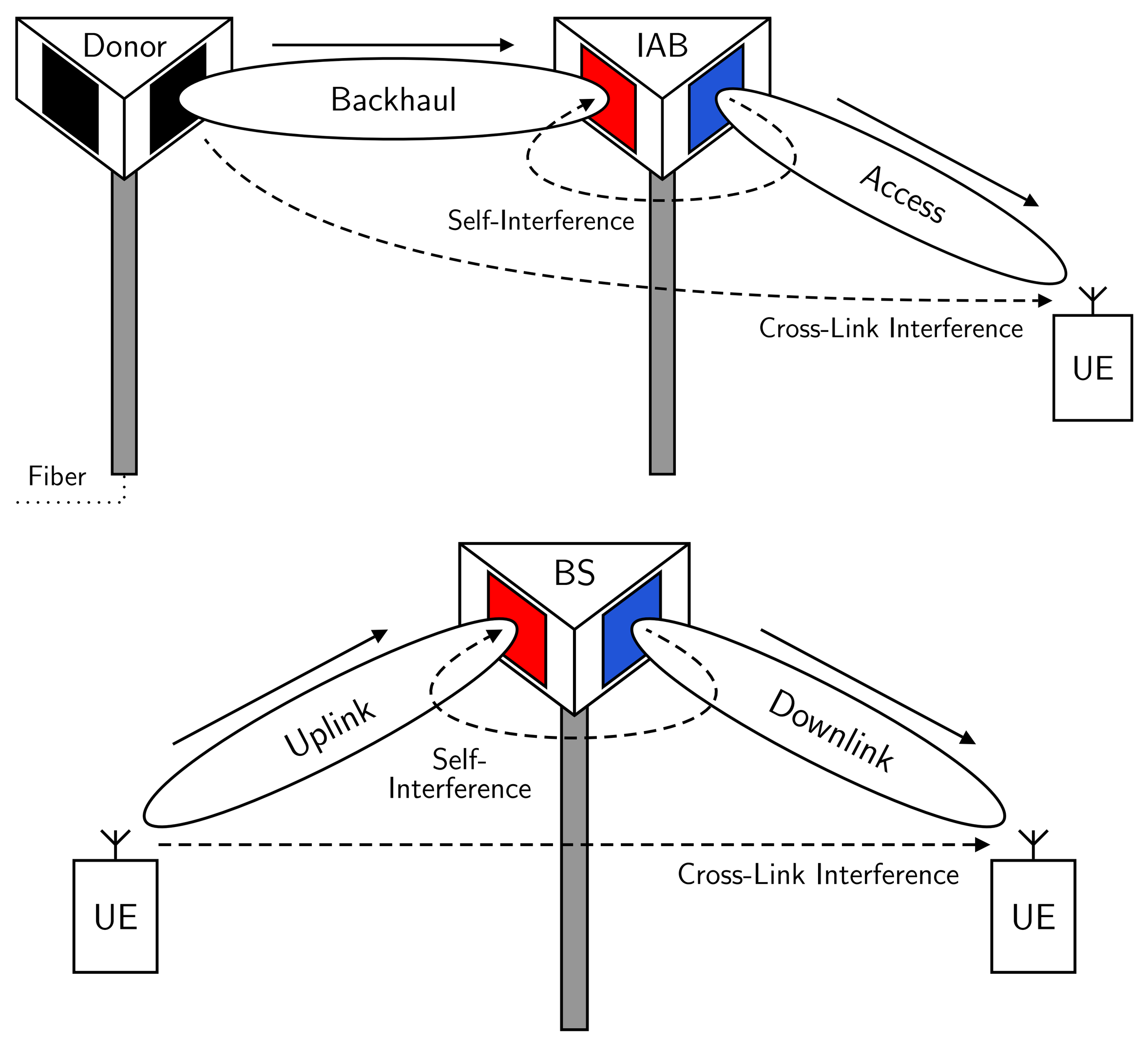
## Why Full-Duplex mmWave Systems?




- Higher spectral efficiency, network throughput.
- Lower latency, especially in multi-hop networks.
- Unlocks scheduling opportunities.
- Efficient medium access control.
- Applications in sensing, IAB, defense, cognitive radio, interference management, feedback, and more.

## Practical Beamforming Solutions

A desirable beamforming-based full-duplex solution:

- low self-interference
- high beamforming gain to downlink and uplink users
- consumes minimal radio resources to configure
- low computational complexity
- operates on limited channel knowledge
- limited phase and amplitude control
- accommodates beam alignment

No prior work accomplishes these goals holistically. Very few accomplish more than two or three.

## Acknowledgments

This work is supported by a NSF Graduate Research Fellowship and is in collaboration with AT&T Labs.

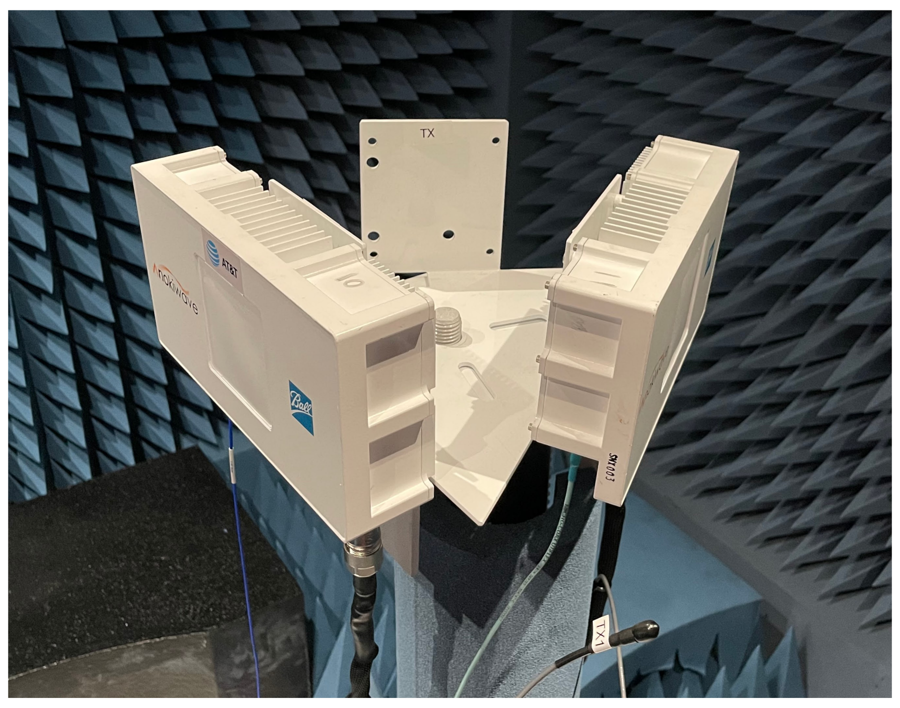
## More Information

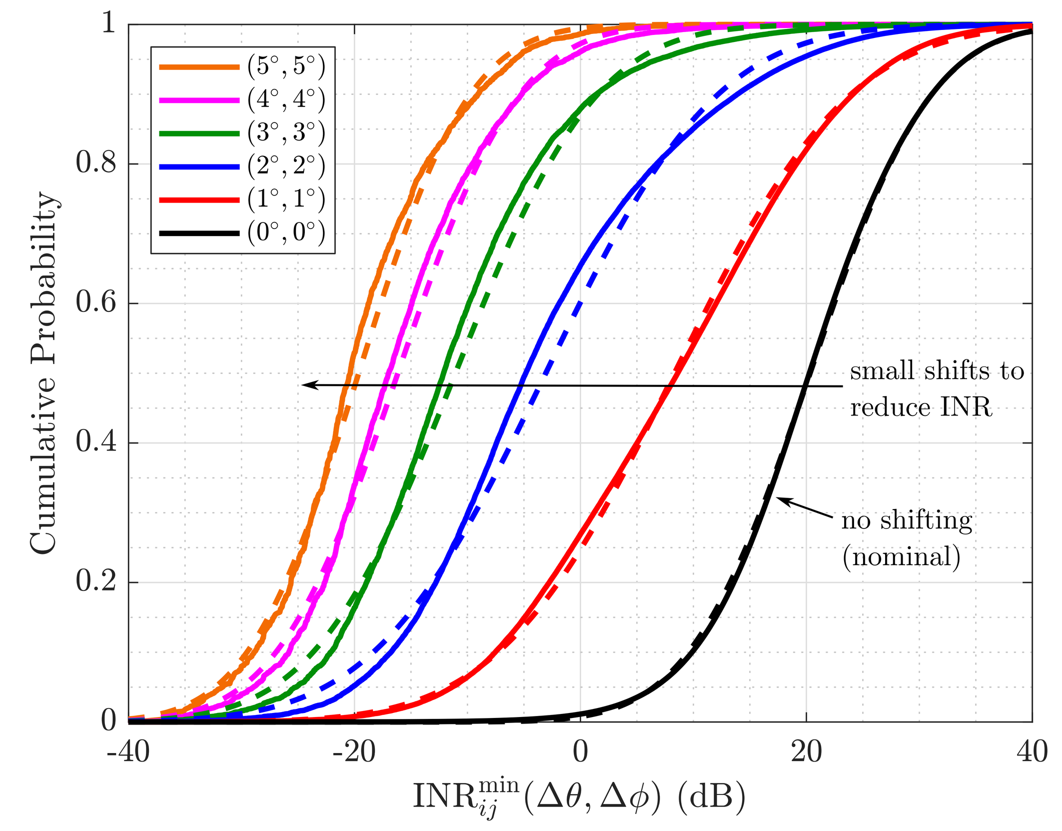
Feel free to email me at `ipr@utexas.edu` and visit my website at `ianproberts.com`.

[1] I. P. Roberts et al., "Beamformed Self-Interference Measurements at 28 GHz: Spatial Insights and Angular Spread," *IEEE Trans. Wireless Commun.*, Jun. 2022.

[2] I. P. Roberts et al., "STEER: Beam Selection for Full-Duplex Millimeter Wave Communication Systems," *IEEE Trans. Commun.*, Aug. 2022.

## Measurements of Self-Interference using 28 GHz Phased Arrays [1]



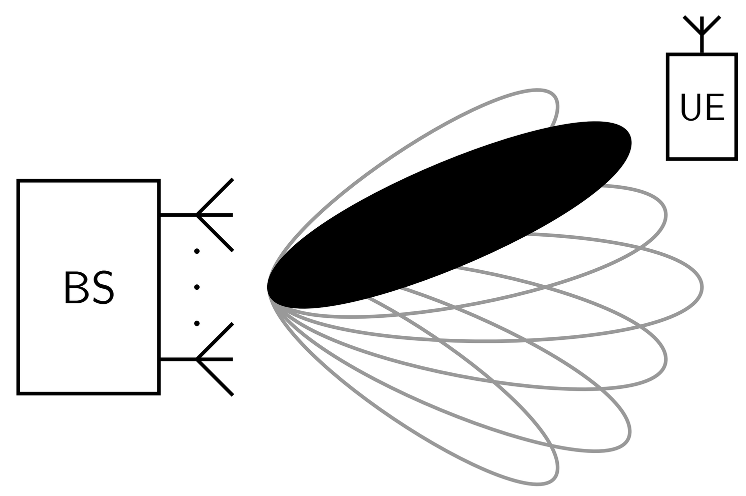



$$\underbrace{P_{\mathrm{SI}}(\theta_{\mathrm{tx}},\phi_{\mathrm{tx}},\theta_{\mathrm{rx}},\phi_{\mathrm{rx}})}_{\text{self-interference power}} = P_{\mathrm{tx}} \cdot \underbrace{\left|\mathbf{w}(\theta_{\mathrm{rx}},\phi_{\mathrm{rx}})^{*}\mathbf{H}\mathbf{f}(\theta_{\mathrm{tx}},\phi_{\mathrm{tx}})\right|^{2}}_{\text{self-interference coupling factor}} \implies \underbrace{\mathsf{INR}_{\mathrm{rx}}(\theta_{\mathrm{tx}},\phi_{\mathrm{tx}},\theta_{\mathrm{rx}},\phi_{\mathrm{rx}})}_{\text{interference-to-noise ratio}} = \frac{P_{\mathrm{SI}}(\theta_{\mathrm{tx}},\phi_{\mathrm{tx}},\theta_{\mathrm{rx}},\phi_{\mathrm{rx}})}{P_{\mathrm{noise}}}$$

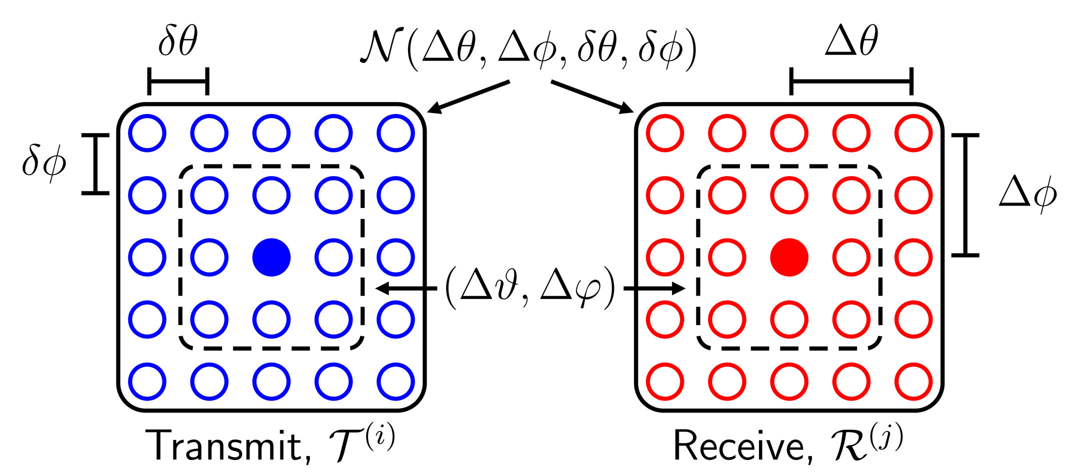
- Transmit and receive beams typically couple prohibitively high degrees of self-interference.
- Slightly shifting the transmit and receive beams can drastically reduce self-interference. $\rightarrow$ Is this useful?

## How Can Beamforming Mitigate Self-Interference and Enable Full-Duplex? [2]

### Beam Alignment is Critical




### Spatial Neighborhood




### Our Approach: STEER

1. Conduct beam alignment as usual.

$$i^{\star} = \underset{i \in \{1,\dots,N_{\mathrm{tx}}\}}{\mathrm{argmax}} \ \mathsf{SNR}_{\mathrm{tx}}\left(\mathbf{f}\left(\theta_{\mathrm{tx}}^{(i)}, \phi_{\mathrm{tx}}^{(i)}\right)\right)$$

$$j^{\star} = \underset{j \in \{1,\dots,N_{\mathrm{rx}}\}}{\mathrm{argmax}} \ \mathsf{SNR}_{\mathrm{rx}}\left(\mathbf{w}\left(\theta_{\mathrm{rx}}^{(j)}, \phi_{\mathrm{rx}}^{(j)}\right)\right)$$

2. Slightly shift transmit and receive beams to reduce self-interference to below some target threshold $\mathsf{INR}_{\mathrm{rx}}^{\mathrm{tgt}}$.

$$\underset{\substack{(\theta_{\mathrm{tx}},\phi_{\mathrm{tx}}) \\ (\theta_{\mathrm{rx}},\phi_{\mathrm{rx}})}}{\mathrm{argmin}} \ \min_{(\Delta\vartheta,\Delta\varphi)} \ \underbrace{\Delta\vartheta^{2} + \Delta\varphi^{2}}_{\text{minimize deviation}}$$

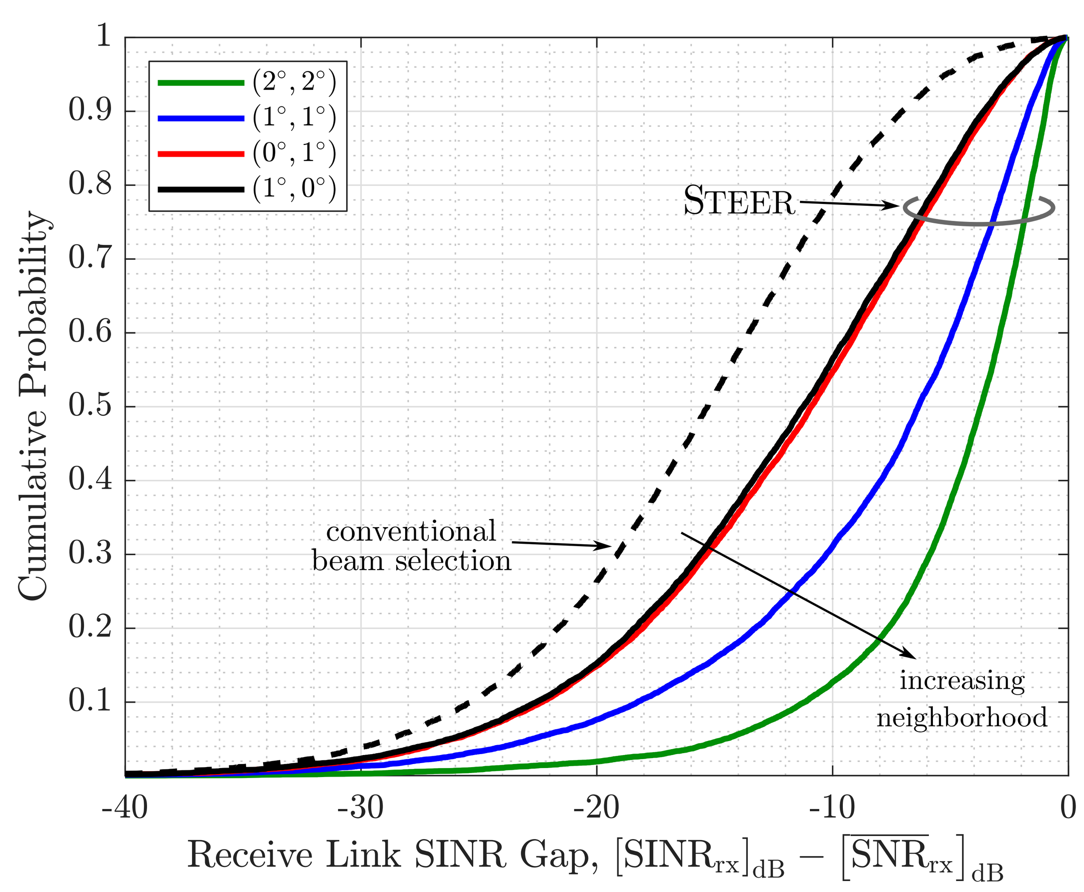
$$\text{s.t.} \ \underbrace{\mathsf{INR}_{\mathrm{rx}}(\theta_{\mathrm{tx}},\phi_{\mathrm{tx}},\theta_{\mathrm{rx}},\phi_{\mathrm{rx}}) \leq \max\left(\mathsf{INR}_{\mathrm{rx}}^{\mathrm{tgt}}, \mathsf{INR}_{\mathrm{rx}}^{\mathrm{min}}\right)}_{\text{self-interference below some feasible target}}$$

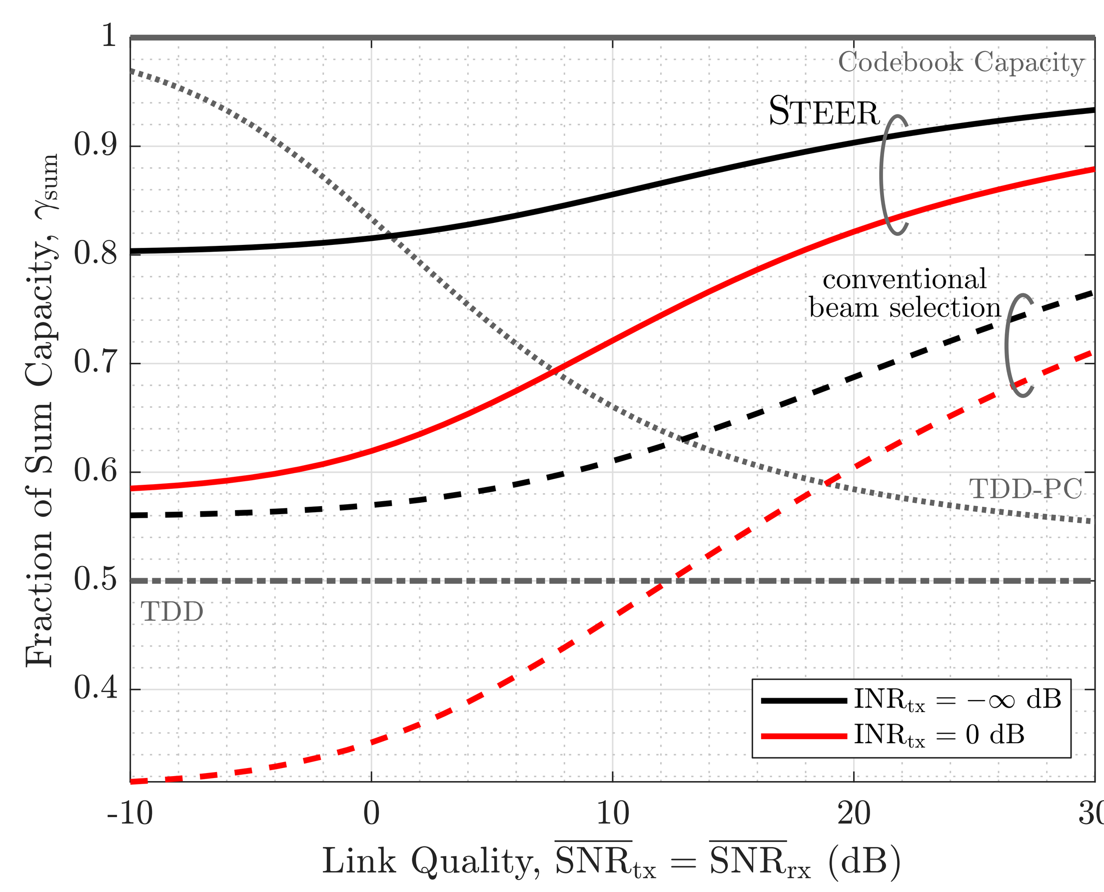
$$\underbrace{\begin{aligned}(\theta_{\mathrm{tx}},\phi_{\mathrm{tx}}) &\in \left(\theta_{\mathrm{tx}}^{(i^{\star})}, \phi_{\mathrm{tx}}^{(i^{\star})}\right) + \mathcal{N}(\Delta\vartheta, \Delta\varphi, \delta\theta, \delta\phi) \\ (\theta_{\mathrm{rx}},\phi_{\mathrm{rx}}) &\in \left(\theta_{\mathrm{rx}}^{(j^{\star})}, \phi_{\mathrm{rx}}^{(j^{\star})}\right) + \mathcal{N}(\Delta\vartheta, \Delta\varphi, \delta\theta, \delta\phi)\end{aligned}}_{\text{steer within neighborhood}}$$

$$\underbrace{0 \leq \Delta\vartheta \leq \Delta\theta, \ 0 \leq \Delta\varphi \leq \Delta\phi}_{\text{upper-bound deviation}}$$

- STEER is executed at the full-duplex BS and requires no over-the-air feedback or modifications to UEs.
- A minimal number of measurements are needed to execute STEER via strategic sorting of beam candidates.

## Performance Evaluation of STEER through Measurement and Simulation




- Compared to conventional beam selection, STEER can greatly reduce self-interference and improve SINR.
- SINR improvement leads to higher spectral efficiency and greater tolerance of cross-link interference.