Eliminating Channel Feedback in Next Generation Cellular Networks

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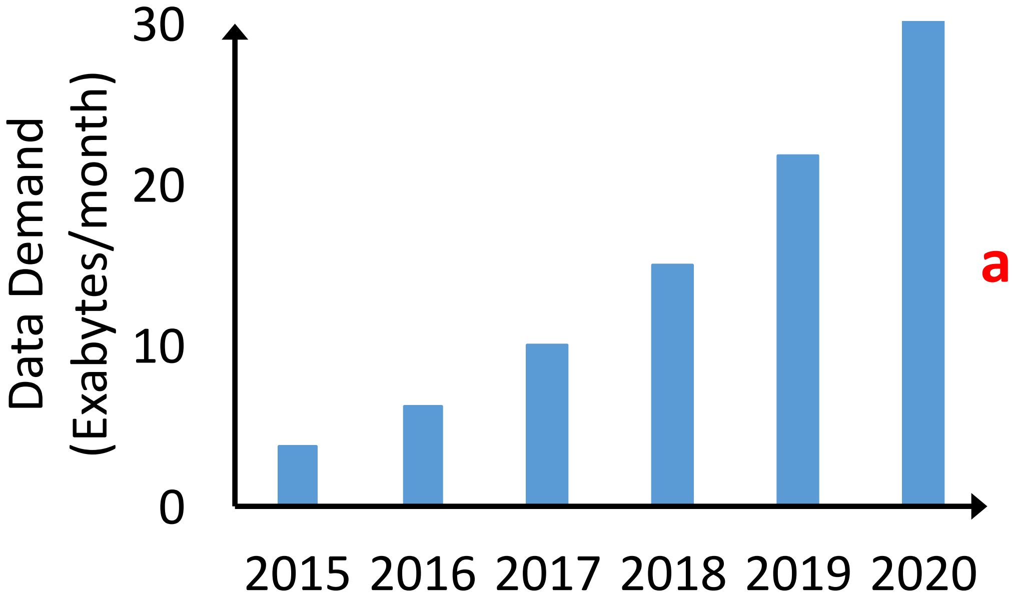
Cellular Traffic is Increasing

Global mobile data traffic will increase 8 fold in 2015-2020

CISCO



Spectrum cannot accommodate this increase

More Antennas

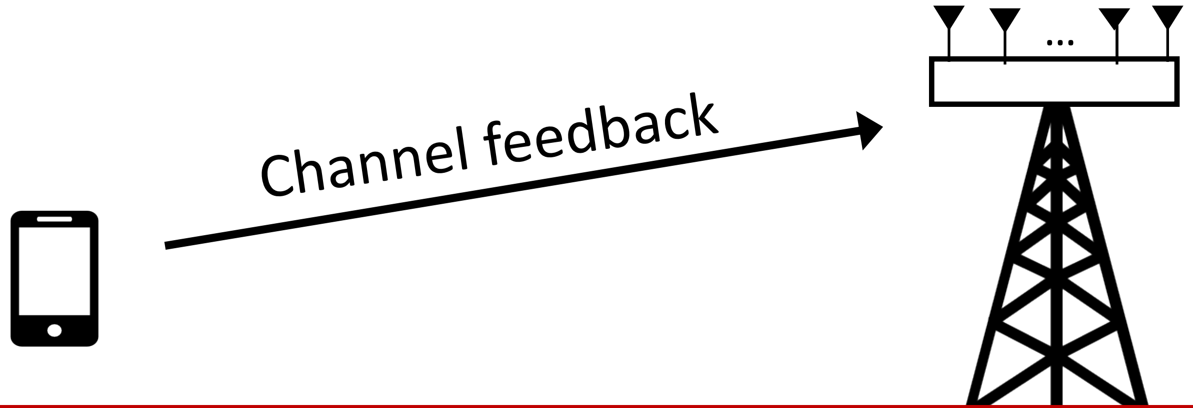
LTE standard body, 3GPP, is proposing multi-antenna solutions in new releases:

- Beamforming
- Coordinated Multi-point
- Full-Dimensional MIMO

Base station needs to know channels to client

Channel Acquisition

Use feedback from the client



Feedback overhead is overwhelming

Feedback is Overwhelming

- Large in current networks, uses lossy compression [3GPP TS 36.211 2010, Irmer et al IEEE Communications 2011]

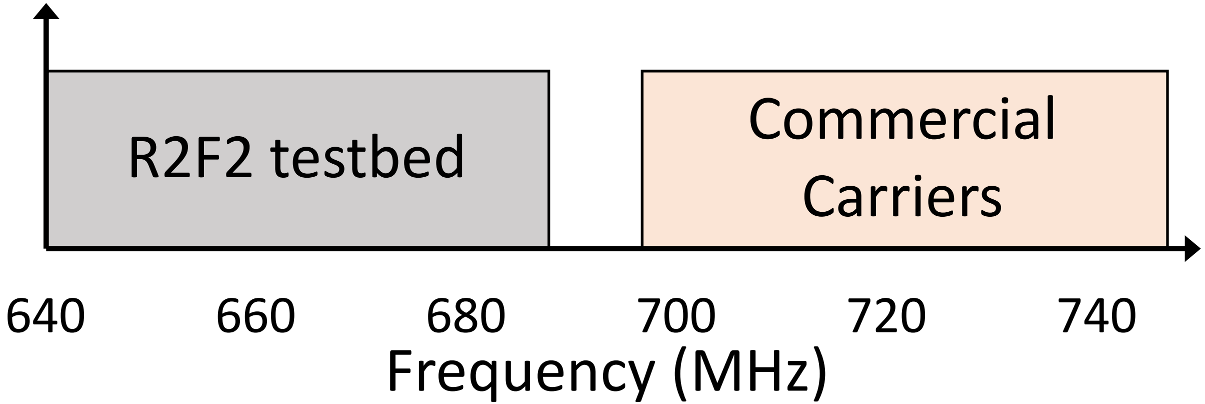
- Prohibitive for future deployments with up to 32 antennas

- According to LTE standard body, 3GPP:

  "Identifying the potential issues of CSI acquisition and developing the proper solutions are of great importance"

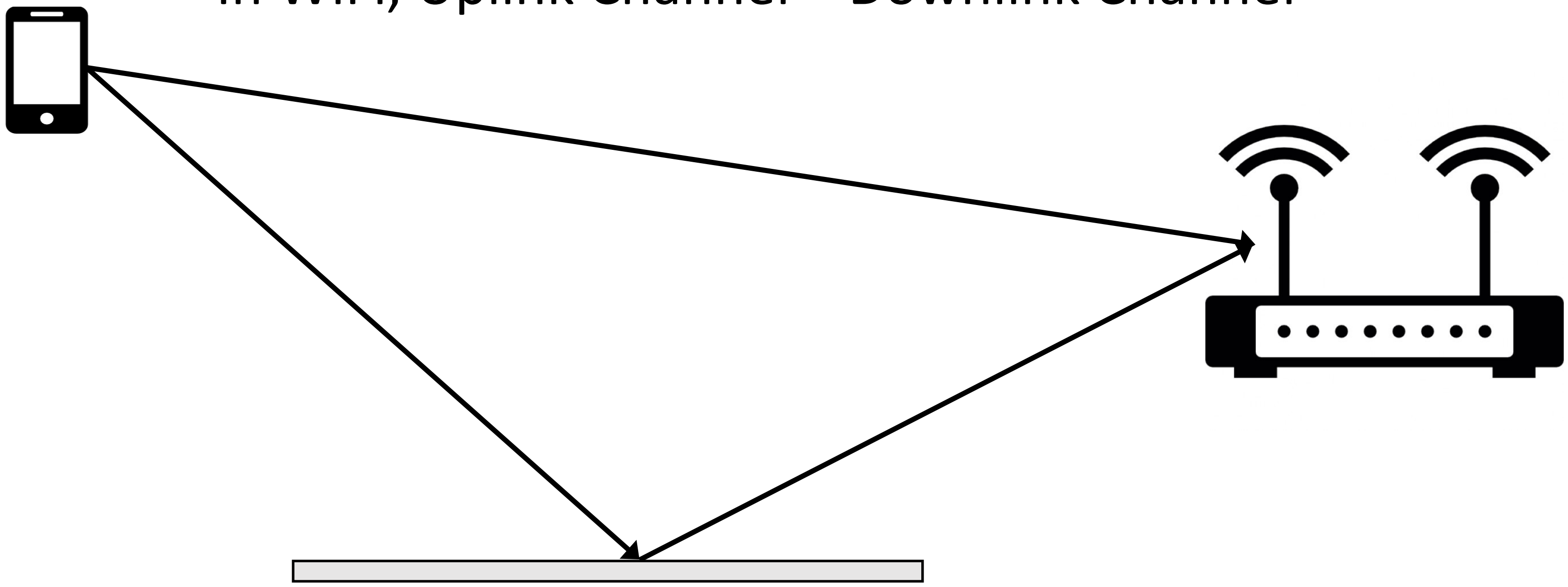
R2F2

- Uses uplink channels to estimate downlink channels
- Removes feedback overhead
- Evaluated indoors and outdoors in white spaces



Idea: Use Reciprocity Like in WiFi

In WiFi, Uplink Channel = Downlink Channel



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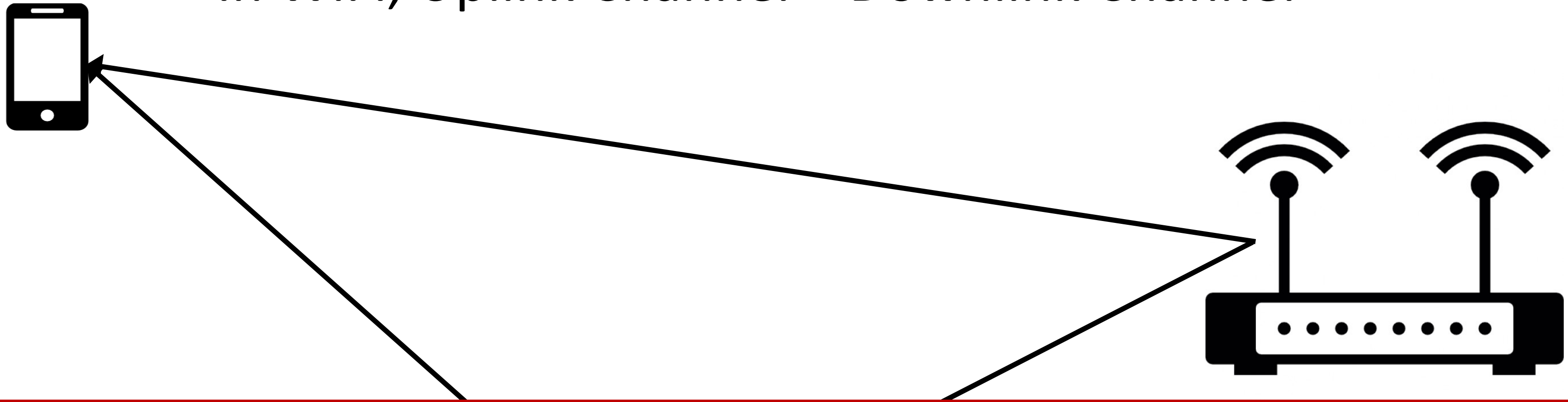

Does not work for cellular networks:
Uplink and downlink on different frequencies

Problem Statement

How do we estimate channels on one frequency from channels on a different frequency?

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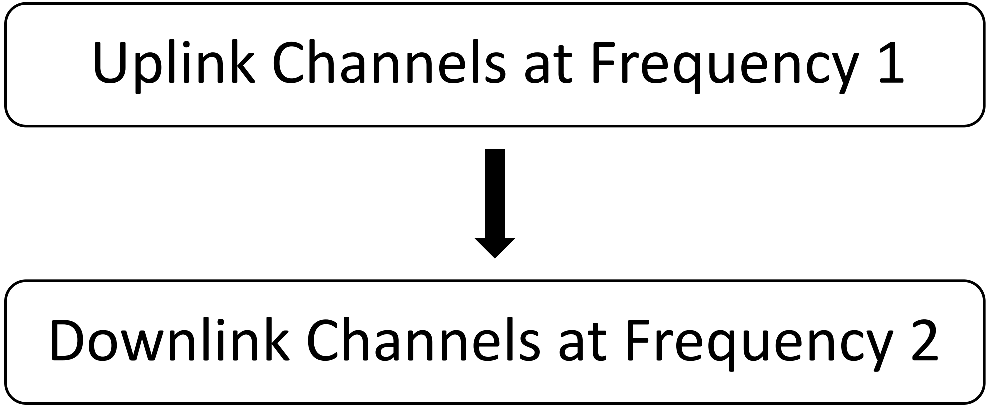
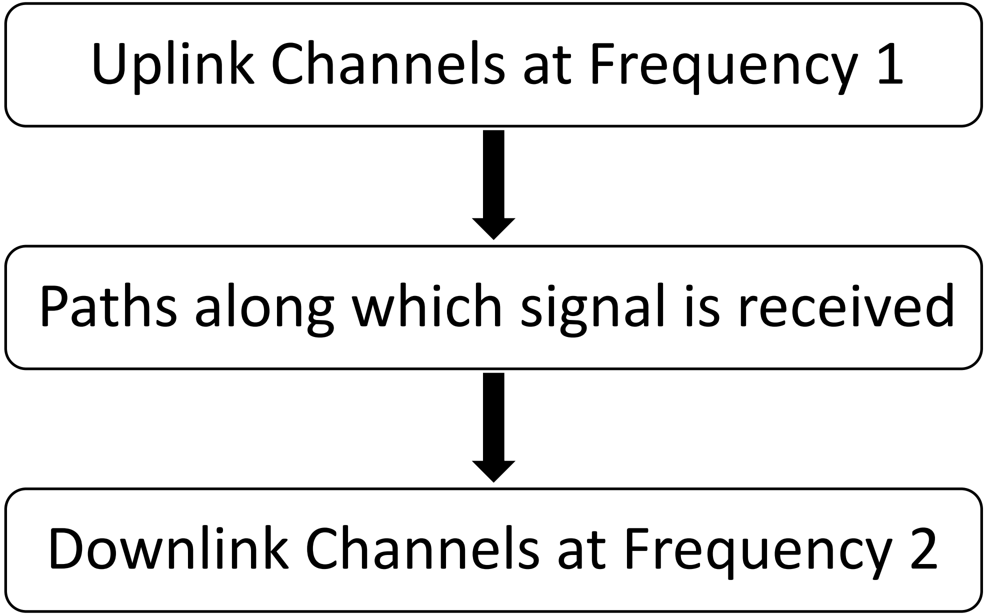
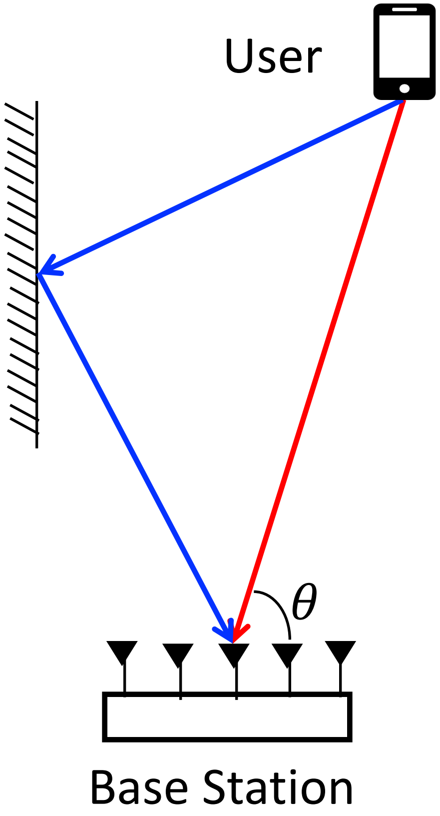
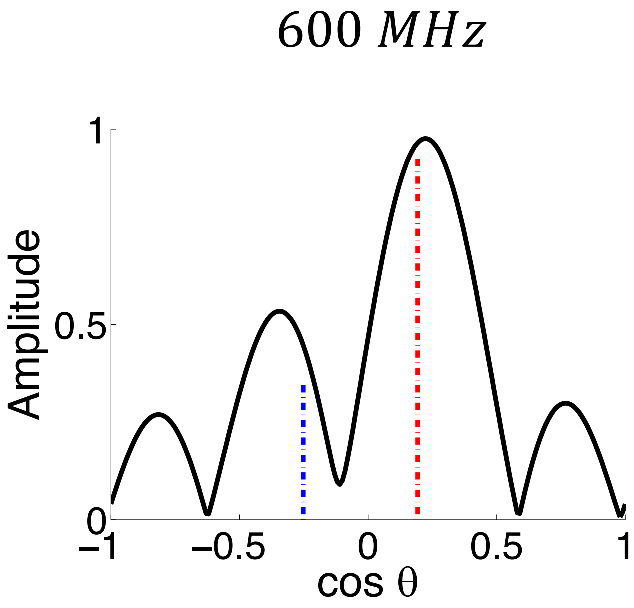


Idea: Same Paths on Uplink & Downlink



RF-based Localization Systems





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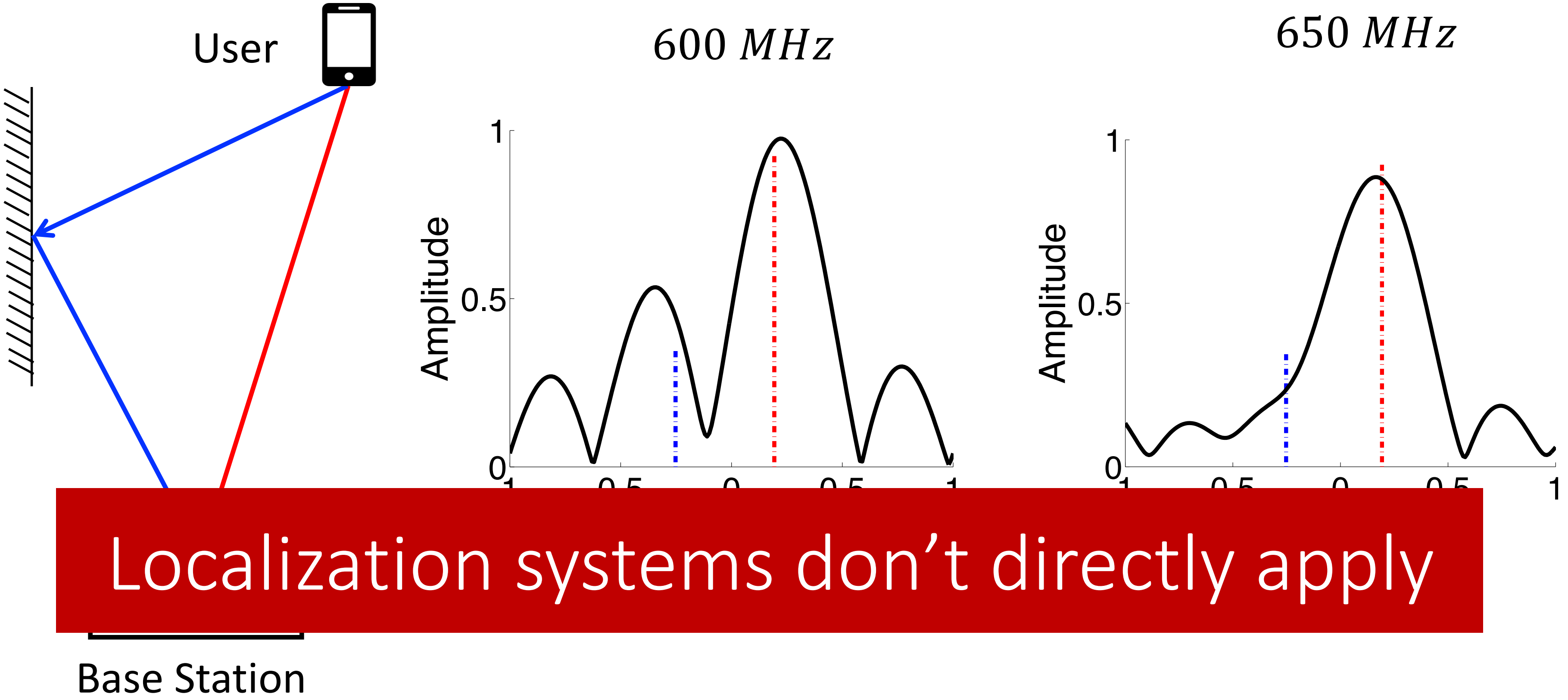
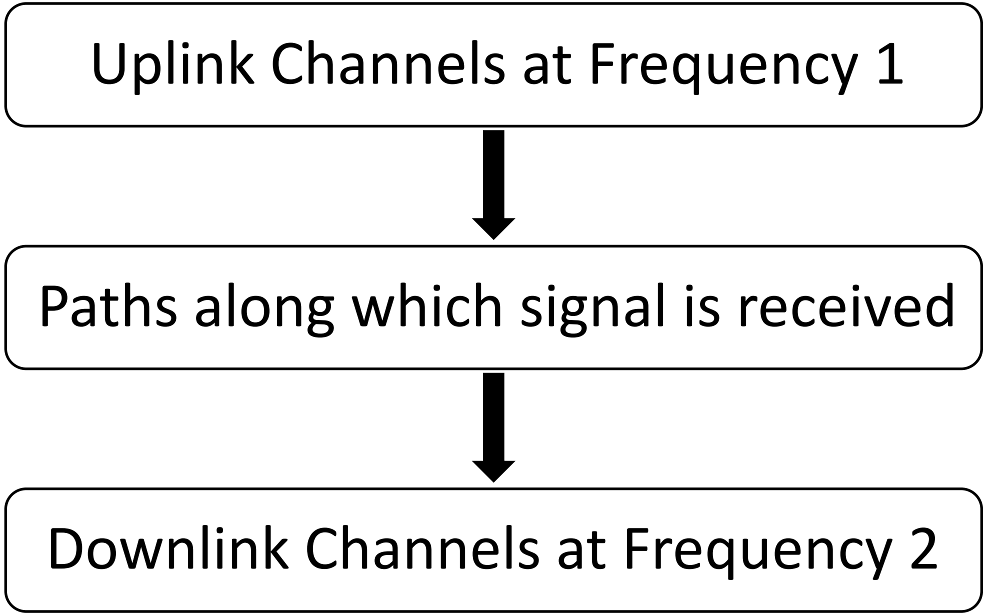
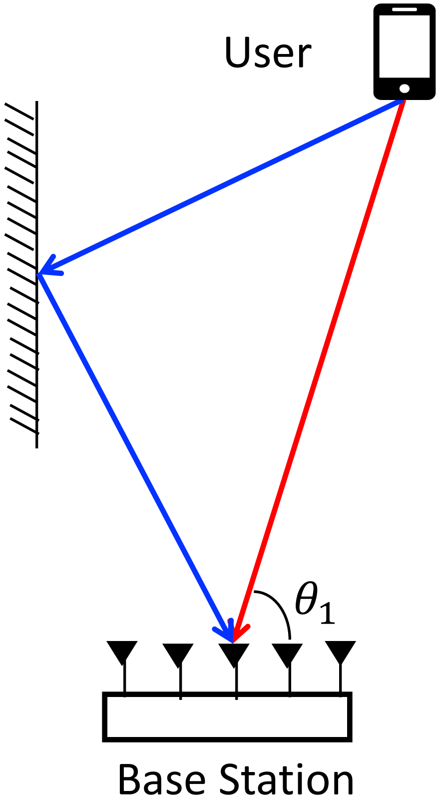


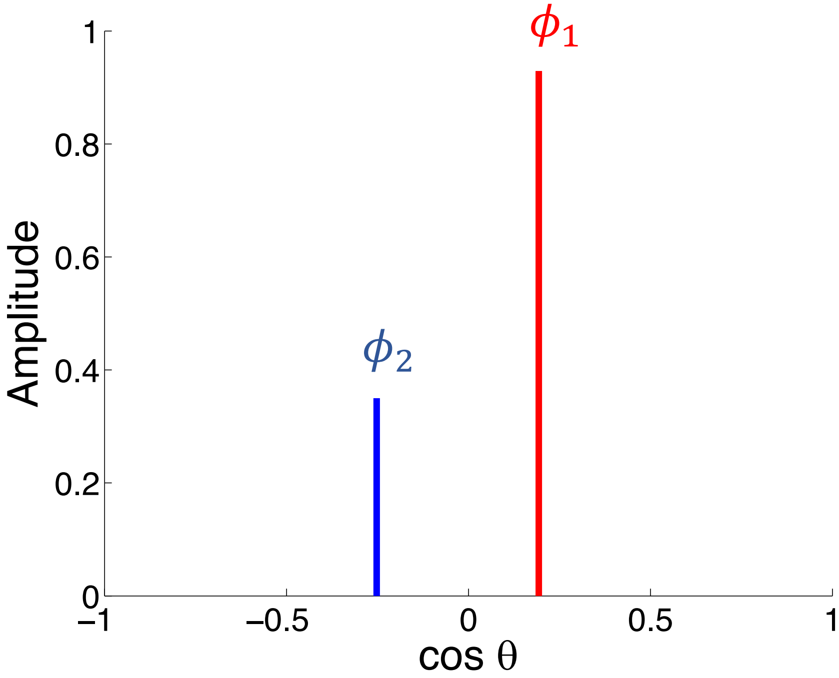
Localization systems don't directly apply

Idea: Same Paths on Uplink & Downlink

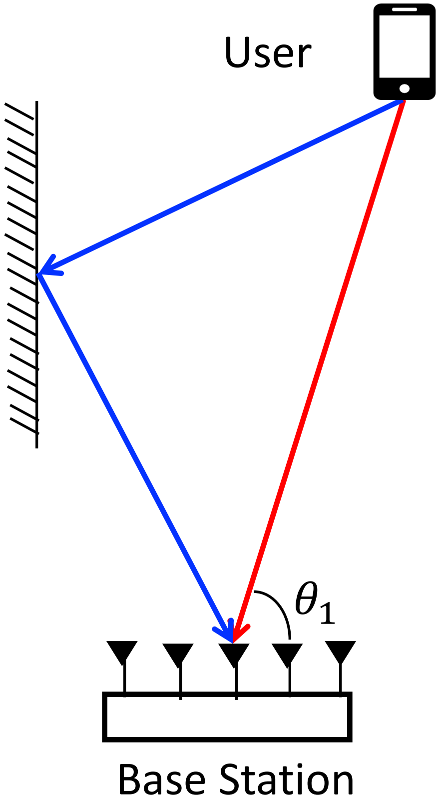


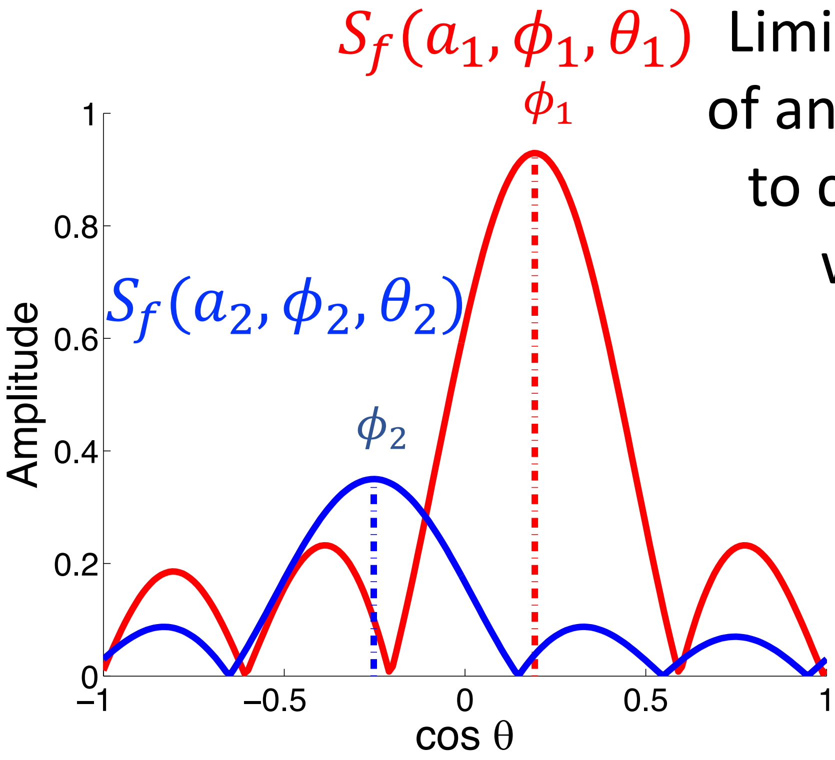
Paths to Channels: Ideal Representation





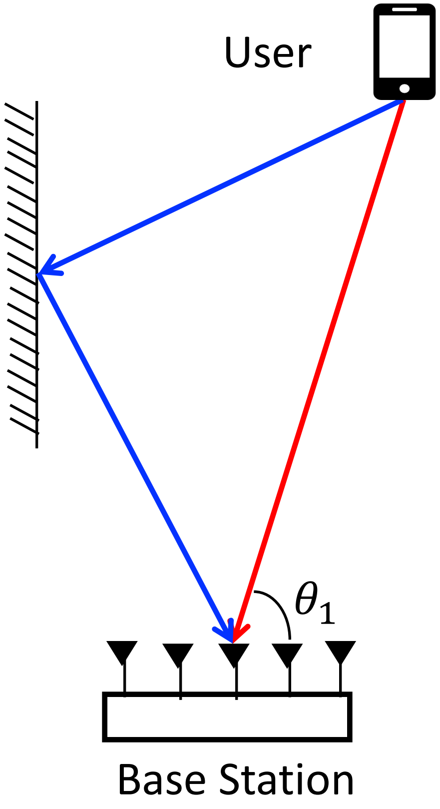
Paths to Channels: Measured Representation



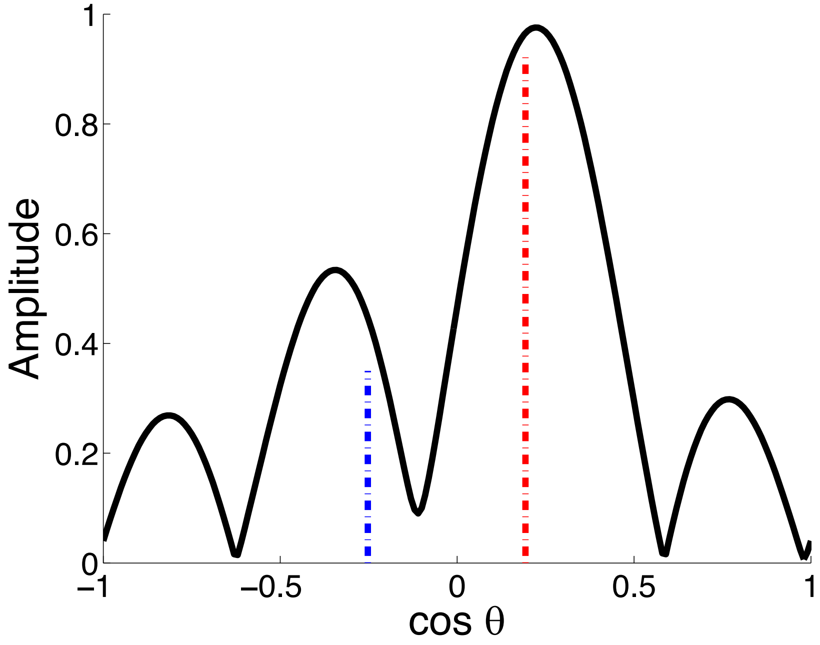


Limited number of antennas leads to convolution with sinc

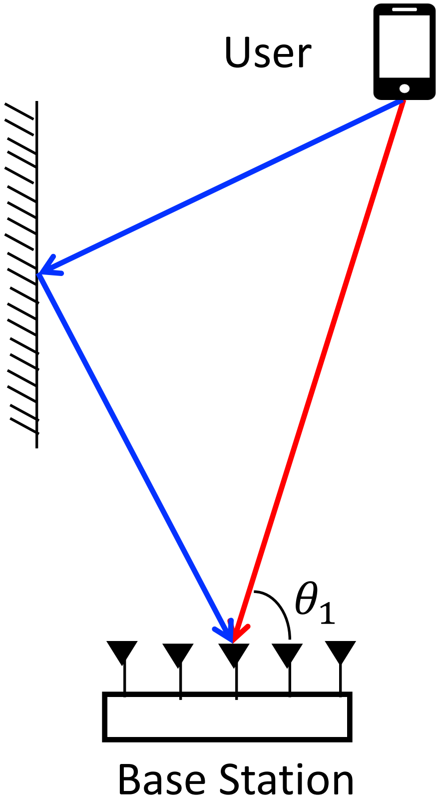
Paths to Channels: Superposition



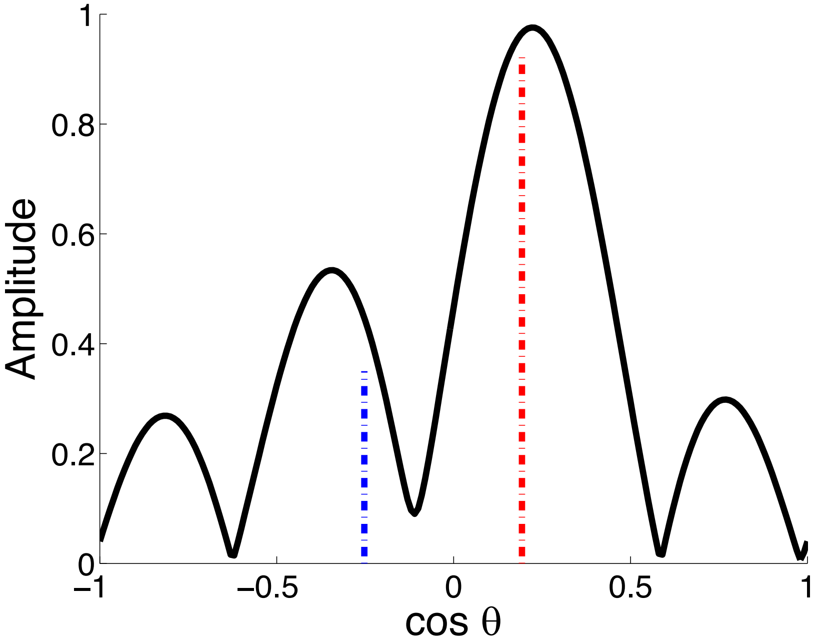
$$S_f(a_1, \phi_1, \theta_1) + S_f(a_2, \phi_2, \theta_2)$$



Paths to Channels: FFT

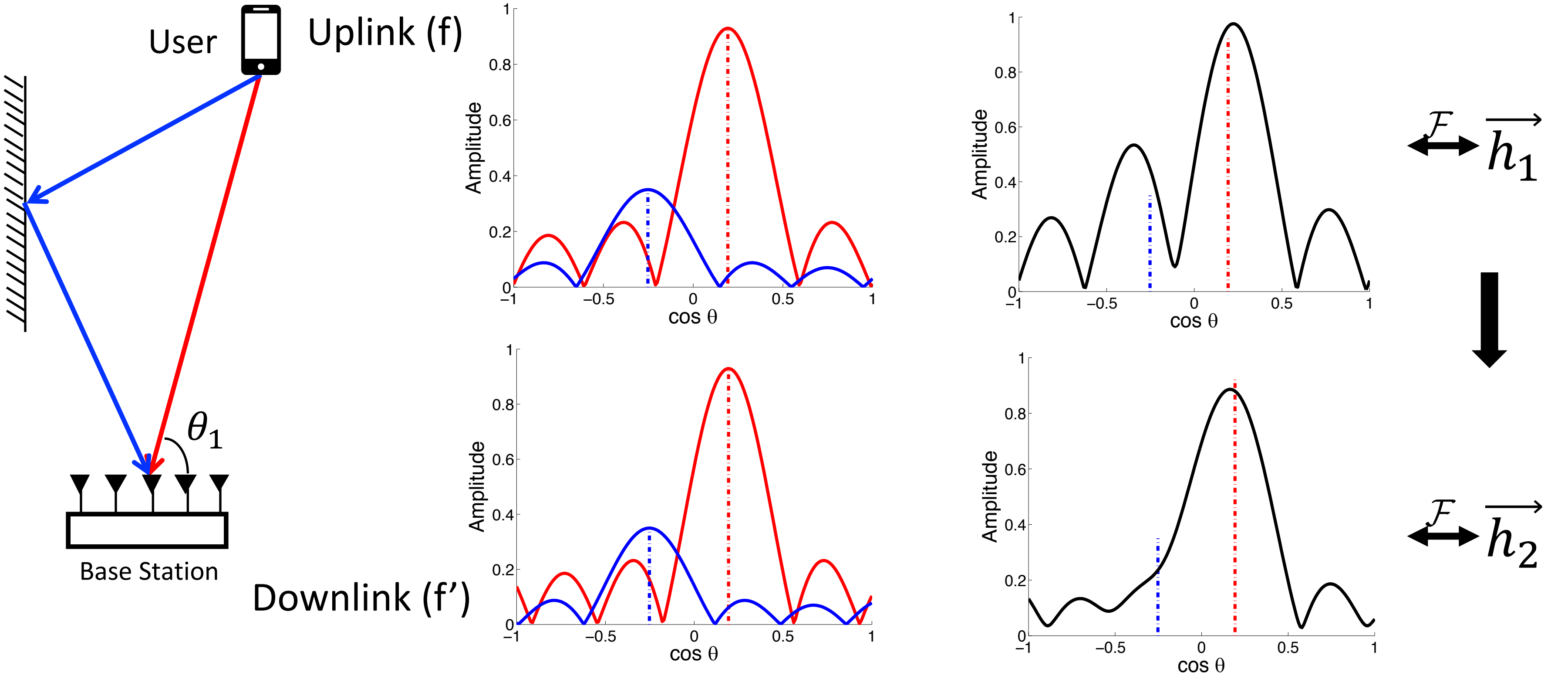


$$FFT(S_f(a_1, \phi_1, \theta_1) + S_f(a_2, \phi_2, \theta_2))$$

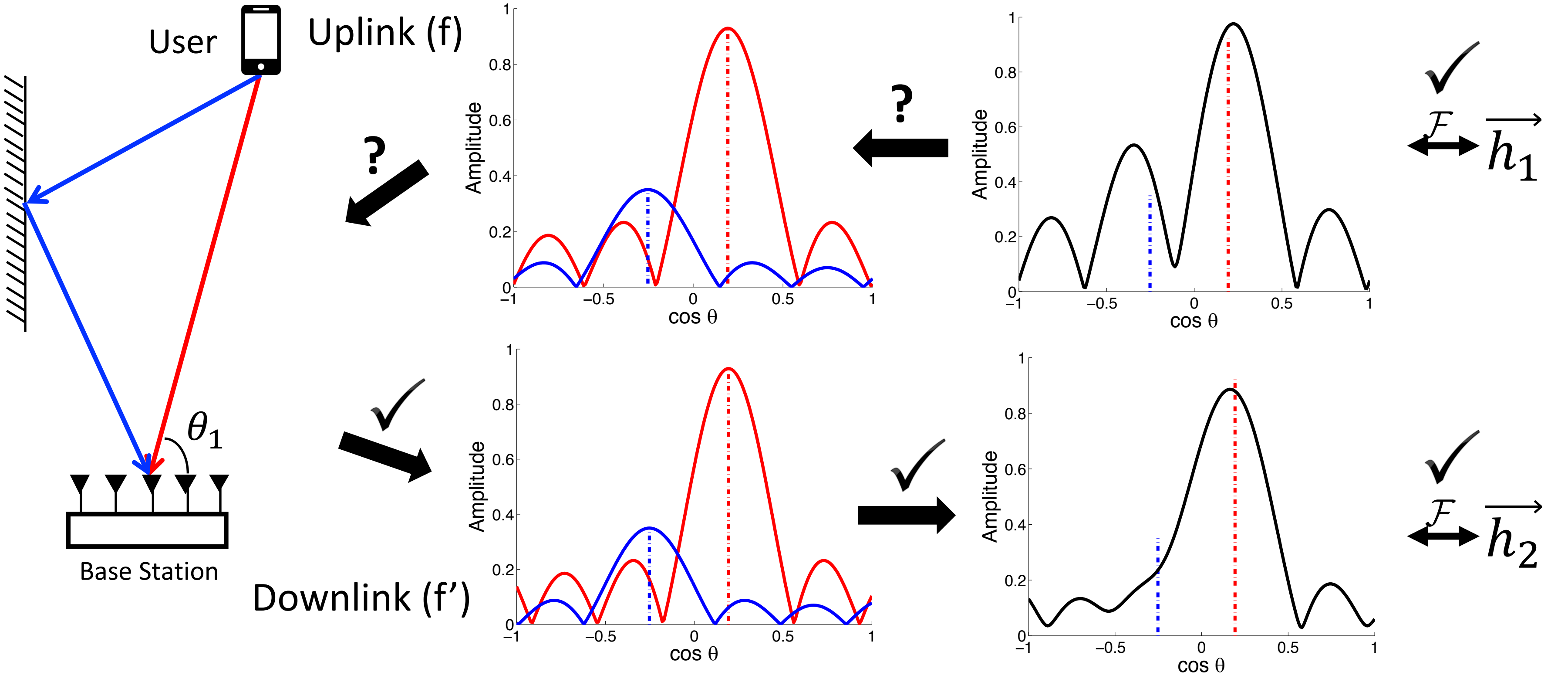


$\overset{\mathcal{F}}{\longleftrightarrow} \overrightarrow{h_1}$

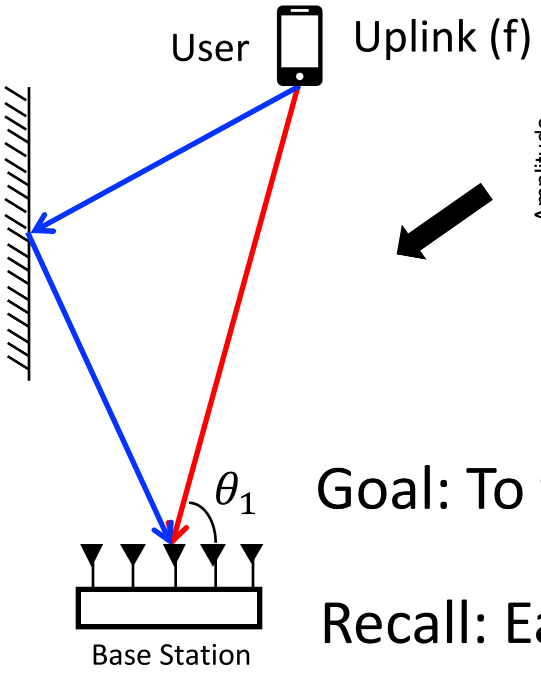
Uplink to Downlink Channels

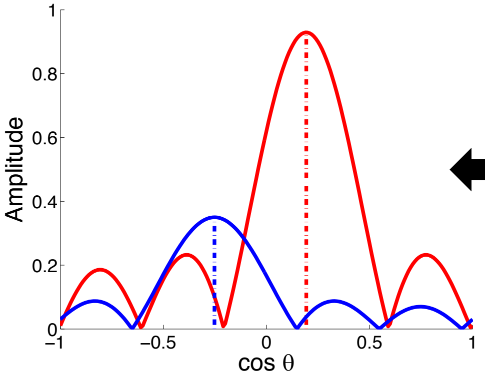


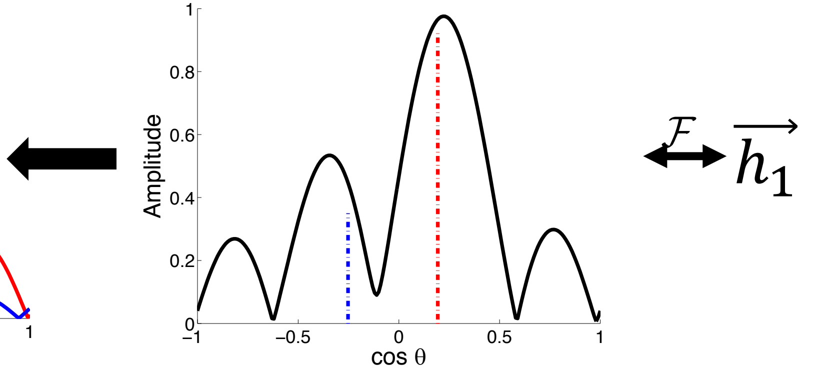
Uplink to Downlink Channels



Channels to Paths



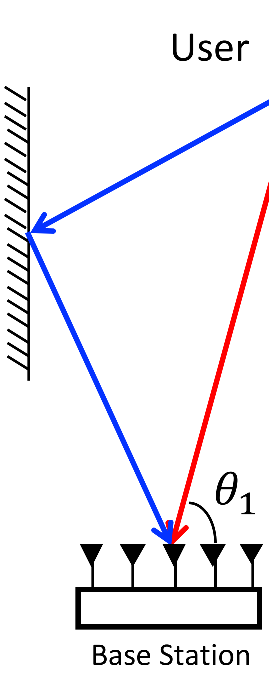


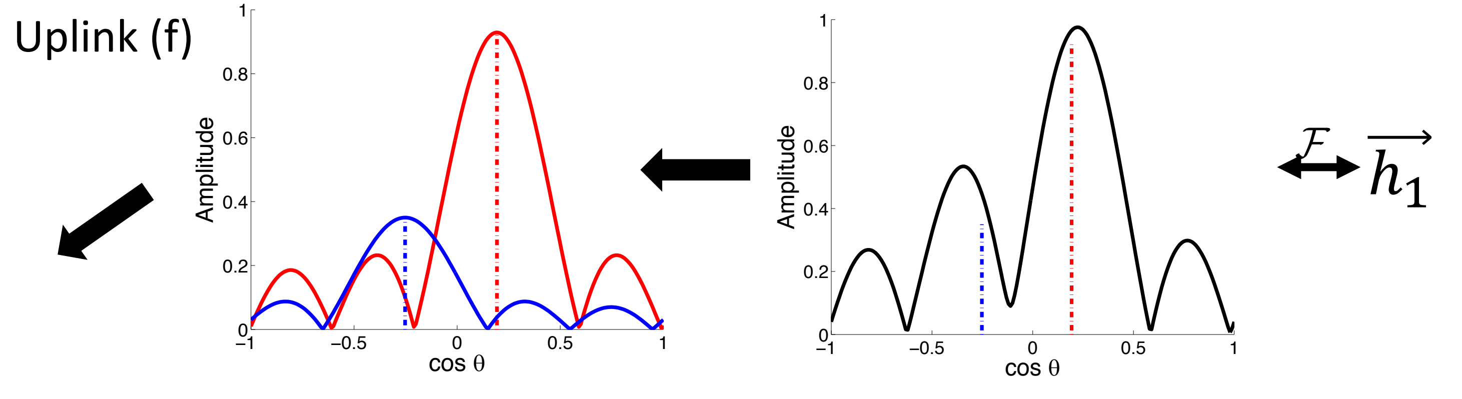


Goal: To find a set of paths, that can produce channels $\overrightarrow{h_1}$

Recall: Each path is represented by (a, ϕ, θ)

Channels to Paths





Goal: To find $\{a_i, \phi_i, \theta_i\}_{i=1}^{N}$, that can produce channels $\overrightarrow{h_1}$

Recall: Each path is represented by (a, ϕ, θ)

Channels to Paths

Goal: To find $\{a_i, \phi_i, \theta_i\}_{i=1}^{N}$, that can produce channels $\overrightarrow{h_1}$

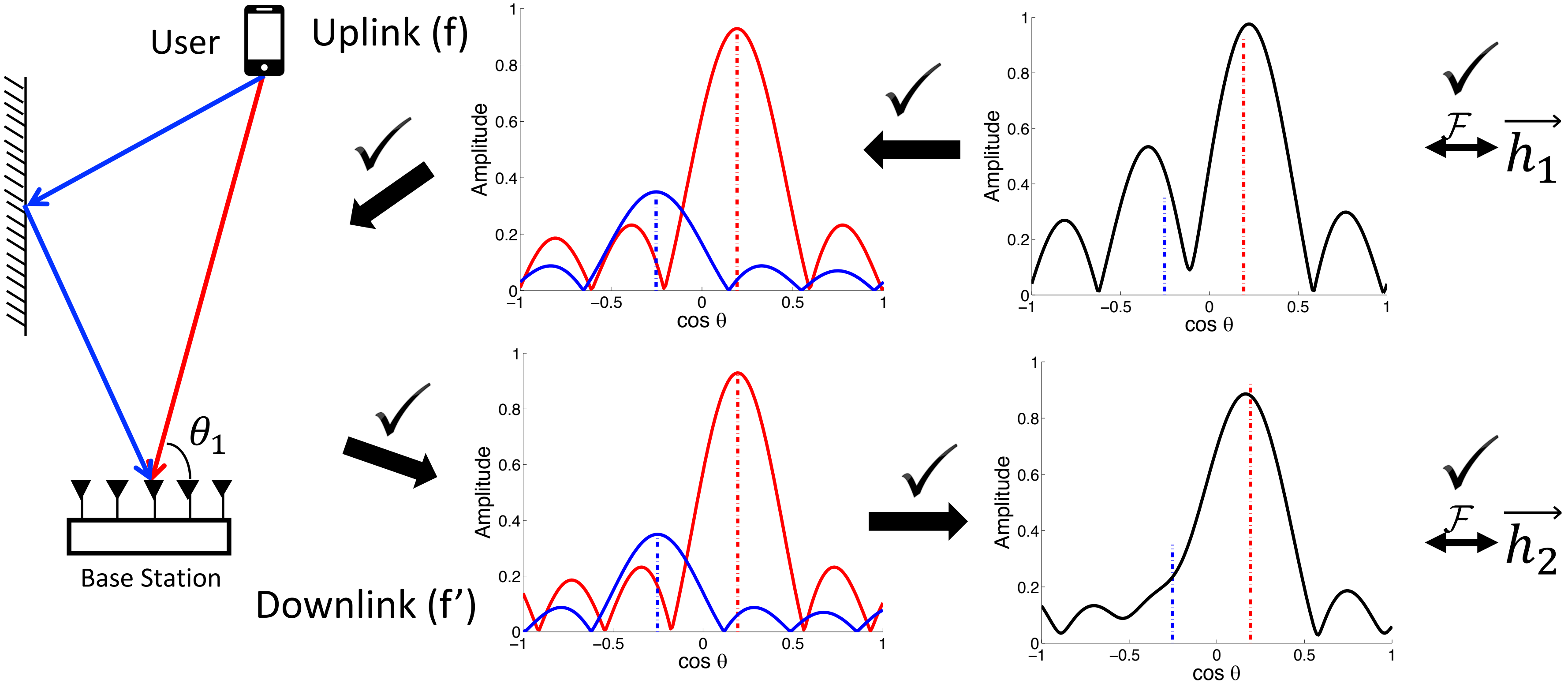
$$\overrightarrow{h_{est}} = FFT\left(\sum_{i=1}^{N} S_f(a_i, \phi_i, \theta_i)\right)$$

$$\{a_i, \phi_i, \theta_i\}_{i=1}^{N} = argmin_{\{a_i,\phi_i,\theta_i\}} \left\| \overrightarrow{h_1} - \overrightarrow{h_{est}} \right\|^2$$

Getting Paths from Wireless Channels

- Optimization is non-linear and constrained
- Solved using standard interior point method
- Approximate initialization using RF-localization methods

Uplink to Downlink Channels



Evaluation

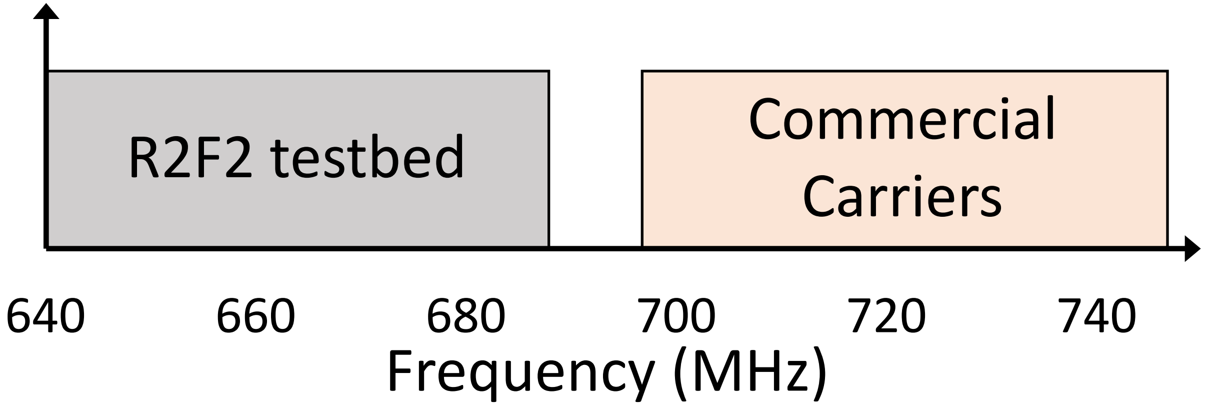
Goal: To measure the accuracy of R2F2 channel estimates

Experimental Setup

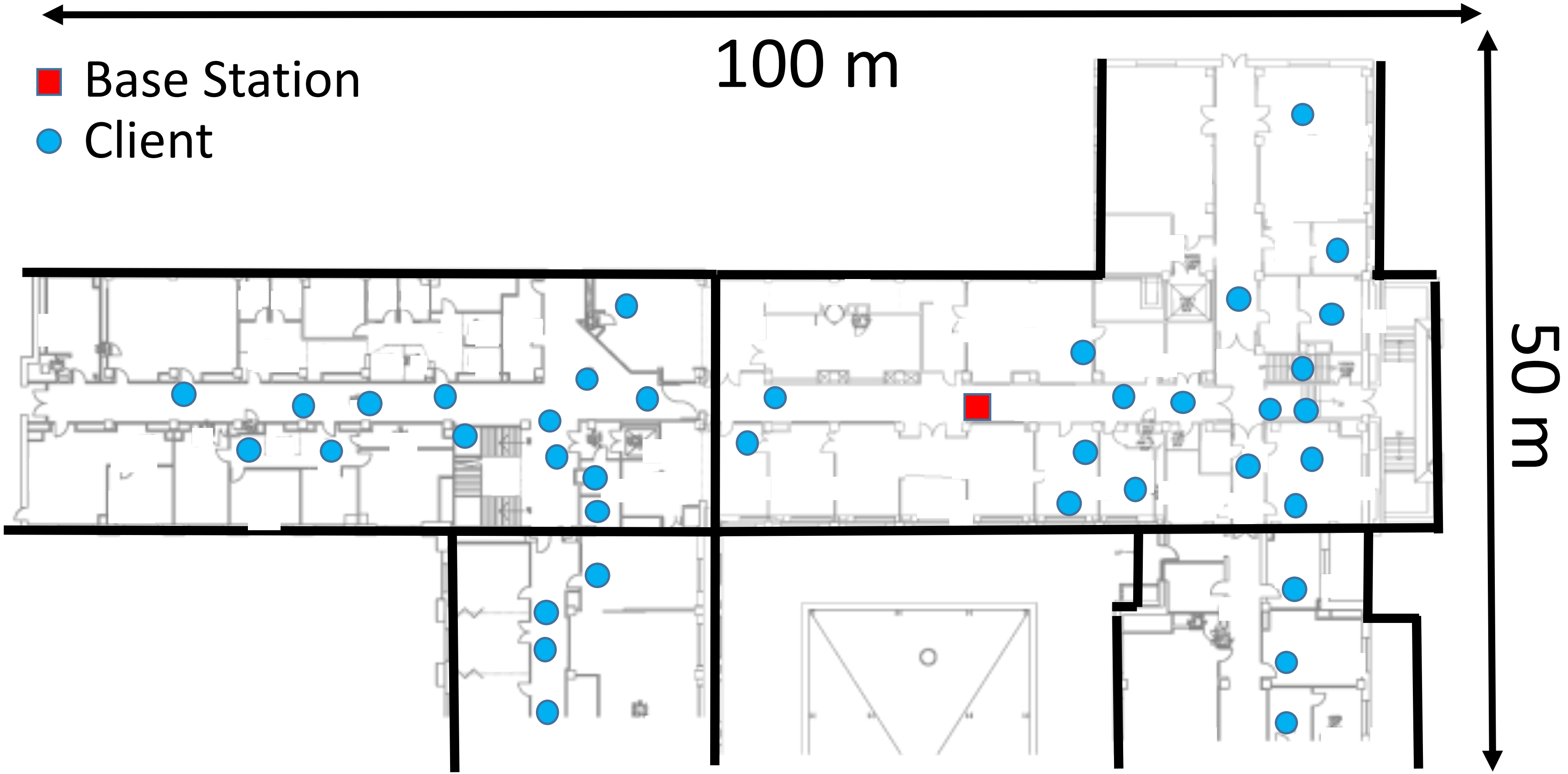
- Used USRP N210 software radios as clients and base stations
- Implemented a 5 antenna LTE base station
- Located base station close to a commercial base station

Frequency Separation

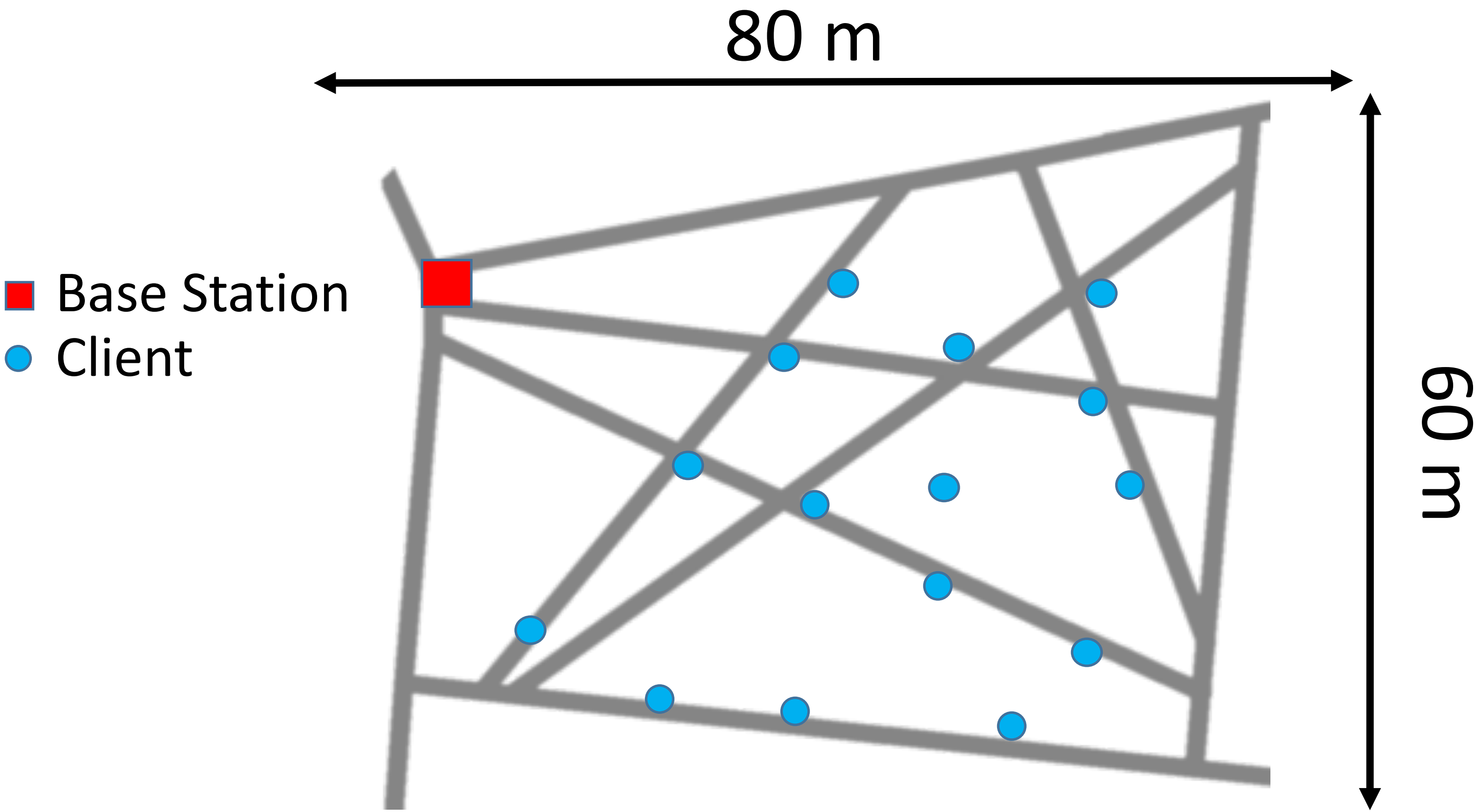
- Used frequencies from 640 to 690 MHz in the White Spaces
- Evaluation at 30 MHz Uplink-Downlink separation
- Same as major AT&T and Verizon deployments



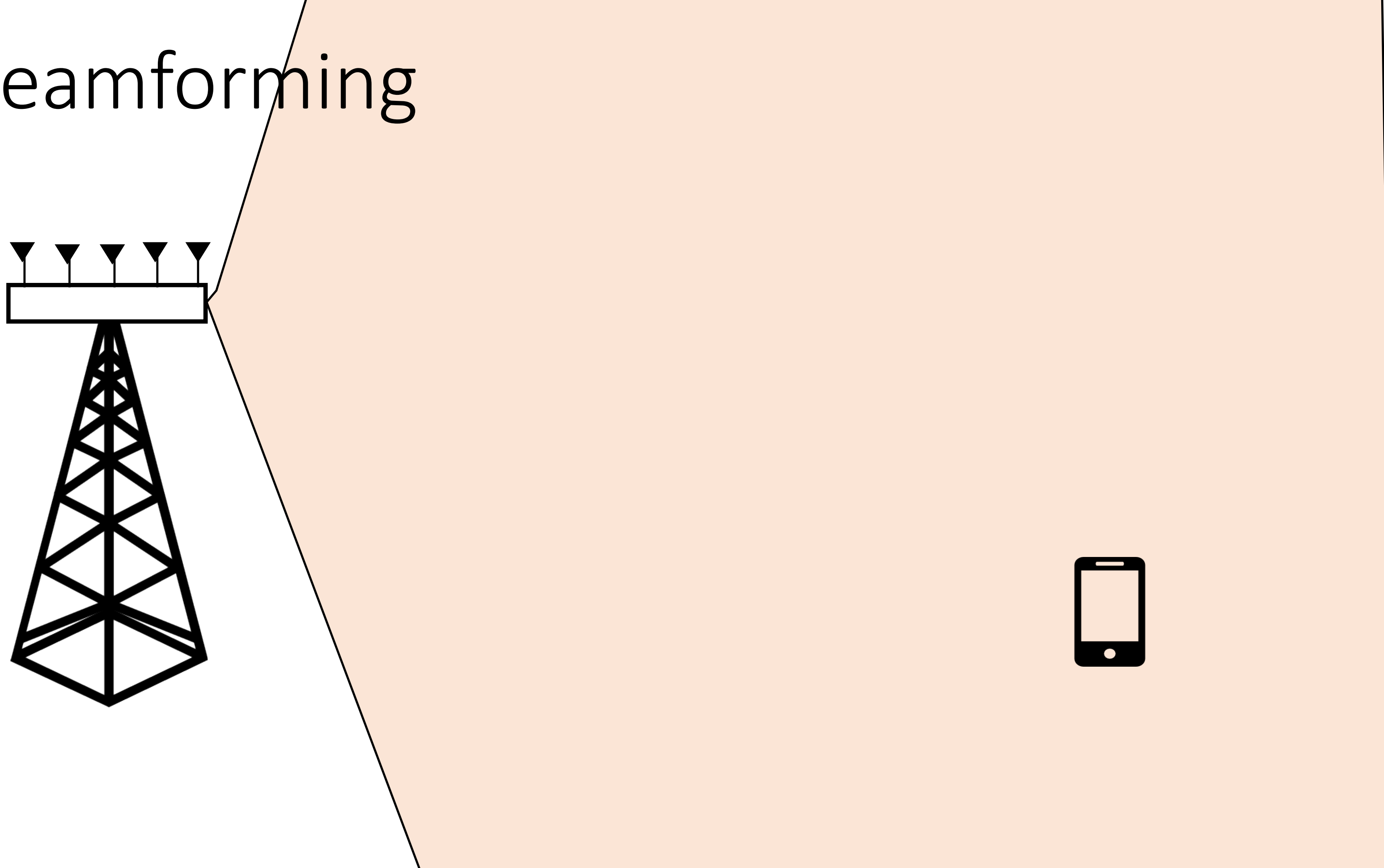
Indoor Testbed



Outdoor Testbed



Beamforming



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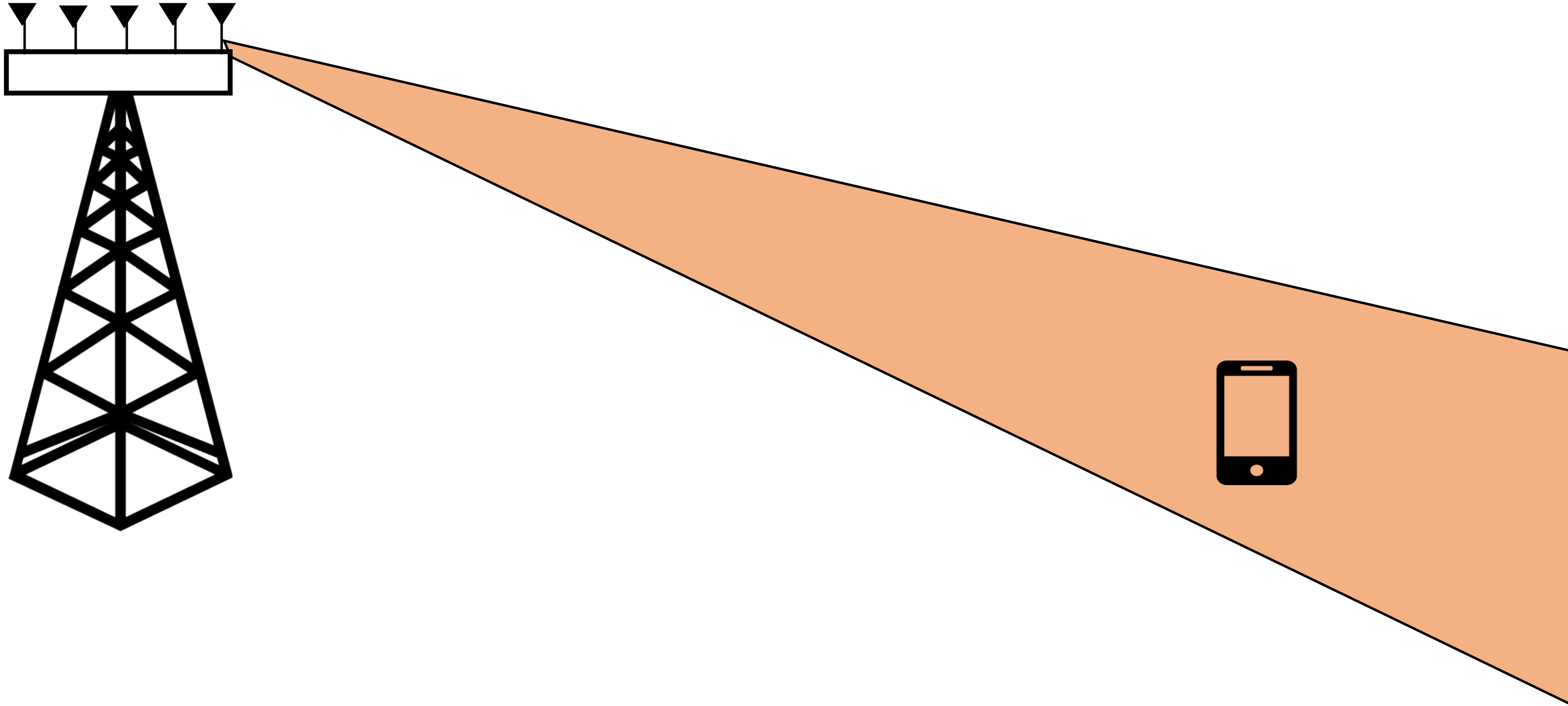
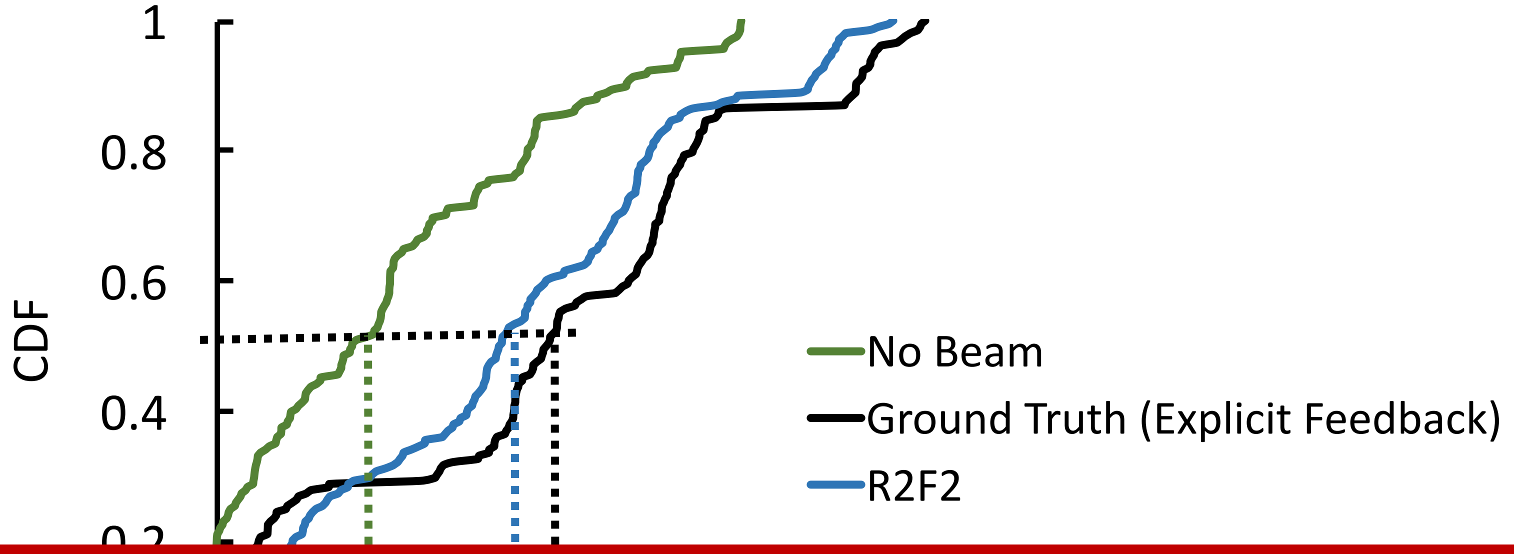
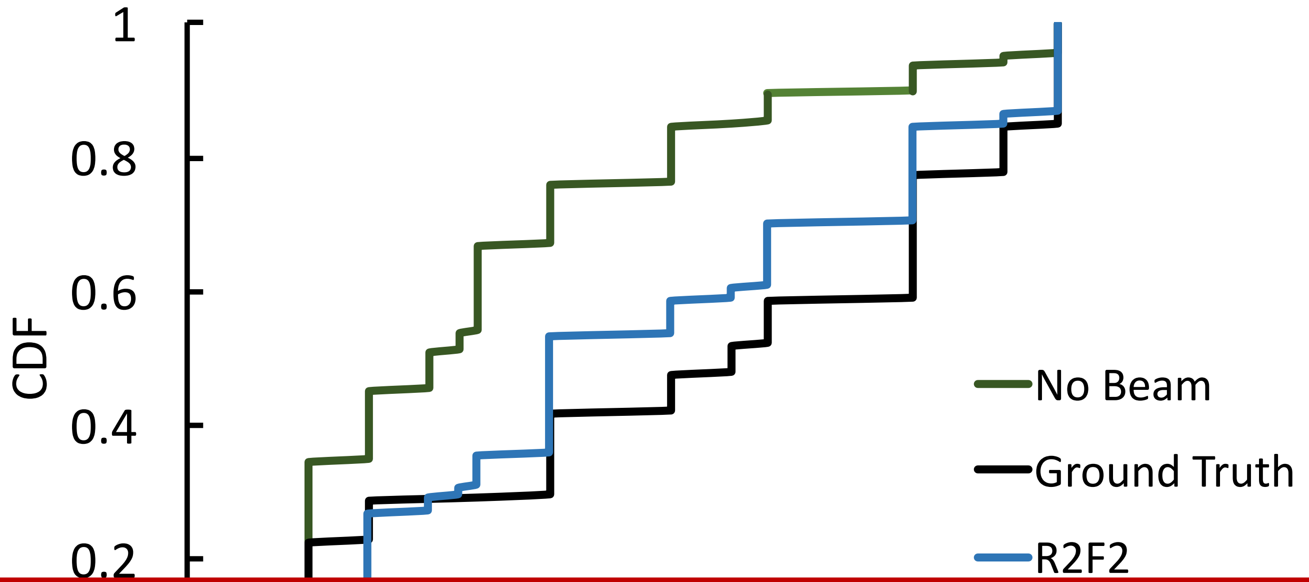


Beamforming Comparison



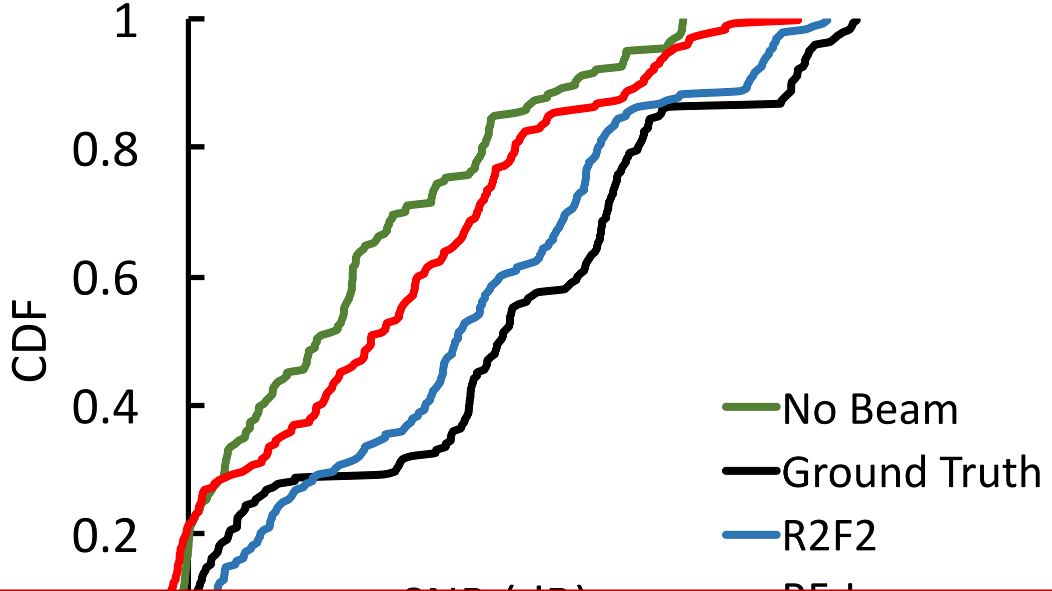
R2F2 delivers 90% of the MIMO SNR gains, with zero feedback

Beamforming Comparison: Data Rate



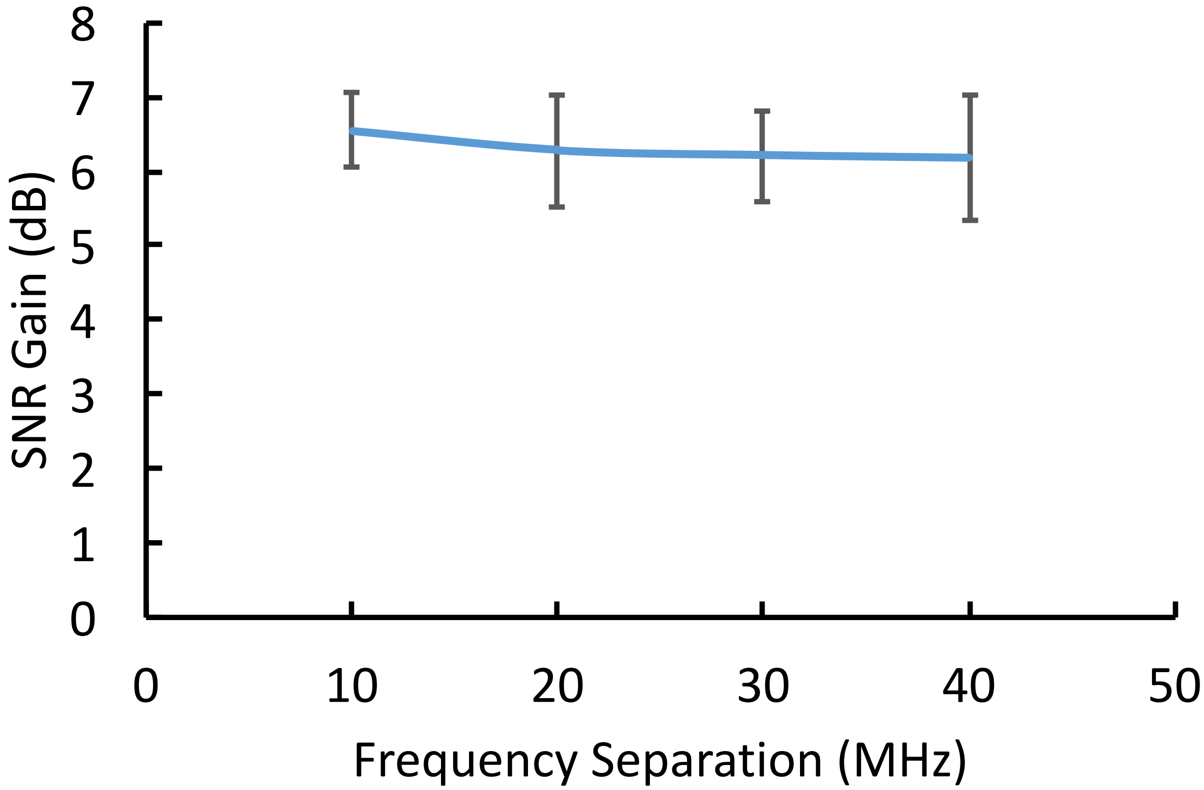
R2F2's achieves 1.7x data rate improvement

Comparison with RF-localization

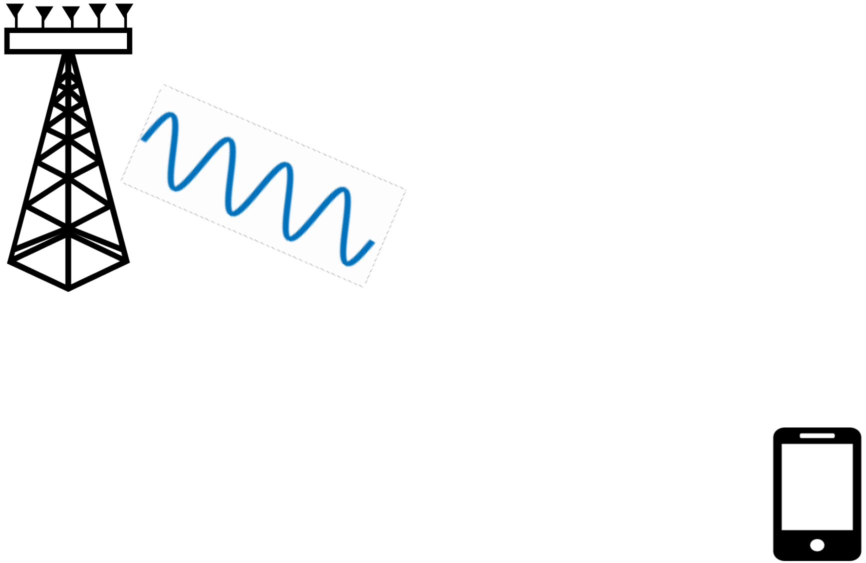


Delivers only 40% of MIMO SNR gains

Effect of Frequency Separation



Application: Edge Client Nulling



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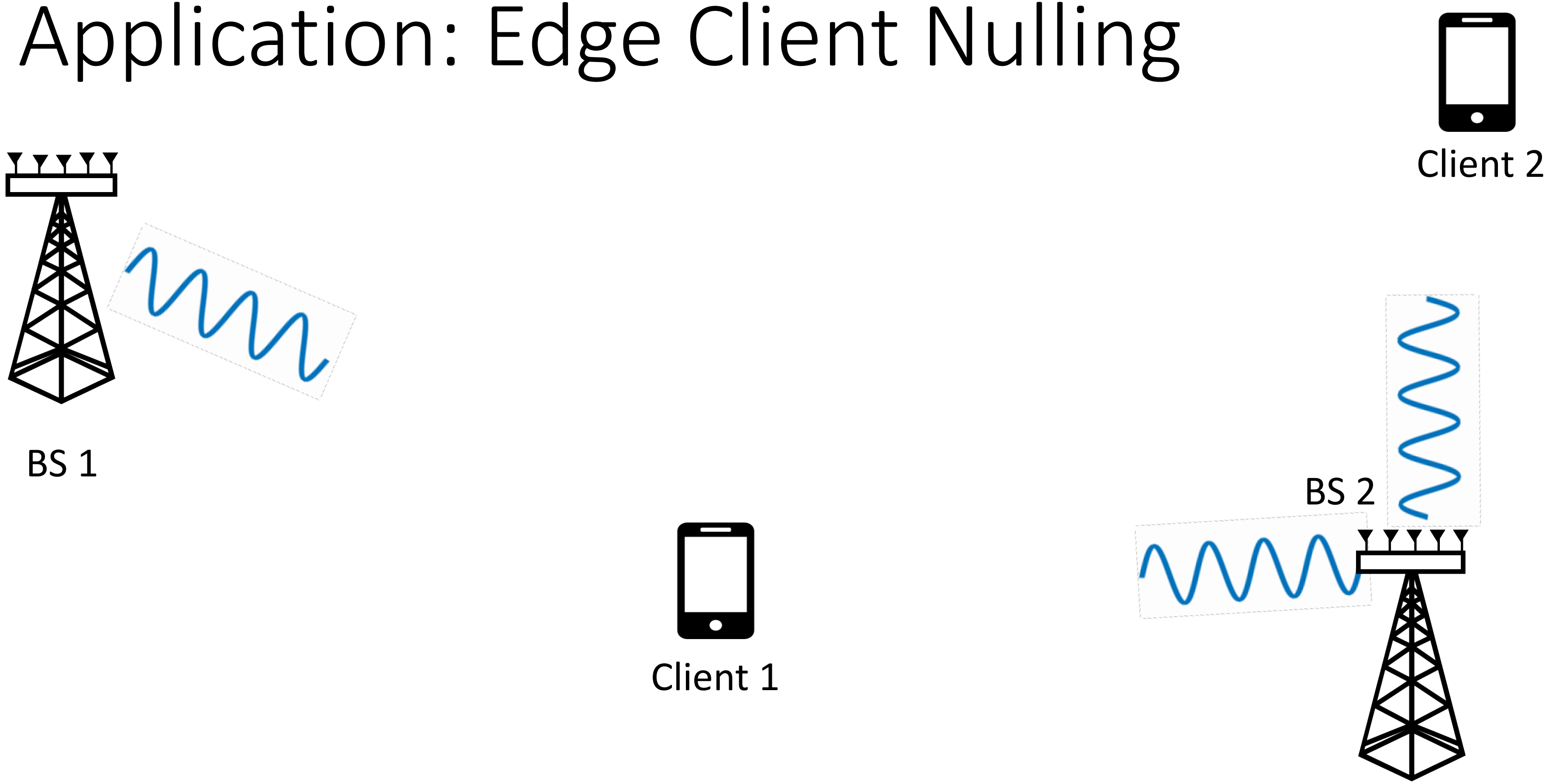
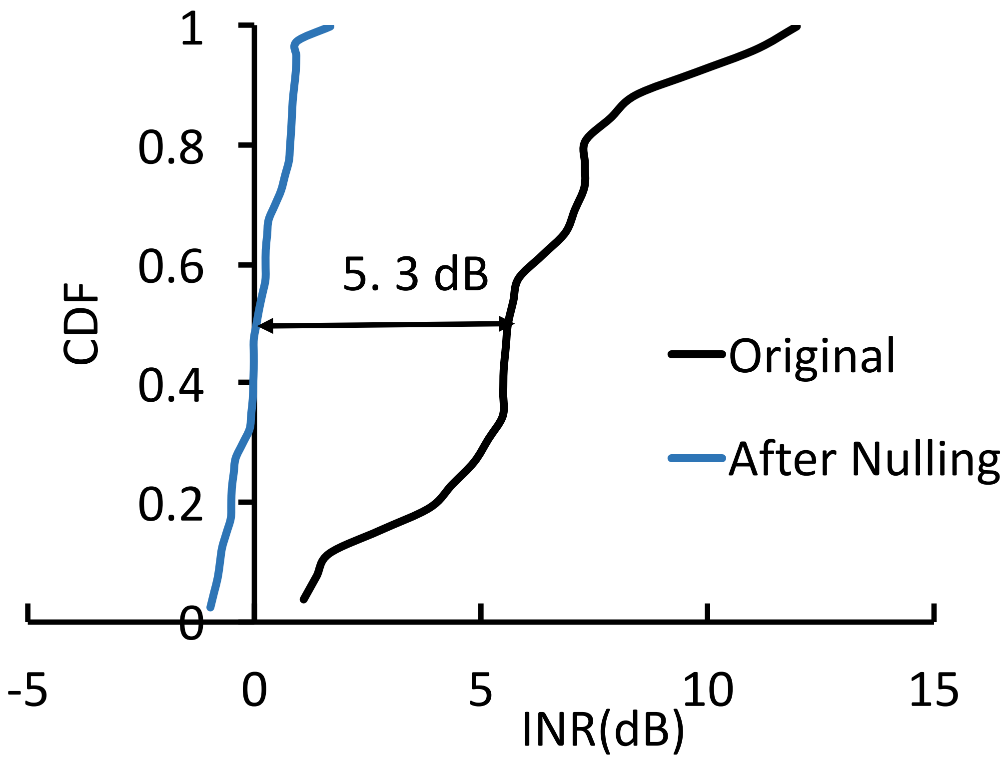


Edge Nulling



Related Work

- **Cellular Networks:** Channel feedback compression [Shuang et al *VTC 11*, Rao et al *14*, Xu et al *Access IEEE 14*], Statistical channel prediction across frequency bands [Han et al *CHINACOM 10,* Hugl et al *COST 02…*]
- **Beyond Cellular Networks:** Channel quality prediction [Sen et al *Mobicom 13*, Shi *et al* NSDI 14, Radunovic et al *CONEXT 11*…], Temporal channel predictions [Cao et al *PMRC 04*, Wong et al *GLOBECOM'05*, Dong et al *GLOBECOM'01*]

Conclusion

- R2F2 estimates channels on one frequency from channels on a different frequency
- R2F2 accurately estimates downlink LTE channels from uplink LTE channels
- R2F2 enables MIMO techniques for FDD systems with zero channel feedback