# Eliminating Channel Feedback in Next Generation Cellular Networks


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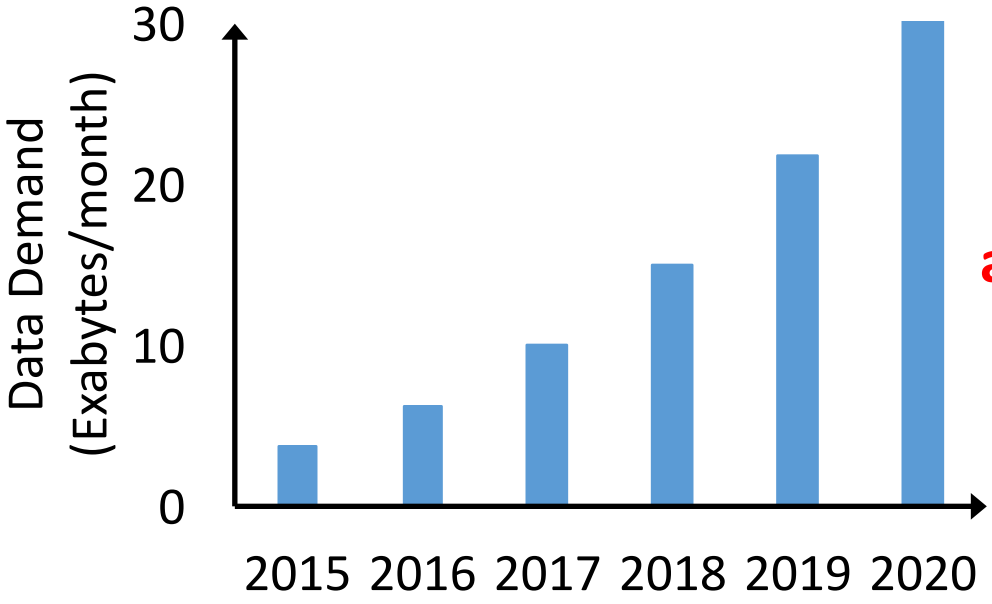
# Cellular Traffic is Increasing

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

***CISCO***




**Spectrum cannot accommodate this increase**

# More Antennas

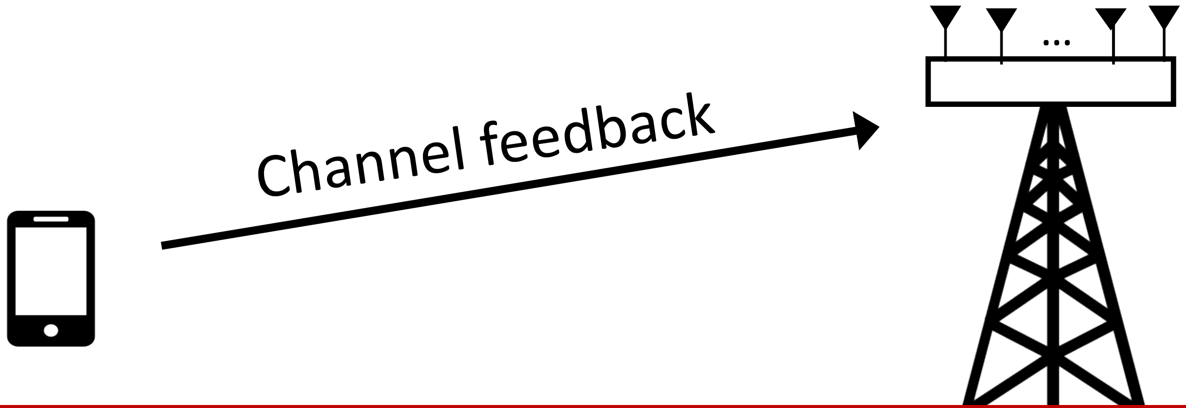
LTE standard body, 3GPP, is proposing multi-antenna solutions in new releases:

- 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]

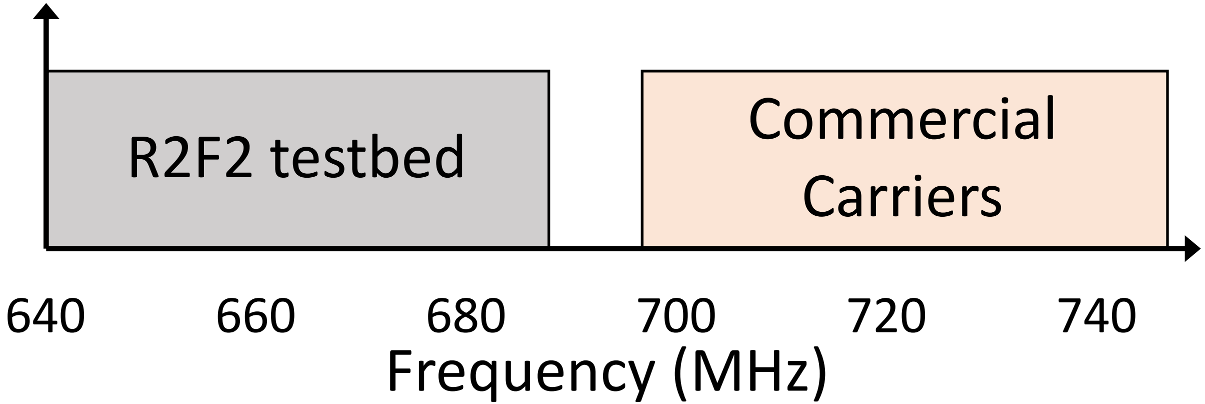
- Prohibitive for future deployments with up to 32 antennas

- According to LTE standard body, 3GPP:

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

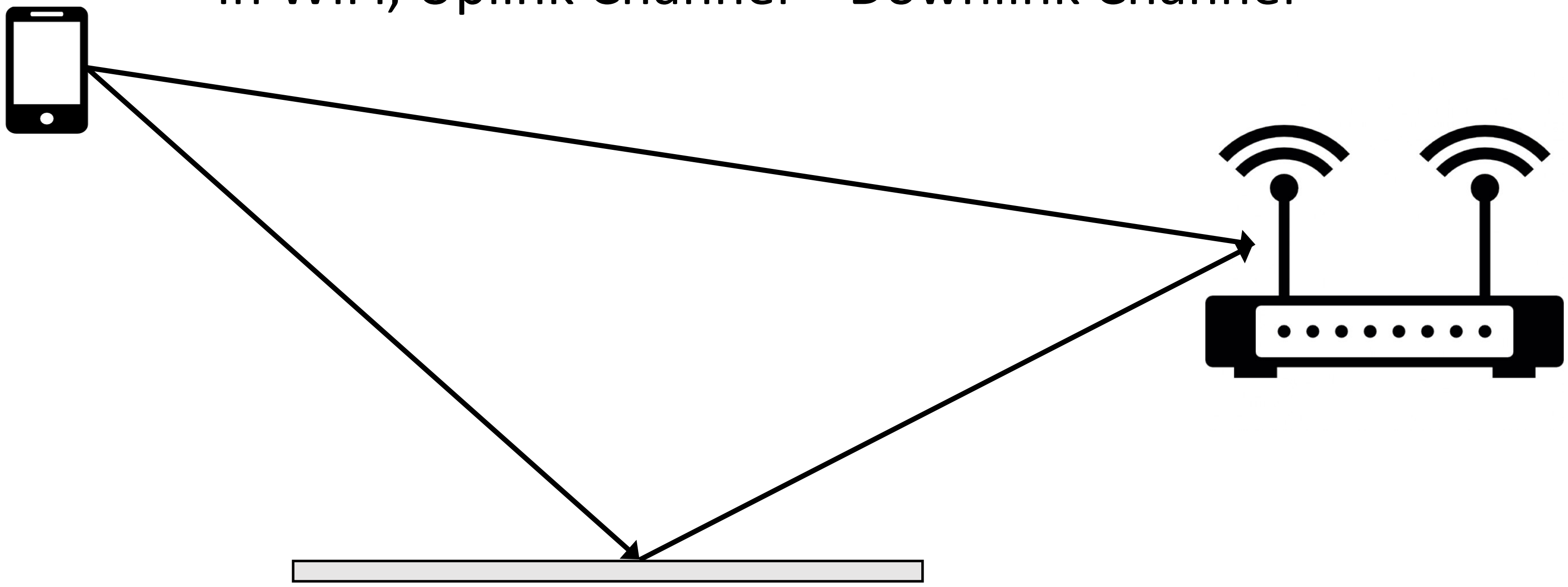
# R2F2

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



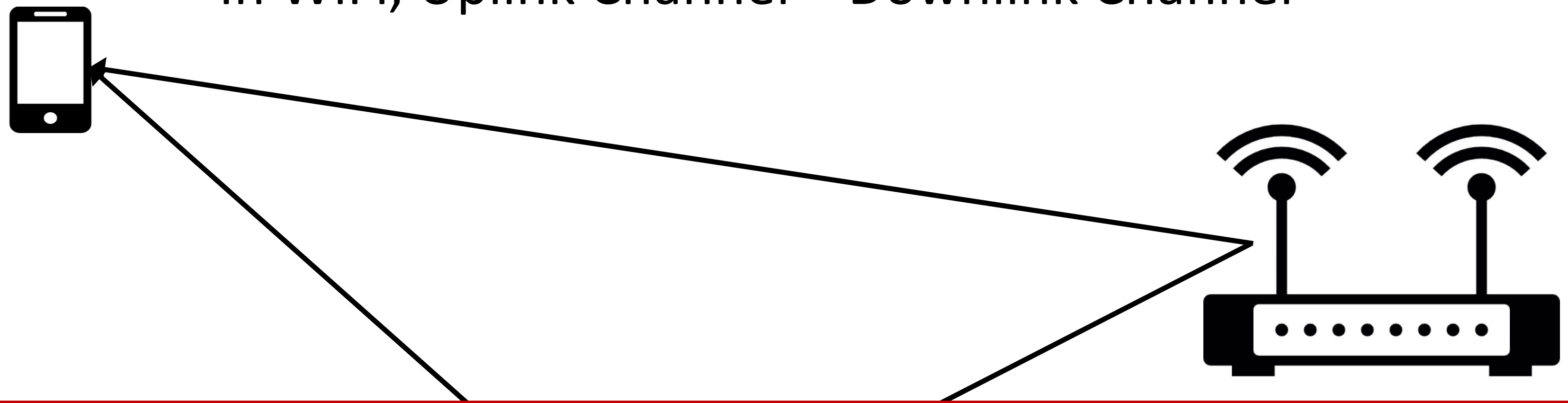
# Idea: Use Reciprocity Like in WiFi

In WiFi, Uplink Channel = Downlink Channel



# Idea: Use Reciprocity Like in WiFi

In WiFi, Uplink Channel = Downlink Channel



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?

# Problem Statement

Uplink Channels at Frequency 1

↓

Downlink Channels at Frequency 2

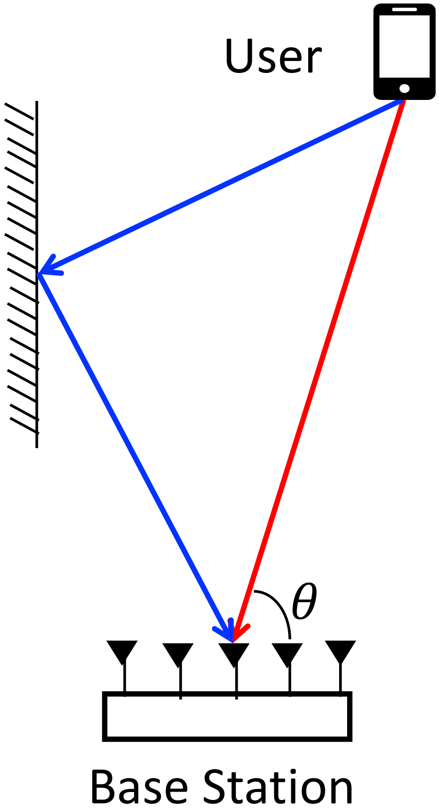
# Idea: Same Paths on Uplink & Downlink

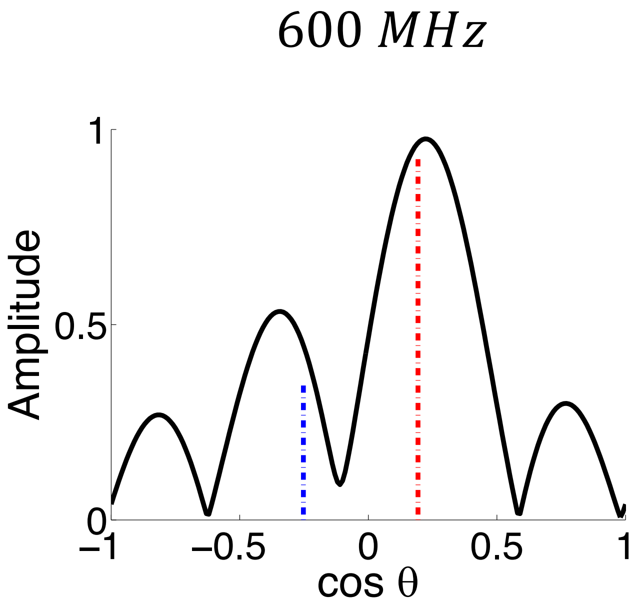
Uplink Channels at Frequency 1

Paths along which signal is received

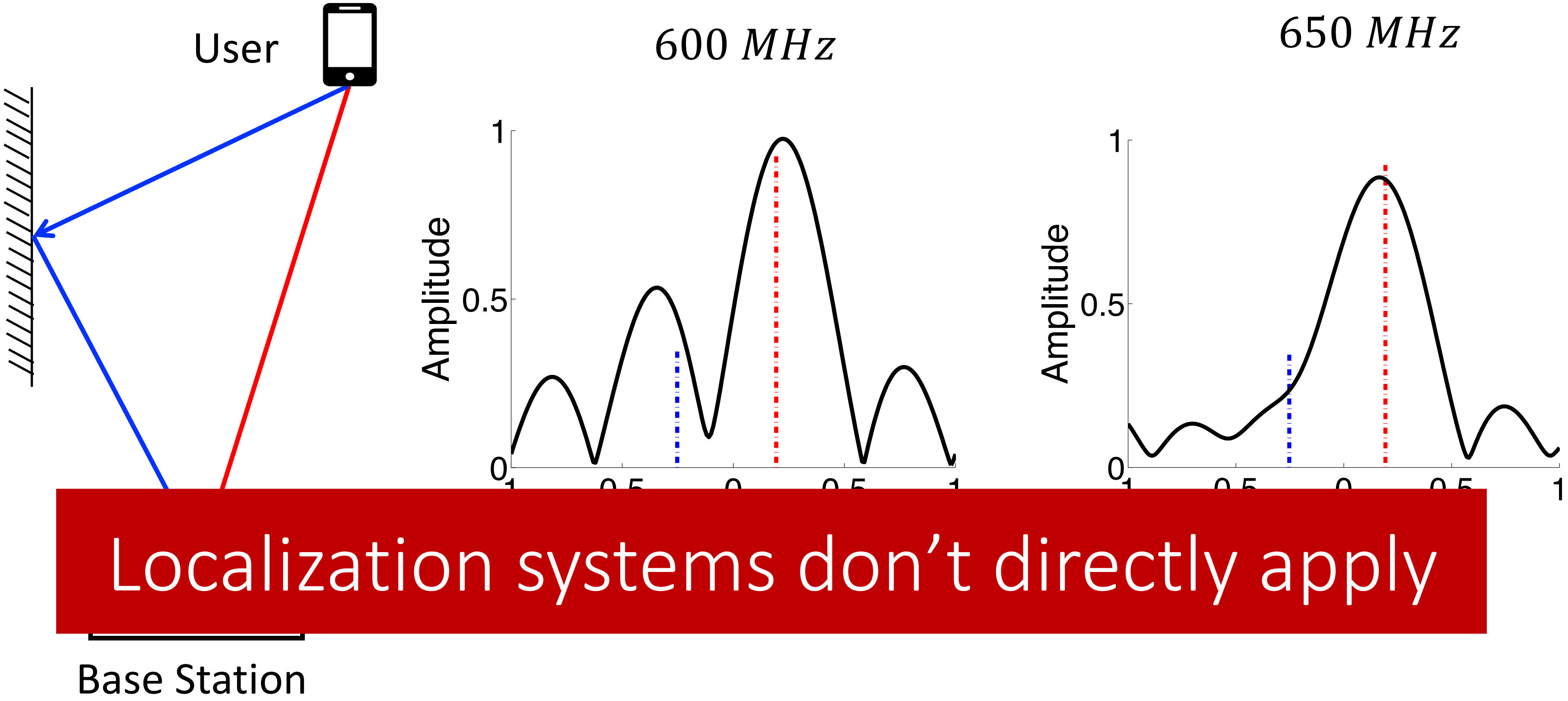
Downlink Channels at Frequency 2

# RF-based Localization Systems



# RF-based Localization Systems




Localization systems don’t directly apply

# Idea: Same Paths on Uplink & Downlink

Uplink Channels at Frequency 1

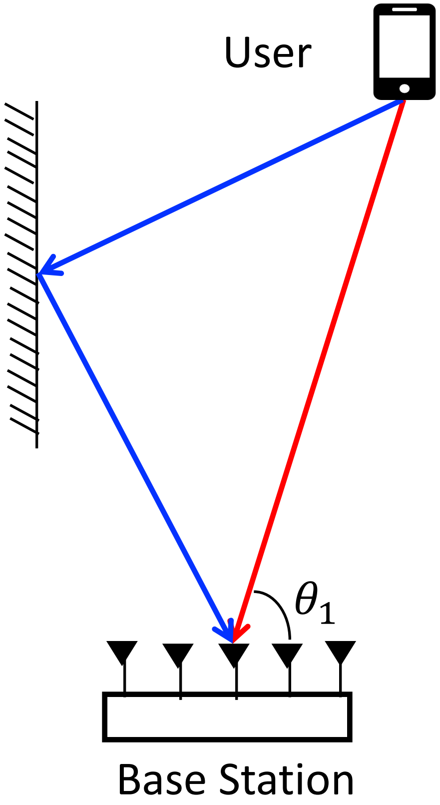
↓

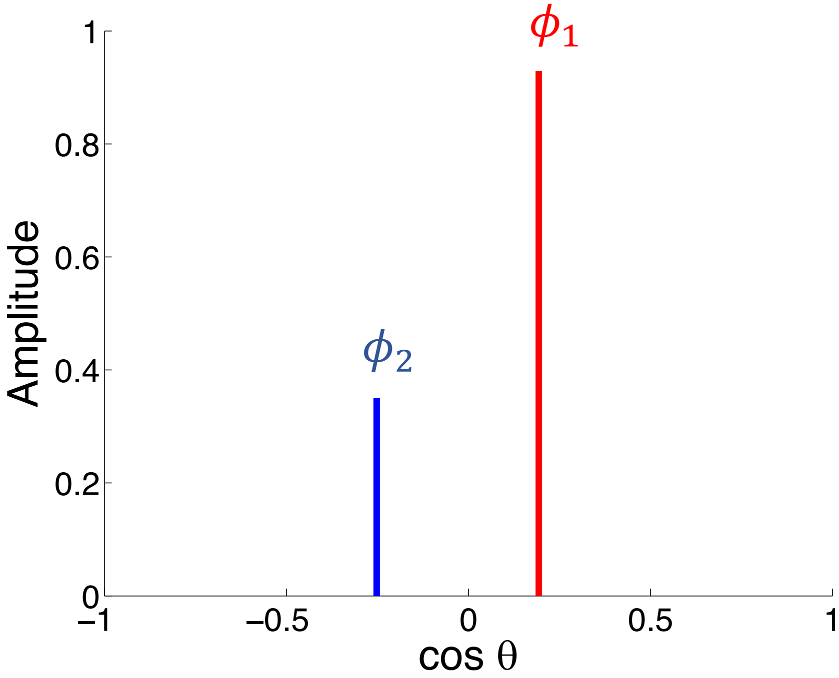
Paths along which signal is received

↓

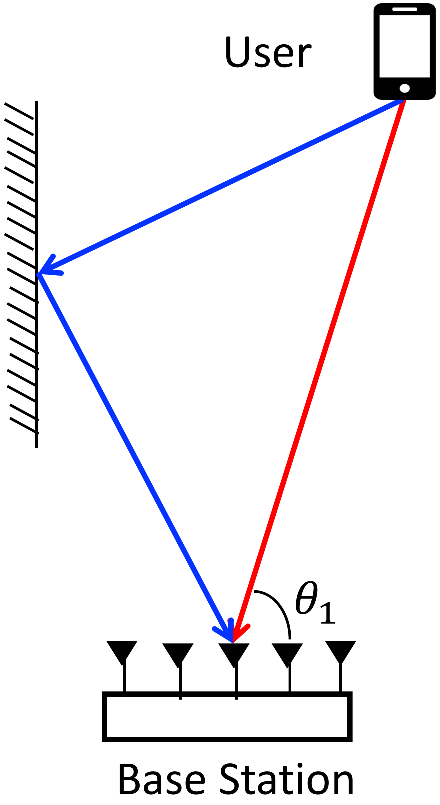
Downlink Channels at Frequency 2

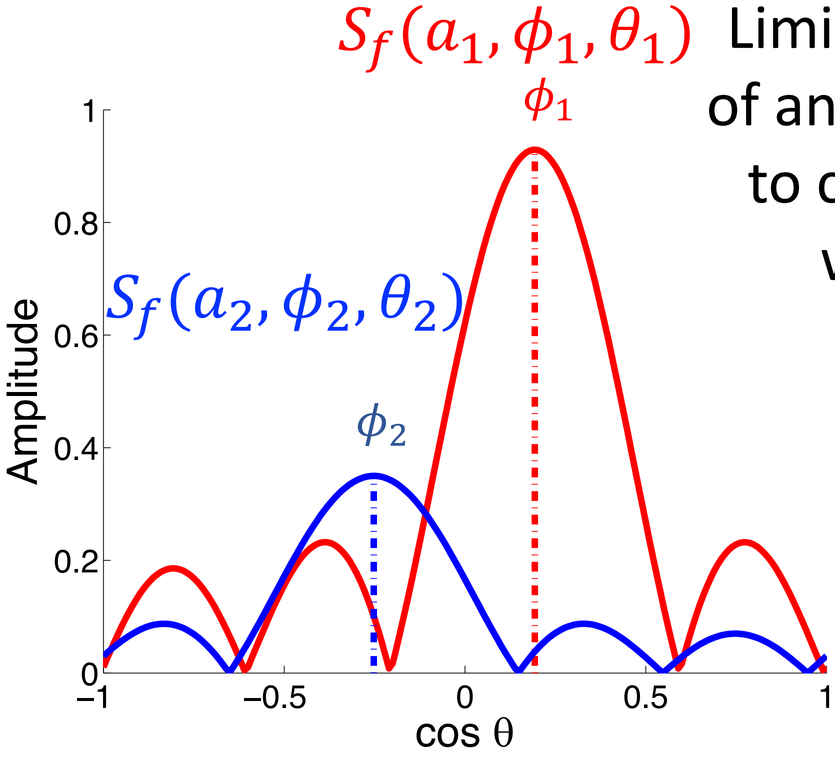
# Paths to Channels: Ideal Representation



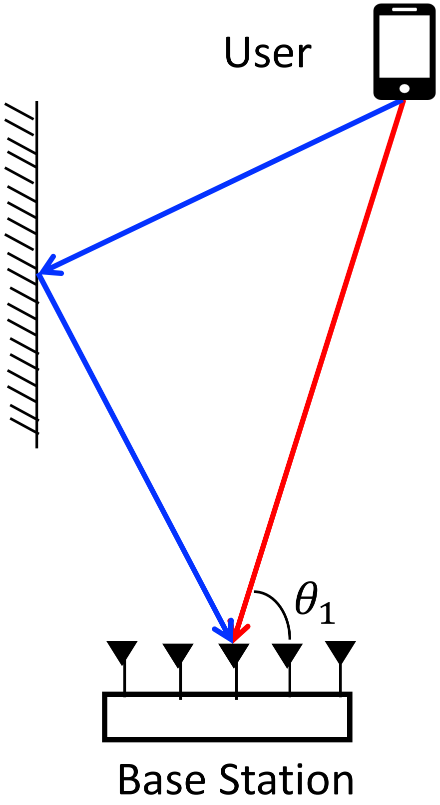
# Paths to Channels: Measured Representation



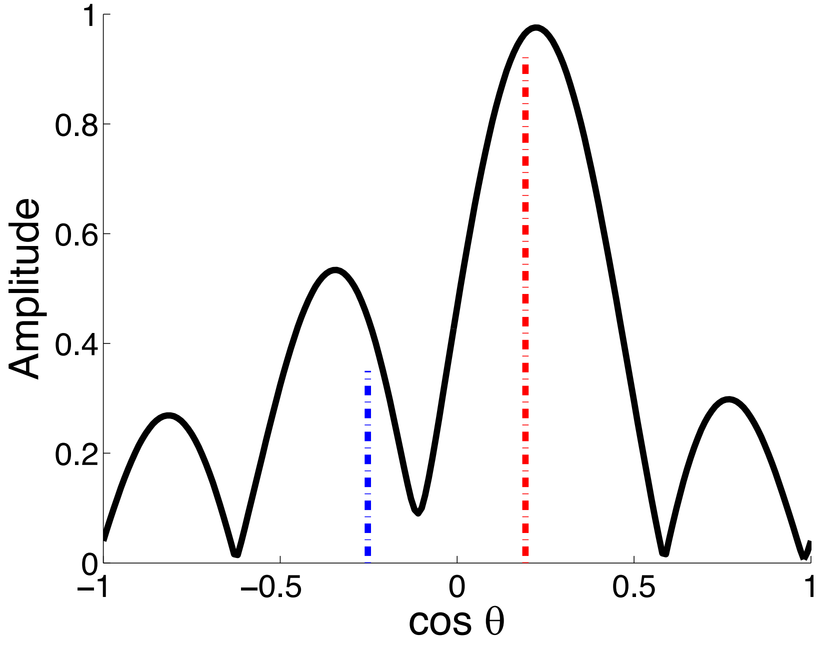




Limited number of antennas leads to convolution with sinc

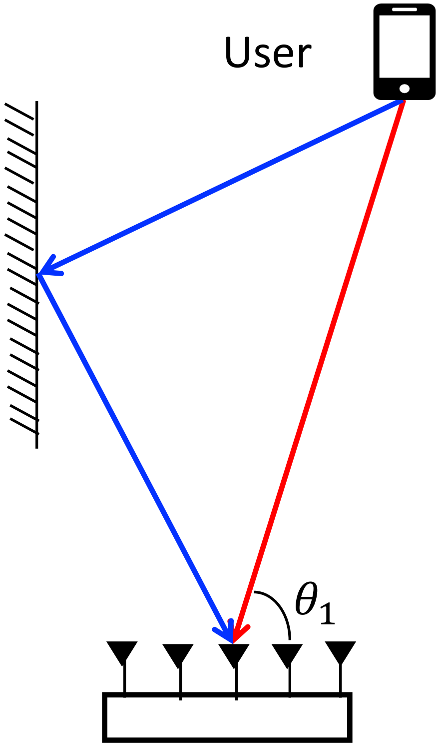
# Paths to Channels: Superposition



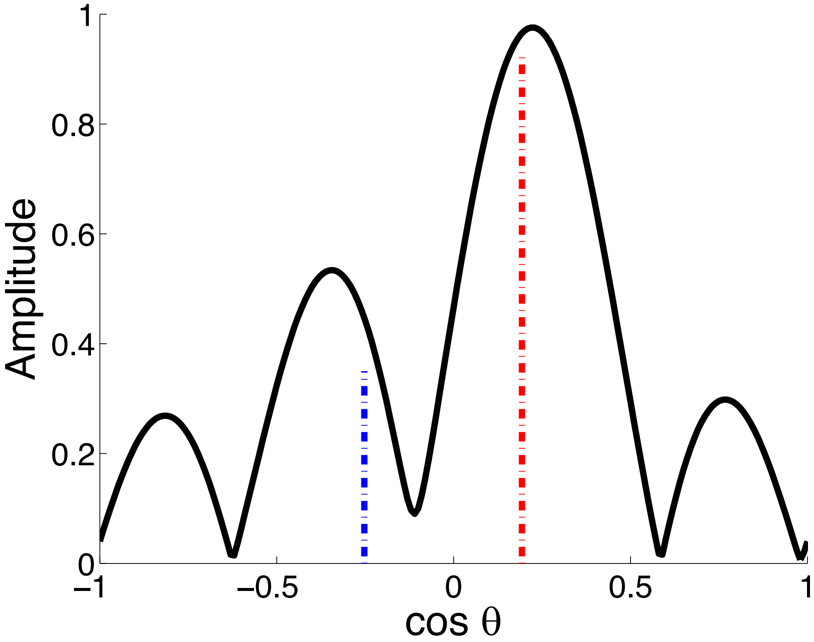

$$S_f(a_1, \phi_1, \theta_1) + S_f(a_2, \phi_2, \theta_2)$$



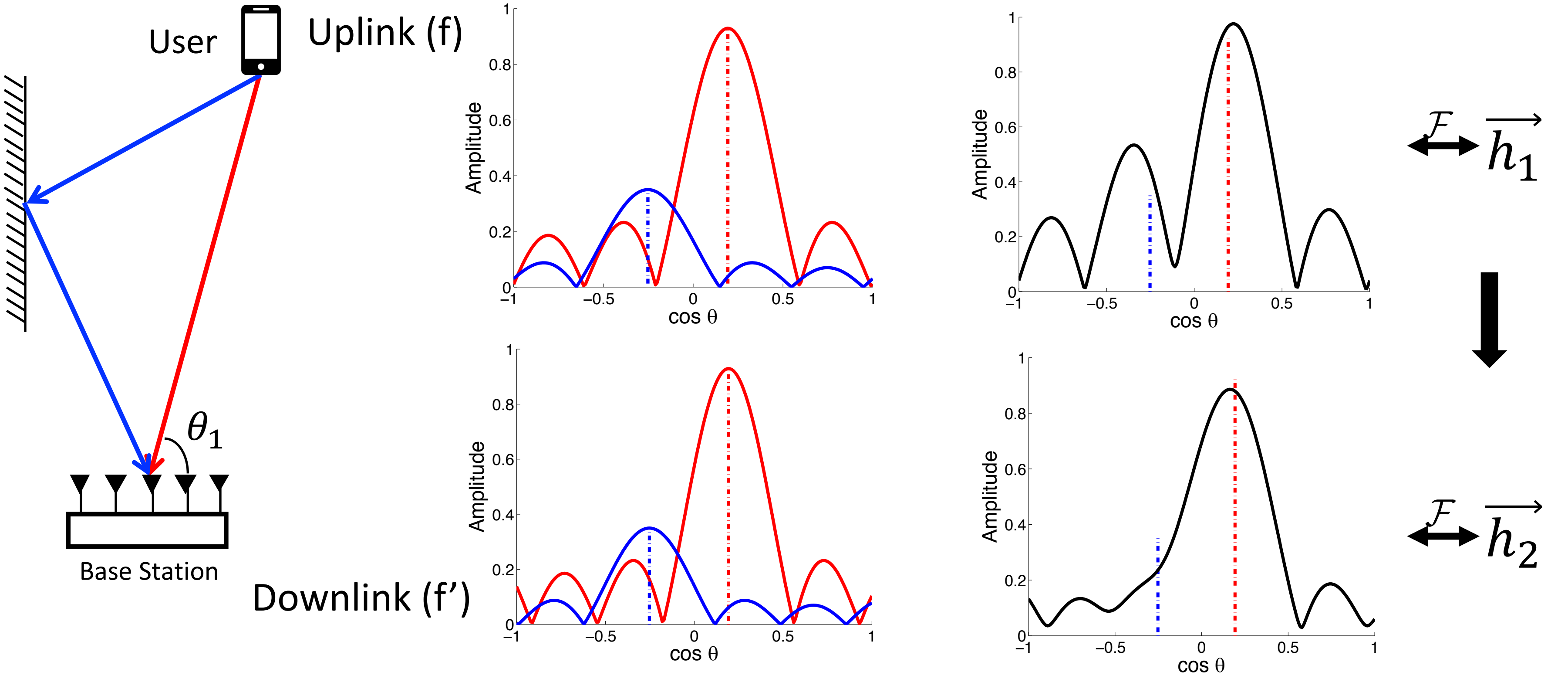
# Paths to Channels: FFT




$$FFT(S_f(a_1, \phi_1, \theta_1) + S_f(a_2, \phi_2, \theta_2)) \overset{\mathcal{F}}{\longleftrightarrow} \overrightarrow{h_1}$$



# Uplink to Downlink Channels



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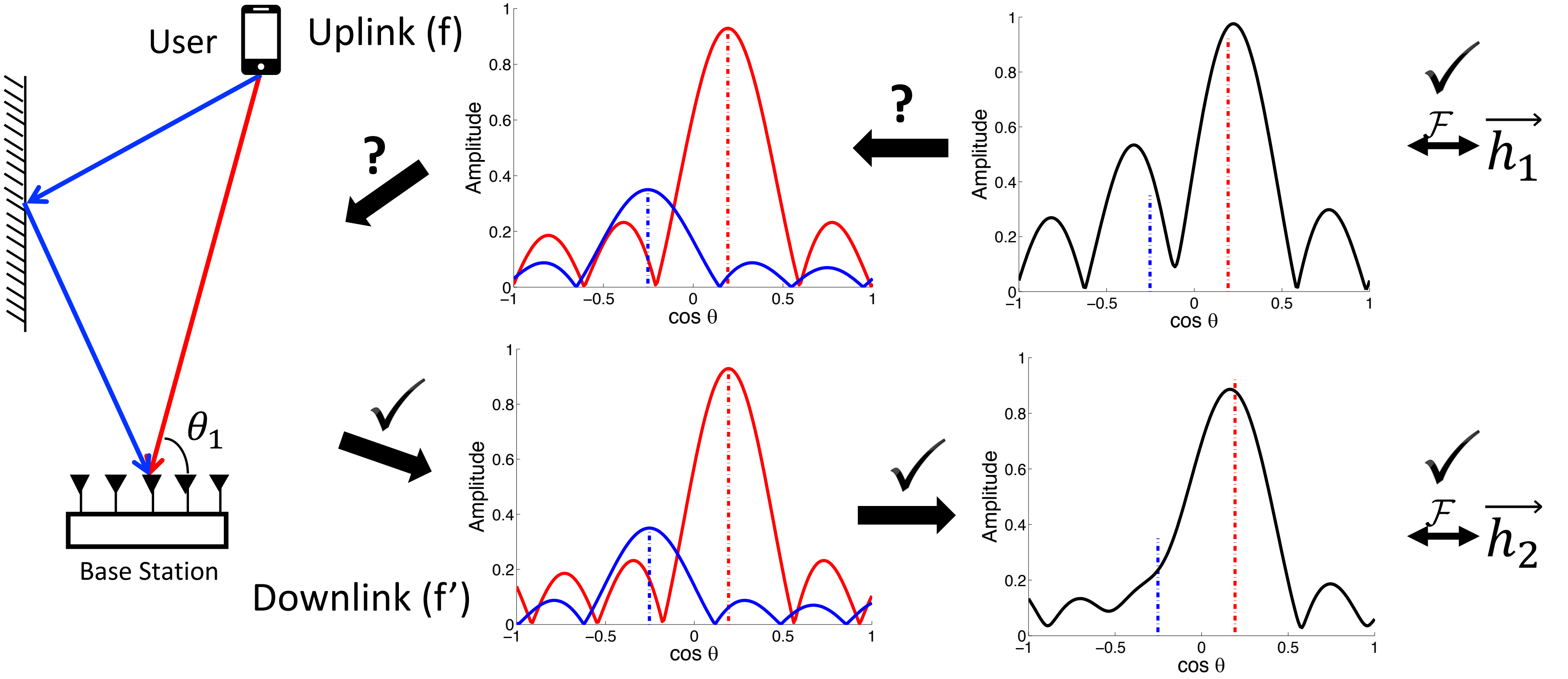
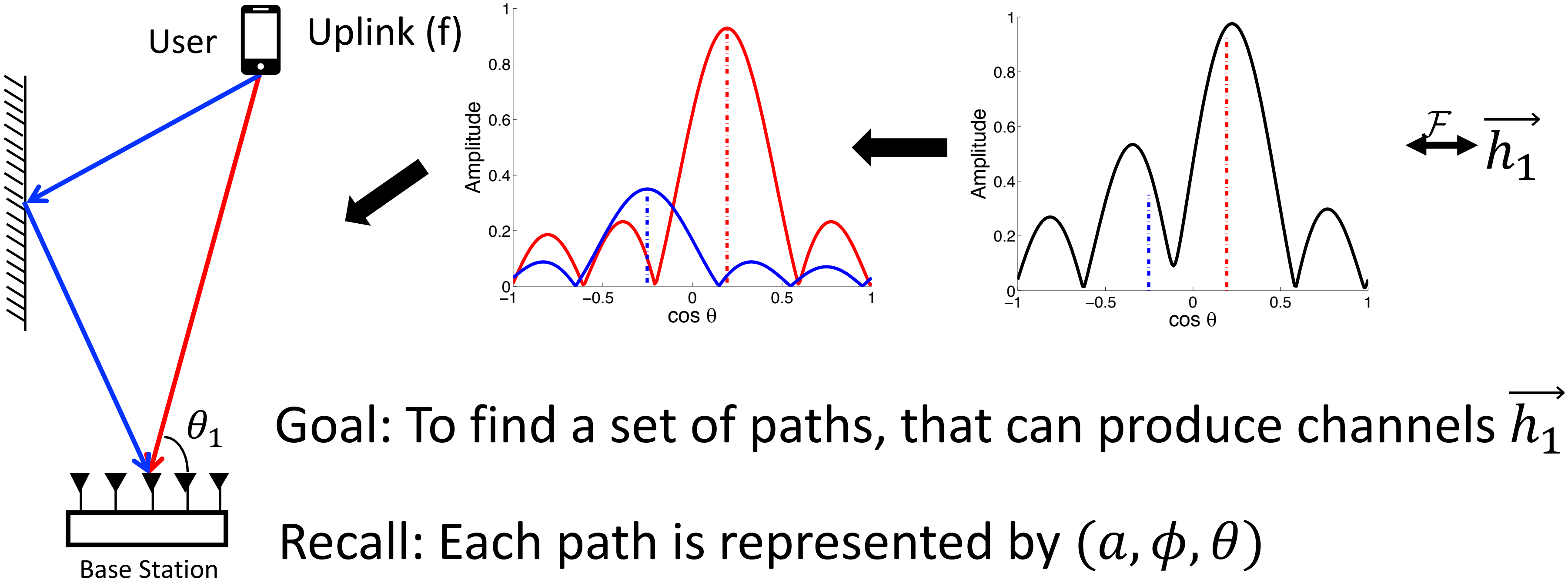


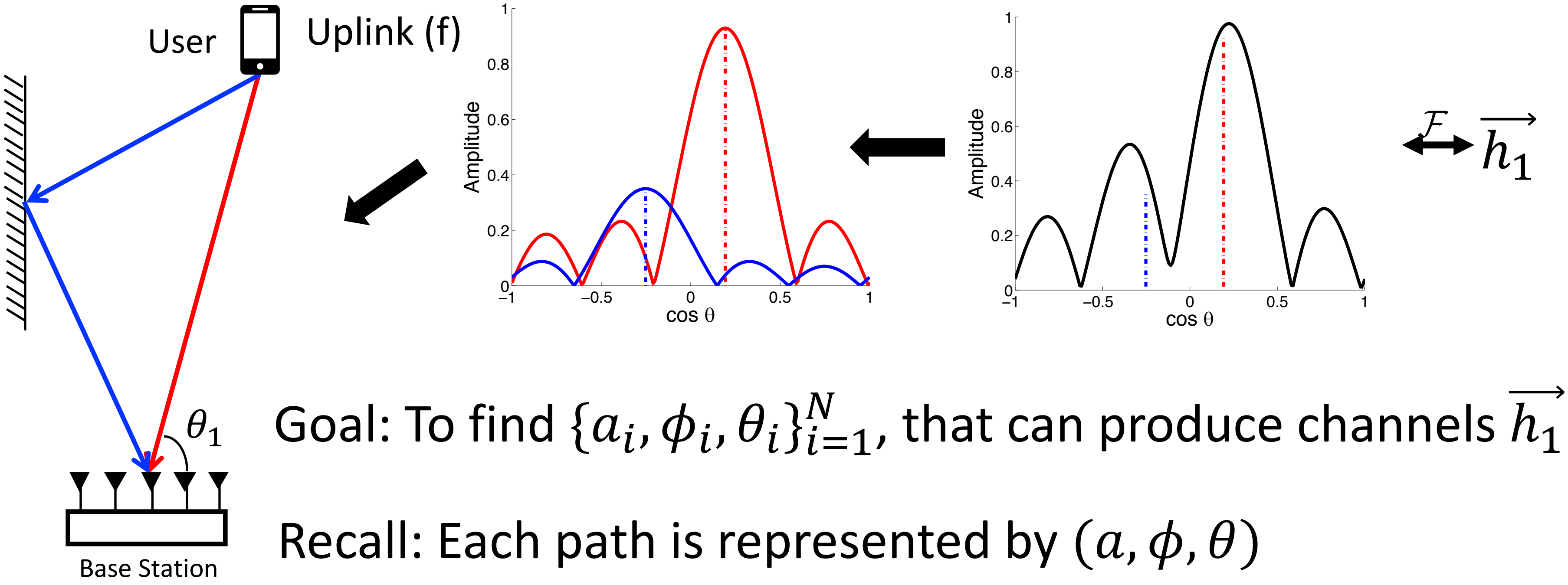
# Channels to Paths




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

Recall: Each path is represented by $(a, \phi, \theta)$

# 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 $(a, \phi, \theta)$

# Channels to Paths

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

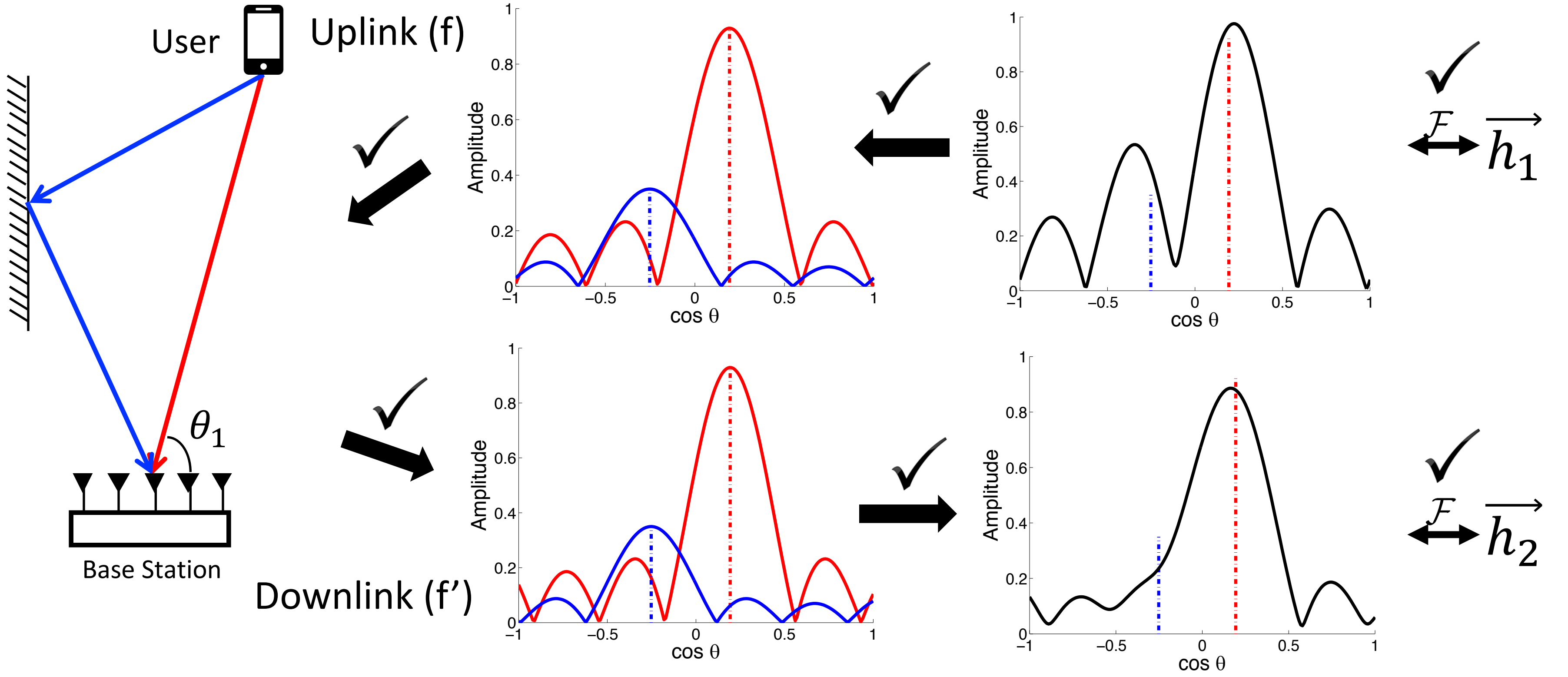
$$\overrightarrow{h_{est}} = FFT\left(\sum_{i=1}^{N} S_f(a_i, \phi_i, \theta_i)\right)$$

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

# 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

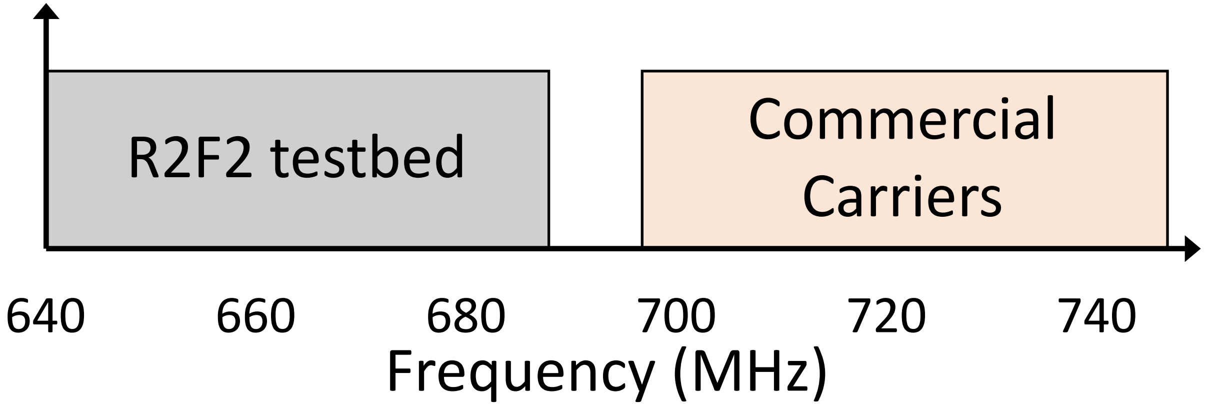
Goal: To measure the accuracy of R2F2 channel estimates

# Experimental Setup

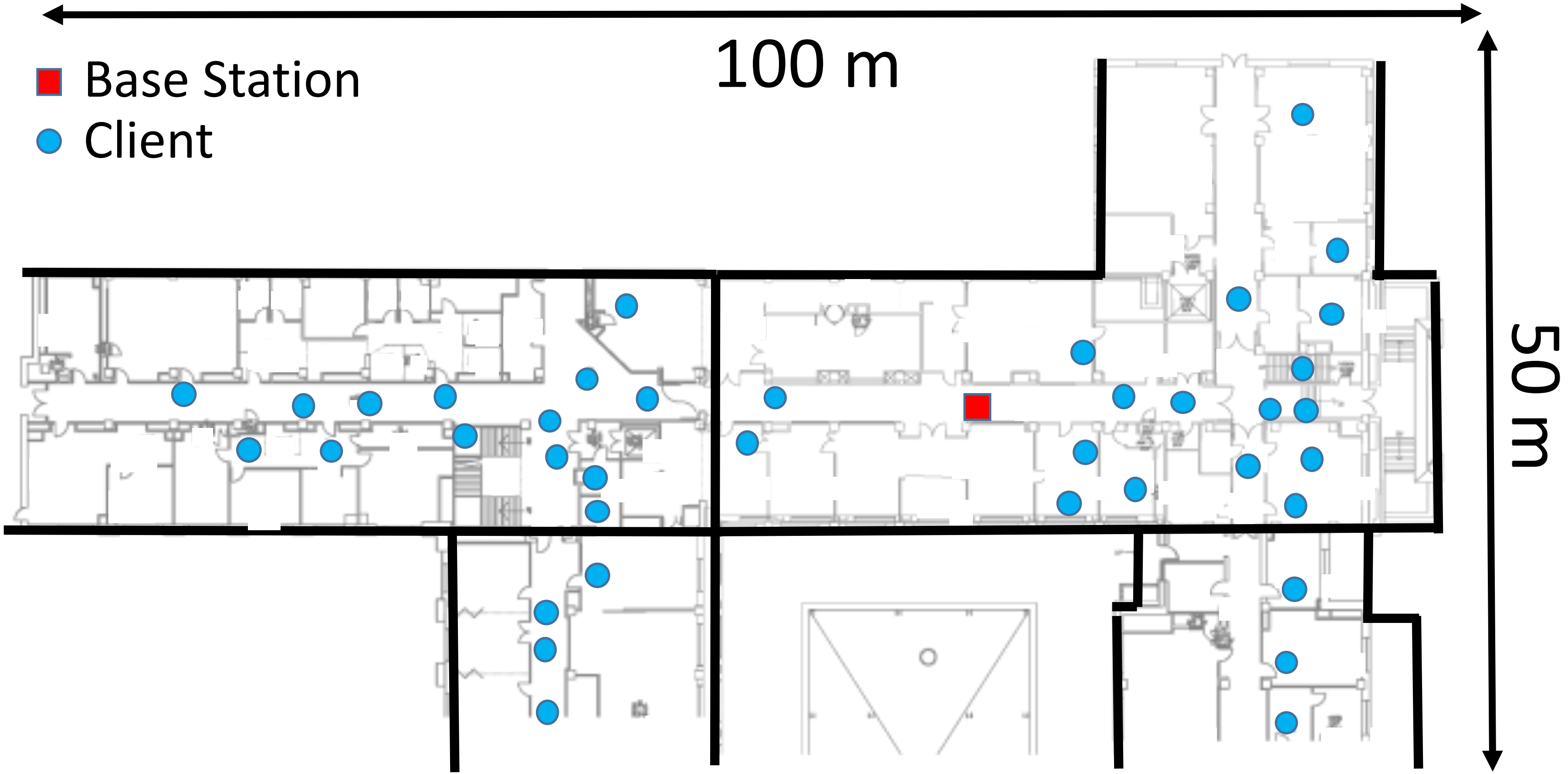
- Used USRP N210 software radios as clients and base stations
- Implemented a 5 antenna LTE base station
- Located base station close to a commercial base station

# Frequency Separation

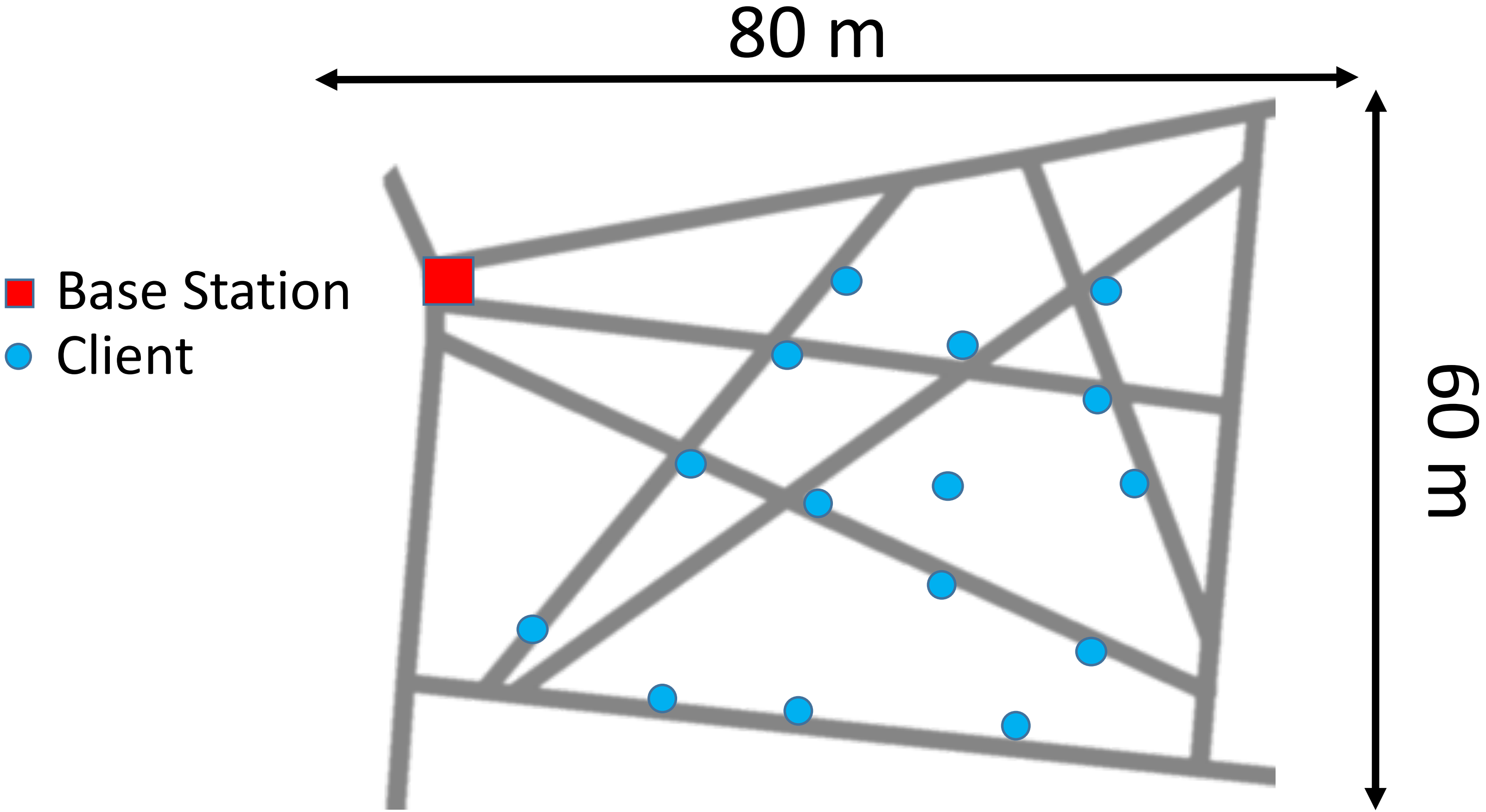
- Used frequencies from 640 to 690 MHz in the White Spaces
- Evaluation at 30 MHz Uplink-Downlink separation
- Same as major AT&T and Verizon deployments



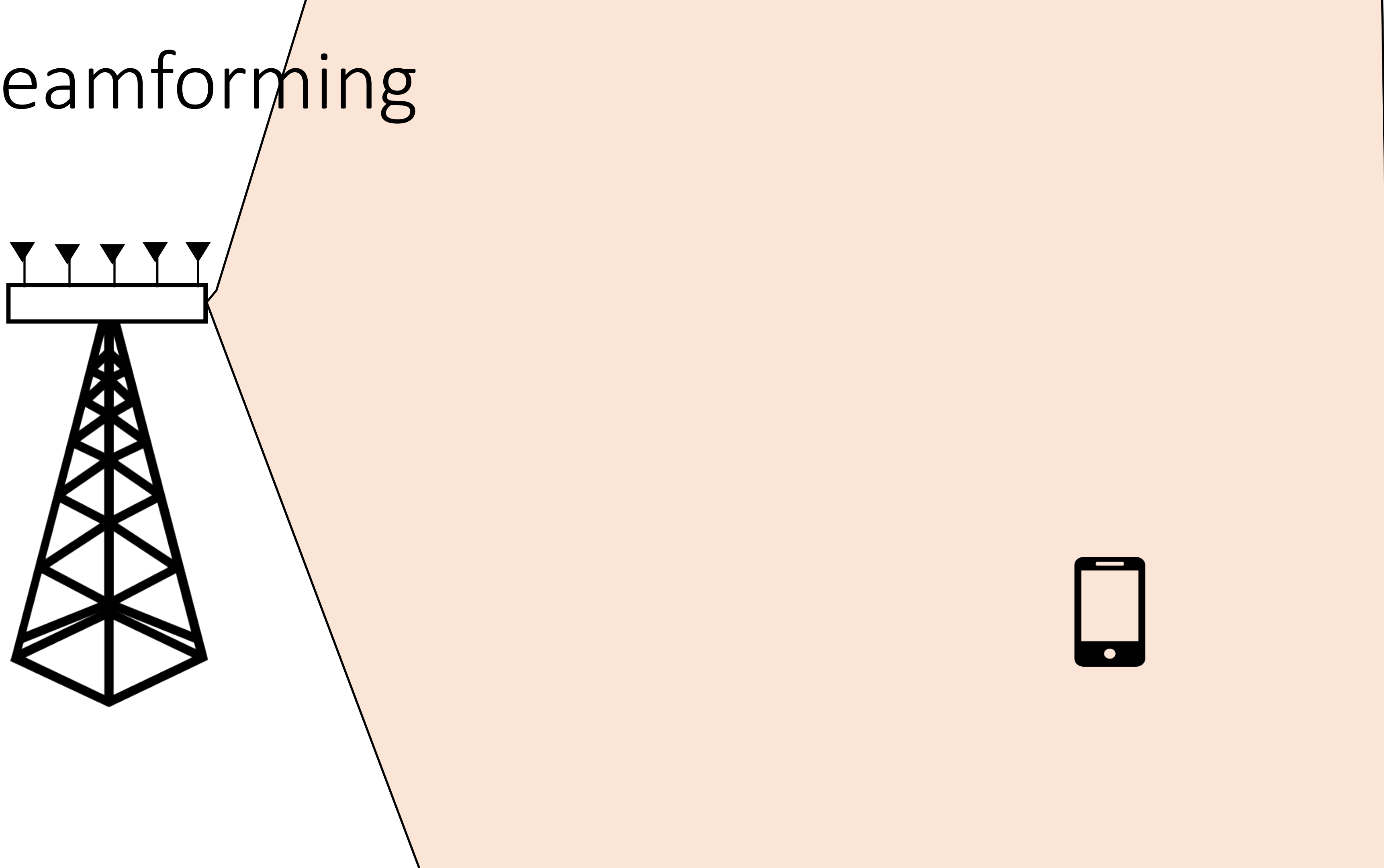
# Indoor Testbed



# Outdoor Testbed



# Beamforming



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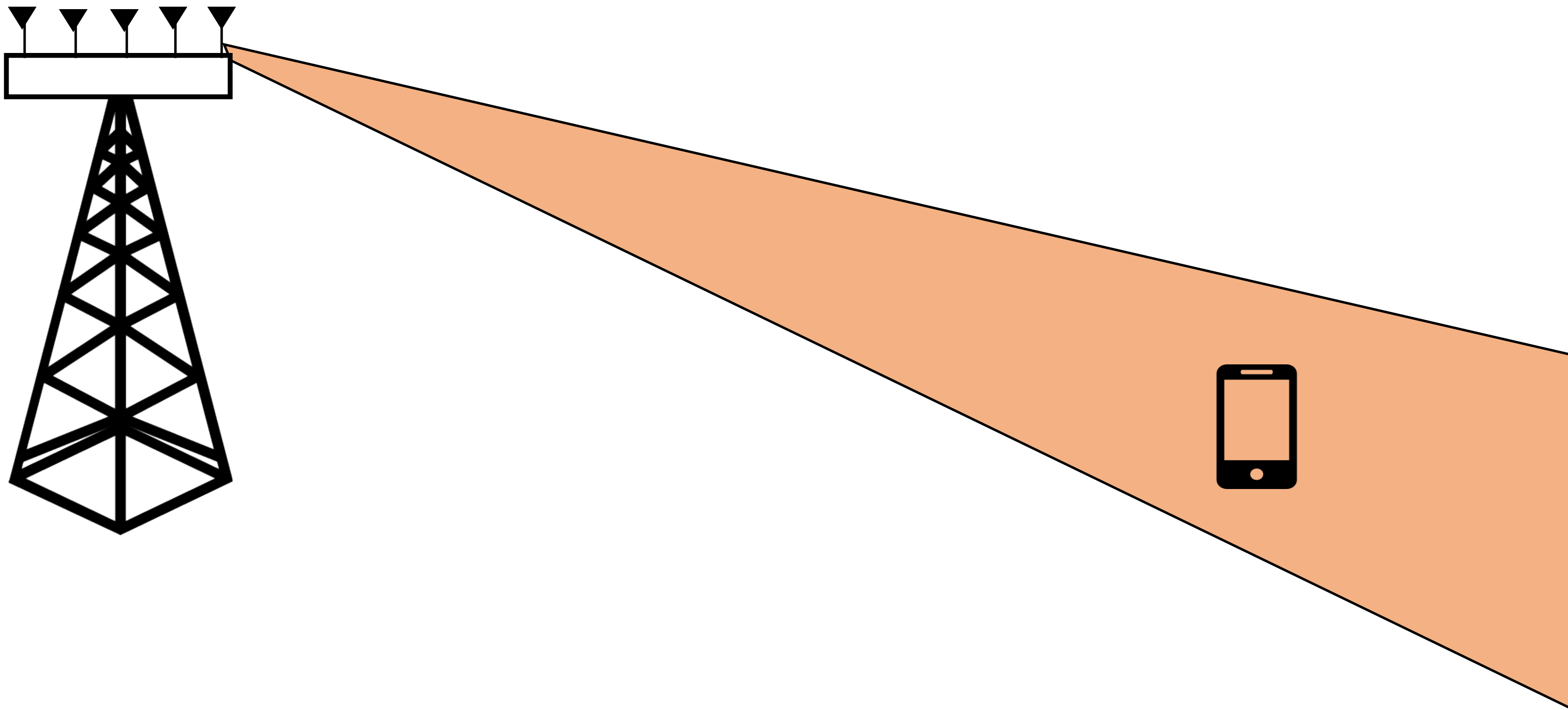
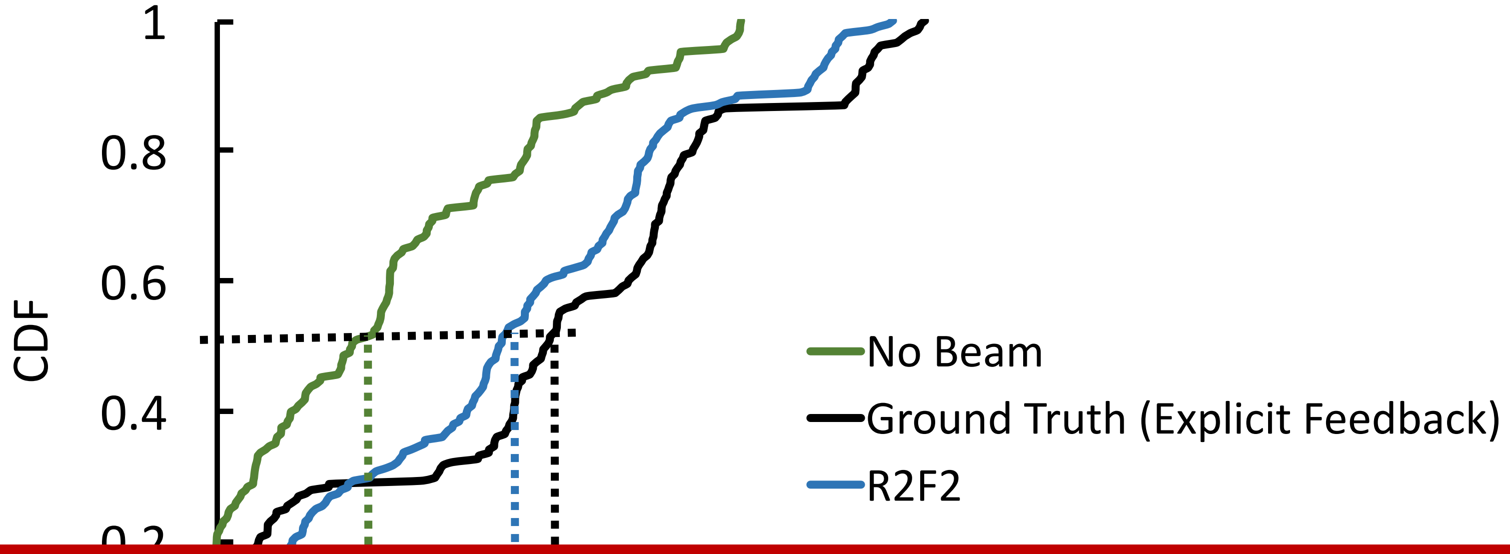
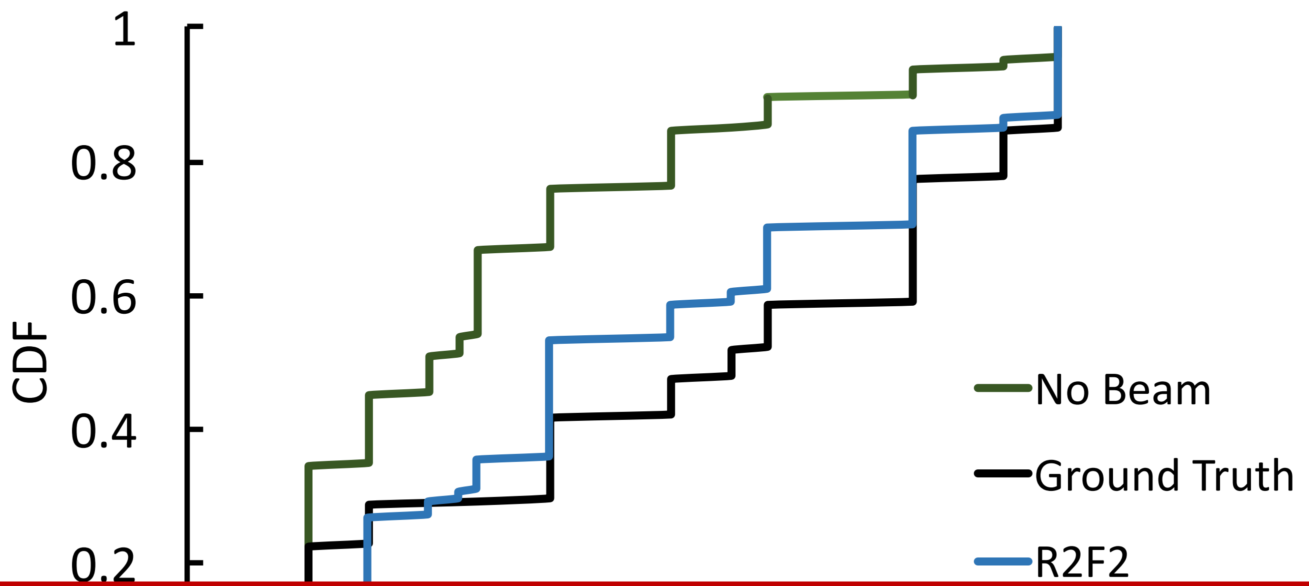


# Beamforming Comparison



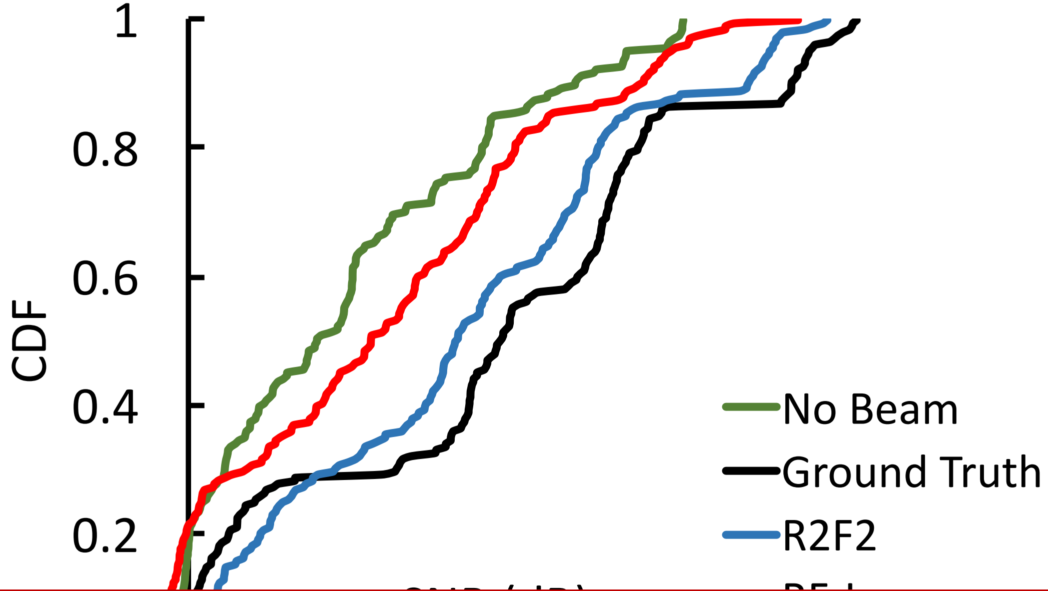

R2F2 delivers 90% of the MIMO SNR gains, with zero feedback

# Beamforming Comparison: Data Rate



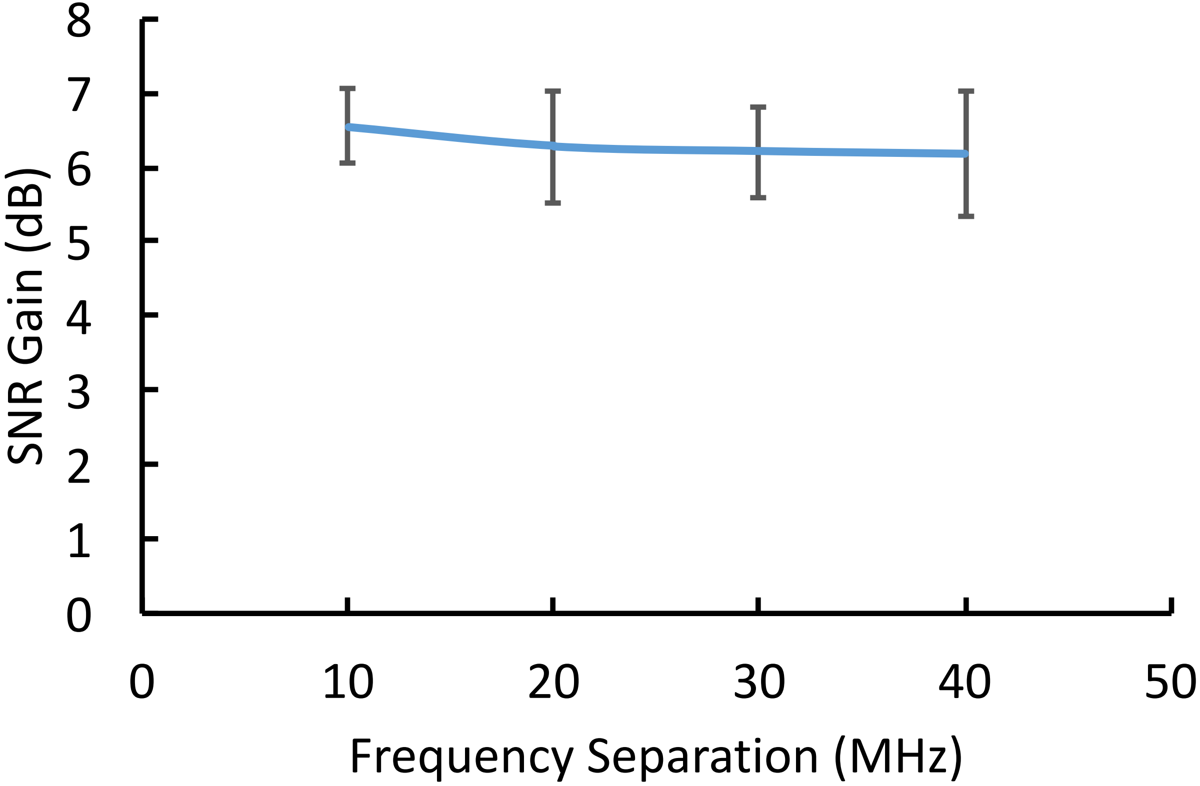

R2F2’s achieves 1.7x data rate improvement

# Comparison with RF-localization

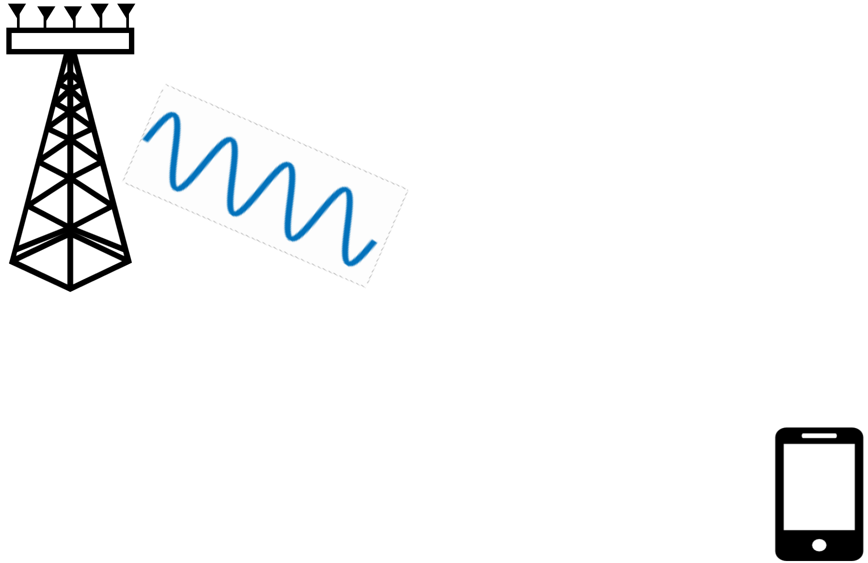



Delivers only 40% of MIMO SNR gains

# Effect of Frequency Separation



# Application: Edge Client Nulling



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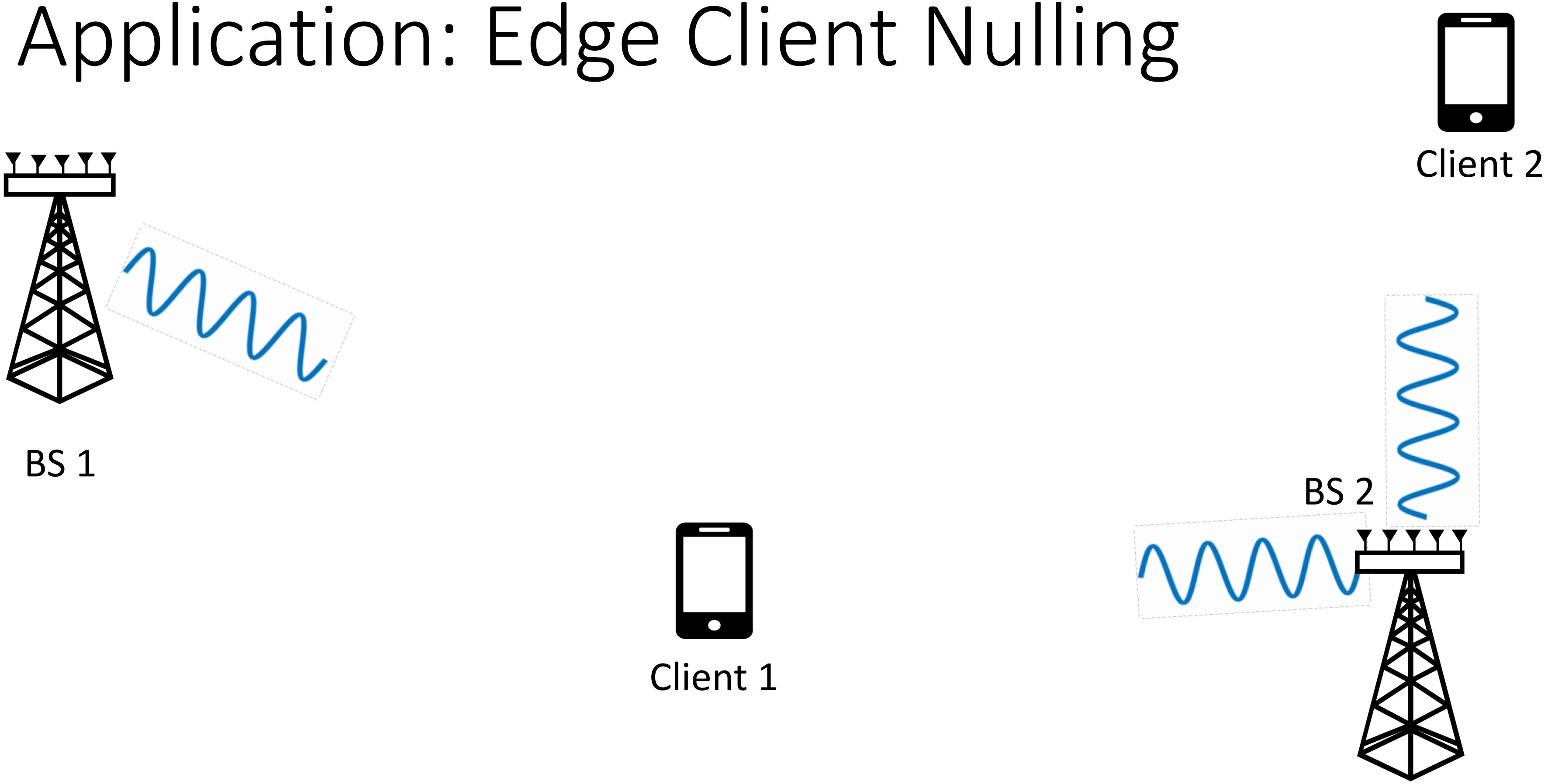
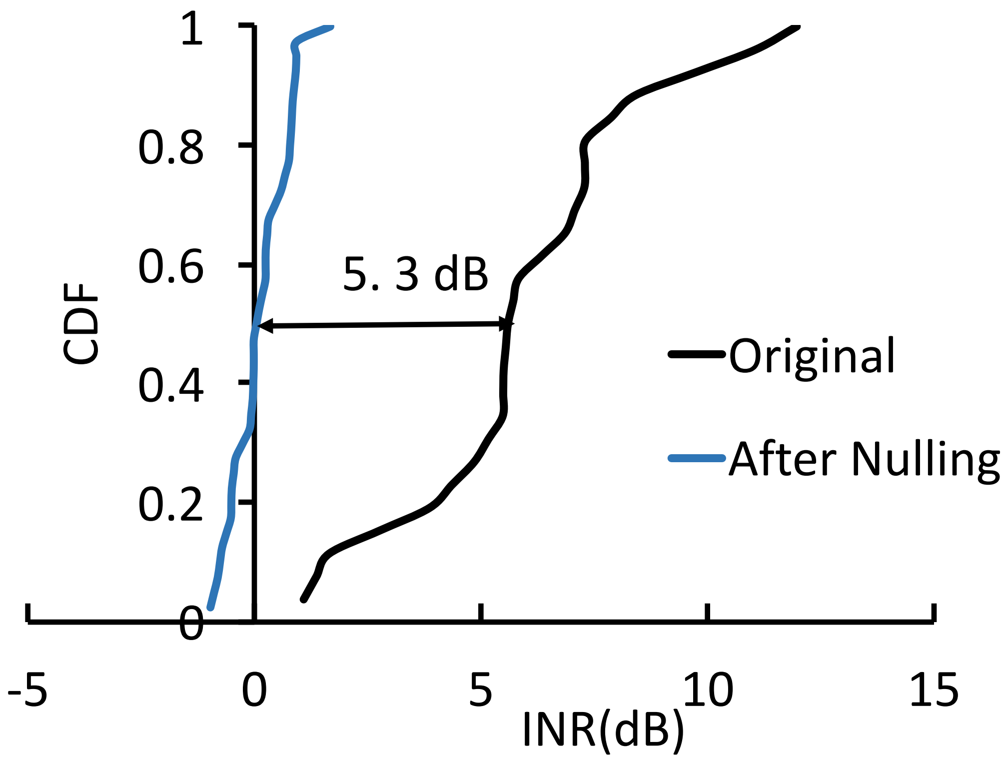


# Edge Nulling



# 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