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

User

Base Station

$\theta$

Amplitude

$\cos \theta$

600 MHz

$\cos \theta$
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

User

Base Station

$$\theta_1$$

$$\phi_1$$

$$\phi_2$$

Amplitude

$$\cos \theta$$

$$0$$

$$0.5$$

$$1$$

$$0$$

$$0.2$$

$$0.4$$

$$0.6$$

$$0.8$$

$$1$$

$$-1$$

$$-0.5$$

$$0$$

$$0.5$$

$$1$$
Paths to Channels: Measured Representation

\[ S_f(a_1, \phi_1, \theta_1) \]  Limited number of antennas leads to convolution with sinc

\[ S_f(a_2, \phi_2, \theta_2) \]
Paths to Channels: Superposition

\[ S_f(a_1, \phi_1, \theta_1) + S_f(a_2, \phi_2, \theta_2) \]
Paths to Channels: FFT

\[ \text{FFT}(S_f(a_1, \phi_1, \theta_1) + S_f(a_2, \phi_2, \theta_2)) \]

\[ F \rightarrow h_1 \]
Uplink to Downlink Channels

\[ F \begin{bmatrix} h_1 \\ h_2 \end{bmatrix} \]

\( \theta_1 \)
Uplink to Downlink Channels

User

Base Station

Uplink (f)

Downlink (f')

\[ \theta_1 \]

\[ \mathcal{F} \]

\[ h_1 \]

\[ h_2 \]
Goal: To find a set of paths, that can produce channels $\vec{h}_1$

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 \( \vec{h}_1 \)

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 \( \vec{h}_1 \)

\[
\vec{h}_{est} = FFT \left( \sum_{i=1}^{N} S_f(a_i, \phi_i, \theta_i) \right)
\]

\[
\{a_i, \phi_i, \theta_i\}_{i=1}^{N} = \text{argmin}_{\{a_i, \phi_i, \theta_i\}} \| \vec{h}_1 - \vec{h}_{est} \|^2
\]
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

User $\rightarrow$ Base Station

Uplink $(f)$

$\theta_1$

Downlink $(f')$

Amplitude

$\cos \theta$

$\overrightarrow{h_1}$

$\overrightarrow{h_2}$
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

- Base Station
- Client
Outdoor Testbed

80 m

60 m

- Base Station
- Client
Beamforming
Beamforming
R2F2 delivers 90% of the MIMO SNR gains, with zero feedback.
Beamforming Comparison: Data Rate

CDF
Datarate (Mbps)

No Beam
Ground Truth
R2F2

R2F2’s achieves 1.7x data rate improvement
Comparison with RF-localization

Delivers only 40% of MIMO SNR gains
Application: Edge Client Nulling
Application: Edge Client Nulling

BS 1

Client 1

BS 2

Client 2
Edge Nulling

![Graph showing the improvement of INR (dB) with nulling. The graph compares 'Original' and 'After Nulling' with a 5.3 dB improvement.]
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