A Working Single Channel, Full Duplex Wireless System

Jung Il Choi, Mayank Jain, Kannan Srinivasan, Richard Swensson, Philip Levis and Sachin Katti

STANFORD UNIVERSITY

Problem Statement

General belief: A wireless node cannot send and receive simultaneously on the same channel.

In-band full-duplex is not possible!

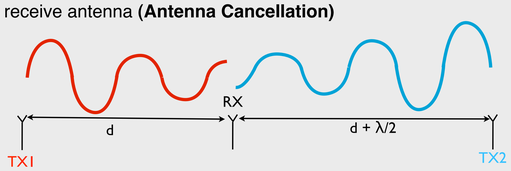
Why not?

Self-interference is too strong (~70dB for 802.15.4)

- Saturates ADC: digital cancellation is not feasible
- Analog (noise) cancellation before ADC is not enough (only 20-30 dB cancellation)

Solution: Antenna Cancellation

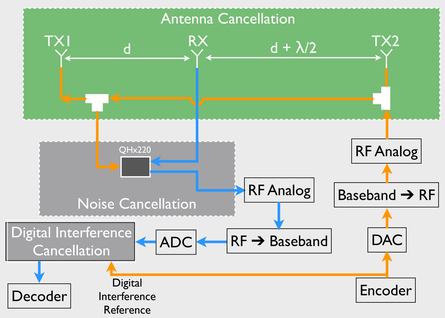
- Position transmit antennas such that they destructively add at the receive antenna **(Antenna Cancellation)**



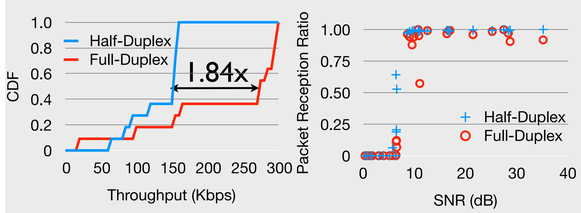
- λ/2 difference in distance gives 180° phase difference between the signals from the two transmit antennas
- After amplitude matching (by adjusting transmit powers at the two antennas), the signals cancel at the receive antenna
- Gives **30dB** reduction in self-interference

Full-Duplex: Current Design

Combines antenna, noise and digital cancellation techniques



Gives ~70 dB reduction: Ready for 802.15.4!!

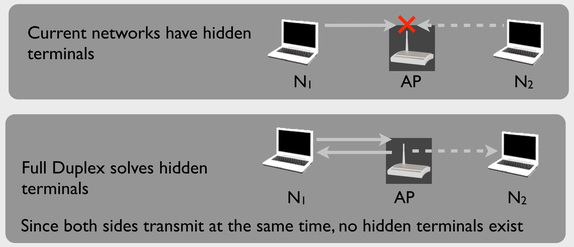


Results:

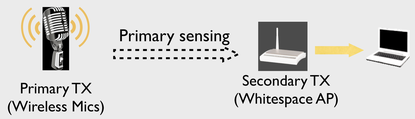
- 1.84x median gain in throughput
- Within 8% of ideal full-duplex operation
- Little loss in reliability: 12% loss on average

Implications

I. No More Hidden Terminals



II. Improved Primary Detection in Whitespaces



Secondary transmitters should sense for primary transmissions before channel use

- traditional half-duplex nodes cannot sense while transmitting and so, can interfere with primary users
- full-duplex systems can sense while transmitting and avoid this interference

III. Network Congestion and WLAN Fairness

Without full-duplex:

- 1/n bandwidth for each node in network, including AP
  Downlink Throughput = 1/n Uplink Throughput = (n-1)/n

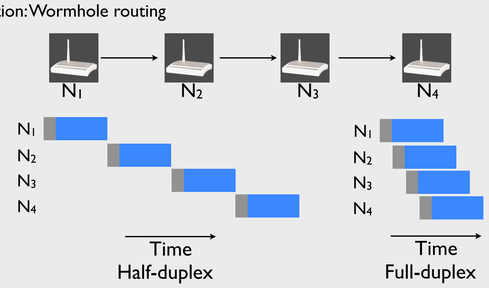
With full-duplex:

- AP sends and receives at the same time
  Downlink Throughput = 1 Uplink Throughput = 1

IV. Reducing Round-Trip Times

Long delivery and round-trip times in multi-hop networks

Solution: Wormhole routing



Limitations/Future Work

I. Power Limitation:

- Current prototype can cancel ~70dB of self-interference
- 802.11-like high power systems can have much higher self-interference
- Needs more efficient noise and digital cancellation techniques

II. Bandwidth Limitation:

- λ/2 difference from antenna cancellation technique can perfectly cancel one frequency component (f) corresponding to λ
- Signal components close to f get good cancellation
- Our current prototype, due to this frequency dependency, is suitable only for narrowband systems such as 802.15.4
- Working on a frequency-independent signal inversion technique to support wide-band systems such as 802.11

III. Sensitivity to Channel Variations:

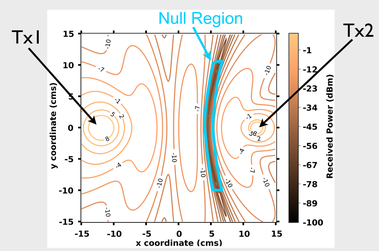
- Current prototype does not adaptively estimate and compensate for varying channel conditions
- Need channel sounding techniques to estimate varying multipath components to provide adaptive noise cancellation and digital cancellation techniques

IV. Full-duplex MIMO support:

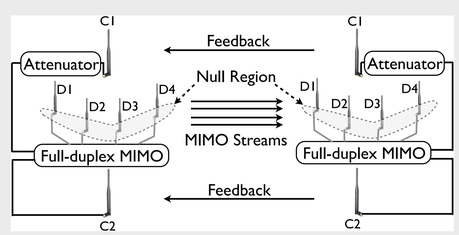
- Full-duplex prototype supports single input single output (SISO) systems
- Need to extend antenna cancellation to support multiple streams as in MIMO systems

A possible extension to support MIMO:

- Antenna cancellation technique creates a sharp null region close to the lower power transmit antenna



- Our proposed extension takes advantage of the null region by placing multiple receive antennas in it

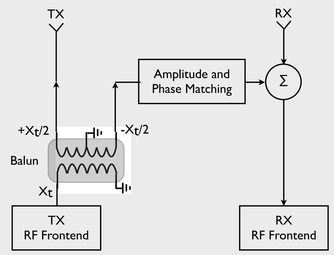


- This extension provides a single feedback channel for all the MIMO forward streams

In This Demo

A 2-Antenna Solution

- No antenna cancellation
- Invert and cancel the transmitted RF signal from received RF signal
- No bandwidth limitation: no λ dependence

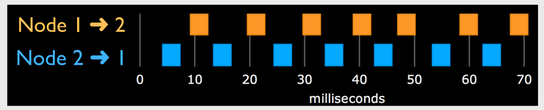


Experiment:

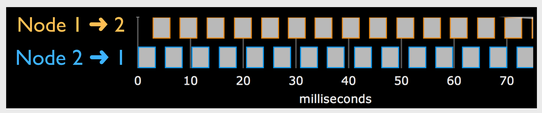
- Each full-duplex node has 2 802.15.4 motes
- Two full-duplex nodes talking to each other as fast as possible

Scenarios:

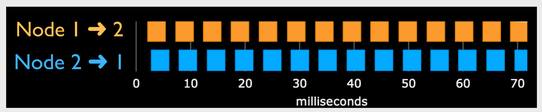
- Half-duplex (CCA ON):traditional radio operation with CSMA
  - Nodes interleave packets



- Half-duplex (CCA OFF):traditional radio operation with CSMA OFF
  - Nodes don't interleave: packets collide



- Full-duplex
  - Nodes don't interleave: packets succeed
  - Double the throughput of half-duplex with CCA ON



Acknowledgements

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