Demo: Remote Experimentation with Open-Access Full-Duplex Wireless in the COSMOS Testbed

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COSMOS FlexICoN wim.net Wireless & Mobile Networking Lab WINLAB CoSMIC

Outline

- COSMOS Overview
- Full-Duplex Wireless
  - Compact Wideband Full-Duplex Wireless
- Integration with COSMOS
- Logging into COSMOS
- Experiments

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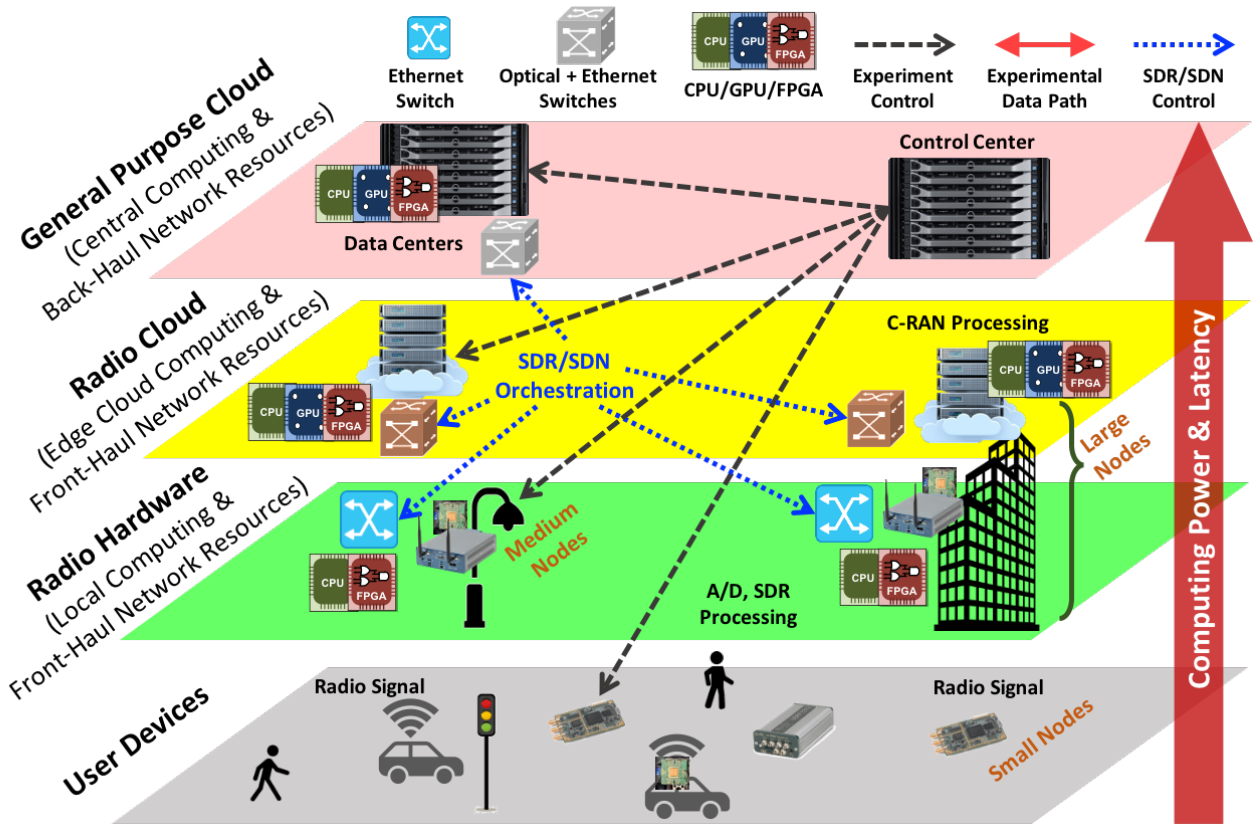
COSMOS Testbed Overview

- COSMOS aims to address the needs of next-generation wireless communications:
  - Low latency (<5ms) and ultra-high bandwidth (multi-Gb/s)
  - Abundant compute resources
  - Real-time applications
  - Real-world investigation of urban environments

- Enablers:
  - 10s of 64 element mmWave arrays
  - 10s of miles of Manhattan dark fiber
  - B5G edge cloud base stations
  - Edge compute
  - **Integration of custom hardware**



COSMOS' multi-layered computing architecture

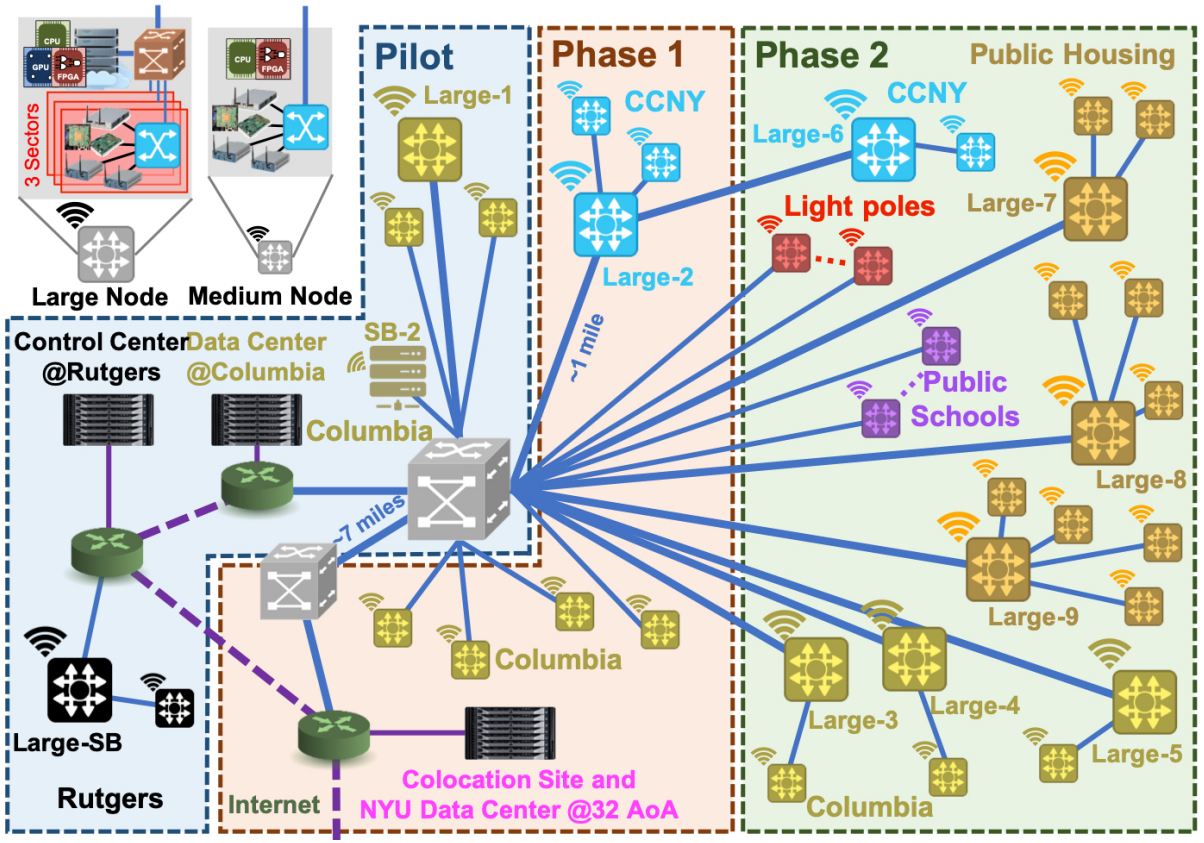
RUTGERS COLUMBIA UNIVERSITY IN THE CITY OF NEW YORK NYU NYC <sh> The City College of New York IBM

- D. Raychaudhuri, I. Seskar, G. Zussman, T. Korakis, D. Kilper, T. Chen, J. Kolodziejski, M. Sherman, Z. Kostic, X. Gu, H. Krishnaswamy, S. Maheshwari, P. Skrimponis, and C. Gutterman, "Challenge: COSMOS: A City-Scale Programmable Testbed for Experimentation with Advanced Wireless," in *Proc. ACM MobiCom'20, 2020*.

COSMOS Testbed Deployment Vision

- West Harlem, area: ~1 sq. mile
- FCC Innovation Zone

- Fiber optic connection from most sites
- Pilot generally available
- Working on phase one



- Two sandboxes (Rutgers, Columbia)
  - Internal environments for controlled experimentation

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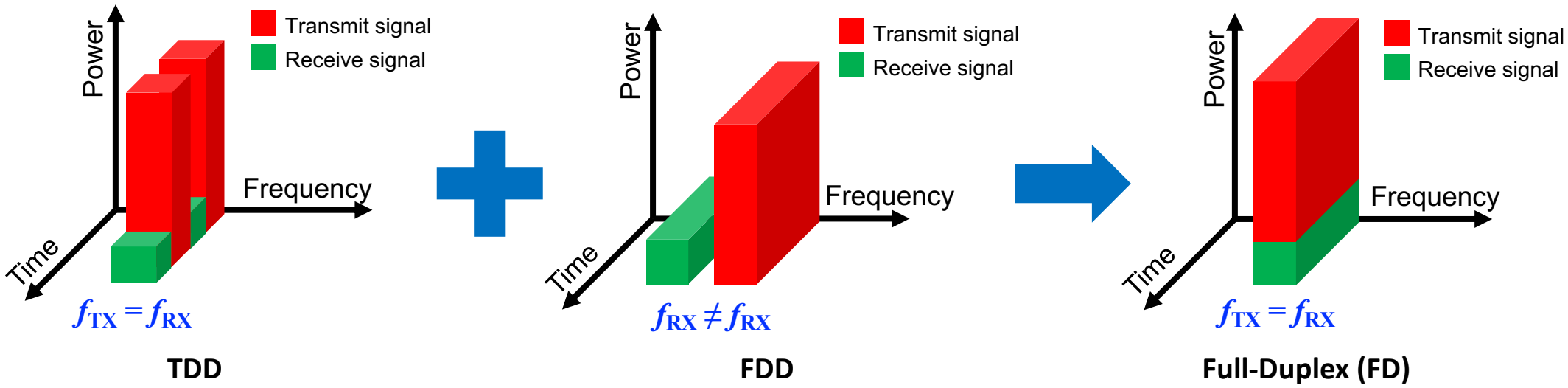
Full-Duplex Wireless

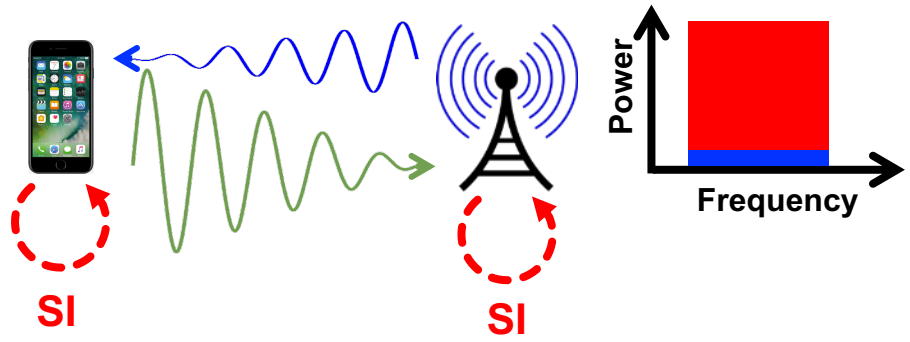
- Legacy half-duplex (HD) wireless systems separate transmission and reception in either:
  - Time: Time Division Duplex (TDD)
  - Frequency: Frequency Division Duplex (FDD)

- (In-band) **Full-duplex (FD)** wireless: simultaneous transmission and reception on the same frequency channel

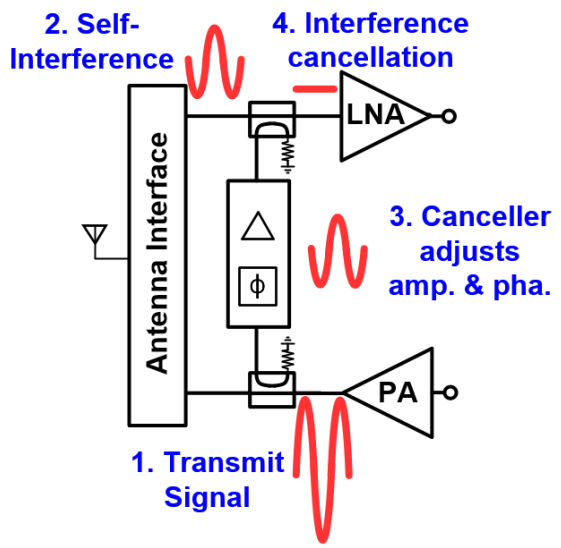


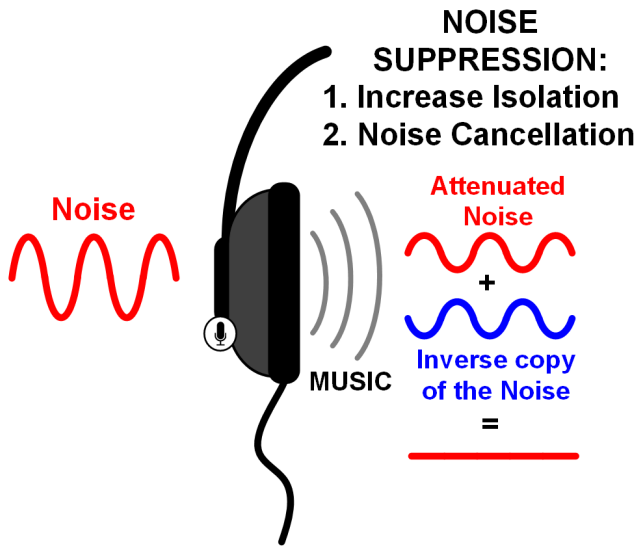
Full-Duplex Wireless

- Benefits of full-duplex wireless:
  - Increased system throughput and reduced latency.
  - More flexible use of the wireless spectrum.



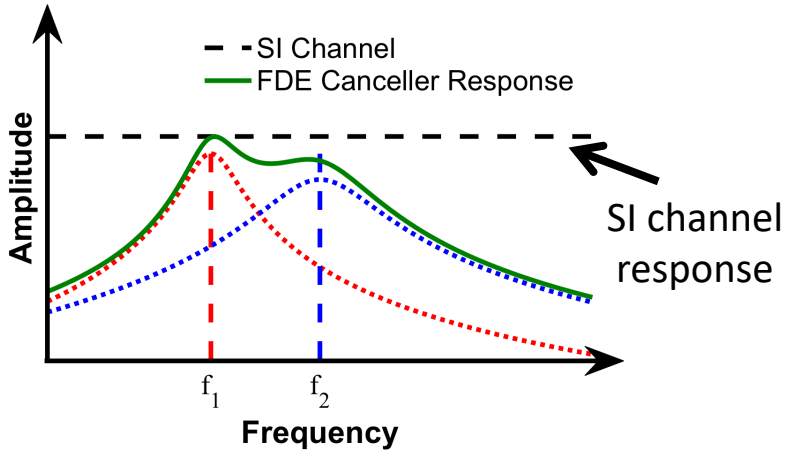
- One of the main challenges: self-interference (SI)
  - Transmitted signal is **billions** of times (**10^9 or 90 dB**) stronger than the received signal.
  - Requires extremely powerful SI cancellation (SIC) across ***antenna***, ***RF***, and ***digital*** domains.



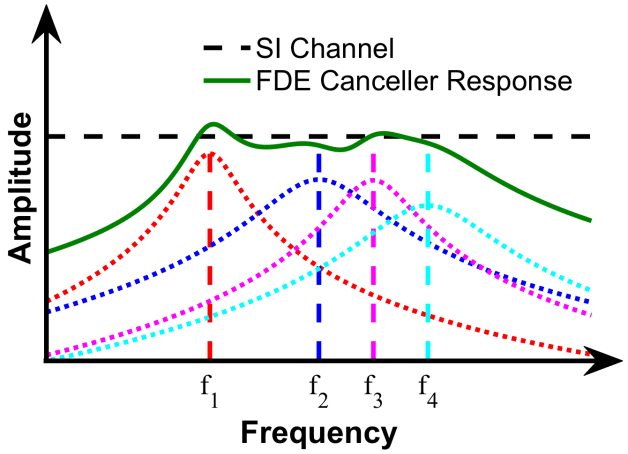


Compact Wideband Full-Duplex Wireless

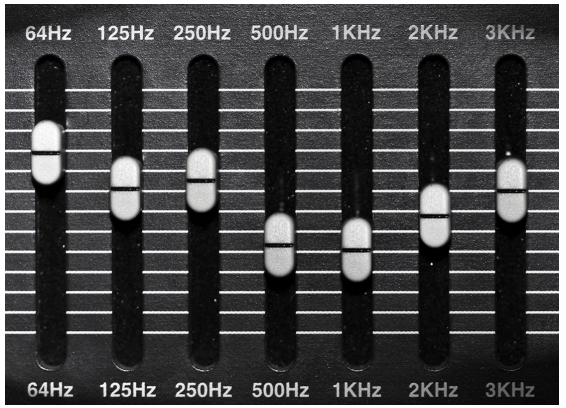
- Prior work: delay line-based cancellers [*Bharadia et al. 2013*, *Korpi et al. 2016*]
  - Difficult to implement long delay lines in ICs due to space constraints.
- **Frequency-domain equalization (FDE) based canceller**: The SI channel can be emulated in the *frequency domain* using reconfigurable RF bandpass filters (BPFs) with amplitude and phase controls. Multiple FDE taps can be used to enable wideband operation.
  - Suitable for compact IC-based implementations.
  - Each FDE tap has four variables: BPF center frequency, BPF quality factor, amplitude, and phase.



2 FDE taps



4 FDE taps



Audio Equalizer

- J. Zhou, T. Chuang, T. Dinc, and H. Krishnaswamy, "Integrated Wideband Self-Interference Cancellation in the RF Domain for FDD and Full-Duplex Wireless", *IEEE J. Solid-State Circuits*, vol. 50, no. 12, pp. 3015–3031, 2015.

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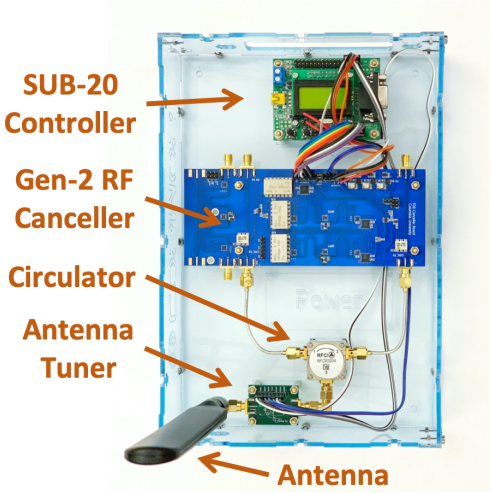
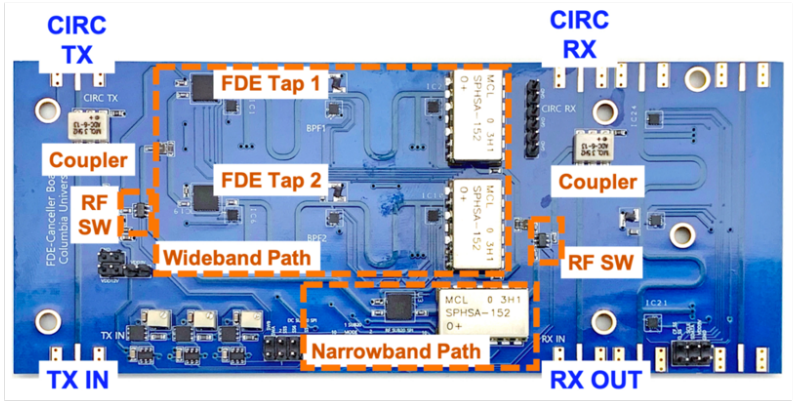
Gen-2 Wideband SI Canceller based on FDE

- For integration in COSMOS, we emulate the FDE RFIC canceller on a printed circuit board (PCB) to provide an easy interface to the SDR platform.
- This 2nd-generation (Gen-2) wideband RF canceller PCB is included alongside an antenna tuner, circulator and SUB-20 controller in the **Gen-2 RF canceller box**.
- Two Gen-2 RF canceller boxes are integrated with USRP2 SDRs and a compute node in COSMOS Sacndbox 2.

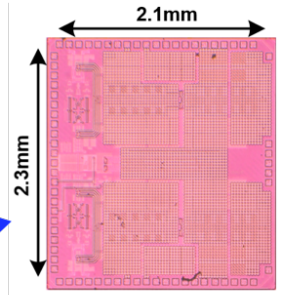


Gen-2 RF canceller box

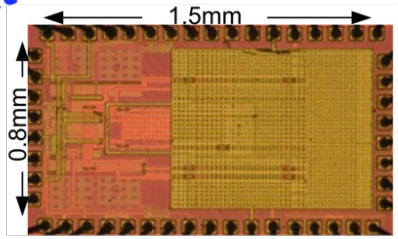


Gen-2 RF canceller PCB

FDE (wideband)

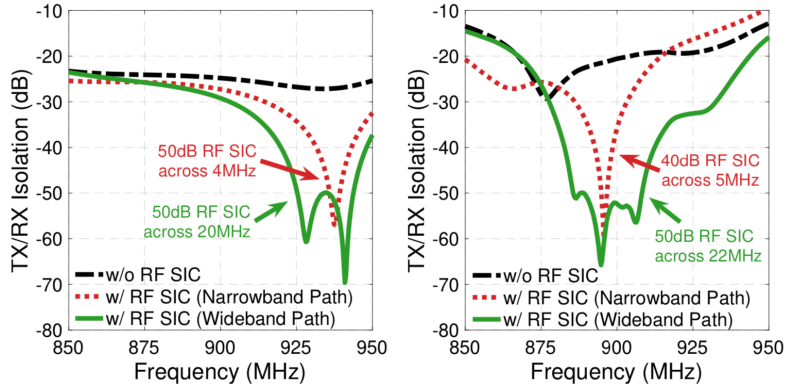


Emulates



Gen-1 (narrowband)

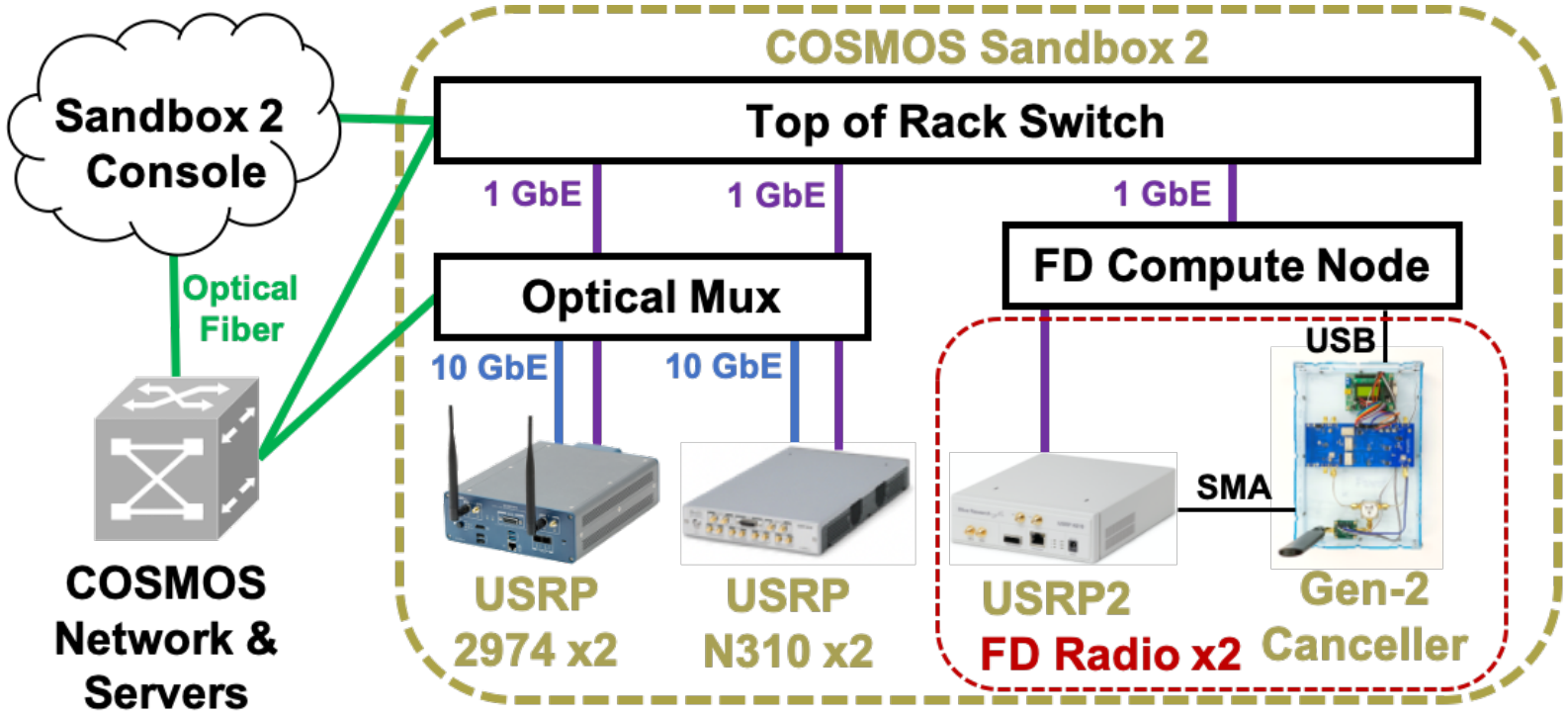
(a) (b)

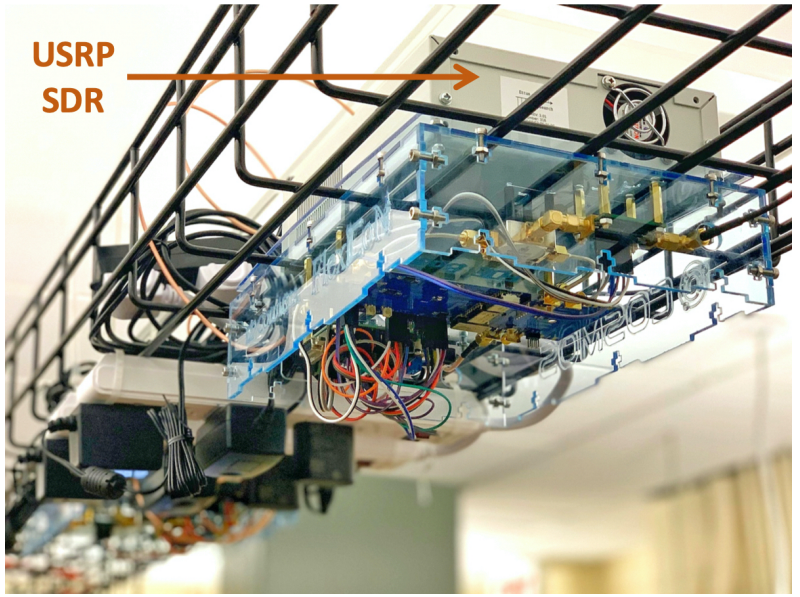


Performance of canceller PCB when the circulator is (a) terminated by 50Ω and (b) connected to an antenna

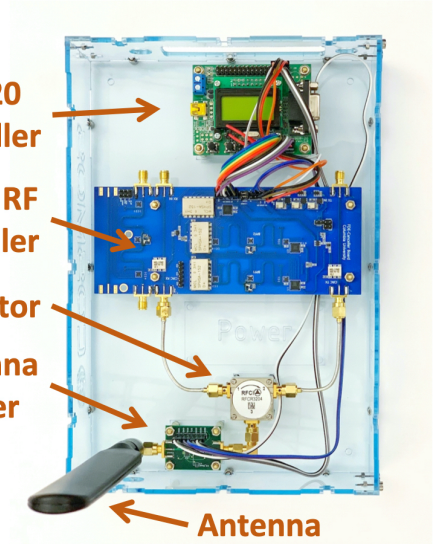
- T. Chen, M. Baraani Dastjerdi, J. Zhou, H. Krishnaswamy, and G. Zussman, "Wideband compact full-duplex wireless via frequency-domain equalization: Design and experimentation," in *Proc. ACM MobiCom'19,* 2019.

Integration with COSMOS





Gen-2 RF canceller box with USRP2 SDR integrated in COSMOS Sandbox 2



- The integrated Gen-2 FD radios are **remotely accessible** to experimenters through the COSMOS Network.

- M. Kohli, T. Chen, M. Baraani Dastjerdi, J. Welles, I. Seskar, H. Krishnaswamy, and G. Zussman, "Open-Access Full-Duplex Wireless in the ORBIT and COSMOS Testbeds," in *Proc. ACM MobiCom'20 Workshop on Wireless Network Testbeds, Experimental evaluation & CHaracterization (WiNTECH '20),* 2020 (invited paper)

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Logging into COSMOS and Accessing the FD Radios

- Login to COSMOS Sandbox 2 over SSH
- Once logged into COSMOS Sandbox 2, SSH into the FD Compute Node
- GNU Radio experiments are run from the FD Compute Node

A full tutorial for using the integrated Gen-2 FD radios in COSMOS (as well as Gen-1 in ORBIT) can be found at this link:

https://wiki.cosmos-lab.org/wiki/Tutorials/Wireless/FullDuplex

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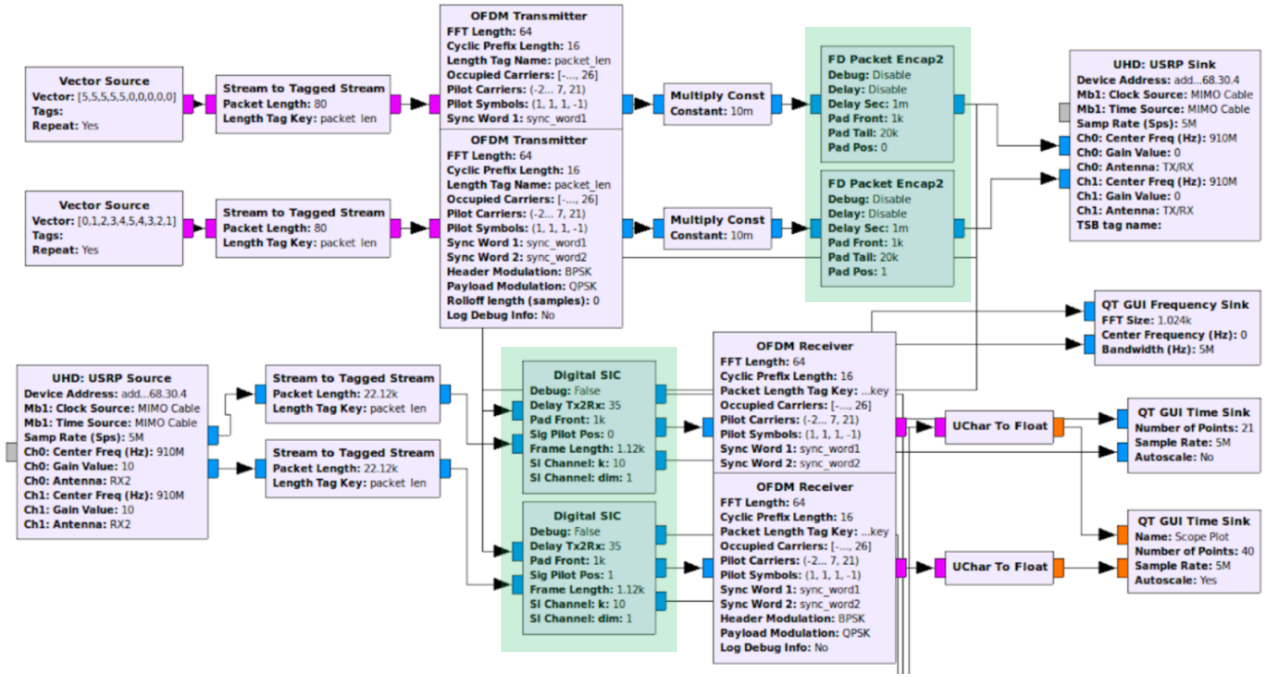
Experiments

- To demonstrate and evaluate the performance of the integrated FD radios, we developed a set of customized out-of-tree (OOT) blocks for GNU Radio.
- The OOT blocks are programmed in C++, allowing for **real-time performance**.
- The developed OOT blocks include:
  - A block for performing digital SIC on the received signal
  - A block for configuring the Gen-2 canceller PCB via the SUB-20 controller
  - Blocks for computing the signal-to-noise ratio (SNR) and packet reception ratio (PRR)



Example GNU Radio flowgraph with customized OOT blocks highlighted in **green**

Conclusion

- We integrated two wideband Gen-2 FD radios in the COSMOS testbed.
- We provide example experiments, such as those demonstrated here.
  - Suitable to be extended to further experimentation scenarios
- The full tutorial for accessing the Gen-2 FD radios and running these experiments can be found at the following webpage: https://wiki.cosmos-lab.org/wiki/Tutorials/Wireless/FullDuplex
- The open-source software can be accessed at https://github.com/Wimnet/flexicon_orbit

Thank you!

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