UC San Diego
JACOBS SCHOOL OF ENGINEERING
Electrical and Computer Engineering

WCSNG
Wireless Communications
Sensing and Networking

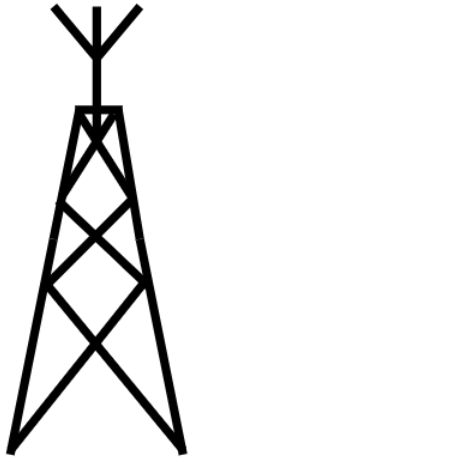
BSMA: Scalable LoRa networks with full duplex gateways

Raghav Subbaraman, Yeswanth Guntupalli, Shruti Jain, Rohit Kumar, Krishna Chintalapudi*, Dinesh Bharadia

UC San Diego, *Microsoft Research

Coordination in LoRa/IoT devices is tough

Soil Moisture Sensor
Low power, Lasts >5 Years



gateway

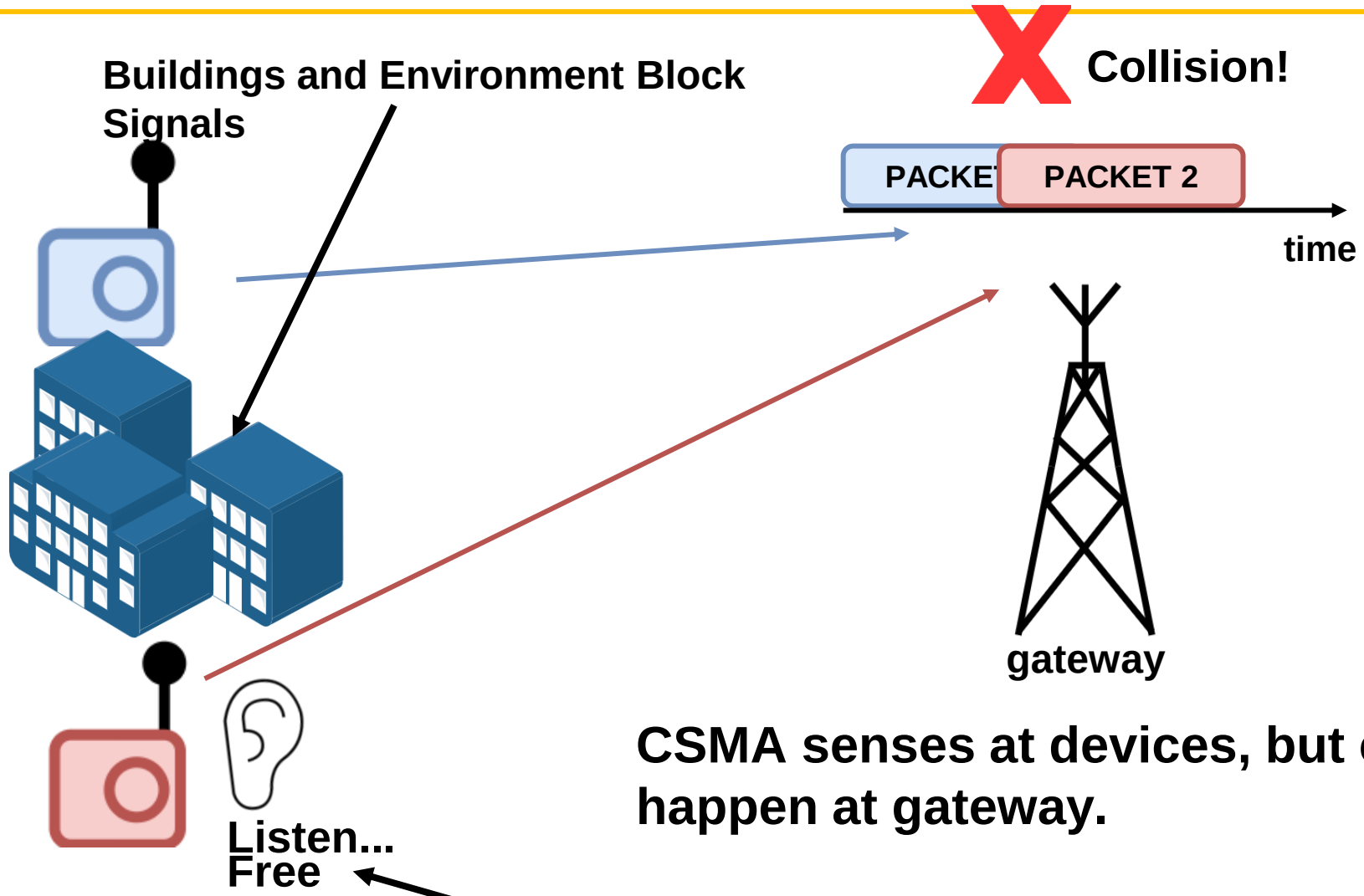
Coordination (multiple access) determines who talks and when

Source: Microsoft Research, BBC and KPBS

Proximity Sensors
Large number, 1000s

Water, Parking Smart Meters
Long range, 2-5 km

Obstructions cause *hidden terminals* ➔ collisions

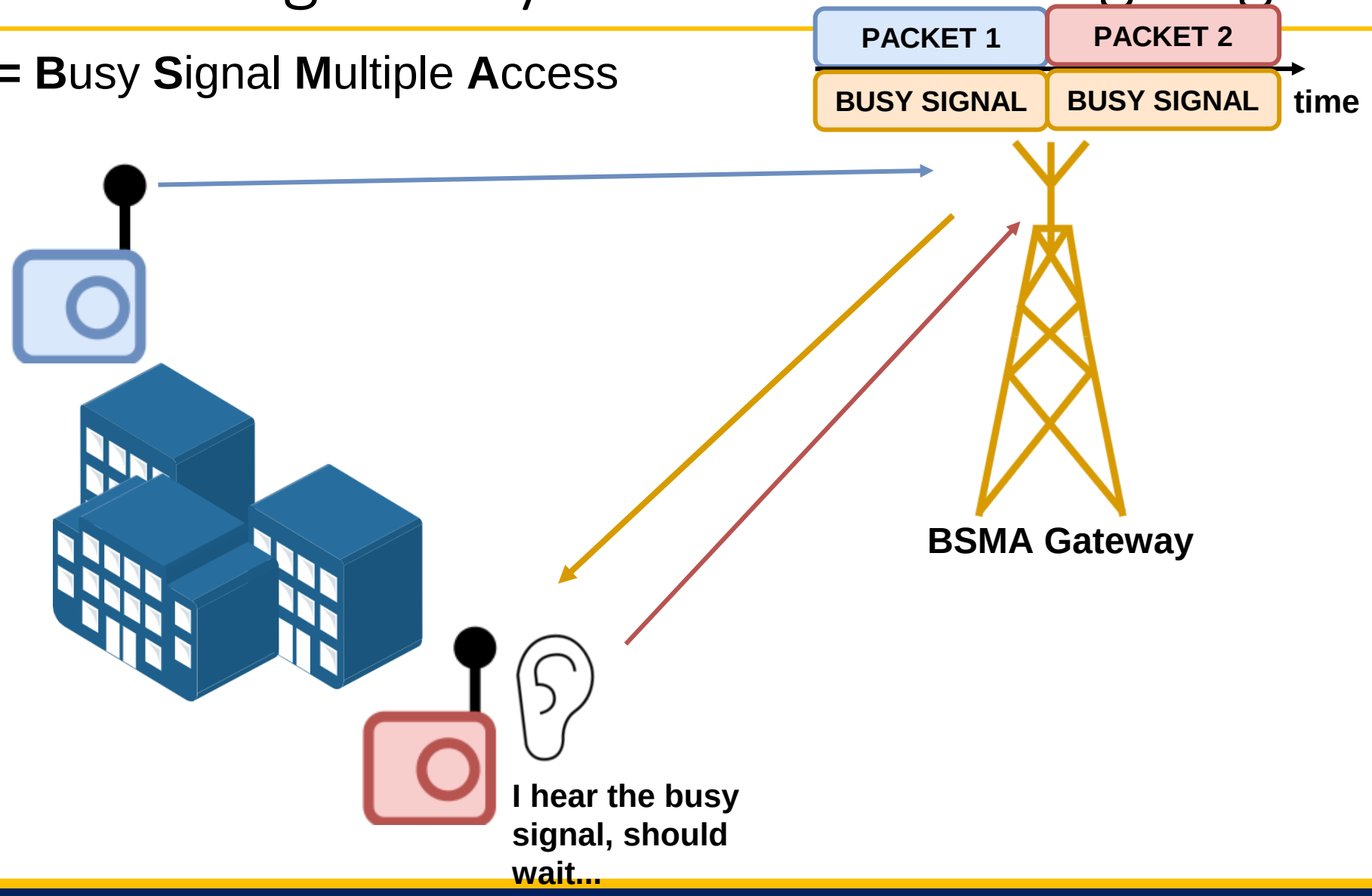


CSMA senses at devices, but collisions happen at gateway.

Wrongly believes that nobody else is talking!

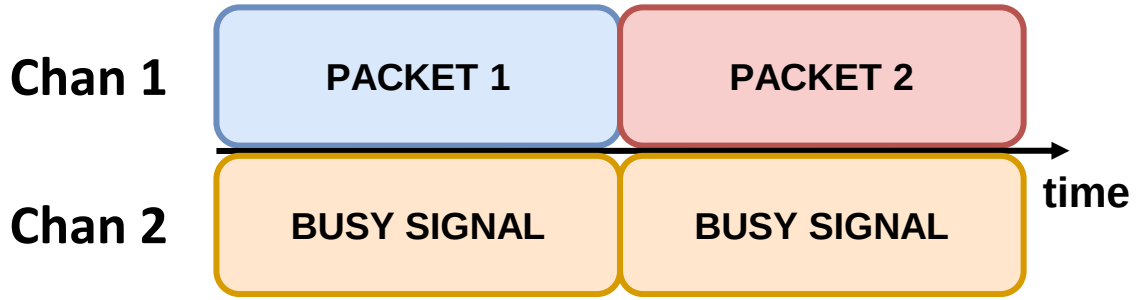
What if the gateway was *aware* of ongoing tx?

BSMA = Busy Signal Multiple Access



No-overhead busy signal

Conventional

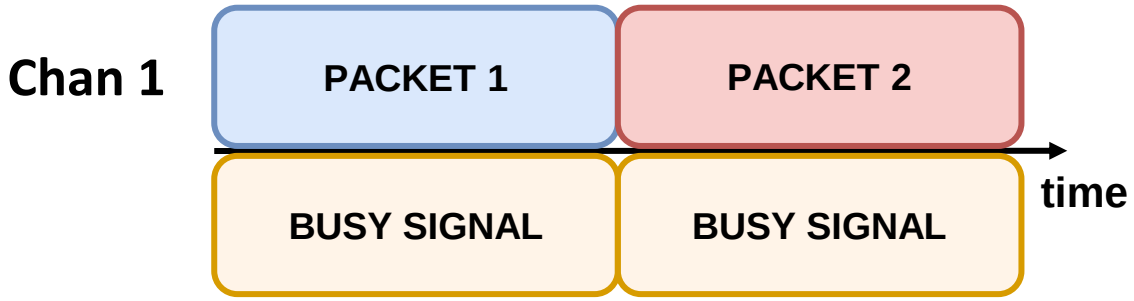


Tobagi and Kleinrock, *Packet Switching in Radio Channels: Part II-The Hidden Terminal Problem in Carrier Sense Multiple-Access and the Busy-Tone Solution*, IEEE TCOM, December 1975

Two freq channels (Comm, Busy)

2x resource use

In Band Full Duplex BSMA



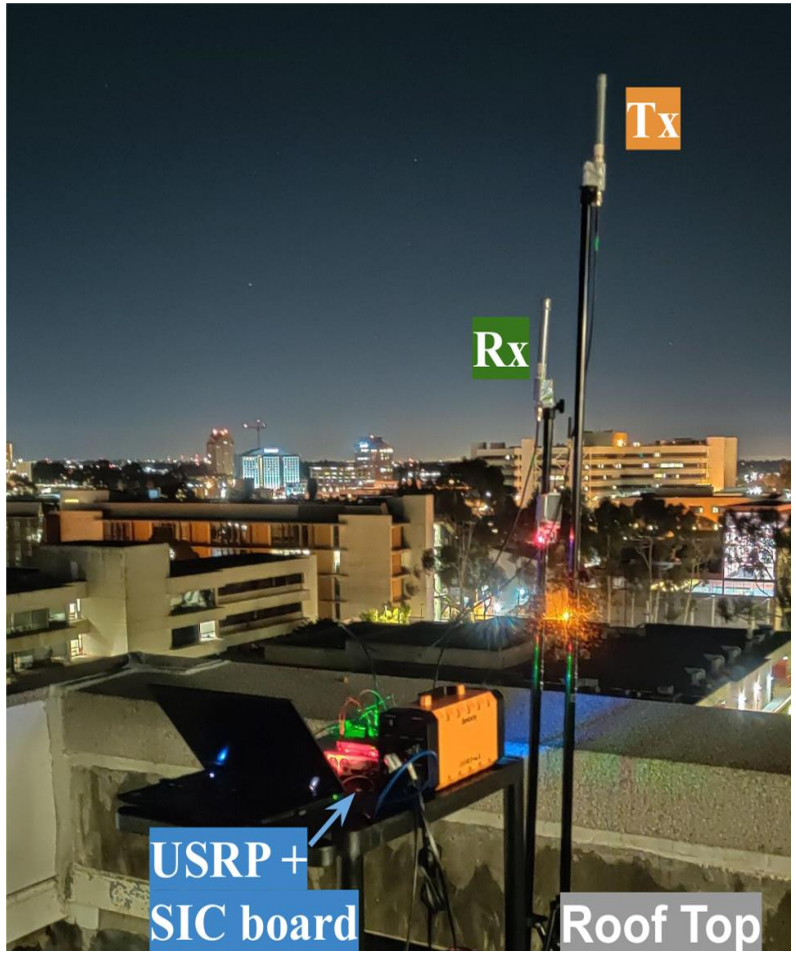
One freq band

No overhead

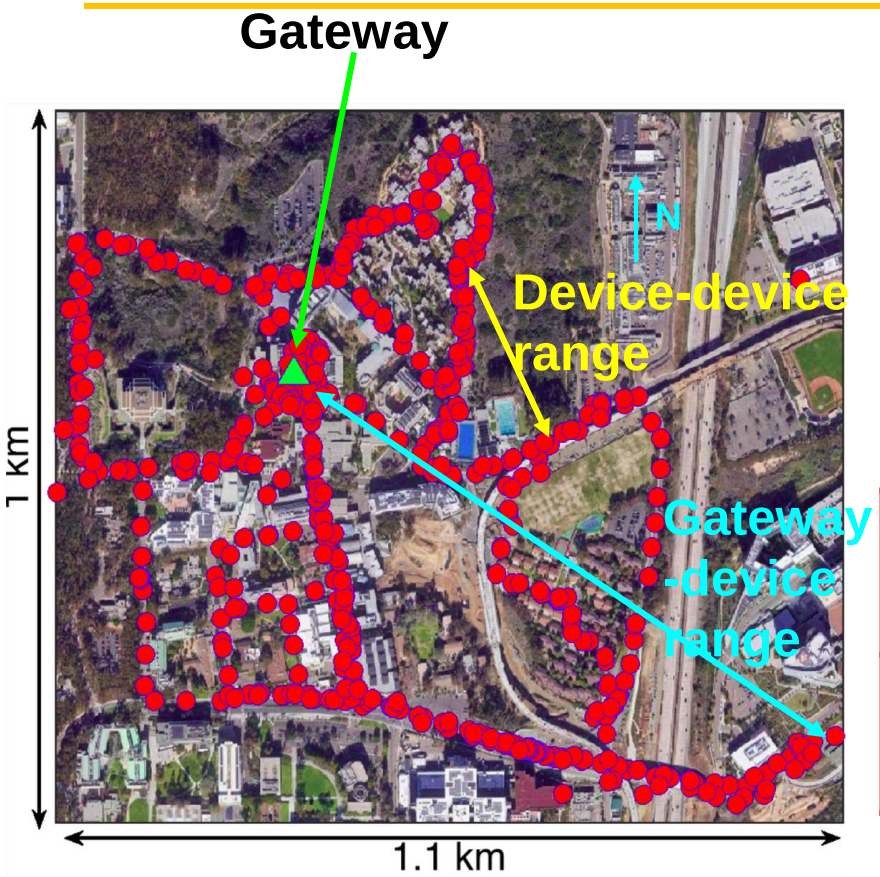
Less collisions, more throughput, energy savings, COTS end-devices

Our contributions

- Extent and effect of hidden terminals
- Building the full duplex BSMA gateway
  - Achieving **million times higher cancellation** than state-of-art
  - Real-time cancellation adaptation and BSMA protocol design
- Results from deployments
  - Urban deployment with COTS LoRa devices
  - 2x better throughput, energy consumption compared to CSMA



Hidden terminals: extent and effect



Sample many gateway-device and device-device links

Test if devices can hear each other

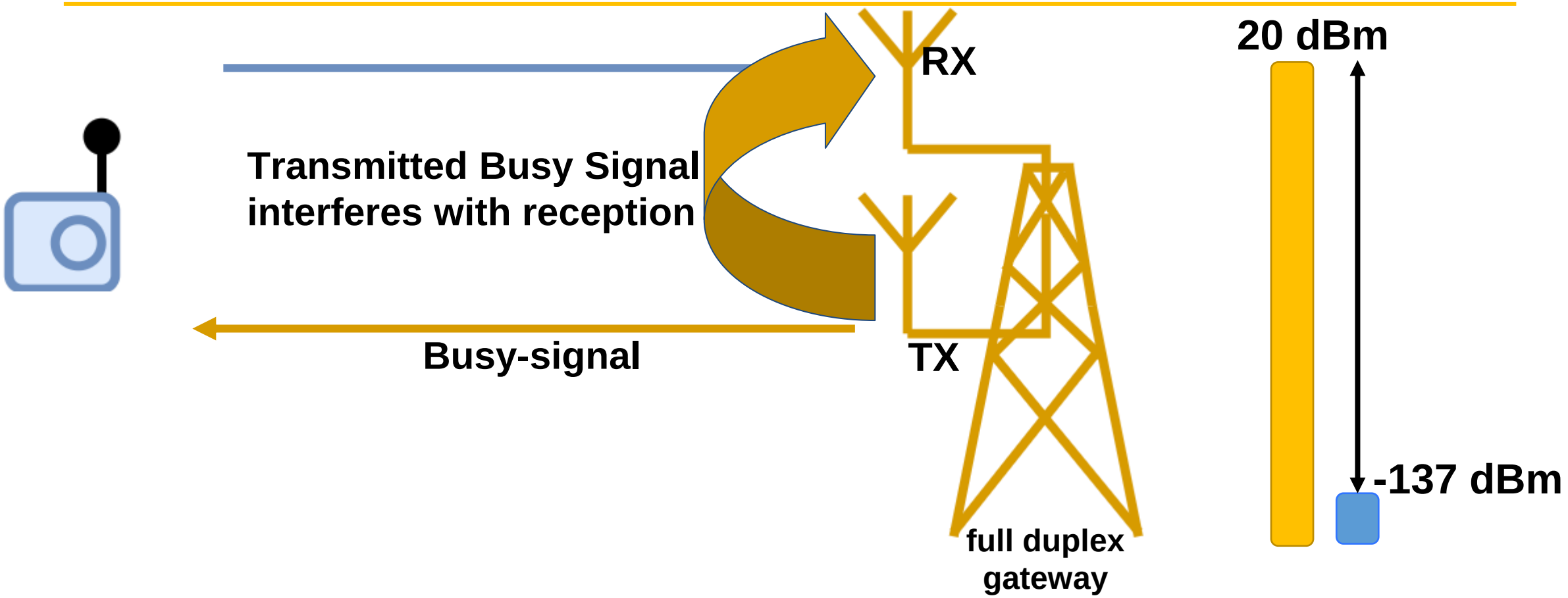
~500 locations, ~1800 links tested

Gateway-device range	device-device range	% of hidden links	ALOHA throughput	CSMA throughput
> 1.2 km	< 600 m	**68 - 77%**	**1x**	**1.1x**

I want to deploy a LoRa network, will CSMA help me?

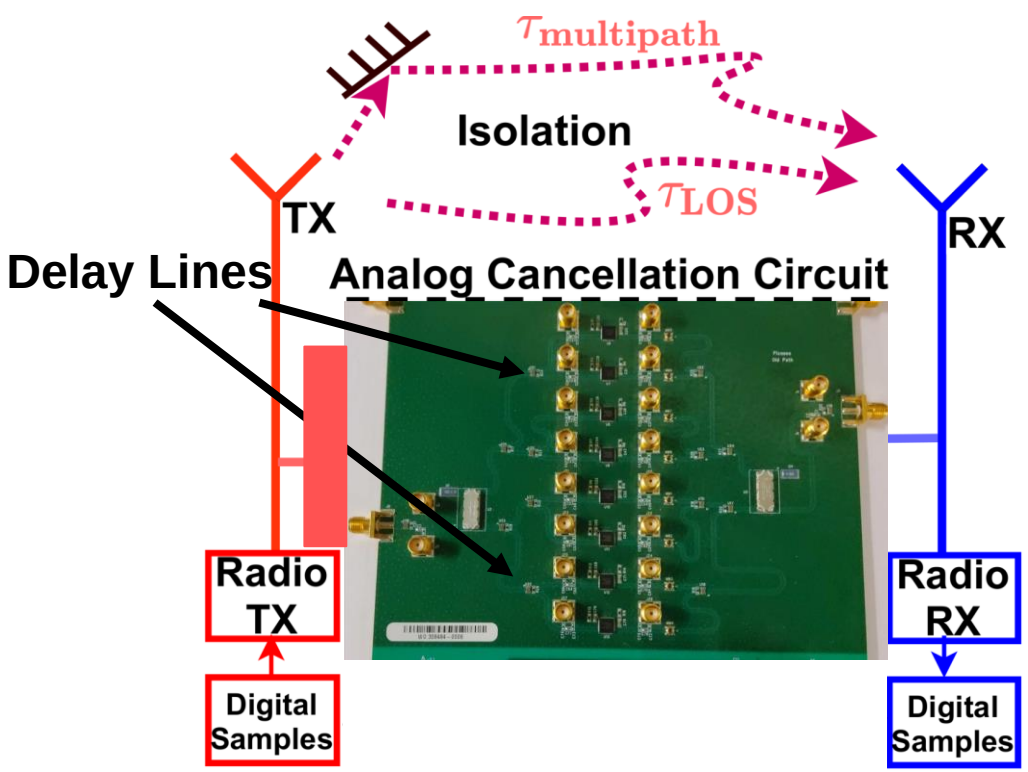
CSMA is no better than ALOHA in urban LoRa deployments

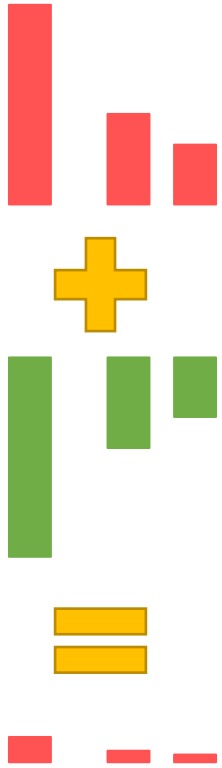
Tx and Rx simultaneously requires cancellation



Cancellation requirement: 157 dB
80 dB more than state of art

Cancellation circuit mimics the self interference





Self Interference (SI)
- Delayed reflections

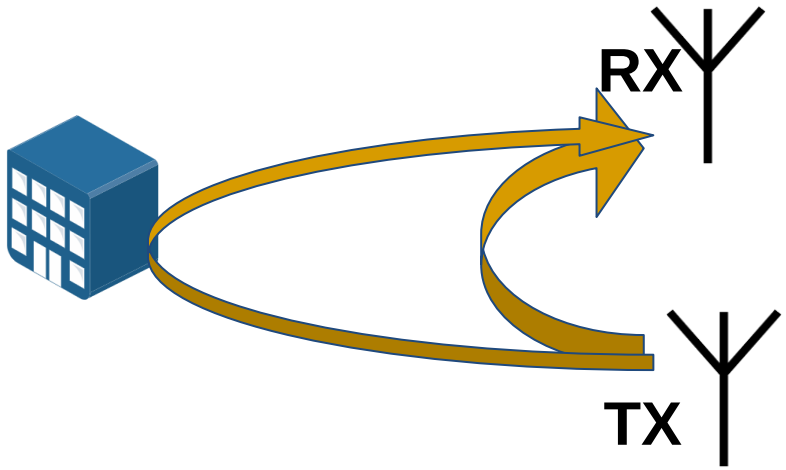
Mimic SI
- Delay lines

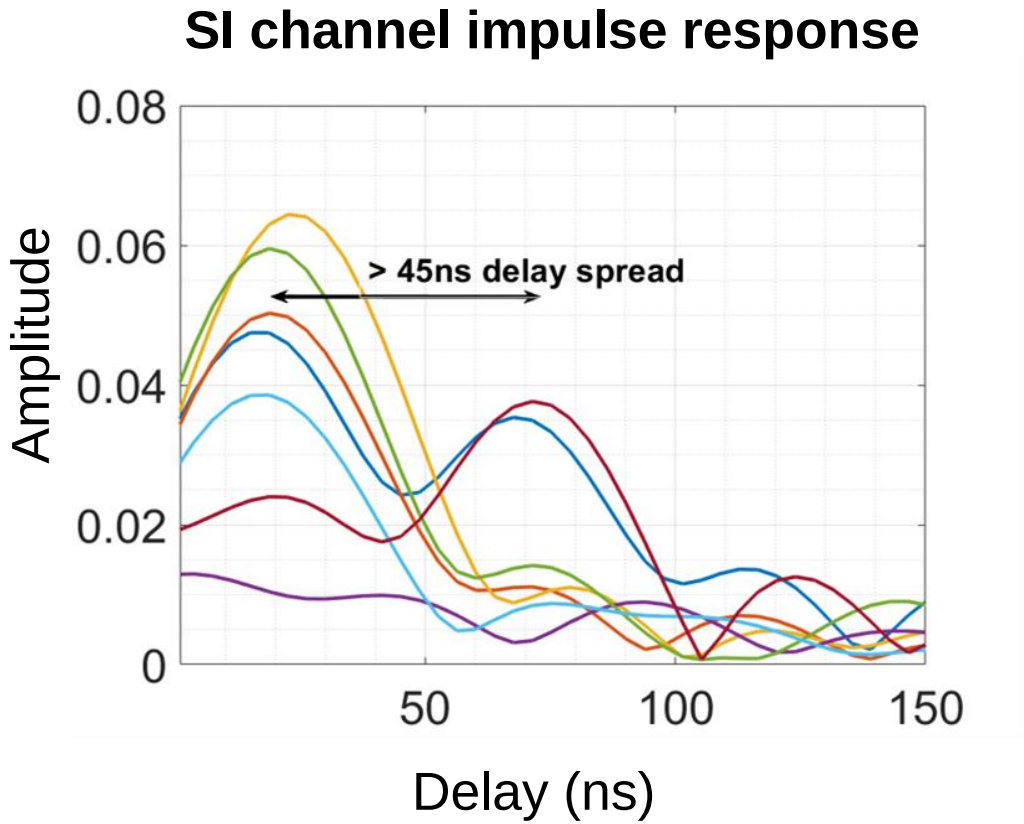
Residual Signal

LoRa, small bandwidth (< 125 kHz)
Easy to mimic SI?

D. Bharadia, E. McMilin, and S. Katti, “Full duplex radios,” in Proceedings of the ACM SIGCOMM 2013

At 900 MHz, we get echoes from far away objects



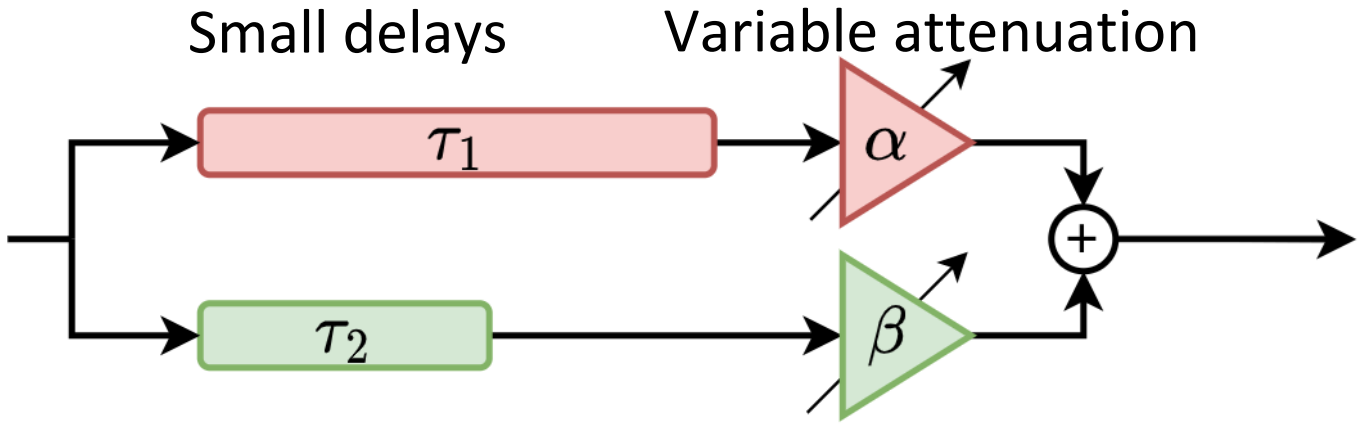


More delay spread -> use long delay lines

Long delay lines -> large loss

45 ns is 10x more than in prior work

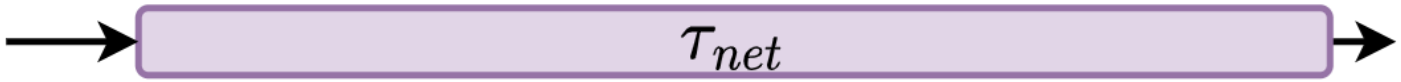
Delay-boosting: large delays from small



$$\tau_{net} \approx \frac{\alpha\tau_1 + \beta\tau_2}{\alpha + \beta}$$

=

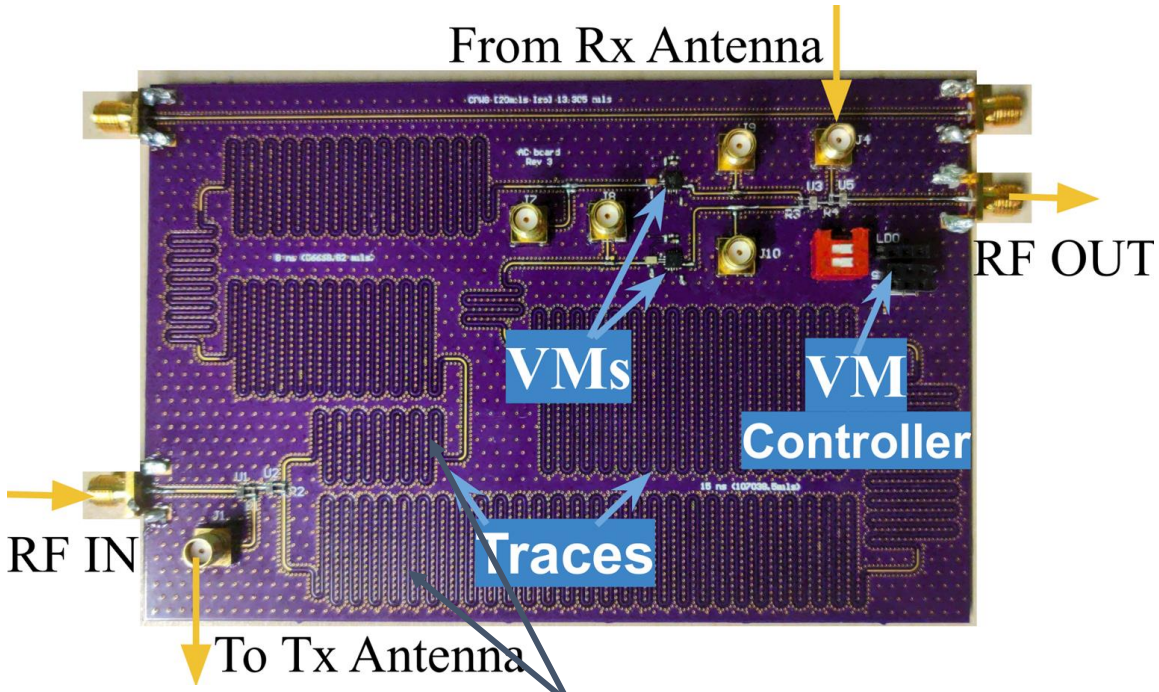
Large variable delay



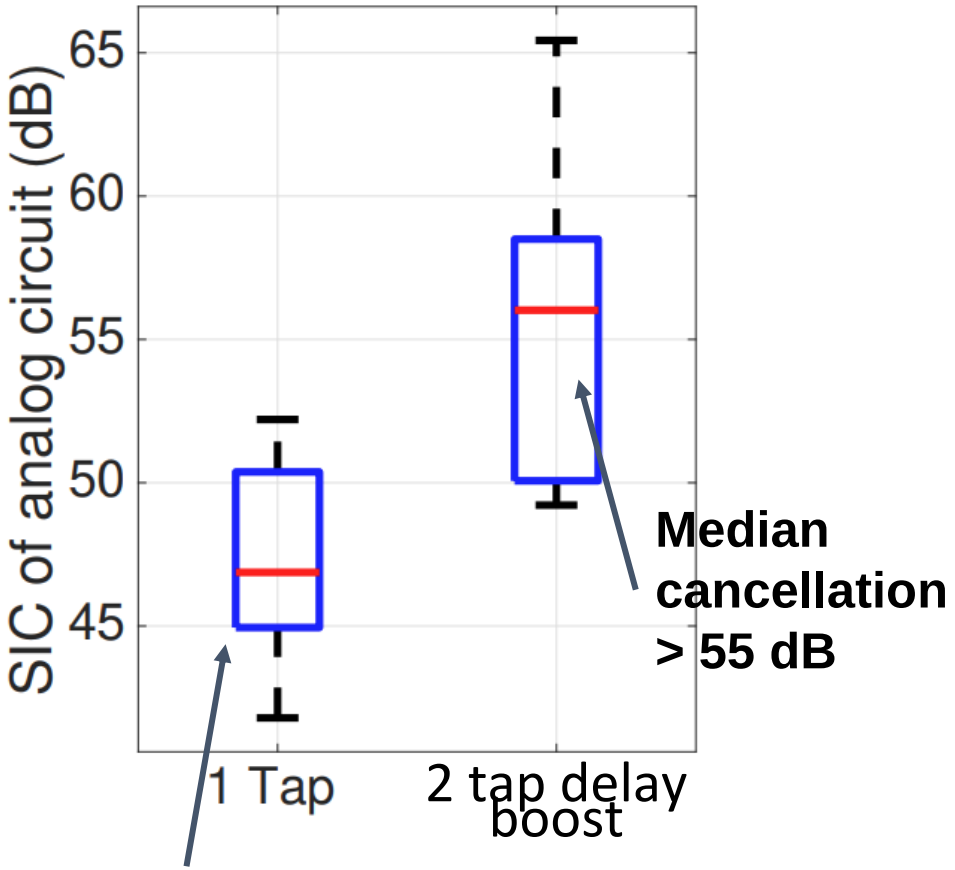
$$\frac{1\times 15 + -0.8\times 8}{1 - 0.8} = 43 \text{ ns}$$

Delays shorter than channel delays work for FD!

2-tap analog canceller PCB and benchmarks



8 ns and 15 ns delays used for boosting
15x10 cm

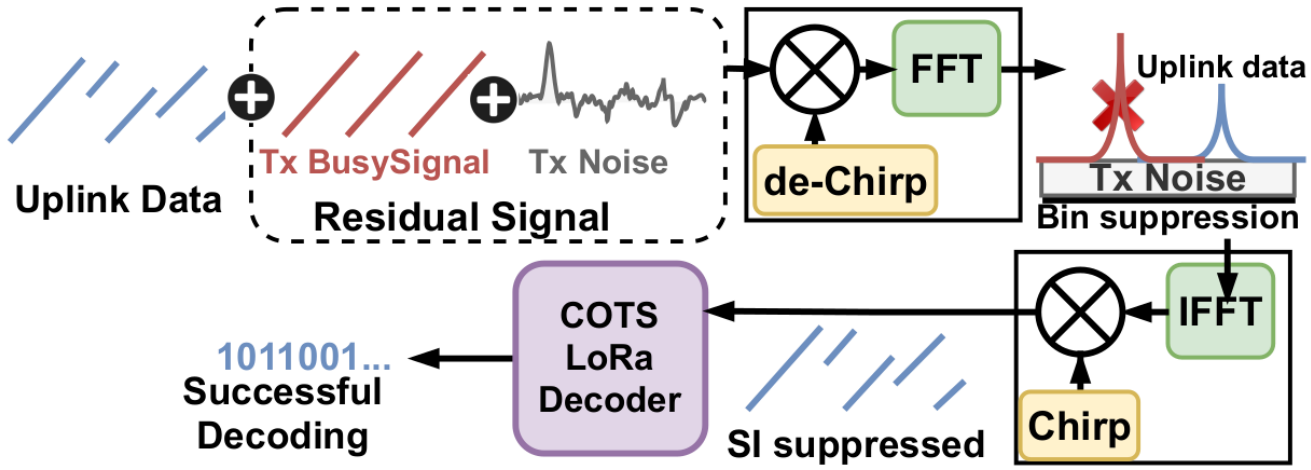


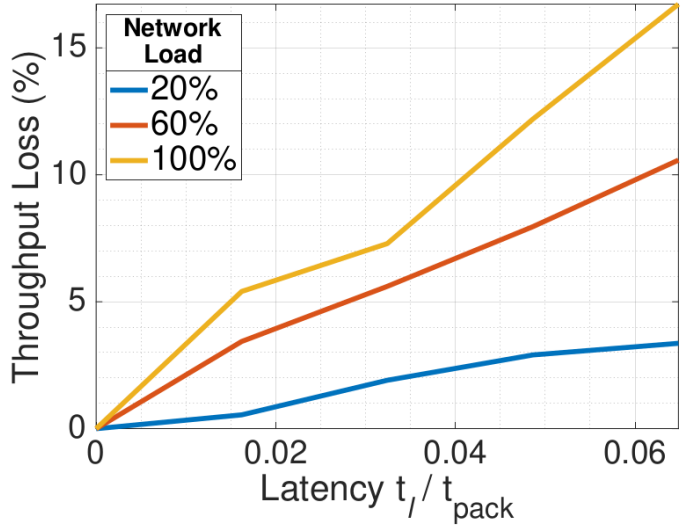
Median cancellation > 55 dB

1 Tap insufficient even for 125 kHz due to large delay spread

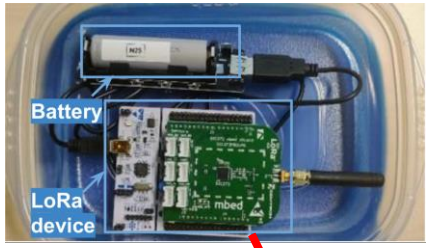
Other techniques in full paper

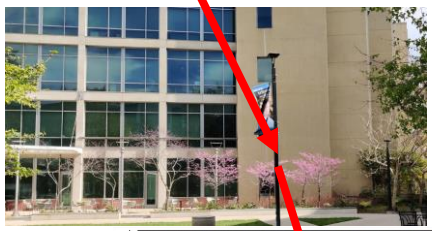
- Delay-boosting – 55 dB
- Antenna Isolation – 50 dB
- Digital + sub-noise floor cancellation
- Busy signal latency control
  - Preamble detection on FPGA
  - Real-time response

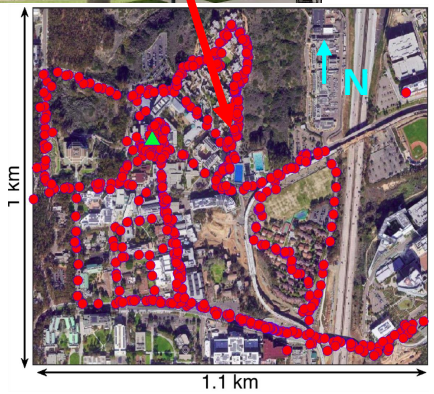


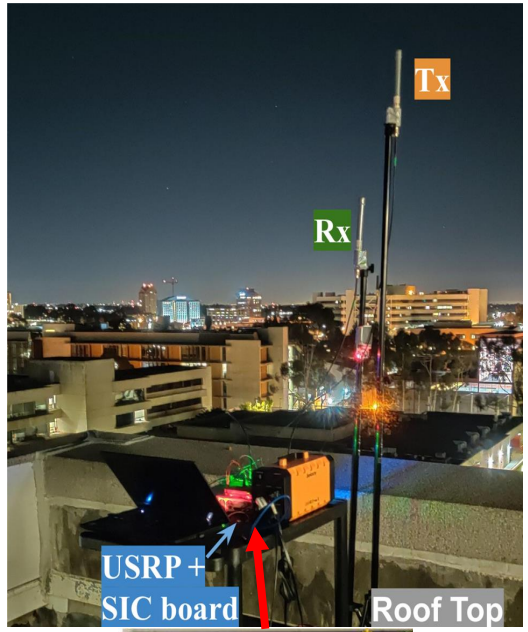


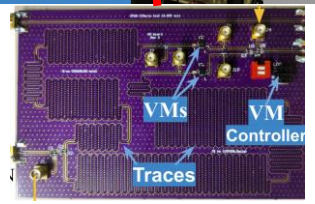
BSMA is evaluated in hardware and simulations



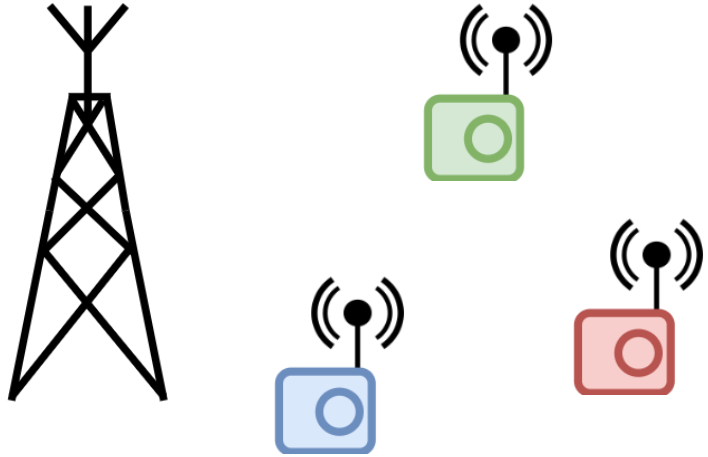








LoRa testbed using COTS gateway(+SDR) and 10+ IoT devices



Event driven simulator in MATLAB

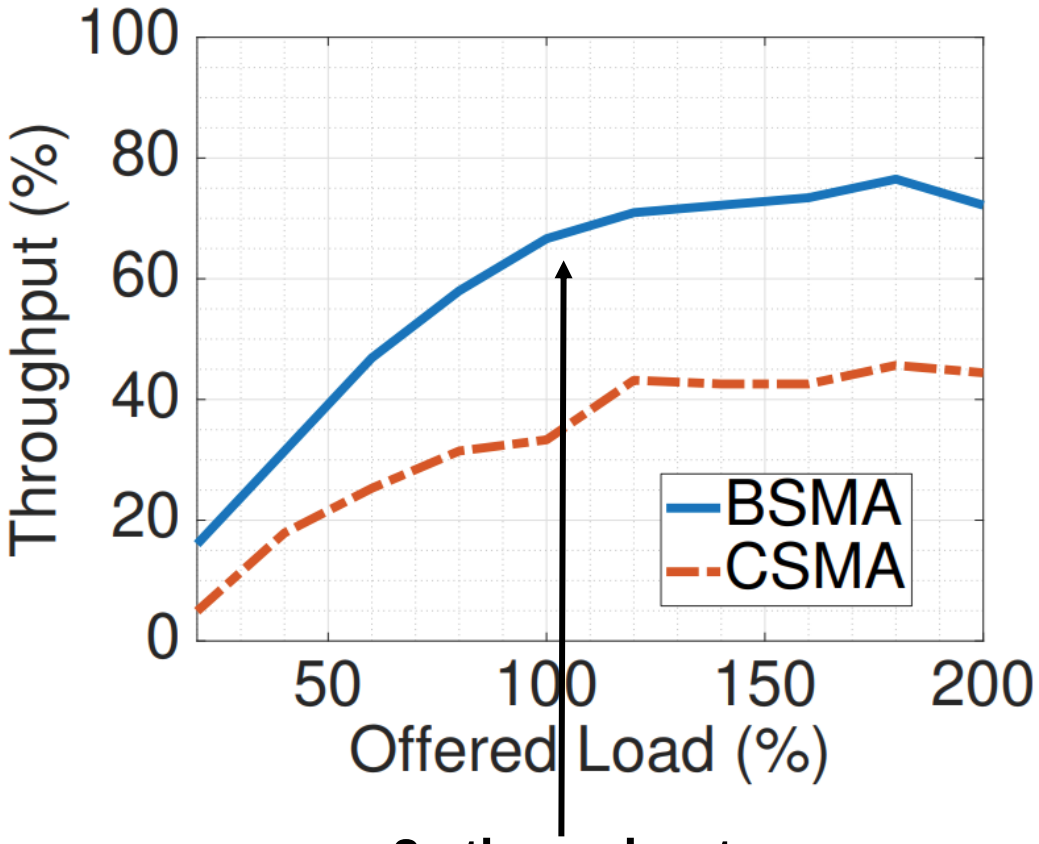
Models physical layer effects

Evaluations with 1000+ devices

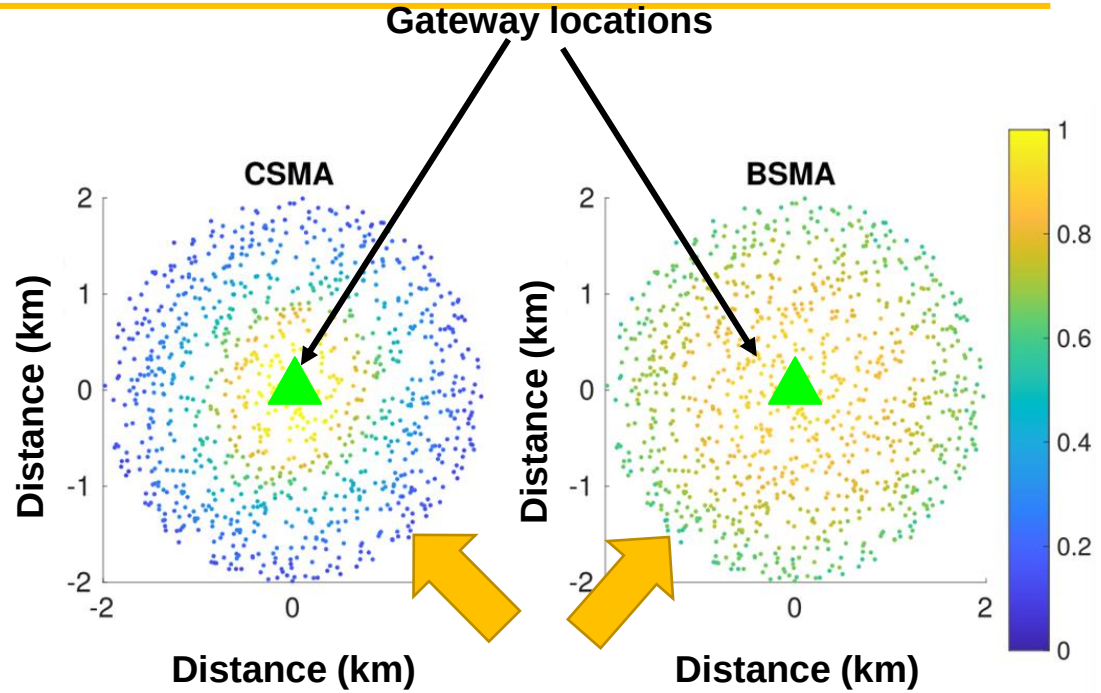
Open source:

github.com/ucsdwcsng/bsma_lora

BSMA improves throughput, PRR ➔ scalability



2x throughput improvement in bursty-loads

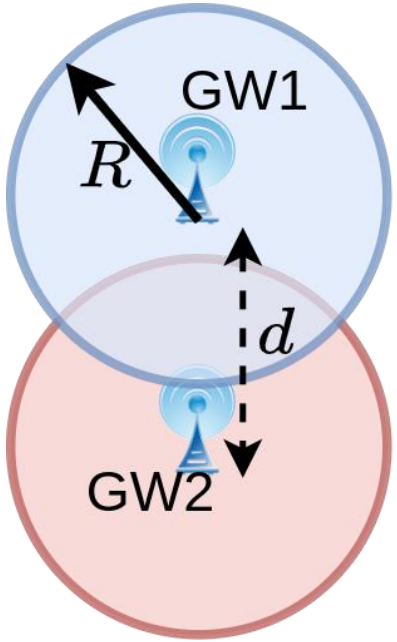


Dots are devices

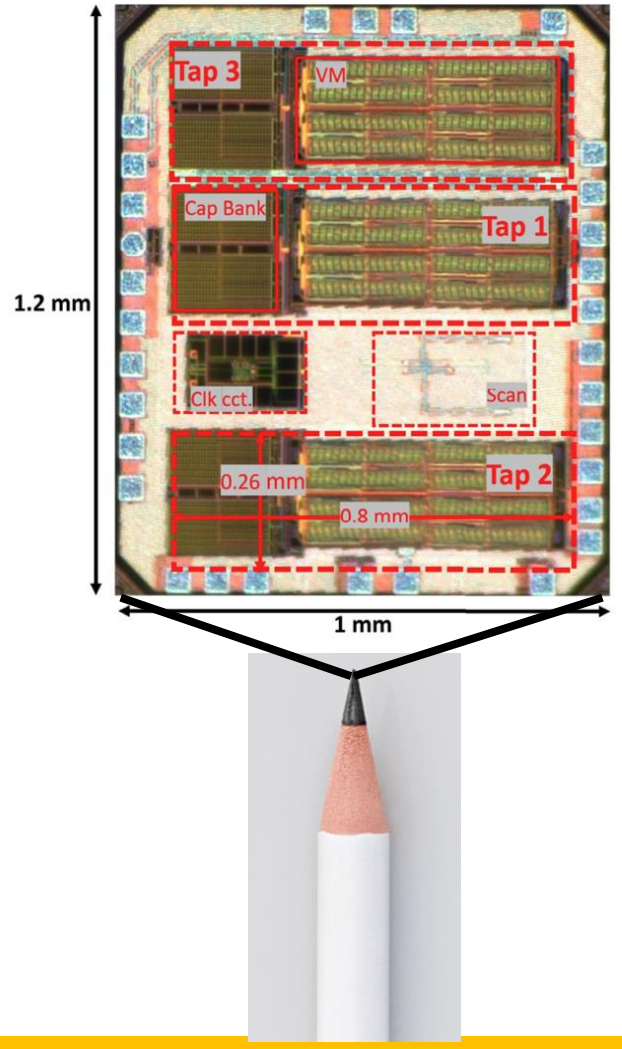
Color signifies the packet reception ratio of the device

BSMA improves PRR and fairness

Full duplex: enabler for spectrum aware operation



Multi-gateway



- Exposed terminals and multi-gateway deployment
- RFIC Multi-channel extension

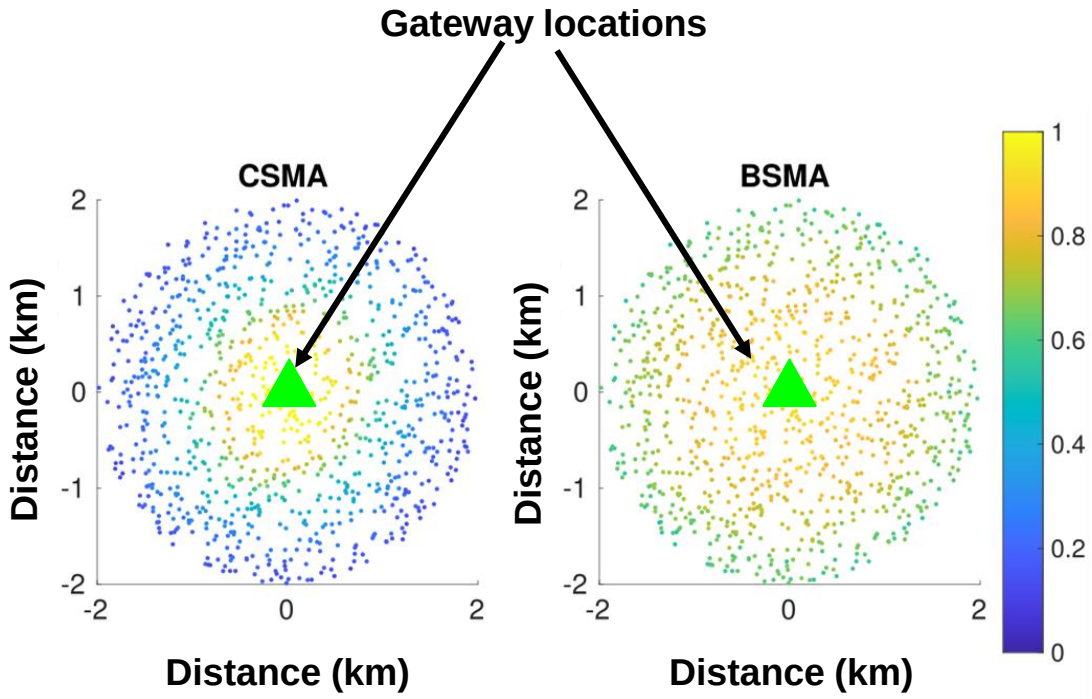
Abolmagd, H., Subbaraman, R., Esmaeeli, O., Guntupalli, Y., Sharkia, A., Bharadia, D. and Shekhar, S., 2022. A Hierarchical Self-Interference Canceller for Full-Duplex LPWAN Applications Achieving 52–70-dB RF Cancellation. IEEE Journal of Solid-State Circuits.

BSMA solves hidden terminals ➔ Scalable LoRa

Full duplex gateways can improve coordination using BSMA

Full Duplex is possible at 900 MHz using delay-boost

BSMA provides measurable gains over CSMA, ALOHA



Open source hardware and simulator:
github.com/ucsdwcsng/bsma_lora

Questions?