NetScatter:
Enabling Large-Scale Backscatter Networks

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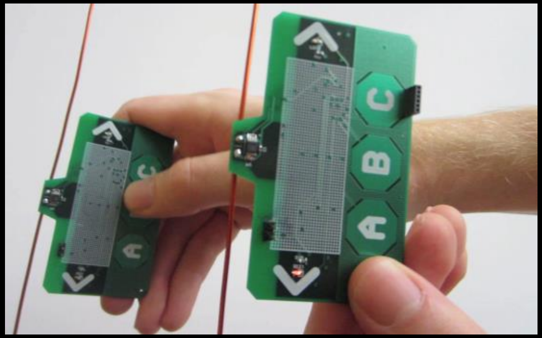
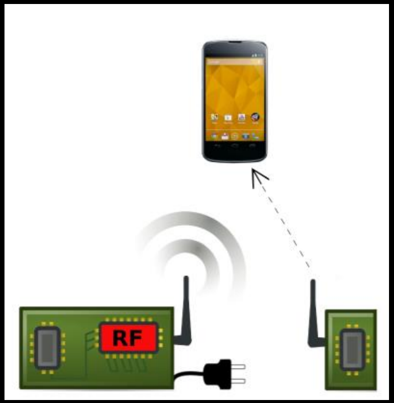
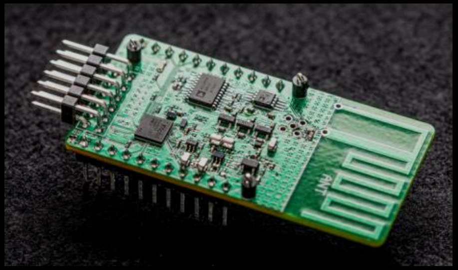
Backscatter Communication



Ambient Backscatter



Passive Wi-Fi



LoRa Backscatter

- 10 years operation with a button cell battery
- Low-cost (10 – 20 cents)
- Long-range coverage (up to km)

Grand Challenge: Long-Range Backscatter Network

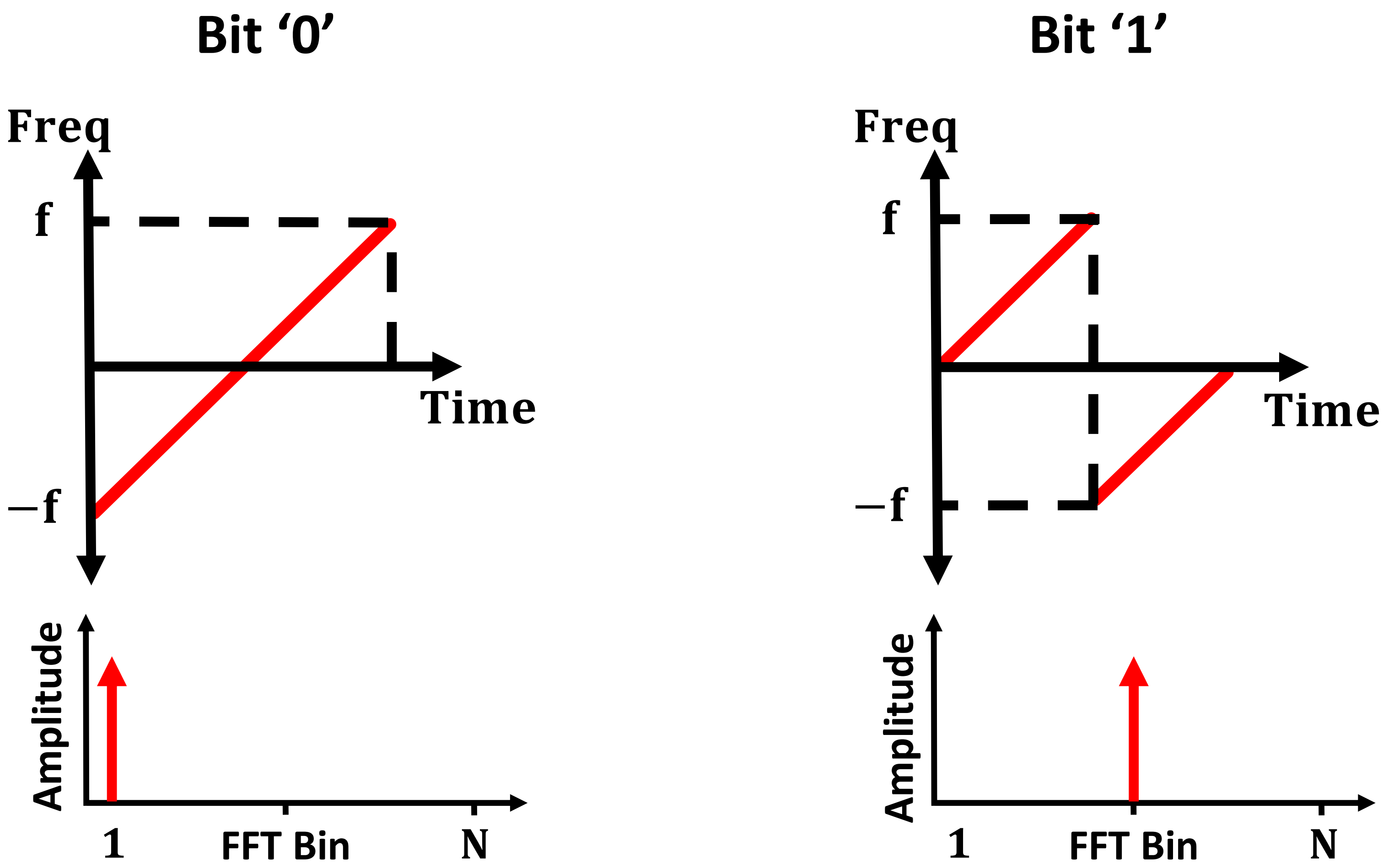
NetScatter

- First backscatter protocol supporting hundreds of concurrent transmissions
- Distributed coding mechanism which works below noise floor and can be decoded using a single FFT
- Network deployment of 256 devices using only 500 kHz
  - Improvements in PHY-layer data rate (7-26x), link-layer throughput (14-62x) and network latency (15-67x)

Outline

- Distributed Chirp Spread Spectrum
- Timing Synchronization
- Near-Far Problem
- Deployment of 256 devices

Chirp Spread Spectrum



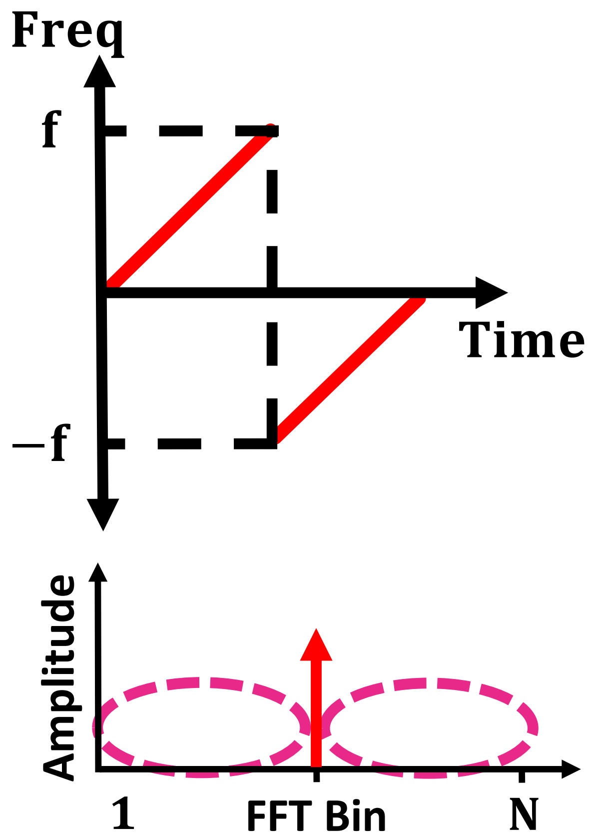
Supports high sensitivity and long-range

Drawbacks of Chirp Spread Spectrum

- Data rate vs range trade-off
- TDMA network (each device 1 kbps)
  - 100 devices in network → **10 bps**
  - 1000 devices in network → **1 bps**

Our Key Observation

Bit ‘1’

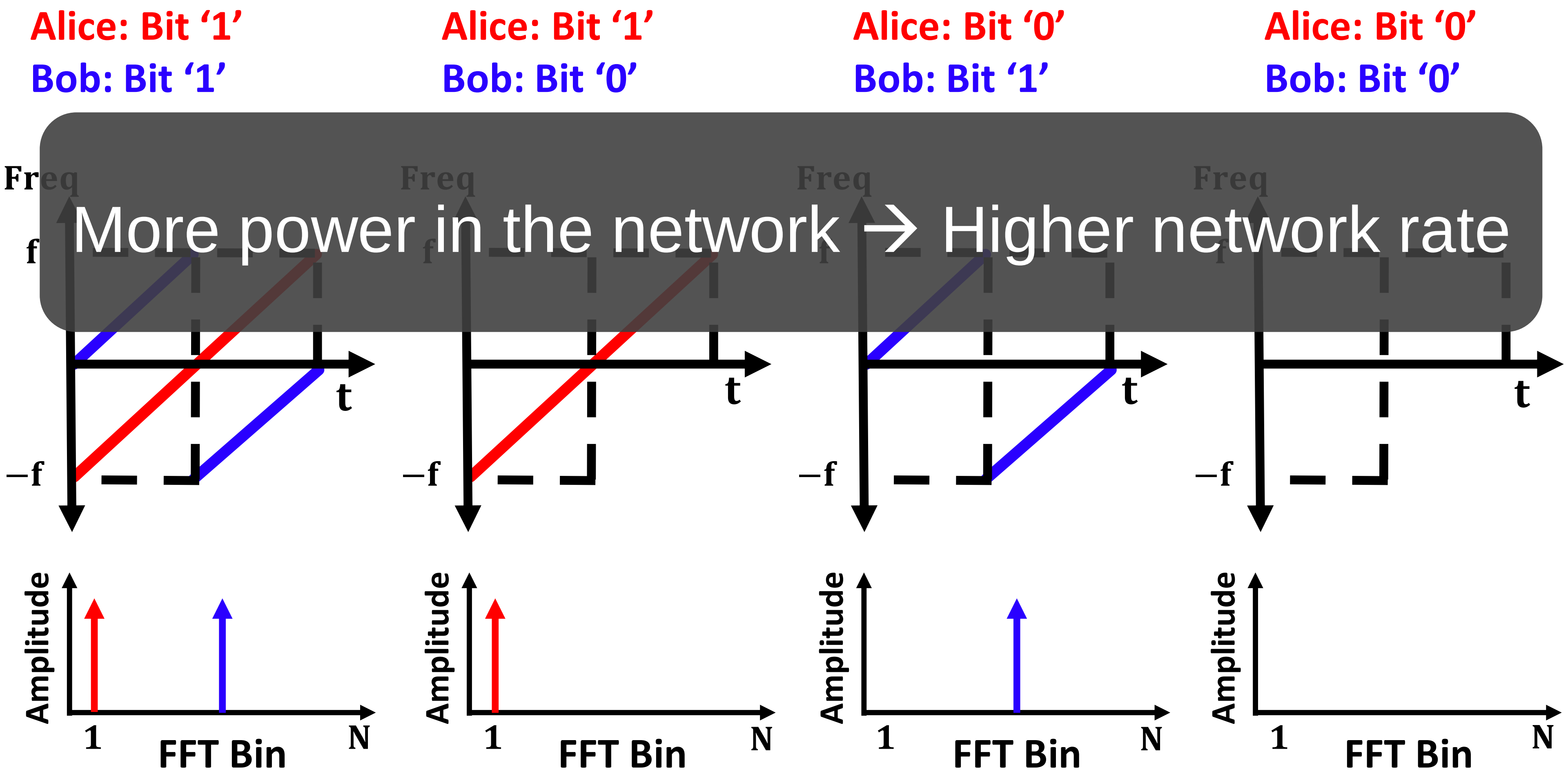


Empty FFT Bins

Our Idea: Distributed CSS

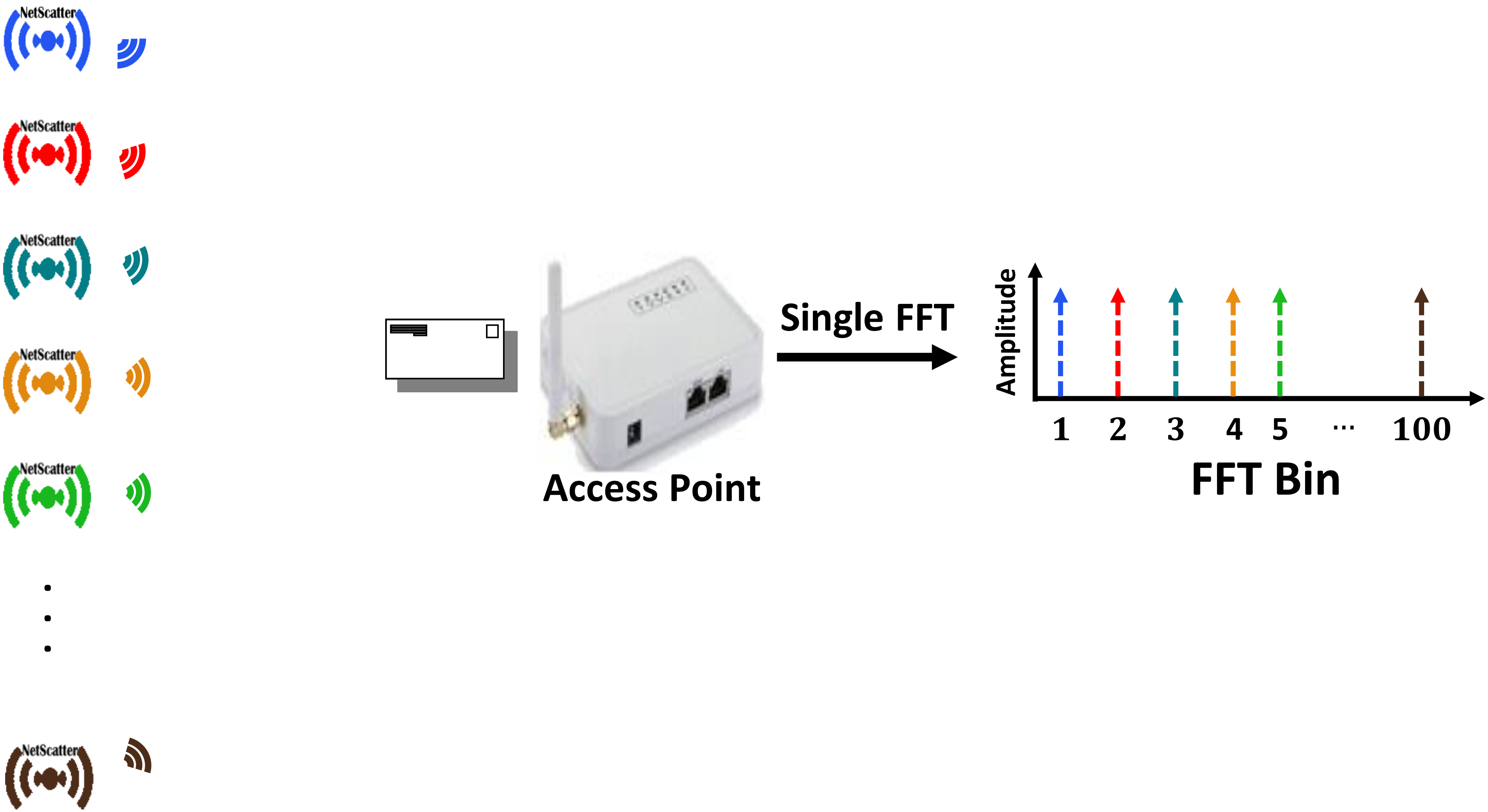
We assign each cyclic shift to a backscatter device

Each device uses ON-OFF keying on cyclic-shift to communicate



More power in the network → Higher network rate

Network of Hundred Backscatter Devices



How Many Concurrent Transmissions Can We Support?

Typical LoRa configuration

- Uses 500 kHz BW
- 512 cyclic-shifts

Theoretically, we can support 512 concurrent transmissions using only 500 kHz BW

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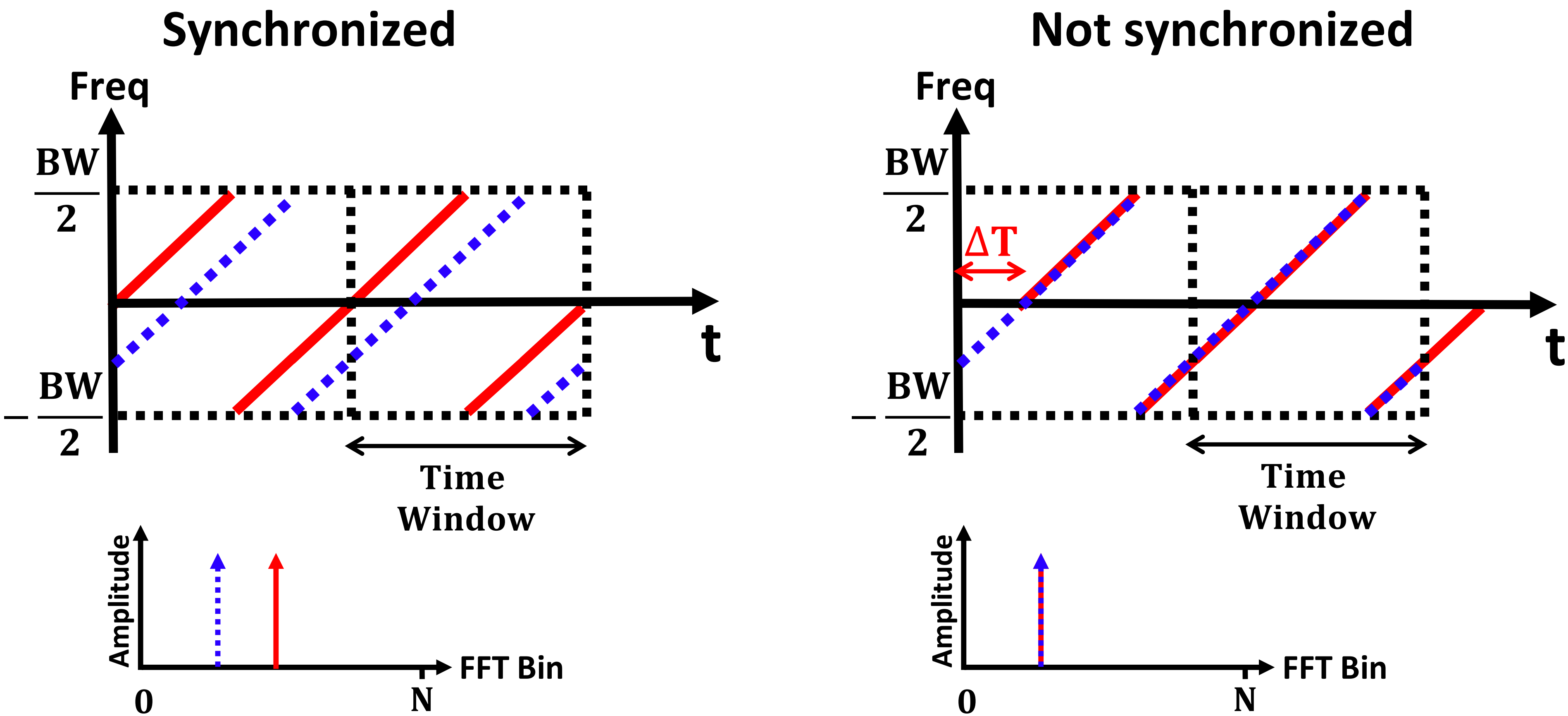
Practical Issues: Timing Synchronization

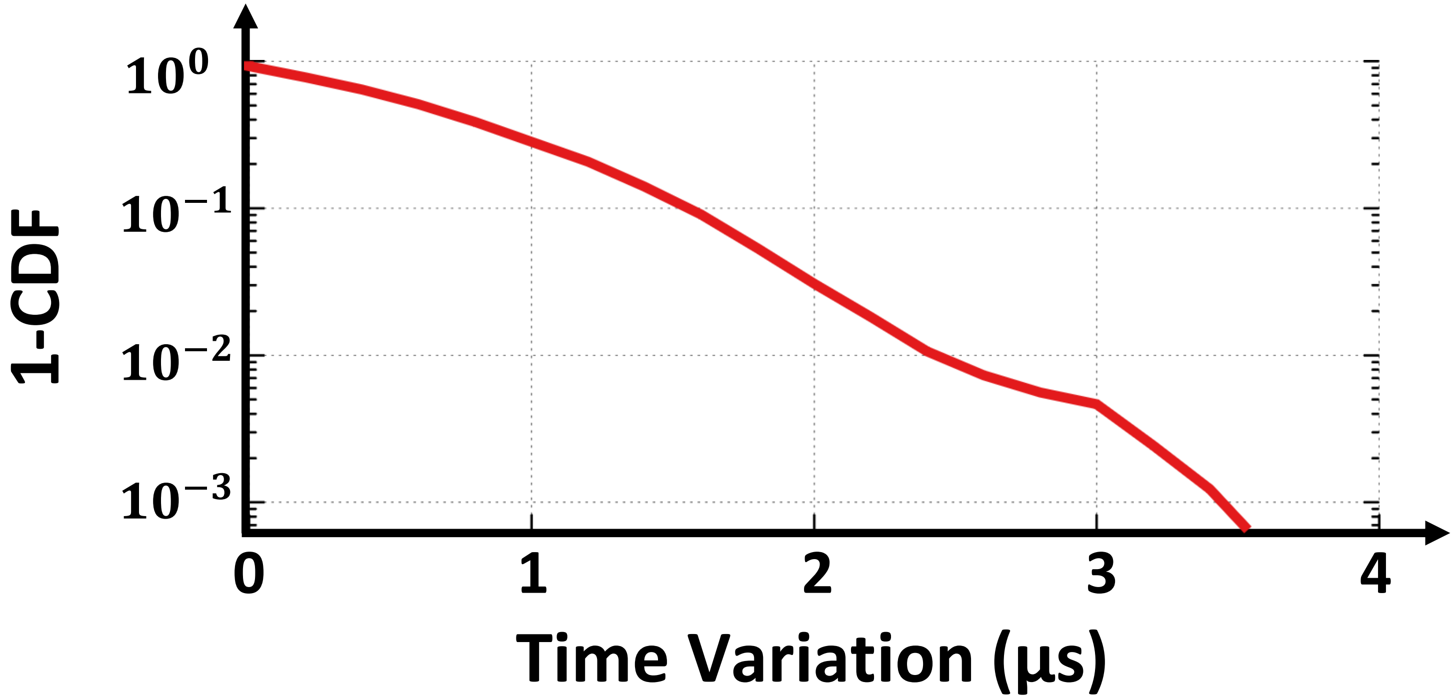
Alice and **Bob**



Causes interference between Alice and Bob

Timing Variation Across Devices

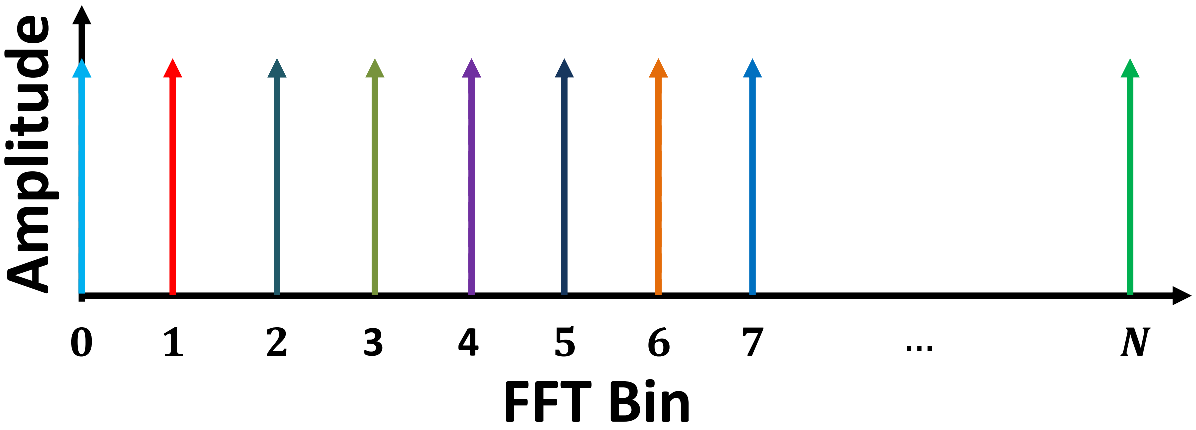
Hardware delay variations cause timing mismatch



2 μs delay translates to 1 FFT bin with 500kHz BW

Timing Synchronization Solution

We use every other cyclic-shift



Reduces concurrent transmissions from 512 to 256

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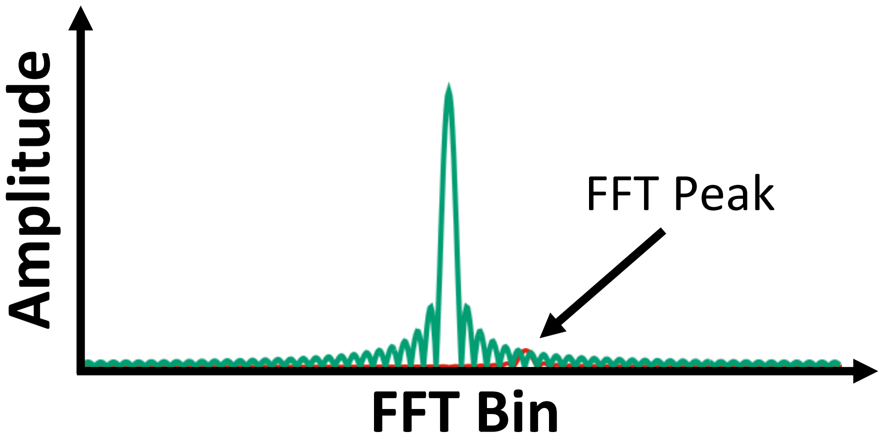
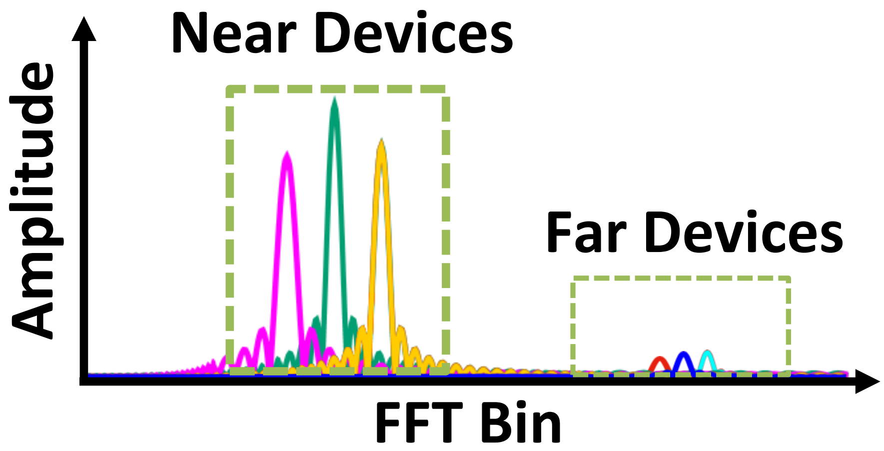
Practical Issues: Near-Far Problem

Access Point



Solution: Power-Aware Cyclic Shift Assignment



Similar power devices are clustered together

How to deal with changes in wireless channel?

Solution: Power Adaptation Algorithm

Each device uses AP’s query to self-adjusts its power

- Achieve 0dB, -4dB and -10dB power gains
- Starting power (-4 dB), increase power (0 dB), reduce power (-10 dB)

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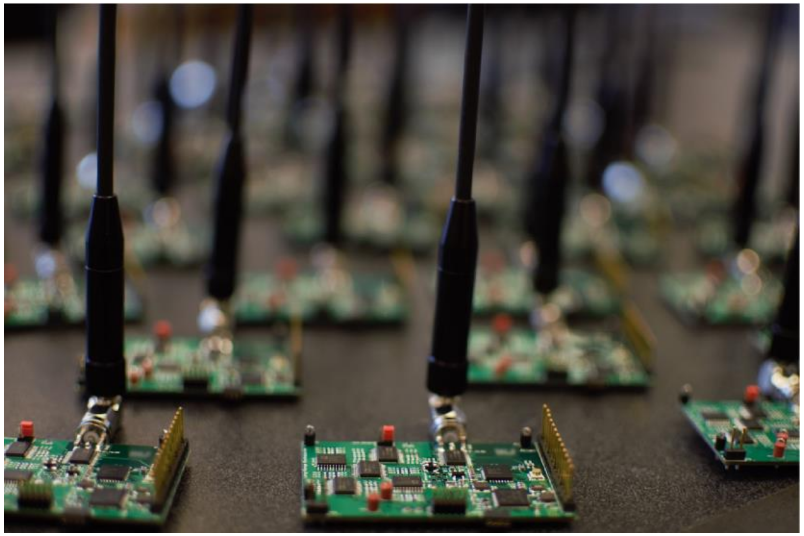
Implementation



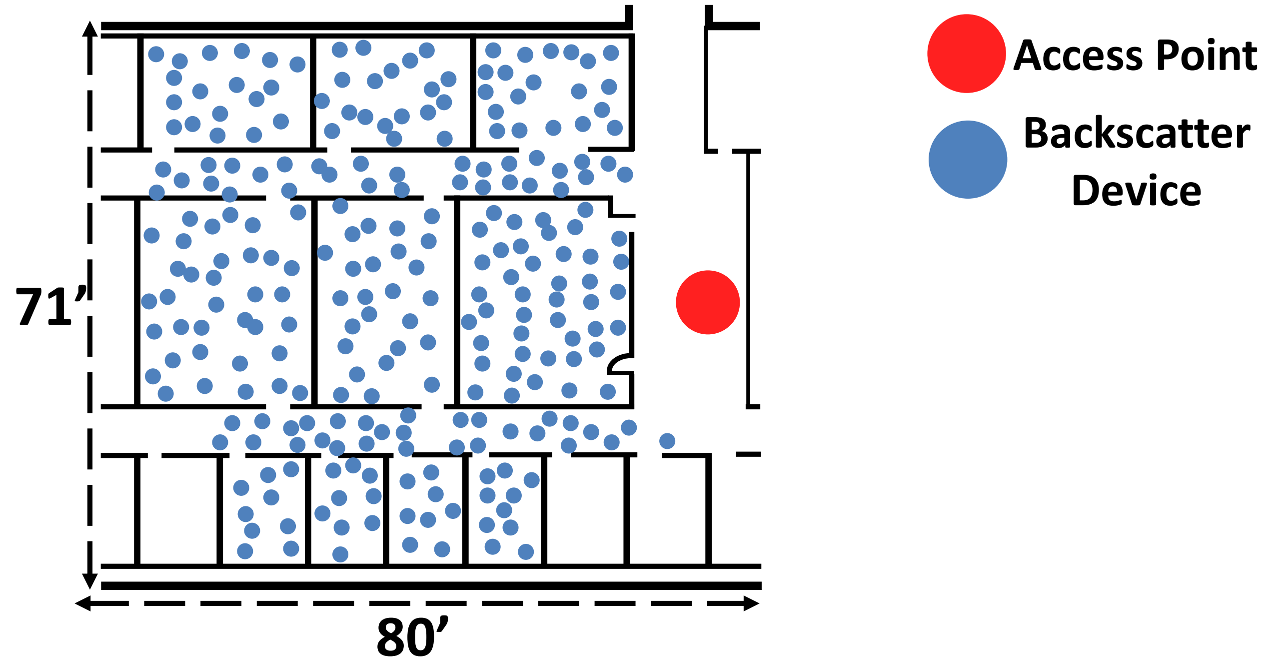
Backscatter device

- Baseband: IGLOO nano FPGA
- Downlink: envelope detector and MSP430
- RF switch: ADG904
- Three levels power adjustment

Access point

- USRP X-300 with UBX-40 daughterboard
- Co-located RX/TX antennas separated by 3 feet

Evaluation: Large-Scale Deployment



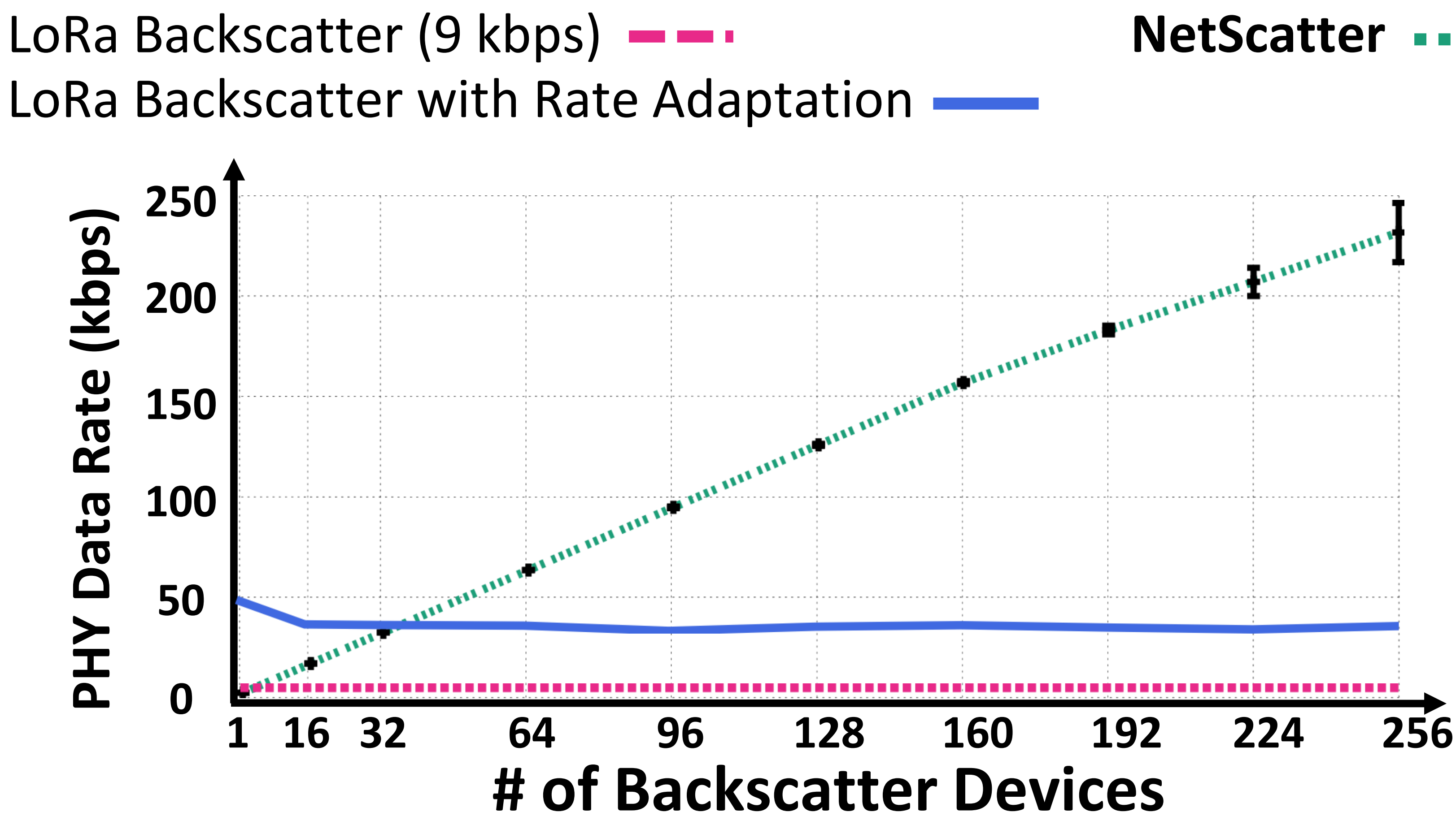
We deployed a network of 256 devices in an office building

Evaluation

We compared NetScatter with:

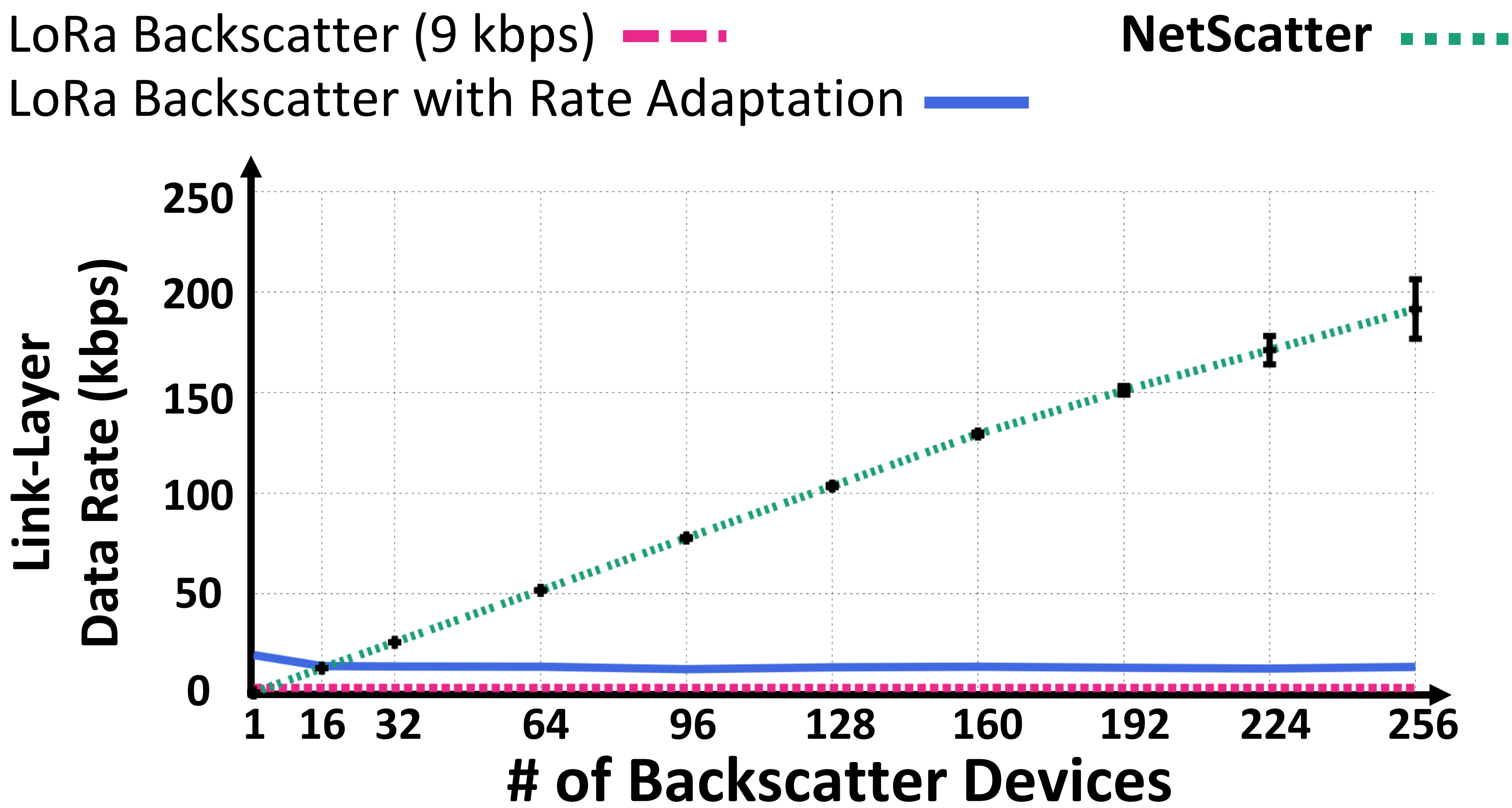
- LoRa-Backscatter (9 kbps)
- LoRa-Backscatter with rate adaptation

Evaluation: Network PHY Data-Rate



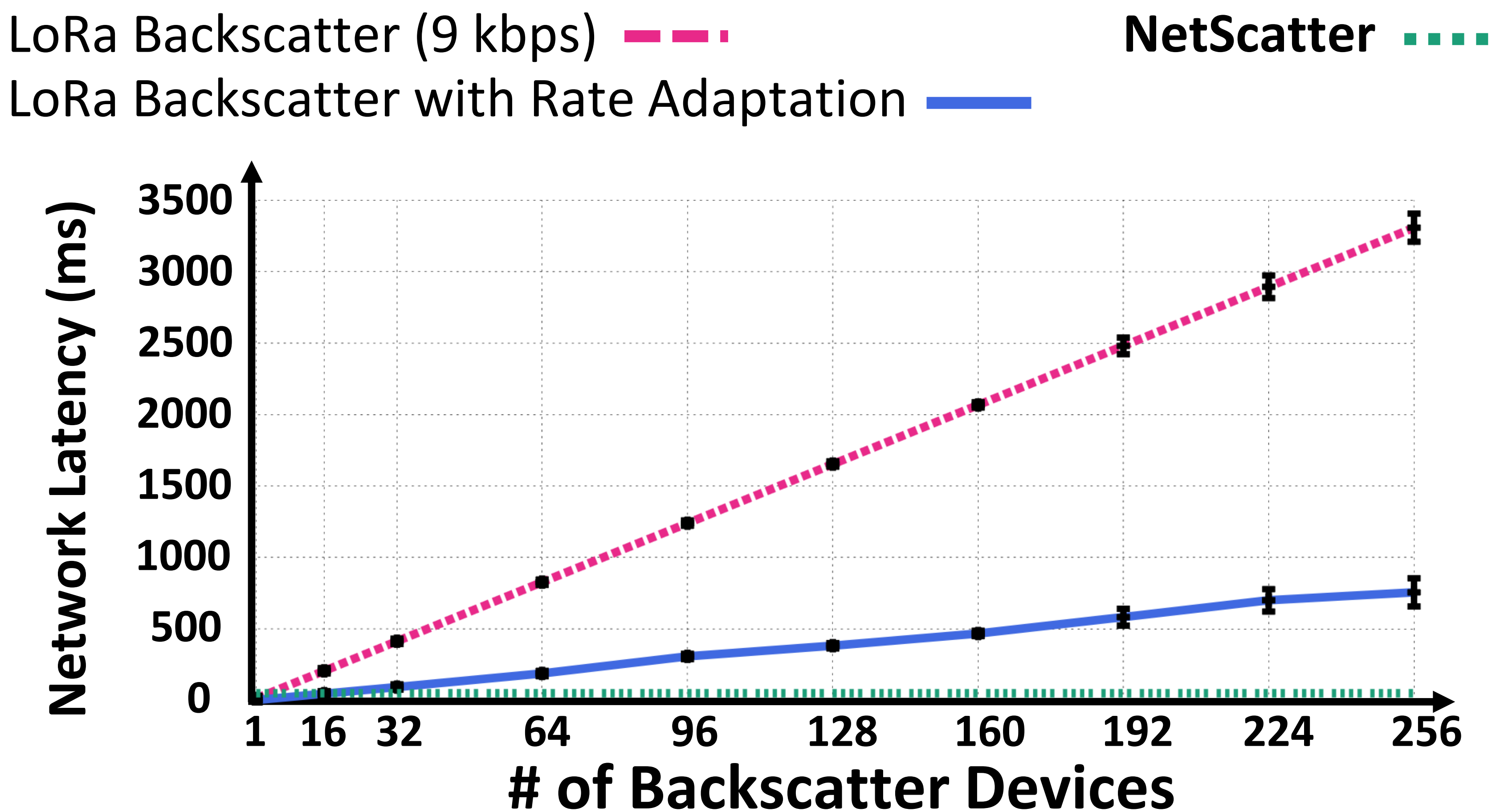
PHY data-rate improves by 7x - 26x

Evaluation: Link-layer data-rate



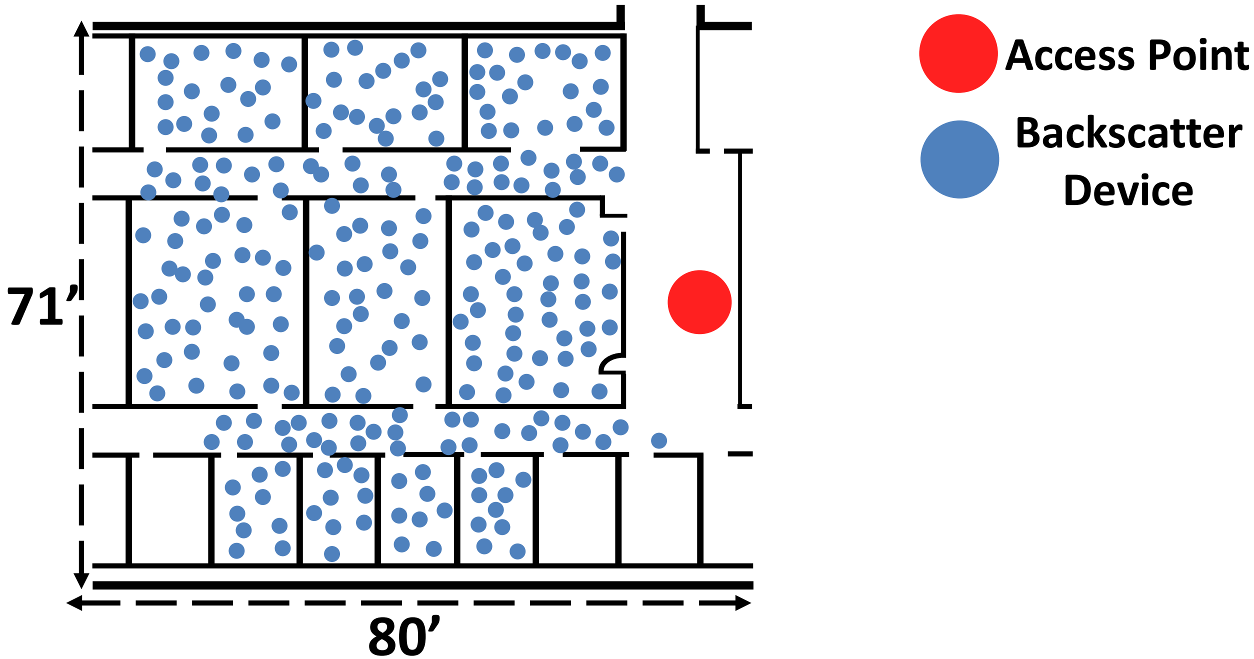
Link-layer data-rate improves by 14x-62x

Evaluation: Network latency



Network latency improves by 15x-67x

NetScatter



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