NetScatter: Enabling Large-Scale Backscatter Networks

Mehrdad Hessar*, Ali Najafi*, Shyam Gollakota

*Co-primary Student Authors
Backscatter Communication

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

Supports high sensitivity and long-range

Bit ‘0’

Freq

\( f \)

\(-f\)

Time

Amplitude

1 FFT Bin

N

Bit ‘1’

Freq

\( f \)

\(-f\)

Time

Amplitude

1 FFT Bin

N

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 $\rightarrow$ 10 bps
  - 1000 devices in network $\rightarrow$ 1 bps
Our Key Observation

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.

Alice: Bit ‘1’
Bob: Bit ‘1’

Alice: Bit ‘1’
Bob: Bit ‘0’

Alice: Bit ‘0’
Bob: Bit ‘1’

Alice: Bit ‘0’
Bob: Bit ‘0’

More power in the network $\rightarrow$ 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
Outline

• Distributed Chirp Spread Spectrum
• Timing Synchronization
• Near-Far Problem
• Deployment of 256 devices
Practical Issues: **Timing Synchronization**

**Alice and Bob**

Synchronized

Not synchronized

Causes interference between Alice and Bob
Hardware delay variations cause timing mismatch.

2 µs delay translates to 1 FFT bin with 500kHz BW.
We use every other cyclic-shift.

Reduces concurrent transmissions from 512 to 256.
Outline

• Distributed Chirp Spread Spectrum

• Timing Synchronization

• Near-Far Problem

• Deployment of 256 devices
Practical Issues: Near-Far Problem

Access Point

FFT Peak

FFT Bin

Amplitude
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)
Outline

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

LoRa Backscatter (9 kbps)
LoRa Backscatter with Rate Adaptation
NetScatter

PHY data-rate improves by **7x - 26x**
Evaluation: Link-layer data-rate

- LoRa Backscatter (9 kbps)
- LoRa Backscatter with Rate Adaptation
- NetScatter

Link-layer data-rate improves by 14x-62x
Evaluation: Network latency

Network latency improves by $15x$-$67x$
We deployed a network of 256 devices in an office building.