LeakyScatter: A Frequency-Agile Directional Backscatter Network above 100 GHz

Atsutse Kludze and Yasaman Ghasempour

USENIX NSDI 2023

4/17/2023
Low-Power Communication

Can be enabled by Backscattering

Backscattering is a Promising Candidate for Low-Power Communication

Backscattered node use the ambient signal to send data back to AP
Today’s Backscattering

Total Number of Low-Power nodes expected to increase to $41.2\text{ billion}!^1$

Current backscattering technology is limited in the total number of users it can support

Towards Backscattering Above 100 GHz

- Wideband – Orthogonal Frequency Division Multiple Access
- Directionality – Spectral reuse with spatial separation

How do we enable backscattering above 100 GHz?
Key Goals

1. Enabling **highly directional, retrodirective links**
2. Enabling **frequency-agile operation** above 100 GHz
3. Enabling **ultra-wide bandwidth** (GHz-Scale)

All performed at zero-power cost
Prior Work: Phase Arrays

Example Schematic of a conjugate phase array

Key Goals

1. Retrodirective
2. Frequency-agile
3. Wideband
4. Low-power

Requires Active Components
Prior Work: Van Atta Arrays

Antenna size $\propto \lambda$
Transmission Line Length $\propto \lambda$

Key Goals

1. Retrodirective
2. Frequency-agile
3. Wideband
4. Low-power
Presenting **LeakyScatter**: The first frequency-agile sub-THz Backscatter Architecture
Key Idea: Create a New PHY-Layer Architecture based on Leaky Wave Antennas (LWAs)

- Design a new PHY-layer architecture that supports directionality at low-power cost and is ultra-wideband

Method: Using Leaky Wave Antennas (LWAs) as the foundational architecture

Key Goals
1. Retrodirective
2. Frequency-agile
3. Wideband
4. Low-power
Primer: Leaky Wave Antennas (LWAs)

- LWAs are traveling wave structures
- Injected signal will leak out into free-space in a **specific angle**

$$\phi(f) = \sin \left( \frac{c}{2bf} \right)$$

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Reciprocal Properties of a Leaky Wave Antenna

\[ \phi_{TX} = \sin^{-1}\left(\frac{c}{2bf_{TX}}\right) \]

\[ \phi^* = \phi_{TX} \rightarrow f^* = f_{TX} \]

We can leverage reciprocity to create retrodirective links.
Dual Slit Architecture

Retrodirective Link Established

\[ \theta_{TX} = \theta_{RX} \]

b = 1mm

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Frequency Agile and Wideband Operation

- Angle-dependent center frequency and bandwidth
- Bandwidth always on a GHz-scale

\[ f = \frac{c}{2b \sin(\theta)} \]

\[ BW = \frac{c}{2b \sin(\theta) \tan(\theta) \Delta\phi} \]
Recap of Key Goals with LWA Architecture

Key features performed at **zero-power cost**!

Key Goals

1. Retrodirective
2. Frequency-agile
3. Wideband
4. Low-power
Aperture-Based Data Modulation for AM

- Backscattered power $\propto$ aperture size
- Changing guided waves’ trajectory $\rightarrow$ changing aperture

$A_{\text{eff}} = \frac{W^2}{2 \tan(2\theta_{\text{rot}})}$

$A_{\text{slit}} = WL$
Scaling to Multi-Users

\[ f_1, f_2, f_3, f_4, f_5 \]

\[ \theta_1^*, \theta_2^*, \theta_3^* \]

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Fabricated LeakyScatter

- Trapezoidal shape slits used to increase coupling efficiency

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Experimental Platform
Experimental Platform

- LeakyScatter
- THz Emitter
- MEMS Mirror
- Broadband Detector
- Rotation Stage
- MEMS Driver
- Translational Stages
Highly Directional Retrodirective Links

• We observe an increase in errors and fluctuations at higher impinging angles.

Average error $\sim 1.9^\circ$
LeakyScatter is Frequency-Agile

- Frequency-Agile achieve across 100 GHz
- GHz-Scale bandwidth achieved across space

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ASK Demonstrated across 100 GHz!

- Bit stream successful demonstrated up to 314 GHz
- Data rate limited by mechanical components and data acquisition rate of our broadband detection
- Ongoing work: Achieving higher order schemes (i.e., QAM) and higher data rate (using electronic components)
Summary and Contributions

• A novel architecture for backscattering above 100 GHz
• Scaling backscattering to multiple users by frequency-space division multiple access
• First work that experimentally demonstrate backscattering above 100 GHz
Thank you