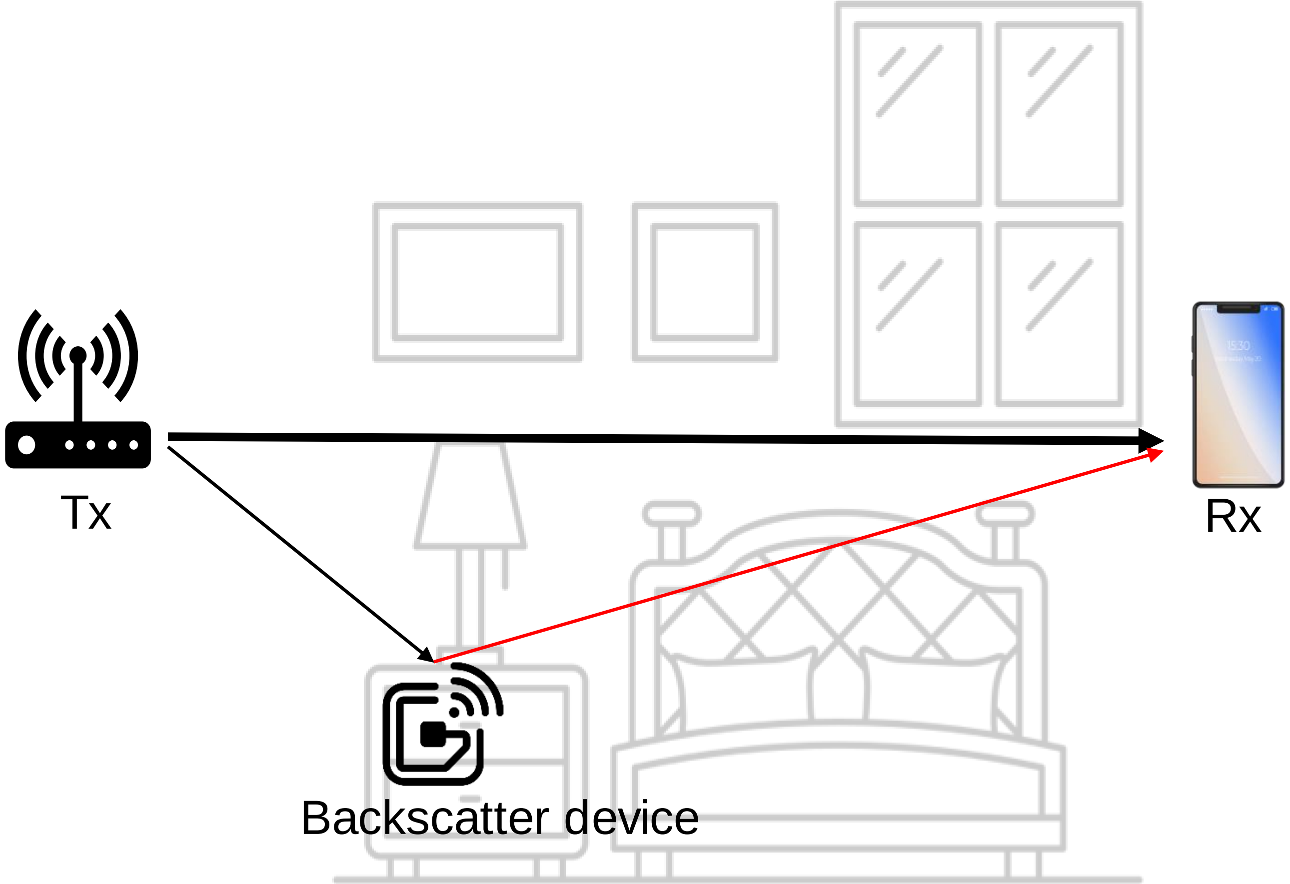
UC San Diego
JACOBS SCHOOL OF ENGINEERING
Electrical and Computer Engineering

WCSNG
Wireless Communications Sensing and Networking

Transforming Communication with Backscatter

Manideep Dunna

What is Backscatter?



- Encode data by reflection
- Change RF signal properties

Backscatter is the manipulation of reflected signals in the environment

Current usage of Backscatter: RFID tags

RFID tags

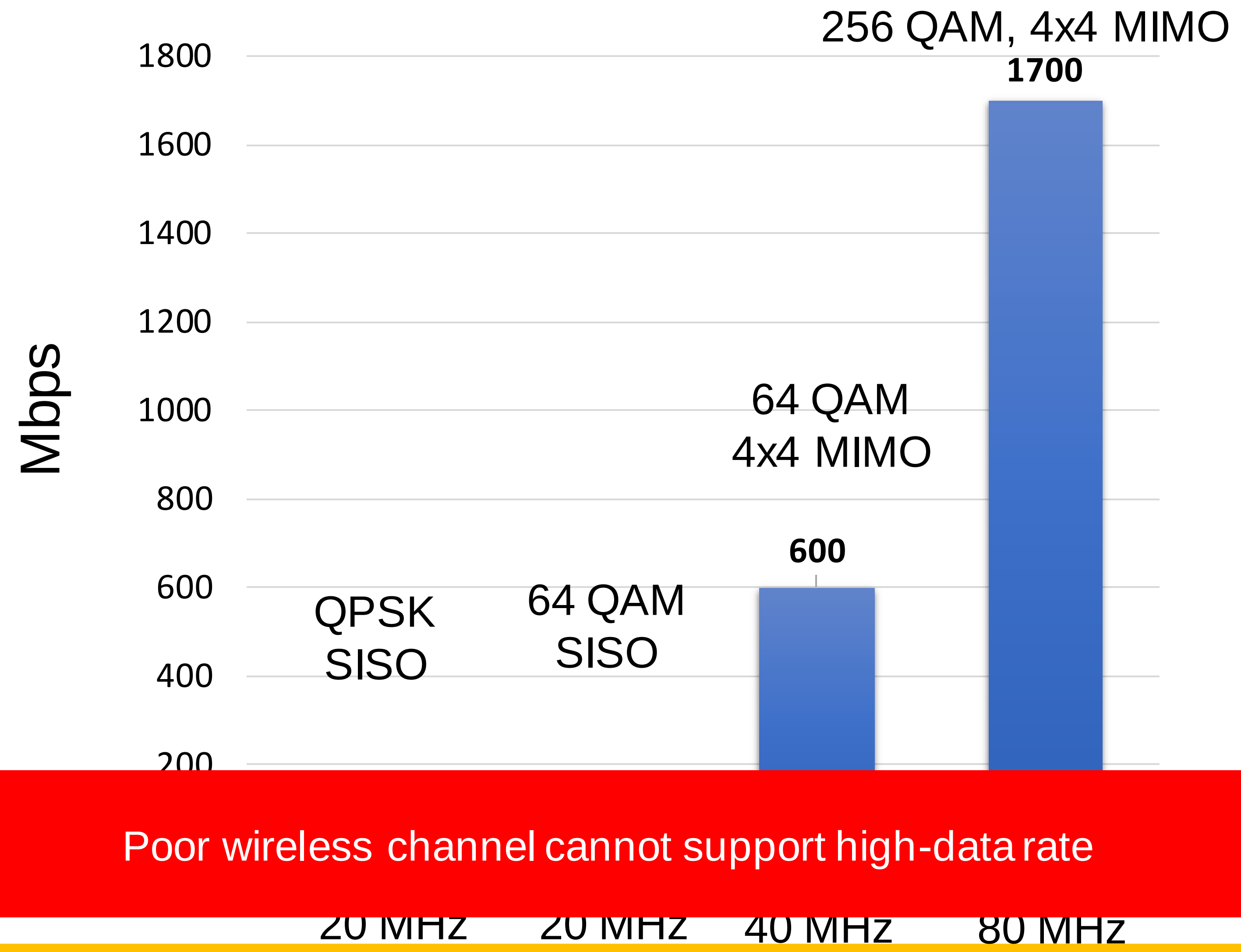
- ❖ RFID is passive
- ❖ Easy to maintain

High data rate: Cornerstone of modern applications

Virtual Reality

Online Gaming

The promise of MIMO 802.11ac



Poor wireless channel cannot support high-data rate

Wireless communication applications

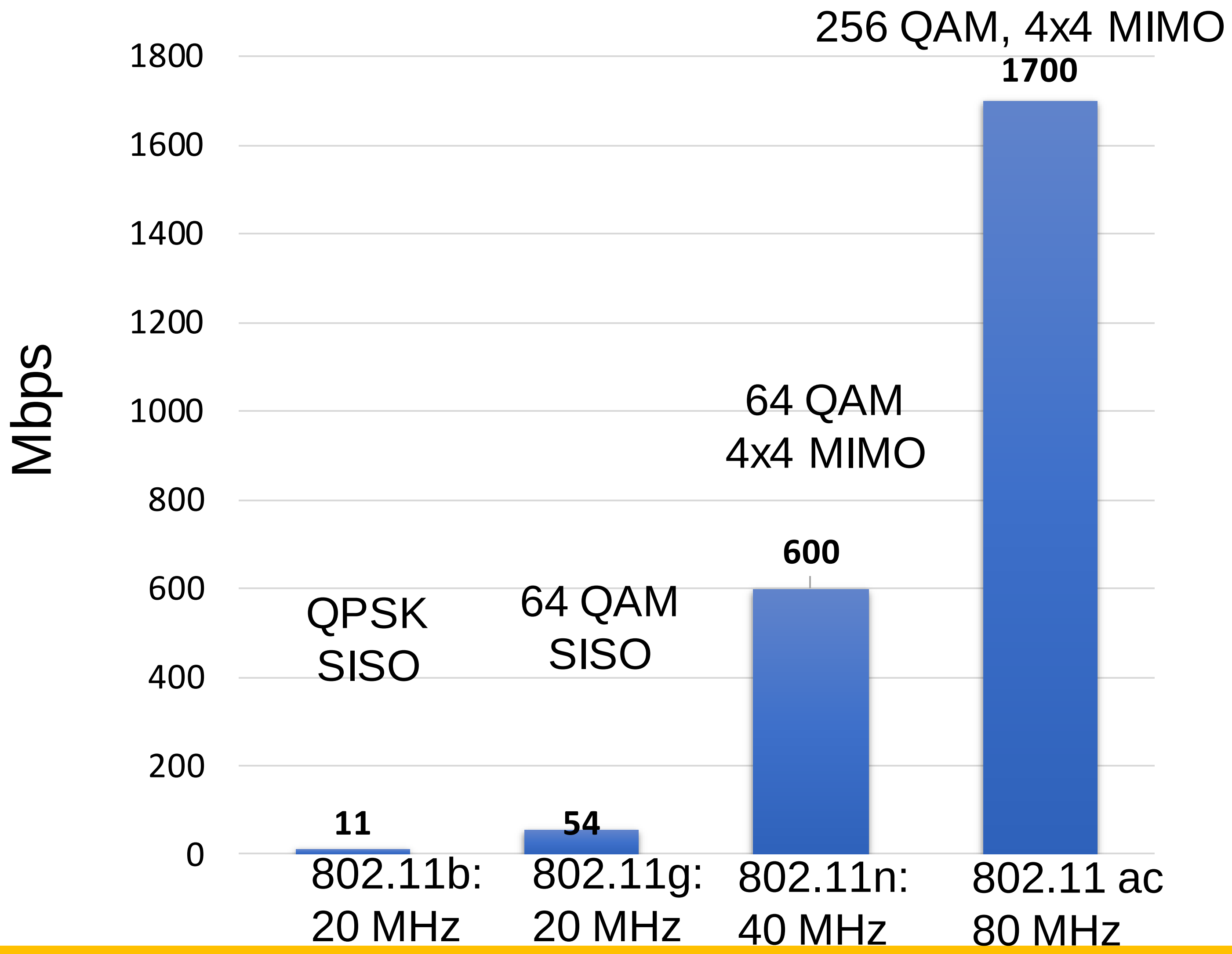
Streaming	IoT devices
	
High Throughput	Low-power & Long-Range Connectivity
Poor wireless channel	Short range

ScatterMIMO: Enabling Virtual MIMO with Smart Surfaces

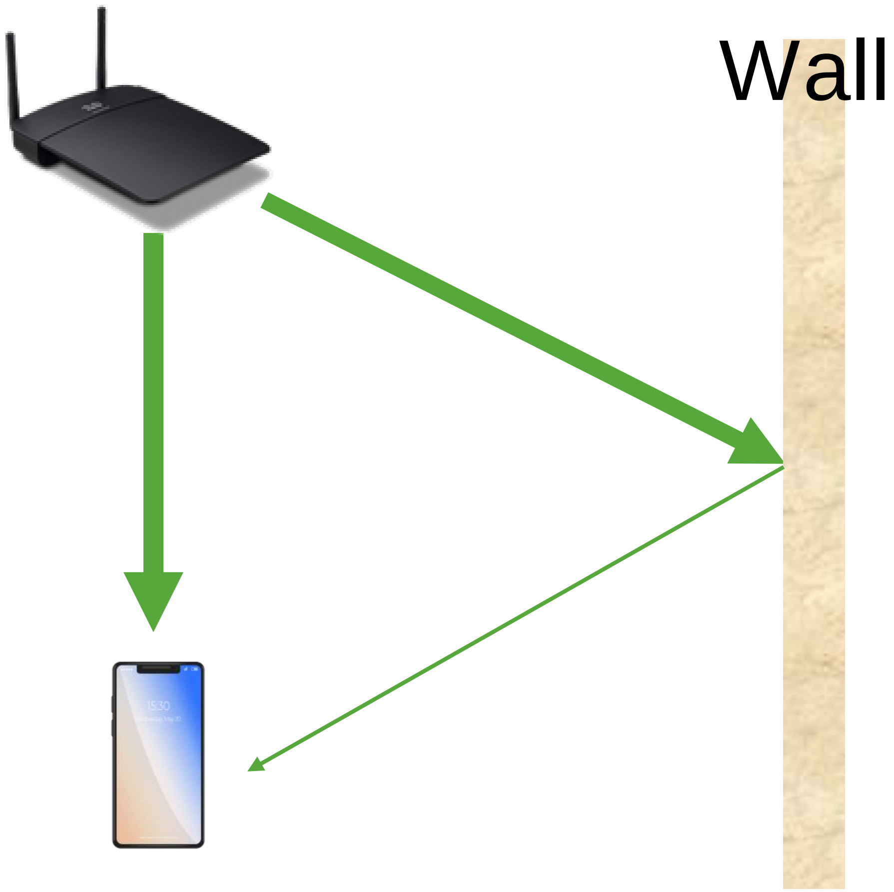
Manideep Dunna, Chi Zhang, Daniel Sievenpiper, Dinesh Bharadia

Mobicom 2020

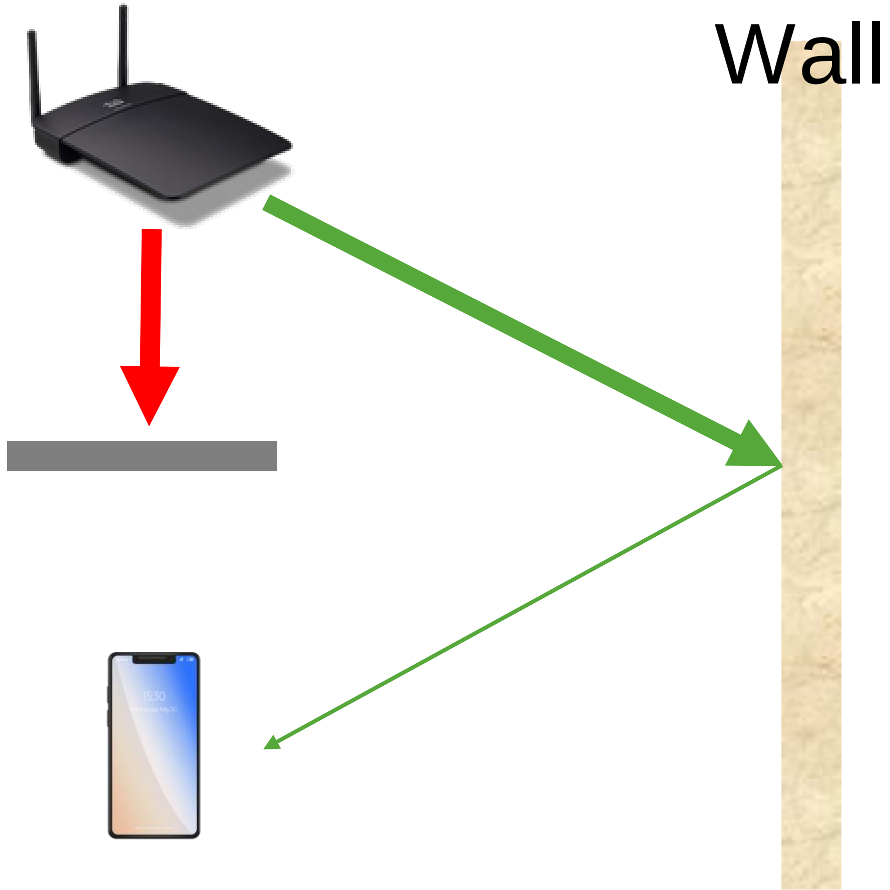
The promise of MIMO 802.11ac



Why don't we get advertised Gbps data-rates?

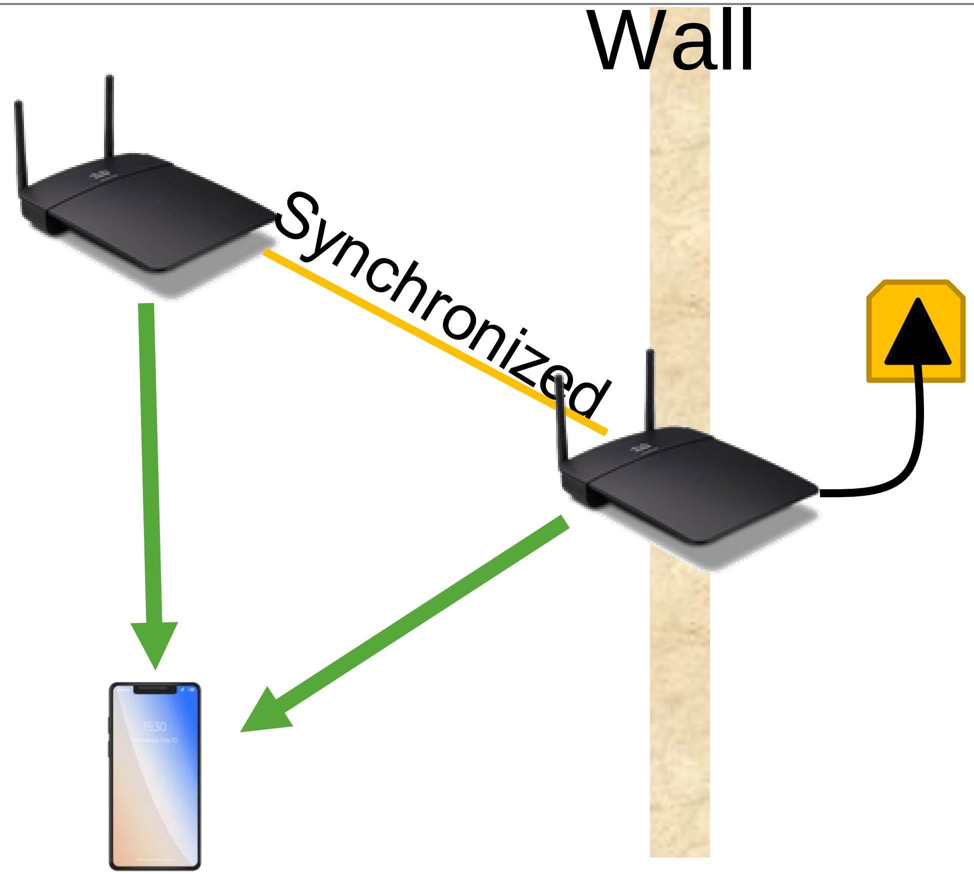


Weak Multipath (Low MIMO rank)



LOS path blockage

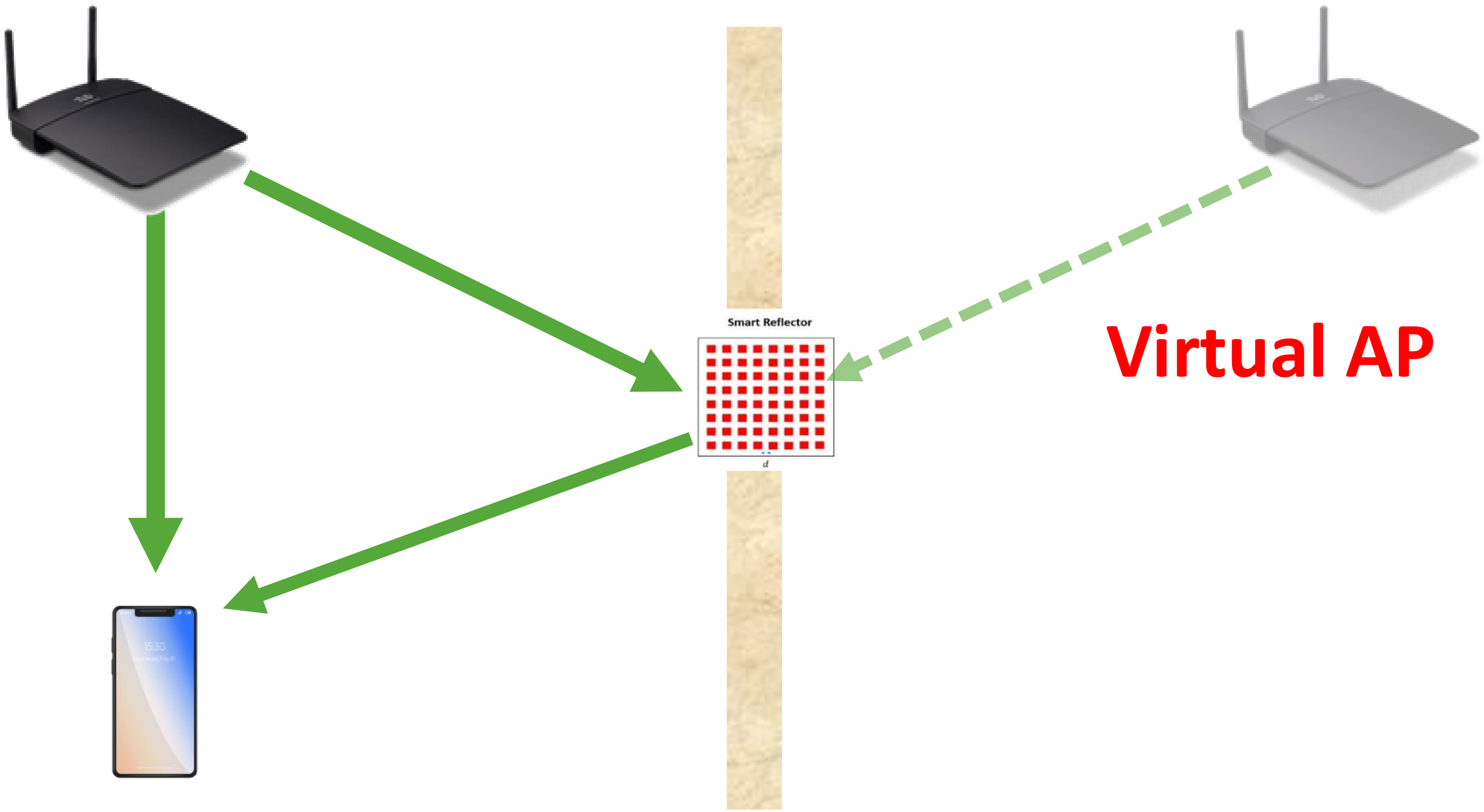
Distributed MIMO



Can we do it passively??

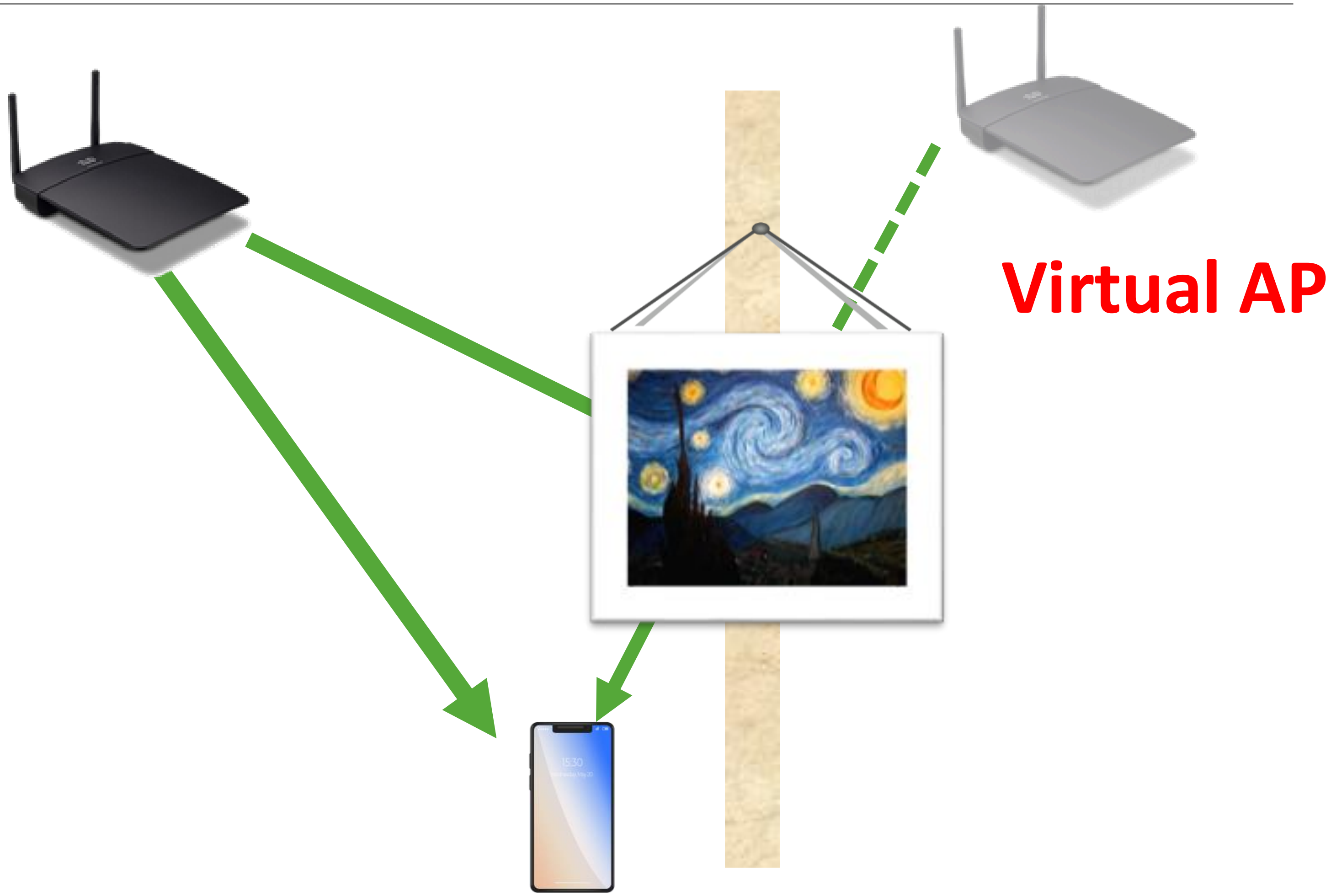
ScatterMIMO: Overview

- Passive
- 2x throughput gain
- 1.5x coverage improvement

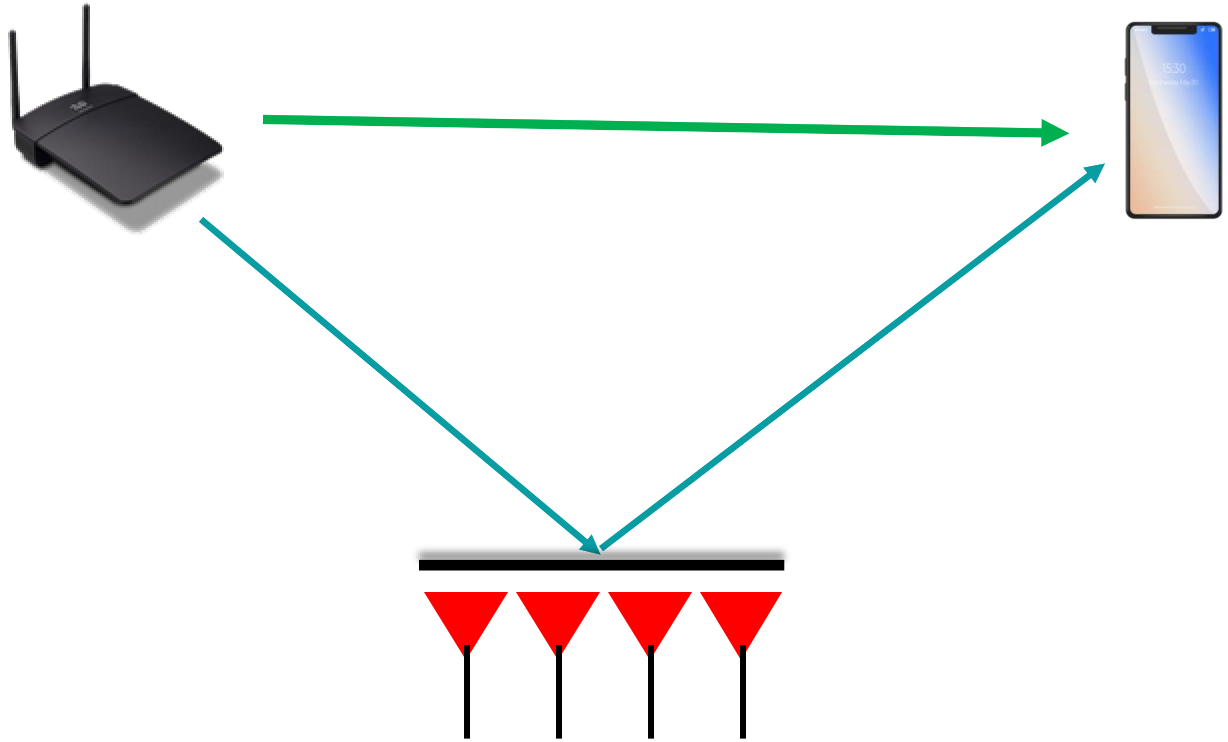


ScatterMIMO: Overview

- Passive
- 2x throughput gain
- 1.5x coverage improvement
- Supports user mobility
- Seamless integration



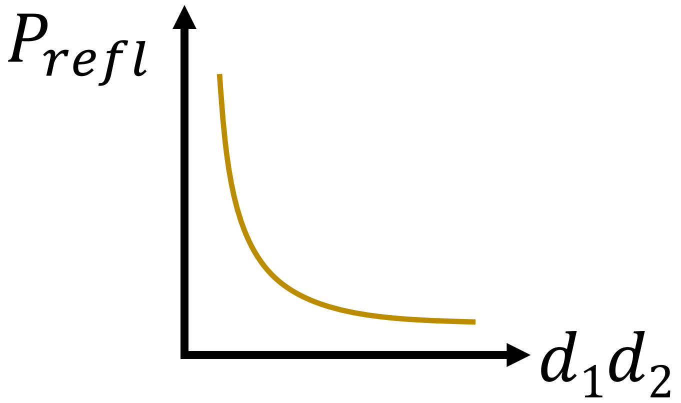
How does the smart surface work?

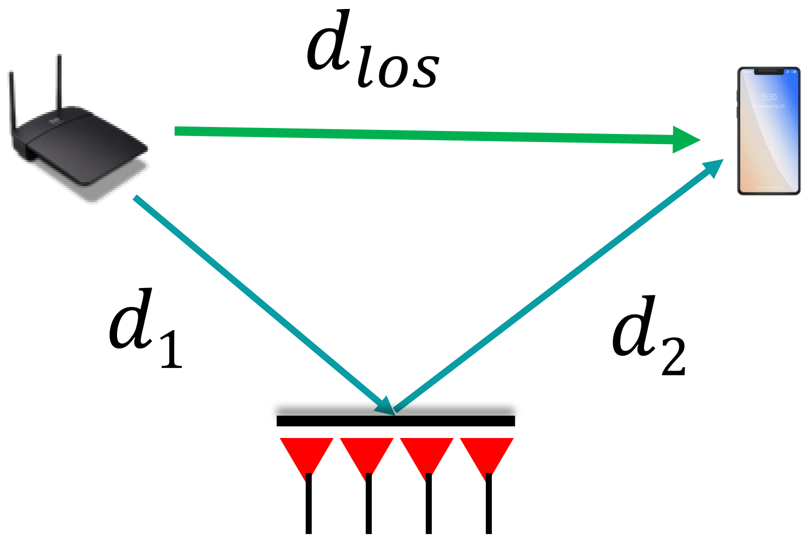


Challenge 1: How to achieve comparable power?

$$P_{los} \propto \frac{1}{(d_{los})^2}$$

$$P_{refl} \propto \frac{1}{(d_1)^2} \frac{1}{(d_2)^2}$$

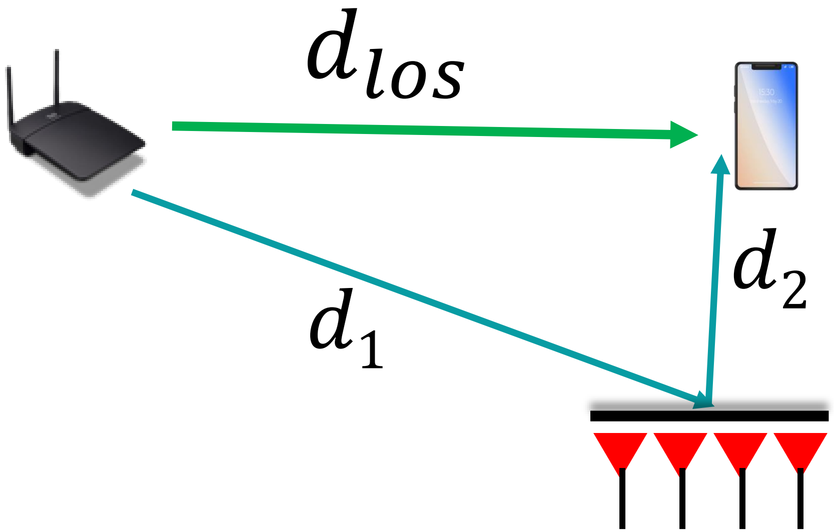




- ❖ Minimize the product $d_1 d_2$ (i.e., $d_1 d_2 \rightarrow 0$)

Challenge 1: How to achieve comparable power?

- Make $d_2 \rightarrow 0$
- Keep smart surface close to the user
- But if the user moves, the smart surface must move



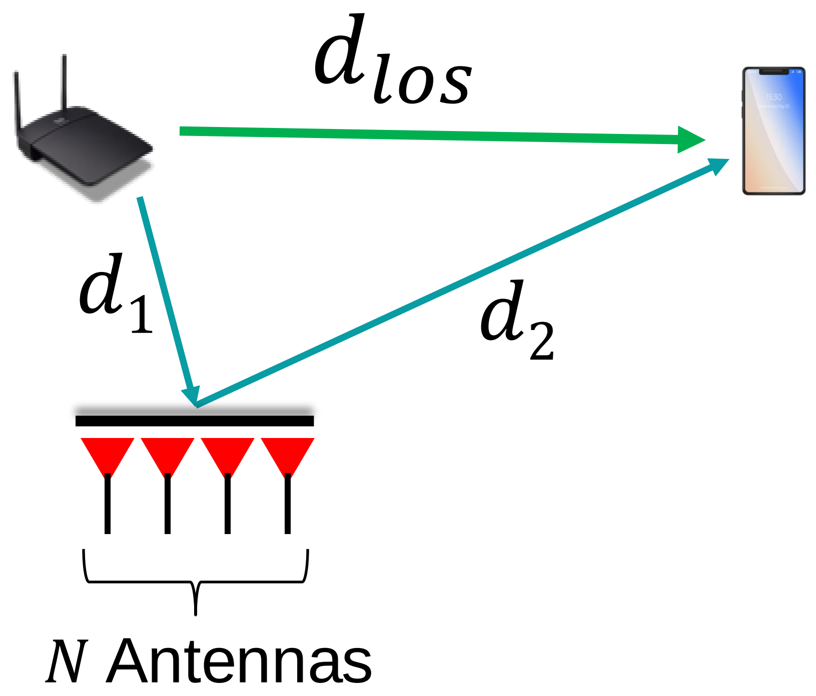
Impractical to move smart surface with mobile user

Challenge 1: How to achieve comparable power?

- Make $d_1 \rightarrow 0$
- Keep the smart surface close to the access point
- Backscattered power is still not high enough

$$P_{refl} \propto \frac{1}{(d_1)^2} \frac{1}{(d_2)^2} \times N^2$$

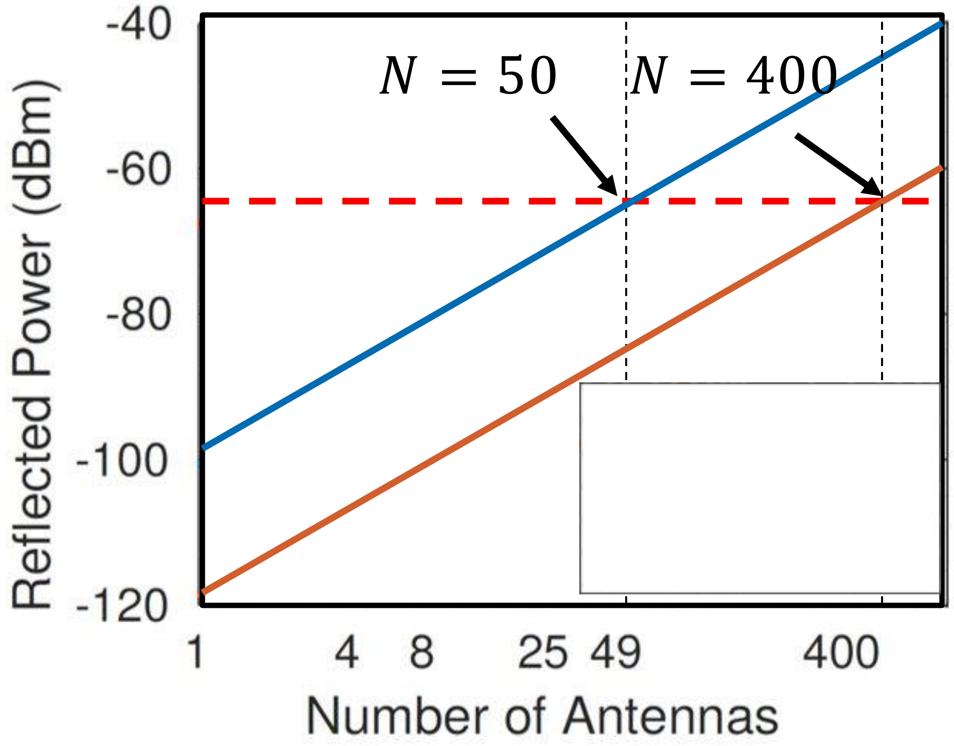
- To have good spatial diversity, place the smart surface in the far field.



Challenge 1: How to achieve comparable power?

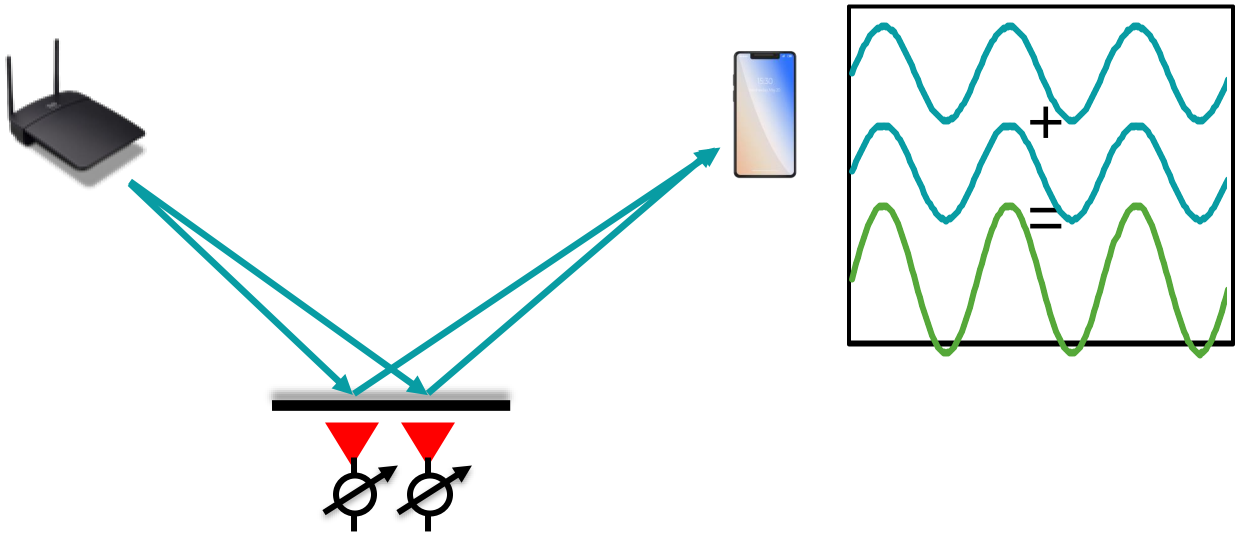
- d_1= 50 cm is in far-field.
- $N = 50$ provides comparable reflected power.

$$P_{refl} \propto \frac{1}{(d_1)^2}\frac{1}{(d_2)^2} \text{ x } N^2$$



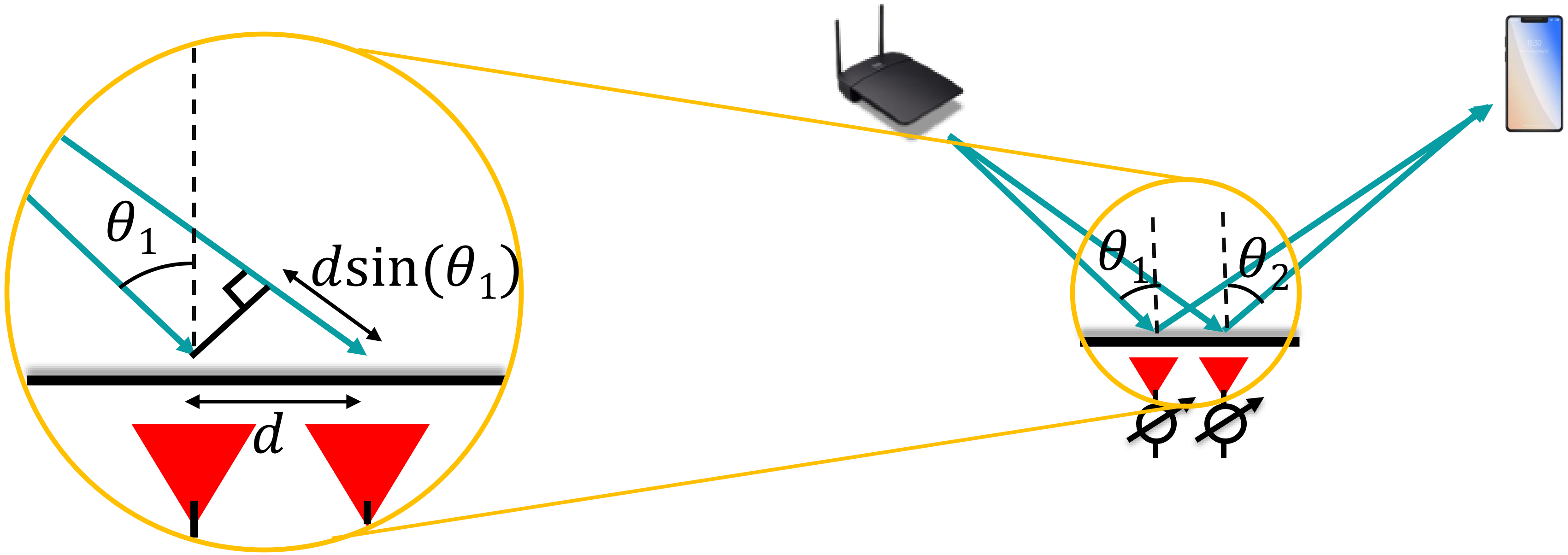
Challenge2: How to constructively combine?

- 50 antennas => 4^{50} phase combinations



2-bit phase shifters

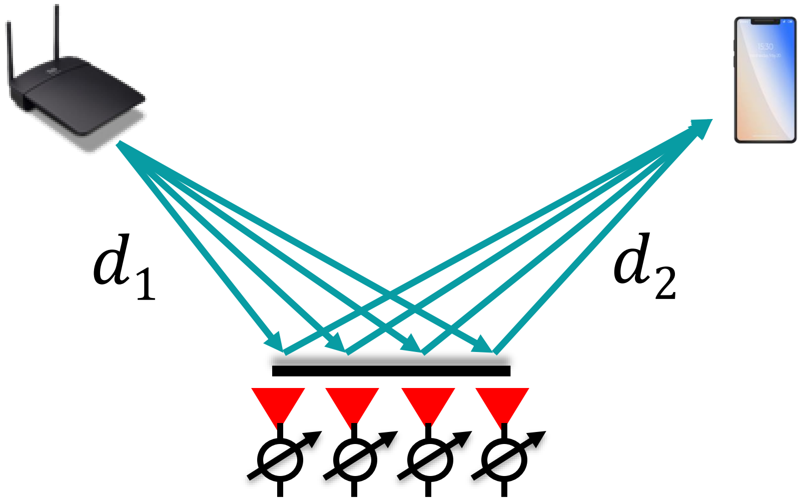
Novel approach: Geometric channel model



Novel approach: geometric channel model

- Path lengths:

$$d_1 + d_2$$
$$d_1 + d_2 + d\sin(\theta_1) - d\sin(\theta_2)$$
$$d_1 + d_2 + 2d\sin(\theta_1) - 2d\sin(\theta_2)$$
$$d_1 + d_2 + 3d\sin(\theta_1) - 3d\sin(\theta_2)$$



- For n[th] antenna, path length =

$$d_1 + d_2 + n(dsin(\theta_1) - dsin(\theta_2))$$

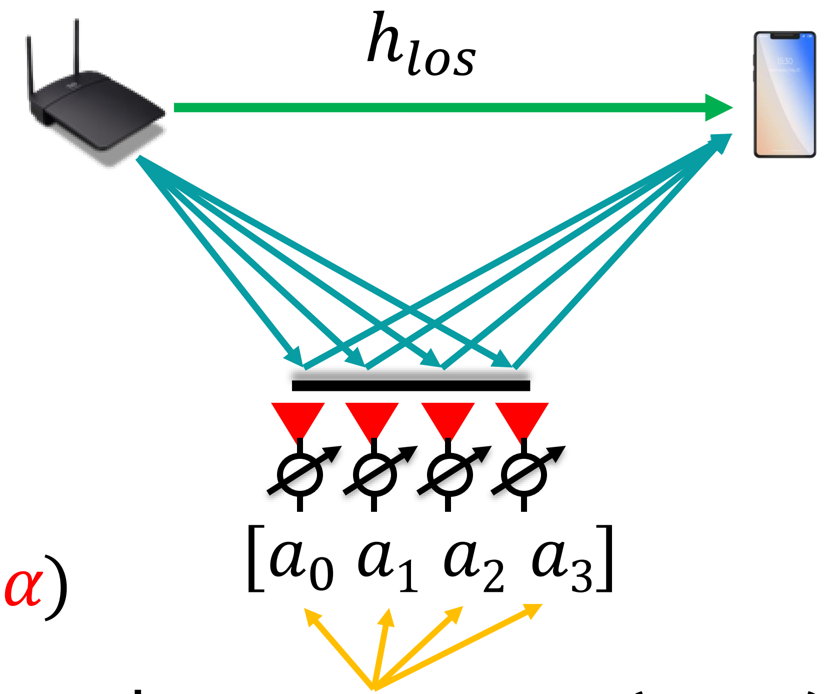
Optimal phase for constructive combining

- Phase difference

$$\alpha = \frac{2\pi}{\lambda}[\mathrm{dsin}(\theta_1) - \mathrm{dsin}(\theta_2)]$$

- Channel response

$$h = h_{los} + h_{refl} \sum_{n=0}^{3} a_n \exp(-jn\alpha)$$



choose $a_n = \exp(+jn\alpha)$

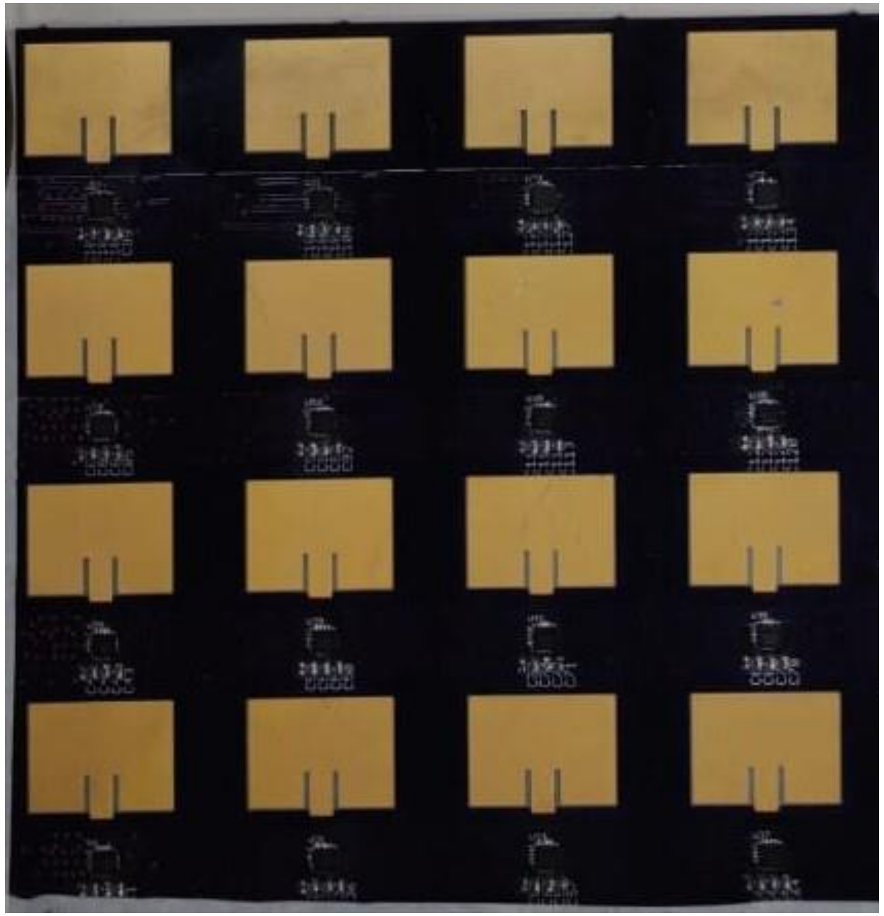
Finding α in 3 easy steps

Applied Phases	Channel Response
1. $[1 \quad 1 \quad 1 \quad 1]$	$h_1 = h_{los} + h_{refl}\left(1 + e^{-j\alpha} + e^{-2j\alpha} + e^{-3j\alpha}\right)$
2. $[1 \quad -1 \quad 1 \quad -1]$	$h_2 = h_{los} + h_{refl}\left(1 - e^{-j\alpha} + e^{-2j\alpha} - e^{-3j\alpha}\right)$
3. $[-1 \quad 1 \quad -1 \quad 1]$	$h_3 = h_{los} + h_{refl}\left(-1 + e^{-j\alpha} - e^{-2j\alpha} + e^{-3j\alpha}\right)$

$$(h_1 - h_3)\overline{(h_1 - h_2)} = 4e^{j\alpha}\left|1 + e^{-2j\alpha}\right|^2 \left|h_{refl}\right|^2$$

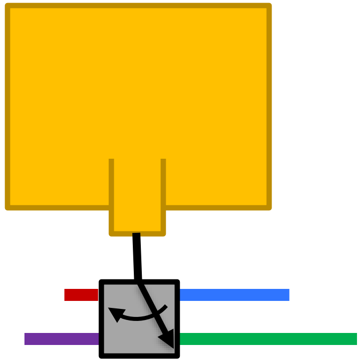
- Just 3 CSI measurements sufficient to optimize the surface.

Smart surface implementation



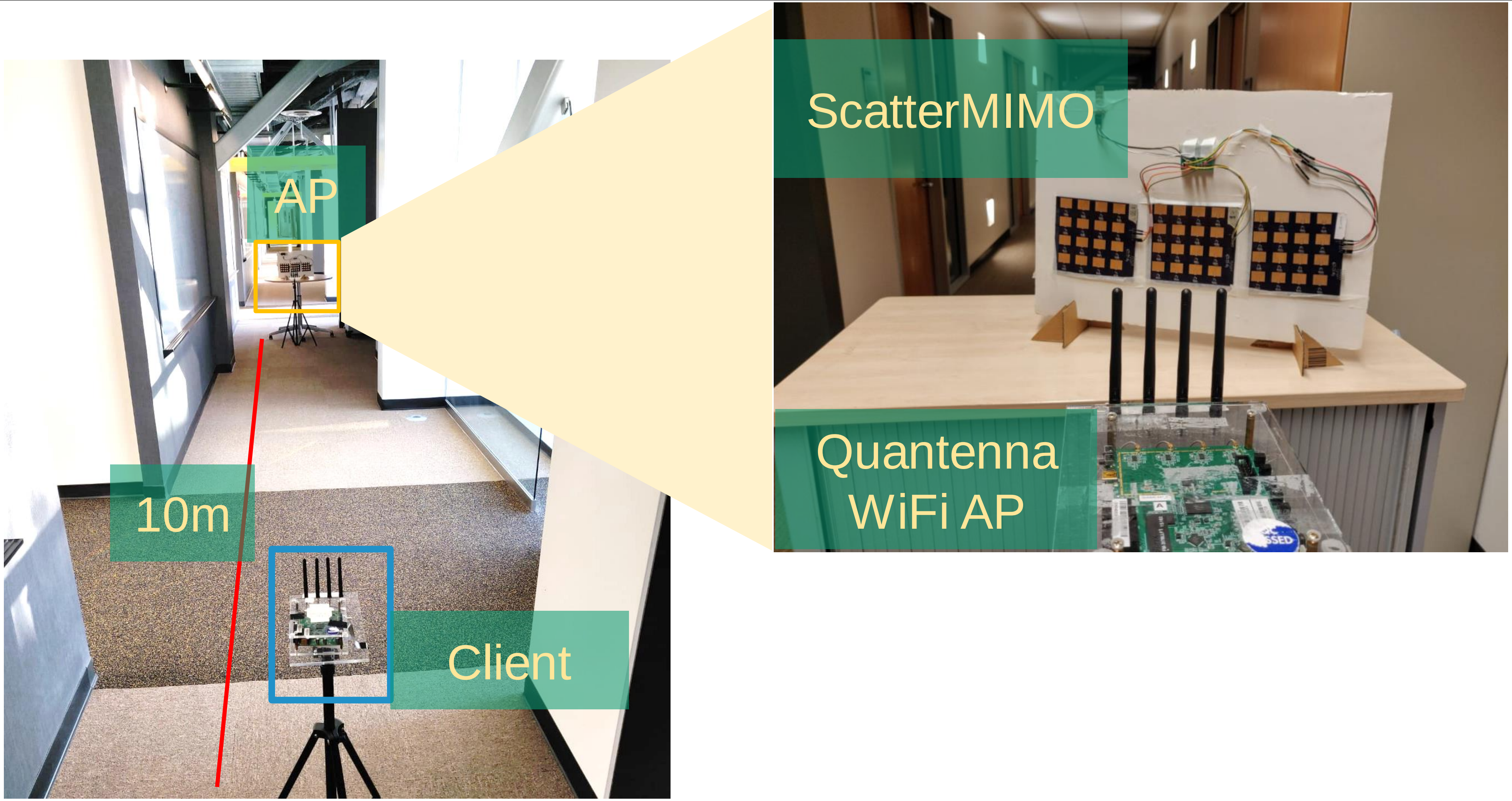
4 x 4 scatterMIMO tile

- Array of 5 GHz patch antennas on a PCB.

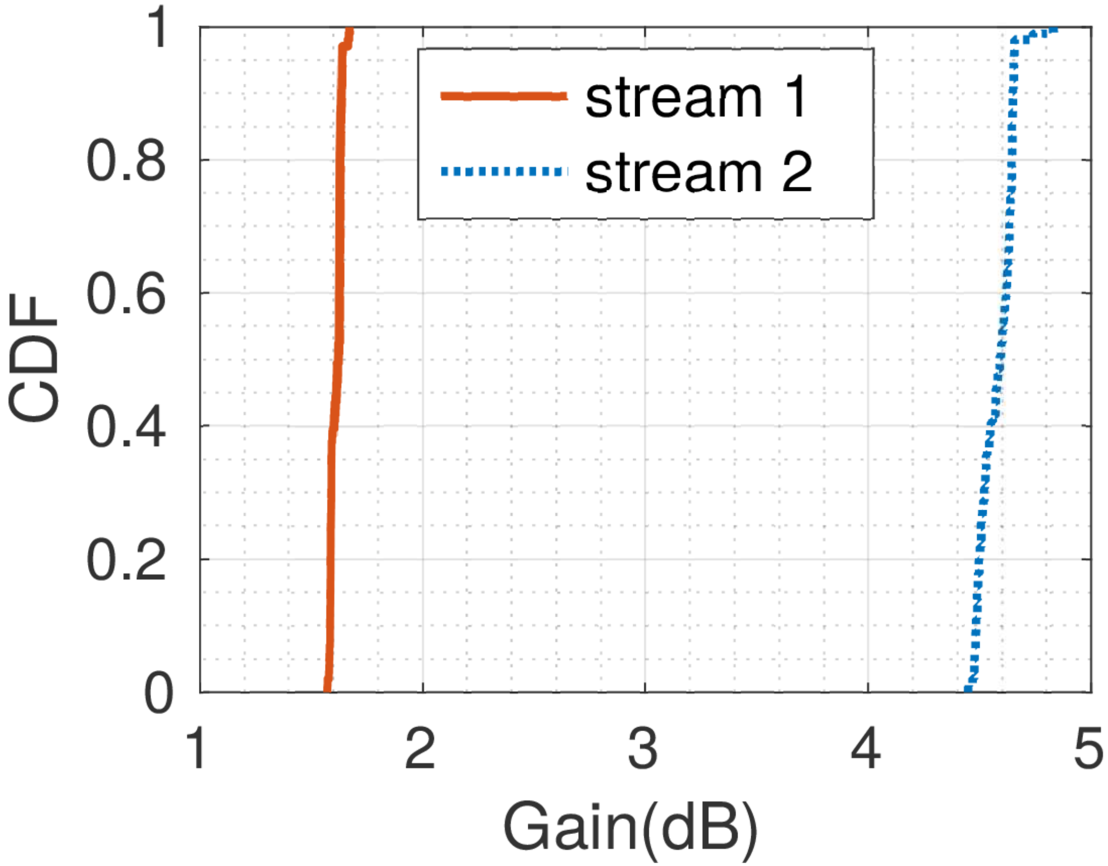


- 2-bit phase shifter – 4:1 RF switch to select one of the $0^{\circ}, 90^{\circ}, 180^{\circ}, 270^{\circ}$ transmission lines.
- Smart surface costs less than $5

Experimental Setup

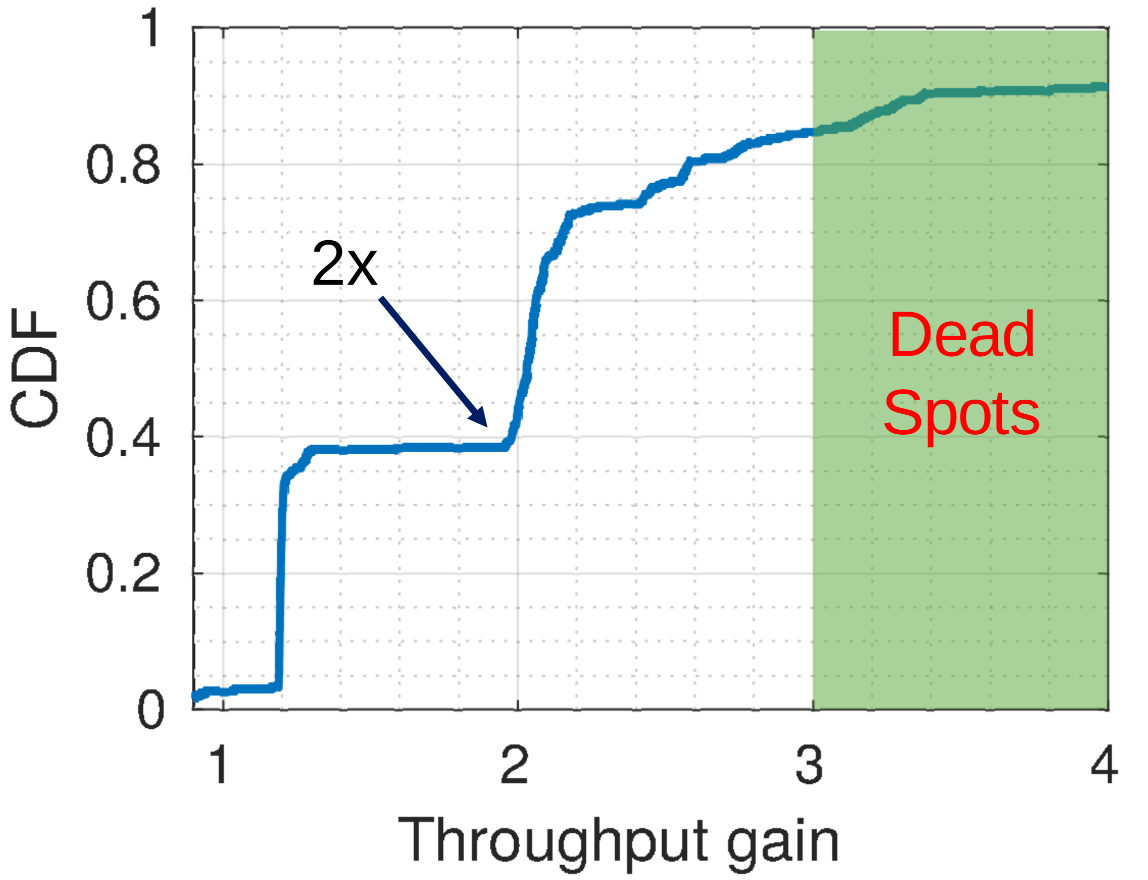


SNR improvement of spatial streams

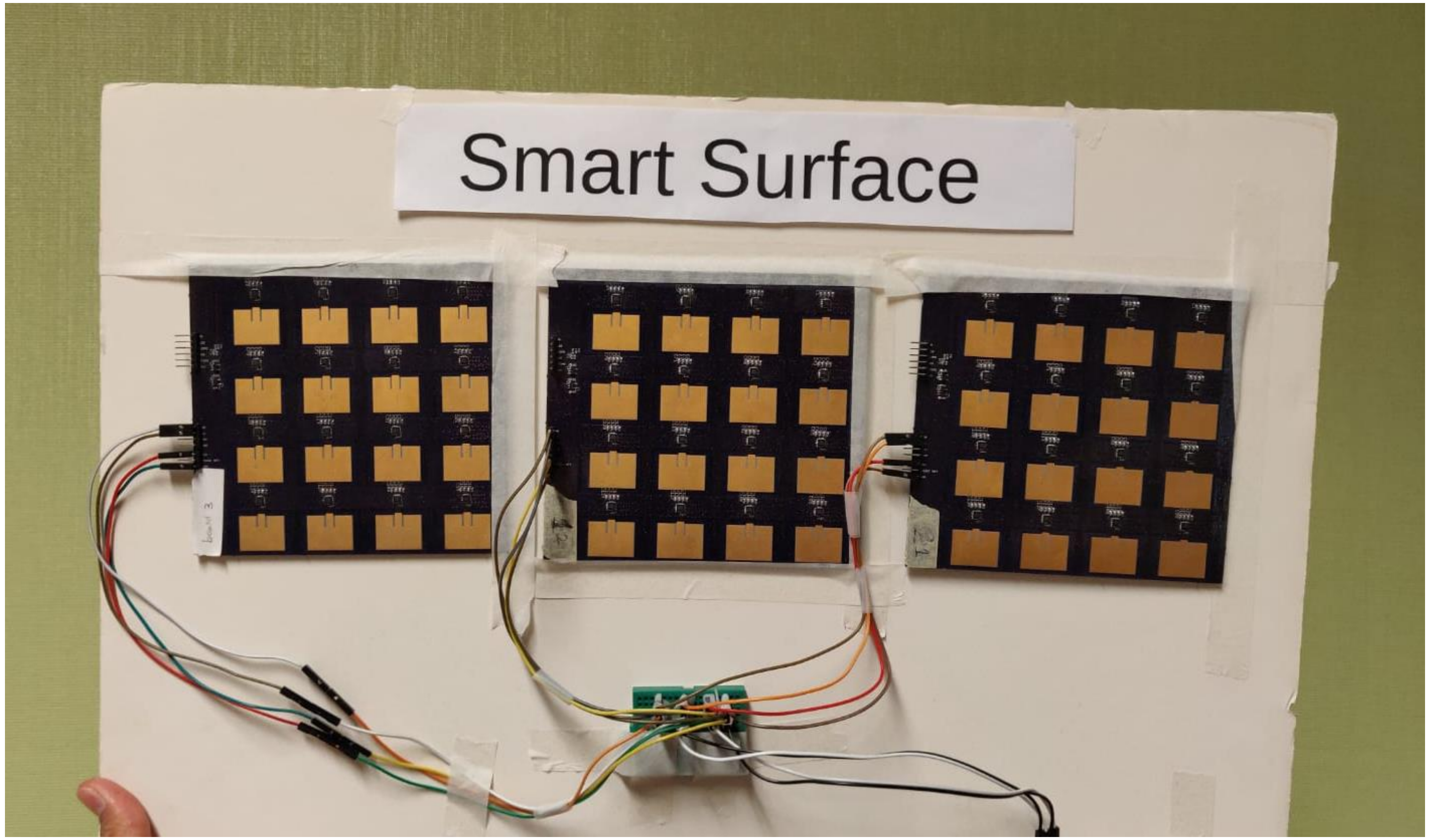


- Improves signal power of both primary and secondary streams
- Secondary stream's SNR improved by **4.5 dB**

Throughput Improvement over baseline



Summary



- Low latency algorithm
- COTS compatibility
- 2x throughput and 45m coverage

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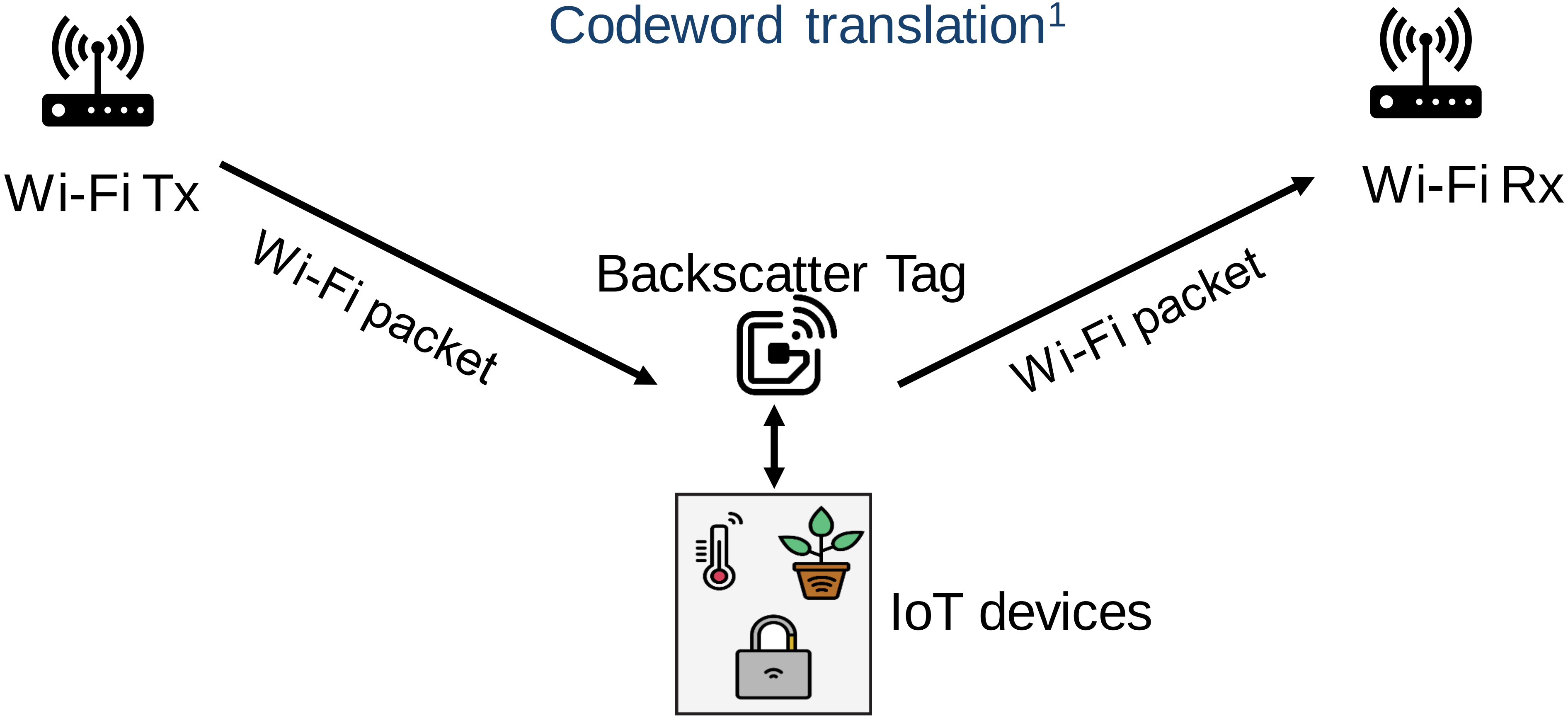
SyncScatter: Enabling Wi-Fi like Synchronization and range for Wi-Fi backscatter communication

Manideep Dunna, Miao Meng, Po-Han Wang, Chi Zhang,
Patrick Mercier, Dinesh Bharadia

NSDI 2021

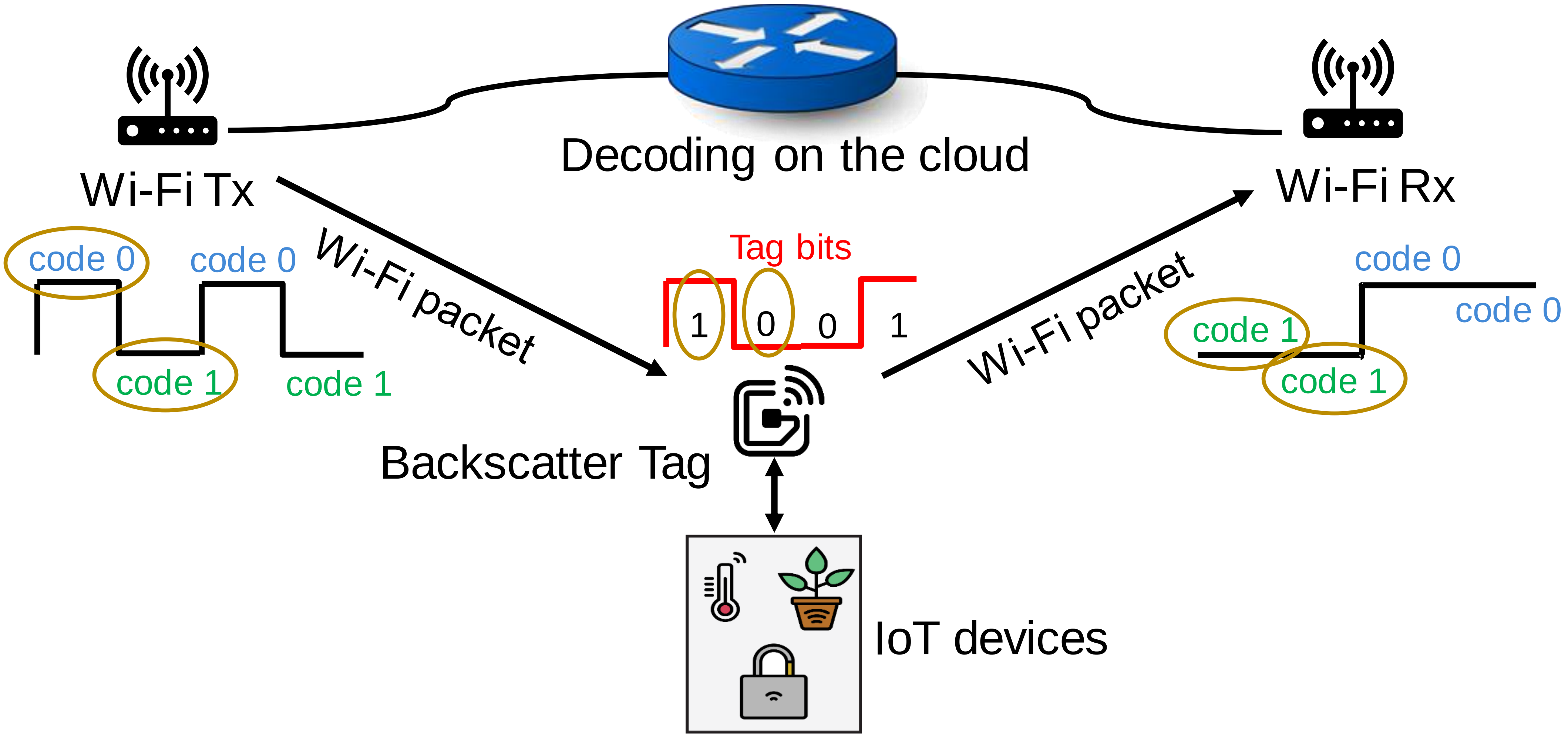
Low power Wi-Fi connectivity

Codeword translation[1]

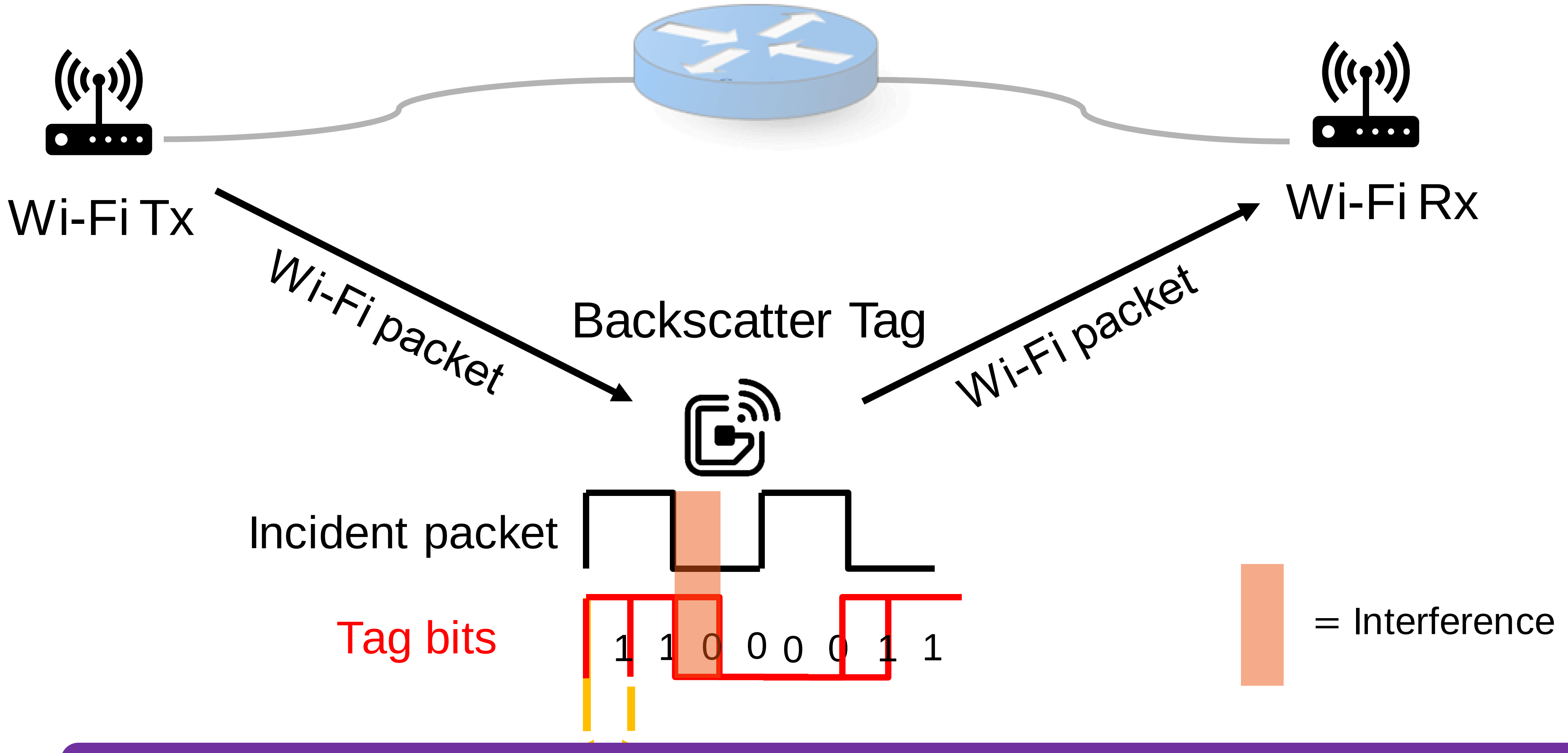


1) HitchHike: Practical Backscatter Using Commodity Wi-Fi (Sensys 2016)

Code-Word Translation



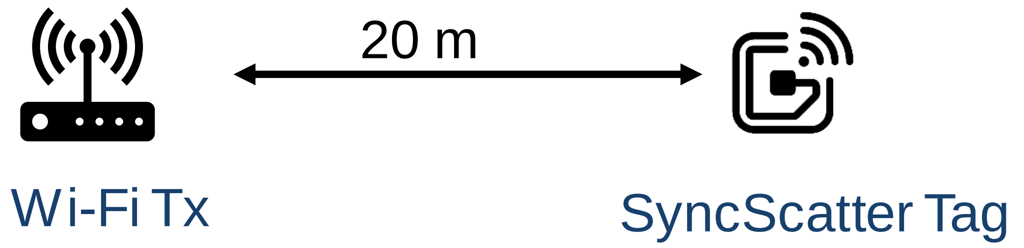
Code-word translation: Closer look



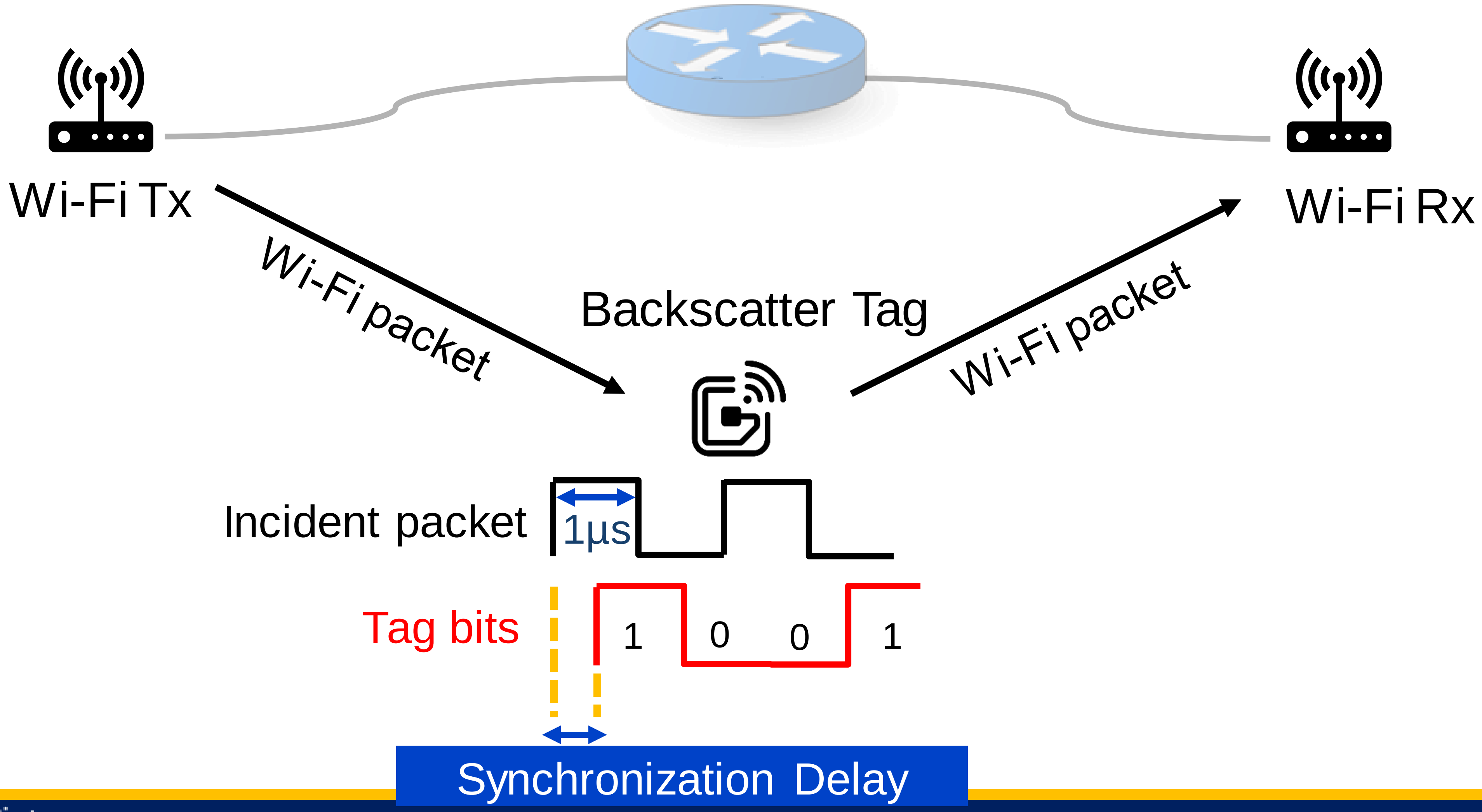
Can we synchronize to the incident Wi-Fi packets?

SyncScatter: Contributions

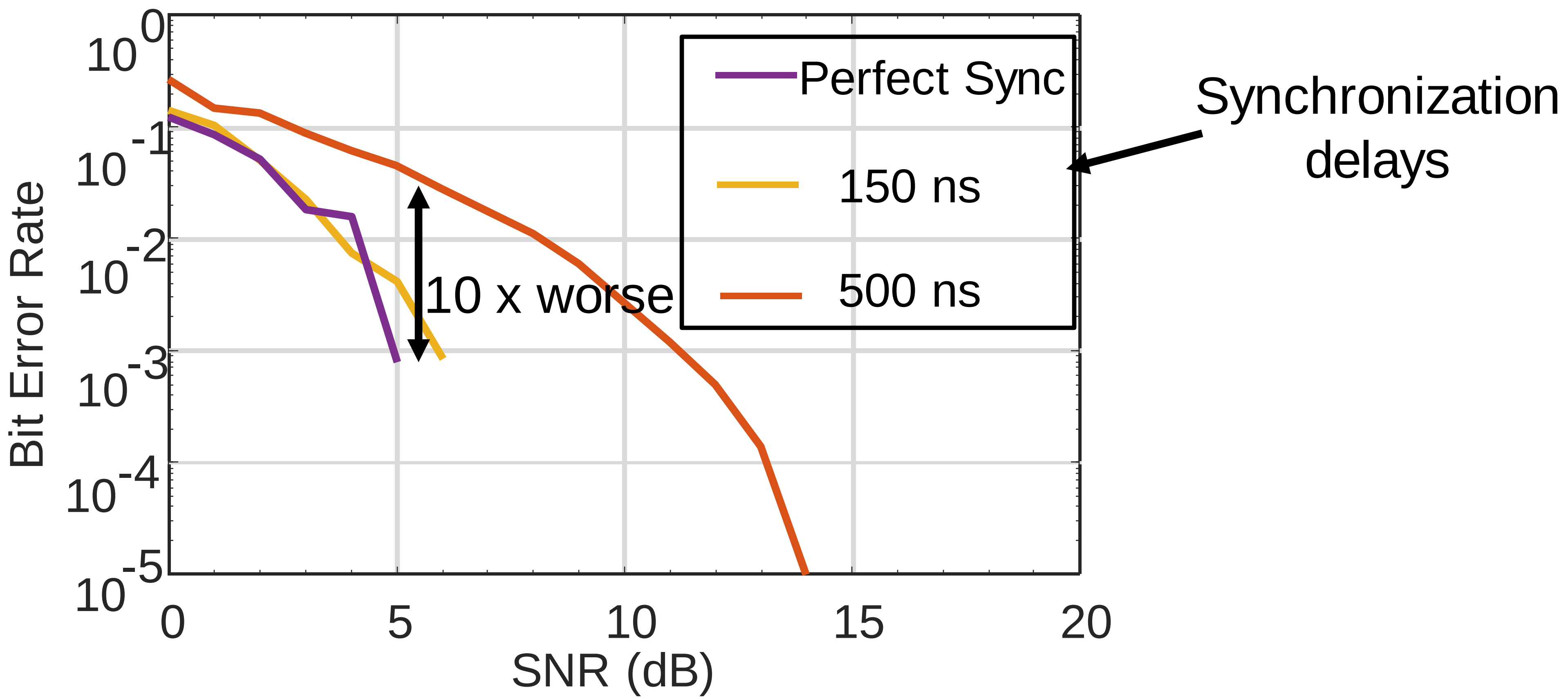
- Stringent synchronization requirements
- Hierarchical wake-up architecture
- 7.6 μW low power Integrated circuit for Synchronized backscatter
- 100x lower Bit error rate
- 4x Range improvement



Synchronization Requirements

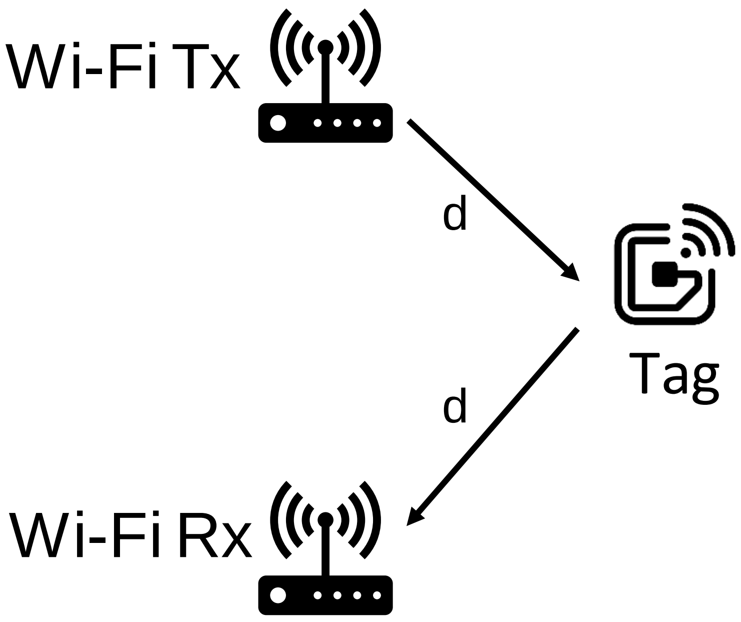


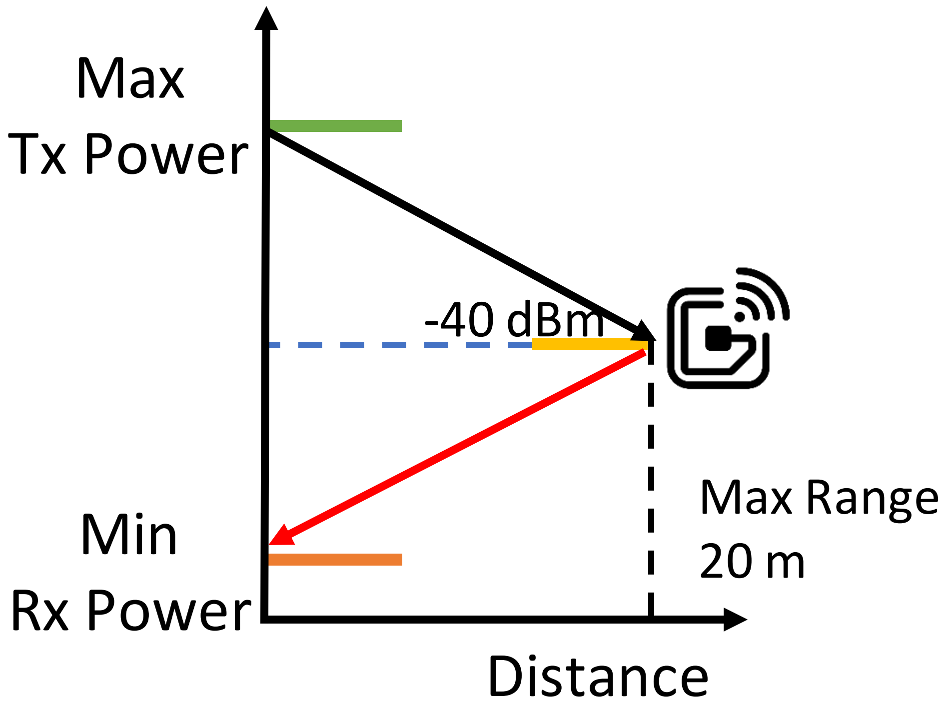
Synchronization Requirements



150 ns synchronization accuracy is necessary

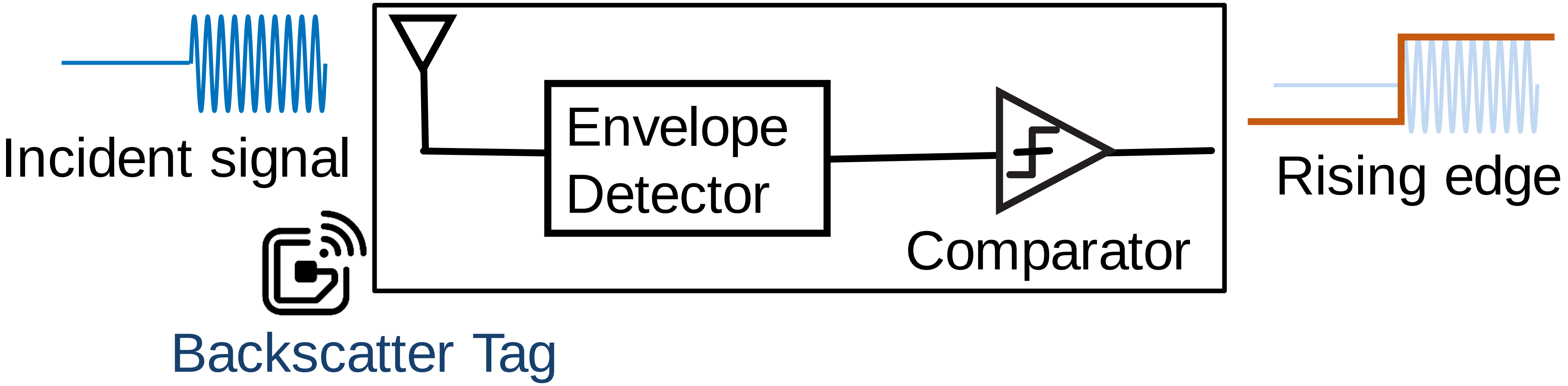
Requirement for long backscatter range





-40 dBm sensitivity needed with 150ns synchronization accuracy

How to Synchronize Incident signal with backscatter tag?



<150 ns

Synchronization accuracy

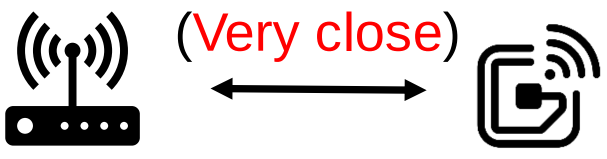
>6.67 MHz

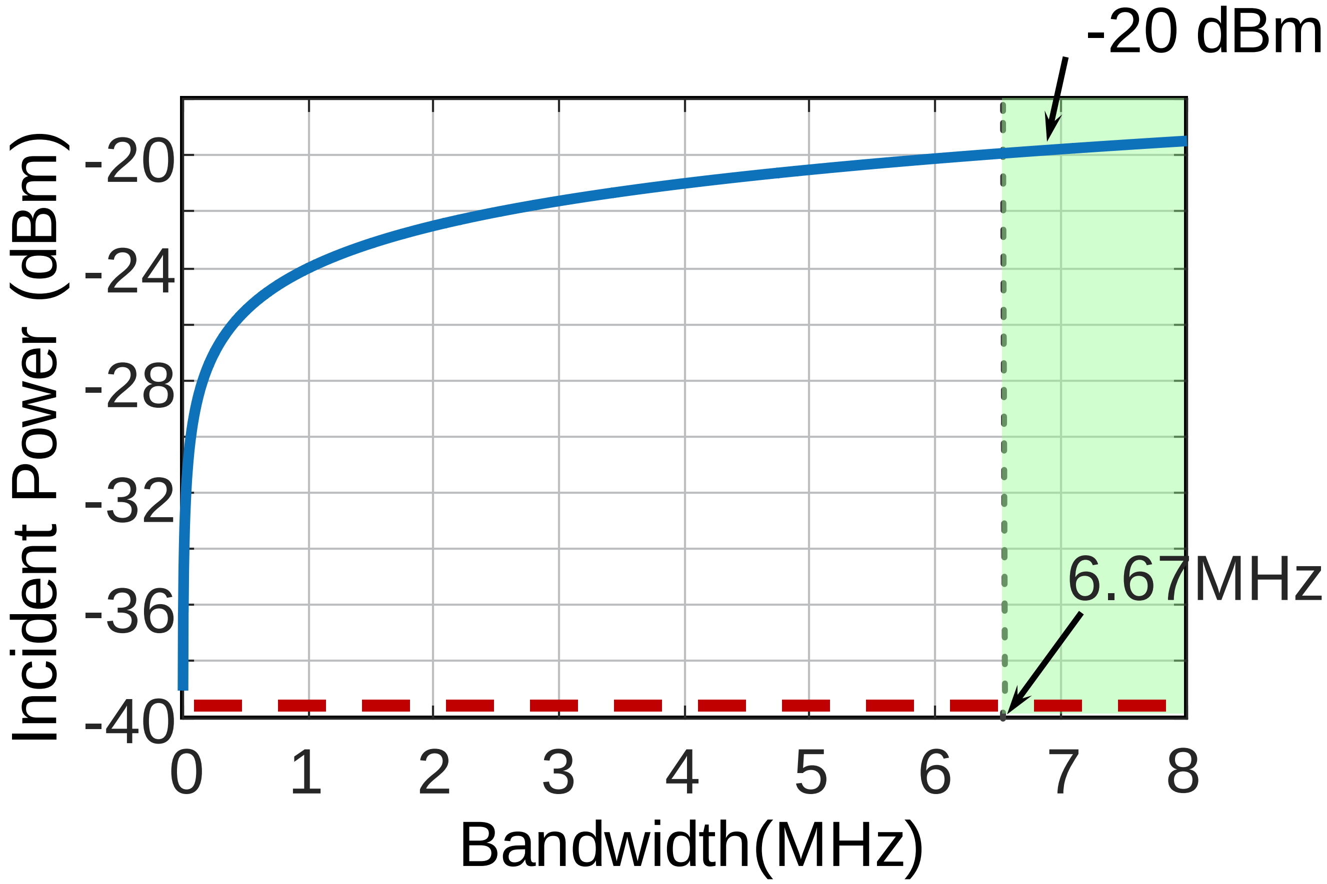
Envelope Detector (ED) Bandwidth

$$\text{ED Bandwidth} \propto \frac{1}{\text{Synchronization accuracy}}$$

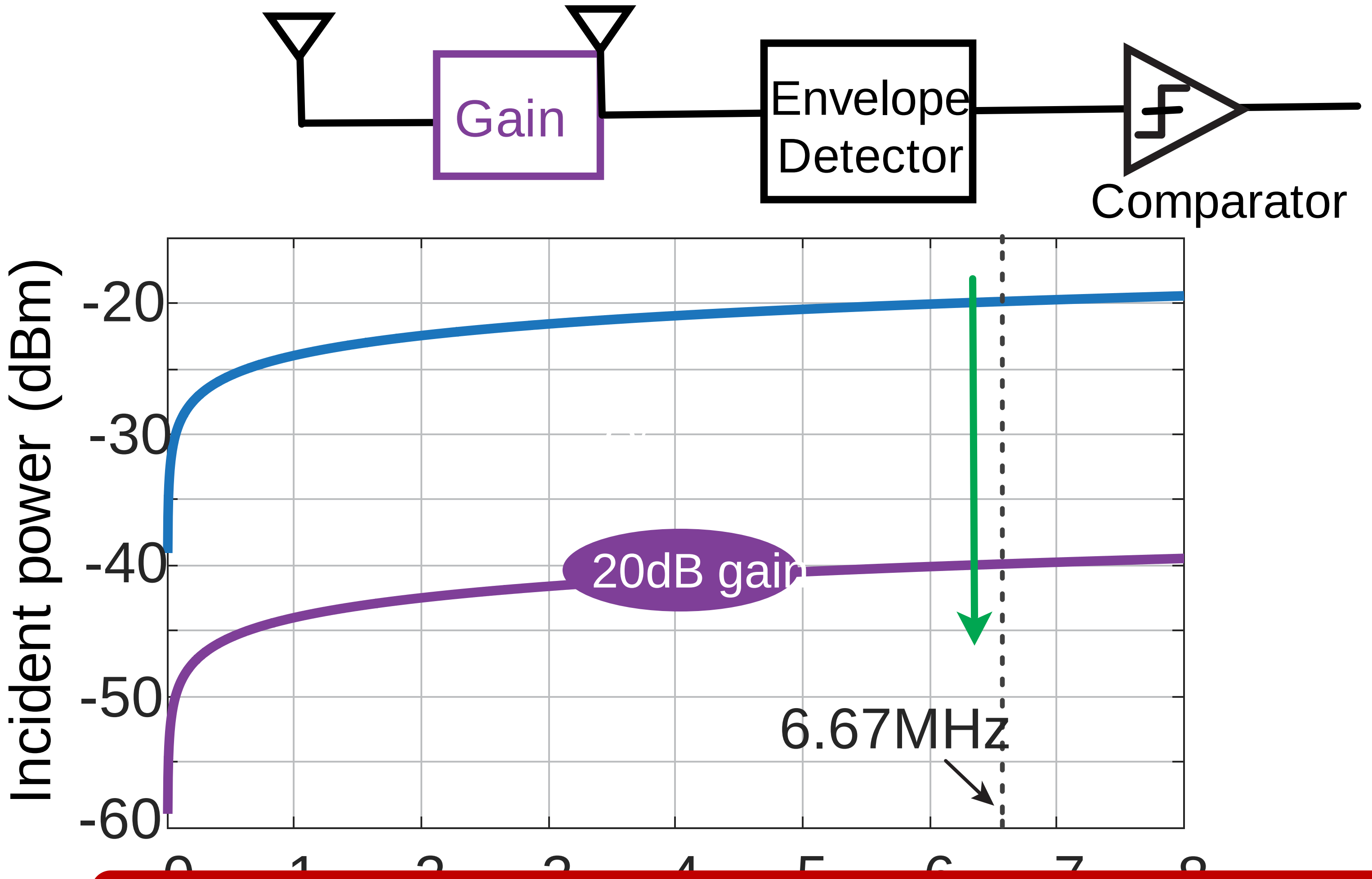
Challenge: How to enable long backscatter range?

Incident signal power > Noise power ∝ ED Bandwidth



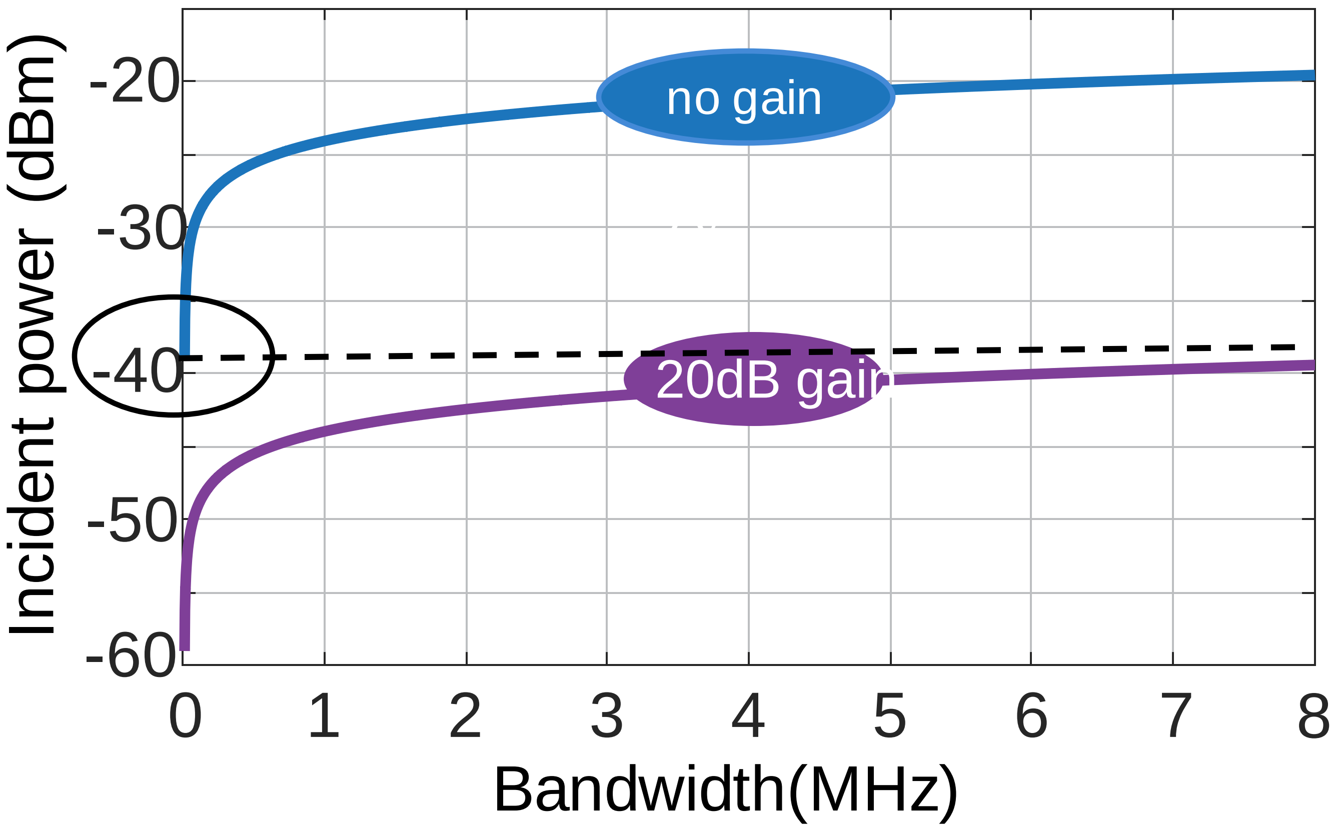


Improving the Tag sensitivity



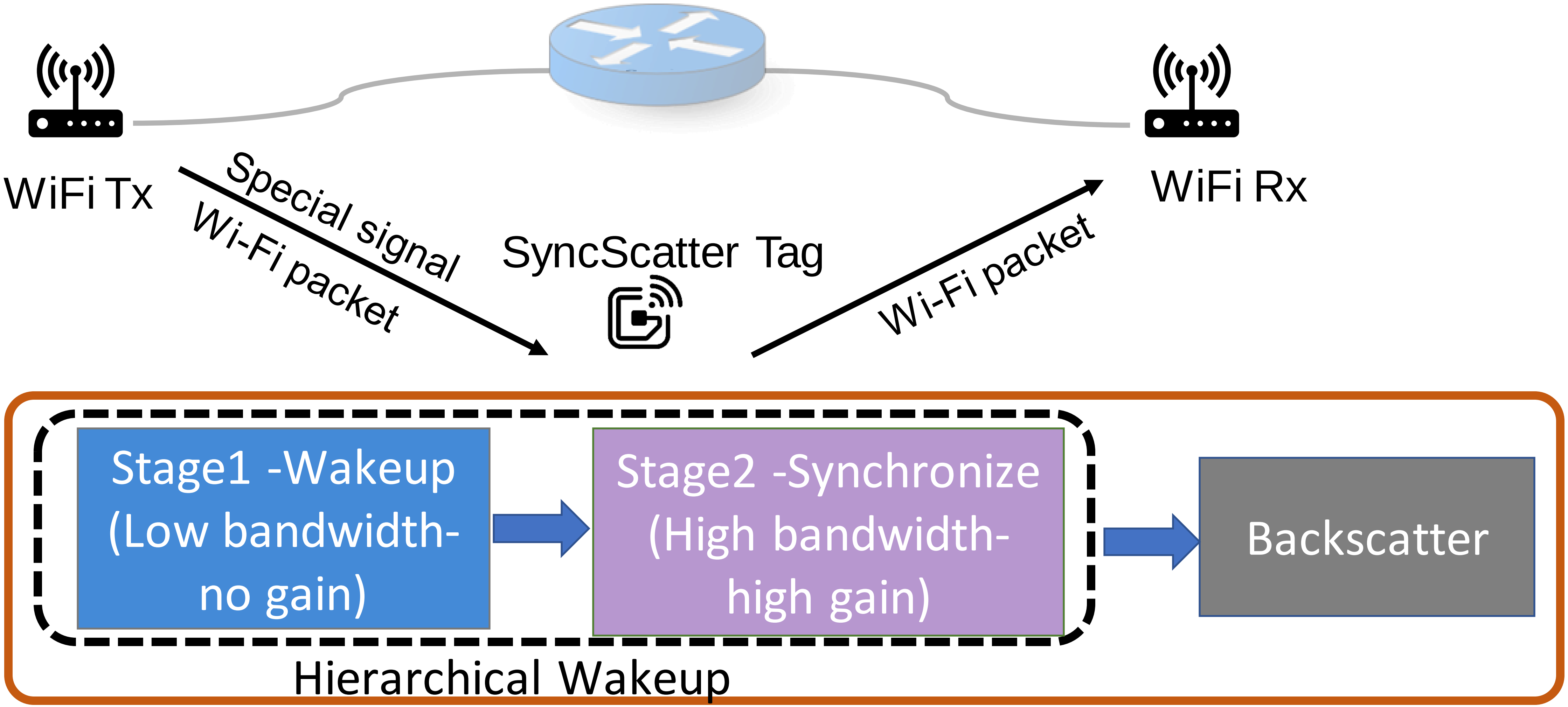
100 x increase in tag's power consumption

Achieving low power operation

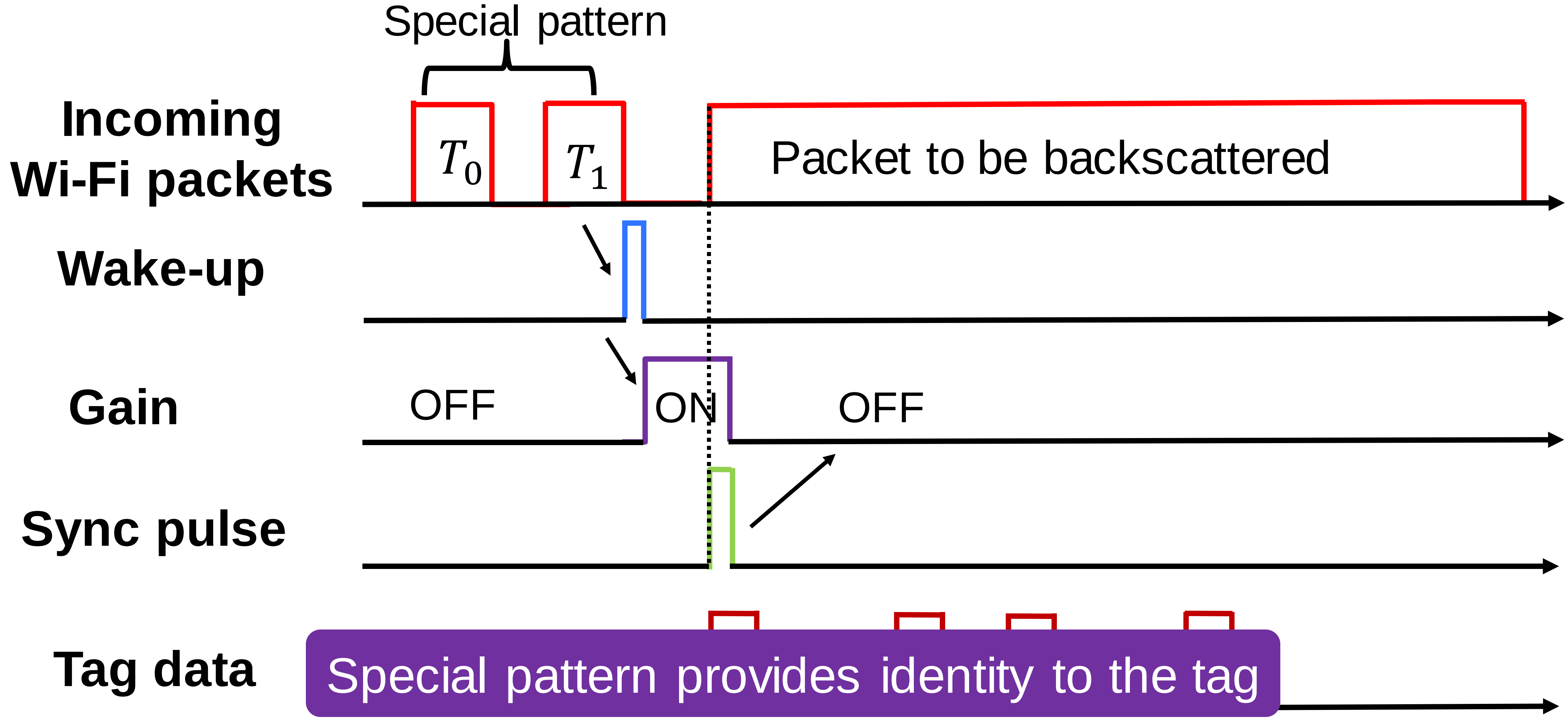


-40dBm incident power is sufficient for low bandwidth

Hierarchical wake-up receiver

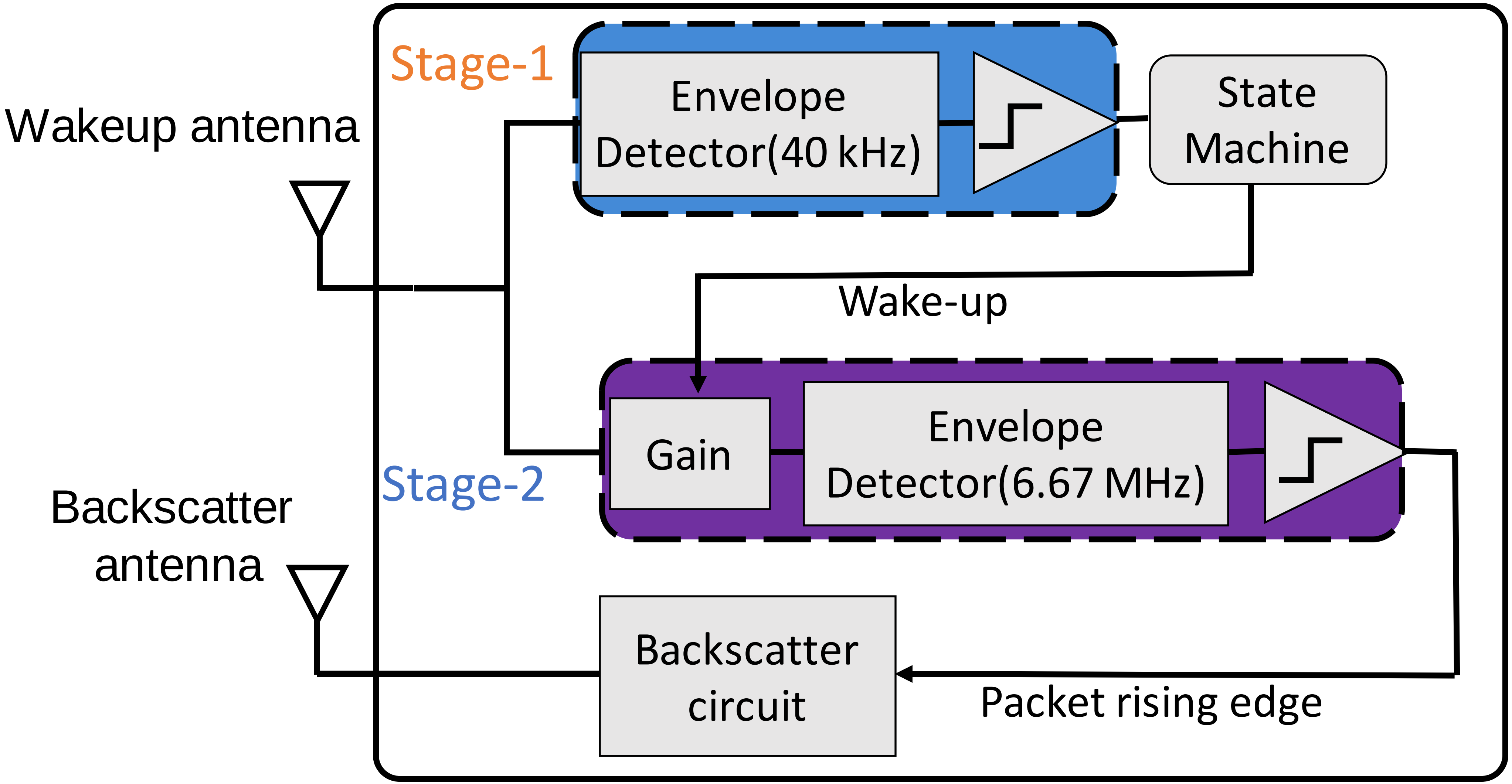


Hierarchical Wake-up receiver: Timing



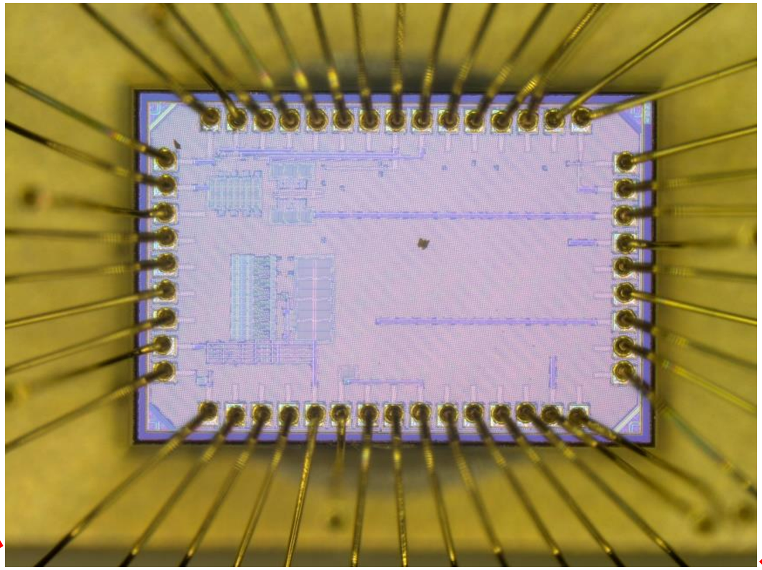
Special pattern provides identity to the tag

Overall tag Design

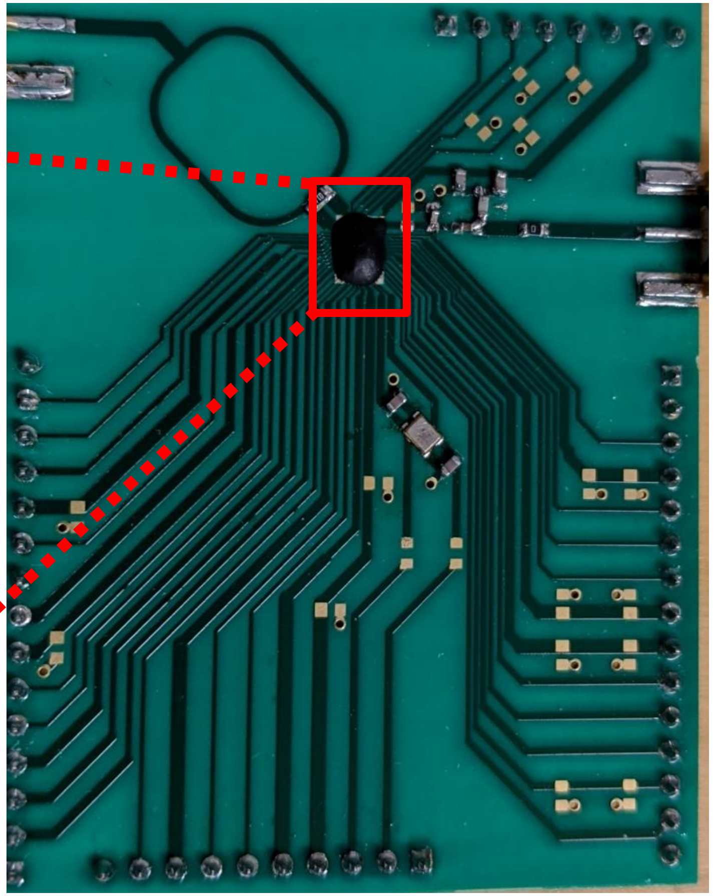


Integrated Circuit development

Tiny Chip – 1.5 mm^2

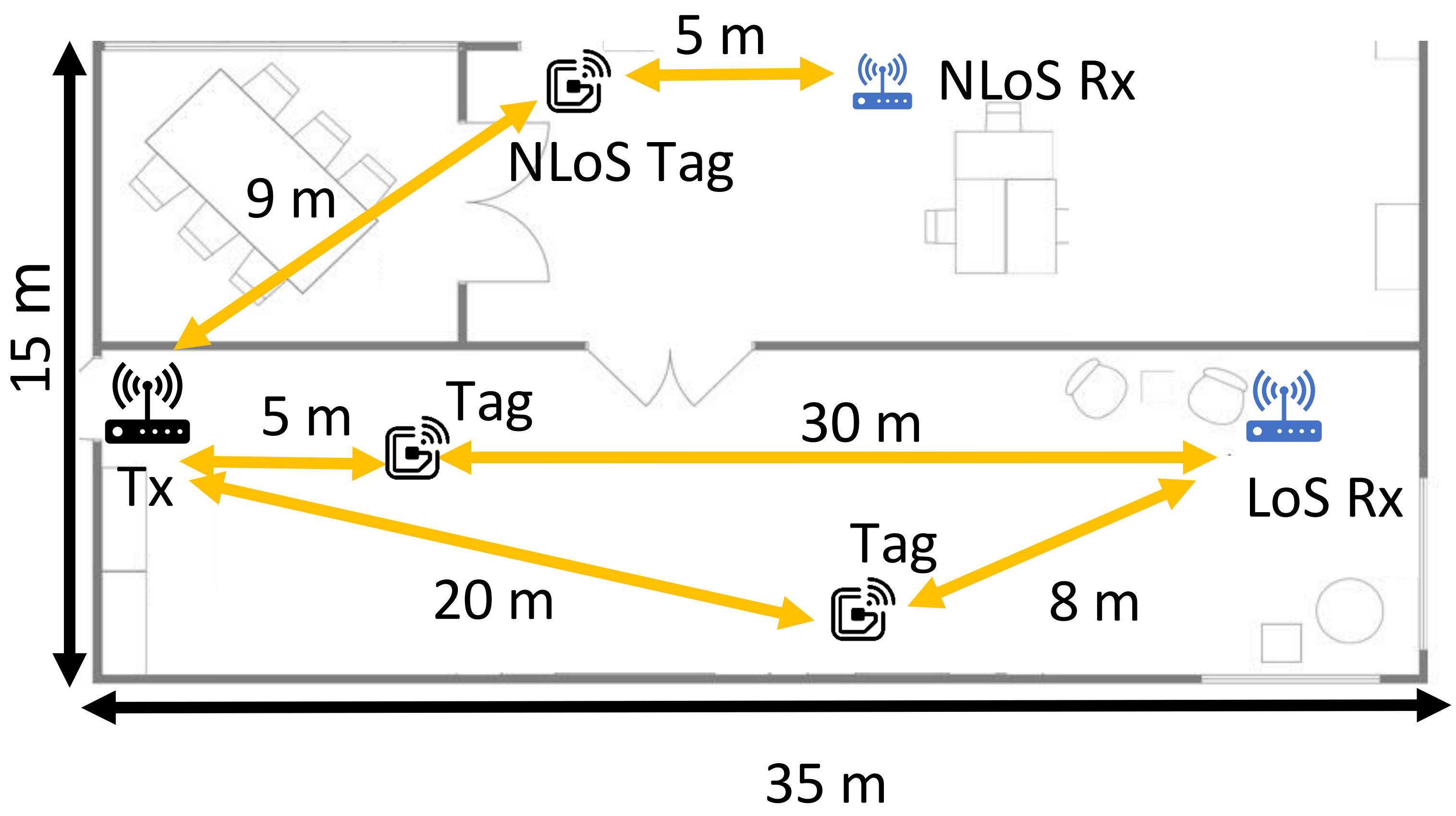


Integrated Circuit (IC)

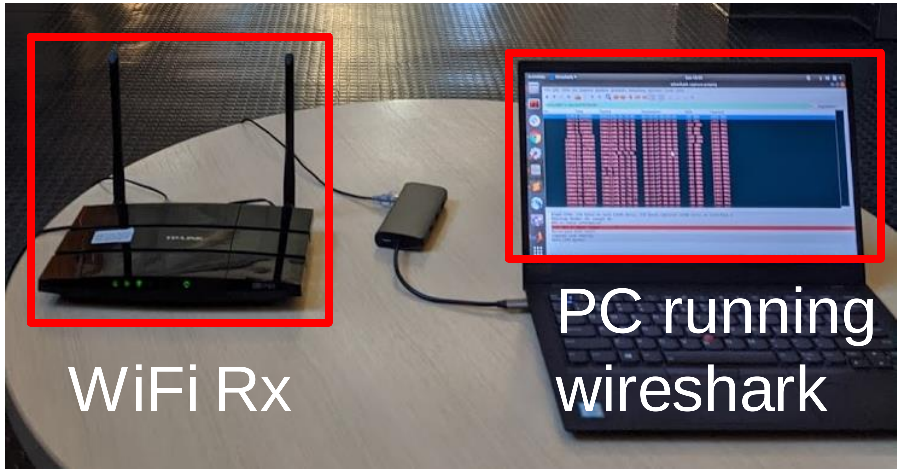


PCB

Evaluation setup



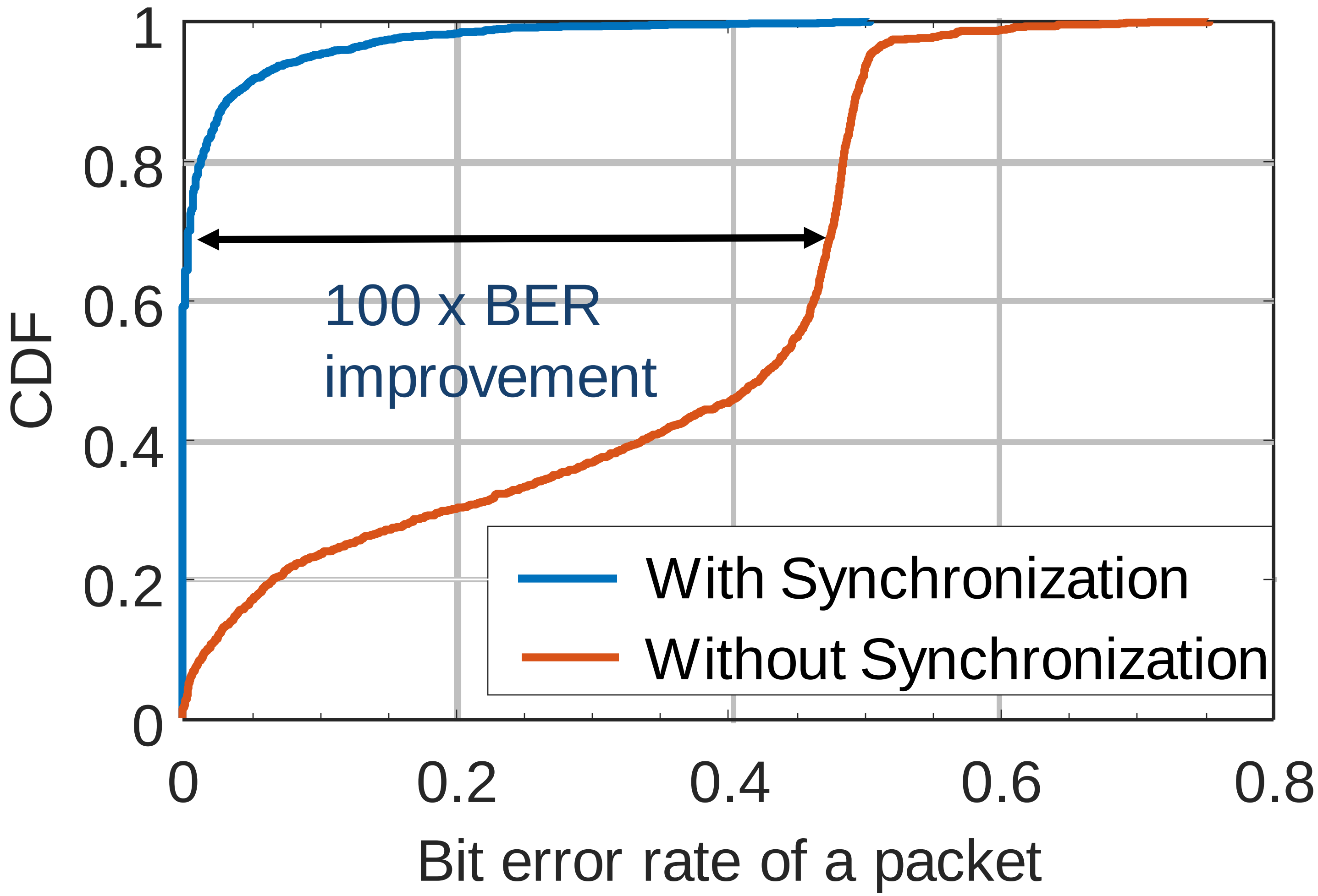
- TP-link WiFi access points
- 24dBm transmit power



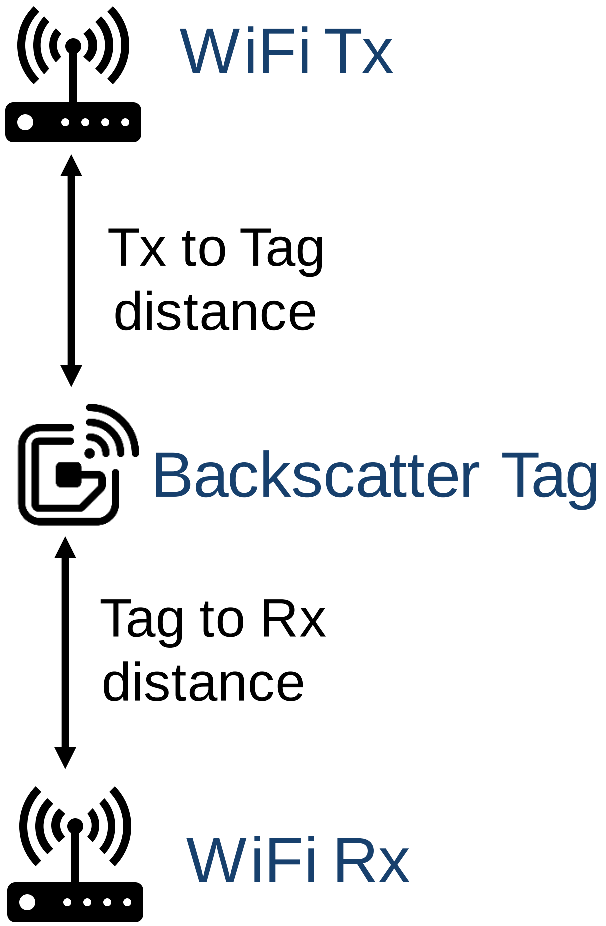
BER improvement

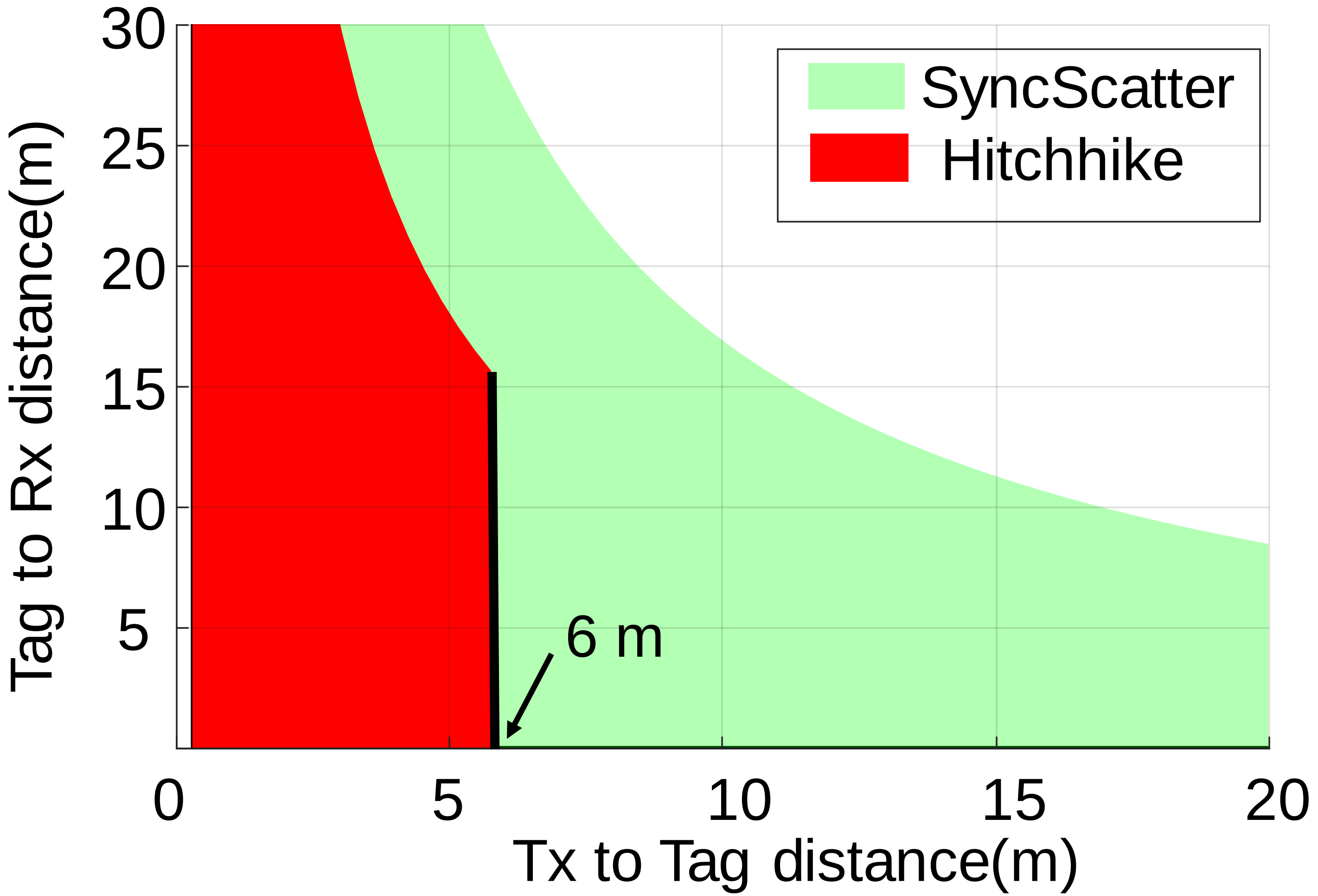
Without Synchronization: BER > 0.2 for 70 % of packets

With Synchronization: BER < 10^{-3} for 70 % of packets



Range improvement





Summary

- Hierarchical wake-up receiver design to achieve synchronization for Wi-Fi backscatter tags
- Extends the backscatter tag range for wide-area deployment
- Supports multi-tag operation

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Press Coverage

ScatterMIMO Smart Surface Runs for a Year on a Button Cell, Doubles Wi-Fi Speeds

Costing as little as $5 per unit to mass produce, the ScatterMIMO tiles boost Wi-Fi range by 50% and double data throughput.

Gareth Halfacree Follow
2 years ago • Communication

Engineer Manideep Dunna says the ScatterMIMO smart surface can be hung like a painting. (: UC San Diego)

UC San Diego News Center

February 17, 2020 | By Liezel Labios

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New Chip Brings Ultra-Low Power WiFi Connectivity to IoT Devices

More portable, fully wireless smart home setups. Lower power wearables. Batteryless smart devices. These could all be made possible thanks to a new ultra-low power WiFi radio developed by electrical engineers at the University of California San Diego.

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ACM TECHNEWS

Chip Brings Ultra-Low-Power Wi-Fi to IoT Devices

By UC San Diego News Center
February 24, 2020
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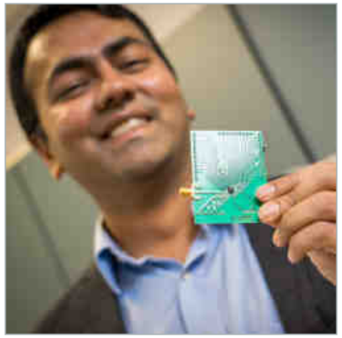

A new ultra-low power Wi-Fi radio developed by engineers at the University of California San Diego enables Internet of Things devices to communicate with existing Wi-Fi networks using 5,000 times less power than todays Wi-Fi radios.

Researchers at the University of California, San Diego (UCSD) have developed an ultra-low-power Wi-Fi radio that enables Internet of Things (IoT) devices to communicate with existing Wi-Fi networks using 5,000 times less power than conventional Wi-Fi.

The new device, housed in a chip smaller than a grain of rice, consumes just 28 microwatts of power while transmitting data at a rate of two megabits per second over a range of up to 21 meters.

The Wi-Fi radio transmits data via backscattering—a technique that takes incoming Wi-Fi signals, modifies the signals, and encodes its own data onto them, before reflecting the new signals onto a different Wi-Fi channel to another device or access point.

UCSD's Dinesh Bharadia said, "You can connect your phone, your smart devices, even small cameras or various sensors to this chip, and it can directly send data from these devices to a Wi-Fi access point near you. You don't need to buy anything else. And it could last for years on a single coin-cell battery."

Thank you

Hosts:

- Prof. Marco Zimmerling
- Kai Geissdoerfer

Advisors:

- Prof. Dinesh Bharadia
- Prof. Patrick Mercier

Collaborators:

- Chi Zhang
- Shihkai Kuo
- Kshitiz Bansal
- Miao Meng
- Sanjeev Ganesh