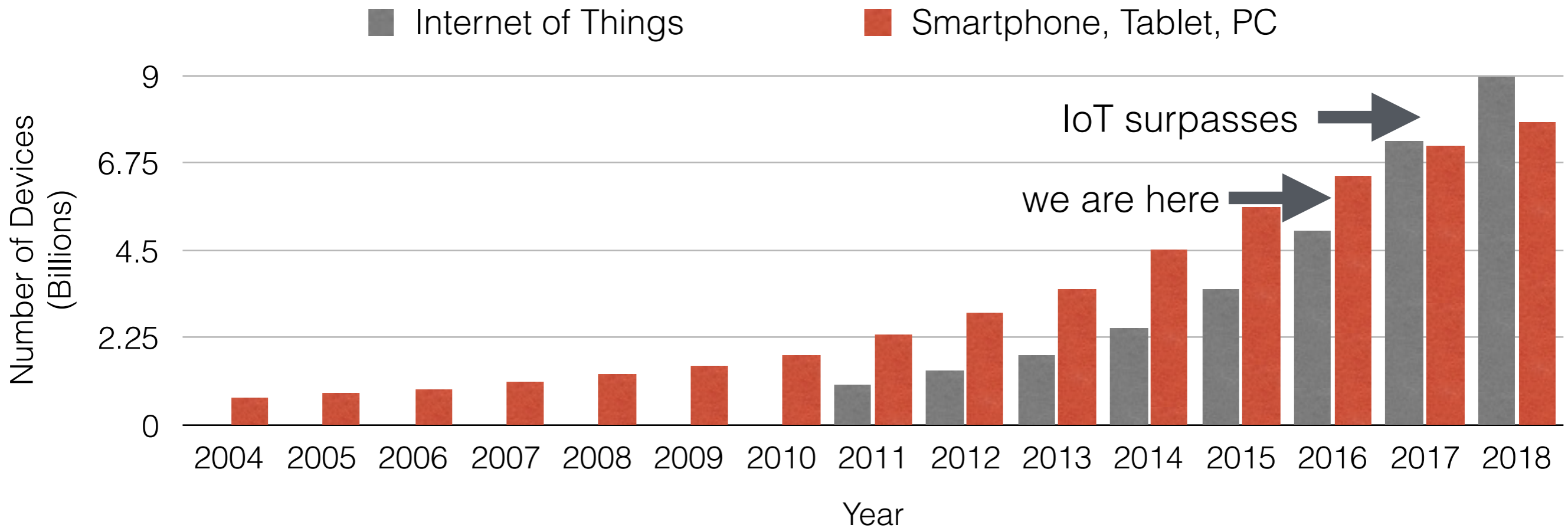


HitchHike: Enabling Backscatter Communication among Commodity WiFi Radios

Dinesh Bharadia
Assistant Professor, UCSD

dineshb@ucsd.edu

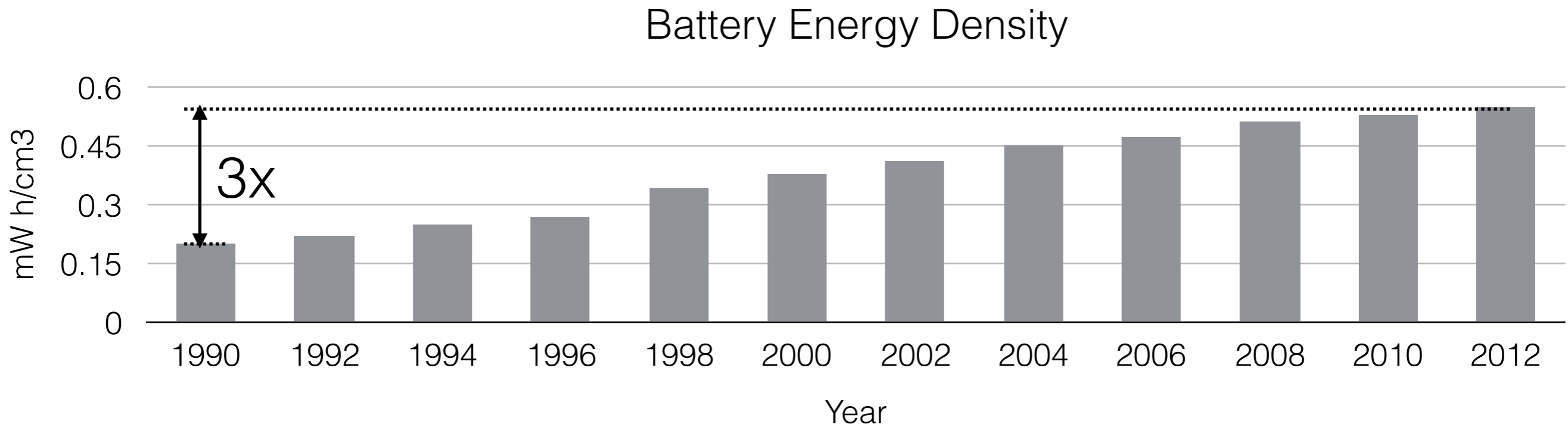
Internet of Things (IoT) — First-class Citizen of Future Internet!



Vision — Ubiquitous Deployment of IoT Devices

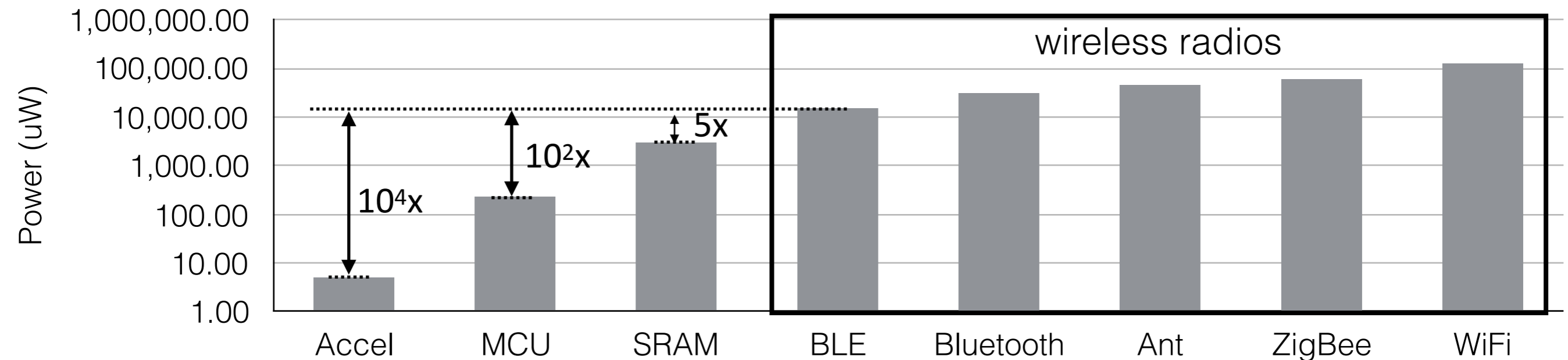


Limiting Factor One — Battery Energy Density



Slow improvement — 3x over 22 years!

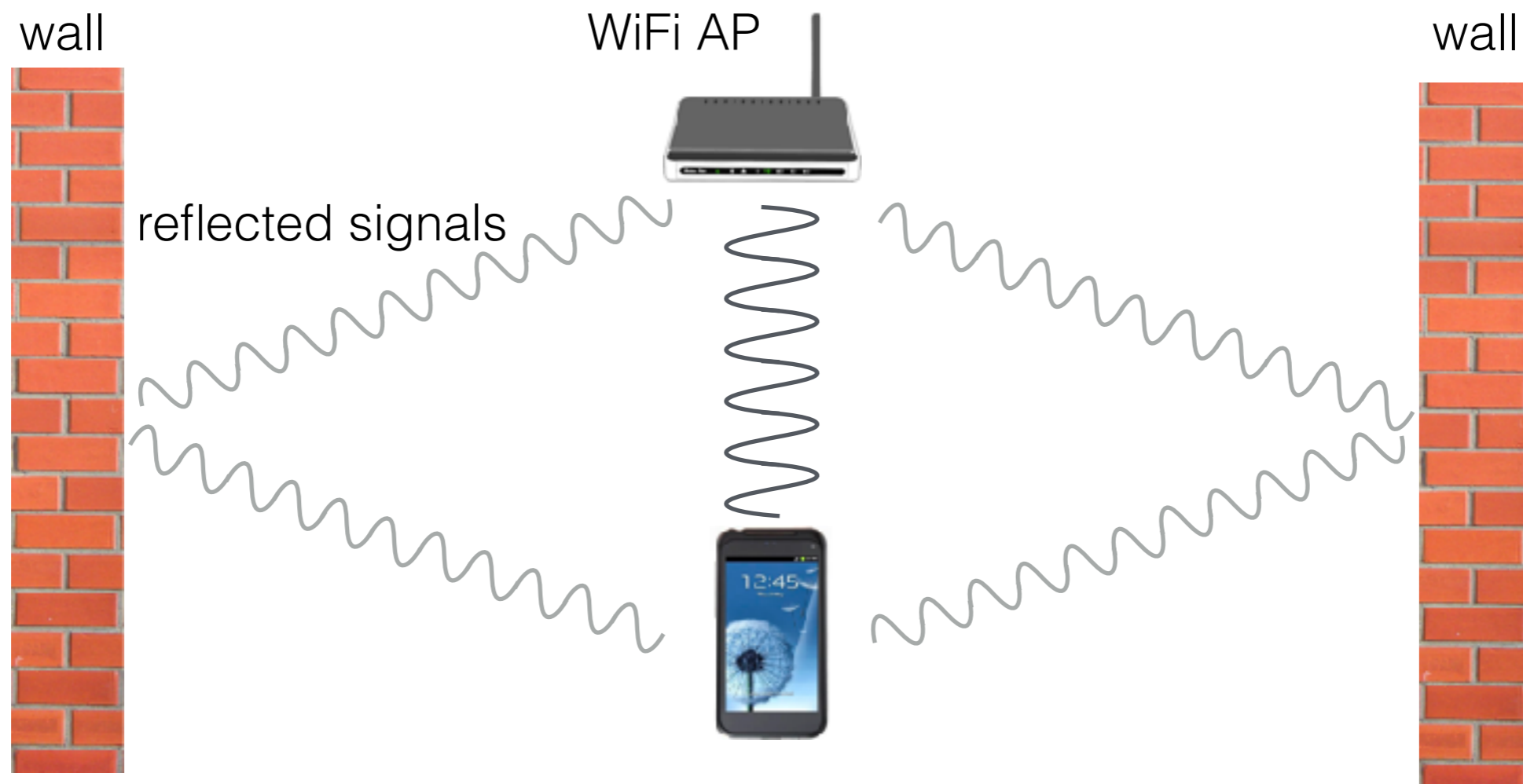
Limiting Factor Two — Wireless Radio Power Consumption



Wireless communication consumes orders of magnitude higher power compared to computation, storage, and sensing.

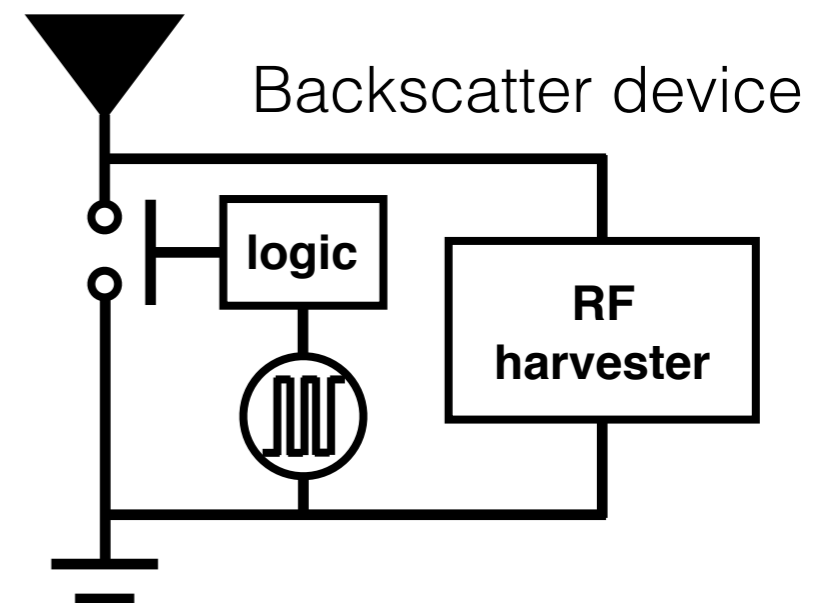
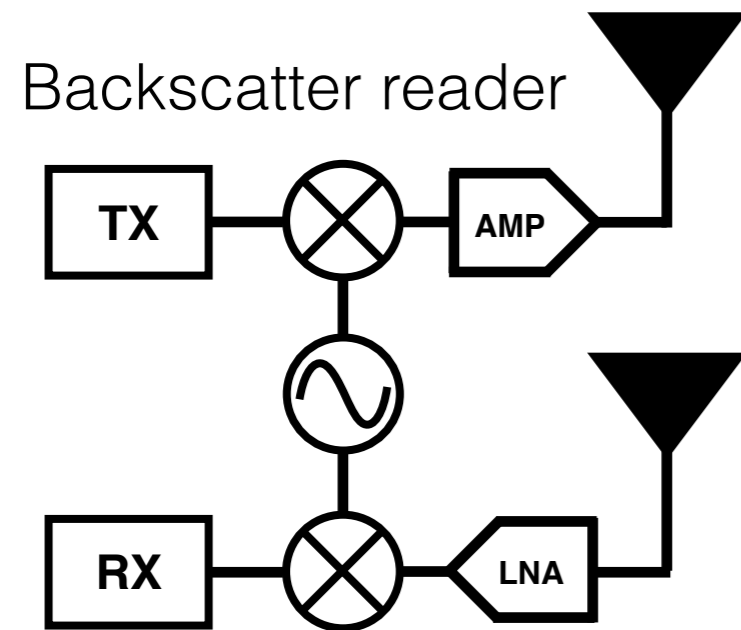
How should we communicate with IoT devices?

Insight — Leverage reflected wireless signals!

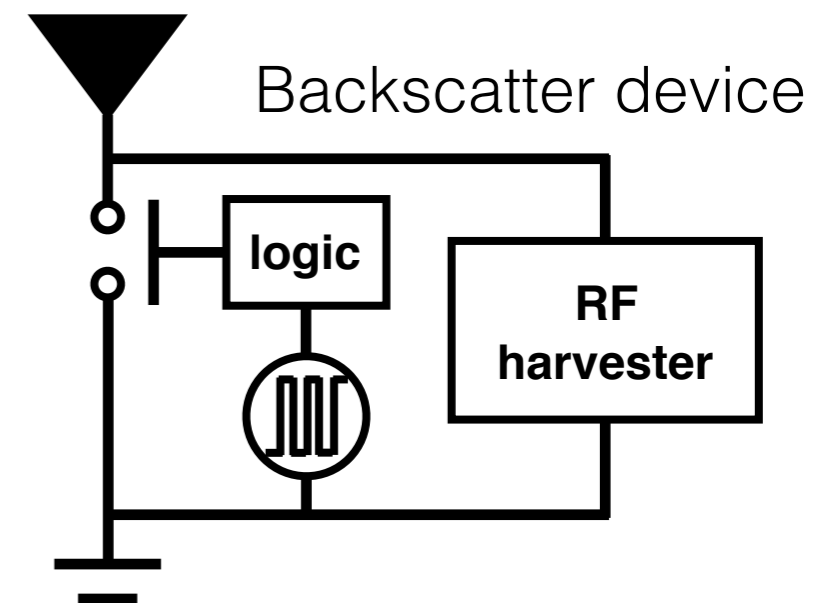
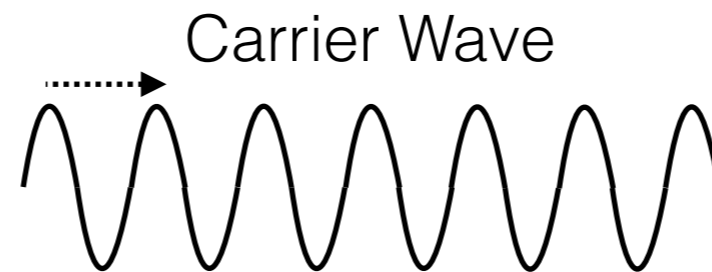
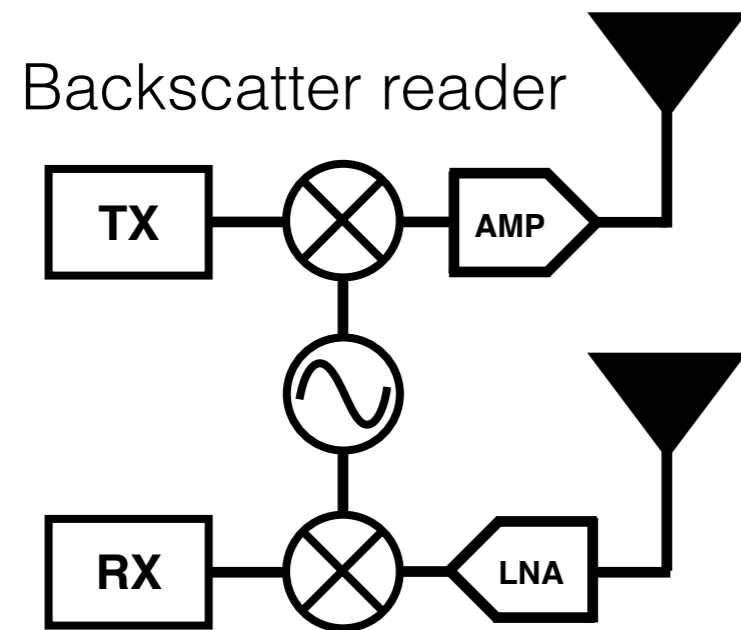


Static reflection does not consume power. Can we leverage reflected wireless signals and embed information there?

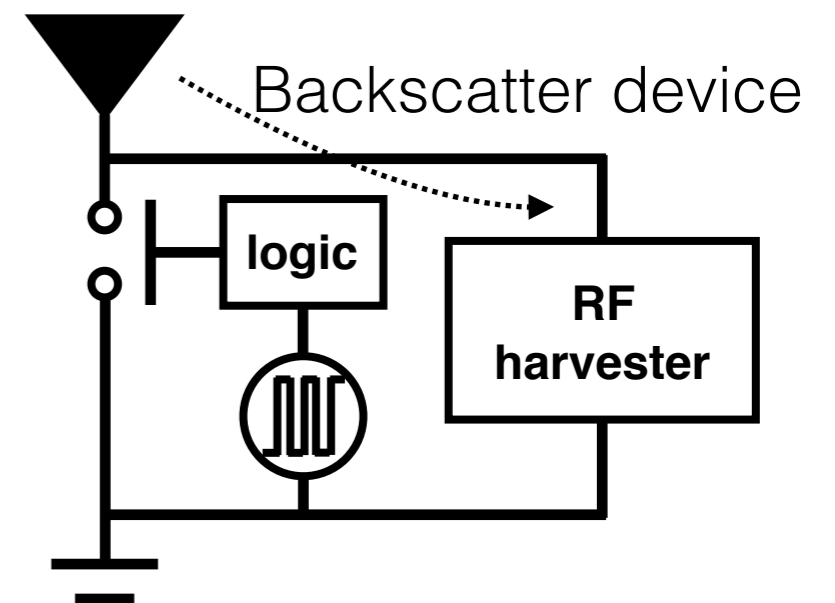
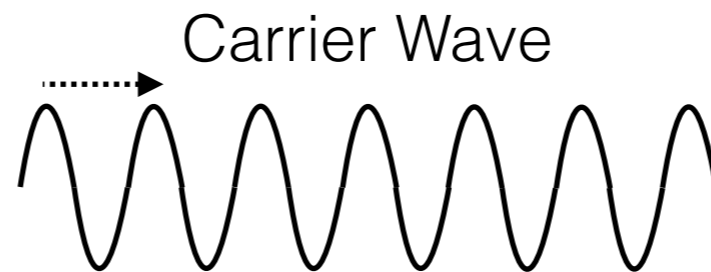
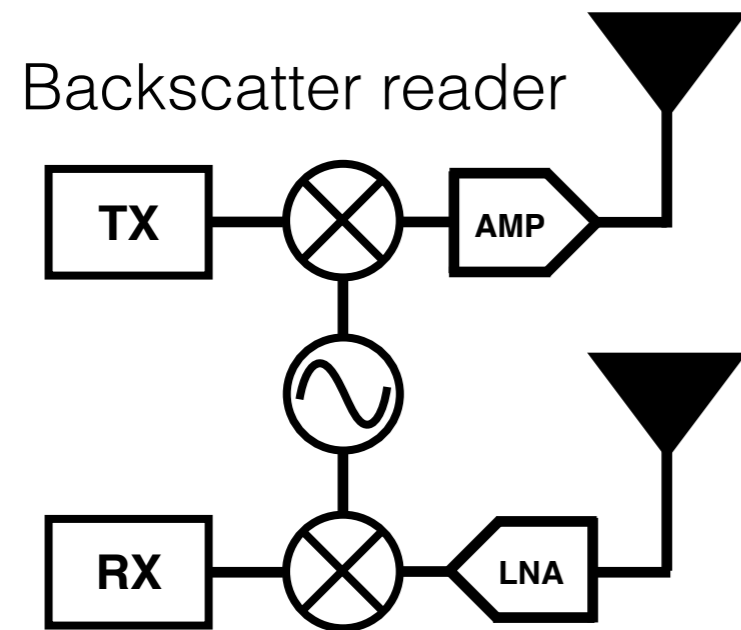
Backscatter — An Ultra Low Power Communication Primitive



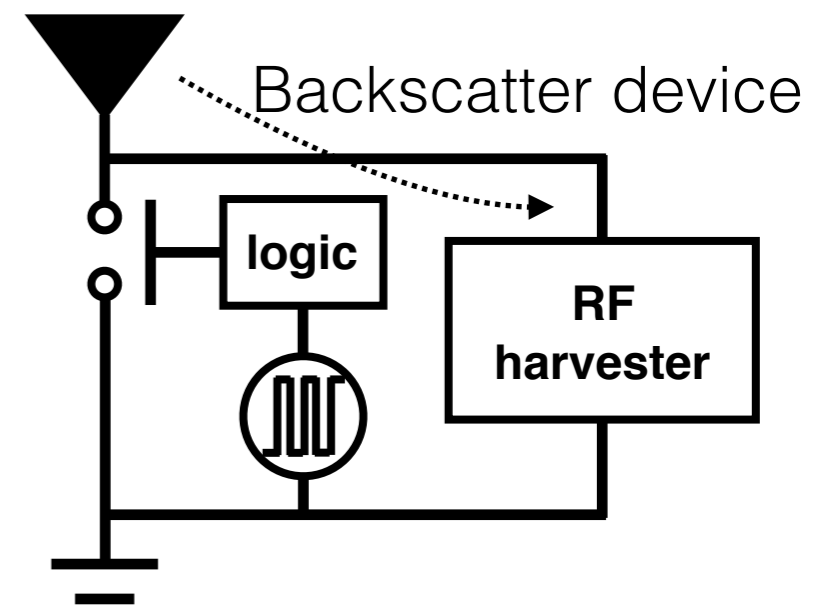
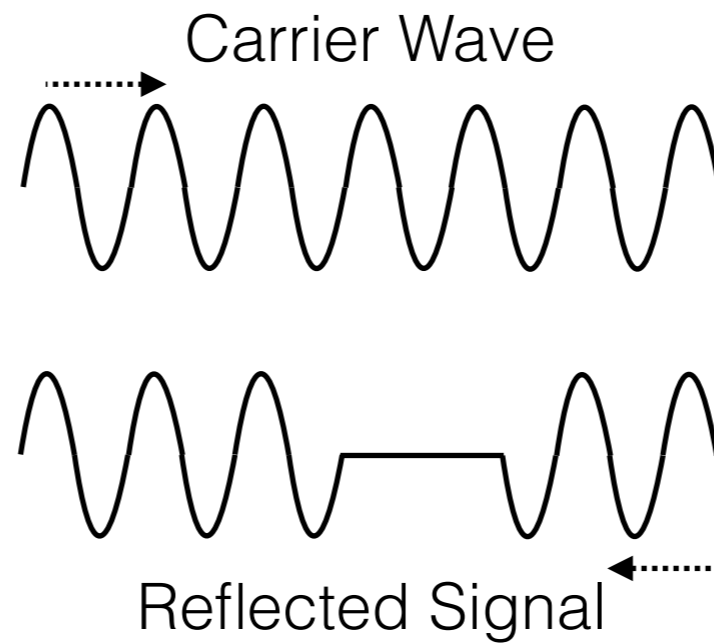
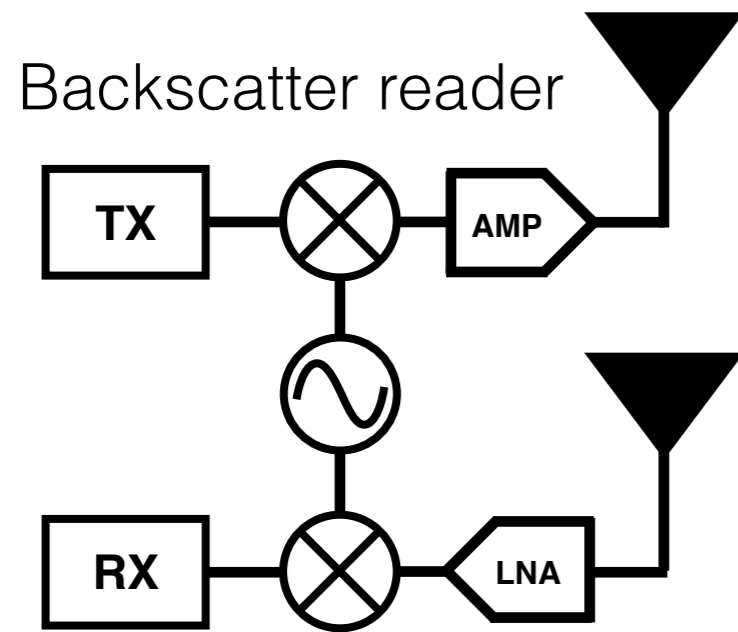
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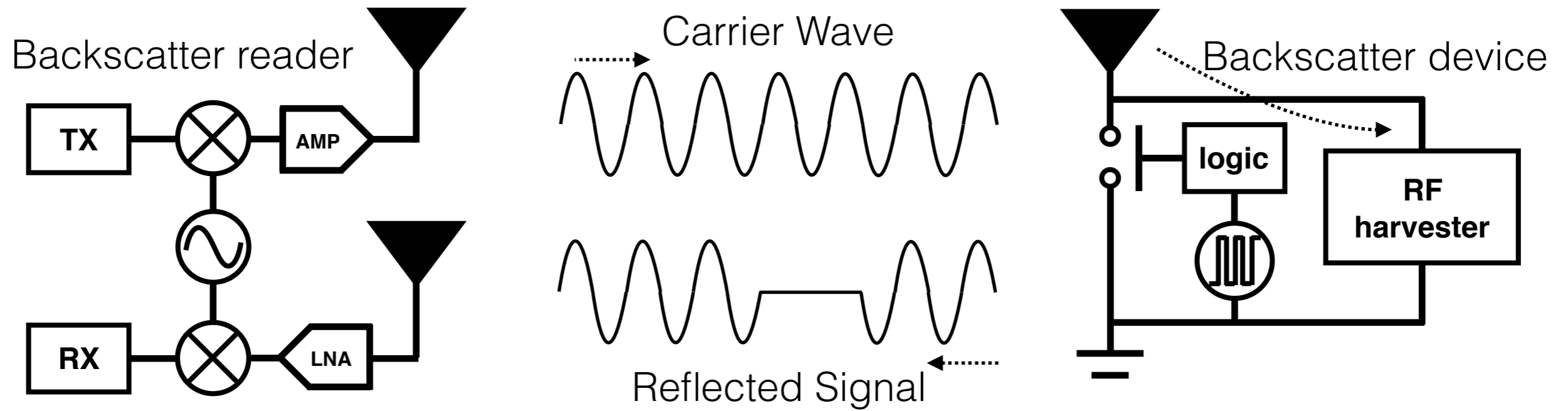
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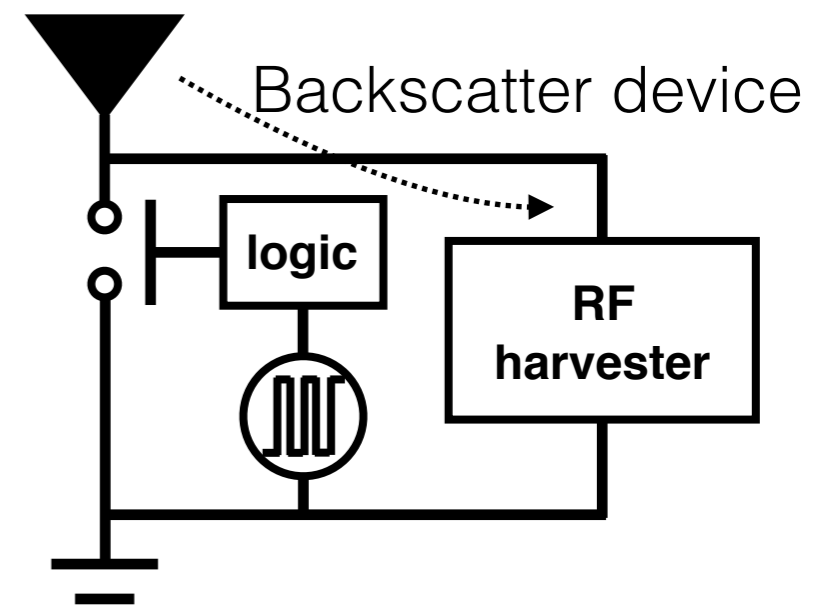
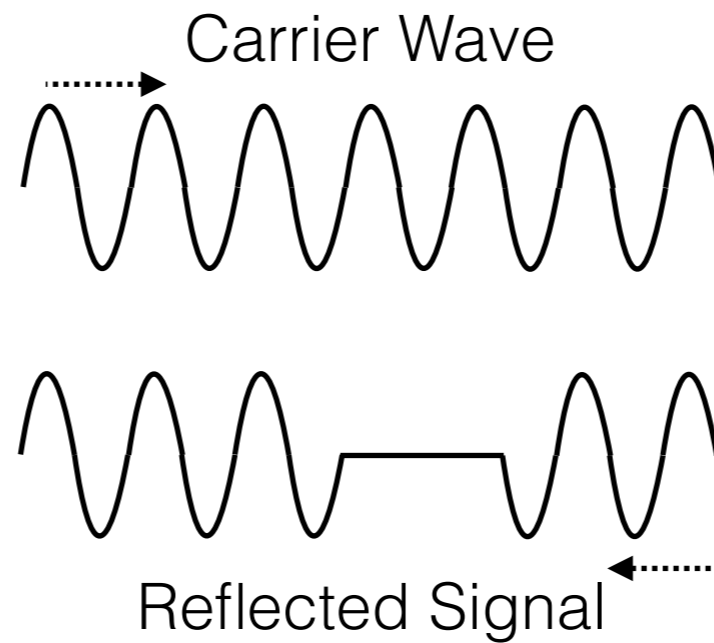
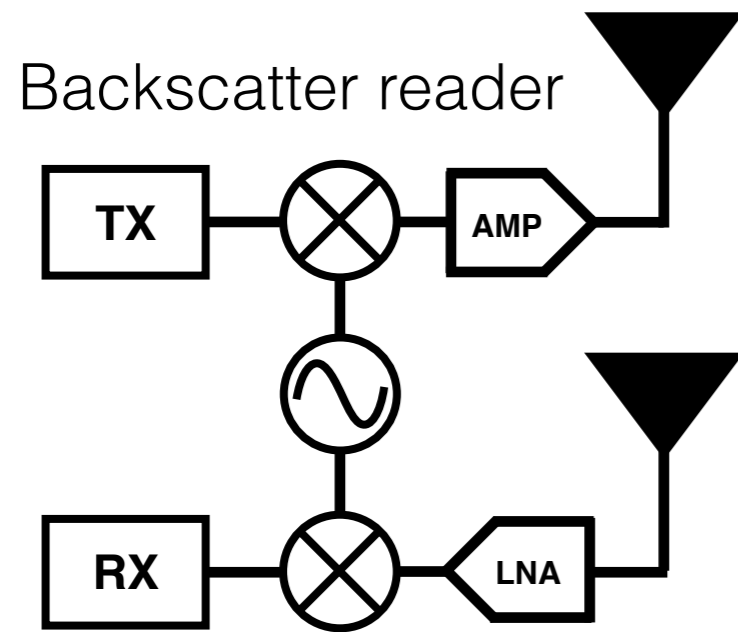
Backscatter — An Ultra Low Power Communication Primitive



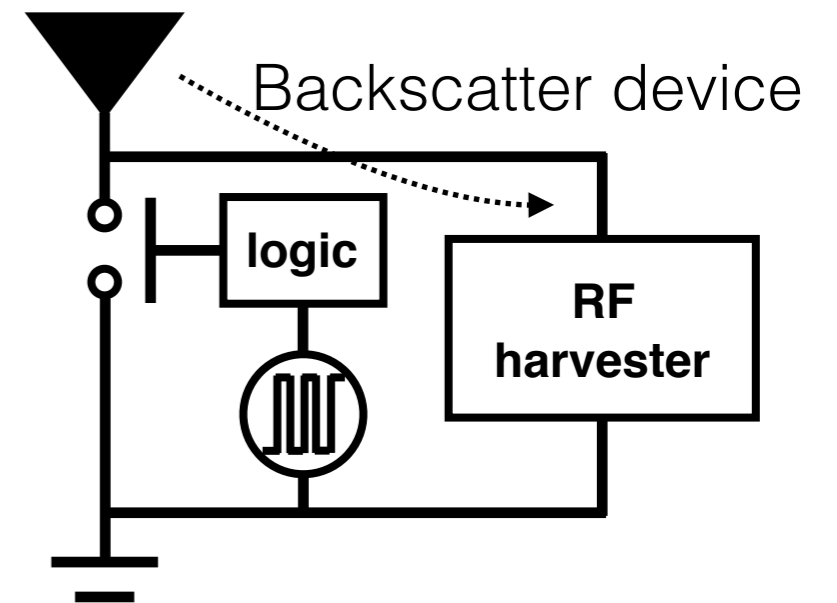
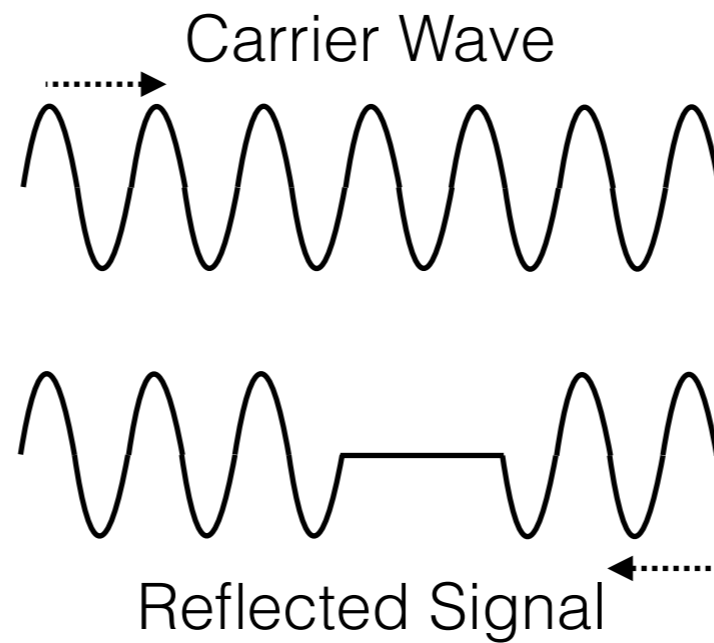
Backscatter enables ultra low-power wireless communication.

What are challenges of using backscatter for IoT devices?

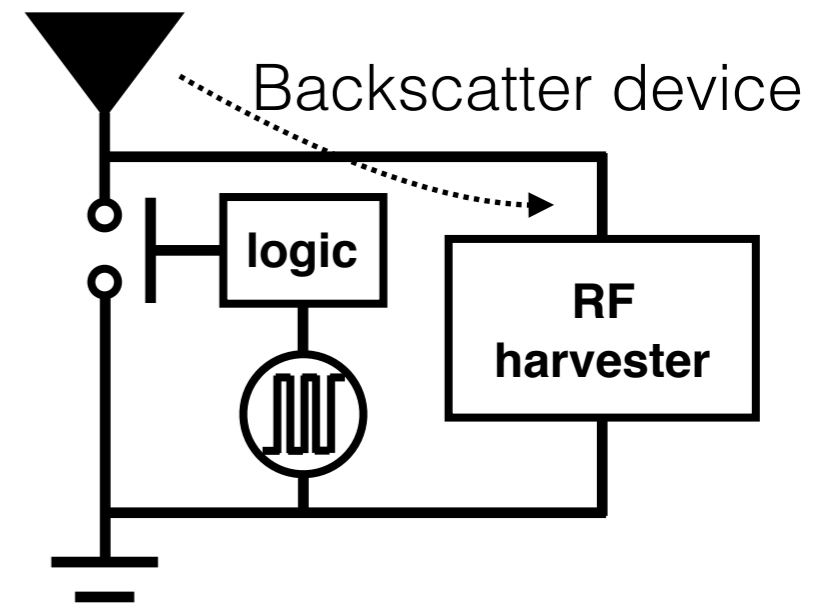
Challenge — Do not have reader infrastructure!



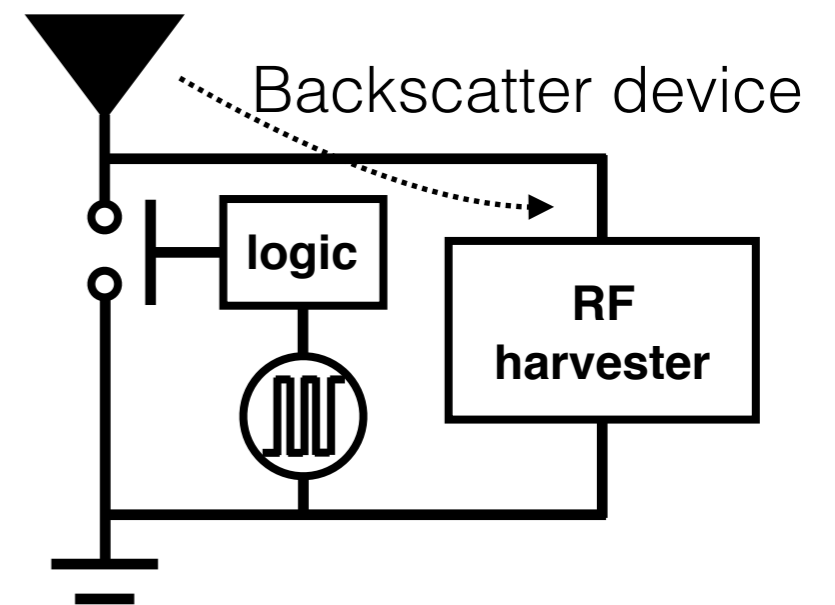
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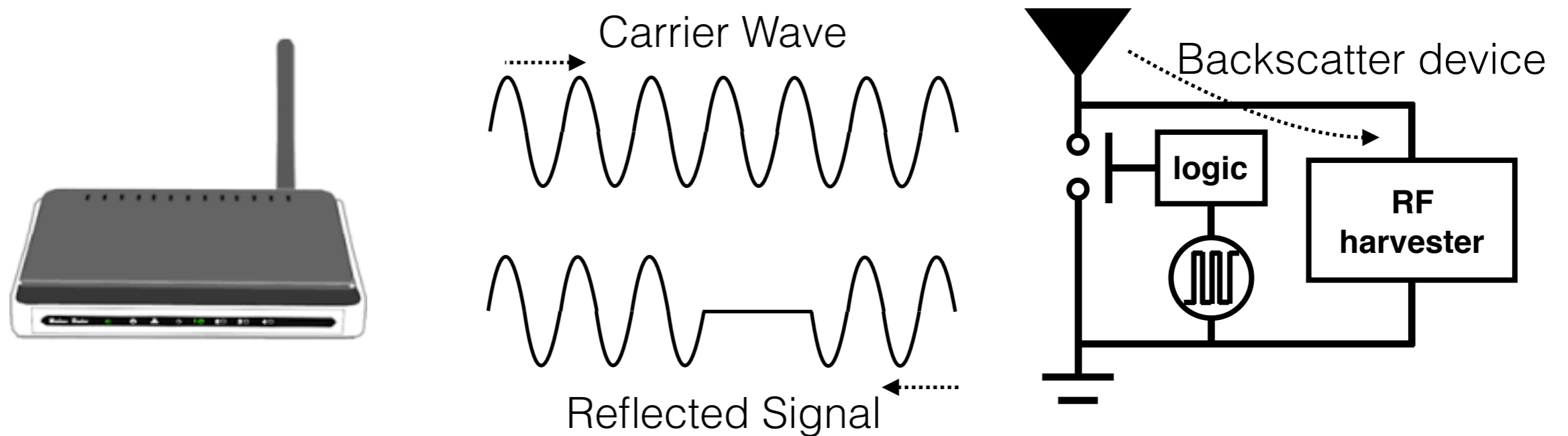


Challenge — Do not have reader infrastructure!



The lack of reader infrastructure prevents the wide deployment of backscatter systems.

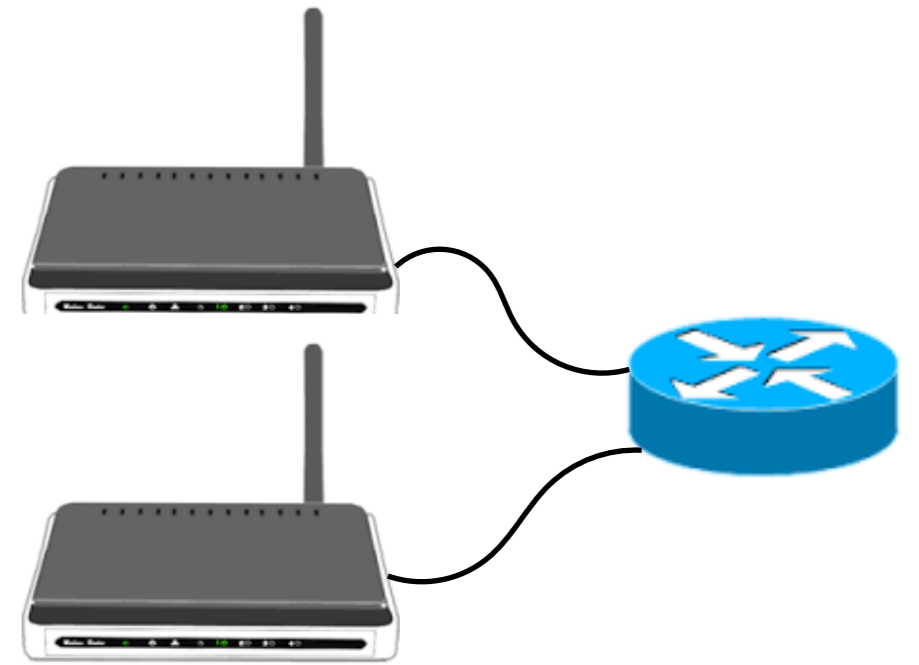
Can we leverage WiFi signals for backscatter?



Can we embed backscatter bits on an existing WiFi traffic?

XoRFi — enabling backscatter communication among commodity WiFi radios

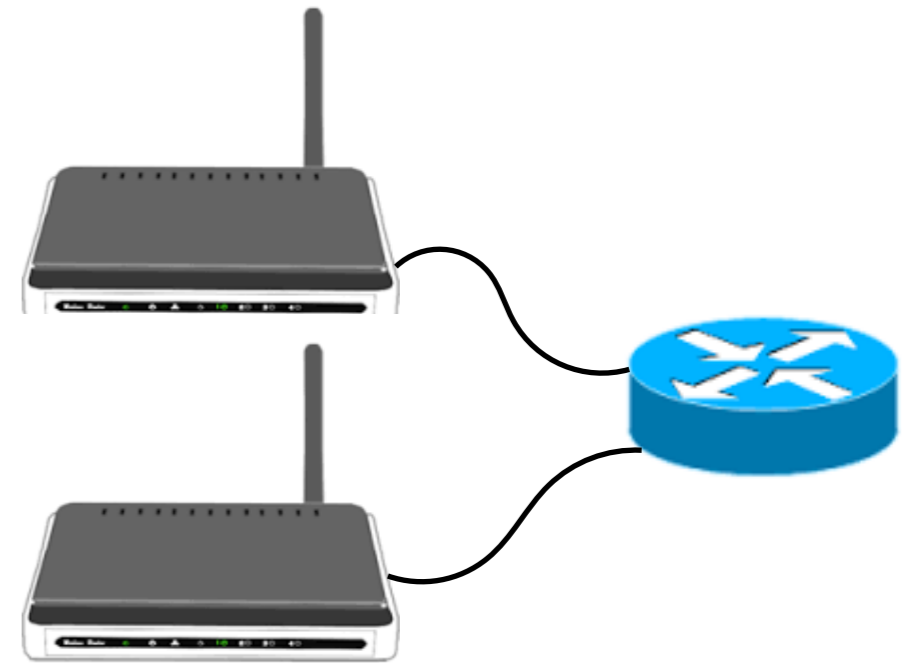
HitchHike — embed backscatter bits on 802.11b WiFi



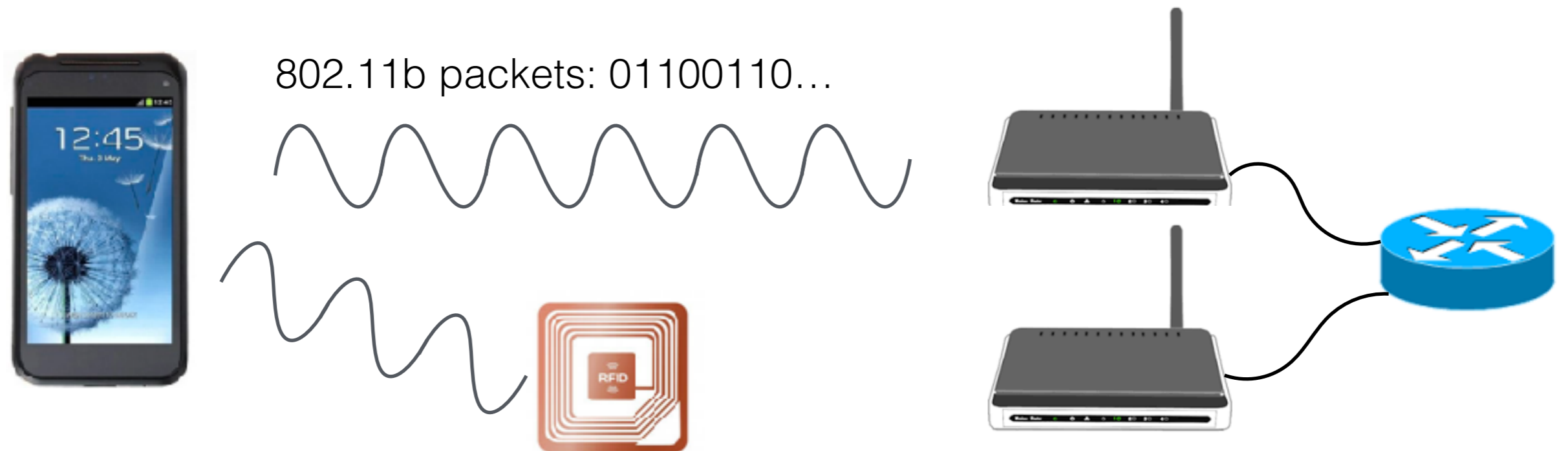
HitchHike — embed backscatter bits on 802.11b WiFi



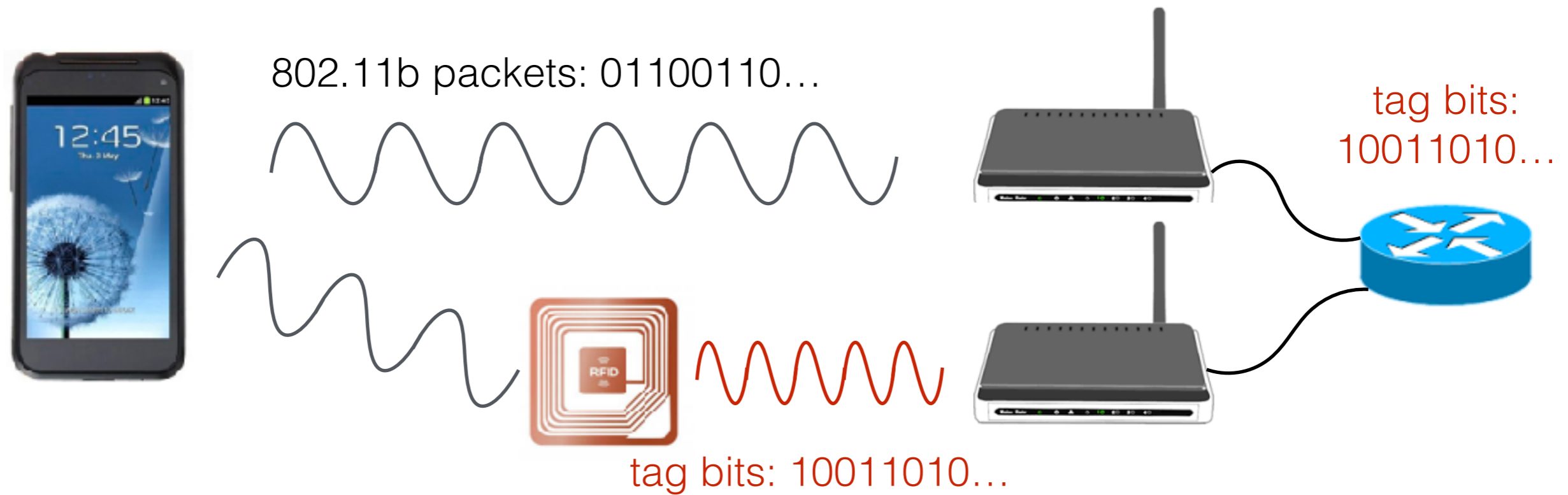
802.11b packets: 01100110...



HitchHike — embed backscatter bits on 802.11b WiFi



HitchHike — embed backscatter bits on 802.11b WiFi

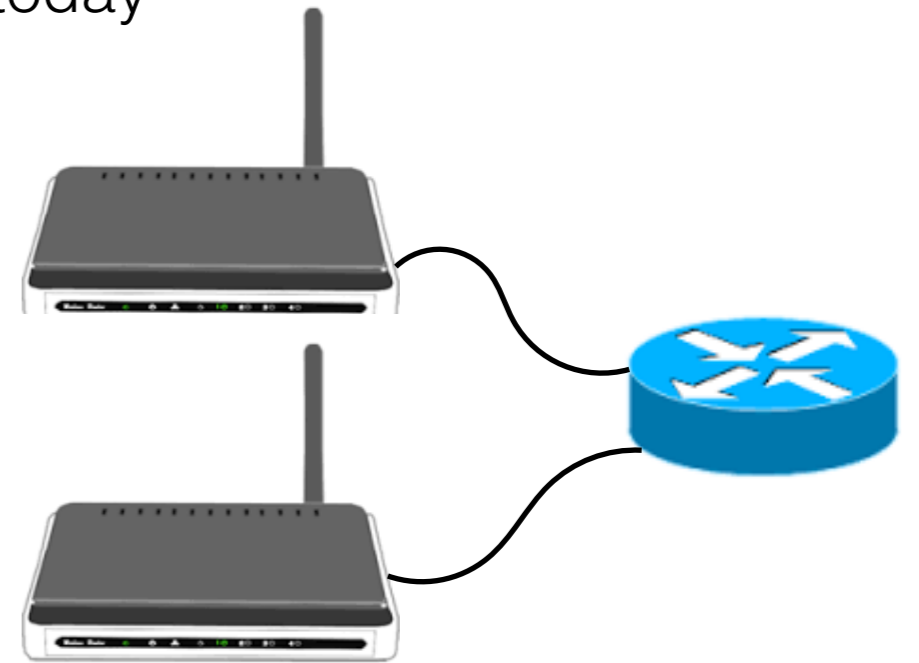


802.11b WiFi Primer

802.11b — a WiFi protocol that supports 11Mbps transmission at 2.4GHz band.
Most smartphones/tablets/laptops support 802.11b today

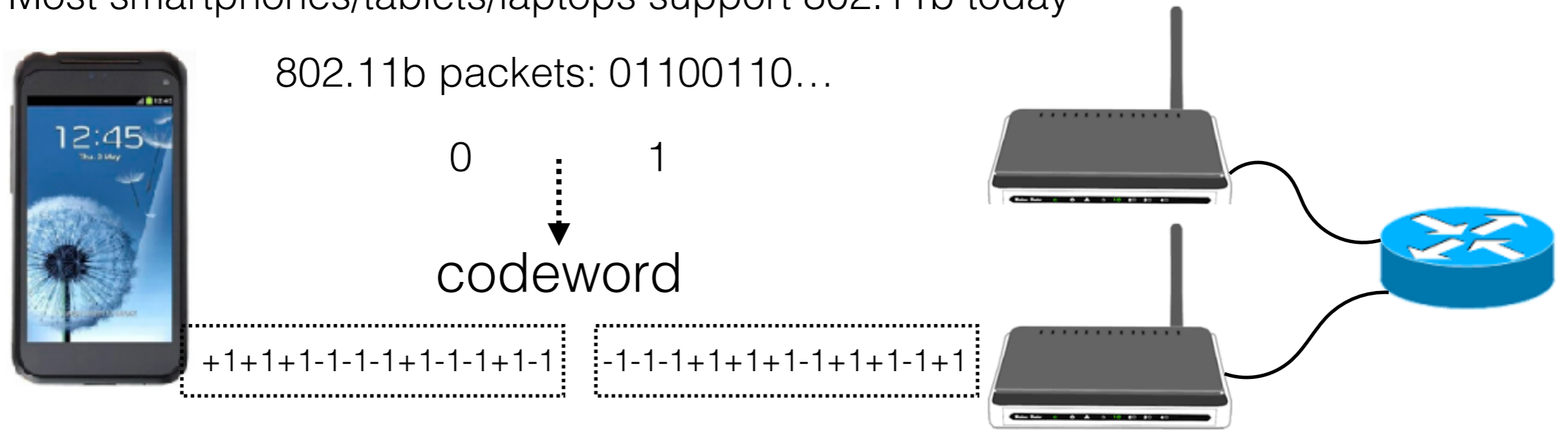


802.11b packets: 01100110...



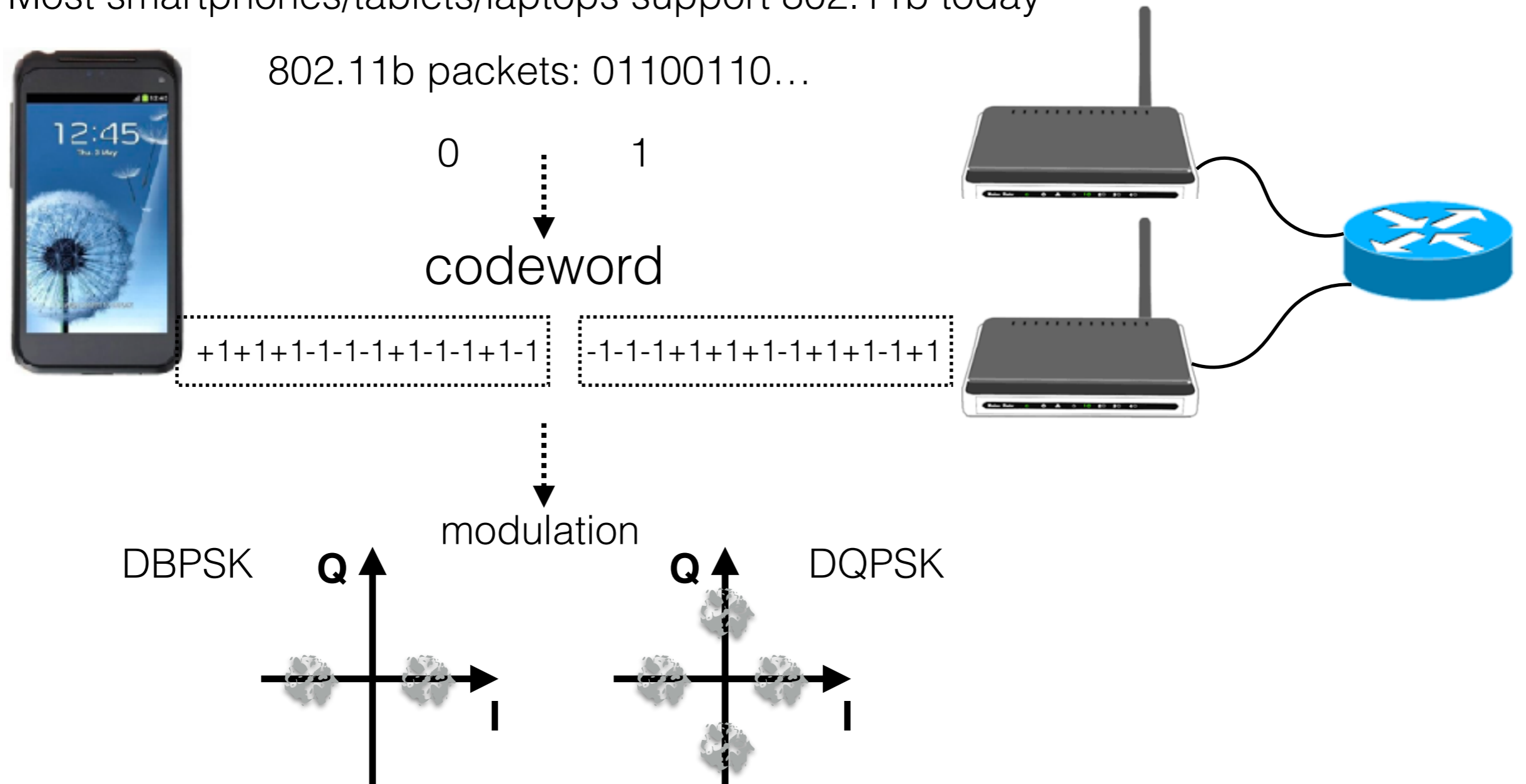
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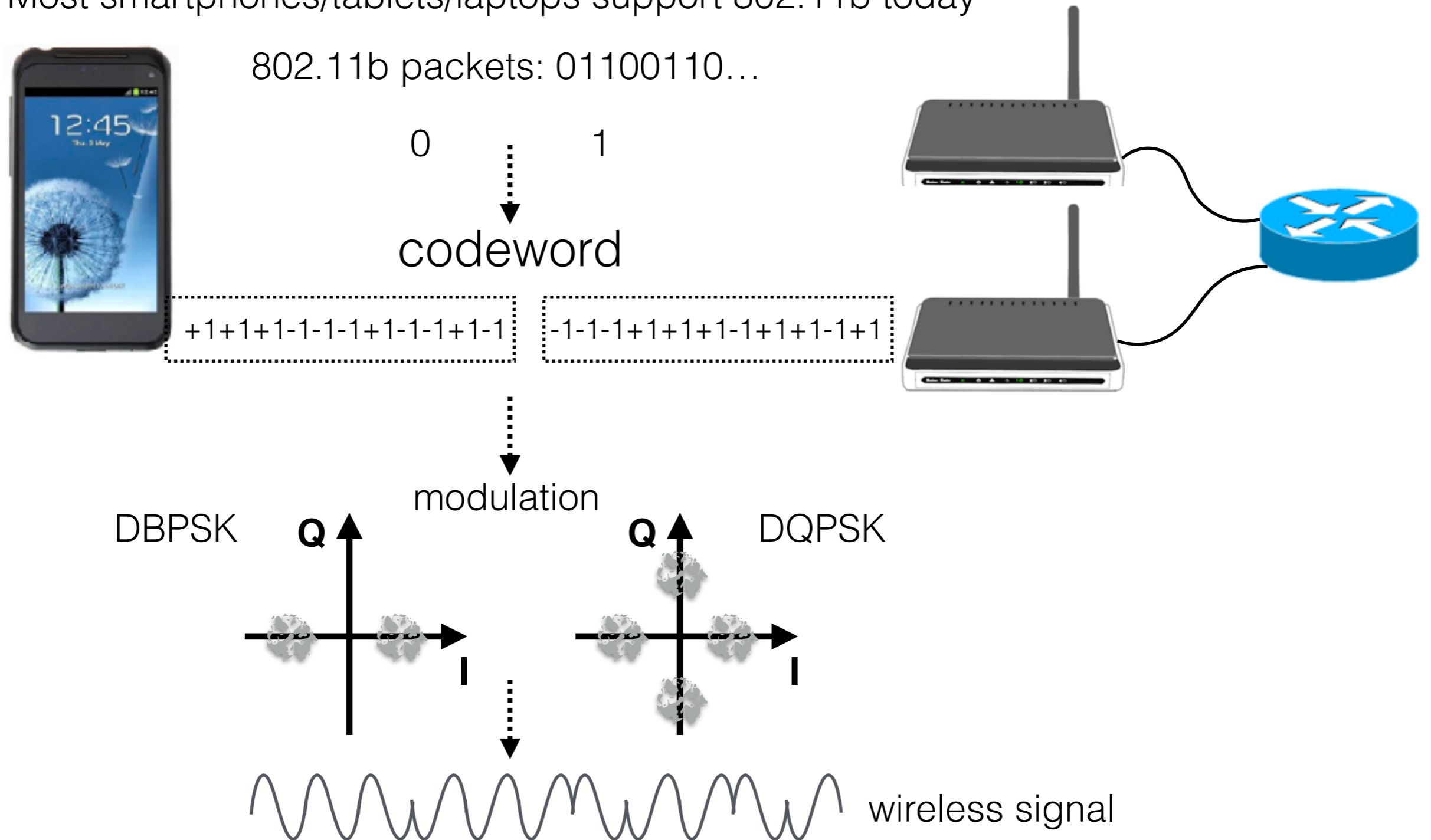
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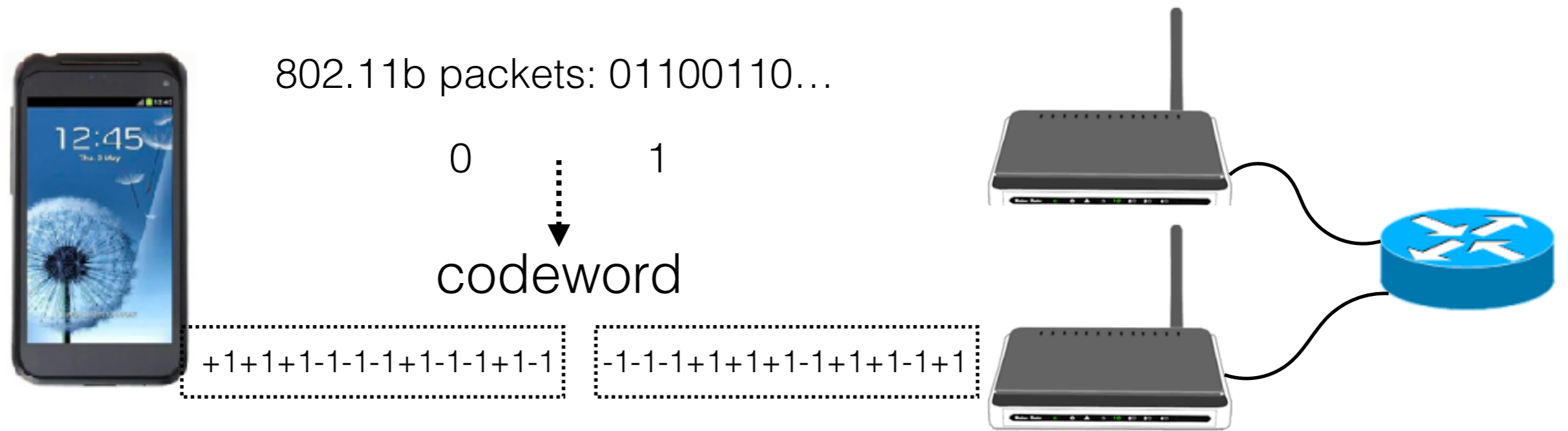


802.11b WiFi Primer

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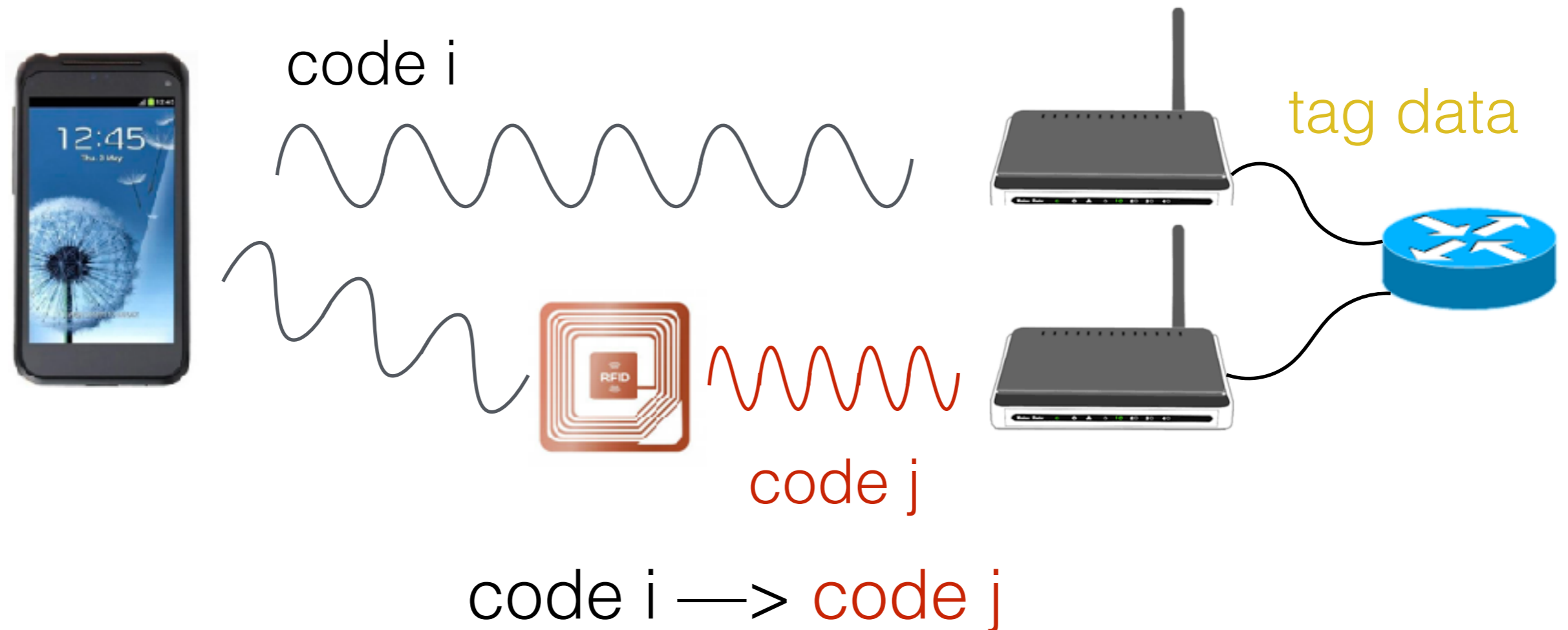
802.11b WiFi Primer



1Mbps: code 0/1, 2Mbps: code 0/1/2/3...

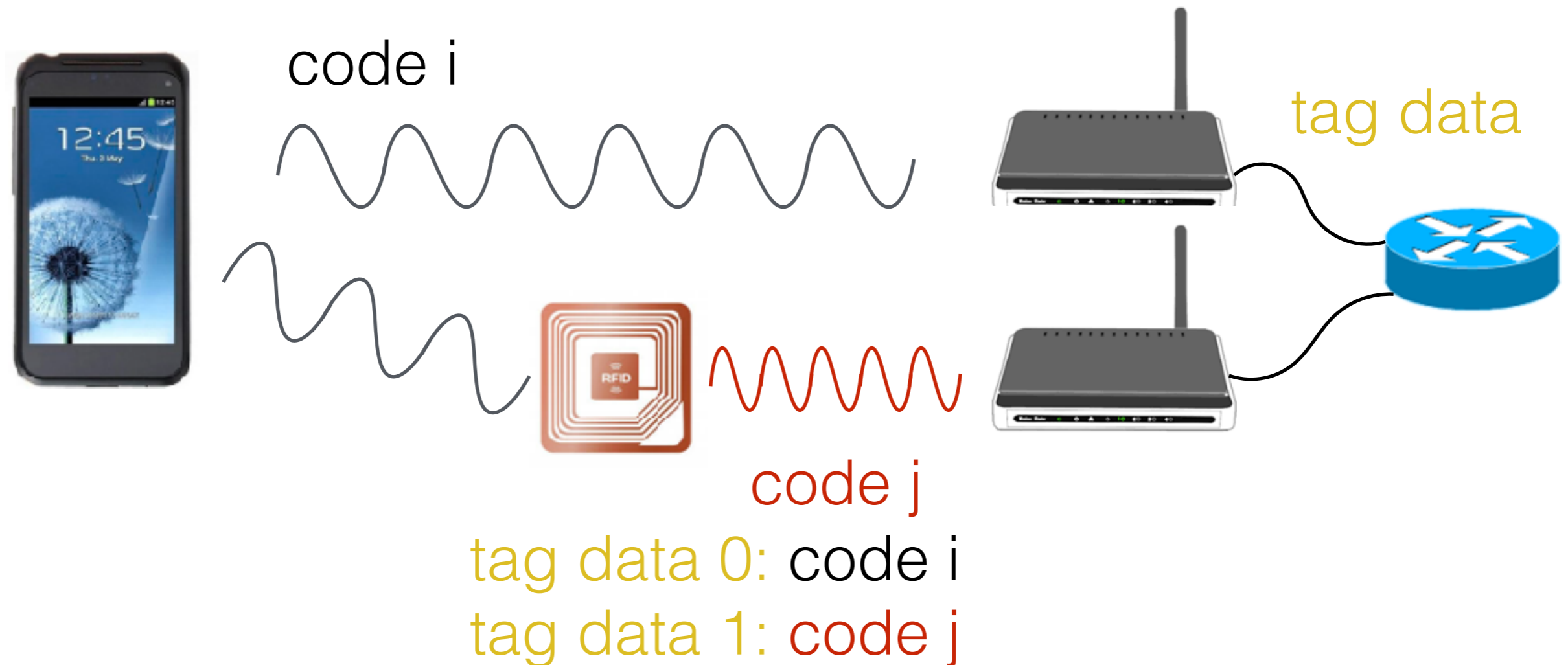
802.11b WiFi uses a finite set of codewords to encode data 0 and data 1.

Key technique — codeword translation



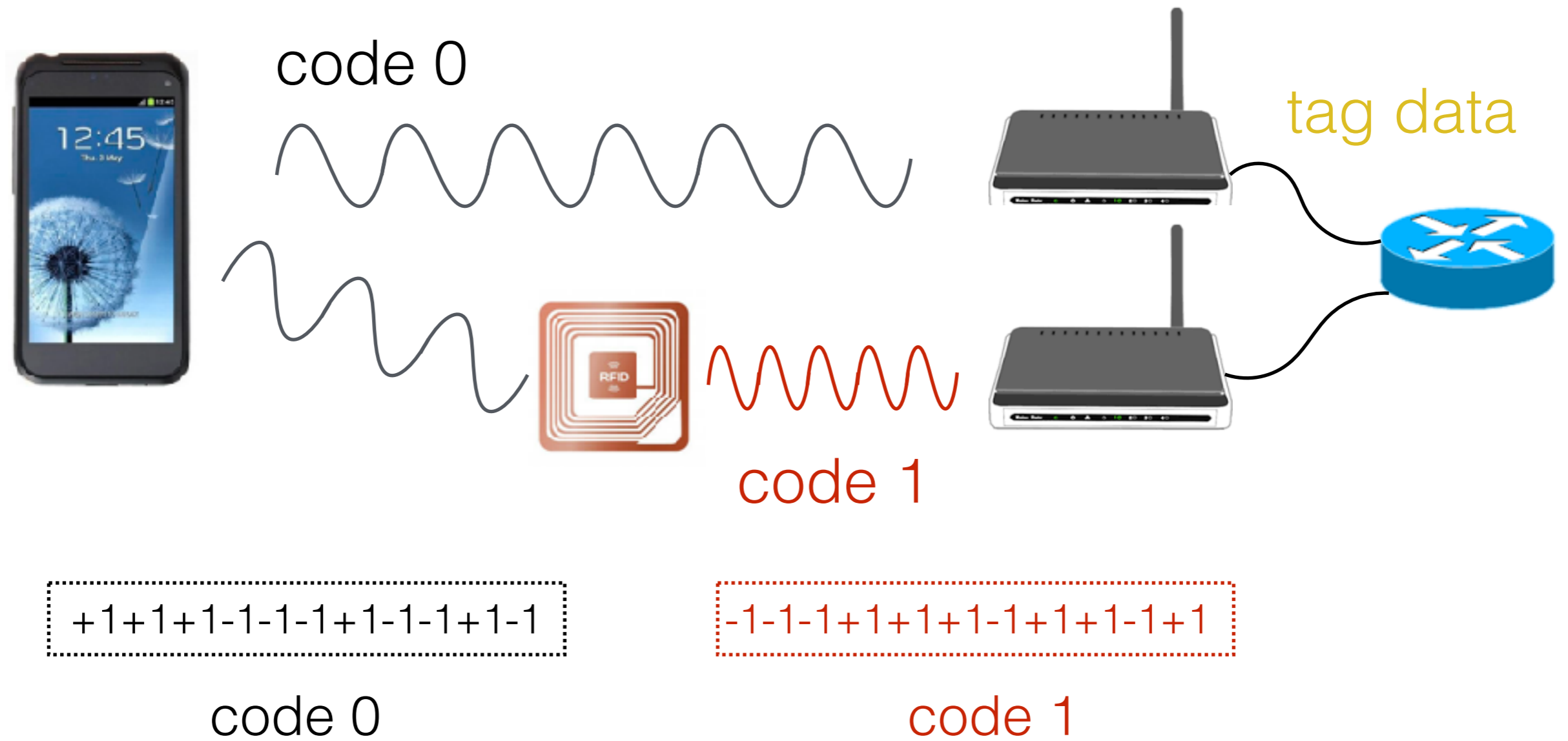
A tag can translate a codeword from transmitter into another codeword within the same codebook.

Key technique — codeword translation

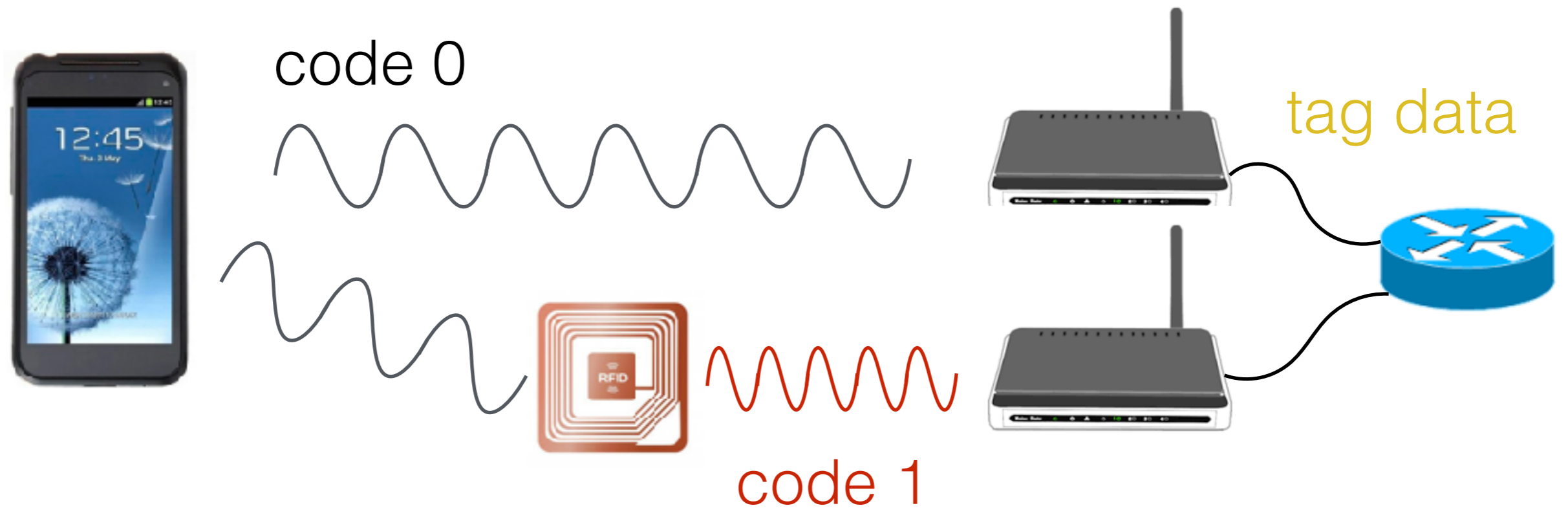


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Codeword translation in 1Mbps 802.11b



Codeword translation in 1Mbps 802.11b



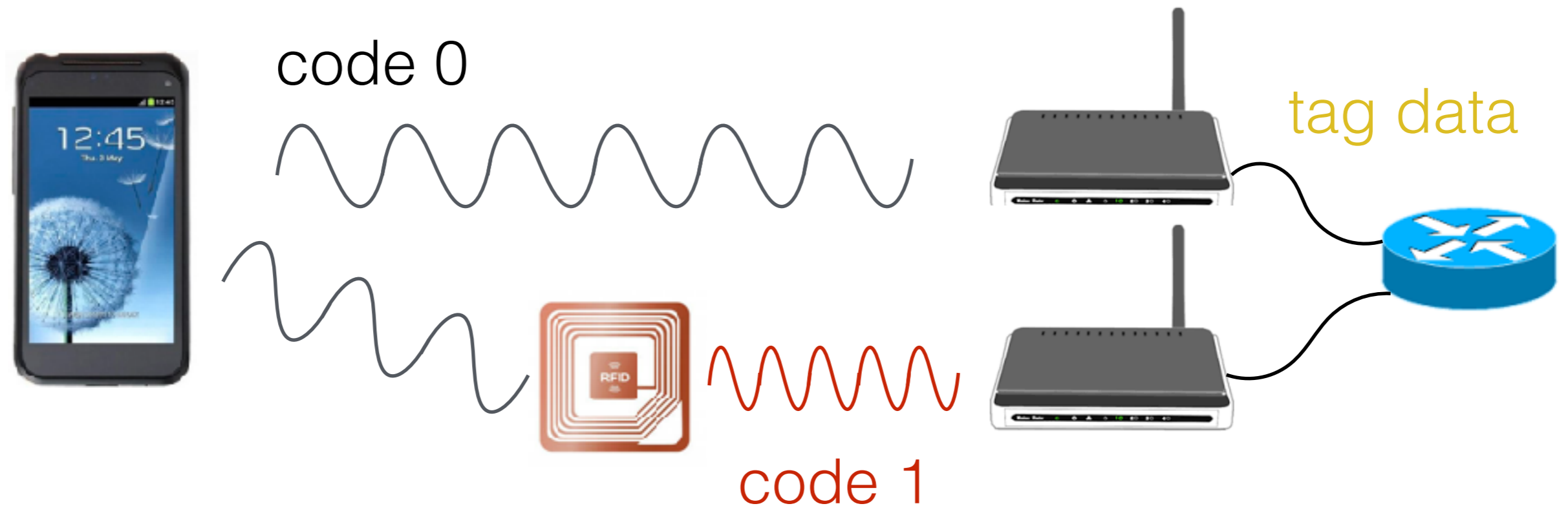
$$\boxed{+1+1+1-1-1-1+1-1-1+1-1} = \boxed{-1-1-1+1+1+1-1+1+1-1+1} * -1$$

code 0

code 1

$$\text{code 0} = \text{code 1} * -1, \text{code 1} = \text{code 0} * -1$$

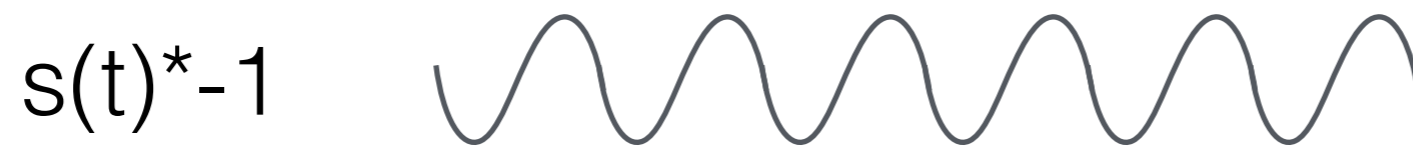
Codeword translation in 1Mbps 802.11b



code 0 \longrightarrow code 1
code 1 \longrightarrow code 0

A tag can translate code 0/1 to code 1/0 by multiplying -1.

What does $*$ -1 mean for a wireless signal?



How should we interpret -1?

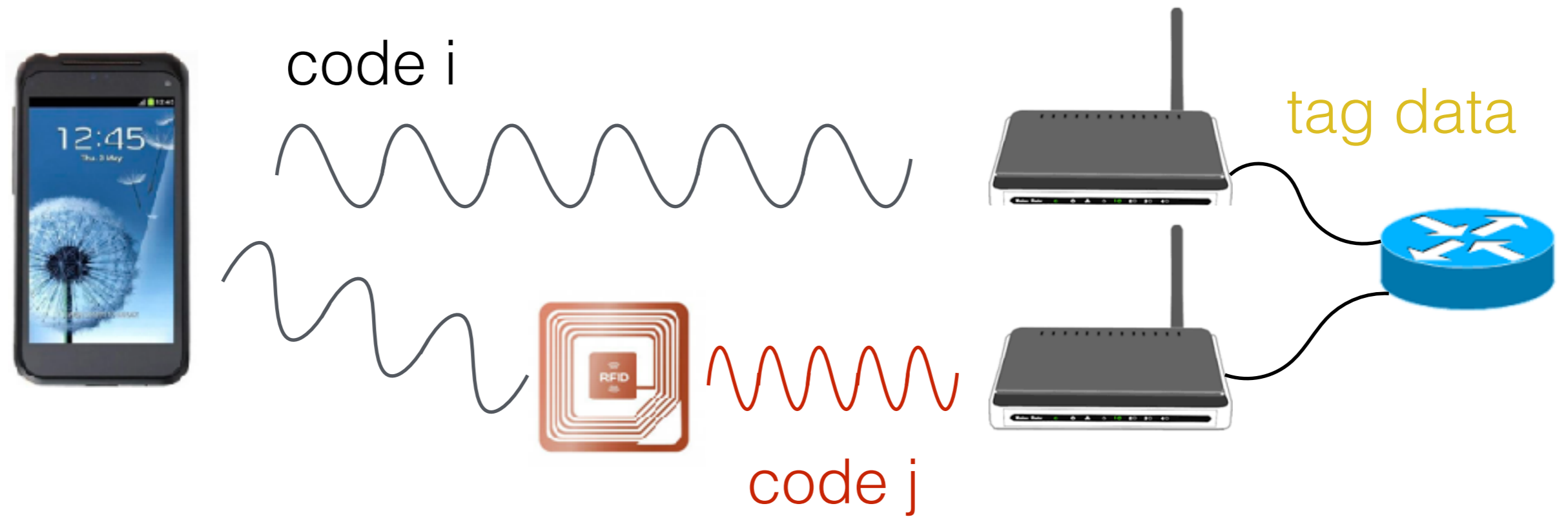
$S(t)$ is inverted

500uW power for a
phase shifter

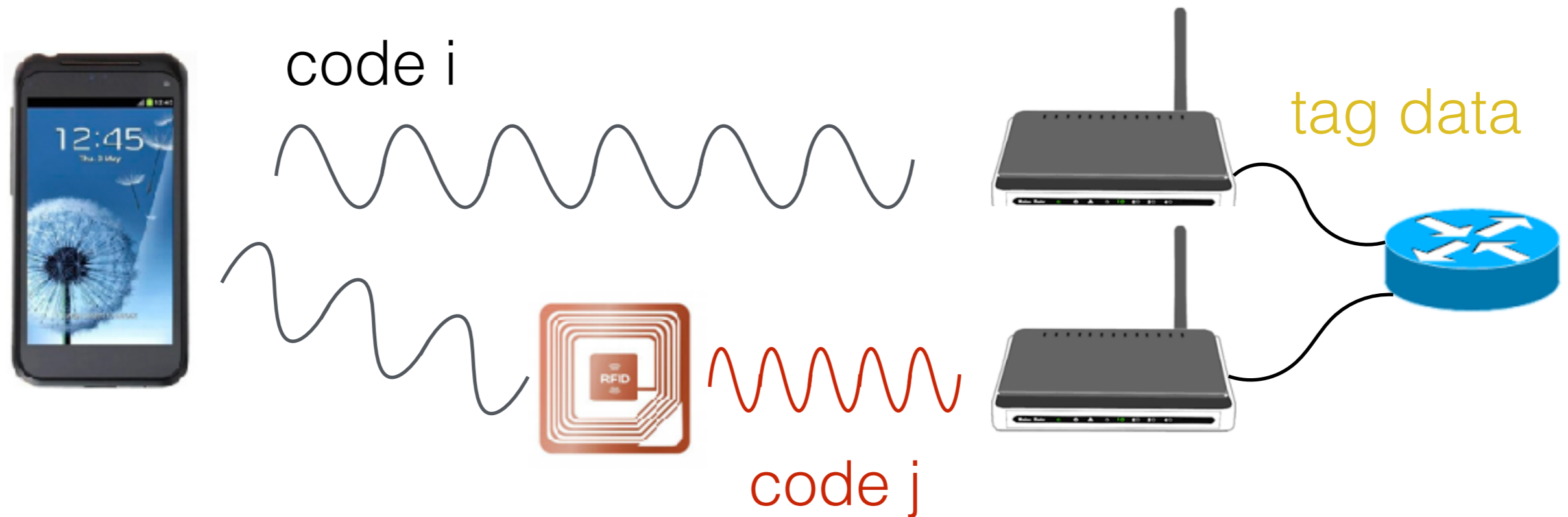
$S(t)$ is delayed

1uW for a 5ns delay

How to build codeword translation in 1Mbps 802.11b?



Why the process of translating codewords is XOR?

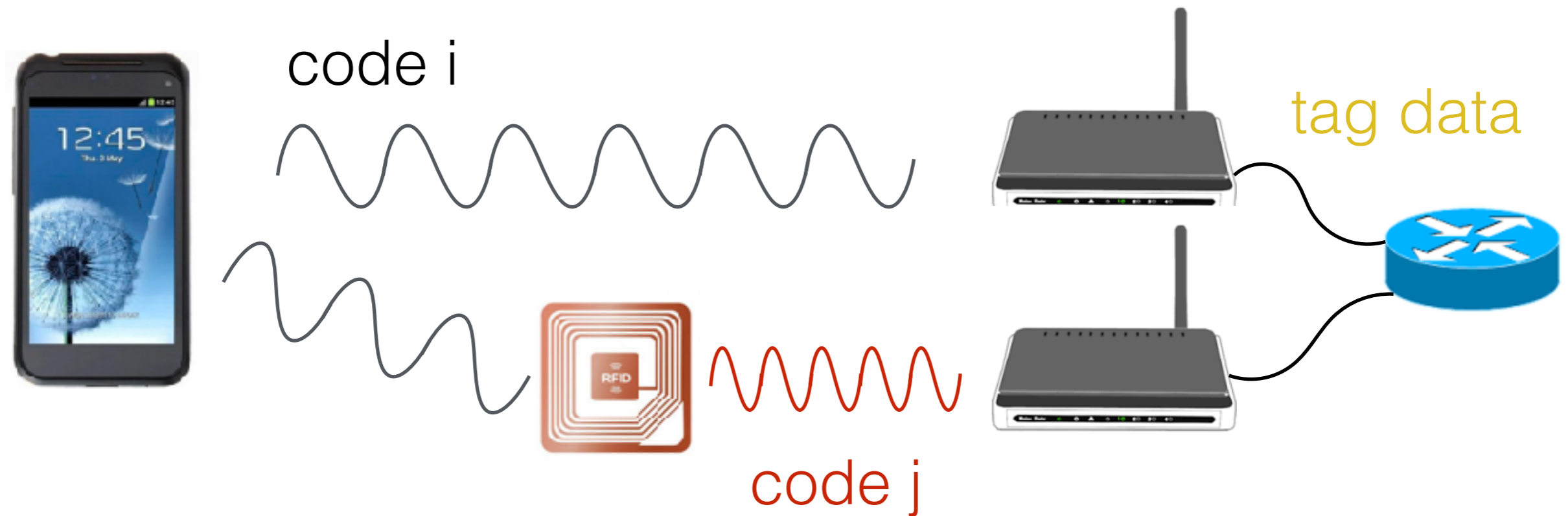


tag data 0: code j = code i

tag data 1: code j = code i * -1

code j = tag data XOR code i

How to decode the tag data?

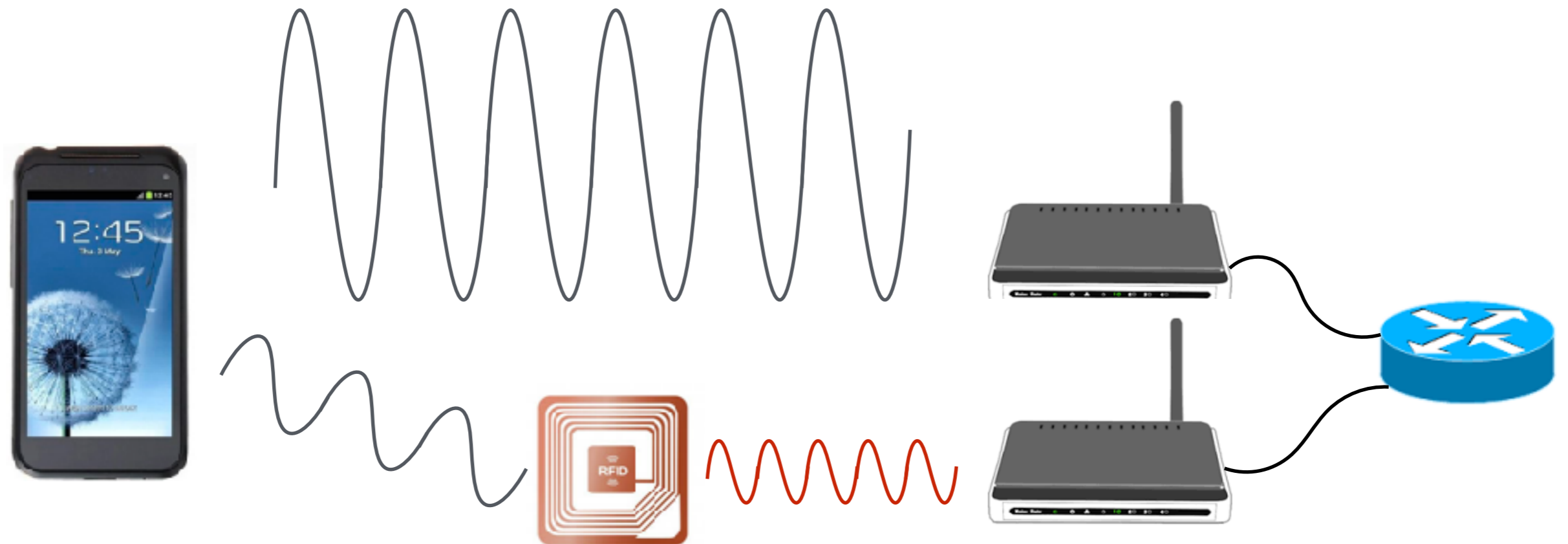


$$\begin{aligned} \text{code } j \text{ XOR code } i &= \text{tag data XOR code } i \text{ XOR code } i \\ &= \text{tag data} \end{aligned}$$

Tag data decoding can be done by performing XOR with the data transmitted by the 802.11b transmitter.

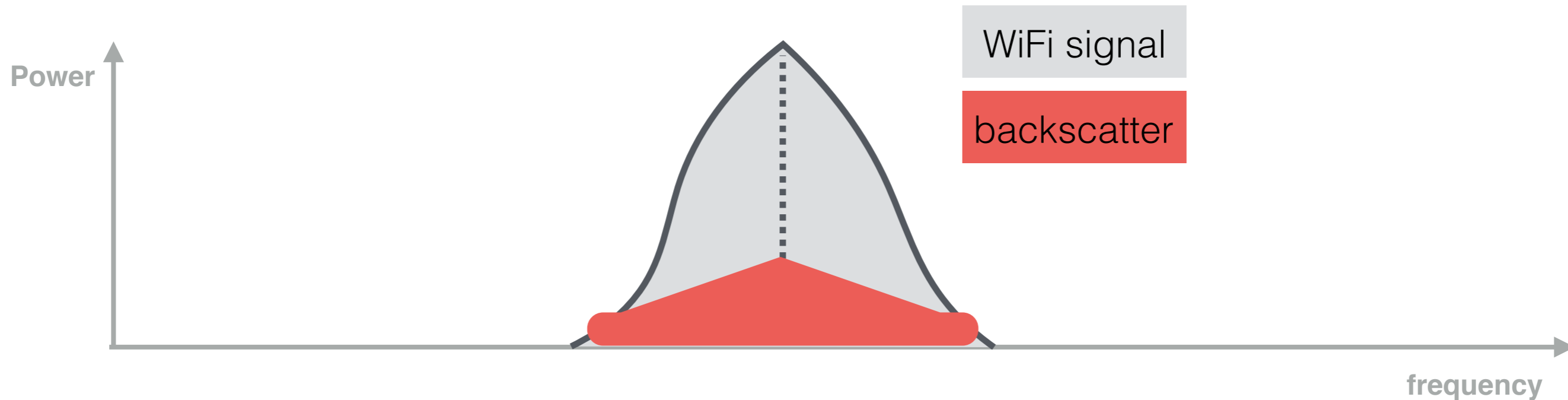
Are we done? Not yet...

We cannot hear the backscattered signal...



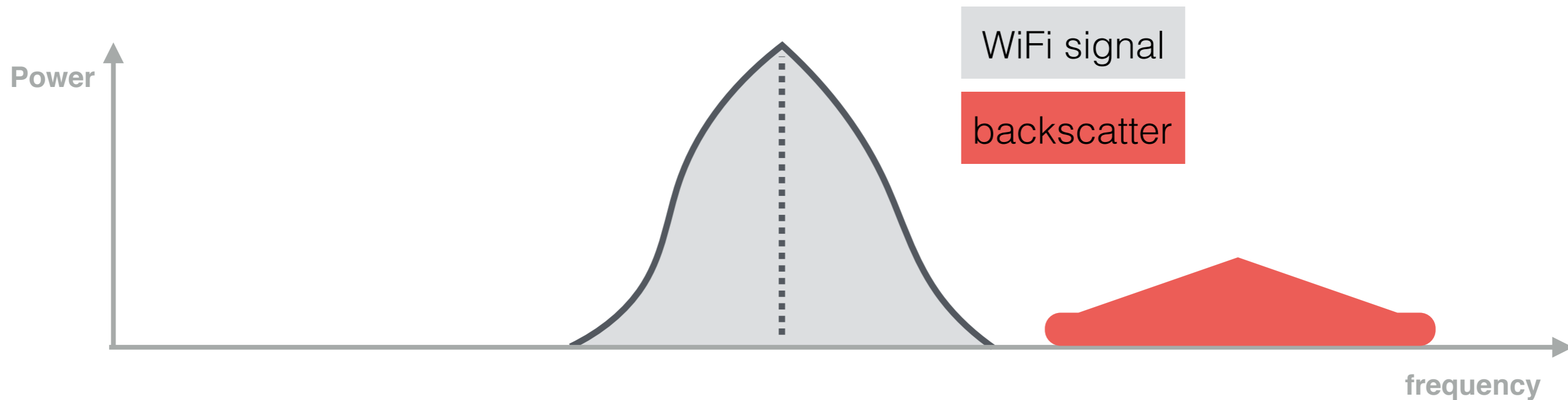
We cannot hear the backscattered signal because the primary 802.11b WiFi signal is much louder!

Why the primary WiFi signal is much louder?



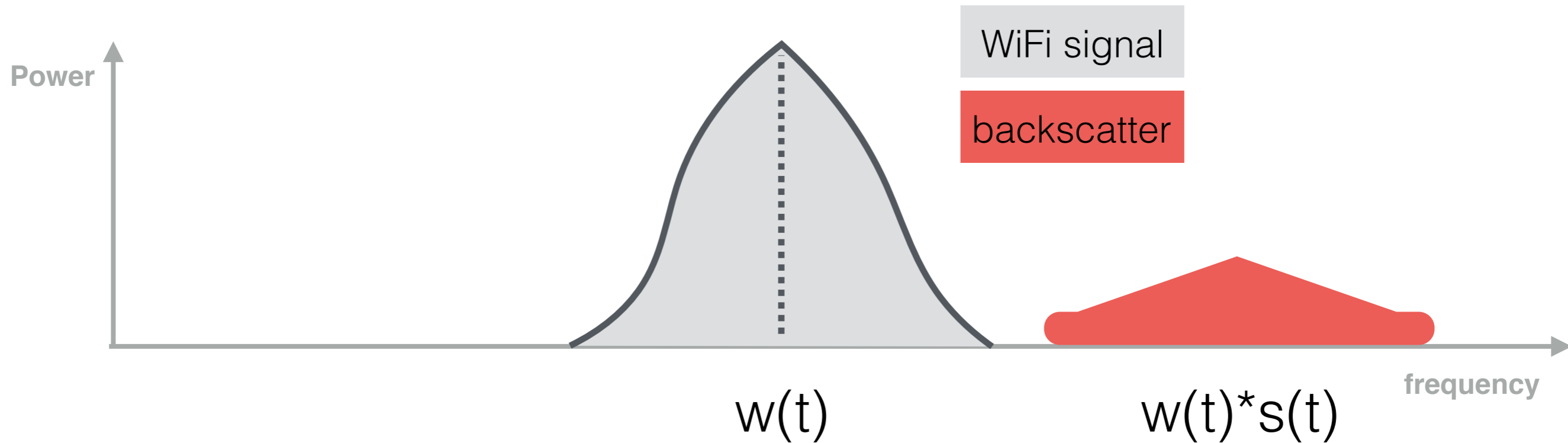
Because the primary WiFi signal and the backscattered signal share the same spectrum.

How to deal with the self-interference from the WiFi?



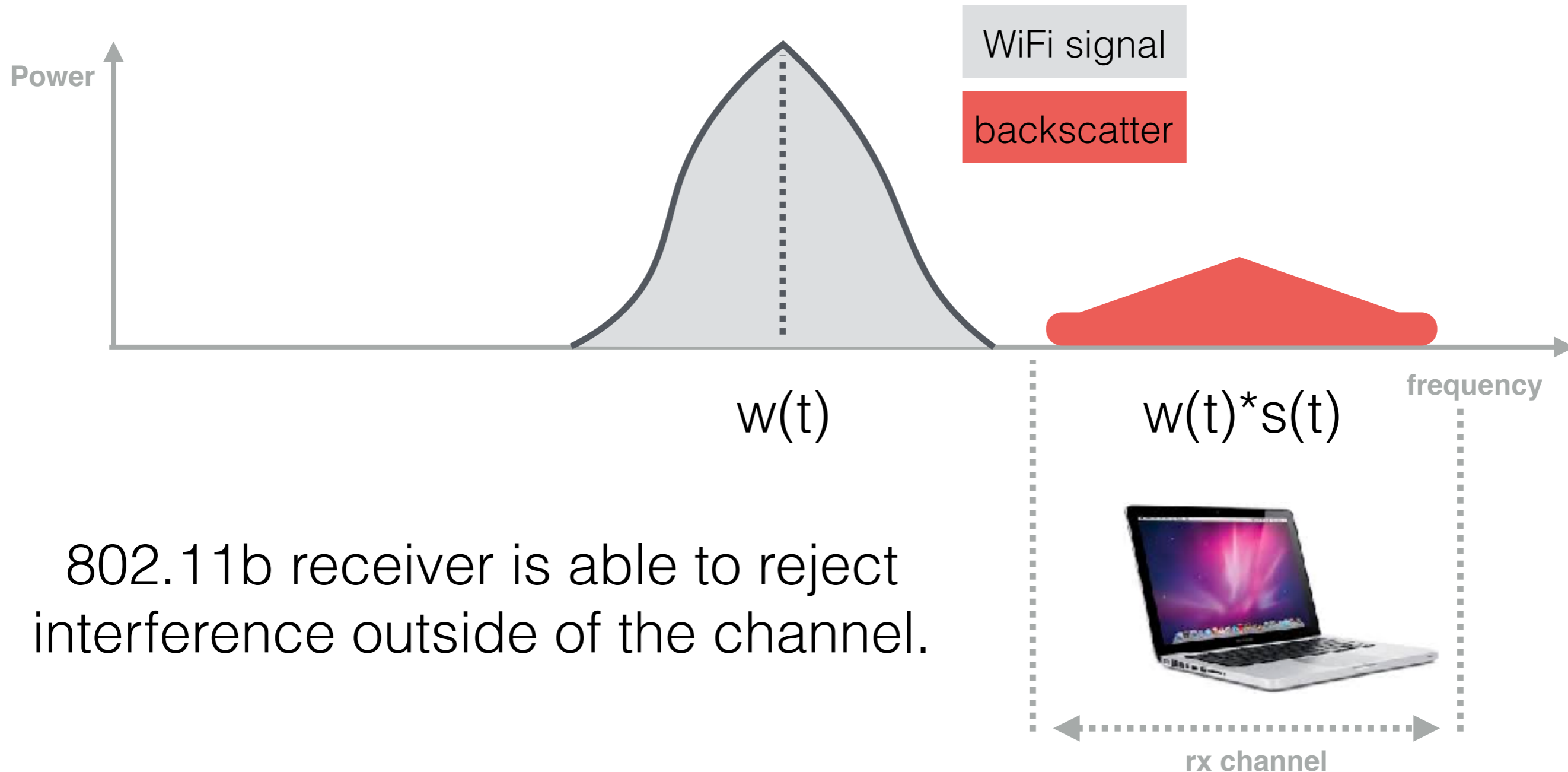
We can move the backscattered signal away from the primary WiFi signal.

How to achieve such frequency shift at the tag?



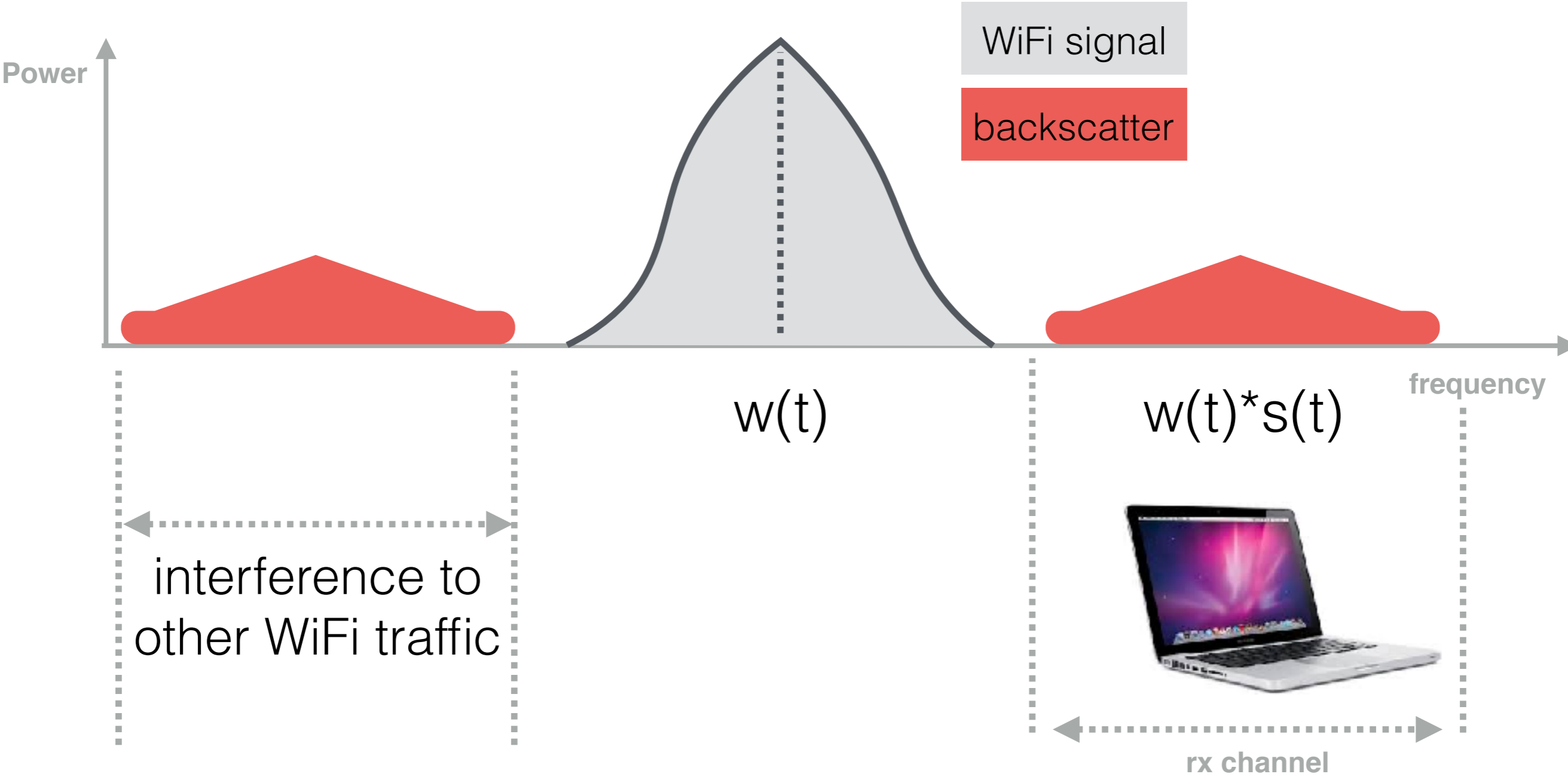
We can multiply the primary WiFi signal $w(t)$ with a square wave $s(t)$ during backscatter.

How to decode the backscatter signal?

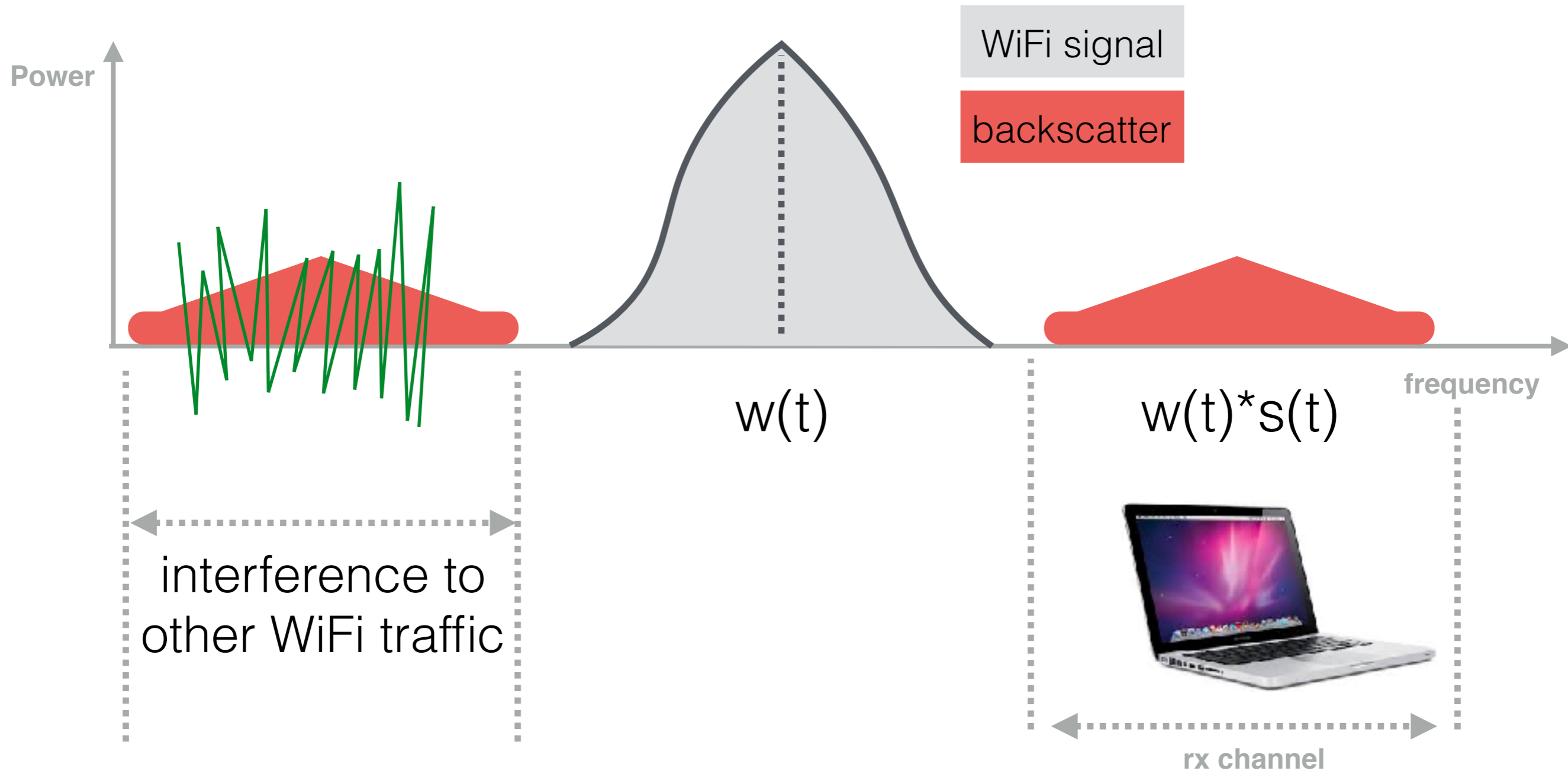


Are we done? Not yet...

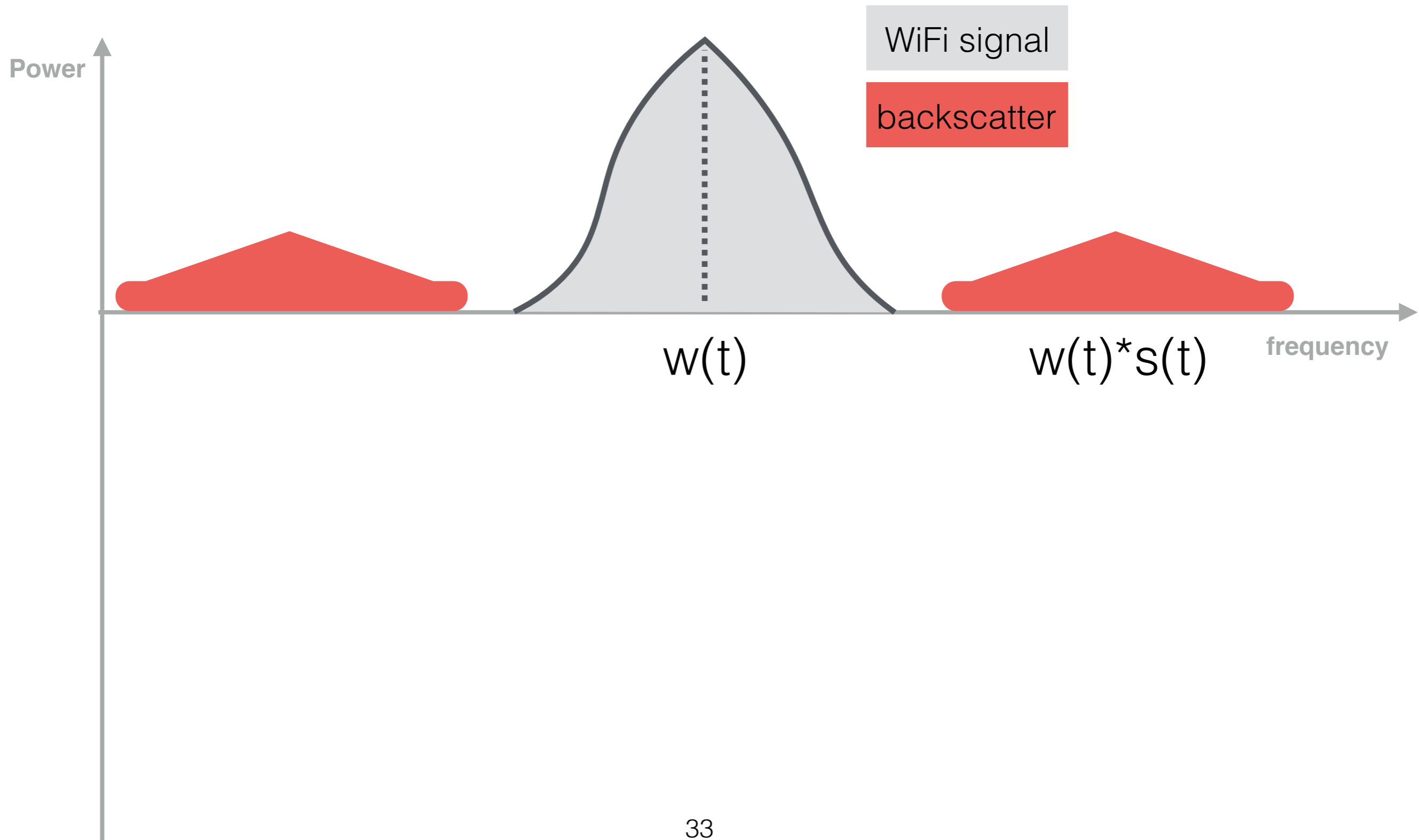
We actually have double side-band backscatter



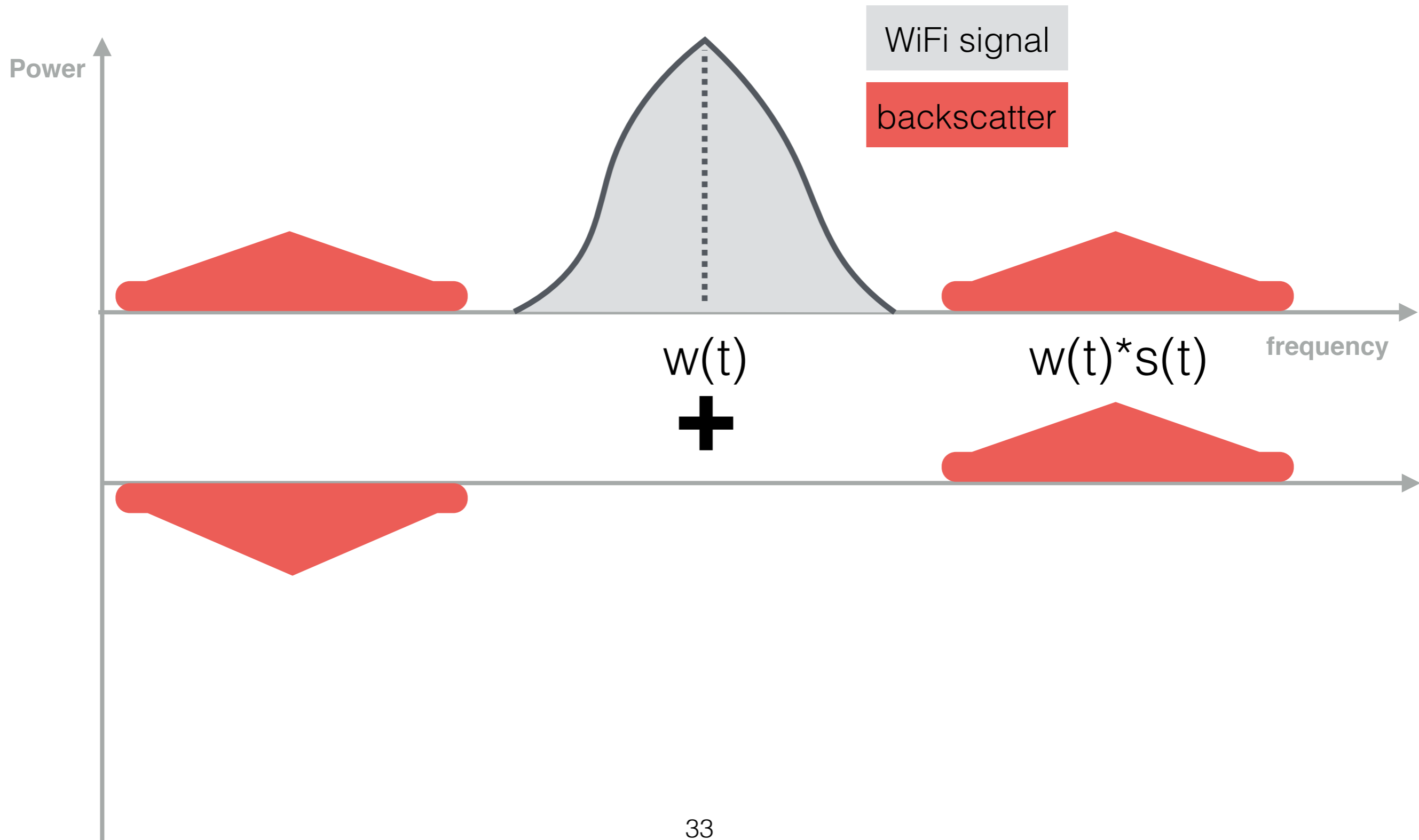
How to eliminate one side of backscatter?



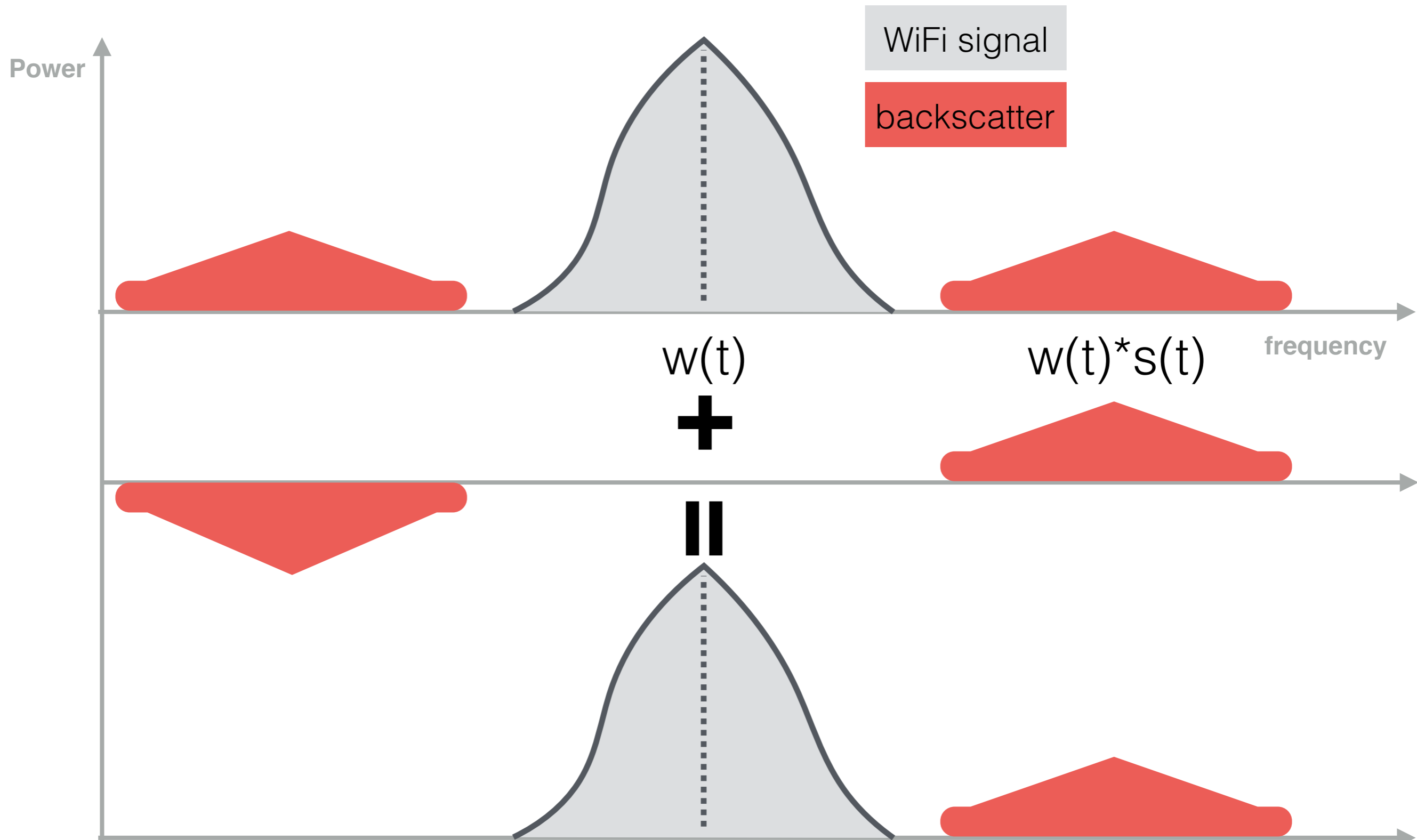
Signal that has a reversed polarity at one side?



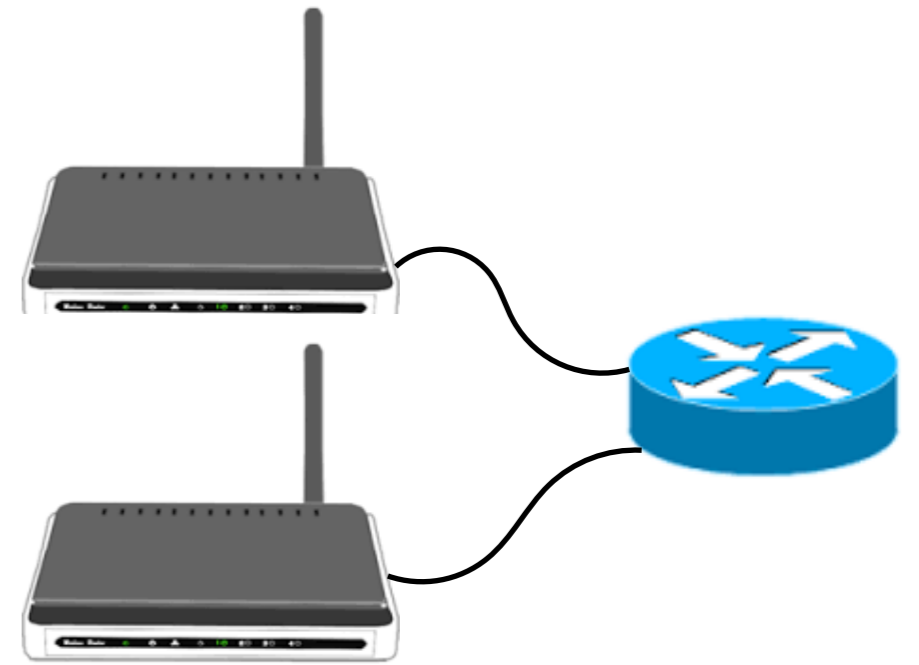
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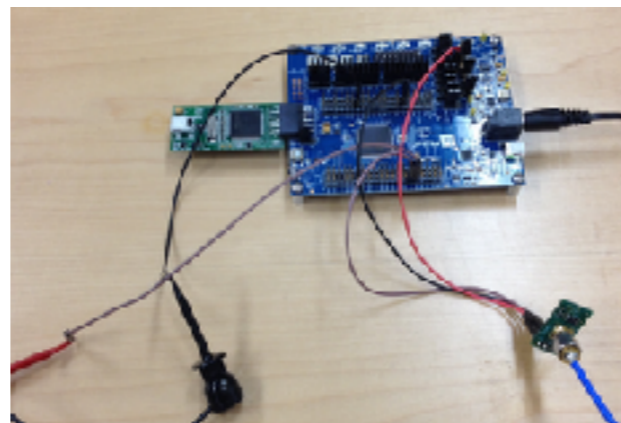
Putting Everything Together



802.11b WiFi transmitter

backscatter tag

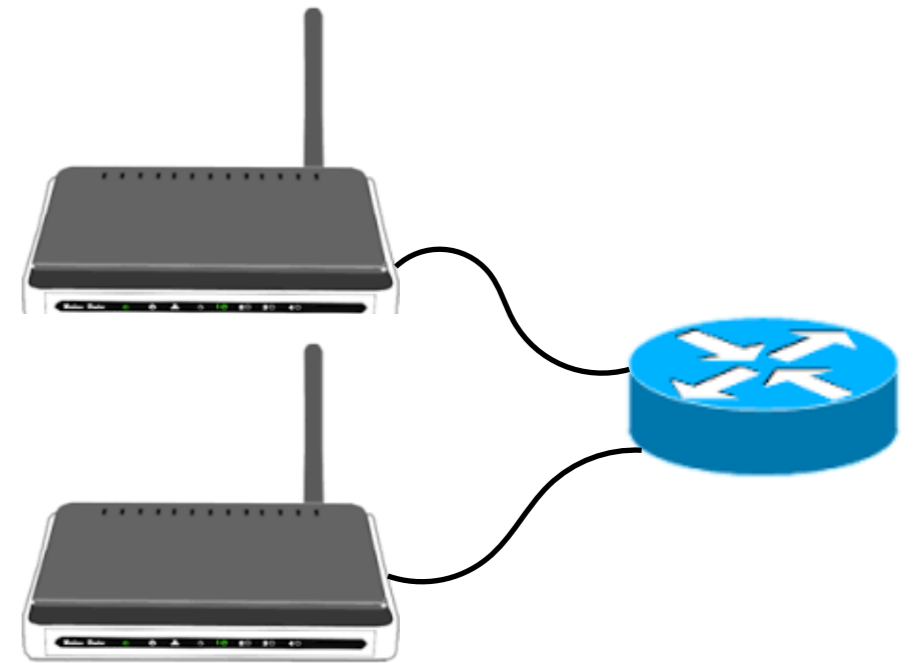
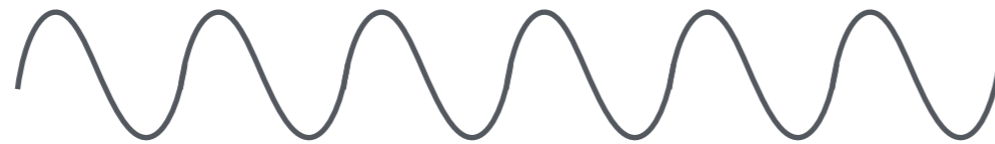
backscatter receiver



Putting Everything Together



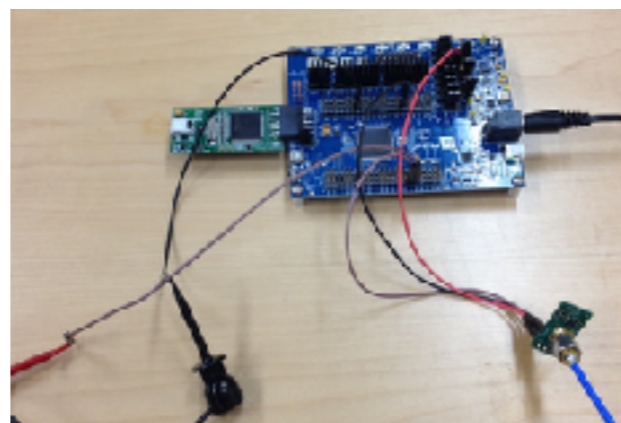
802.11b packets: 01100110...



802.11b WiFi transmitter



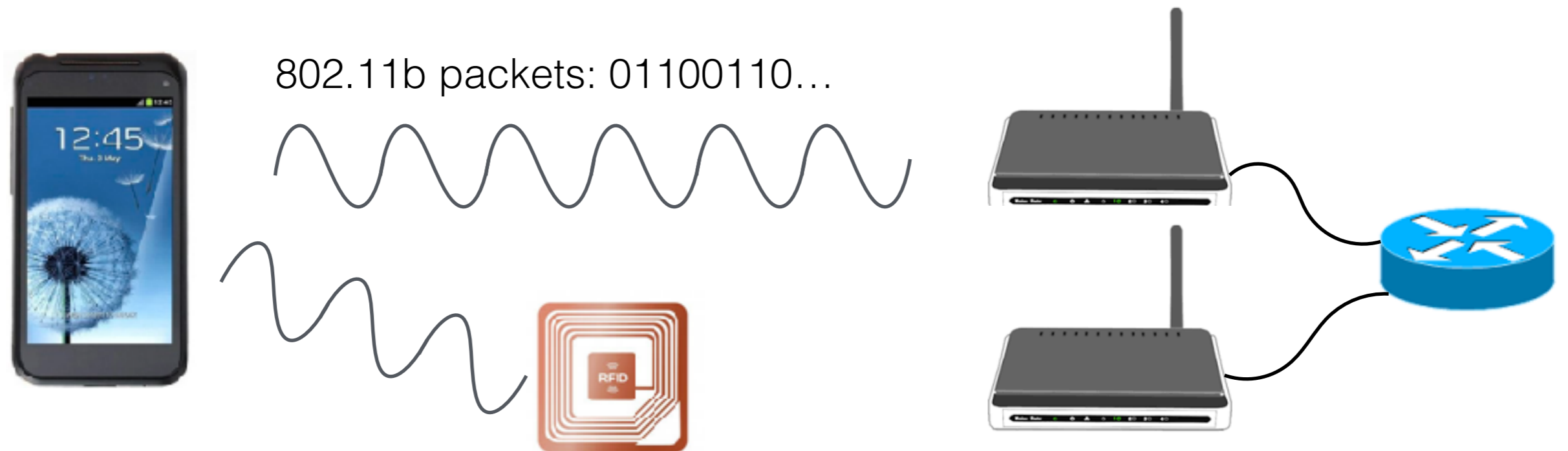
backscatter tag



backscatter receiver



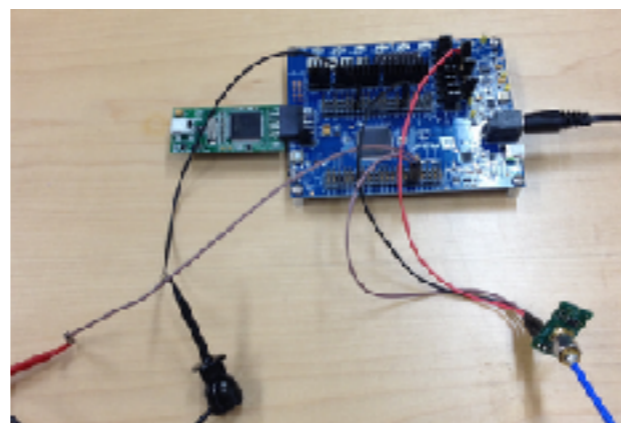
Putting Everything Together



802.11b WiFi transmitter



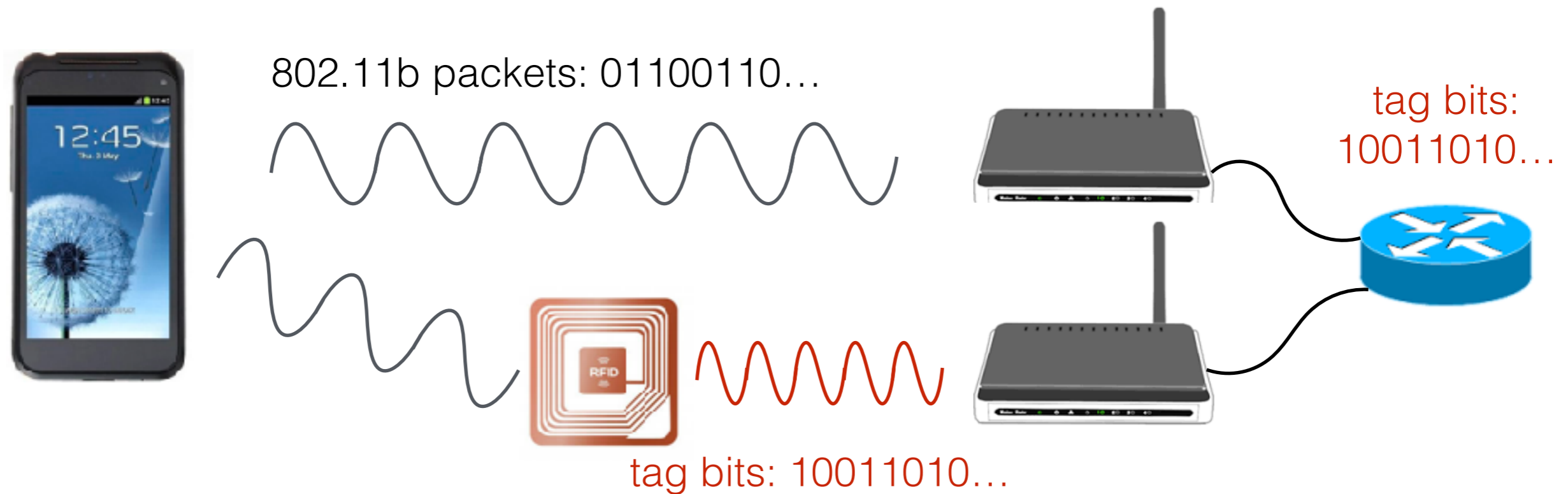
backscatter tag



backscatter receiver



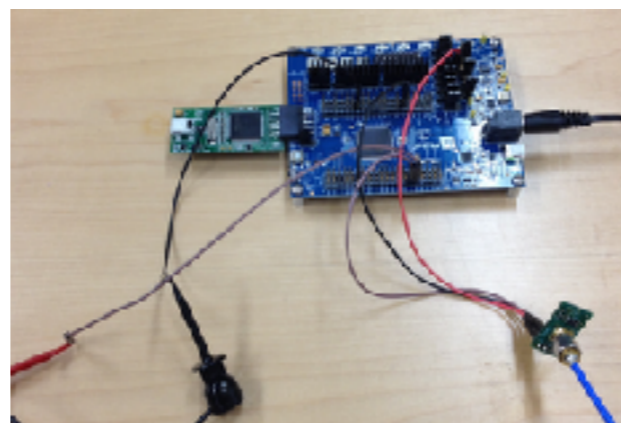
Putting Everything Together



802.11b WiFi transmitter



backscatter tag



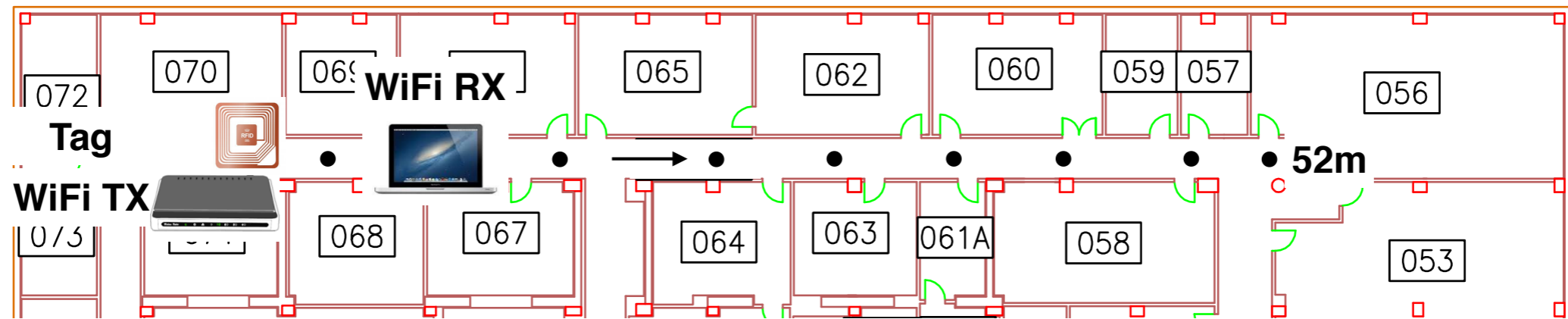
backscatter receiver



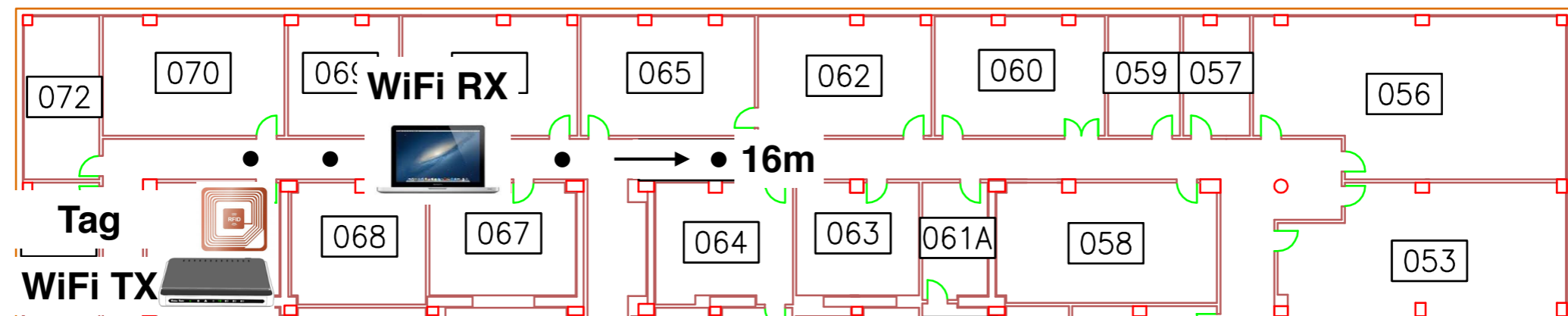
XoRFi system deployment

Packard building

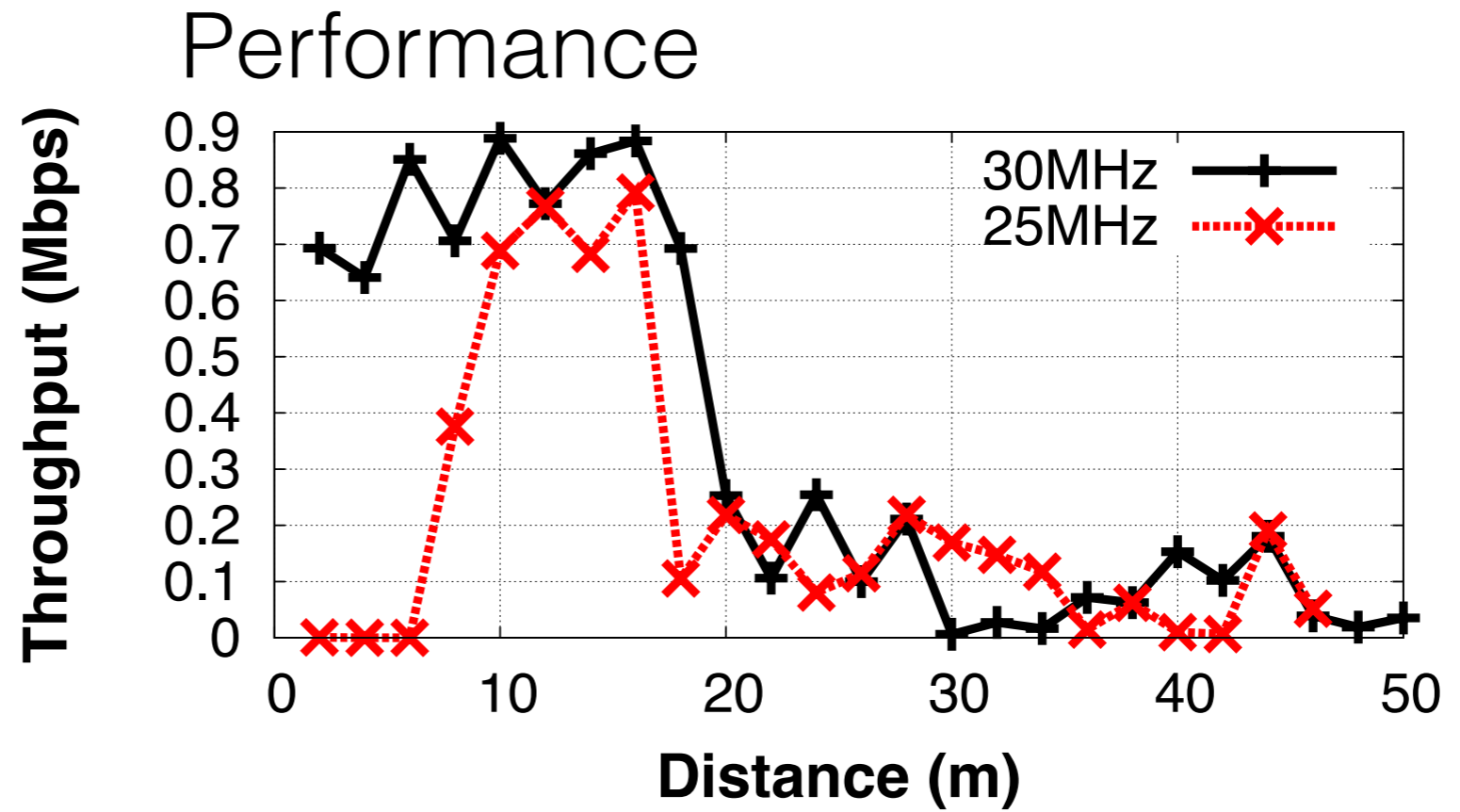
line-of-sight deployment



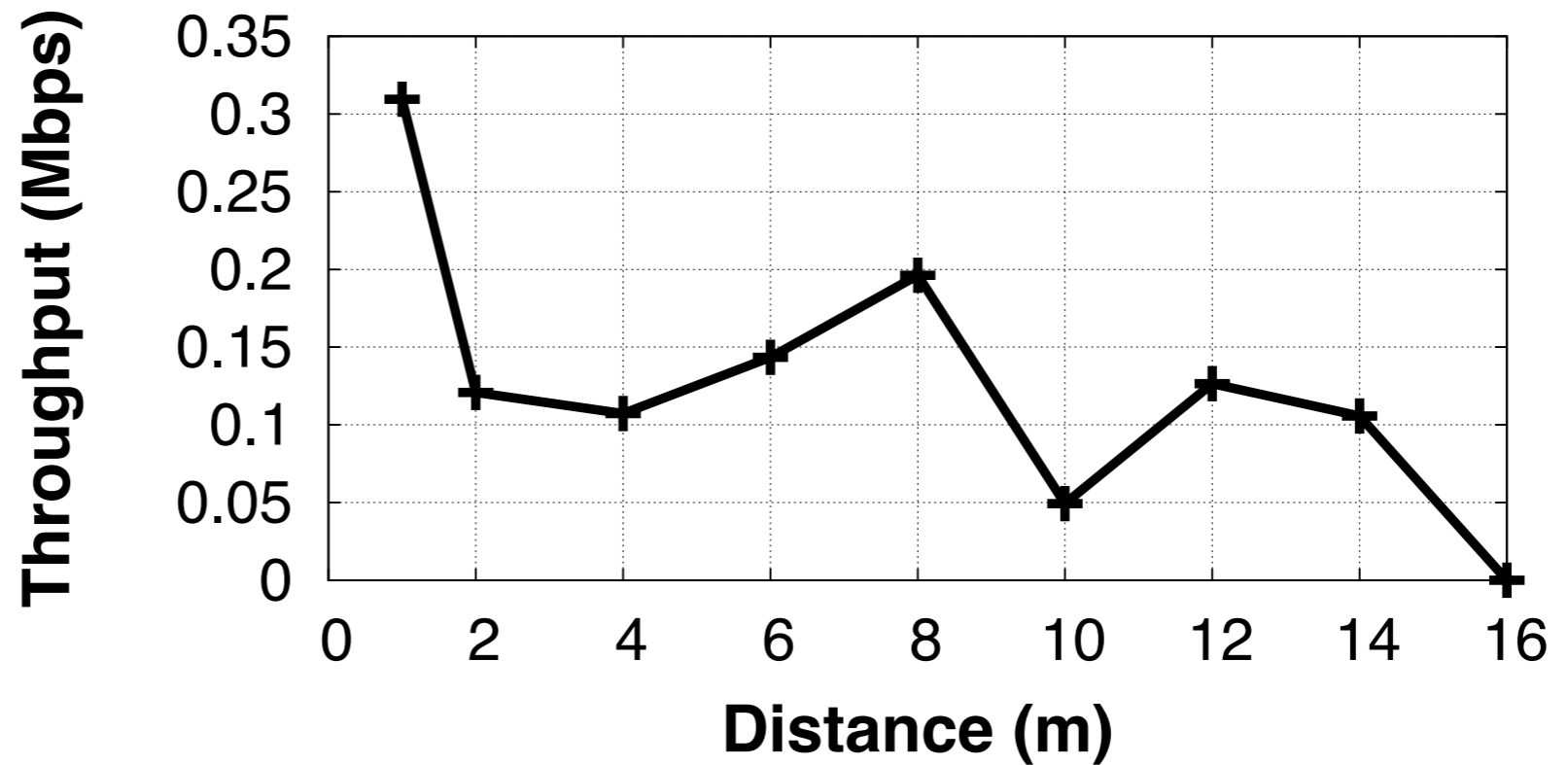
non-line-of-sight deployment



line-of-sight deployment



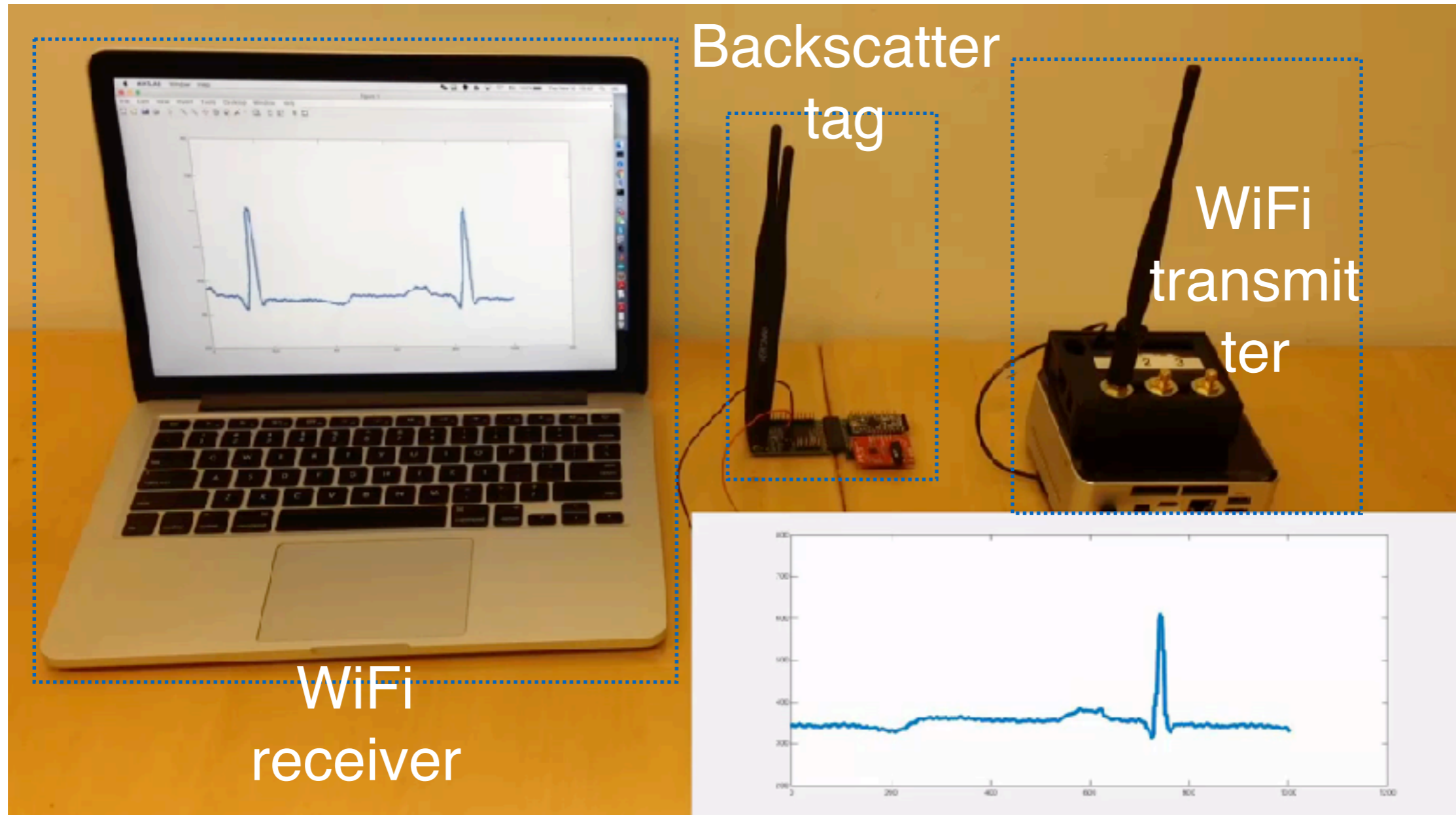
non-line-of-sight deployment



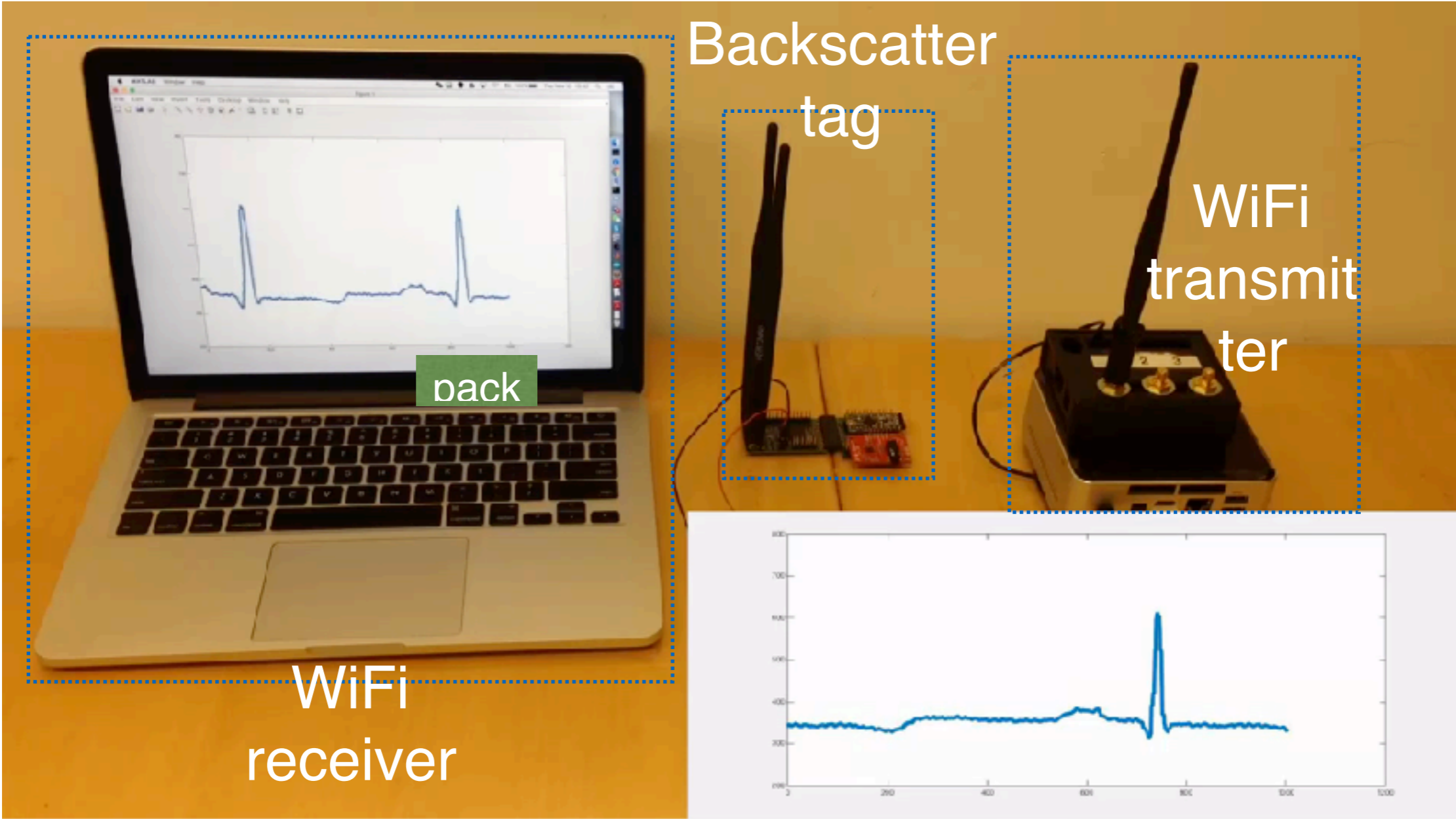
Conclusion

- Wireless research is about having fun
- XoRFi — a novel backscatter communication system that can be built using off-the-shelf components
- XoRFi — a system that is able to communicate with commodity WiFi radios with close to zero power consumption

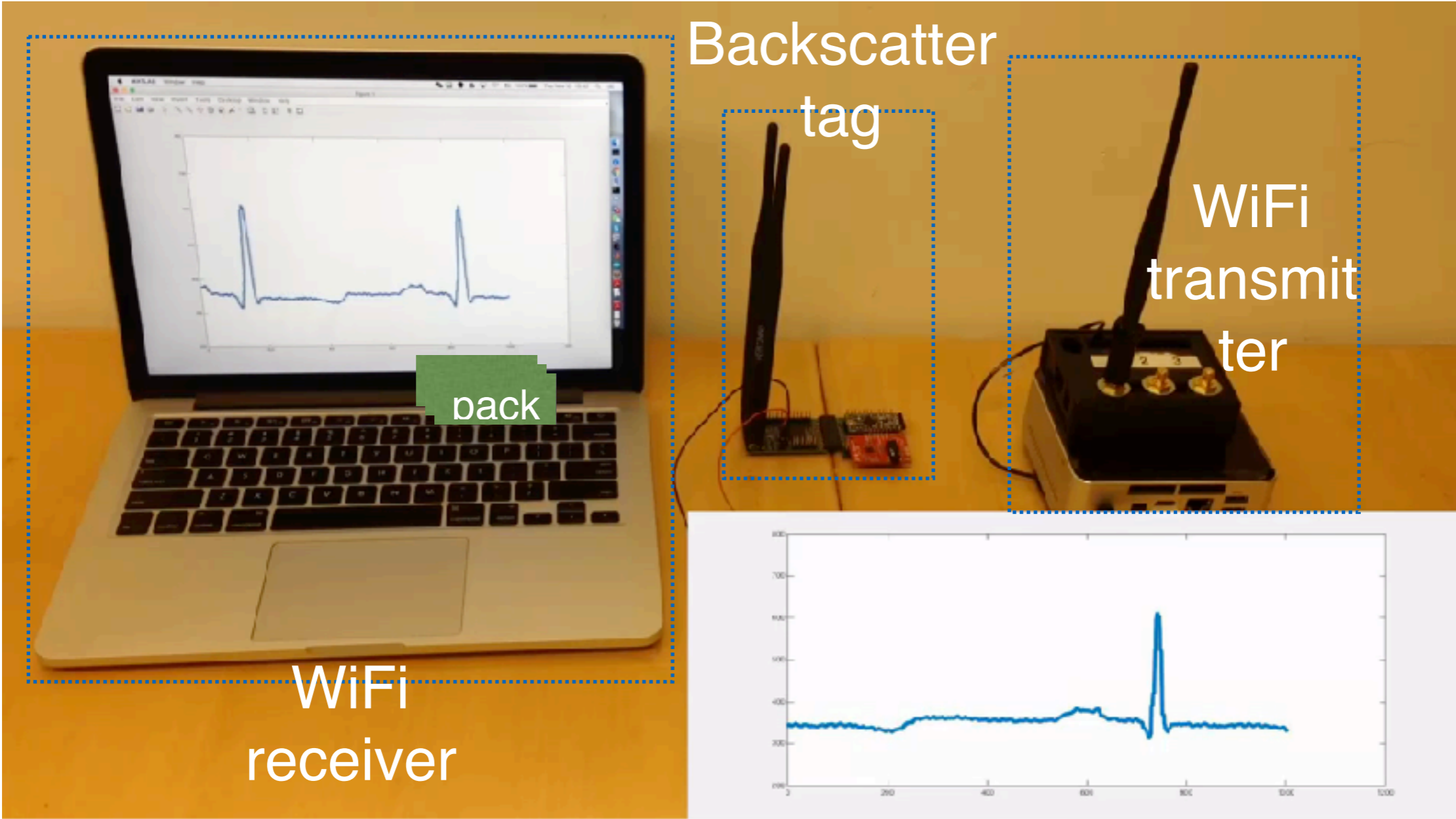
Demo: backscattering ECG sensing data with WiFi radios



Demo: backscattering ECG sensing data with WiFi radios

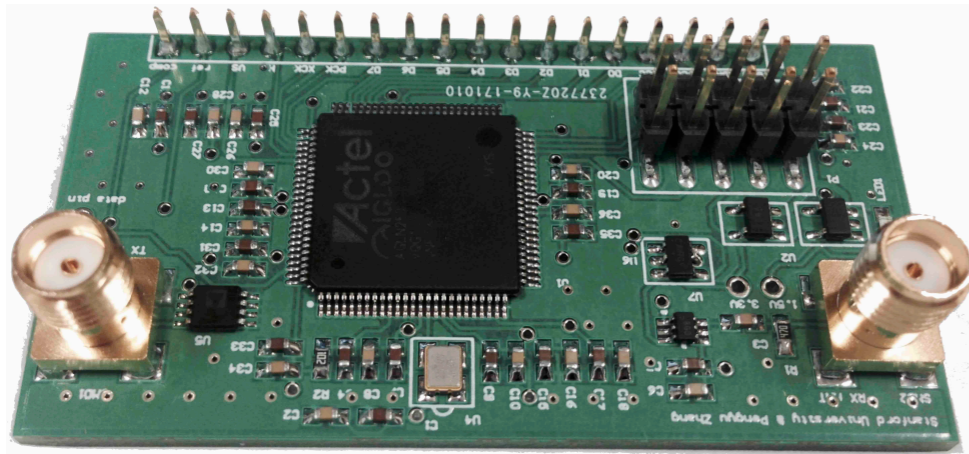


Demo: backscattering ECG sensing data with WiFi radios



Prototype: used for teaching

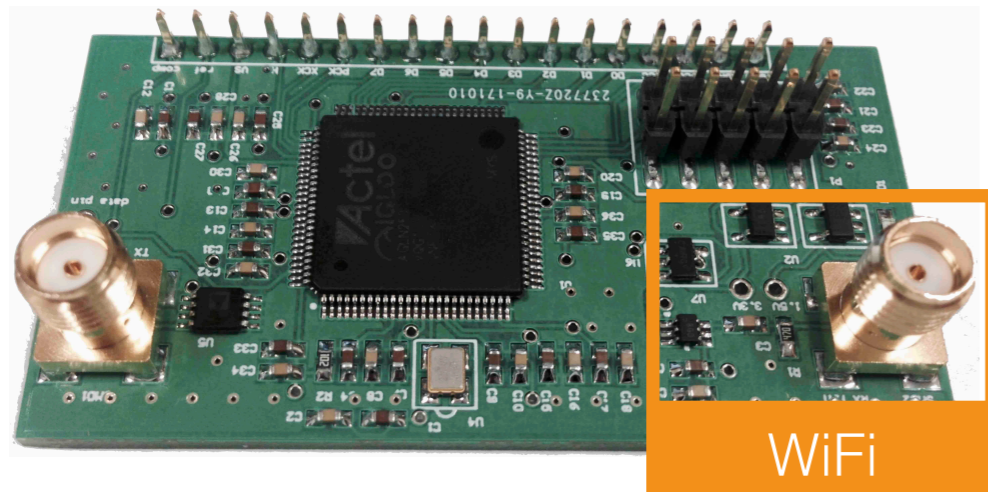
backscatter radio board



Open sourced platform: <https://github.com/pengyuzhang/HitchHike>

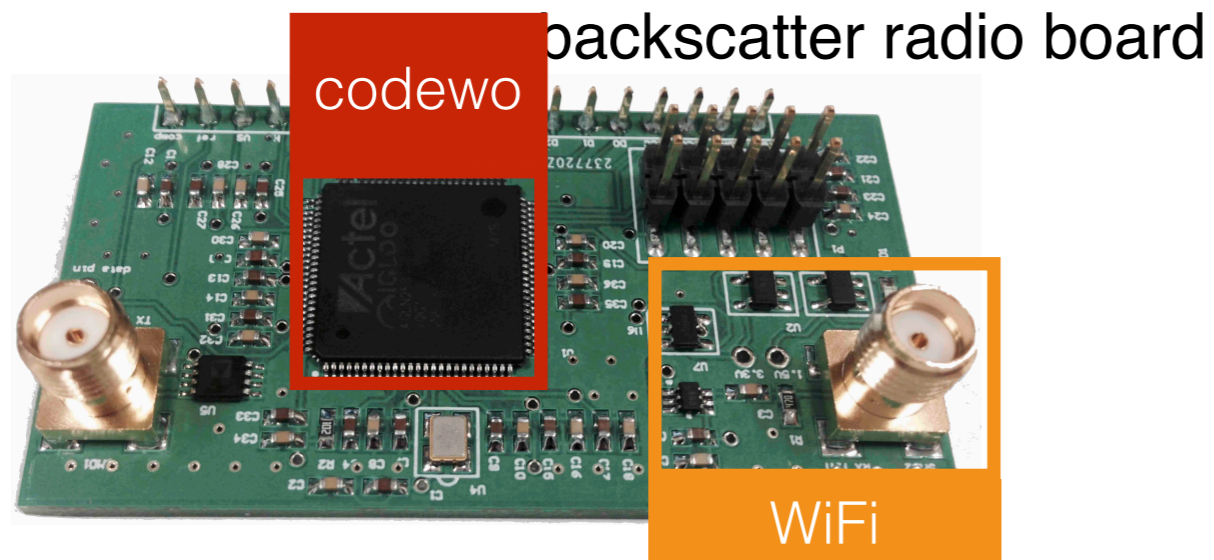
Prototype: used for teaching

backscatter radio board



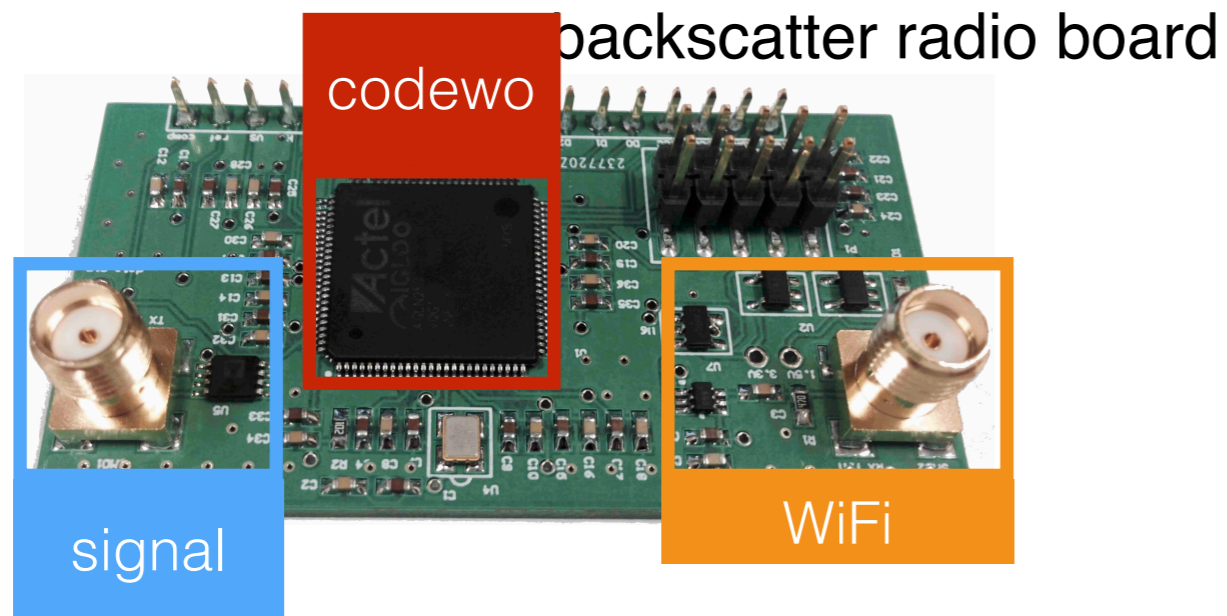
Open sourced platform: <https://github.com/pengyuzhang/HitchHike>

Prototype: used for teaching



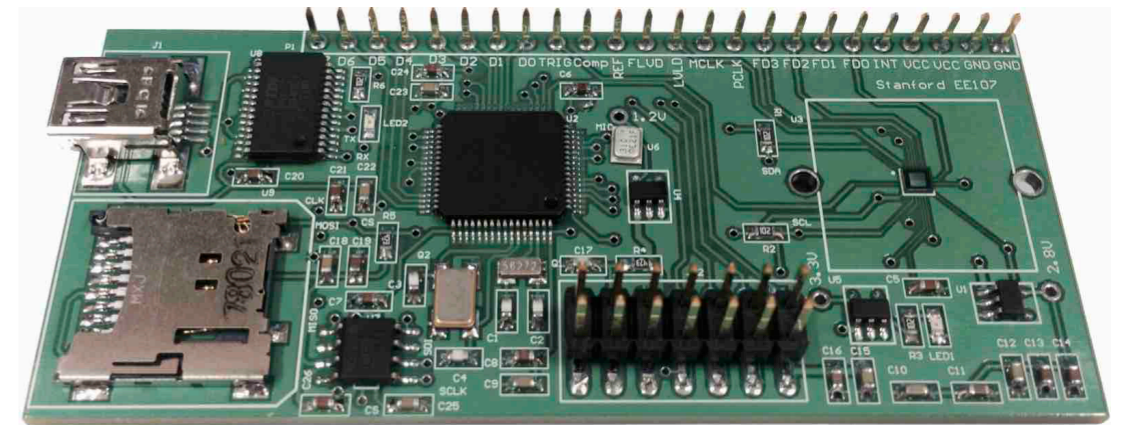
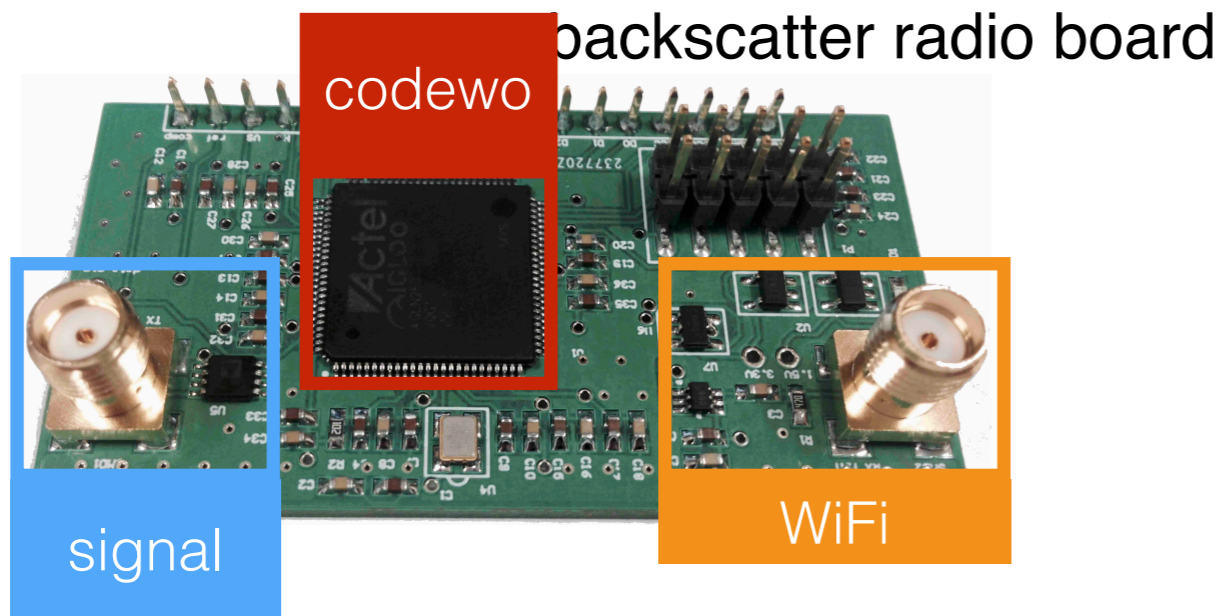
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Open sourced platform: <https://github.com/pengyuzhang/HitchHike>

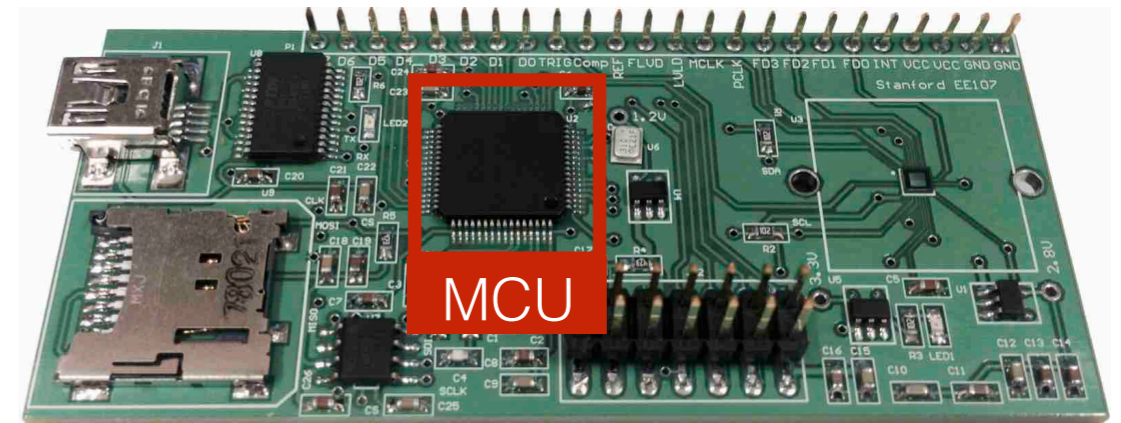
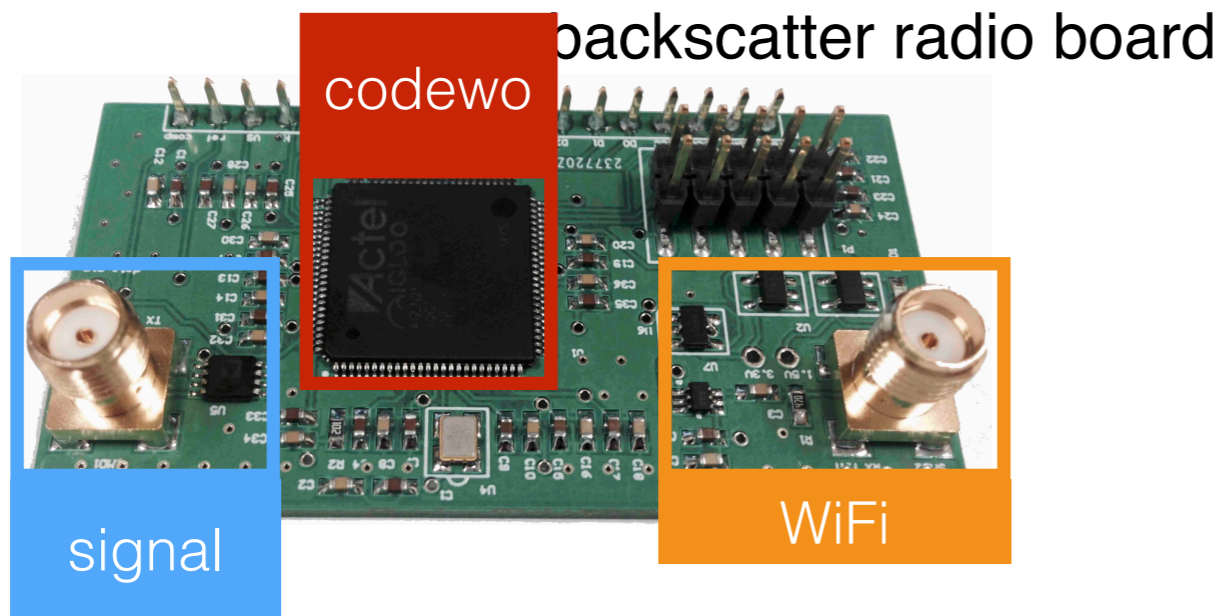
Prototype: used for teaching



speech and image sensing board

Open sourced platform: <https://github.com/pengyuzhang/HitchHike>

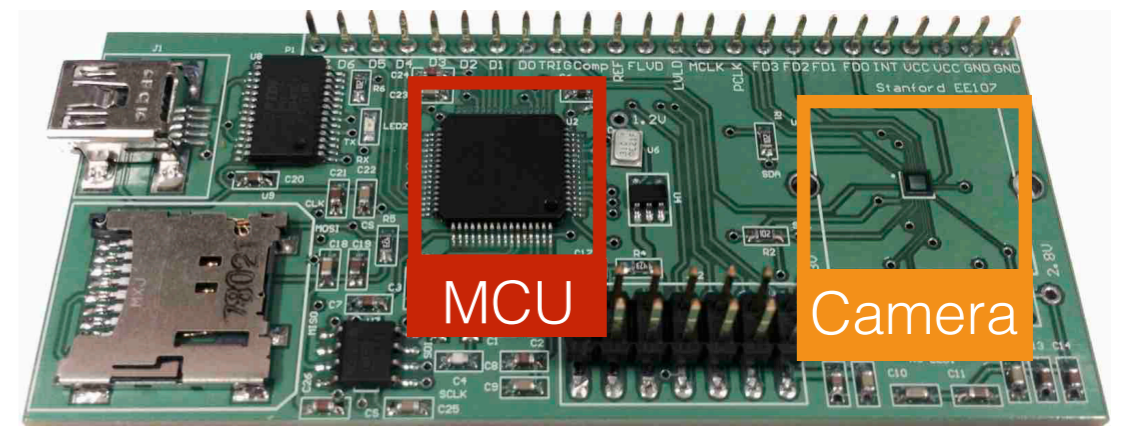
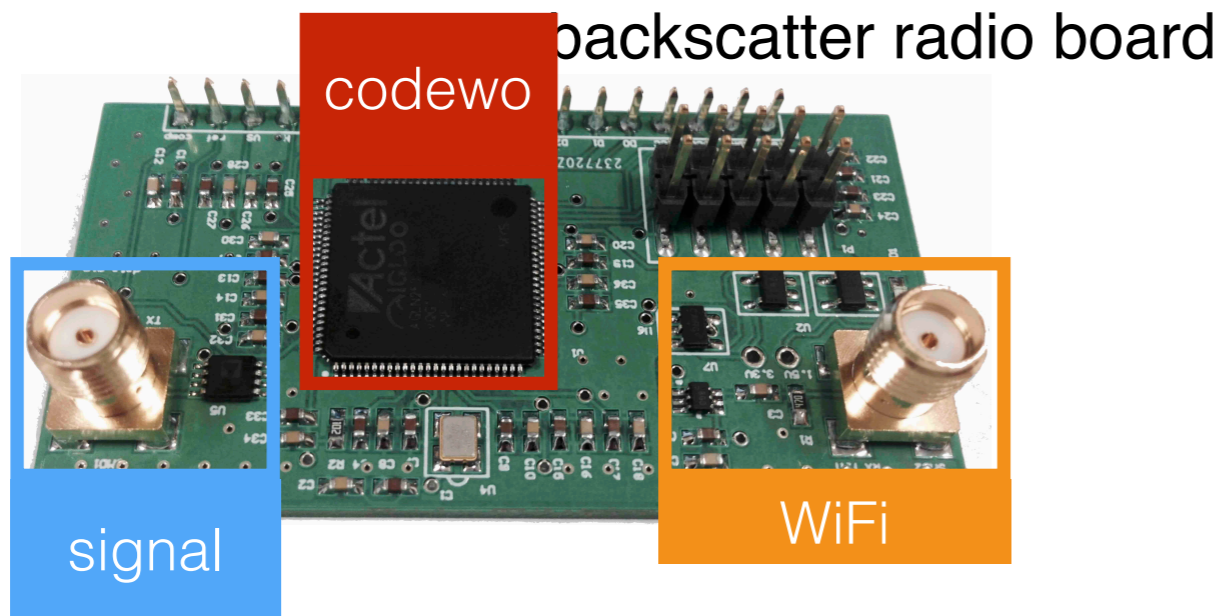
Prototype: used for teaching



speech and image sensing board

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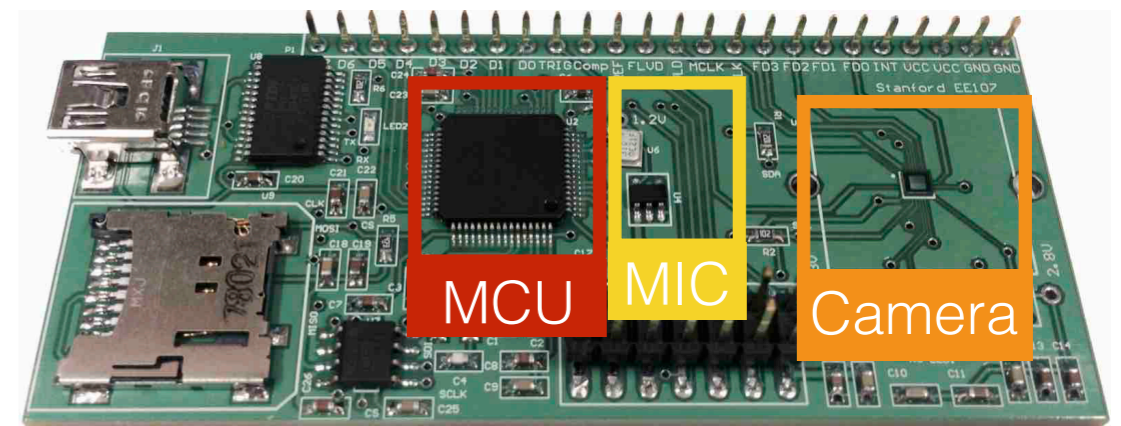
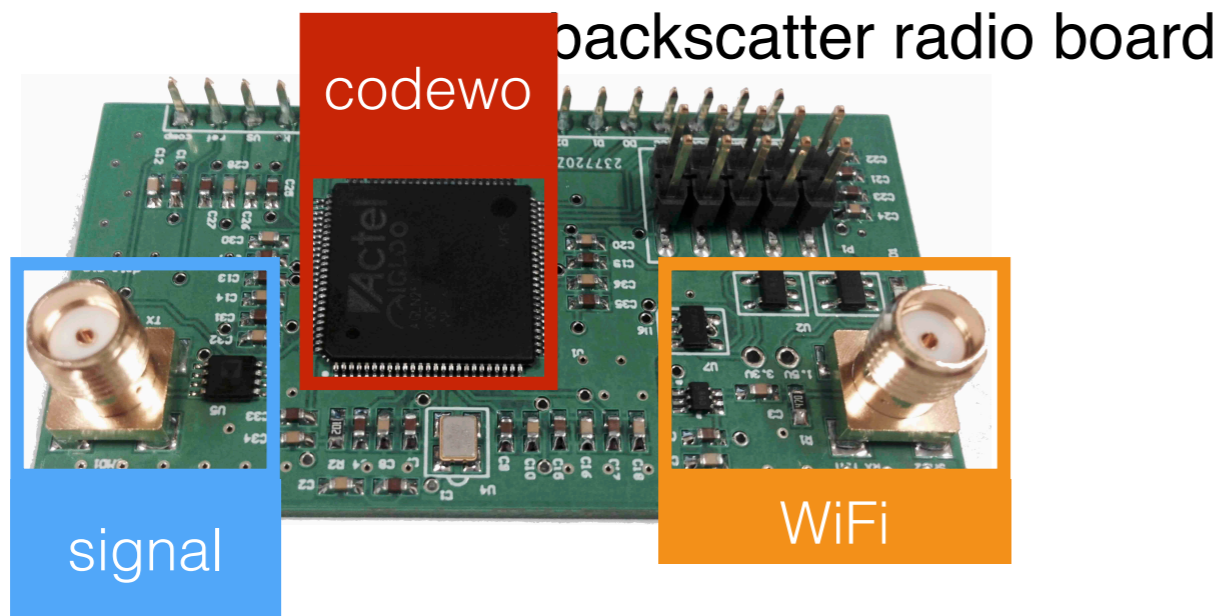
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speech and image sensing board

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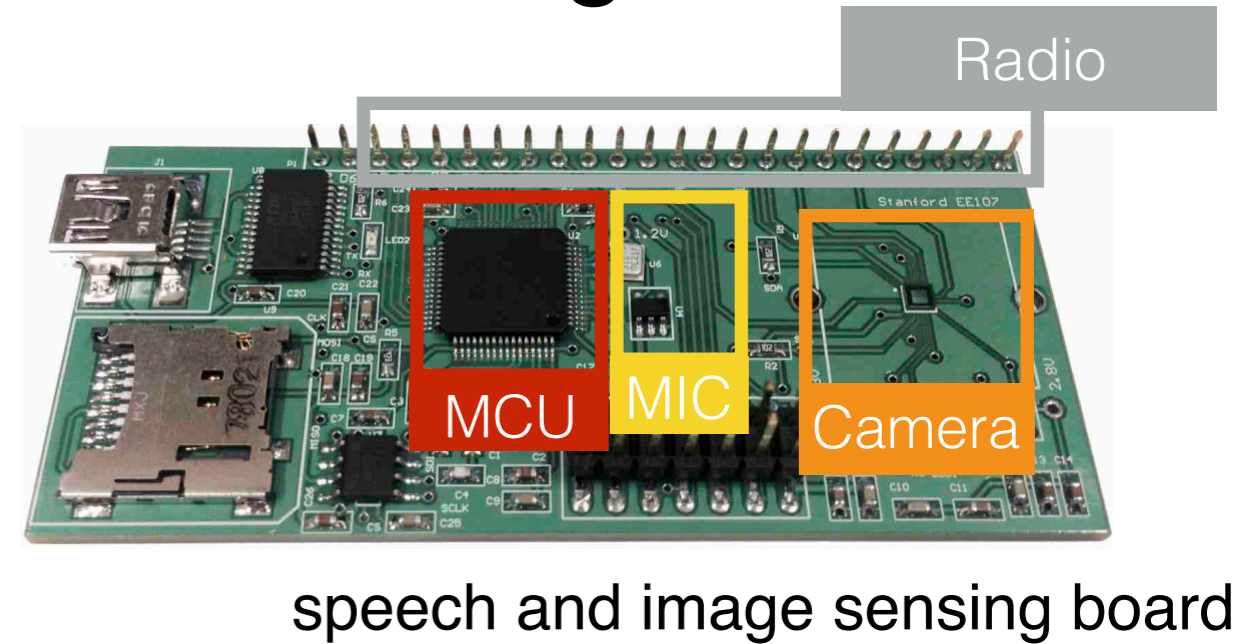
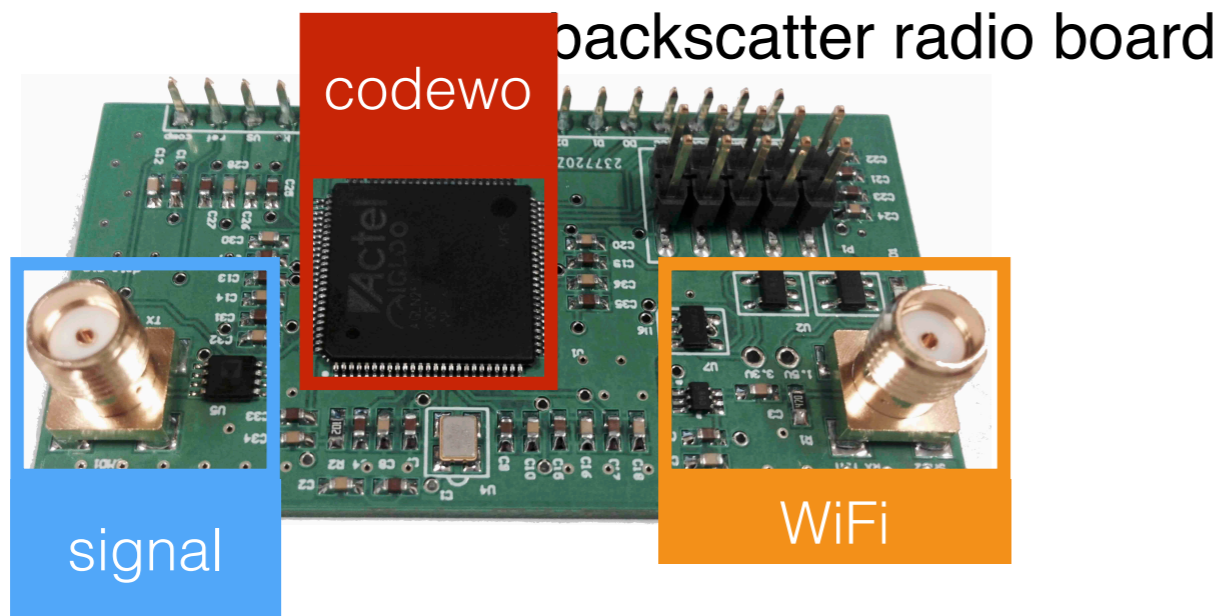
Prototype: used for teaching



speech and image sensing board

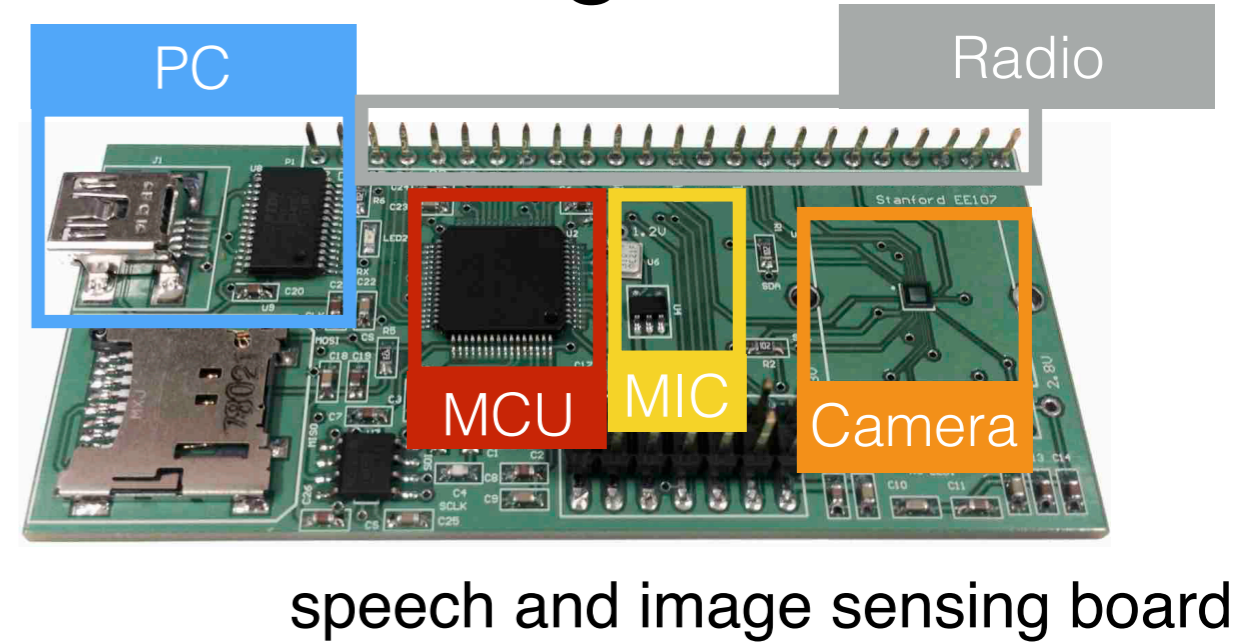
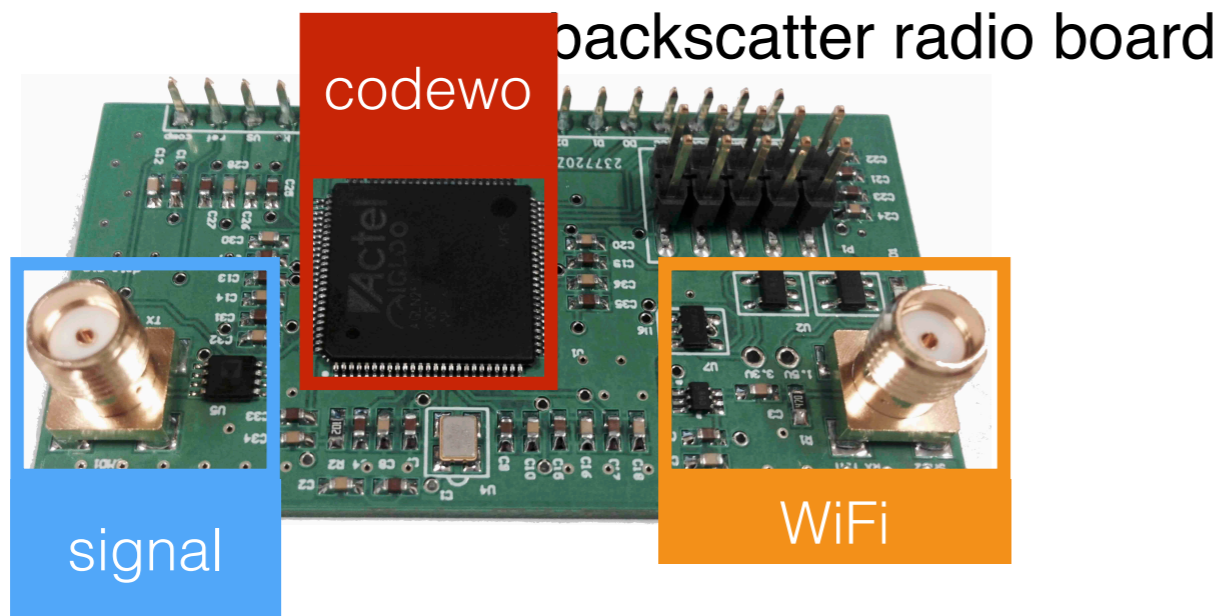
Open sourced platform: <https://github.com/pengyuzhang/HitchHike>

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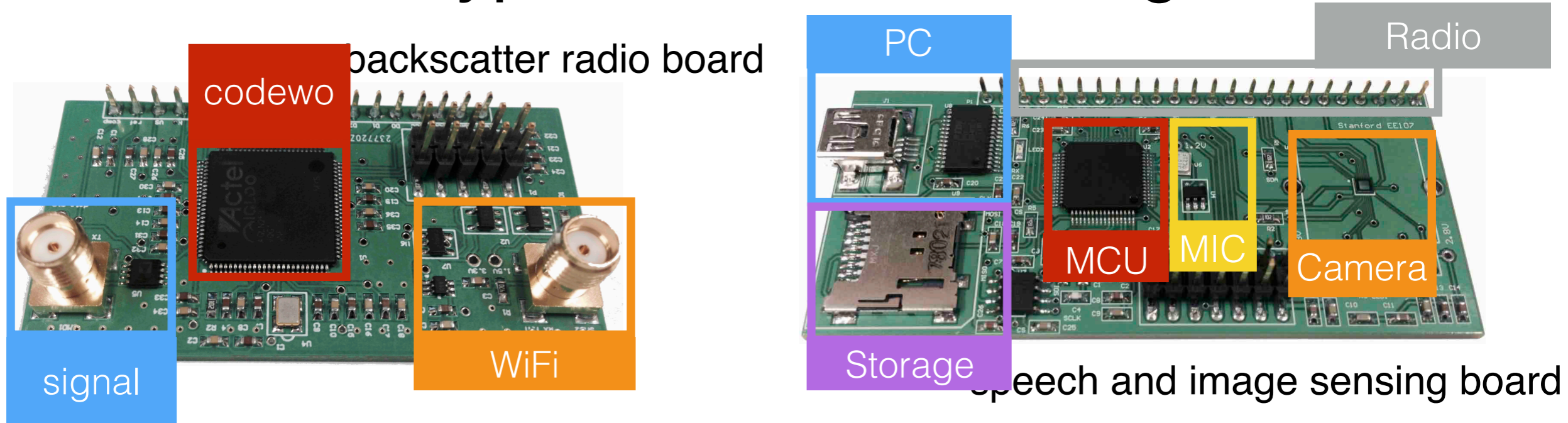
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