HitchHike: Enabling Backscatter Communication among Commodity WiFi Radios

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

![Graph showing the growth of Internet of Things (IoT) devices from 2004 to 2018. The graph indicates that IoT surpasses Smartphone, Tablet, and PC combined in 2018.]

- Internet of Things (IoT) devices surpass Smartphone, Tablet, and PC combined in 2018.
- We are here.
Vision — Ubiquitous Deployment of IoT Devices
Limiting Factor One — Battery Energy Density

Slow improvement — 3x over 22 years!
Wireless communication consumes orders of magnitude higher power compared to computation, storage, and sensing.
How should we communicate with IoT devices?
Static reflection does not consume power. Can we leverage reflected wireless signals and embed information there?
Backscatter — An Ultra Low Power Communication Primitive

Backscatter reader

Backscatter device

TX

AMP

RX

LNA

logic

RF harvester
Backscatter — An Ultra Low Power Communication Primitive

Backscatter reader

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Carrier Wave

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Backscatter — An Ultra Low Power Communication Primitive
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Backscatter reader

Backscatter device

TX

AMP

RX

LNA

Carrier Wave

Reflected Signal

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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TX

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Carrier Wave

Reflected Signal

Backscatter device

logic

RF harvester
Challenge — Do not have reader infrastructure!

- Carrier Wave
- Reflected Signal

Backscatter device

Logic

RF harvester
Challenge — Do not have reader infrastructure!
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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
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802.11b packets: 01100110…
HitchHike — embed backscatter bits on 802.11b WiFi

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802.11b packets: 01100110…
tag bits: 10011010…
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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

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0 1
codeword

+1+1+1-1-1+1-1+1+1-1-1-1+1+1+1-1+1+1-1-1-1+1-1-1+1-1+1-1-1-1+1-1-1+1-1+1-1-1-1
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0 1
codeword

DBPSK Q

DQPSK Q
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802.11b packets: 01100110…

0 1
codeword
+1+1+1-1-1+1-1-1-1-1-1-1-1-1-1-1-1-1-1-1
-1-1-1+1+1+1-1+1+1-1+1+1-1+1

DBPSK
modulation
wireless signal

DQPSK
802.11b WiFi Primer

802.11b packets: 01100110…

0 1
codeword

+1+1+1-1-1-1+1-1+1-1+1-1+1
-1-1-1+1+1+1-1+1+1-1+1+1

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.
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Codeword translation in 1Mbps 802.11b
Codeword translation in 1Mbps 802.11b

code 0
+1+1+1-1-1-1+1-1-1+1-1-1

code 1
-1-1-1+1+1+1-1+1+1-1+1

tag data

\[ +1+1+1-1-1-1+1-1-1+1-1-1 = -1-1-1+1+1+1-1+1+1-1+1 \times -1 \]

\[ \text{code 0} = \text{code 1} \times -1, \text{code 1} = \text{code 0} \times -1 \]
Codeword translation in 1Mbps 802.11b

A tag can translate code 0/1 to code 1/0 by multiplying -1.
What does * -1 mean for a wireless signal?

\[ s(t) \]

\[ s(t)^{-1} \]

How should we interpret -1?

S(t) is inverted

S(t) is delayed

500uW power for a phase shifter

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 \( j = code \ i \times -1 \)

code \( j = tag \ data \ XOR \ code \ i \)
How to decode the tag data?

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 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?

802.11b receiver is able to reject interference outside of the channel.
Are we done? Not yet…
We actually have double side-band backscatter
How to eliminate one side of backscatter?

- WiFi signal
- backscatter

$w(t)$

$w(t) * s(t)$

interference to other WiFi traffic

rx channel
Signal that has a reversed polarity at one side?

- WiFi signal
- Backscatter
Signal that has a reversed polarity at one side?

\[ w(t) + w(t) \times s(t) \]
Signal that has a reversed polarity at one side?

\[ w(t) + w(t) \times s(t) \]
Putting Everything Together

802.11b WiFi transmitter  backscatter tag  backscatter receiver
Putting Everything Together

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802.11b WiFi transmitter
backscatter tag
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Putting Everything Together

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802.11b WiFi transmitter  backscatter tag  backscatter receiver
Putting Everything Together

802.11b WiFi transmitter

backscatter tag

backscatter receiver

802.11b packets: 01100110…
tag bits: 10011010…
tag bits: 10011010…

12:45

802.11b WiFi transmitter
XoRFi system deployment

Packard building

line-of-sight deployment

non-line-of-sight deployment
Performance

Throughput (Mbps)

Distance (m)

30MHz
25MHz

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
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Prototype: used for teaching

backscatter radio board

Open sourced platform: https://github.com/pengyuzhang/HitchHike
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codewo

signal

WiFi

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codewo

signal

WiFi

speech and image sensing board

MCU

Camera

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backscatter radio board

codewo

signal WiFi

speech and image sensing board

MCU MIC Camera

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codewo

WiFi

Radio

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PC

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MIC

Camera

Radio

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