Leveraging Ambient LTE Traffic for Ubiquitous Passive Communication

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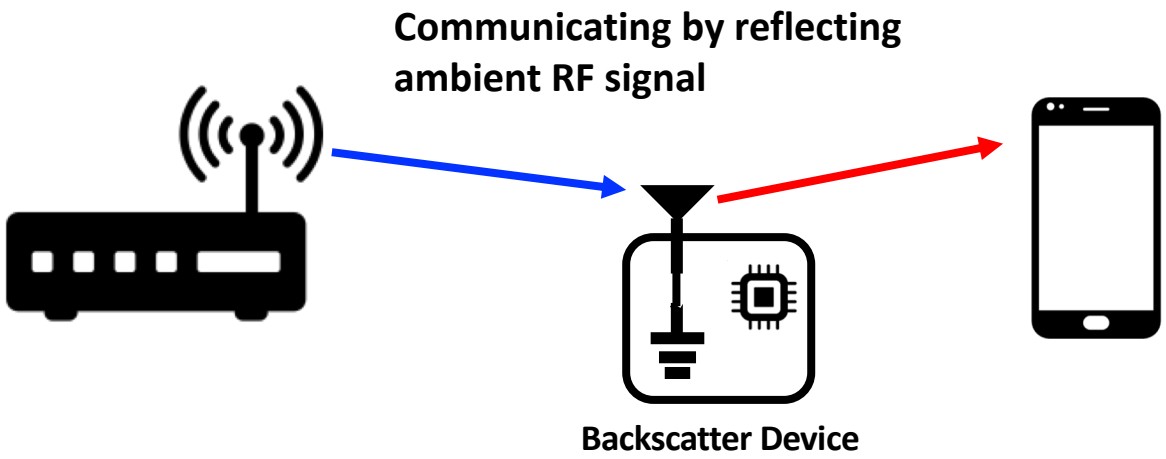
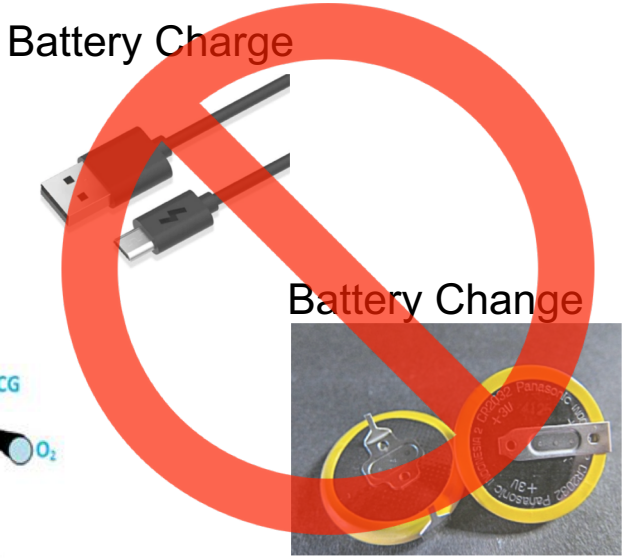
Backscatter: Ultra-low-power wireless communication (promising future IoTs)

Communication @ a few to tens of μW



Ultra low power or Maintenance-free IoT



State-of-the-art: Ambient Signal Backscattering

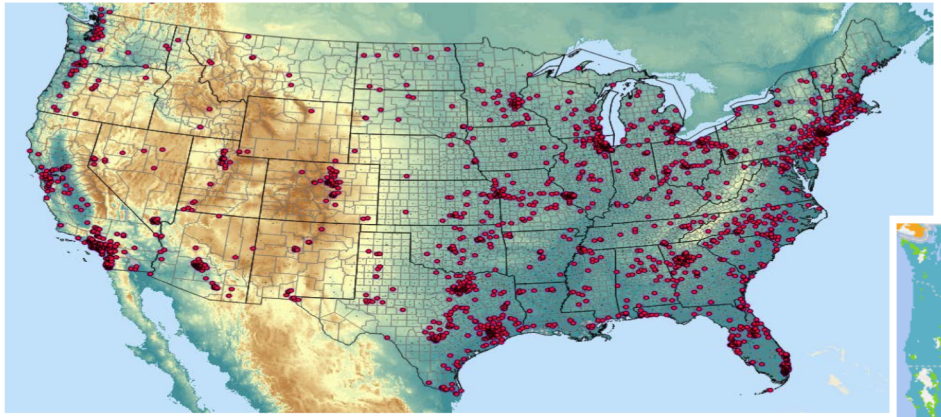
WiFi Backscatter [SIGCOMM'14]
BackFi[SIGCOMM'15]
HitchHike[SenSys'16]
FreeRider[CoNEXT'17]
MOXcatter[MobiSys'18]
etc.

Interscatter [SIGCOMM'16]
FreeRider [CoNEXT'17]
etc.

FreeRider [CoNEXT'17]
etc.

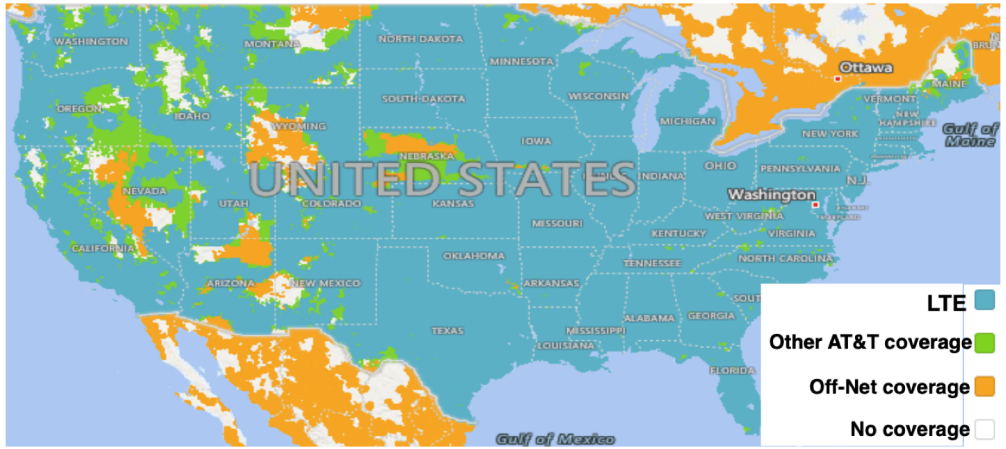
LoRa Backscatter [IMWUT'17]
PLoRa [SIGCOMM'18]
Netscatter [NSDI'19]
etc.

LTE Has Much Wider Coverage



LoRa Coverage

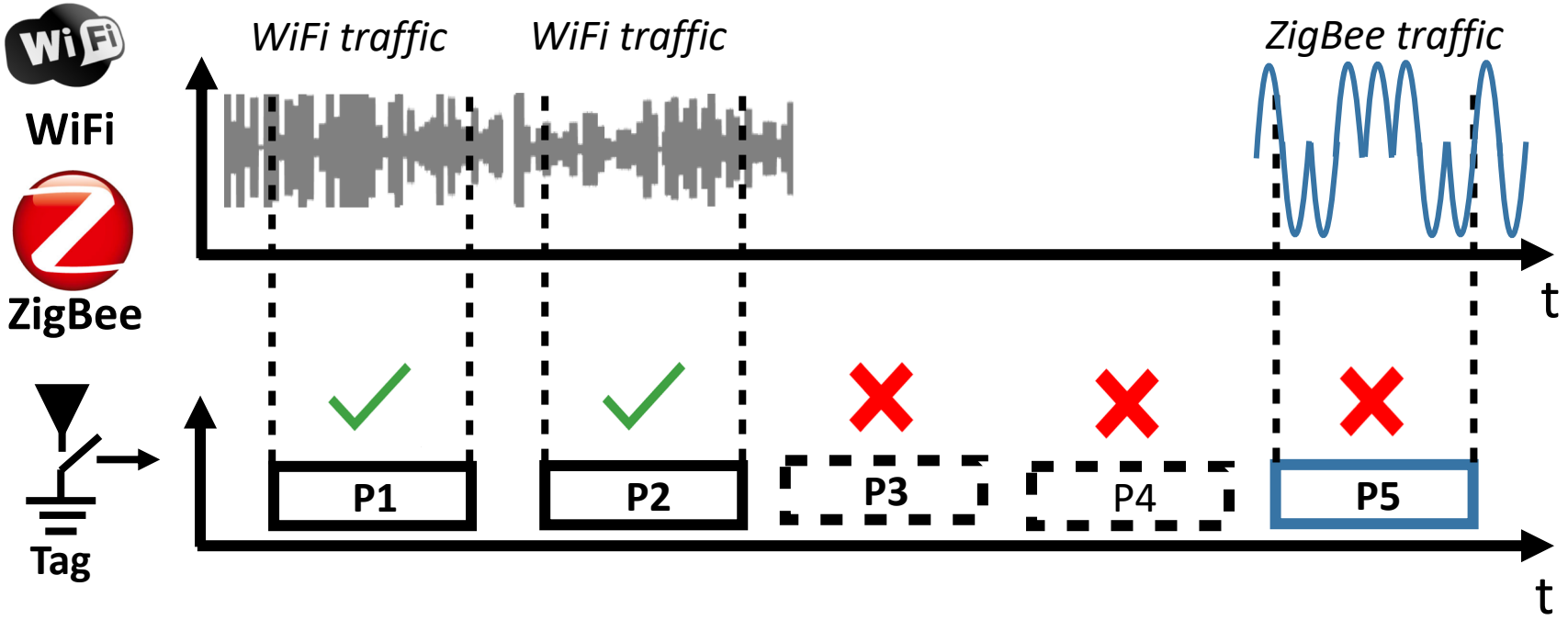
(source: LoRaWAN)



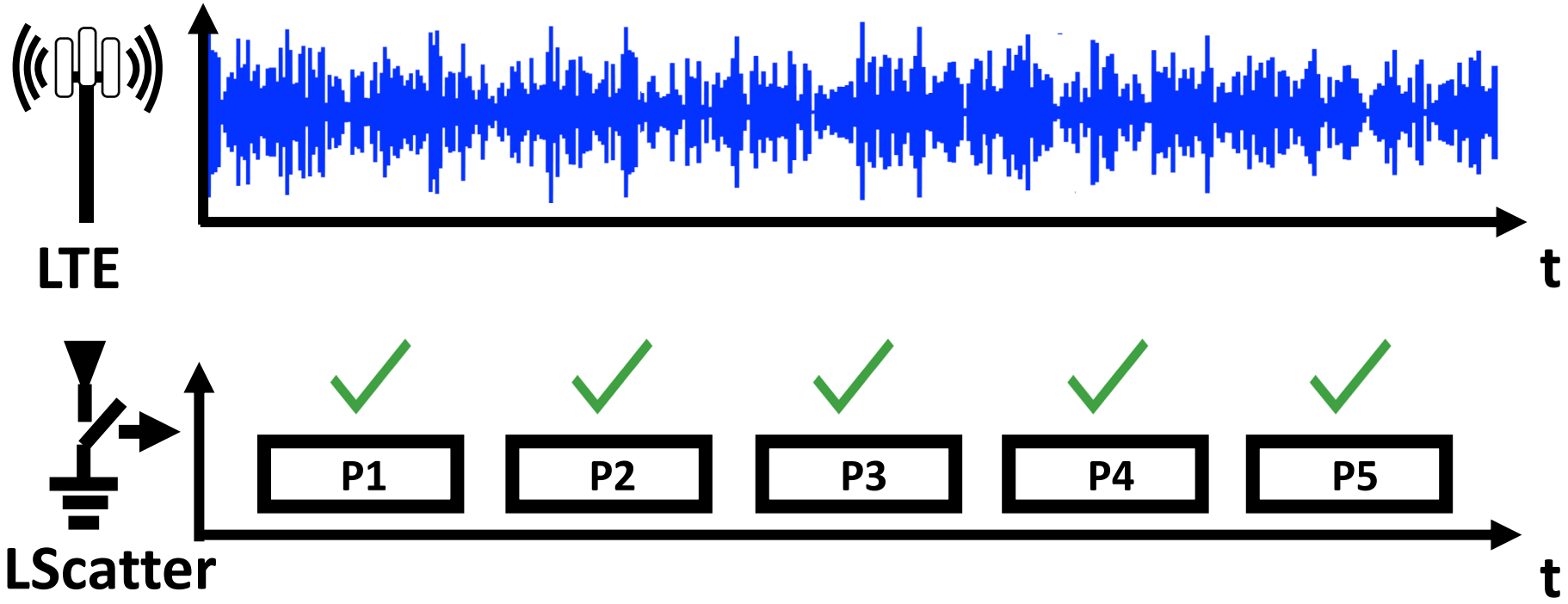
LTE Coverage

(source: AT&T)

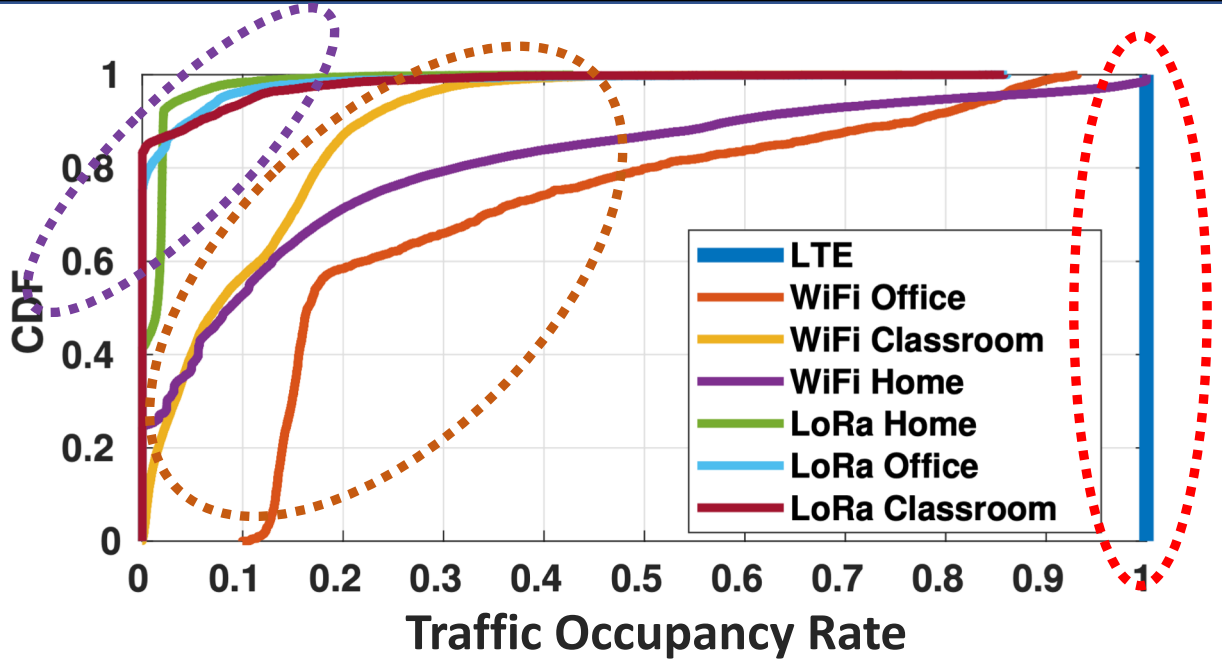
Problem 2: Intermittent Traffic and Shared Spectrum



Dedicated LTE Band and Continuous Signal



On-site Measurements (Statistic)

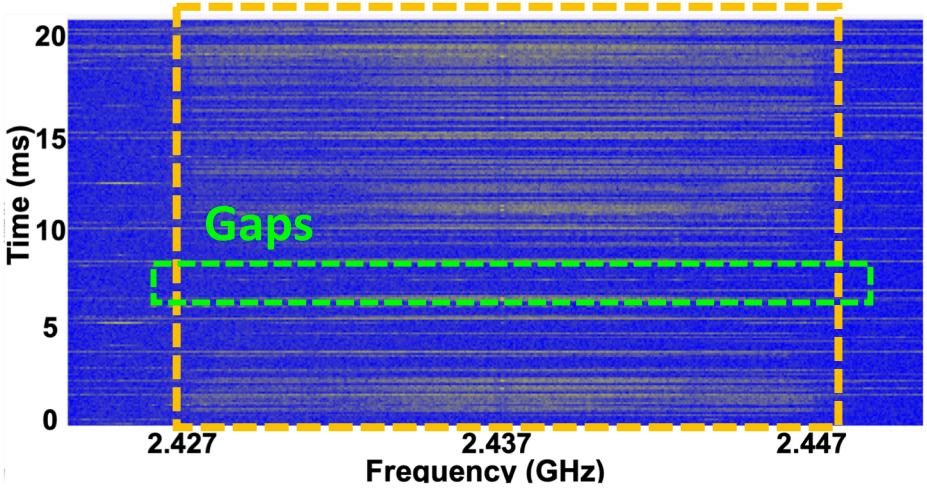


LTE Traffic keeps high occupancy over time.

LoRa, WiFi, and LTE traffic measured for a whole week

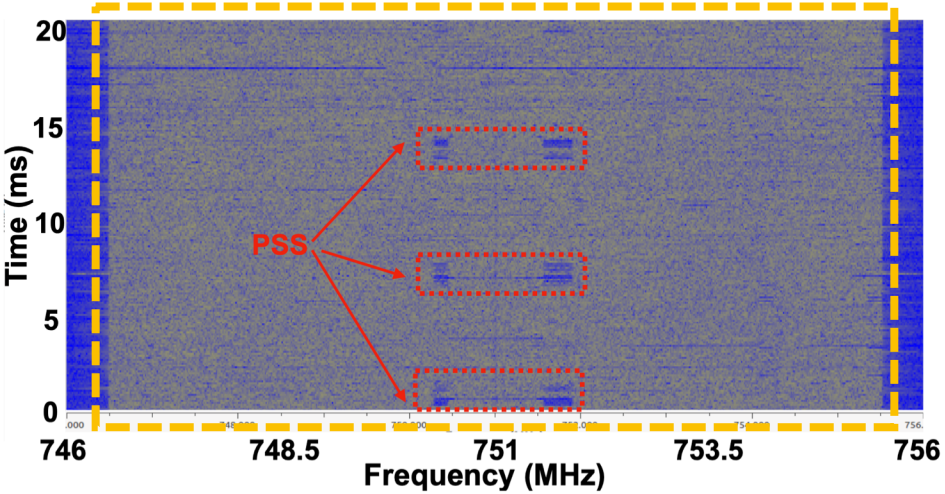
On-site Measurements

Intermittent Traffic



WiFi Spectrogram

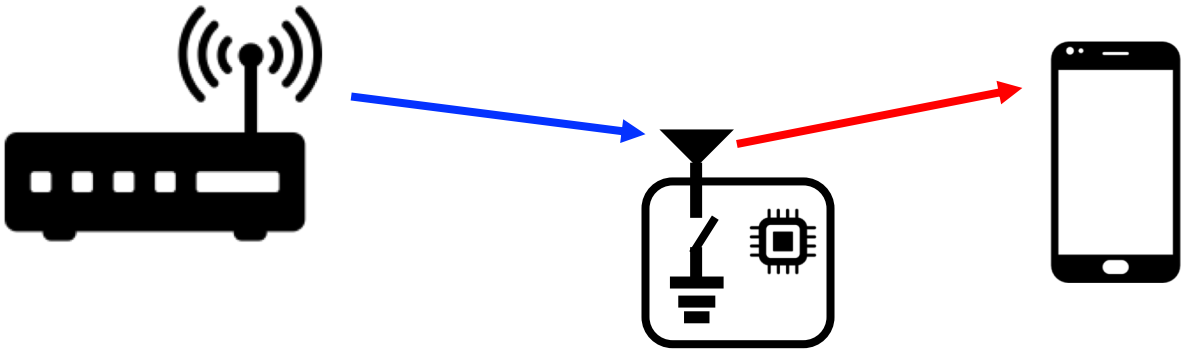
Continuous Traffic



LTE Spectrogram

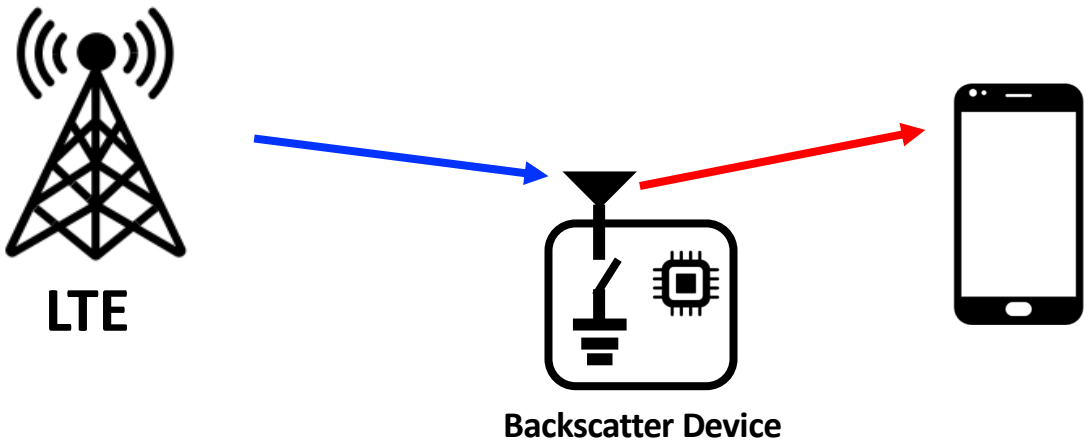
Hindrance to Ambient Backscatter

- The bursty and intermittent traffic patterns make the backscatter system unreliable.
- The shared channel makes backscattering even harder.



LScatter: Backscattering Ambient LTE Signal

- Ubiquitous LTE coverage
- Continuous LTE excitation signal

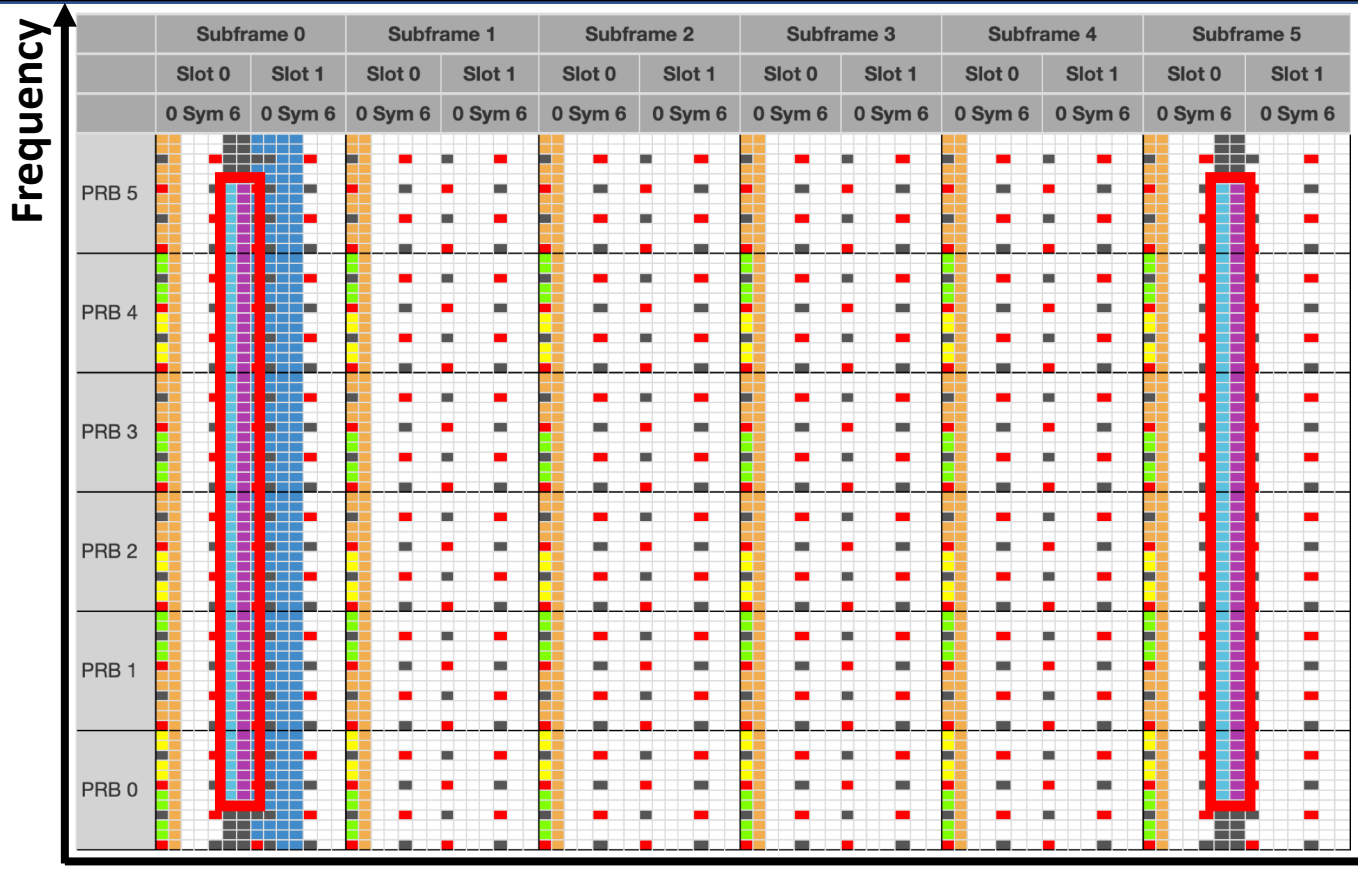


Major Challenges

- **How to ensure critical information remains unmodified after backscattering?**

- **How to modulate the LTE signal to achieve high throughput?**

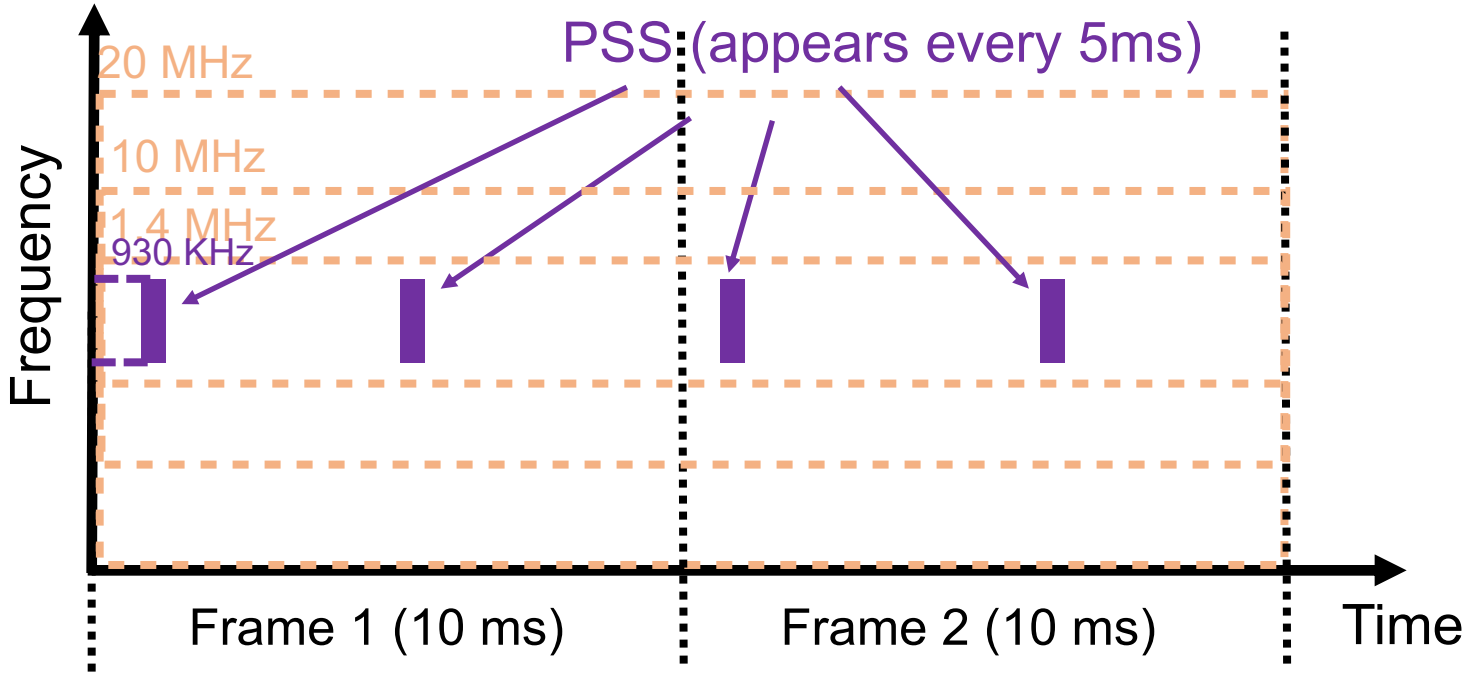
LTE Frame Structure



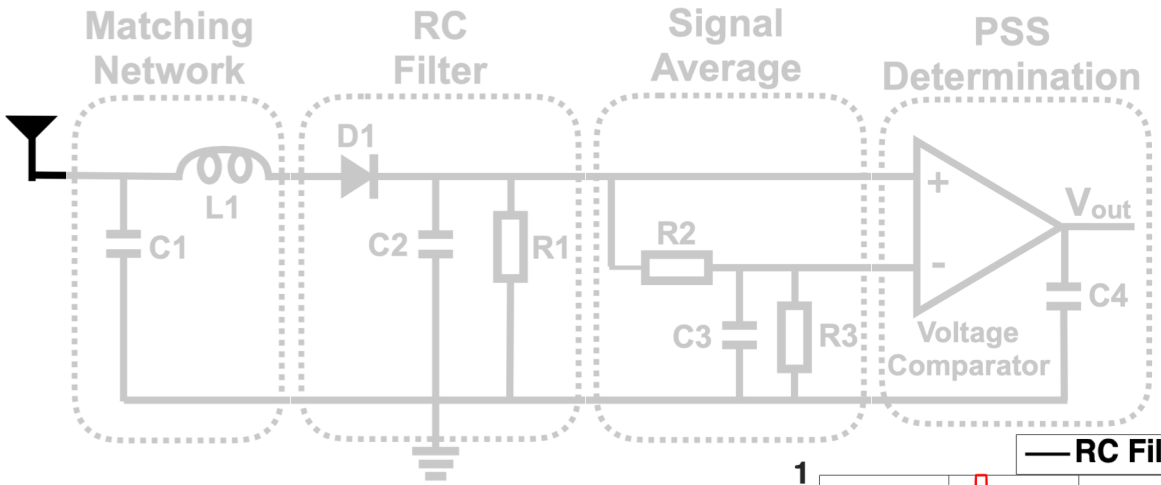
Color Legend

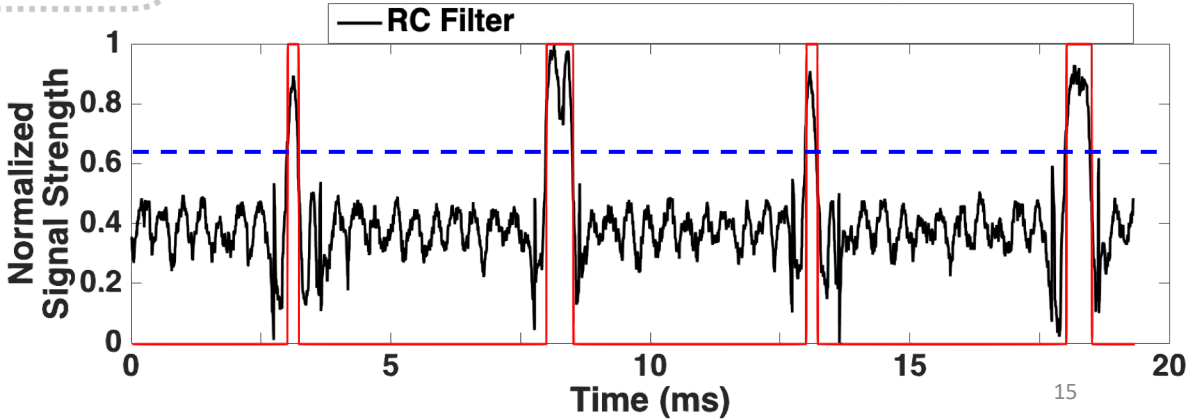
- PDCCH
- PBCH
- PSS
- SSS
- PDSCH
- Reserved
- Ref Signal
- PCFICH
- PHICH
- TDD Uplink
- Guard Period

Using Periodical Signal to SYNC



Low Power Circuit to extract and sync with PSS





Major Challenges

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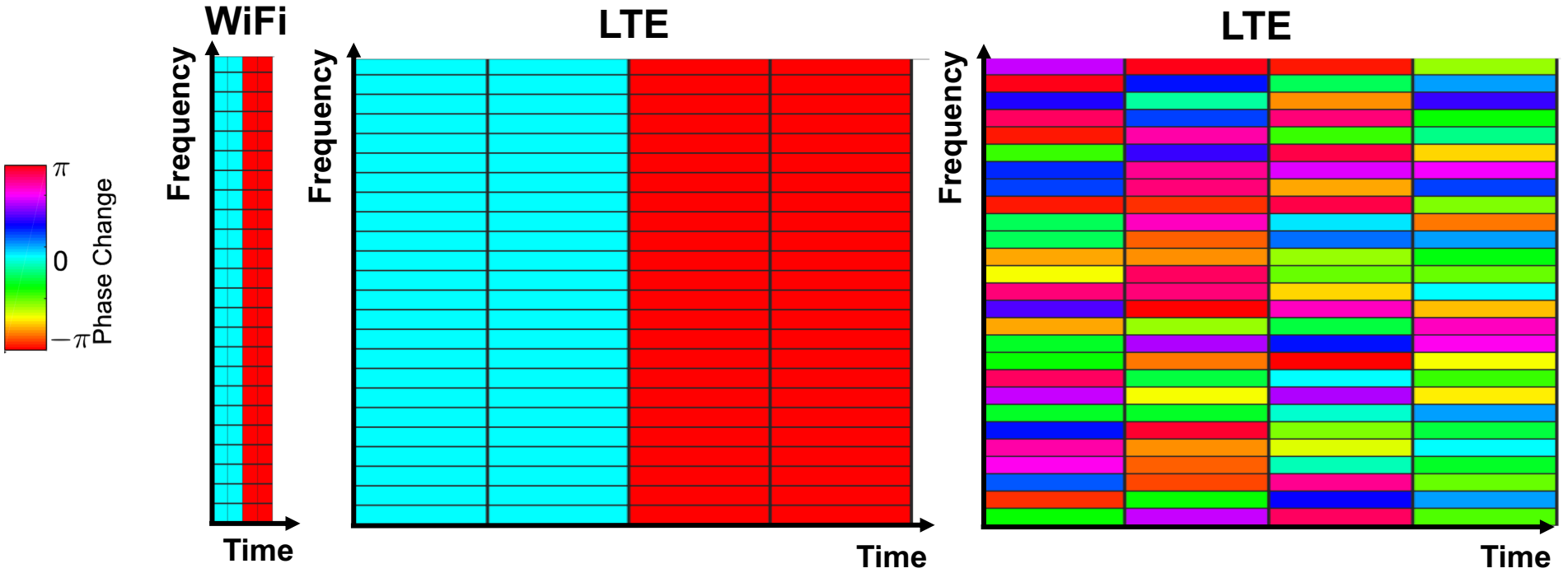
- **How to modulate the LTE signal to achieve high throughput?**

High Efficient LTE Backscattering



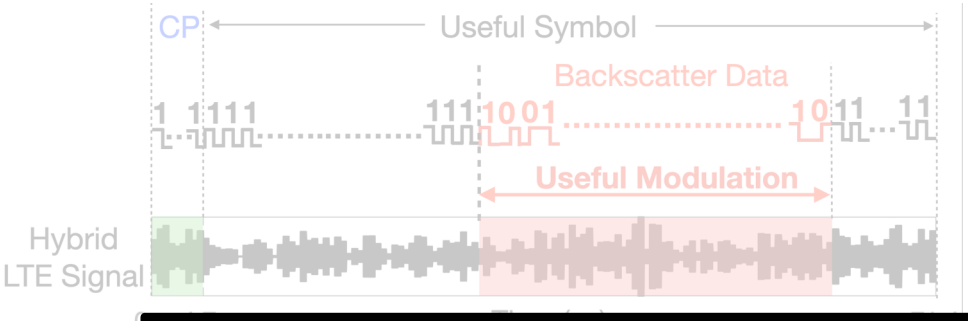
Symbol Duration=4us
Throughput=~60Kbps

Symbol Duration= 66.7us
Throughput=~4Kbps

Basic-timing Unit Modulation
Throughput= ~13Mbps!

More Challenges

Handling cyclic prefix and inter symbol interference

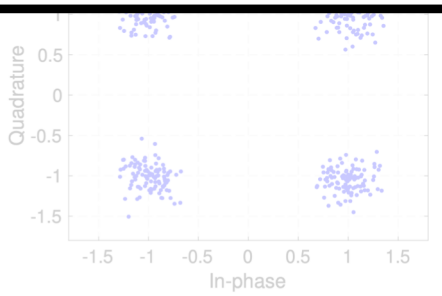


Demodulation error correction

Please refer to our paper for details

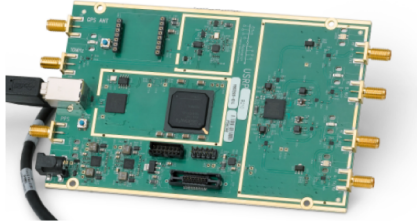
Modulation offset determination

$$\Theta = \underset{\theta_n \in \{0,\pi\}}{\operatorname{argmin}} \sum_{\substack{k=0 \\ k \neq r}}^{K-1} || Y_k Y_r^* - (\sum_{n=0}^{K-1} x_n e^{j(\theta_n - \frac{2\pi nk}{K})})(\sum_{n=0}^{K-1} x_n^* e^{j(\frac{2\pi nr}{K} - \theta_n)}) ||$$

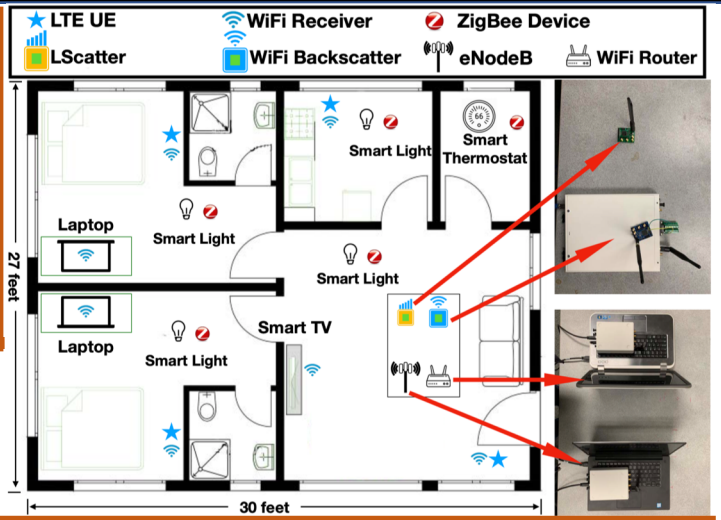


Experimental Setup

LScatter Tag

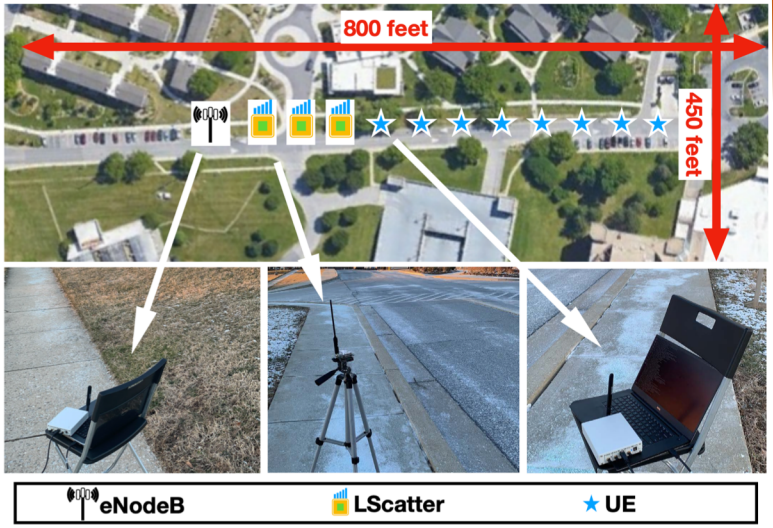


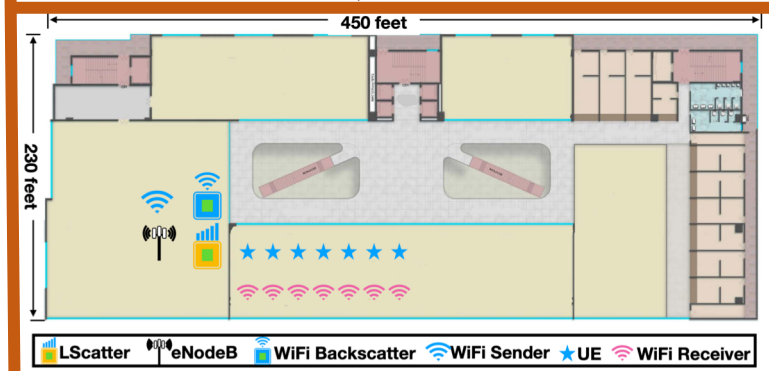
USRP B210 with srsLTE eNodeB & UE



Home

Outdoor

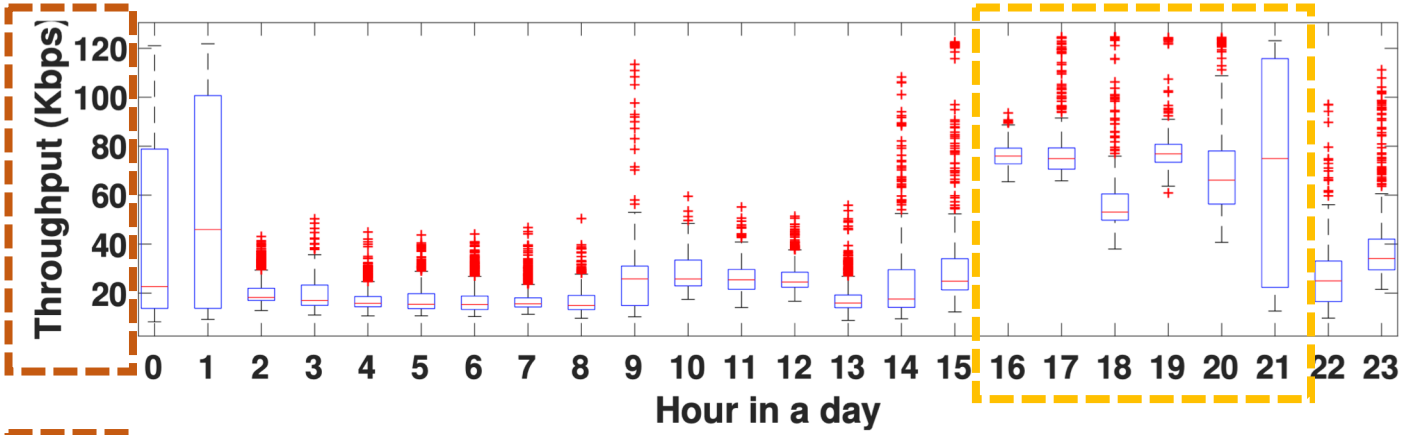




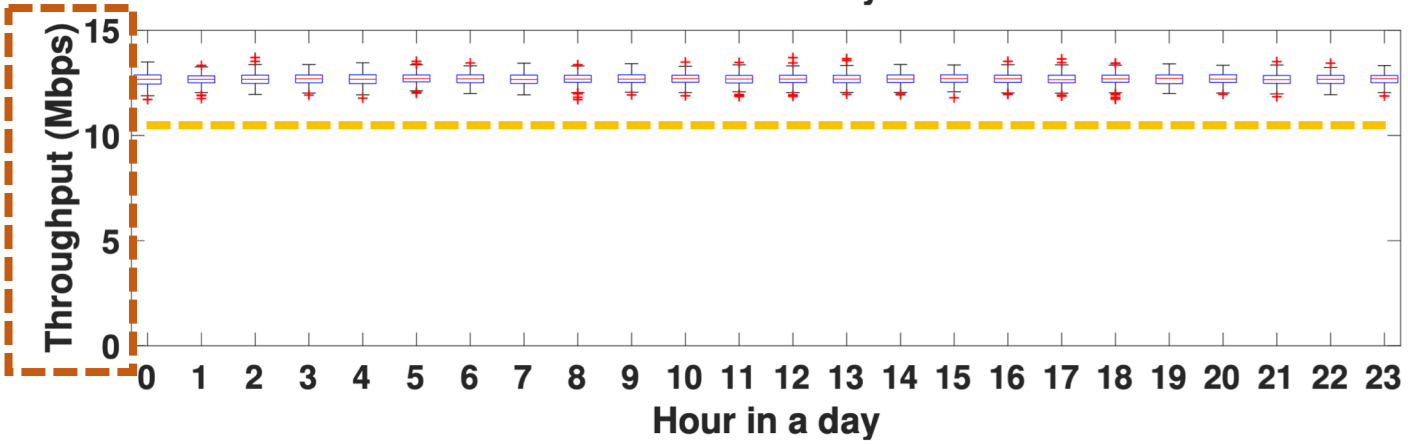
Shopping Mall

LScatter shows a resilient performance during a day while WiFi backscatter's performance fluctuates

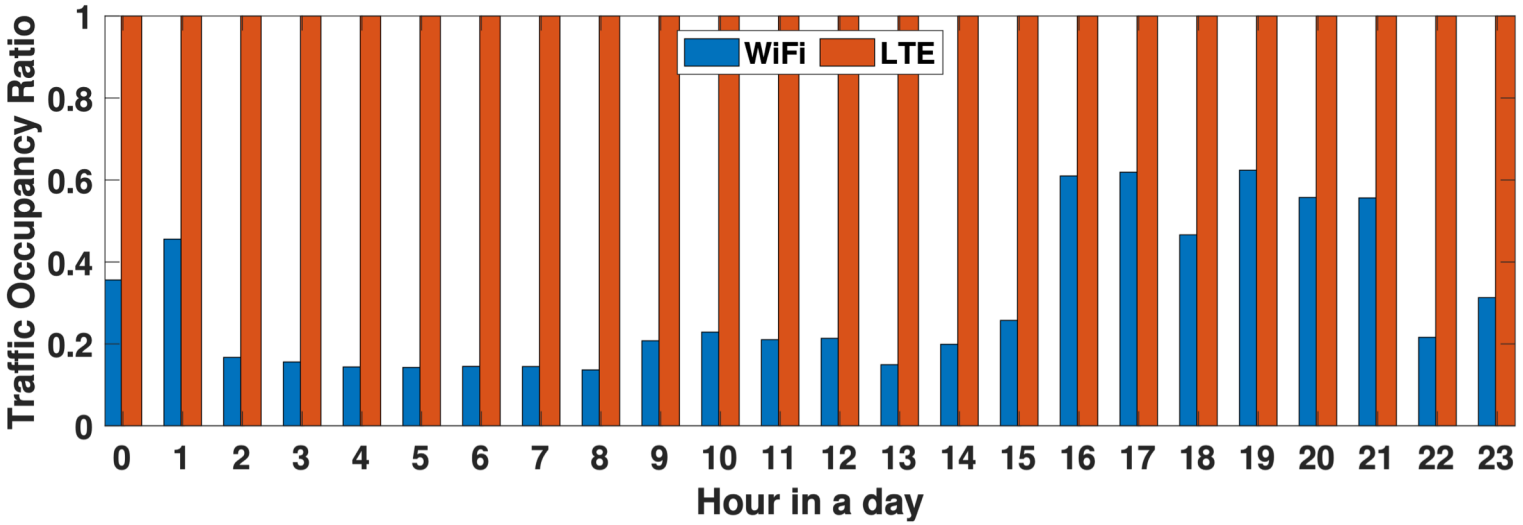
WiFi Backscatter



LScatter

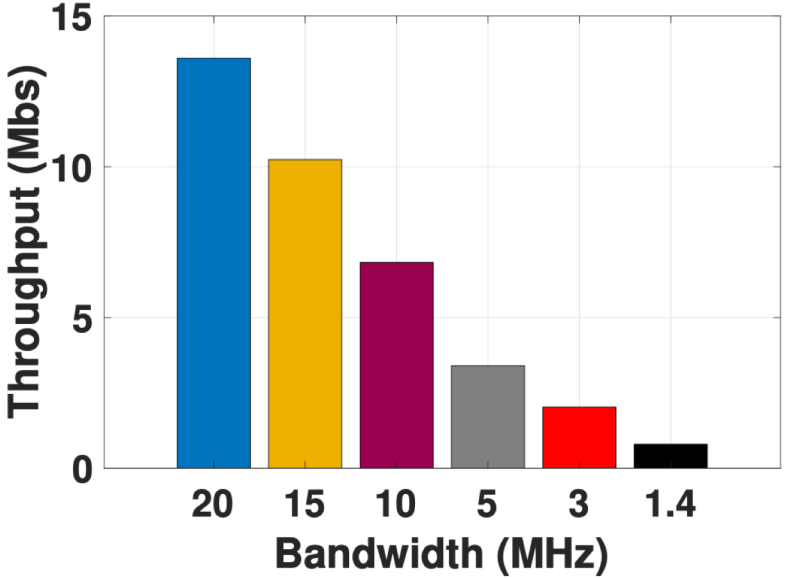


Traffic Occupancy Ratio

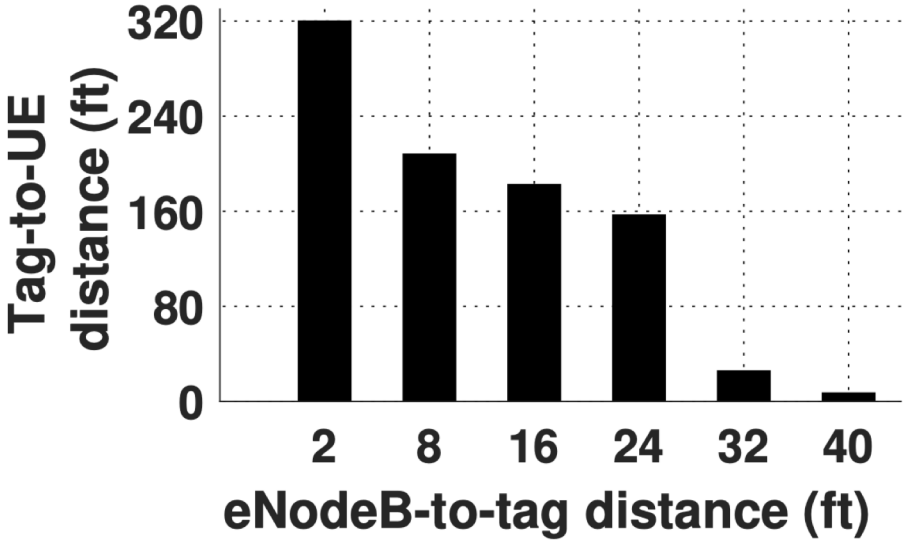


LTE has full coverage in time domain while WiFi traffic depends on usage

Impact of LTE Bandwidth and Communication Distance

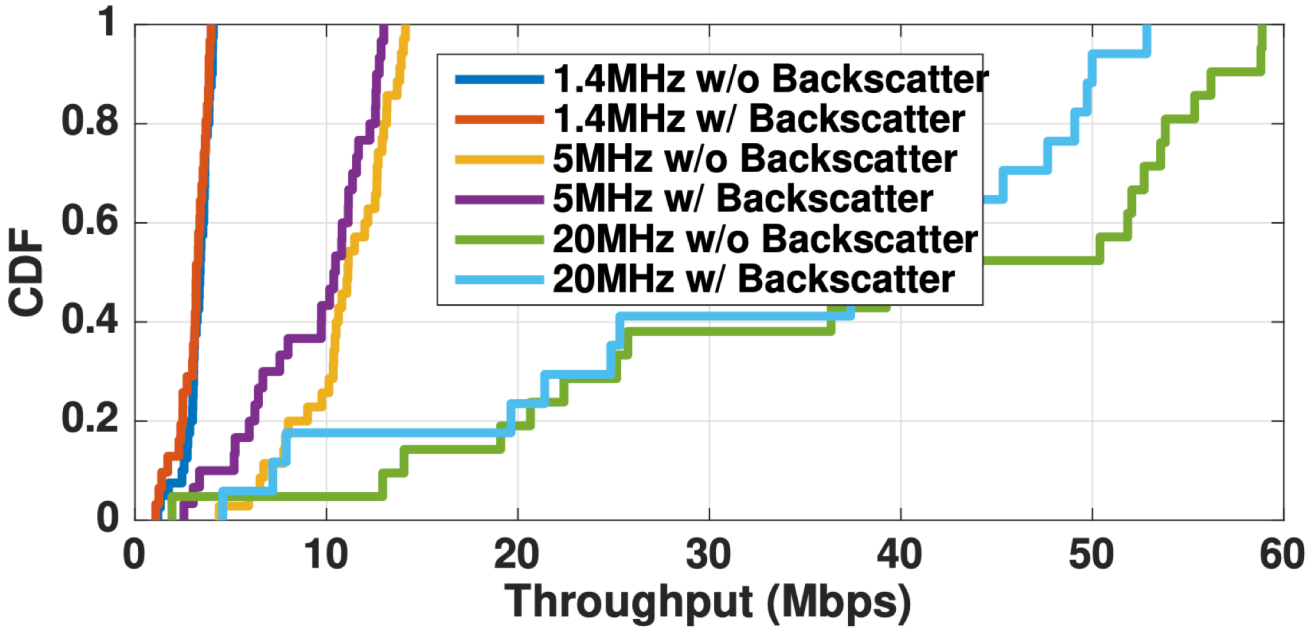


LScatter supports variety of different LTE bandwidth



With higher TX power of cellular tower, LScatter can achieve longer distance.

Impact to Original LTE Communication



While backscattering, LScatter generates negligible impact to original LTE communication

Conclusion

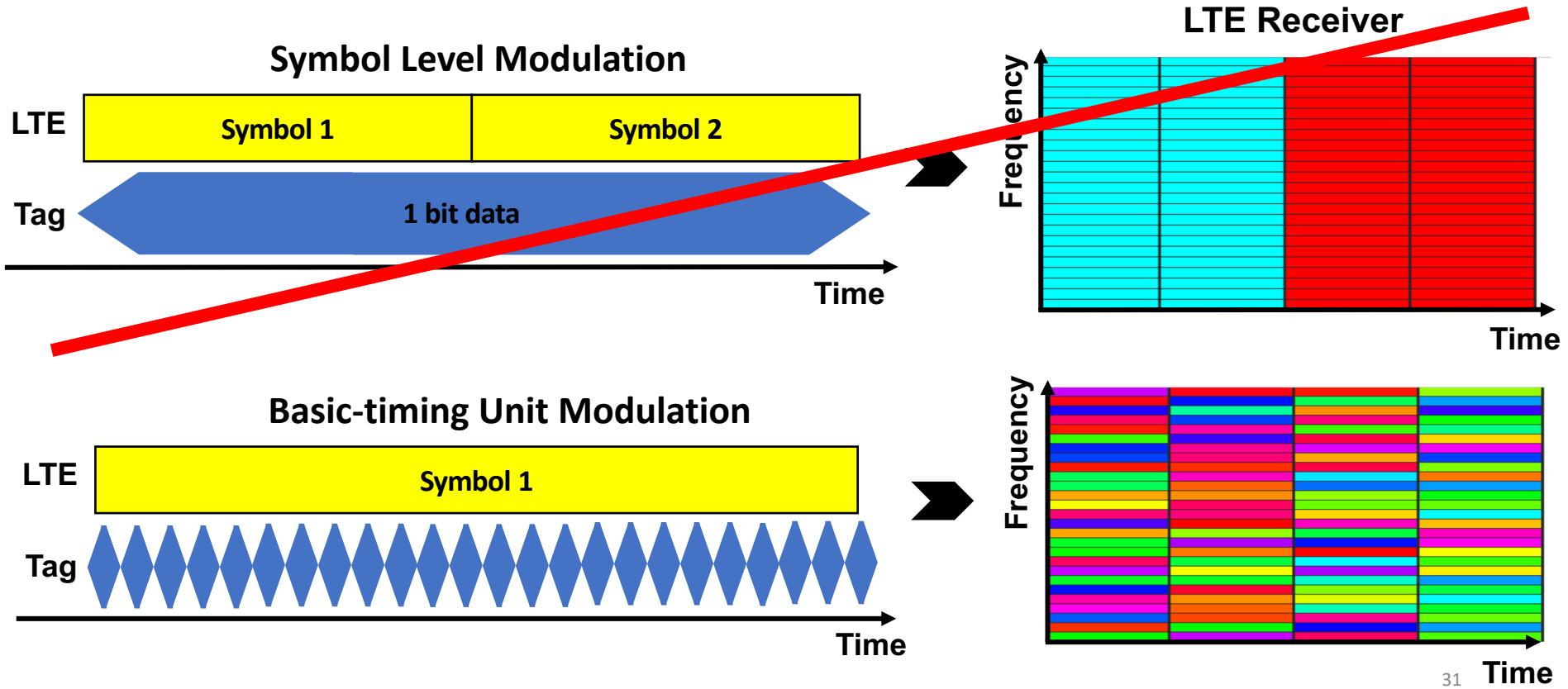
- **We considered a new aspect of backscatter communication: ubiquitous coverage in time and space domains.**
- **We demonstrated it is possible to backscatter the constantly strong and widely available LTE signal.**
- **We extensively evaluated our backscatter system in three different real-world scenarios.**

Thanks!

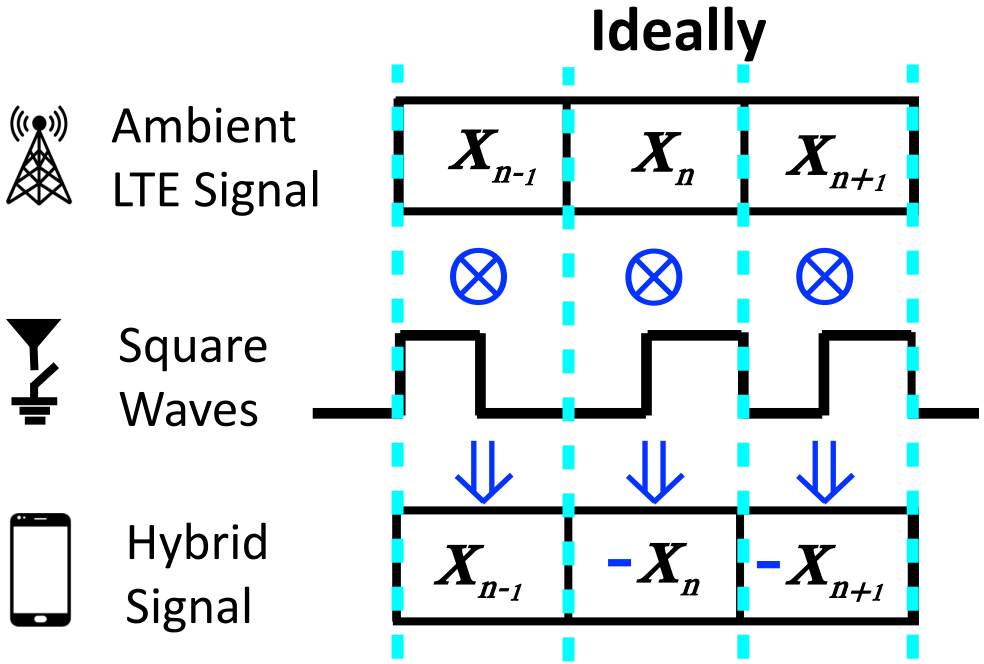
Challenges

1. How to ensure critical information remains unmodified after backscattering?
2. How to modulate the LTE signal to achieve high throughput?
3. How to correct phase offset to successfully demodulate?

High Efficient LTE Backscattering

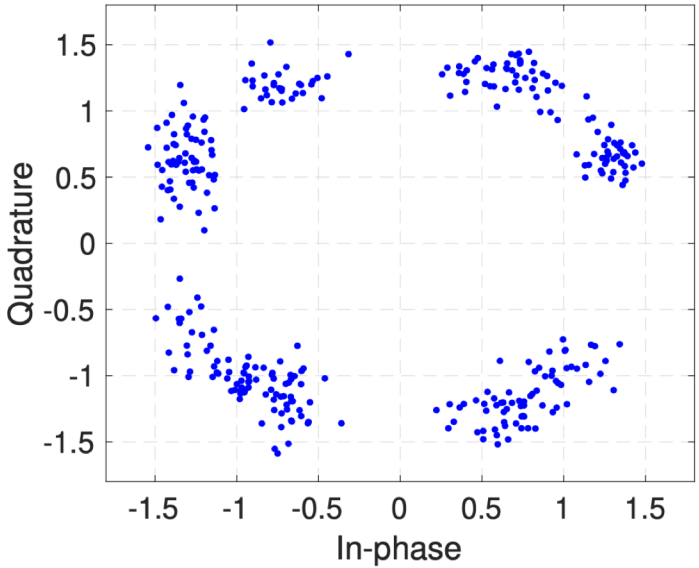


Phase Offset Caused by Backscatter

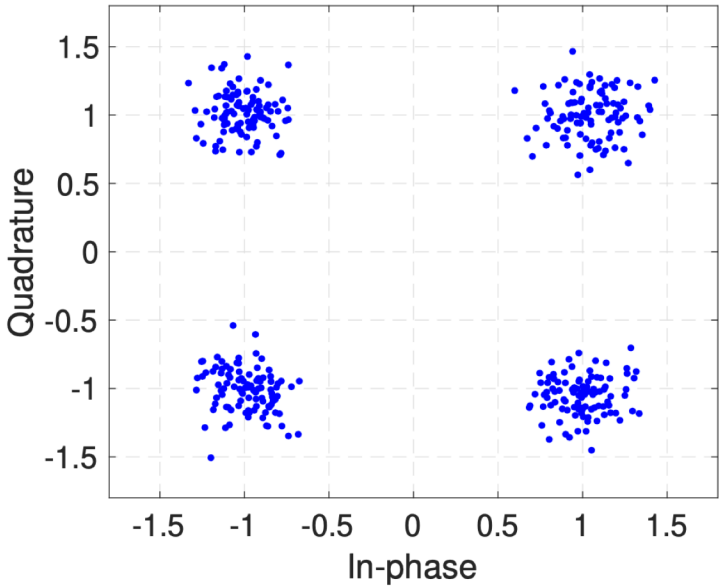


$$Y_k Y_r^* = \left(e^{j\varphi} \sum_{n=0}^{K-1} \left(x_n e^{j\theta_n} e^{\frac{-j2\pi nk}{K}} \right) \right) \left(e^{-j\varphi} \sum_{n=0}^{K-1} \left(x_n e^{j\theta_n} e^{\frac{-j2\pi nk}{K}} \right) \right)$$

Phase Offset Elimination Example



Received signal with phase offset



Phase offset eliminated