A Robust Algorithm for Sniffing BLE Long-Lived Connections in Real-time

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Outline

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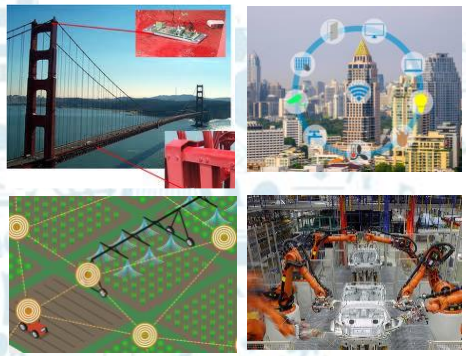
Background

Internet of Things (IoT)

Smart Health

Smart Transportation

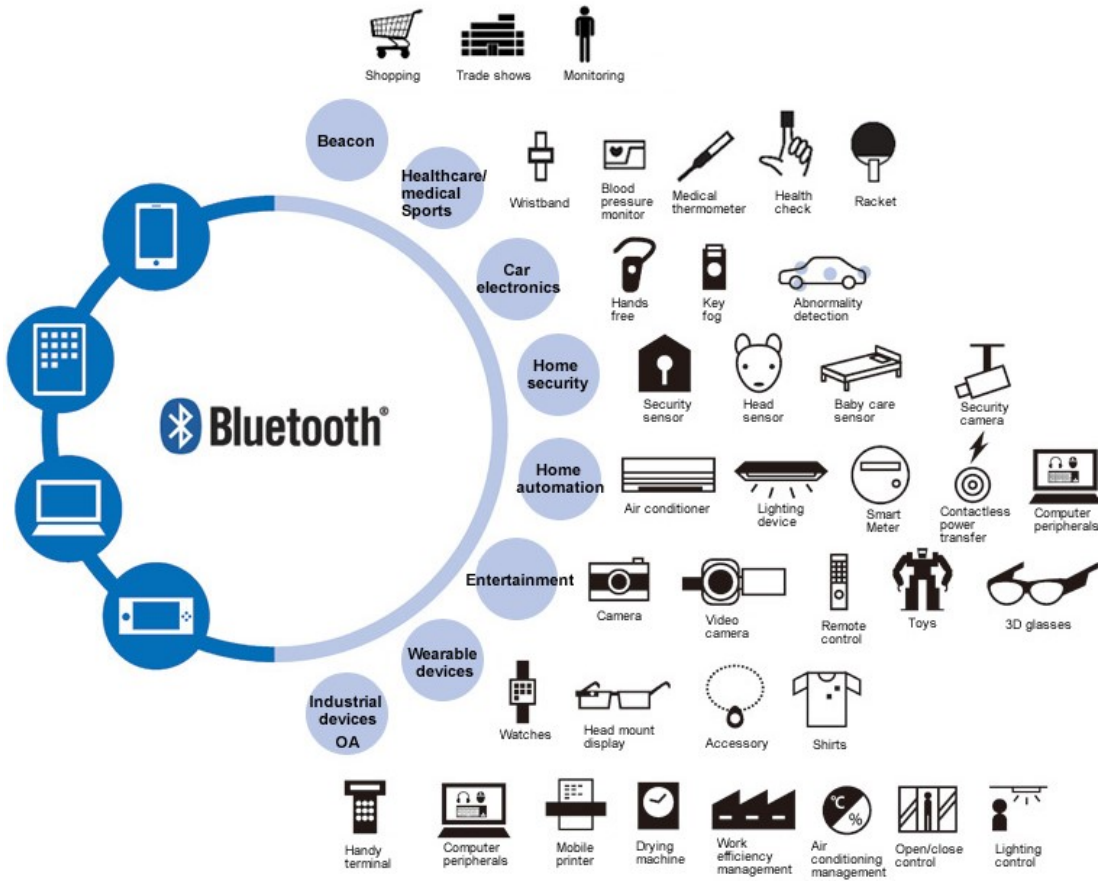


Smart Industry

Smart Energy

Background

Bluetooth Low Energy (BLE) in IoT



Background

BLE Preliminaries

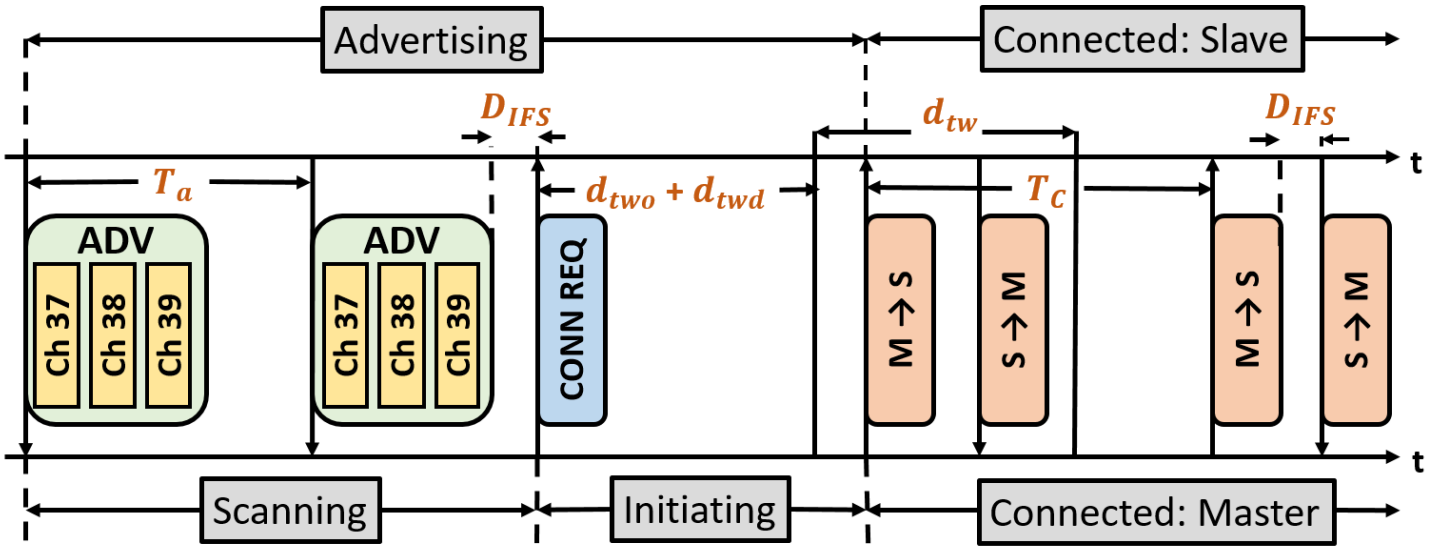
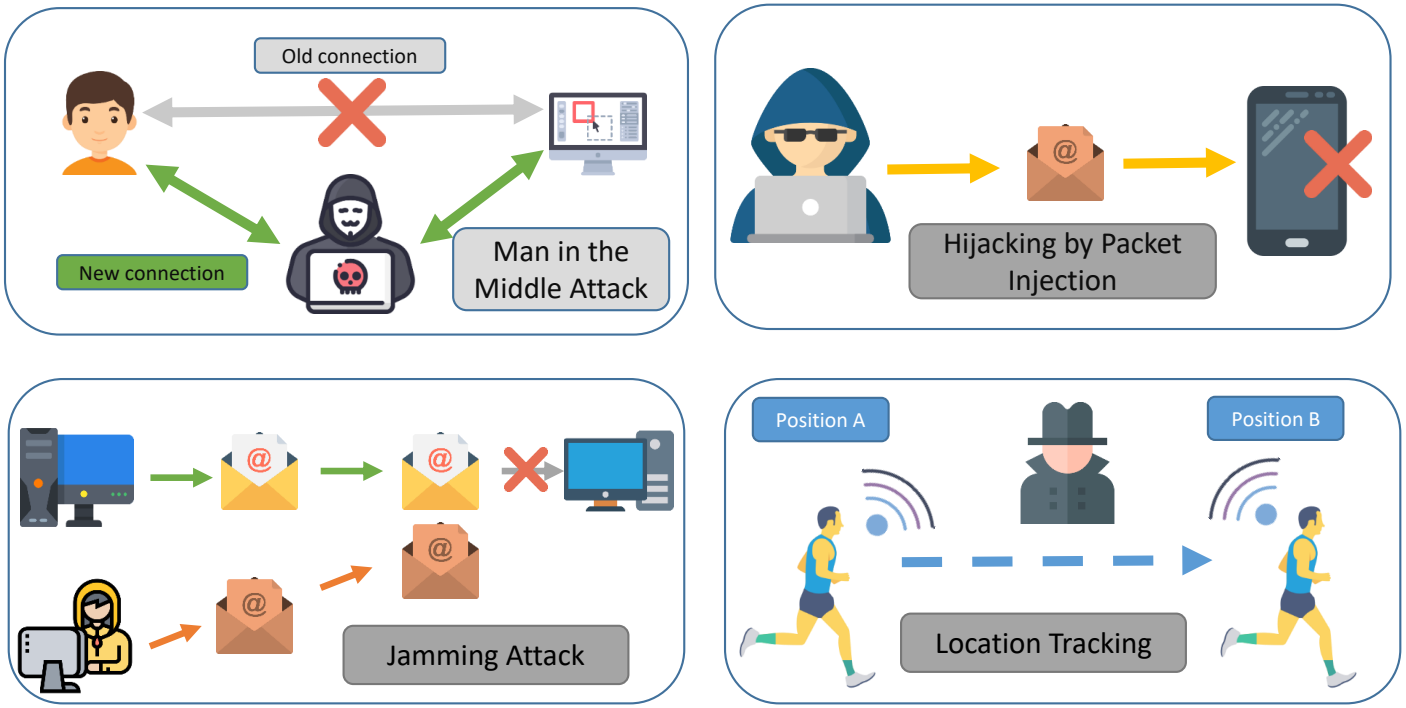


Figure: BLE Link Layer states

- Connection parameters(Access address, Hop interval, Channel map and Hop increment) are exchanged during "initiating state"
- Adaptive frequency hopping (AFH) - Channel map updates based on the channel condition

BLE Security & Privacy

BLE Security - Current State



- BLE suffers from various attacks and can be detected by intrusion detection system;
- Not well investigated paradigm - BLE sniffing

Challenges

Sniffing BLE is hard!

- Wide-band receivers are bulky and costly!
- Three parameters needed to follow a BLE connection - hop interval, hop increment and channel map are exchanged during Advertisement phase
- In connected state BLE use Frequency hopping spread spectrum and AFH

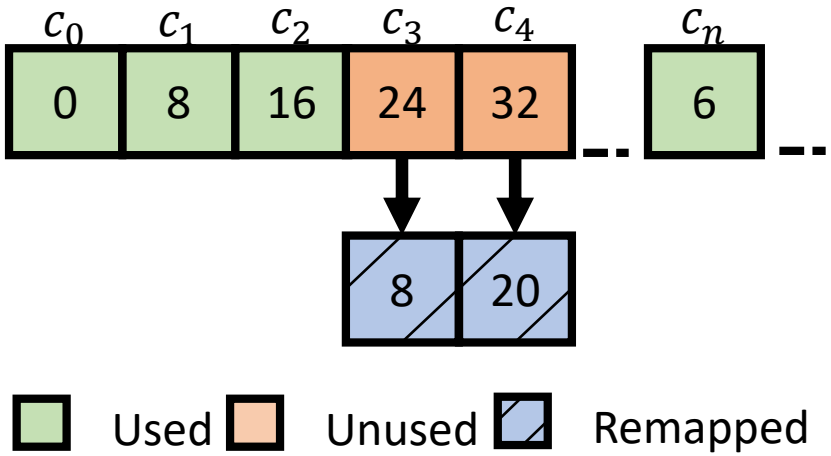


Figure: BLE channel selection algorithm

Contributions

Our contributions -

- Developed algorithm to sniff BLE in connected state
- We used a single-channel and low-cost radio sniffer Ubertooth One for implementation and evaluation
- Our algorithm runs in real-time and is prone to AFH of BLE
- Proposed algorithm can calculate AFH parameters with 96% accuracy and sniff more than 80% transmitted data

Outline

Adversary Model

System Model

- We consider an indoor environment
- Most of the BLE devices are in connected state
- Some are in advertisement state

Attack Model

- Consider adversary is in close proximity to victim BLE devices
- Has limited resources in terms of equipment and computation
- Uses single-radio sniffer

Determining Hop Interval

- BLE AFH has a period of 37
- We stay on a single BLE channel and determine the time difference $\Delta t'$ between adjacent packet receptions
- We compare and analyze the set of $\Delta t'$ and find the repetitive pattern
- The sum of $\Delta t'$ in a single pattern is T which accounts for 37 hops.
- We get the connection interval as,

$$c_{int} = \frac{1}{37} \sum \Delta t \tag{1}$$

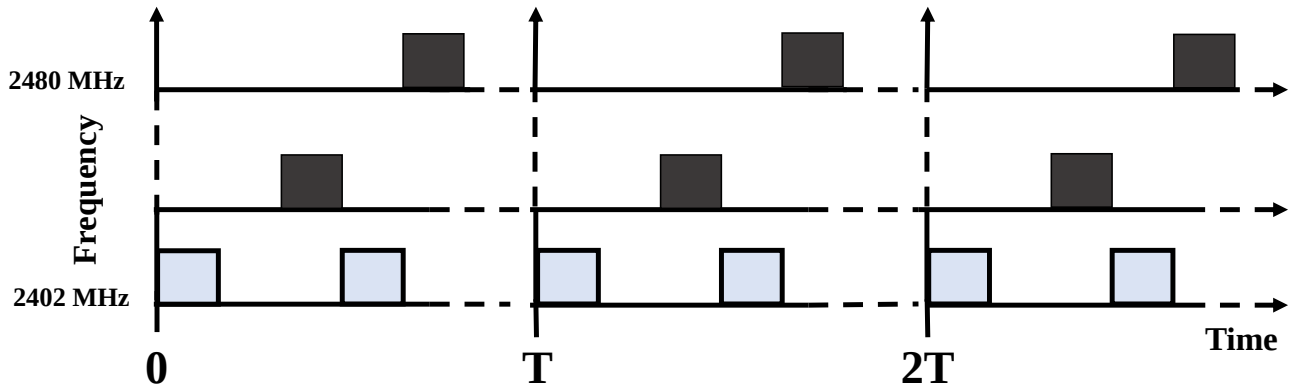


Figure: BLE frequency hopping diagram where the blue block represents the observed channel

Determining Hop Increment

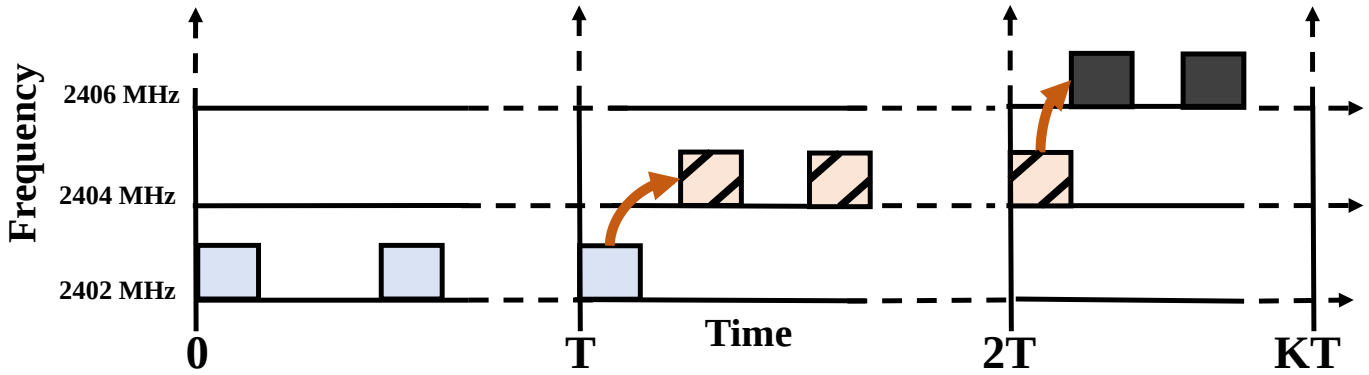


Figure: Hop increment for multiple appearances of a channel within a period

- At t_1, t_2 we observe channel c_1 and c_2, then $h = \frac{t_2 - t_1}{c_{int}}$ and

$$h_{inc} = \frac{(c_2 - c_1)^{-1}}{h} \bmod 37 \tag{2}$$

- channel map is less than 37 and channels repeat in a period
- n, m appearances of c_1, c_2 has $n \times m$ hop intervals
- Increasing channels in calculation increases probability of determining hop interval correctly - for 3 channels, probability is more than 50%

Determining Channel Map

- We hop using the channel selection algorithm,

$$c_{n-1} = (c_n + h_{inc}) \bmod 37, \tag{3}$$

- Channels in which BLE connection appeared are in the channel map
- If synchronization lost - repeat channel map detection algorithm

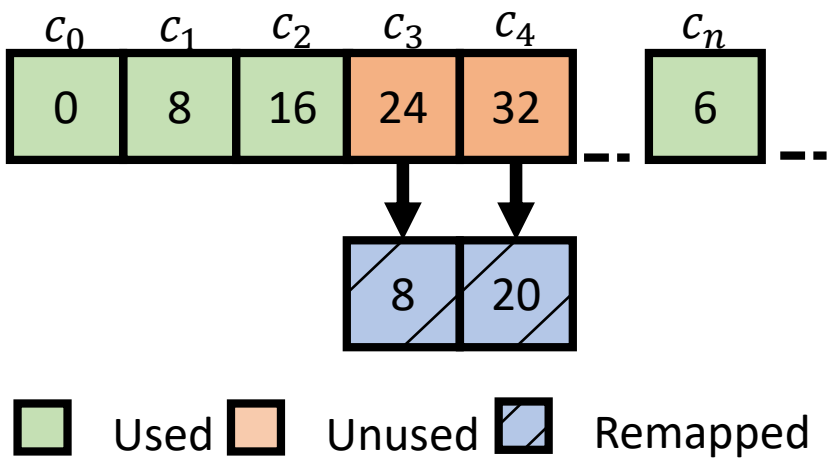


Figure: Determining channel map for BLE

Outline

Experimental Setup

Experimental setup

- We use two Ubertooth One with a Linux PC to implement the algorithm
- One Ubertooth runs in default follow mode and the other runs our algorithm
- We use Cypress BLE as test devices
- Channel map is set to update every 15s, 30s and 60s

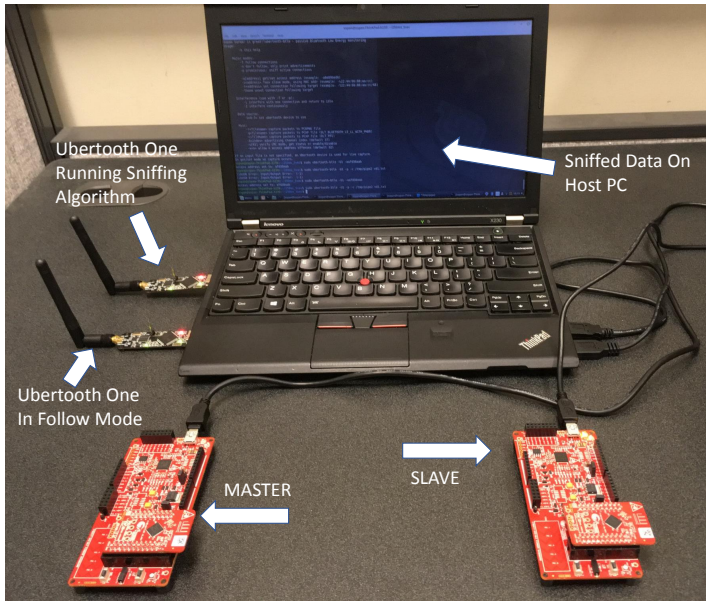


Figure: Experiment setup in an indoor controlled environment

Performance Evaluation

Latency and accuracy in determining AFH parameters

- Latency is measured in hops

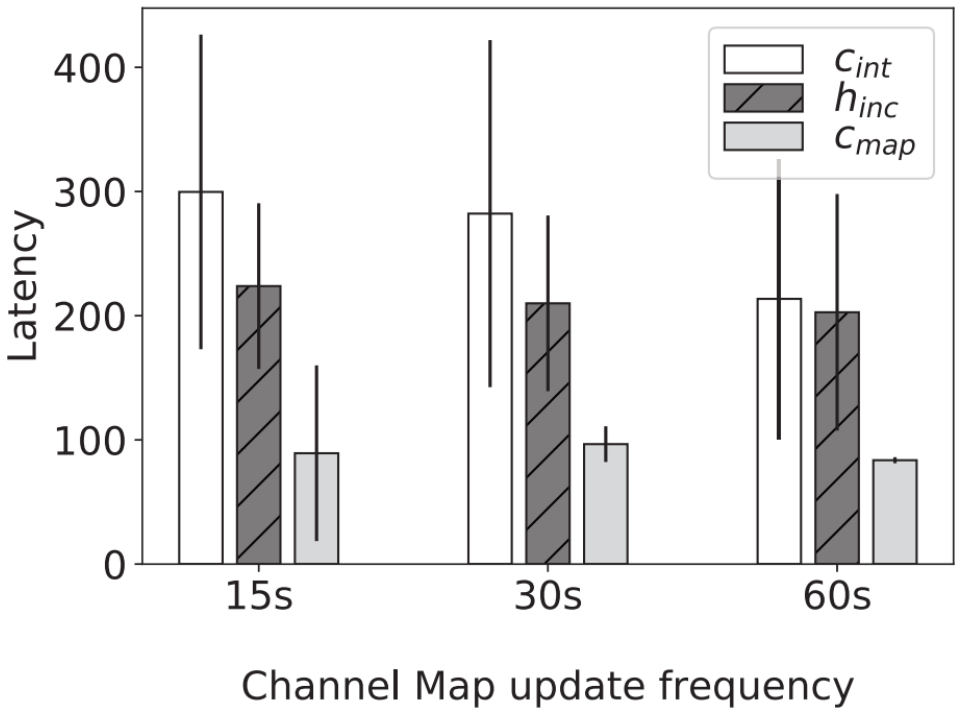


Figure: Latency in deriving BLE AFH

Parameter	15s	30s	60s
c_{int}	100%	100%	100%
h_{inc}	100%	96%	96%
c_{map}	100%	96%	96%

Table: Accuracy for determining BLE AFH parameters

Performance Evaluation

Accuracy in sniffing BLE packets

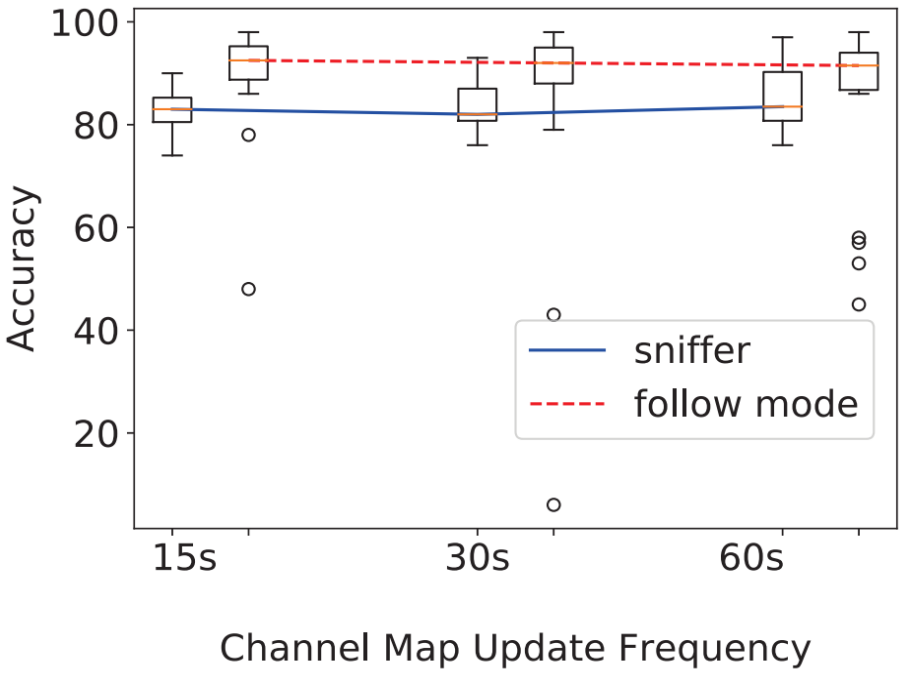


Figure: Sniffing accuracy in 100 ms data sending rate

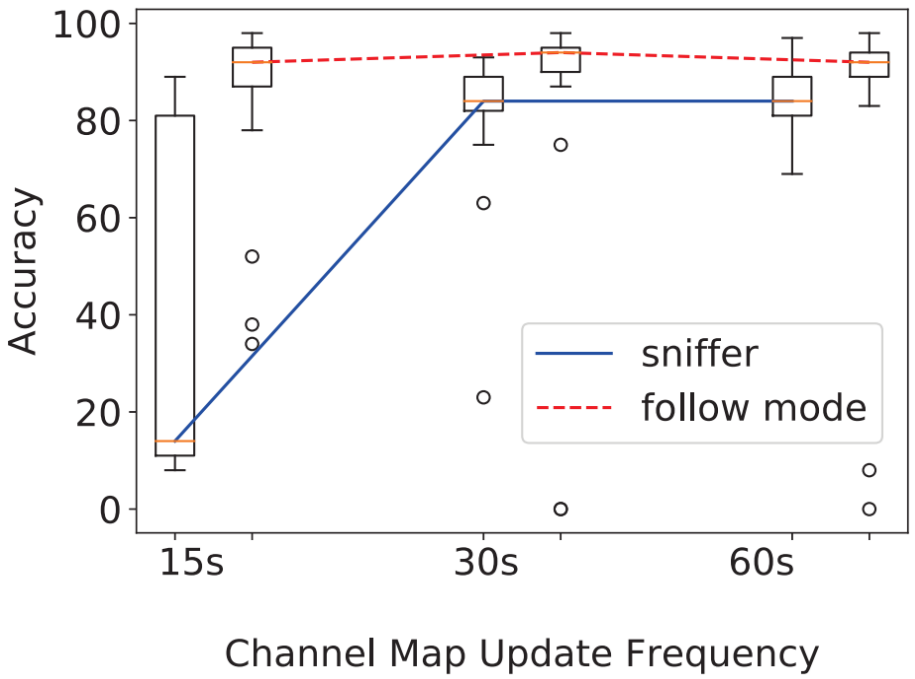


Figure: Sniffing accuracy in 250 ms data sending rate

Outline

Conclusion and Future Work

Conclusion

- We are able to sniff BLE in connected state and extract its AFH parameters
- Our algorithm didn't rely on reading the PDU data but only the access address
- We were able to calculate AFH parameters with 96% accuracy and sniff more than 80% of the transmitted data

Available at: `https://github.com/sopan-sarkar/ubertooth`

Future work

- Estimate the channel occupancy of the target BLE device and get an idea of the channel map
- Determine the access address of the target BLE device from the pool of sniffed access addresses

Thank You!