On Practical Selective Jamming of Bluetooth Low Energy Advertising

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Outline

- Motivation,
- Problem Statement,
- System Model,
- Bluetooth LE Advertising Primer,
- Proposed Jamming Solution,
- Evaluation,
- Countermeasures,
- Conclusion & Future Work.

Motivation

- The *Bluetooth Low Energy* (BLE) protocol stack gave rise to whole new class of devices: **BLE beacons**
- Beacons are small, often battery-powered devices, that continuously broadcast information by using the *BLE Advertising* process
- Despite their limited functionality they can be used to implement complex services, e.g.:
  - Targeted advertisement
  - Mobile Payment authentication (e.g. PayPal)
  - Indoor Navigation

Motivation (II)

- BLE beacons have seen a steady rise in popularity:
  - 72% of all retailers are expected to have beacon technology installed until 2019,
  - Hence the **security of BLE beacons** is worth investigating.
- BLE is prone to jamming attacks like any wireless technology,
- Purpose of this work is to discuss the risk of such a jamming attack on BLE beacons,
- Common definition for risk:

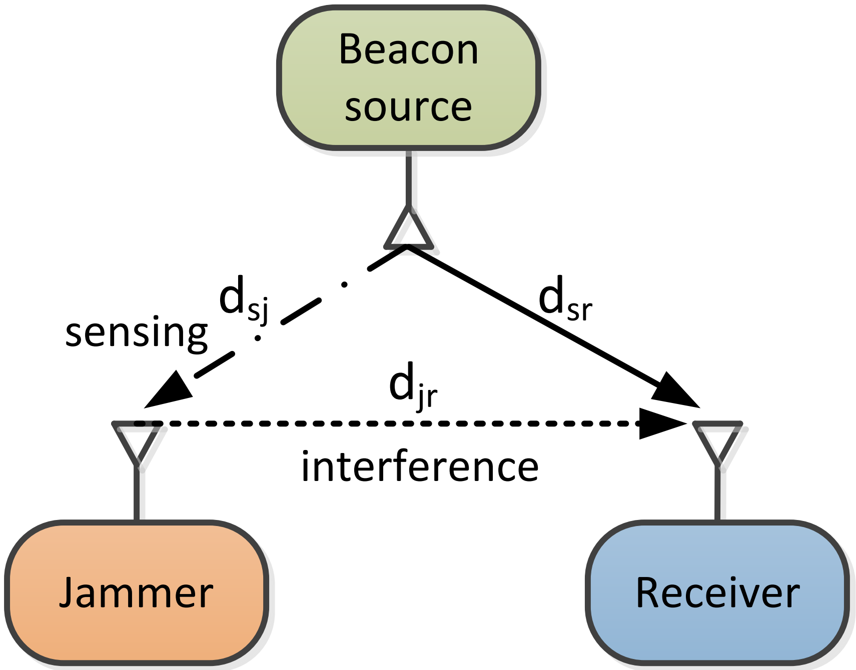
Risk = Likelihood x Impact

Problem Statement

- We devised **five criteria** to evaluate the risk of a jammer:
  - Jamming success (impact),
  - Energy-efficiency (impact),
  - Cost (likelihood),
  - Possible countermeasures/detection methods (likelihood & impact),
  - Ability to selectively jam targets (impact).
- Can we build a jammer that is optimized for this criteria?
  – A low-cost, energy-efficient selective jammer

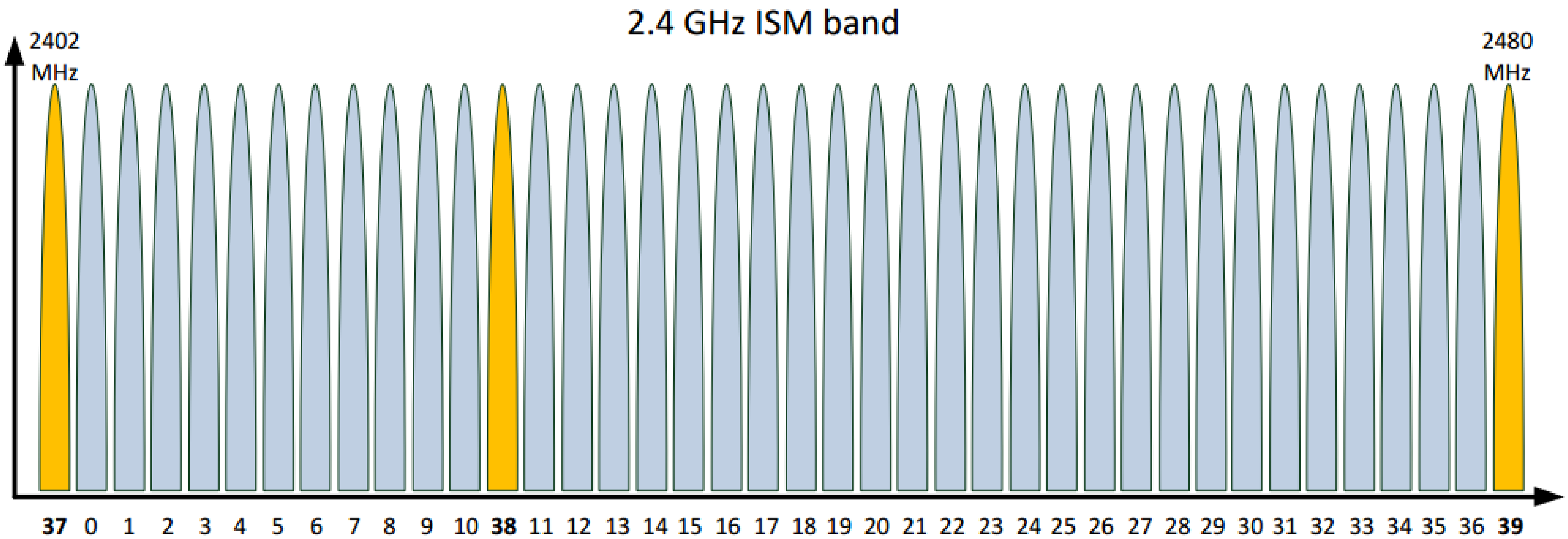
System Model

- We consider the basic scenario consisting of:
  - A BLE beacon source emitting BLE advertisement packets,
  - A receiver which performs passive scanning for BLE adv packets,
  - A single jammer node.



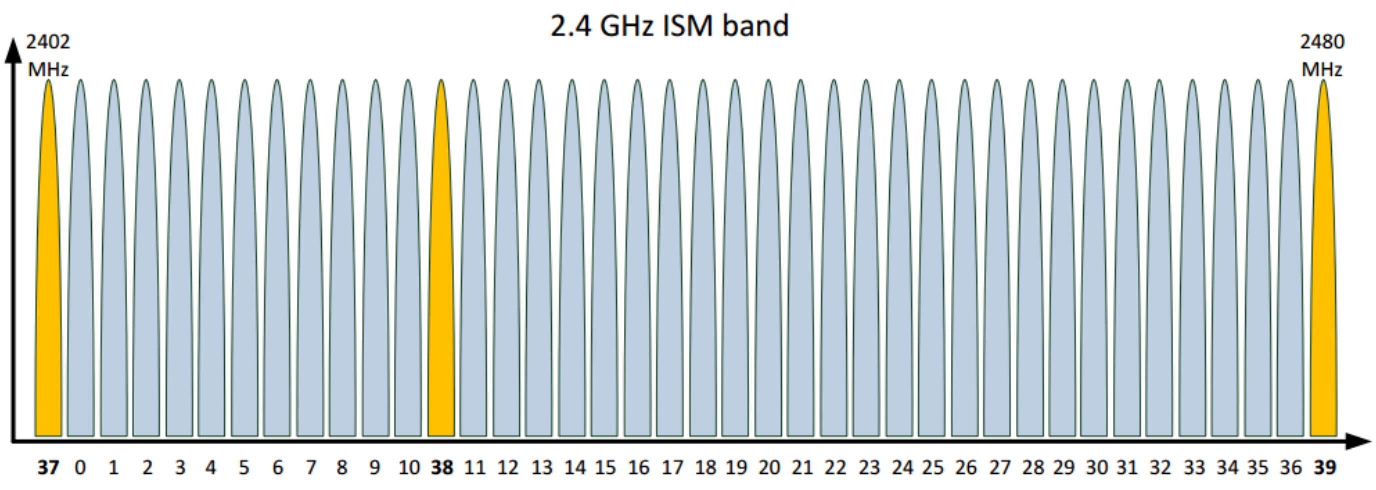
Bluetooth LE Advertising Primer

- BLE operates in 2.4 GHz ISM band,
- Bit rate: 1 Mbit/s -> 1 bit = 1 µs air time
- 40 channels, 2 MHz each:



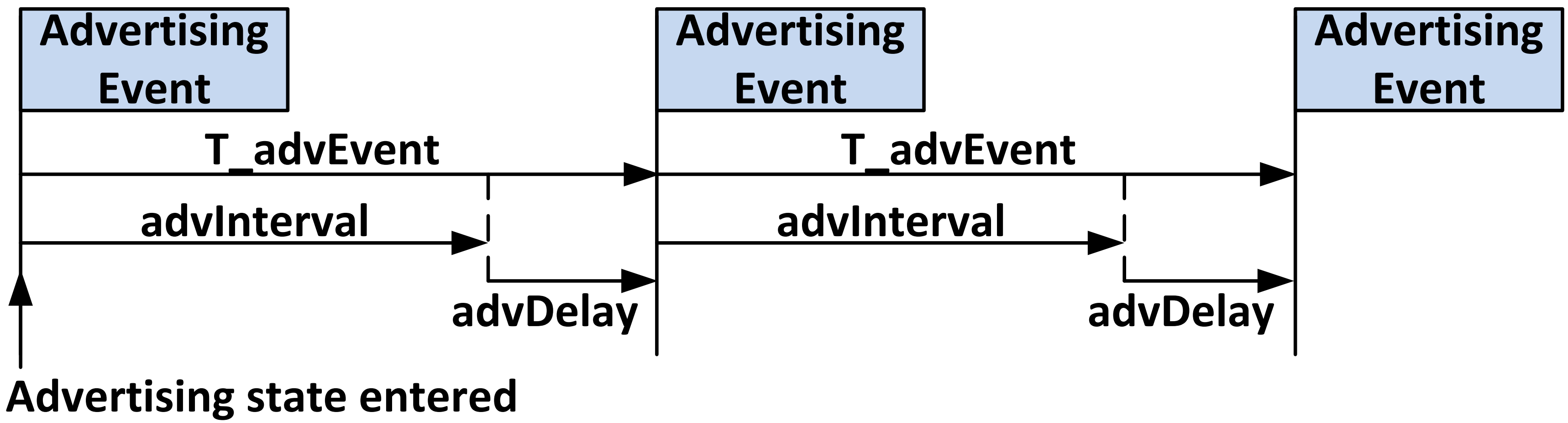
Bluetooth LE Advertising Primer (II)

- Advertising channel: channels **37**, **38** and **39** (**yellow**),
- Advertising Channel are spread across the spectrum to avoid interference (Wi-Fi),
- Advertising uses a **frequency hopping** scheme to improve **robustness**, i.e. a beacon is transmitted on different adv. channels.



Bluetooth LE Advertising Primer (III)

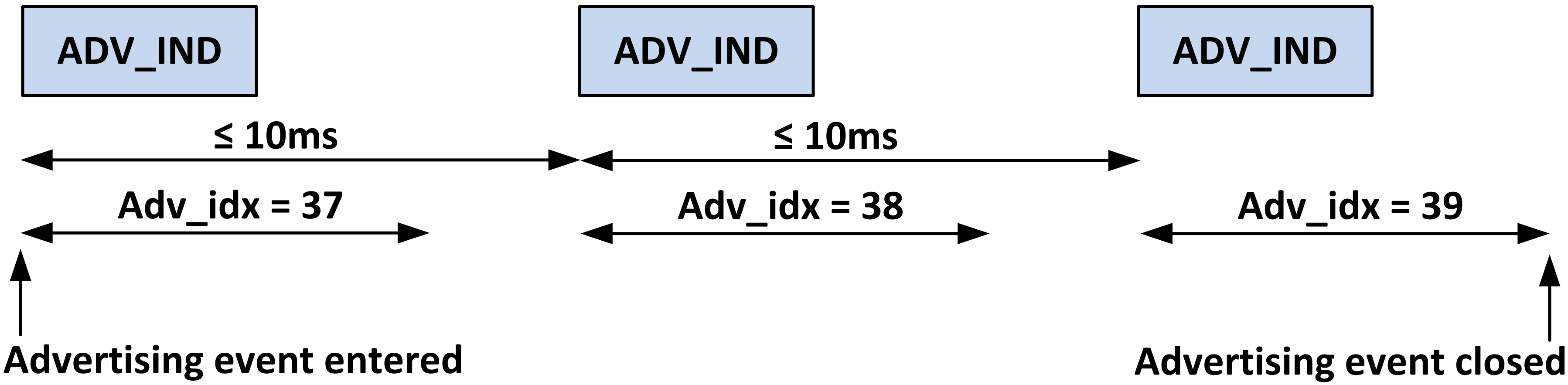
- Advertising takes place at a regular interval ***advInterval*** (>20ms) with an added pseudo-random delay ***advDelay*** (between 0.625ms and 20ms) for collision avoidance.



- **Note**: During each *Advertising Event* the beacon is transmitted on all (!) three advertising channels.

Bluetooth LE Advertising Primer (IV)

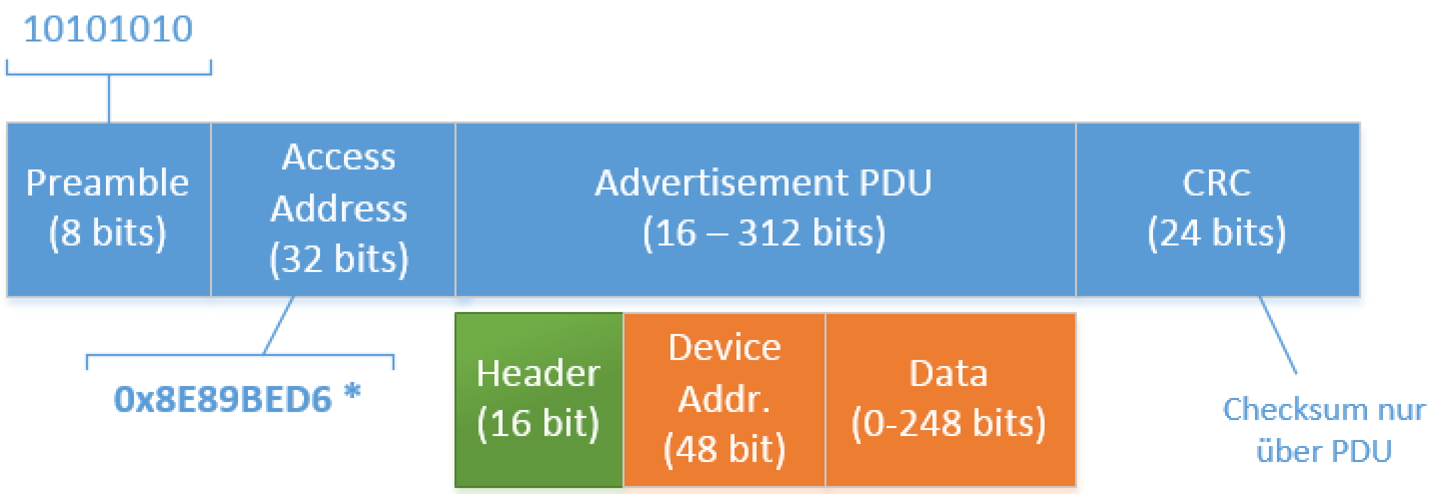
- During each *Advertising Event* a beacon **hops** through all used advertising channels (mostly all 3) in **ascending order**.



- Two subsequent advertising packets within one Adv. Event must be less than 10 ms apart. **A mimimum time is not specified.**

Bluetooth LE Advertising Primer (V)

- Basic BLE framing:



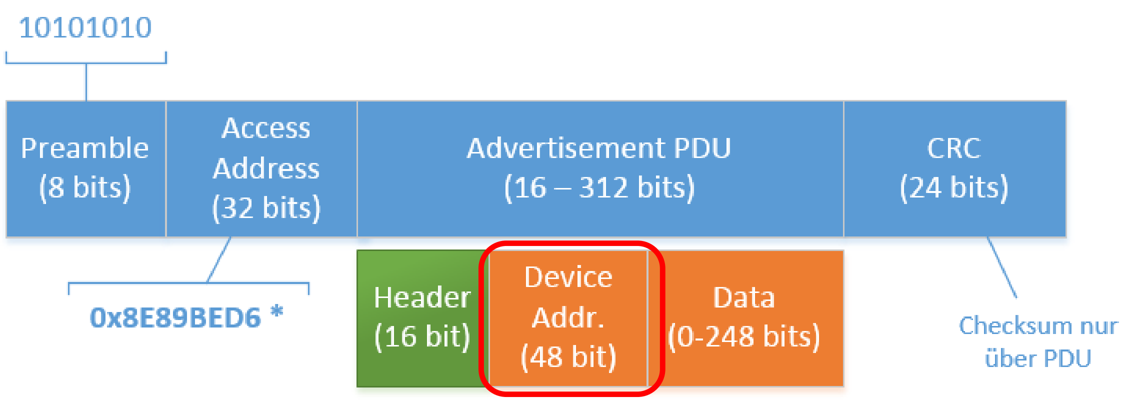
- Preamble + Access Address used as correlation code,
- No Forward Error Correction (FEC), so every bit error results in a corrupted packet (detected using CRC)

Jammer Design Principles

- We use commercially **off-the-shelf** (COTS) hardware that is BLE capable
  - Minimizes the cost,
  - This hardware is often already optimized for low energy consumption
- To save energy we employ a **narrow-band jamming** scheme with frequency hopping
  - Doesn’t waste energy on unused bandwidth,
  - Makes our jammer harder to detect.
- The duration of the **jamming signal** can be kept at a minimum (no FEC in BLE)

Proposed Jamming Solution

- Selective, reactive narrow-band jammer:
  - Because we can only jam a single BLE channel at a time (-> narrowband) fast **channel hopping** has to be applied,
- The jammer is pre-programmed using an API:
  - Two options: **white list or black list** of device addresses to be jammed,
  - Configuration of the BLE adv. channels being used.

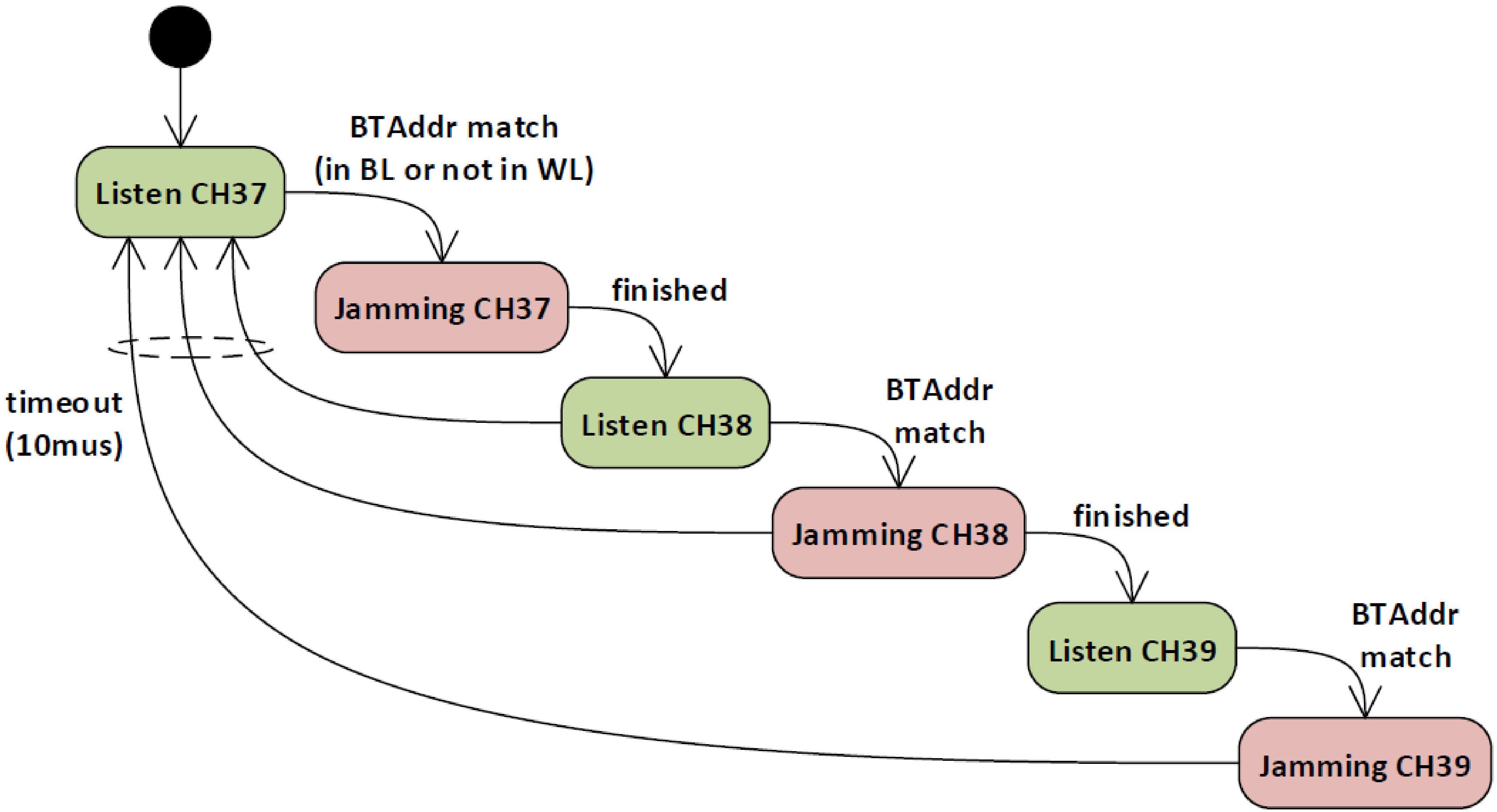


Proposed Jamming Solution (II)

- Jammer consists of two components:
  1. **Detection**: jammer **decodes packets on-the-fly** to decide whether to jam this particular packet based on the **device address**,
  2. **Jamming**: on successful detection the jammer emits a short jamming signal.

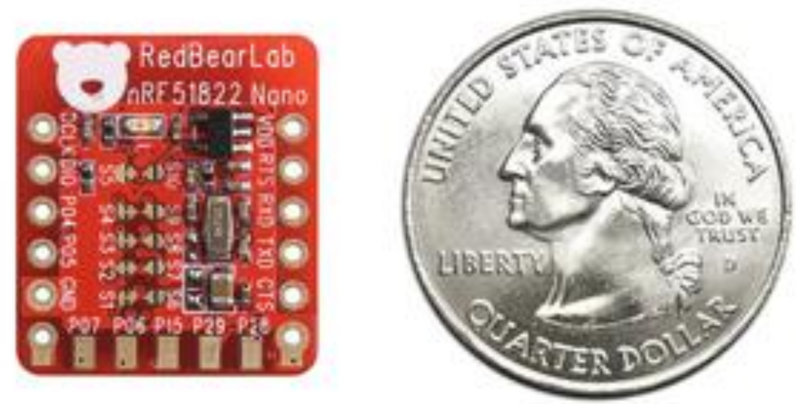
Selective, Reactive Narrow-band Jammer

- FSM of jammer w/ all 3 Adv channels used:



Implementation Details

- Jammer node: RedBearLab BLE Nano
  - BLE devkit equipped with a Nordic nRF51822 SoC and an integrated antenna,
  - nRF51822 is equipped with a BLE capable transceiver,
  - Max TX power: +4dBm,
  - Cheap: ca. 20 €,
  - Fast turn-around time (time needed to switch from receiving to trans-mitting): 140 μs,
  - Easily programmable

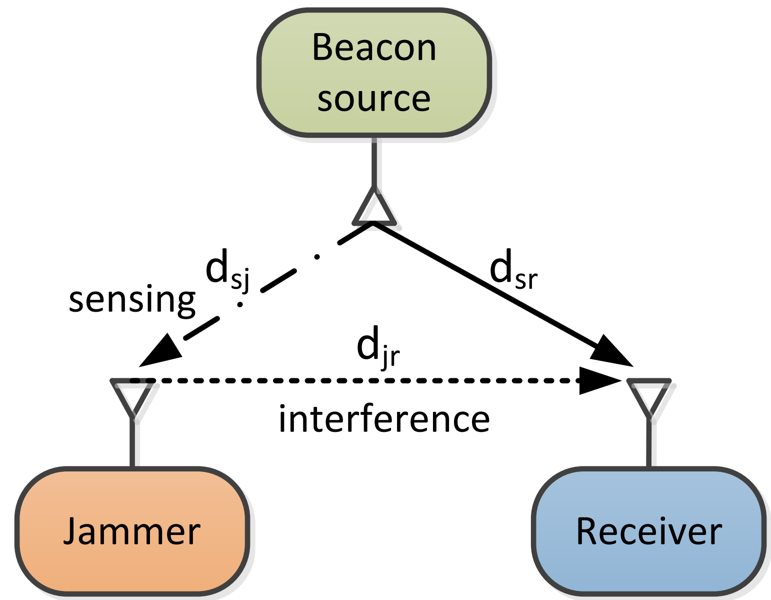


Evaluation Methodology

- Primary performance **metric** is **Advertising Success Rate**:

$$\textbf{ASR} = \frac{\text{\# correctly received BLE adv. events}}{\text{total number of transmitted BLE adv. events}}$$

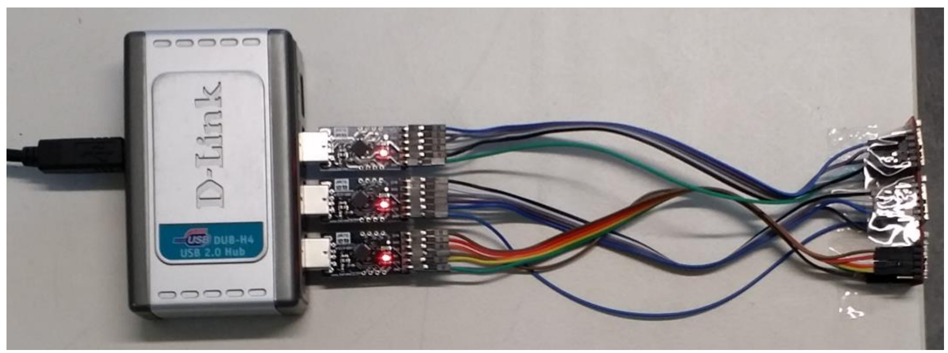
  - **Objective**: min. ASR, i.e. ASR=0 is perfect jamming.
- Another **metric** is the area covered by the jammer:
  - Spatial area around the jammer with ASR < τ



Experiment setup.

Evaluation Methodology (II)

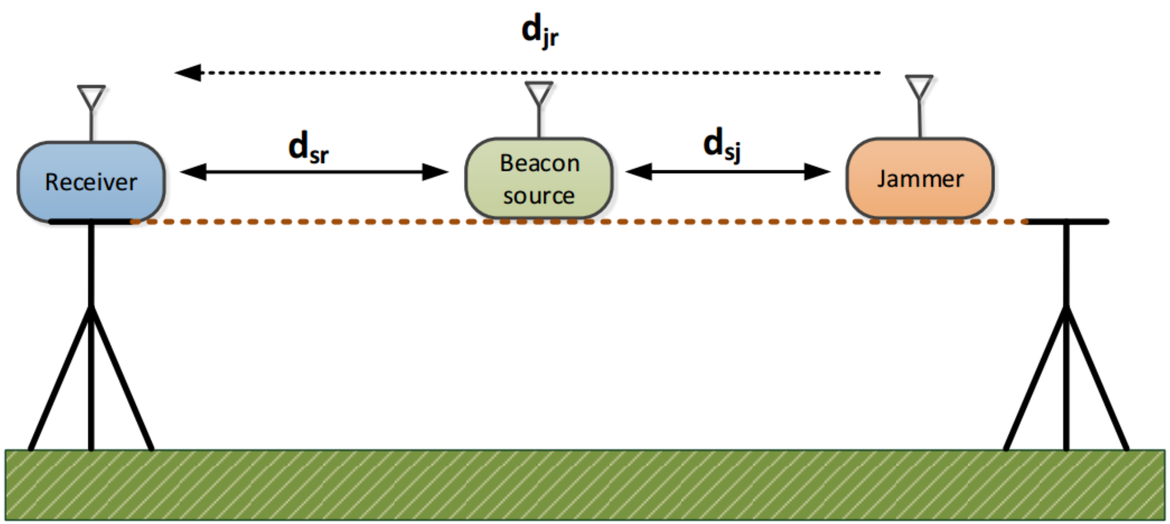
- Receiver:
  - Optimal receiver, i.e. dedicated Rf receiver (BLE Nano) for each BLE Adv. channel,
  - Every packet is logged (+CRC packets) using *Nordic Sniffer* and written to PCAP file for post-analysis in MATLAB,



- Sender:
  - Commercial beacon (Gigaset G-Tag)
    - Adv. interval of 1 sec + all 3 Adv channels

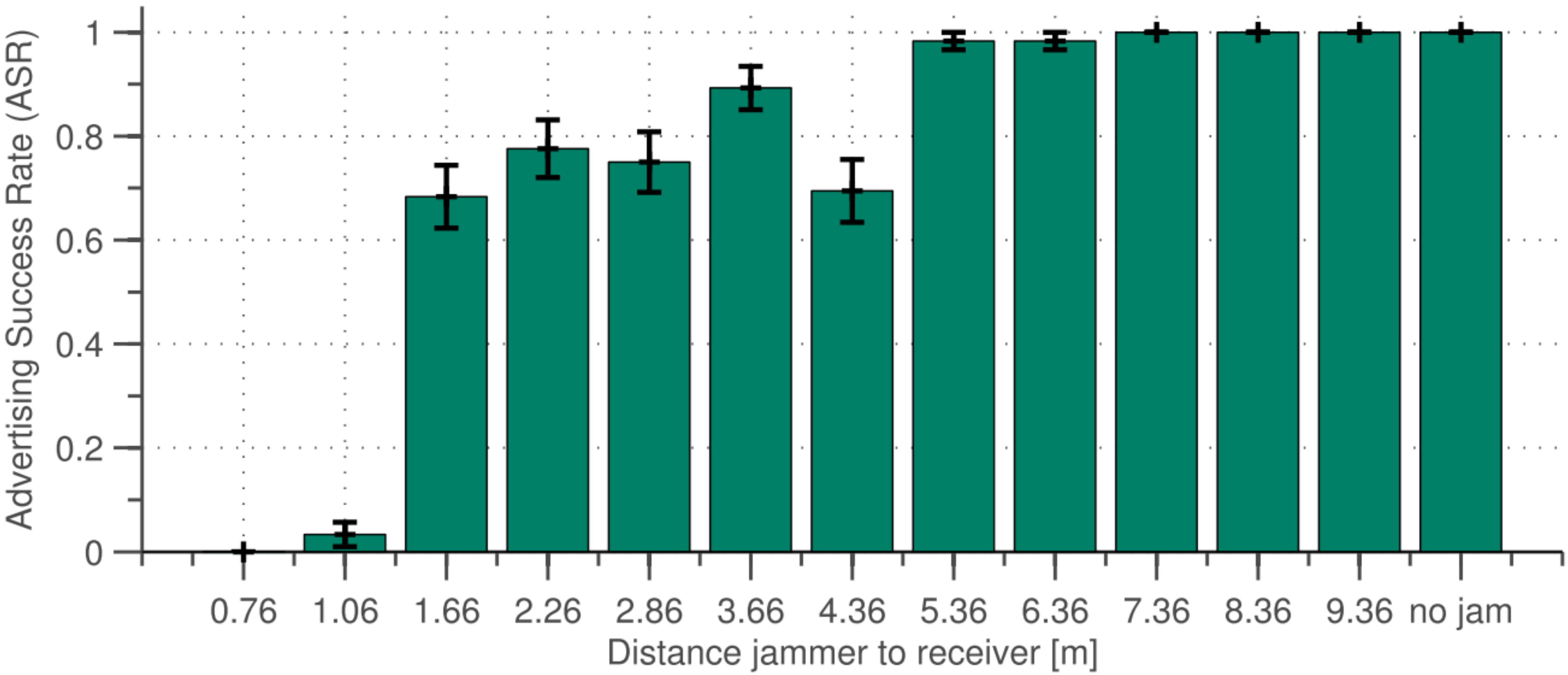
Evaluation Methodology (III)

- We set-up an outdoor experiment:
  - Beacon source, jammer and receiver are put on a line elevated by 1 m from the ground (grass field),
  - Distance between beacon source and the receiver was set to d_sr=3.7 m,
  - The distance between the jammer and receiver (d_jr) nodes were varied from 1 to 10 meters.



Results

- At d=76 cm the ASR is zero, i.e. jammer successfully jam each transmitted BLE adv. frame transmitted on each channel (37, 38 and 39),
- At d=100 cm the ASR=3%,
- Note: TX power of jammer was just 4 dBm.



Countermeasures

- We can divide countermeasures into two categories
  1. Attack Detection
     – Detect the presence of the jammer to allow further actions to be taken, e.g. removal of jammer,
     – Decoy packets & K-mean clustering
  2. Attack Mitigation
     – Actions that limit the impact of the jammer.

Countermeasures – Attack Mitigation

- Use **random channel hopping**
  - Our jammer cannot adapt to random hopping pattern, i.e. adv. channels are used in random order,
  - But, we can use three jammer nodes, each configured to listen on a particular channel => no hopping required.
- Use **randomized device addresses** for BLE beacons,
- Use of **short BLE frames**
  - Our jammer's ability to jam is limited by its reaction time, i.e. 174 µs, => BLE payloads > 19 bytes,
  - But, the two most popular beacon protocols *iBeacon* and *Eddystone* both have larger payloads.

Conclusions & Future Work

- **Can we build a low-cost, energy-efficient selective BLE jammer?**
  - Yes, we can (with some limitations)

- Due to the low effort necessary, potential victims should anticipate jamming attacks
  - Especially if they have a commercial interest in their beacon network (e.g. retailers)
- Ongoing research: how to deal with BLE beacons whose device addresses is **randomized**.