Experimental security study of WirelessHART

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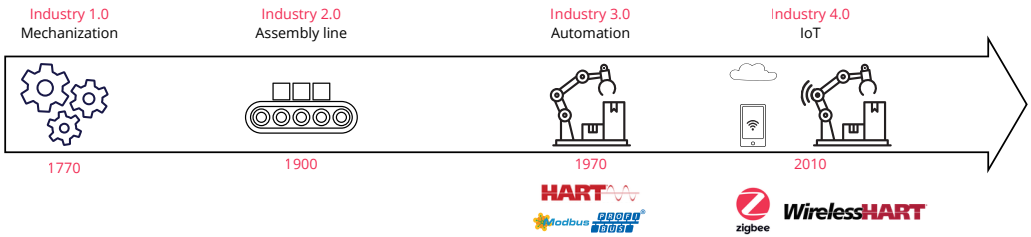
May 2026

Who am I?

- Final year INSA student
- TLS-SEC program: cybersecurity
- Last year internship: WirelessHART security analysis in LAAS-CNRS
- Focus on industrial security and IIoT

Industrial Context

- **Evolution of Industry**
  - From automation to industry 4.0
  - Digitalization and system interconnection
  - Emergence of Industrial IoT (IIoT)
- **Industrial Protocols**
  - Wired protocols: Modbus, PROFIBUS
  - Limited scalability



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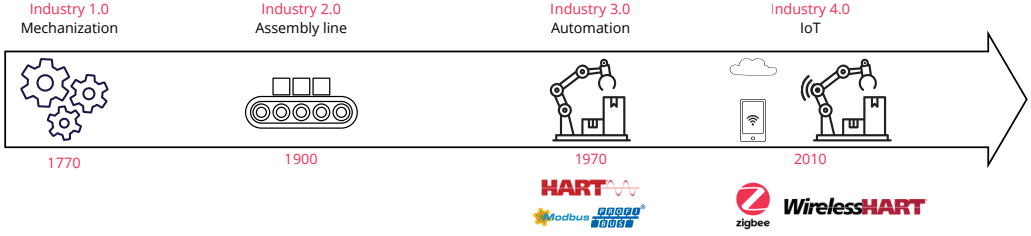
  - Limited scalability
- **Adoption of Wireless Technologies**
  - WirelessHART, ISA100.11a, Zigbee
  - Flexible deployment, lower cost
- **Challenges**
  - Security concerns (cyberattacks, data integrity)
  - Coexistence with legacy systems



During this presentation

Focus on WirelessHART

- Sniffer
  - WirelessHART fundamentals
  - WirelessHART communications
  - Implementation
- Attacks
  - Mass-deauthentication
  - Time desynchronization

WirelessHART use cases

Pharmaceutical

WirelessHART use cases

Pharmaceutical

Petrochemical

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Energy

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- Limited existing research
  - Less studied than other wireless protocols
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Objectives

- Design a low-cost open-source sniffer
- Enable controlled traffic injection
- Evaluate practical attacks on WirelessHART

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- Based on the IEEE 802.15.4 physical layer
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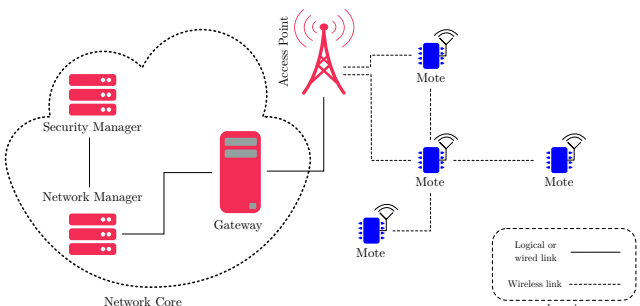

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  → License-free
- Based on the IEEE 802.15.4 physical layer
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- Mesh networking
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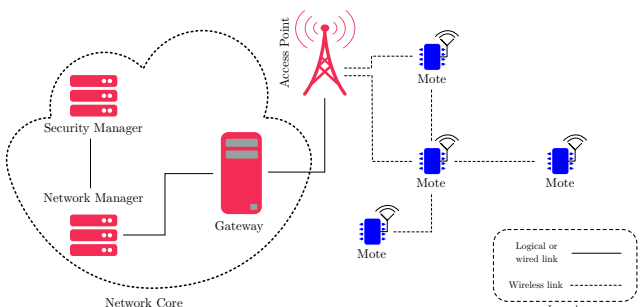
- Time Division Multiple Access
  → Deterministic
- Frequency Hopping Spread Spectrum
  → Interference resilience



WirelessHART communications

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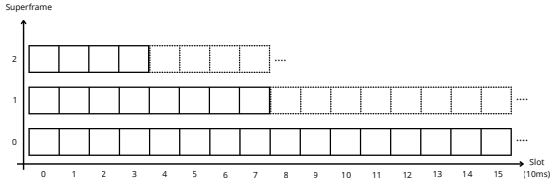

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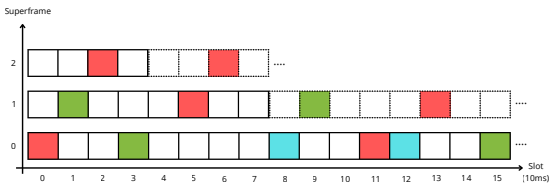

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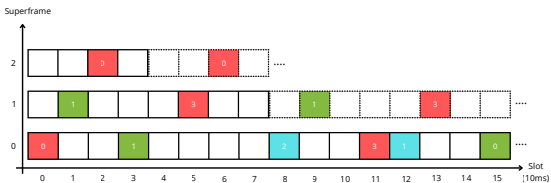

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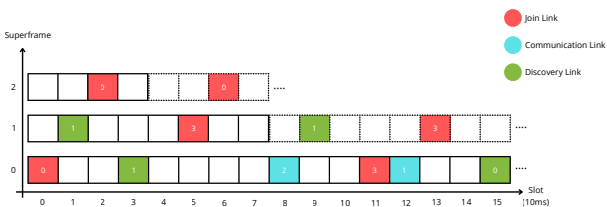

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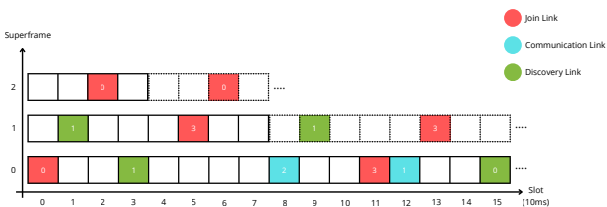
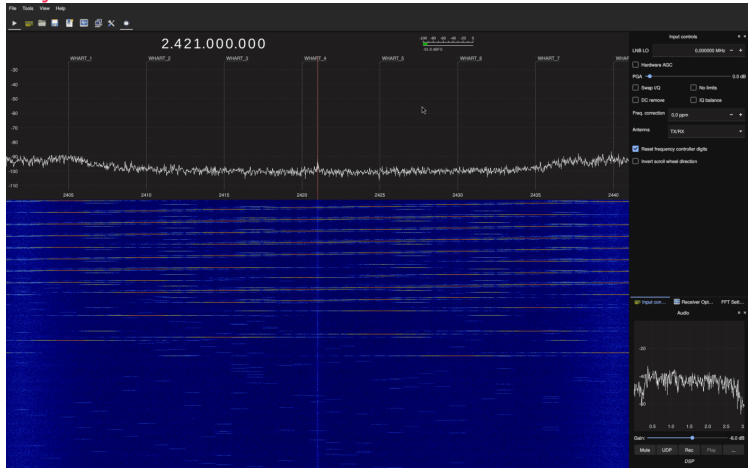
- **Management:** The *Network Manager* is the only responsible for the configuration of the network, scheduling communications and managing the routing table.



WirelessHART communications

Spectrum Analyzer



WirelessHART communications

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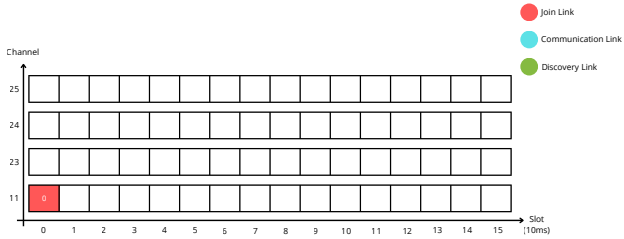

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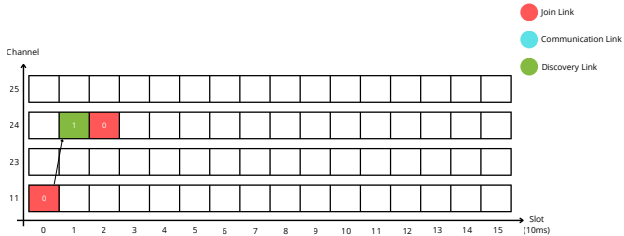

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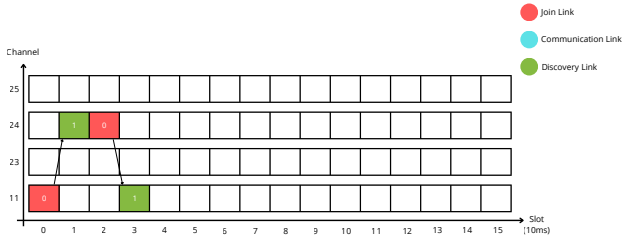

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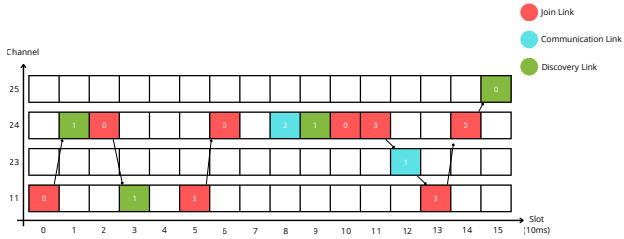

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WHAD – Wireless HAcking Devices

Open-source wireless security framework

- Supports BLE, ZigBee, LoRaWAN...
- Unified host/hardware radio interface

Three components

- `whad-client` – host-side
- `ButteRFly` – dongle firmware
- `whad-protocol` – communication protocol

WirelessHART Sniffer

10 ms slots / 2 ms RX windows
⇒ host-side processing not feasible

ButteRFly (firmware)

- Active channel computation
- Radio channel switching
- Hardware timer for slot synchronization
- Time adjustment from ACK fields
- Packet capture & forwarding via `whad-protocol`

whad-client (Python)

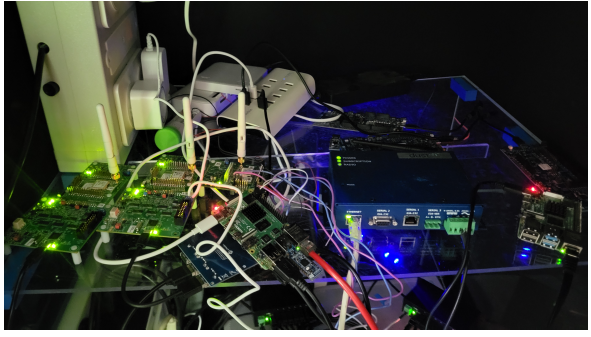
- Packet decryption & encryption
- Injection frame generation
- Unobserved link inference (exploration algorithm)
- WirelessHART dissection via **Scapy**
- Logging & capture export

Experimental Setup: Dust Network

- **Hardware Platform**
  - Dust Networks technology (Analog Devices)
- **Network Composition**
  - One gateway: Network manager + security manager + AP
  - Multiple motes

Sniffer evaluation

Experience	Duration	Environment	Number of motes	Traffic	Sniffer	**Total**
A	14 h	Lab	Gateway + 2 motes	Normal	Snif_4	14601
					Snif_{FH}	14593
					Loss rate	**0.05%**
B	45 mins	Domestic	Gateway + 5 motes	Continuous ping	Snif_4	25500
					Snif_{FH}	22288
					Loss rate	**12.6%**



From Sniffing to Attacks

- Next step: **Attacks**
- Performing attacks requires understanding:
  - How devices communicate
  - How security mechanisms are applied

→ Communication phases and security

Communication Phases

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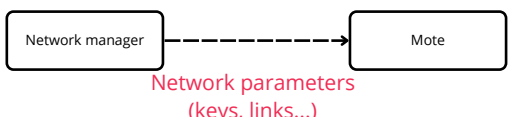

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- **Join Phase**
  - Mote sends a *join request* to the Network Manager
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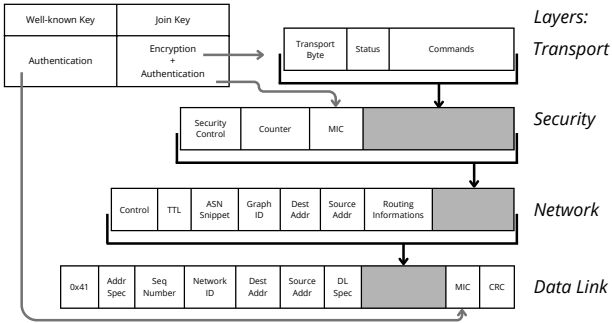
  - Allocation of communication links and network parameters
- **Secure Communication Phase**
  - Communications scheduled
  - Data encrypted and authenticated

WirelessHART security

Cryptographic keys

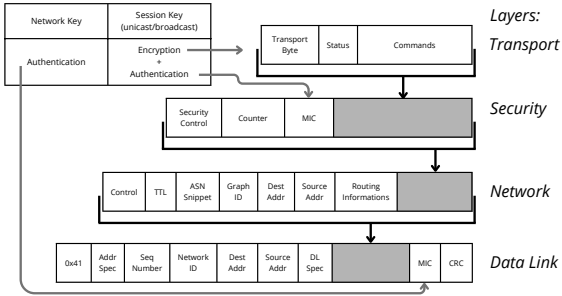
- **Well-known key:**
  - used for MIC calculation during advertising and joining at Data Link Layer (DLL)
- **Join key:**
  - pre-shared
  - secure the joining (handshake): encryption + authentication



WirelessHART security

Cryptographic keys

- **Network key:**
  - shared between all the network (Data Link Layer)
  - used to authenticate messages.
- **Session Keys:**
  - **Unicast:** confidentiality between nodes.
  - **Broadcast:** for broadcast messages.



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Based on AES-128 CCM*

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  - **DL-MIC:** integrity of the whole PDU at Data Link Layer

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  - **NWK-MIC:** integrity of encrypted data at Network Layer
  - **DL-MIC:** integrity of the whole PDU at Data Link Layer
- **Anti-replay:** use of nonce derived from the ASN.

Threat model

Assumptions

- Passive & active access to the radio medium
- Association key compromised (trash-can attack, default/weak/predictable keys)
- Passive eavesdropping of an association to recover other keys

Threat model

Attacker goals

- **Confidentiality:** intercept sensor data & infer industrial processes
- **Integrity / Authenticity:** inject malicious frames by spoofing a legitimate node
- **Availability:** suspend one or more motes

Join key extraction

Trash can attack

OTA attacks

Mass-deauthentication

Time desynchronization

Mass-deauthentication

Principle

- Exploits the Suspend command (opcode `0x3CC`)
- Orders a mote to suspend between two ASNs
- Broadcast $\Rightarrow$ simultaneous suspension of multiple motes

Requirements

- K_{network}, $K_{\text{session\_broadcast}}$
- Knowledge of communication links

Mass-deauthentication

Impact

- Partial or total DoS of the wireless network
- Disruption of control loops & industrial processes
- May require **manual intervention** to recover

Evaluation

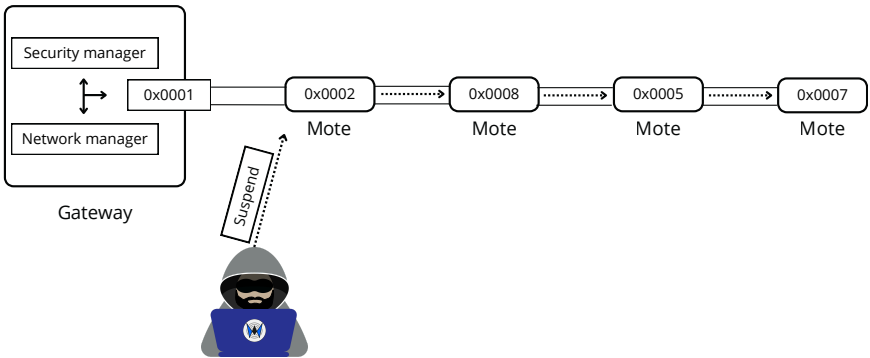
- Theorized in 2015[a]
- Never experimented due to lack of offensive tooling

[a] Duijsens, Master thesis

Mass-deauthentication scenarios

Denial of Service

- Suspend of 1M slots $\triangleq$ 170 mins



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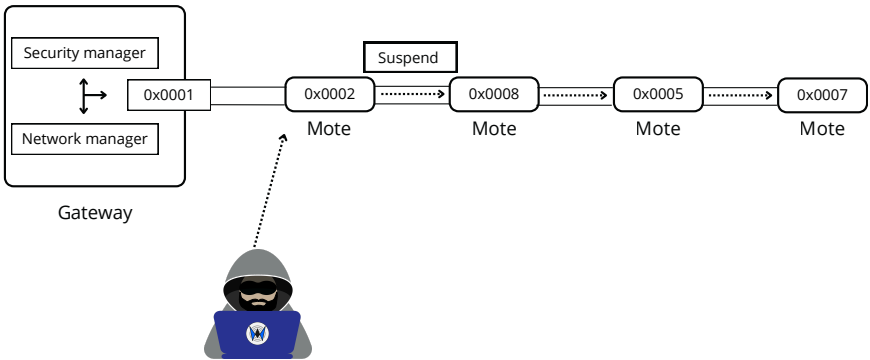

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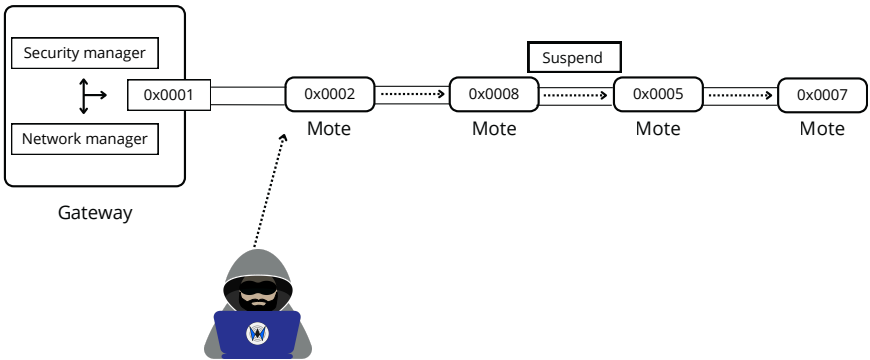

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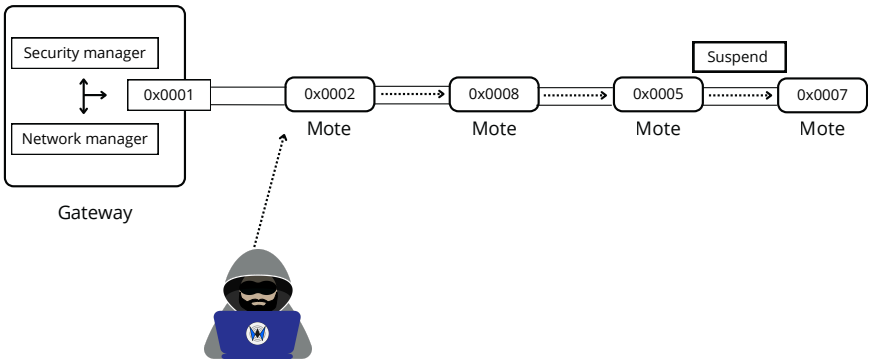

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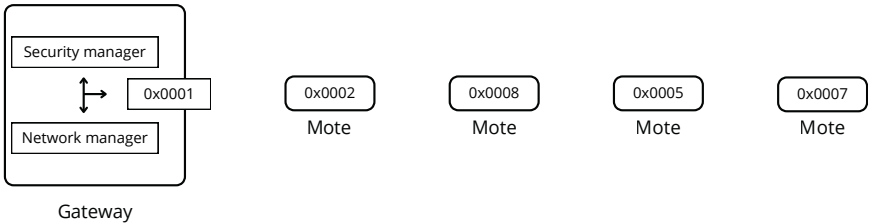

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Forced re-association

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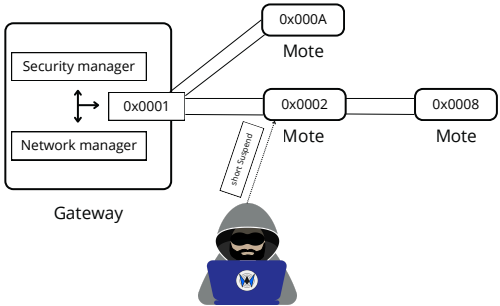

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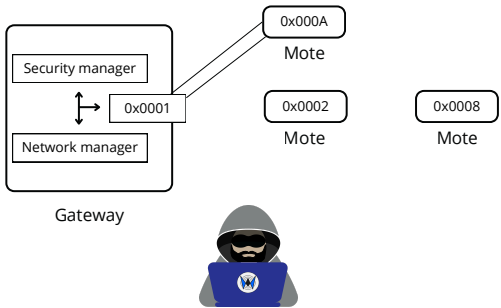

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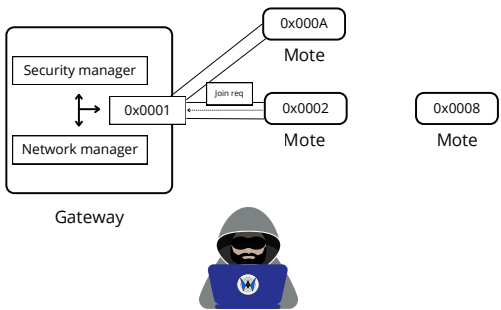

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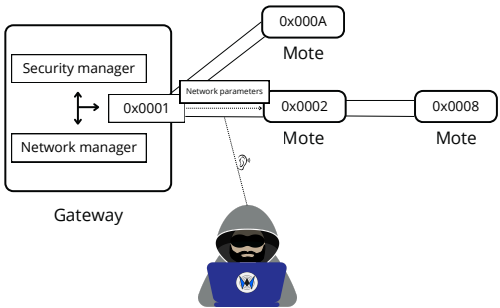

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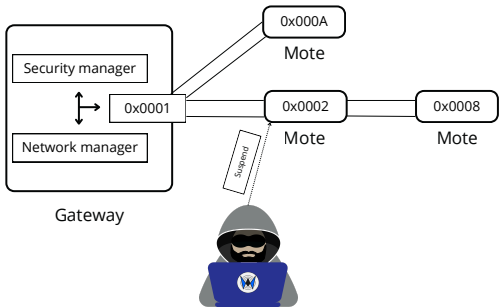

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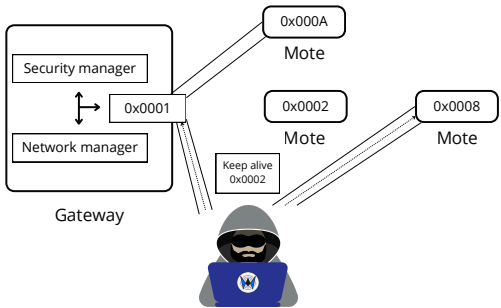


Mass-deauthentication demo

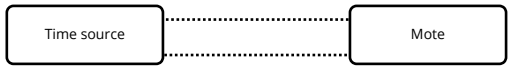
Mass-deauth attack

Time desynchronization

Neighbors

Two communicating nodes on DLL

For each peer, there exists one time source



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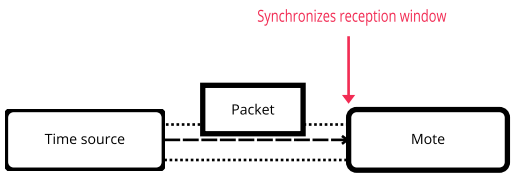

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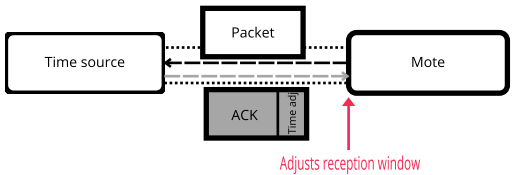
Synchronization

- The reception time from time source
- Ack contain field **Time adjustment**



Neighbors

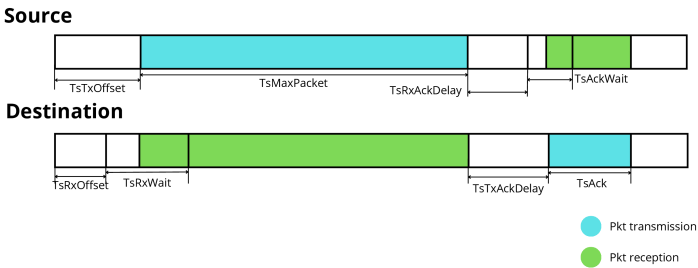
Time desynchronization

Principle

Spoof time source and send delayed traffic until desynchronizing the reception window (TsRxWait)

Impact

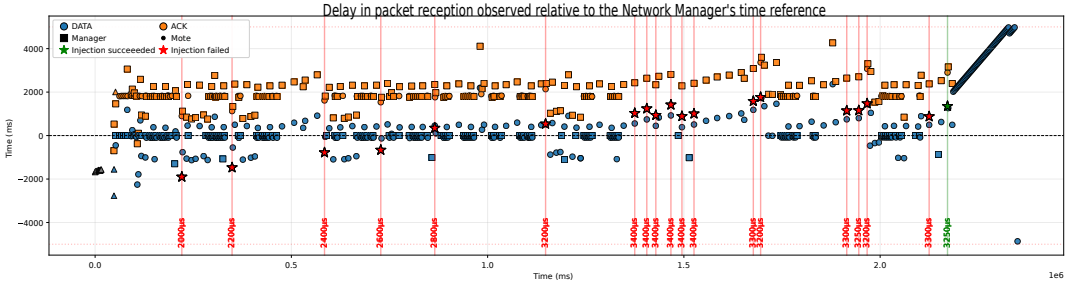
- Slot desynchronized
- Channel hopping delayed
- Denial of Service



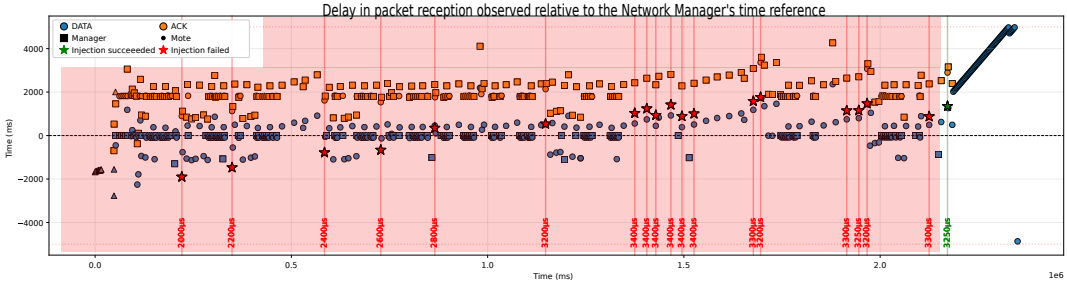
Time desynchronization demo

Time desynchronization attack

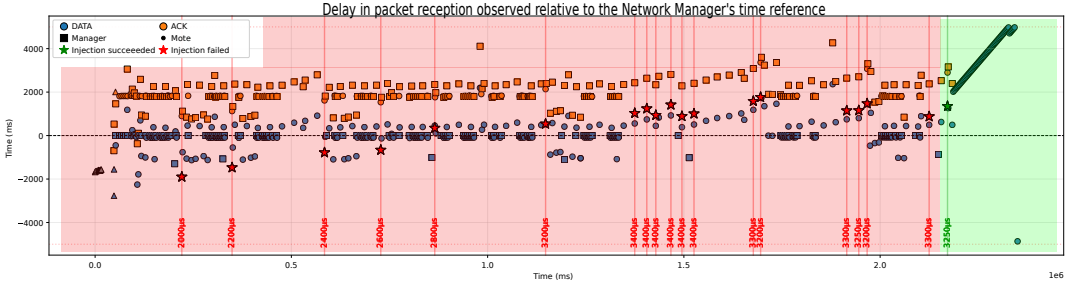
Time desynchronization evaluation



Time desynchronization evaluation



Time desynchronization evaluation



Countermeasures

Different K_{join}

- Enforce per mote Join key
- Limits compromise to a single mote

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Detect abnormal time adjustments

- Detect abnormal values of time adjustment
- Reject large synchronization drifts

Conclusion & Perspectives

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- WirelessHART remains insufficiently studied
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Perspectives

- Continue studying WirelessHART and test different attacks such as jamming
  - Propose an open-source stack of the WirelessHART network
  - Analyse dust network gateway mechanism
- Investigate IT/OT interactions
- Develop accessible and low-cost tooling for other wireless protocols

Thank you!

WHAD-client

https://github.com/whad-team/whad-client

ButteRFly

https://github.com/whad-team/butterfly

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