ISCAS 2025
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Hacking Health: Unveiling Vulnerabilities in BLE-Enabled Wearable Sensor Nodes

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Sara Ghoreishizadeh, Anna Maria Mandalari

University College London

Background

- Global Market for **Wearable Sensor Nodes → $33.85 billion** in 2023
- **537 million adults living with diabetes** globally in 2021
- **10% are living with type 1 diabetes**
- Year **2045**, **1 out of every 8 adults** → around **783 million** individuals, will be diagnosed with diabetes

https://www.grandviewresearch.com/industry-analysis/wearable-medical-devices-market

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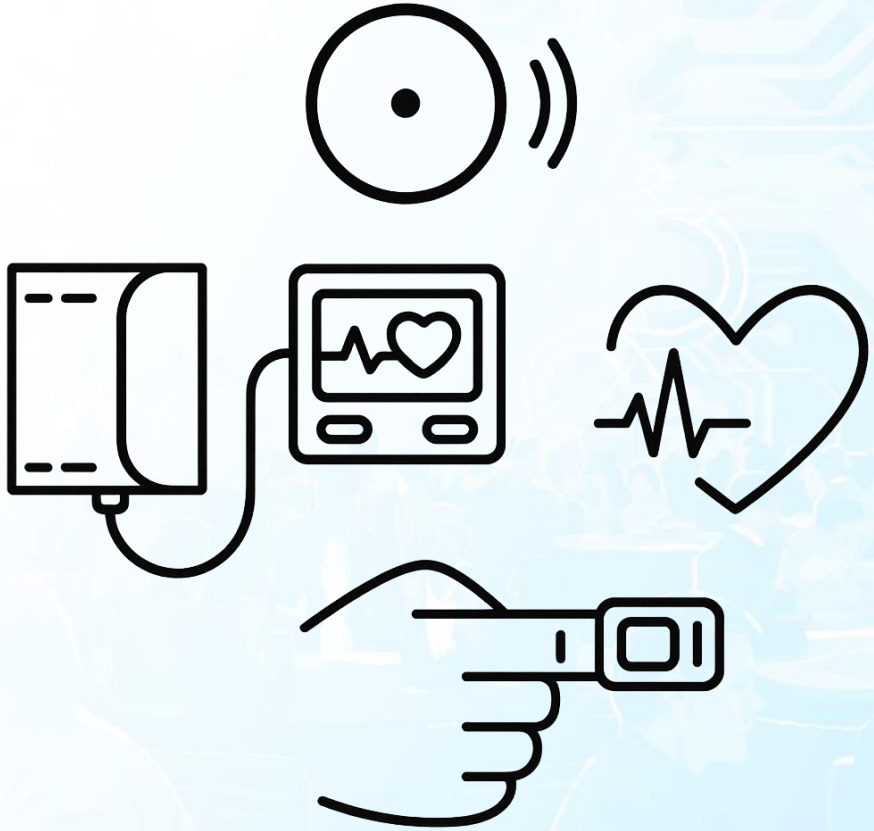
Wearable Sensor Nodes

Continious Glocuse Monitors (CGM)

Blood Pressure Monitors (BPM)

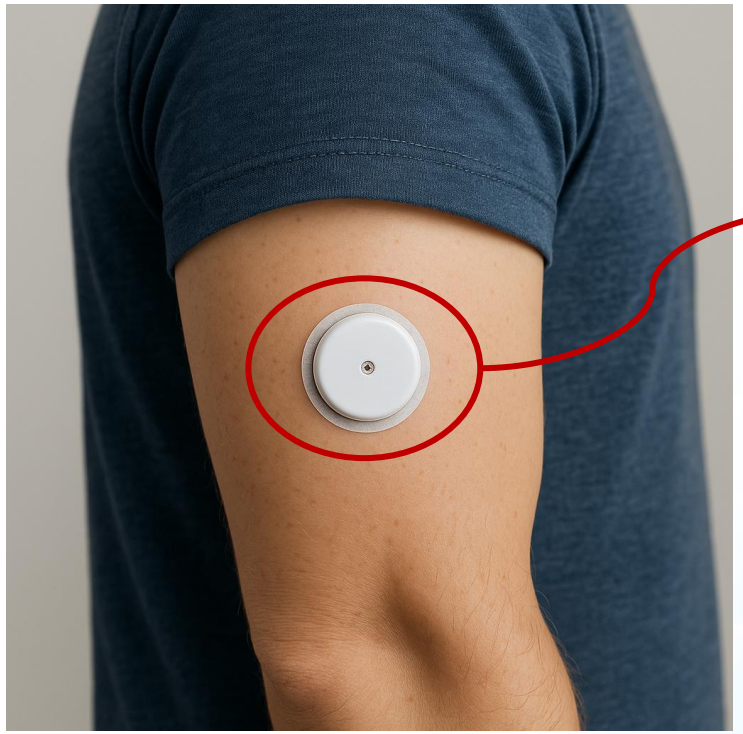


Electrocardiograms (ECG)

Oximeters

Continuous Glucose Monitors

Continuous Glucose Monitors



Artificial Pancreas
Closed Loop Control

Problem Statement

- **Wearable sensor nodes** connected via wireless protocols
  → **Bluetooth Low Energy (BLE) → Cybersecurity risks.**
- **Patient safety, data integrity**, and the **reliability** of essential healthcare systems
  → **Artificial Pancreas technology.**
- **Single-protocol** wireless communication systems, like **BLE**
  → **Insufficient** to protect against sophisticated **cyber threats.**
- **Uncover** these **vulnerabilities → Healthcare manufacturers**, **policymakers**, and **security researchers → Enhance** the **security** and **resilience** of wearable sensor nodes.

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Common Wireless Attacks in BLE

- Man in the Middle (MITM) → Manipulation of Data

Man in the Middle

Common Wireless Attacks in BLE

- Man in the Middle (MITM) → Manipulation of Data

Man in the Middle

- Denial of Service (DoS) → Loss of View

Denial of Service

Common Wireless Attacks in BLE

- Man in the Middle (MITM) → Manipulation of Data

Man in the Middle

- Denial of Service (DoS) → Loss of View

Denial of Service

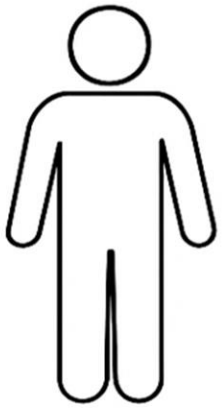
- Sniffing → Eavesdropping

Sniffing

Threat Model

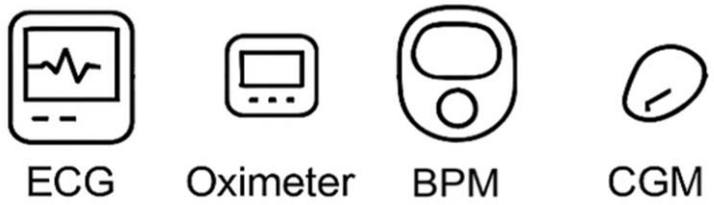
Victim:

- Blood pressure lability
- Heart arrhythmia
- Hypoxemia
- Diabetes

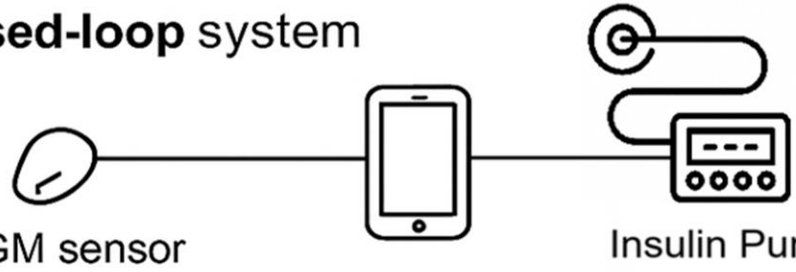


System:

Open-loop system

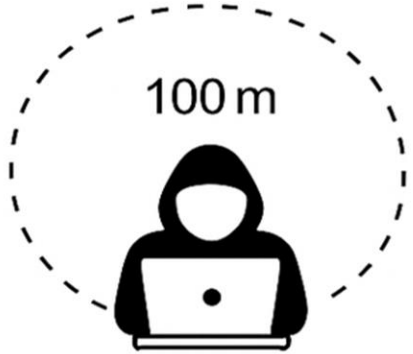


Closed-loop system



Adversary:

BLE 4.0 / BLE 5.0

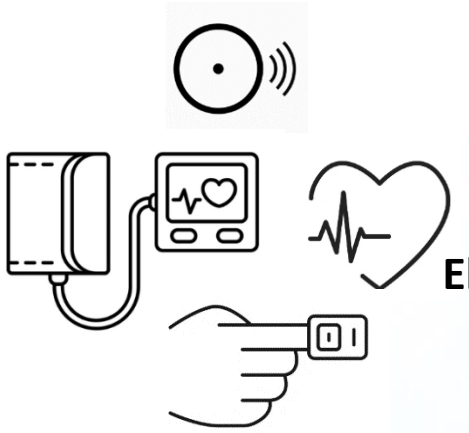


Passive (Sniffing/Eavesdropping) and
Active (MITM, DoS)

Testbed & Experimental Setup

Dexcom ONE and
FreeStlye Libre2
Continious Glocuse Monitors (CGM)

Wellue Blood Pressure Monitors (BPM)



SnapECG and
DuoEK Wellue
Electrocardiograms (ECG)

Oxylink and
SleepO2 1400
Oximeters

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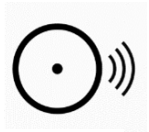
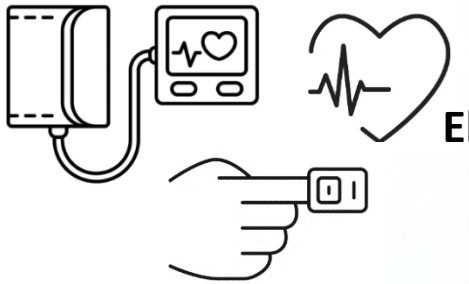


Wellue Blood Pressure Monitors (BPM)



Oxylink and
SleepO2 1400
Oximeters

nRF52840 Nordic
Sniffer Dongle

SnapECG and
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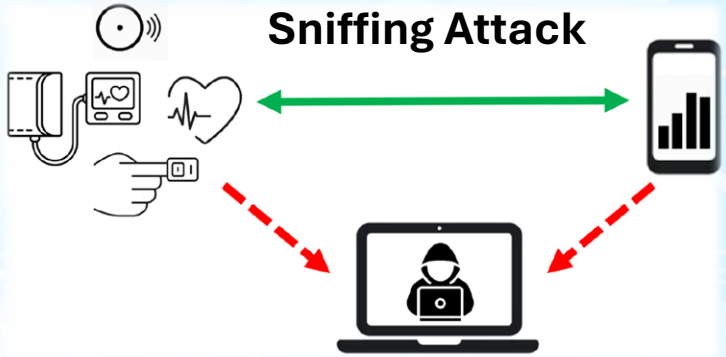

iPhone 13 Pro/Google Pixel 3

Wireshark Tool

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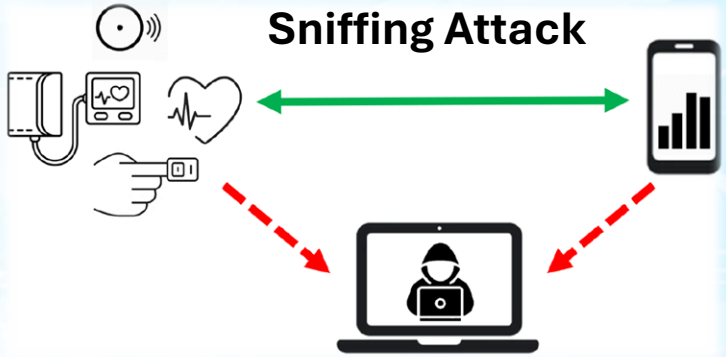
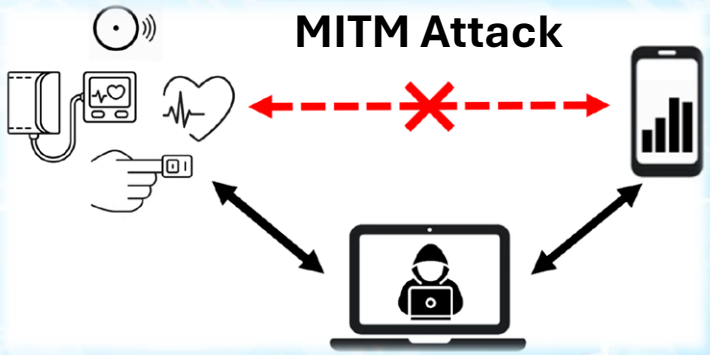
Bluetooth 4.0
Adapter USB
Dongles



Wireshark Tool



Kali Linux
Mirage Tool

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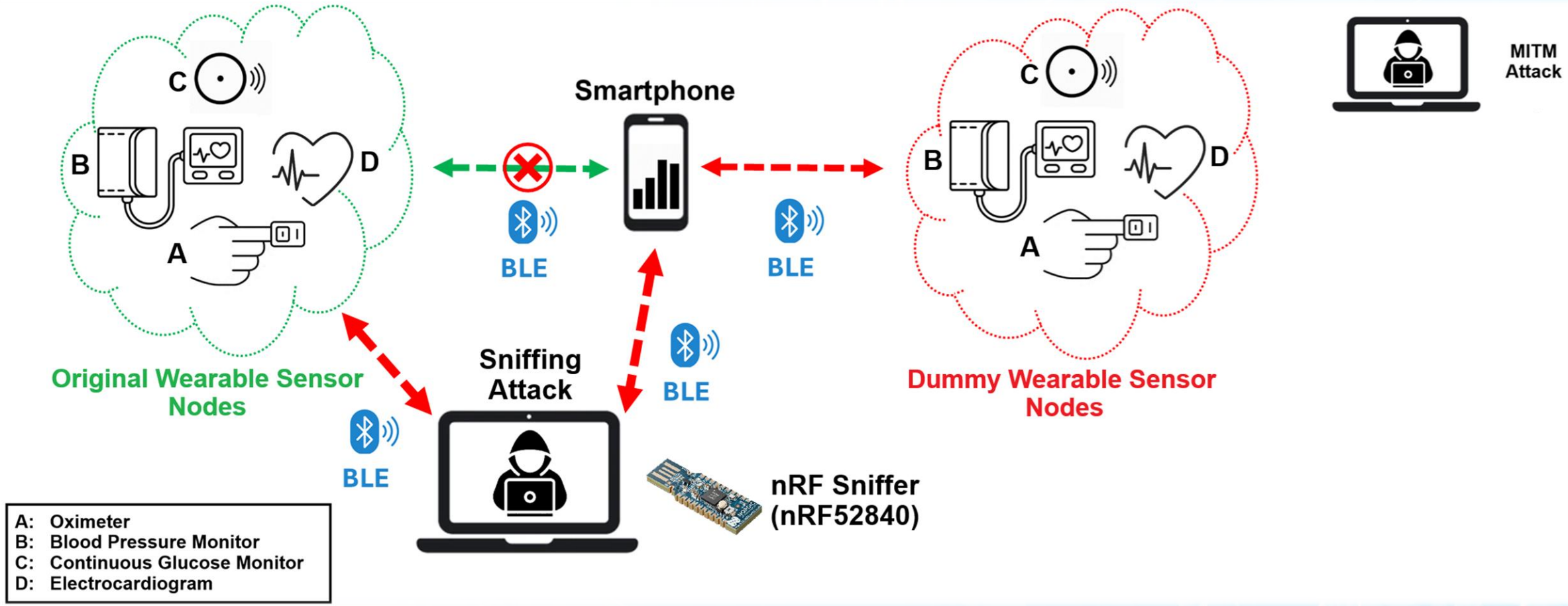
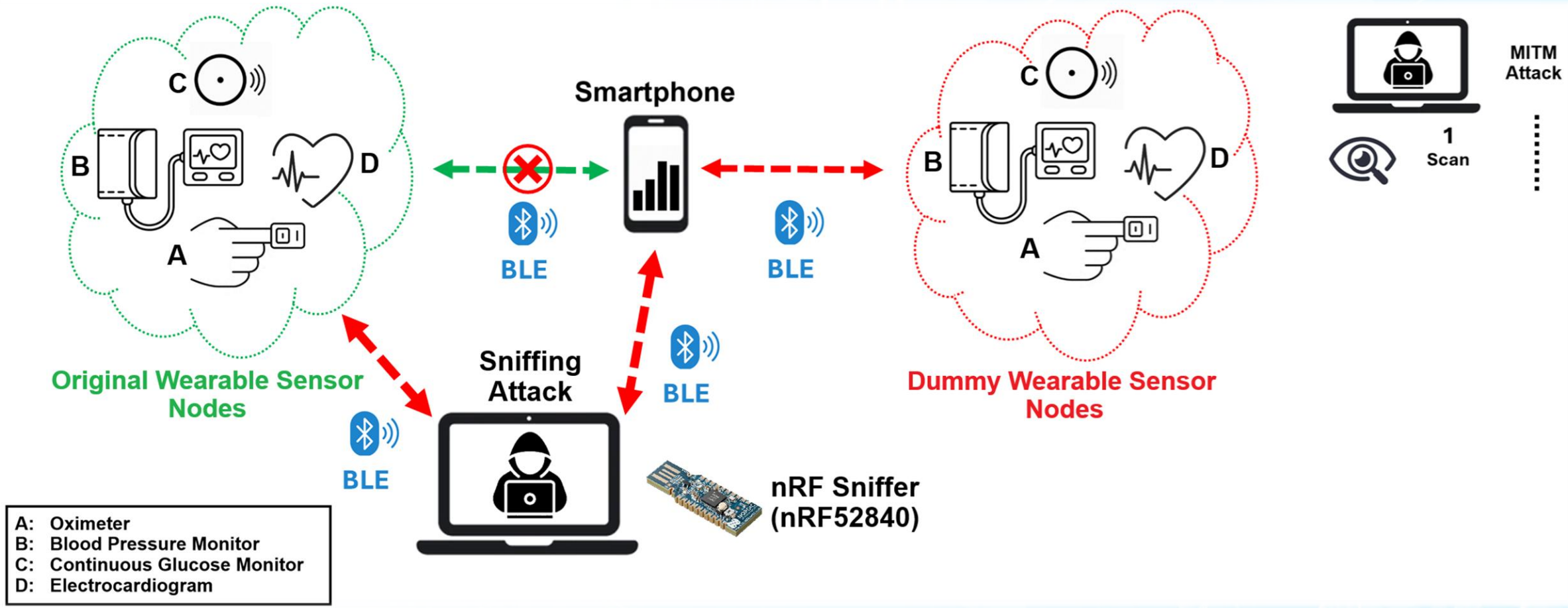
MITM & Sniffing Auditing Methodology



MITM & Sniffing Auditing Methodology



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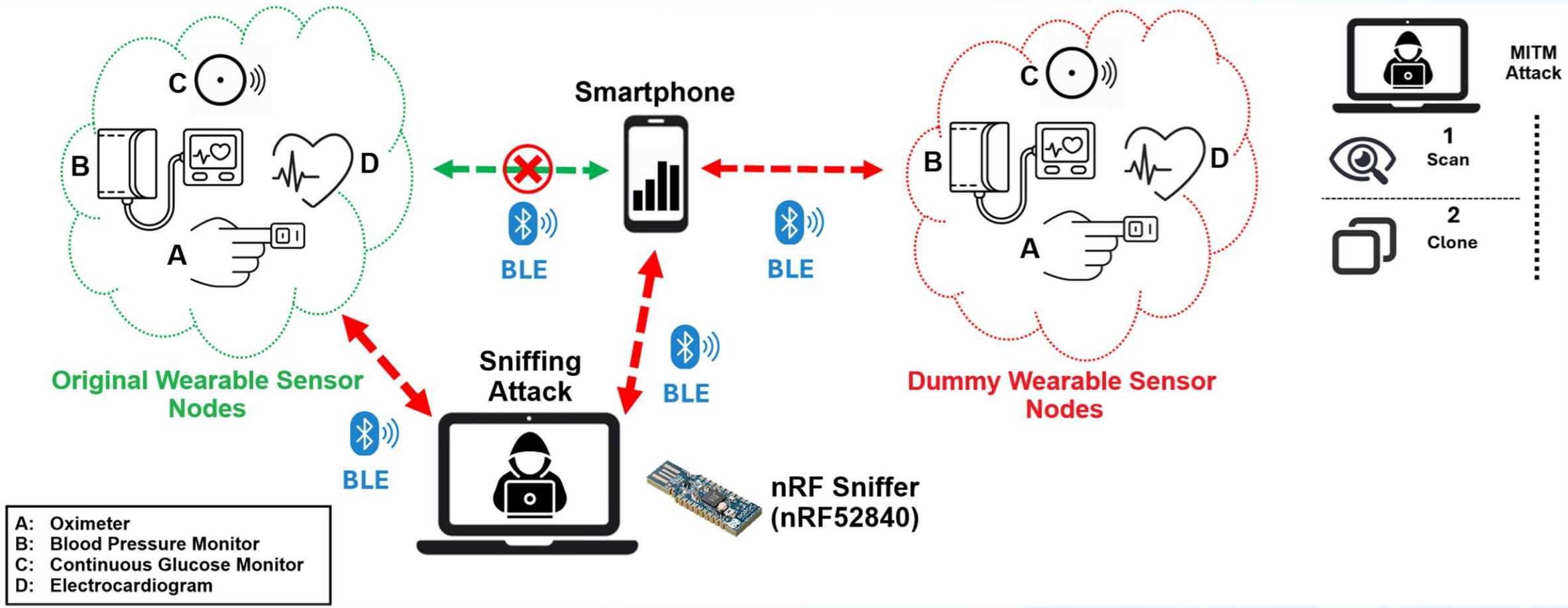

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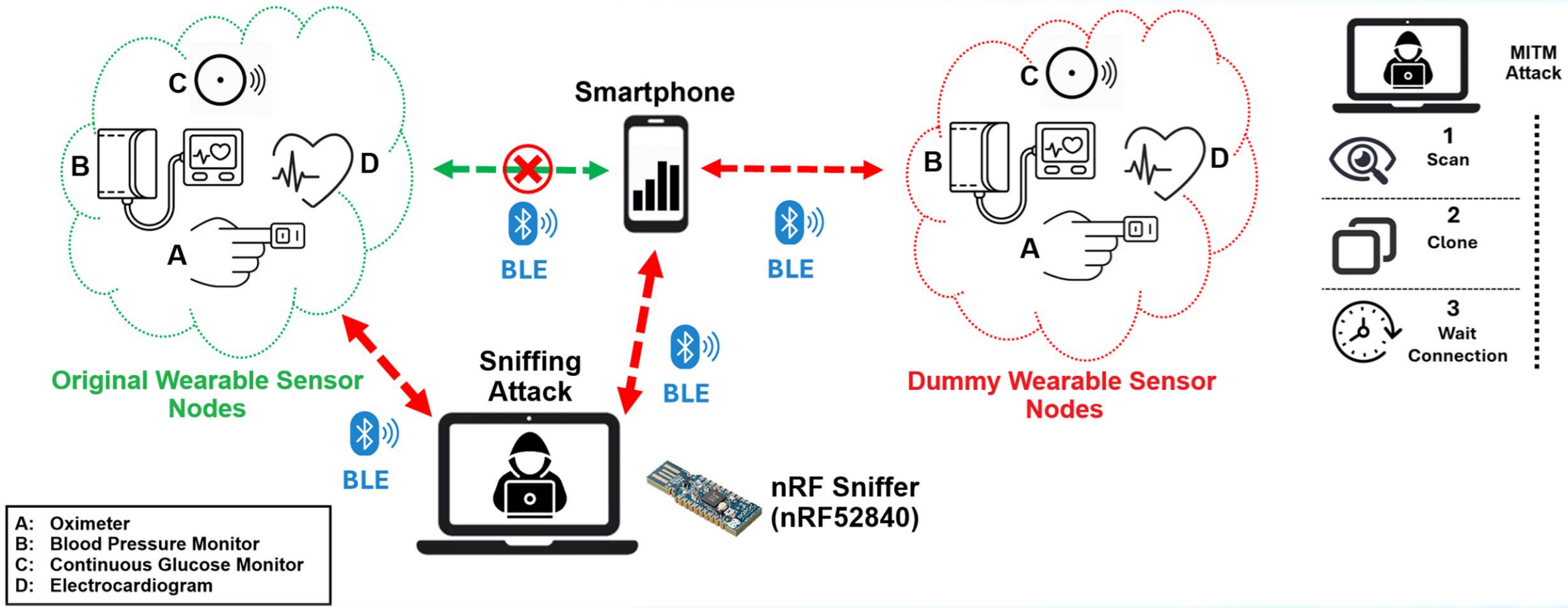

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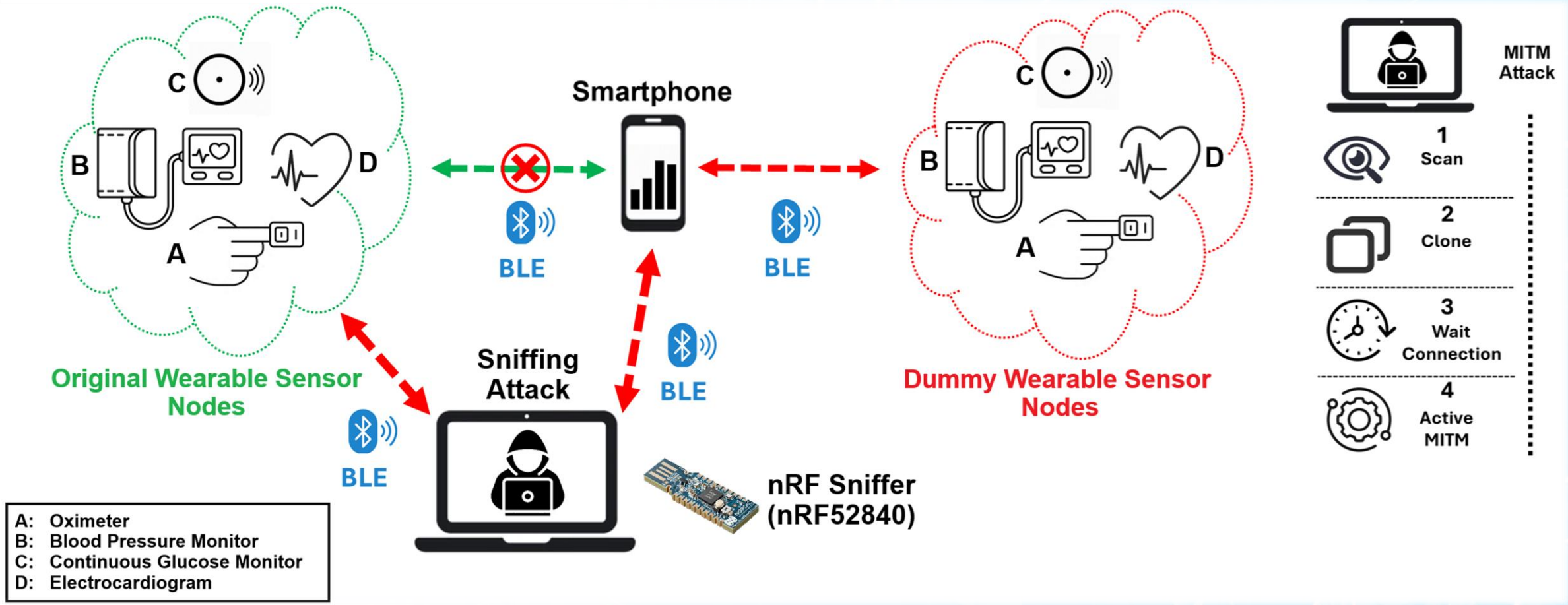

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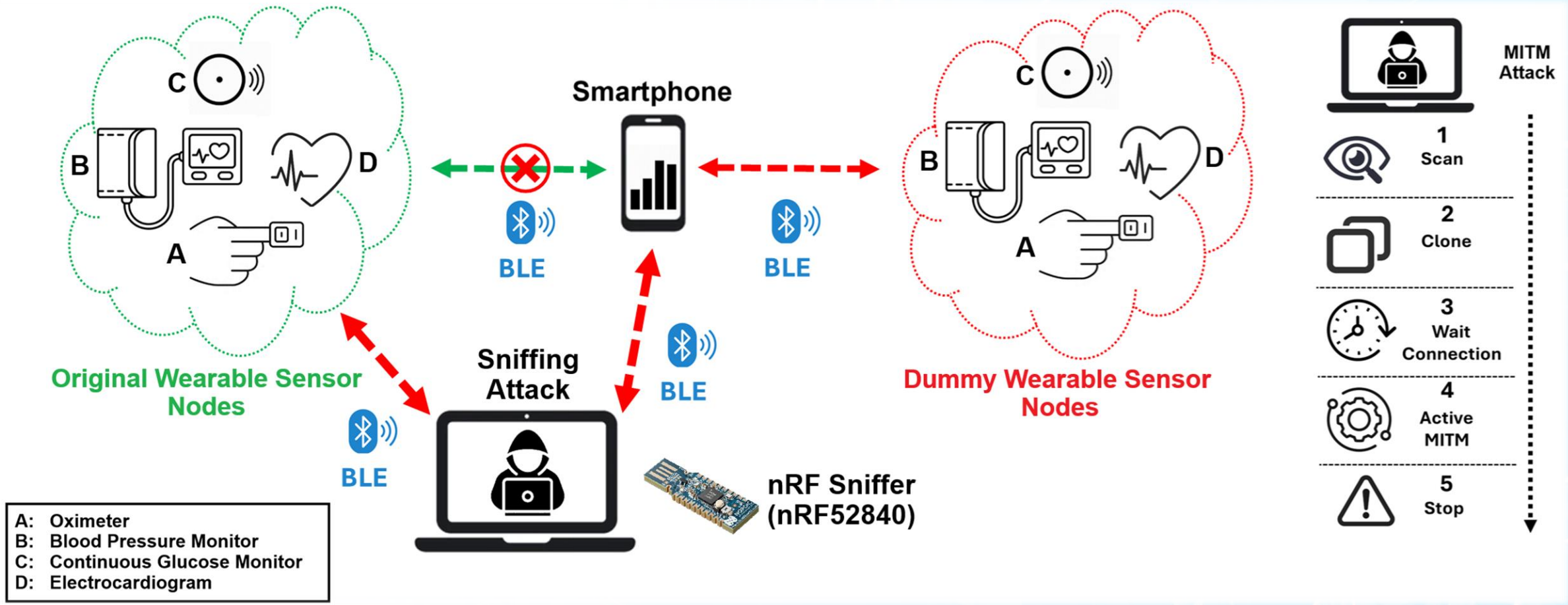
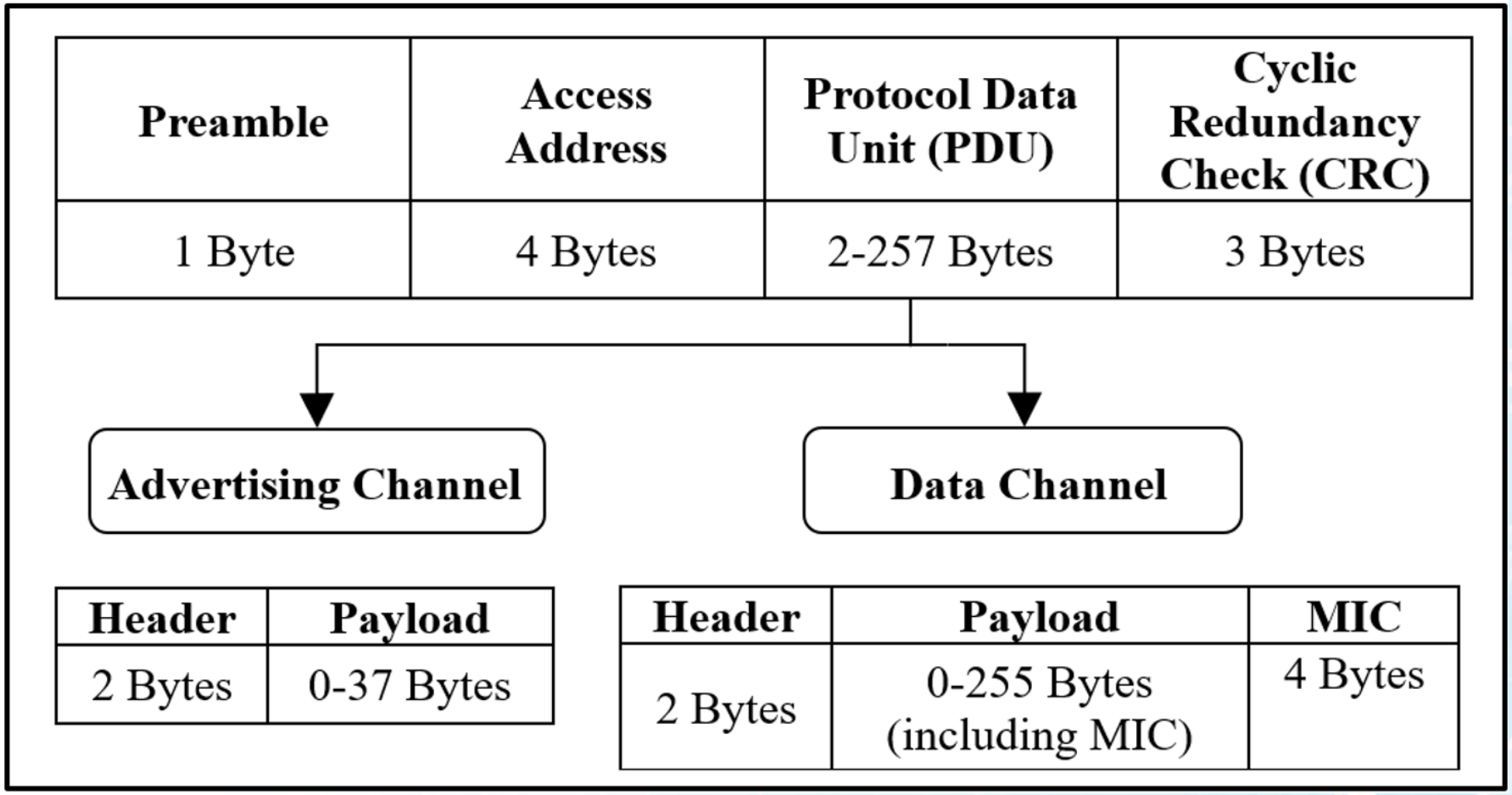


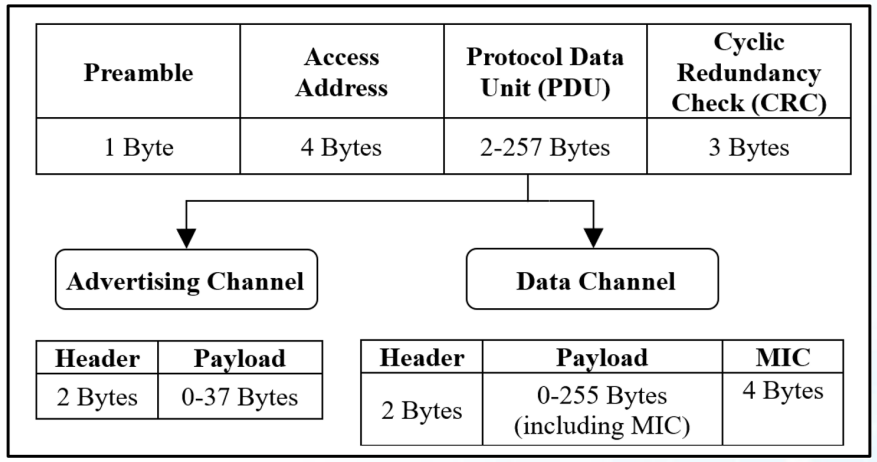
Bluetooth Low Energy – Packet Format



Bluetooth Low Energy – Packet Format

Oxylink Oximeter Encrypted Payload Content:

Handle “0x19”: 5500ff00000d00615e00000000004200070e0100



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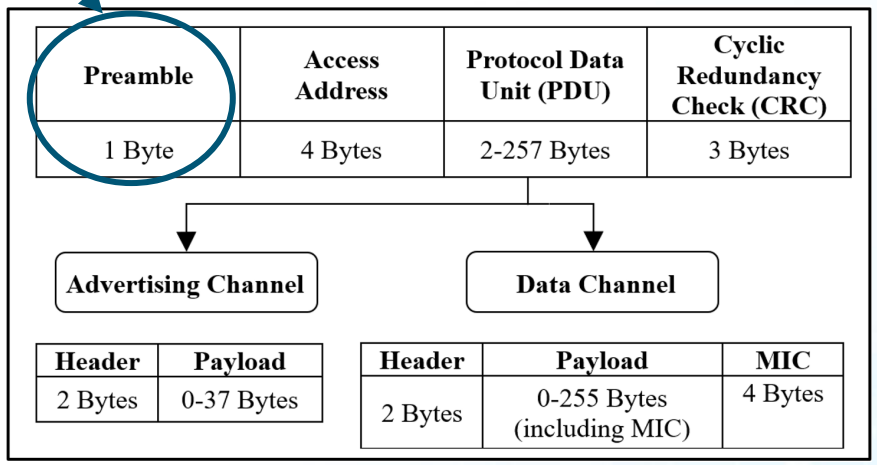

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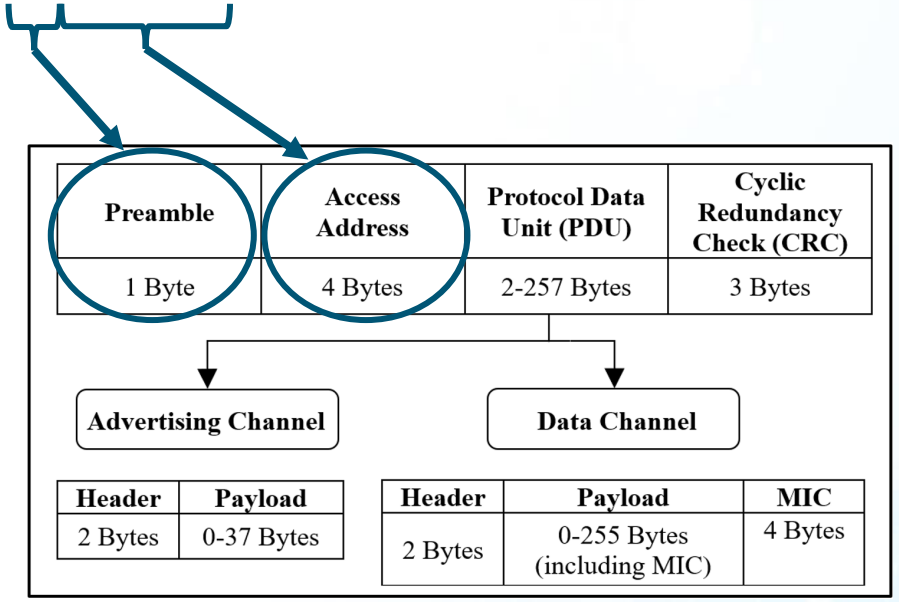

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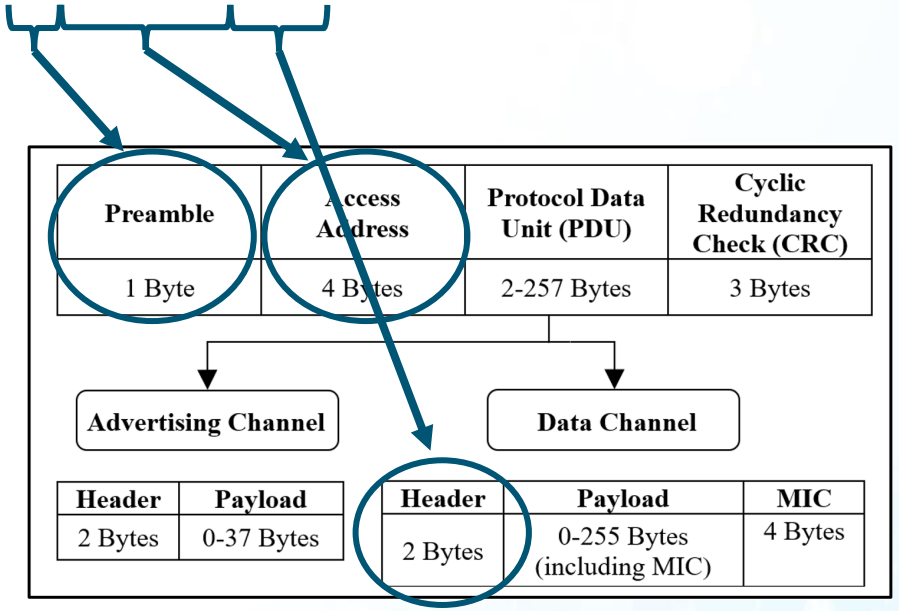

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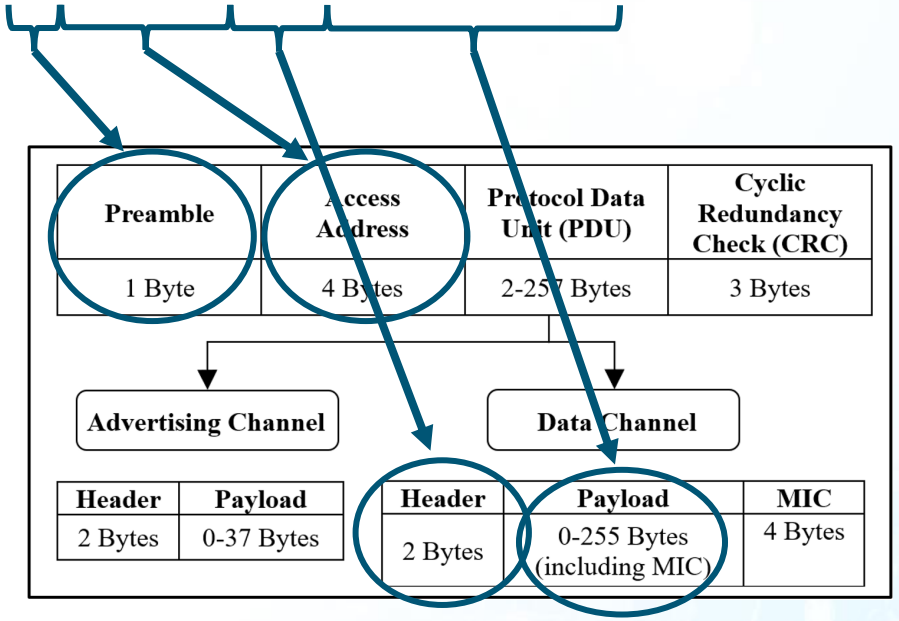

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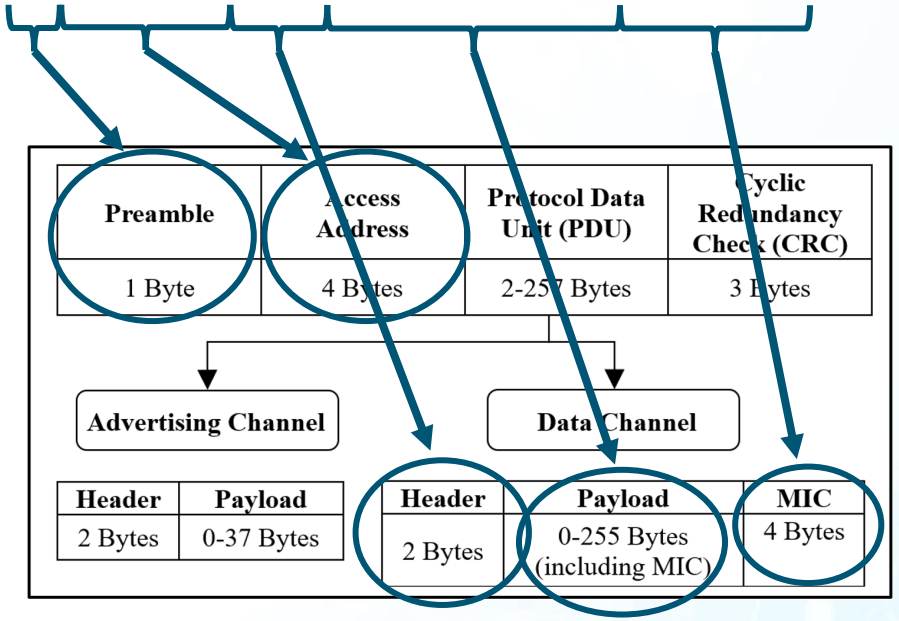

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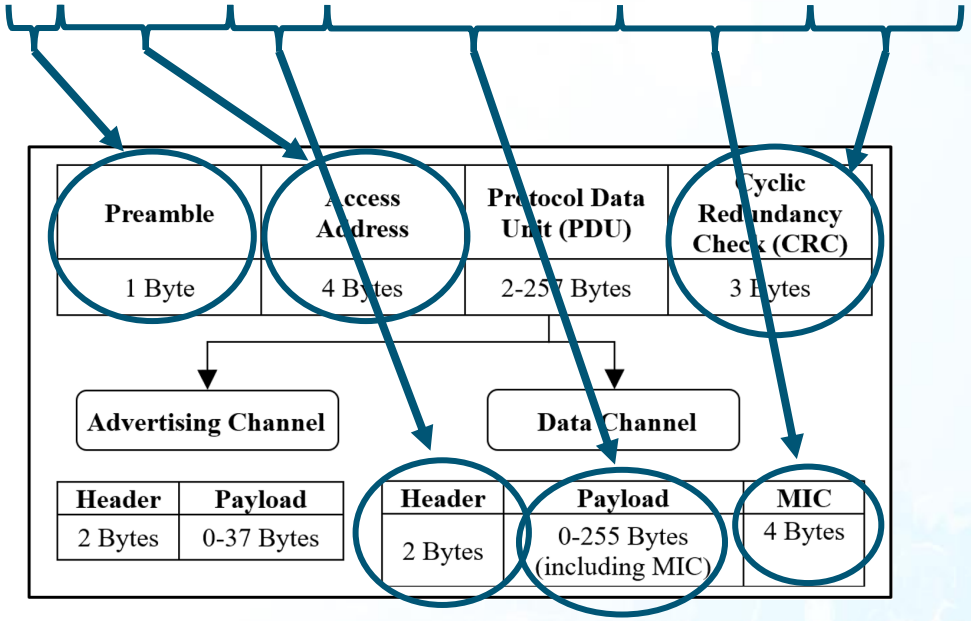

Bluetooth Low Energy – Packet Format

Oxylink Oximeter Encrypted Payload Content:

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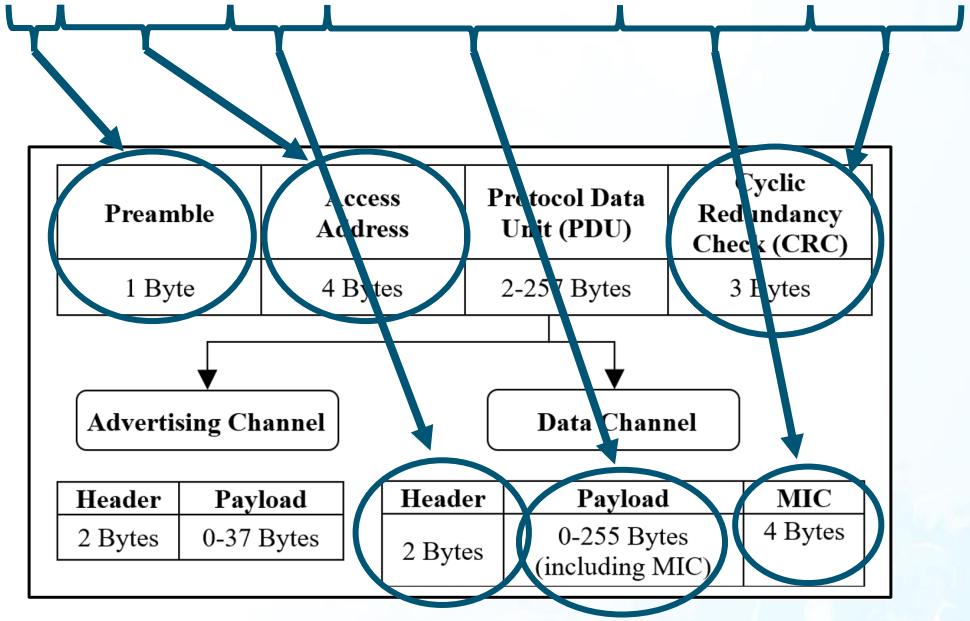
615e00000000



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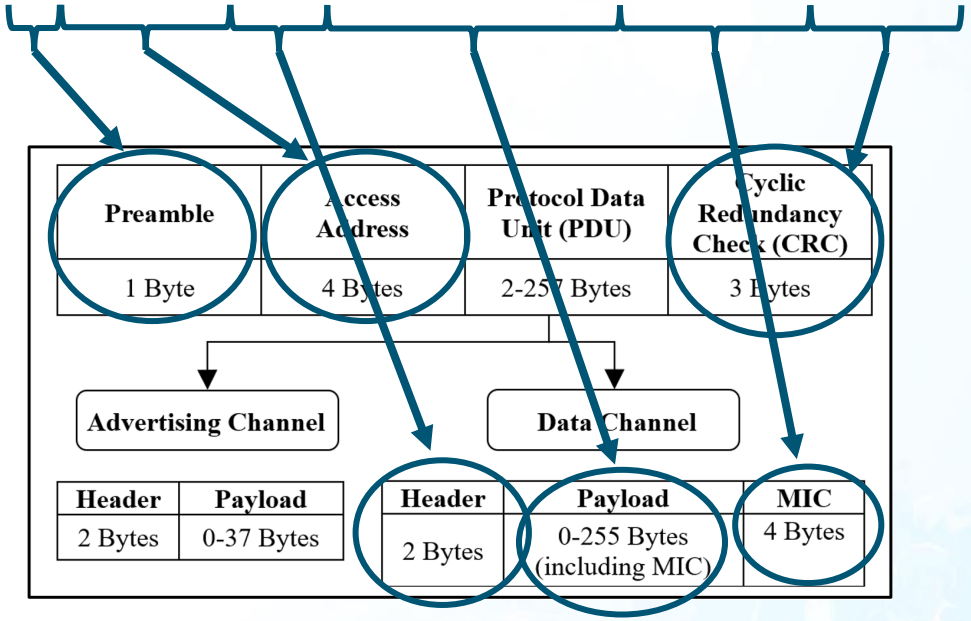

615e00000000

61 (hex) = 97 (dec)

97% Oxygen Level

5e (hex) = 94 (dec)

94/min Heart Rate

Bluetooth Low Energy – Packet Format

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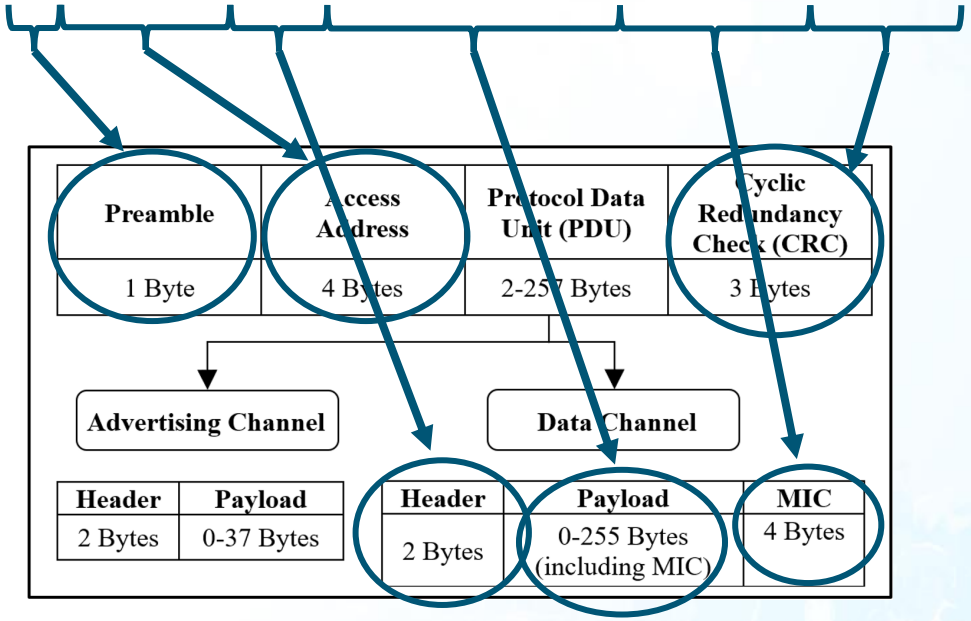

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Original: Handle “0x19”: 5500ff00000d00615e0000000004200070e0100

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Key: “39”

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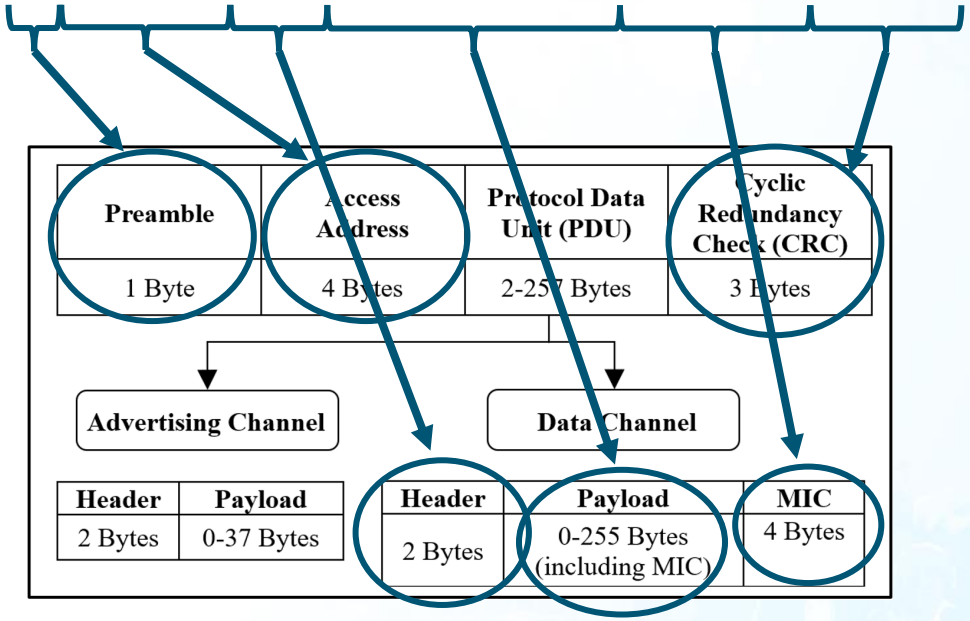

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94/min Heart Rate

Original: Handle “0x19”: 5500ff00000d00615e0000000004200070e0100

Replay: Handle “0x19”: 5500ff00000d006041000000000550000050100

???

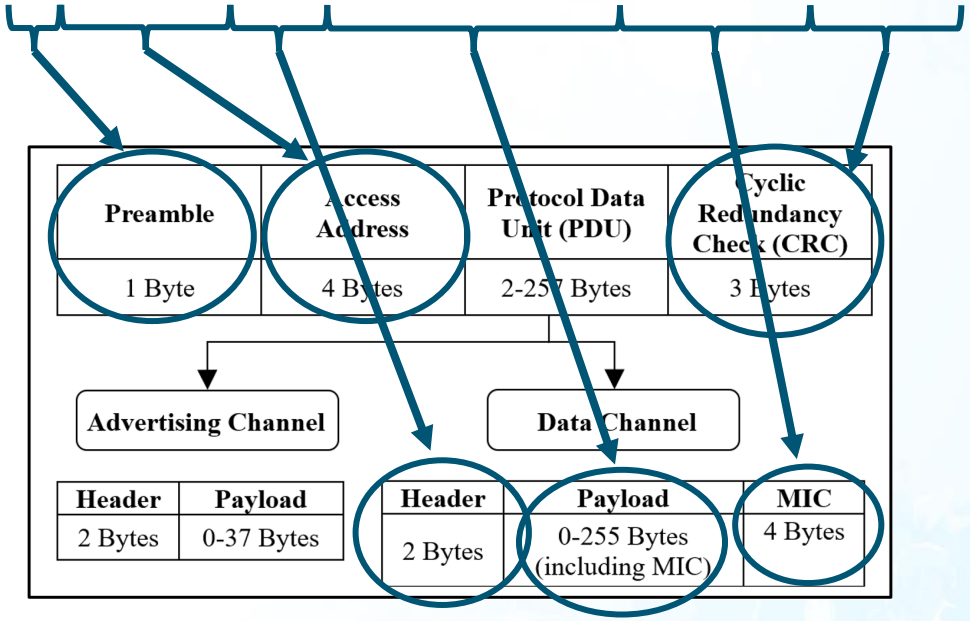
Key: “39”

Key: “db”

Bluetooth Low Energy – Packet Format

Oxylink Oximeter Encrypted Payload Content:

Handle “0x19”: 5500ff00000d00615e0000000004200070e0100



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94/min Heart Rate

???

Key: “39”

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Original: Handle “0x19”: 5500ff00000d00615e0000000004200070e0100

Replay: Handle “0x19”: 5500ff00000d006041000000000550000050100

60 (hex) = 96 (dec)

96% Oxygen Level

41 (hex) = 65 (dec)

65/min Heart Rate

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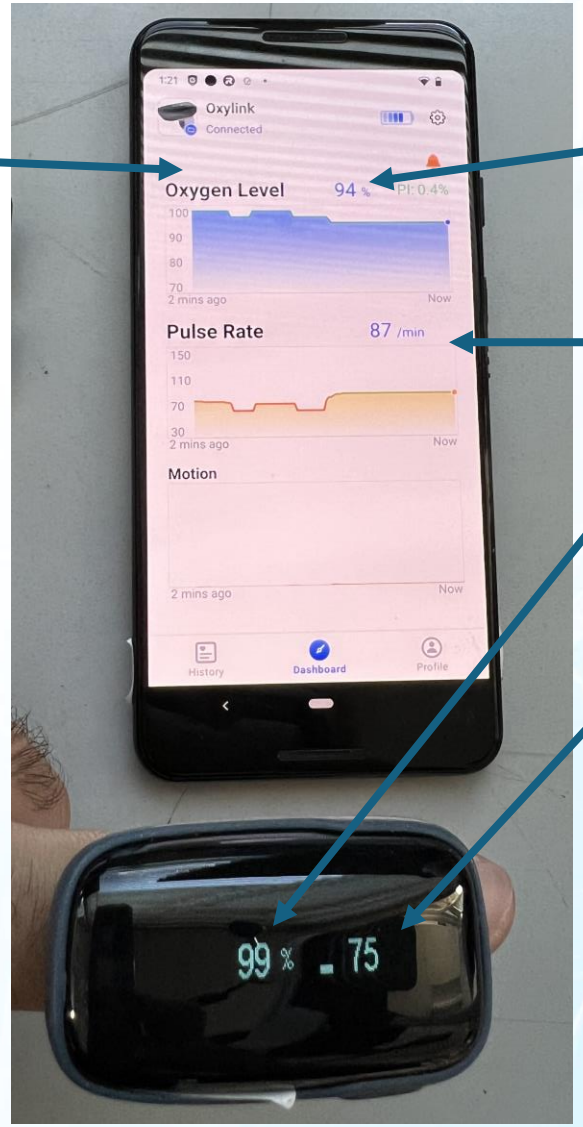
Oximeter Experimental Results (MITM Attacks)

ViHealth App
Real-time Data
Manipulation



Oxygen Level
Manipulation

Pulse Rate
Manipulation

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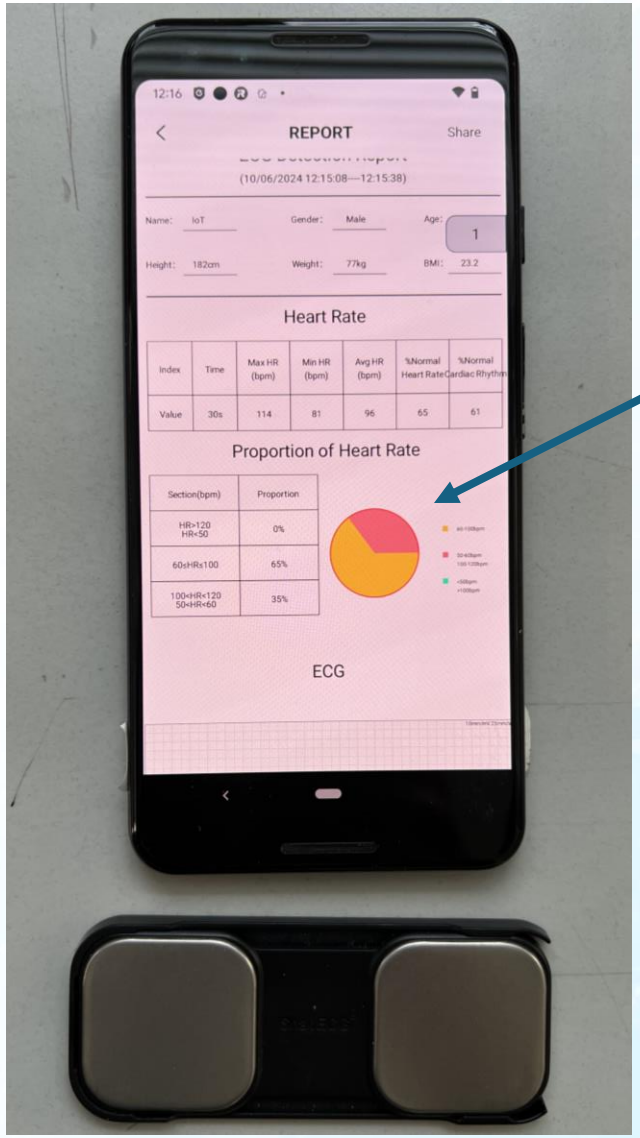
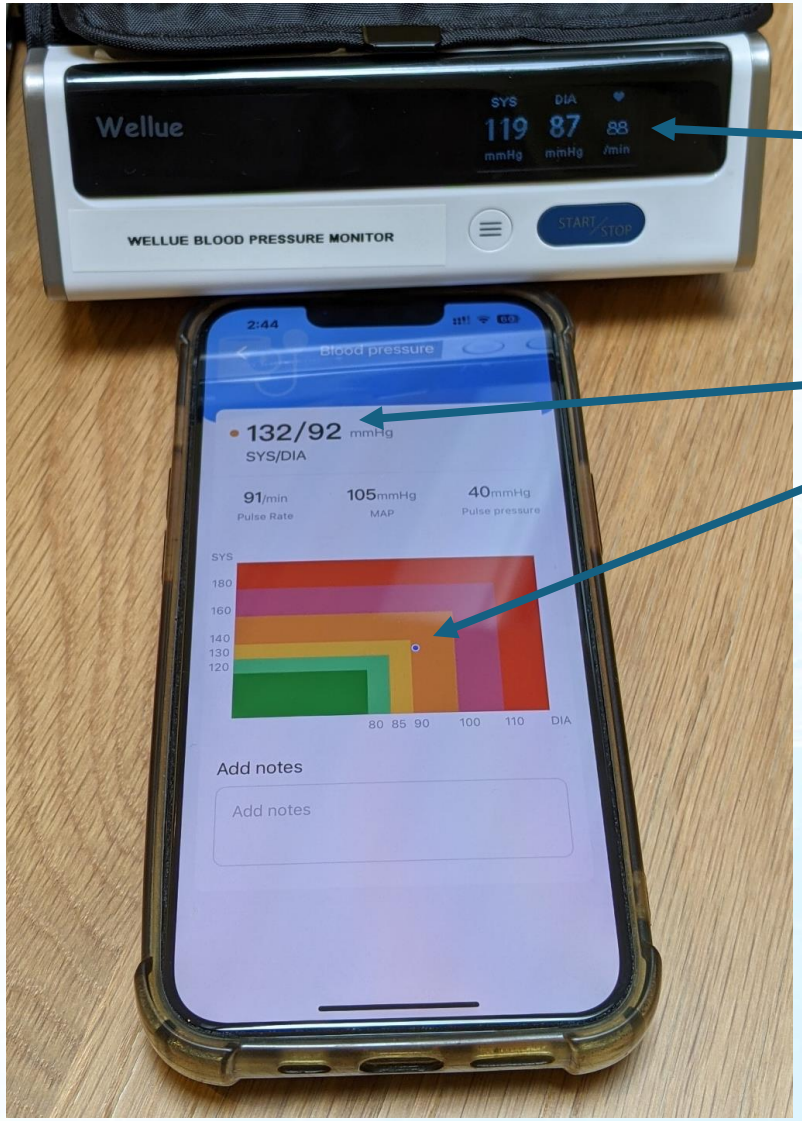
ECG Experimental Results (MITM Attacks)



Unhealthy Report

BPM Experimental Results (MITM Attacks)



Typical Normal Reading

Hypertension Stage 1

CGMs Improved Security Mechanisms

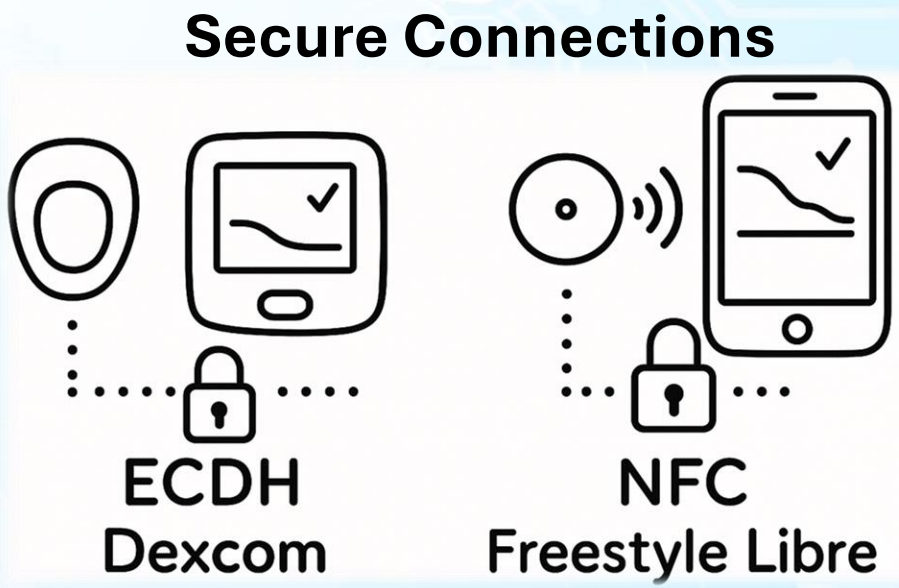
Secure Connections (for initial pairing and keys exchange):

- **Elliptic Curve Diffie-Hellman (ECDH).**

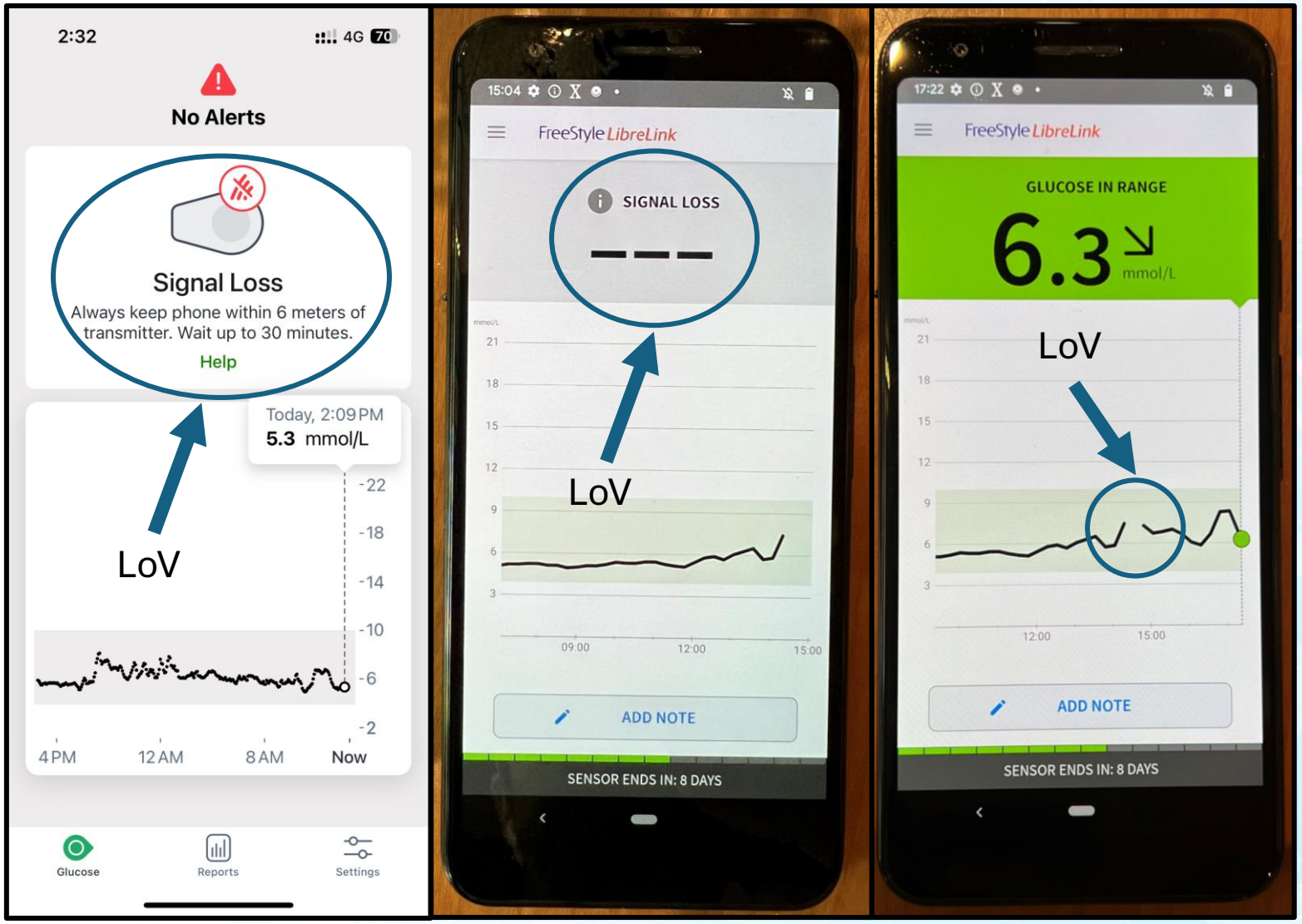
  → Private keys → Public keys → ECDH → Shared secret →
  KDFs → rand → EDIV → IVs →

Session key

- **Near Field Communication (NFC).**

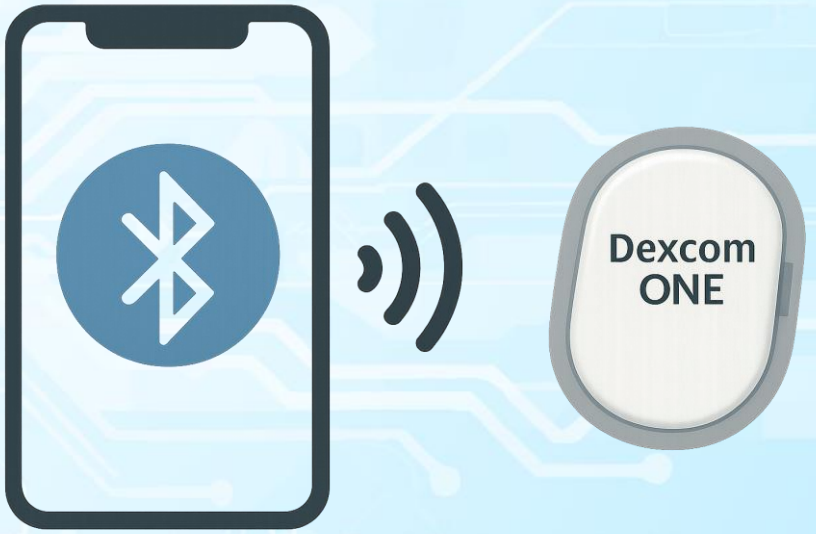


CGM Experimental Results (DoS Attacks)



Sniffing Experimental Results – Example (Dexcom ONE CGM)

- **Initial Pairing Process (ECDH Key Exchange):**
  - **Public Key (Master and Slave)**
  - **Random Key (Master)**
  - **Pairing Confirmation (Slave)**
  - **DHKey checks (Master and Slave)**



- **Established Session (Post-Pairing Communication):**
  - **Random Number (rand):** All zeros.
  - **Encrypted Diversifier (EDIV):** Non-random or default value.
  - **Session Key Diversifiers (SKDm, SKDs):** Secure, randomized session key generation.
  - **Session Initialization Vectors (IVm, IVs):** Sufficiently randomized.

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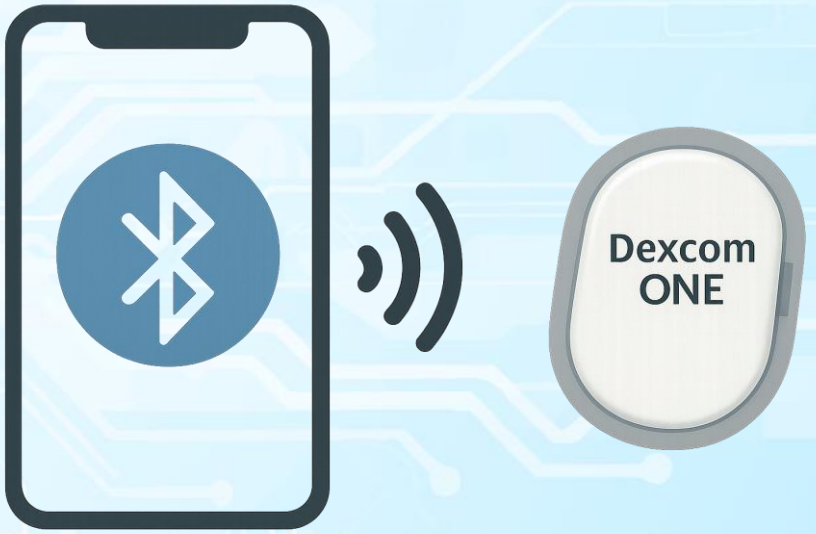
Sniffing Experimental Results – Example (Dexcom ONE CGM)

- **Initial Pairing Process (ECDH Key Exchange):**
  - **Public Key (Master and Slave)**
  - **Random Key (Master)**
  - **Pairing Confirmation (Slave)**
  - **DHKey checks (Master and Slave)**



- **Established Session (Post-Pairing Communication):**
  - **Random Number (rand):** All zeros.
  - **Encrypted Diversifier (EDIV):** Non-random or default value.
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  - **Session Initialization Vectors (IVm, IVs):** Sufficiently randomized.

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Key Findings

Devices	Types of Attacks			
	Sniffing (Eavesdropping)	**Passive MITM (Eavesdropping)**	**Active MITM (Data Manipulation)**	**DoS (Loss of View)**
SnapECG **(ECG)**	✓	✓	✓	✓
DuoEK Wellue **(ECG)**	✓	✗	✗	✓
OXYLINK **(Oximeter)**	✓	✓	✓	✓
SleepO2 1400 **(Oximeter)**	✓	✓	✓	✓
Wellue BP2A 2031 **(BPM)**	✓	✓	✓	✓
Dexcom ONE **(CGM)**	✓	✗	✗	✓
FreeStyle Libre 2 **(CGM)**	✓	✗	✗	✓

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Responsible Disclosure

- **DexCom Inc.** responded and addressed the findings → D1+ includes improved security.
- Other **manufacturers** (i.e. Abbott Laboratories, Nanjing Xijian, and Shenzhen Viatom) were contacted, but **did not respond.**
- All **experiments** were conducted in a **controlled lab environment.**
- No sensitive **health data** was **exposed** in our testing.

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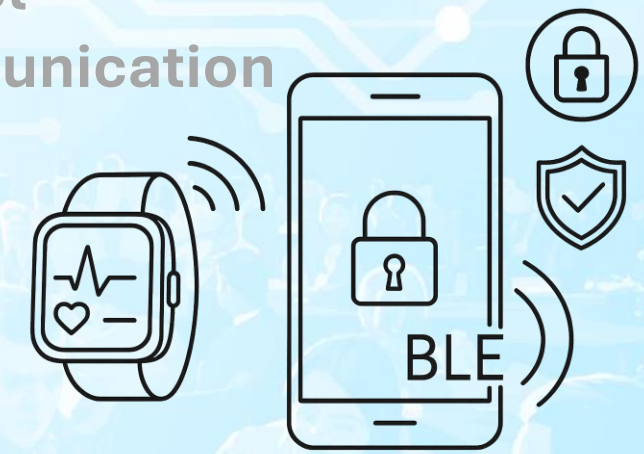
Conclusion

- Significant **vulnerabilities** in BLE-enabled **Wearable Sensor Nodes** → **legacy pairing** and **secure connections** protocols.
- **Impacts and implications** → potential application of pioneering **hacking techniques** on sensitive **Wearable Sensor Nodes**.
- Importance of not relying solely on a **single wireless protocol** → instead depending on a **multilayered cybersecure communication system** for improved **security** and **reliability**.
- Call to action for **manufacturers & stakeholders** to address these issues.



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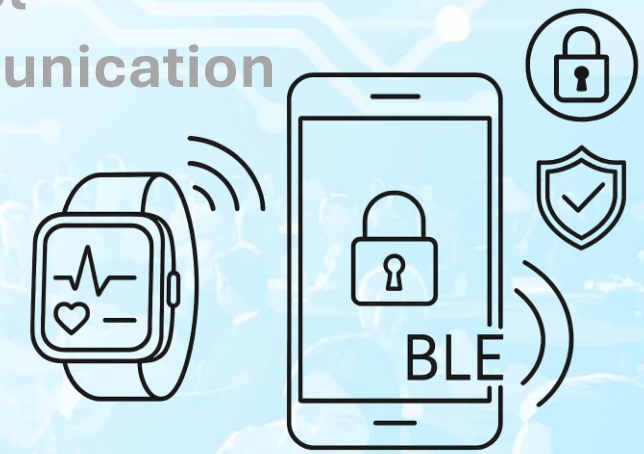

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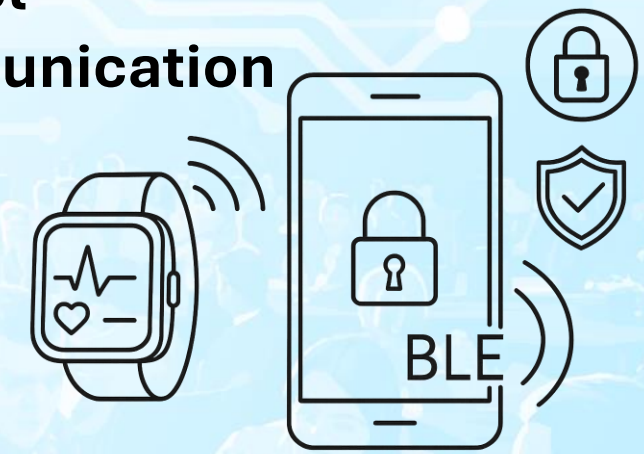

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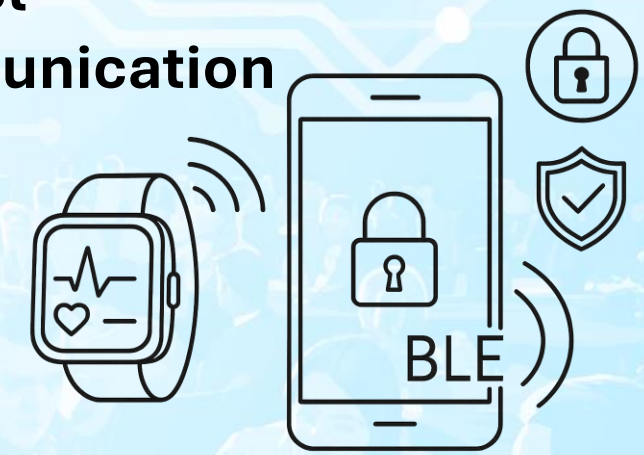

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Thanks

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