Uncovering Vulnerabilities in Bluetooth Devices with Automated Binary Analysis

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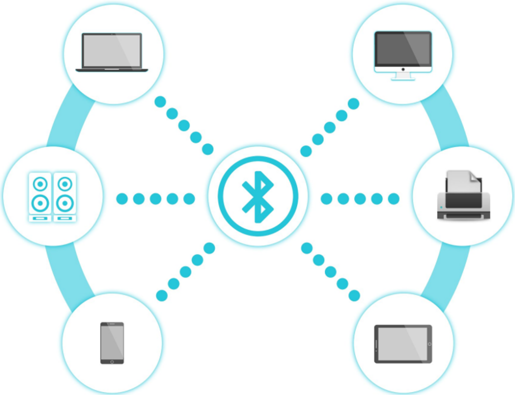
What is Bluetooth

Bluetooth wireless technology

- Low-cost, low-power
- Short-range radio
- For ad-hoc wireless communication
- For voice and data transmission



What is Bluetooth

Google

Contact tracing

Why Named Bluetooth

Harald "Bluetooth" Gormsson

- King of Denmark 940-981.
- He was also known for his bad **tooth**, which had a very dark **blue-grey** shade.
- He united the Tribes of Denmark.

The Bluetooth wireless specification design was named after the king in 1997, based on an analogy **that the technology would unite devices the way Harald Bluetooth united the tribes of Denmark into a single kingdom**.

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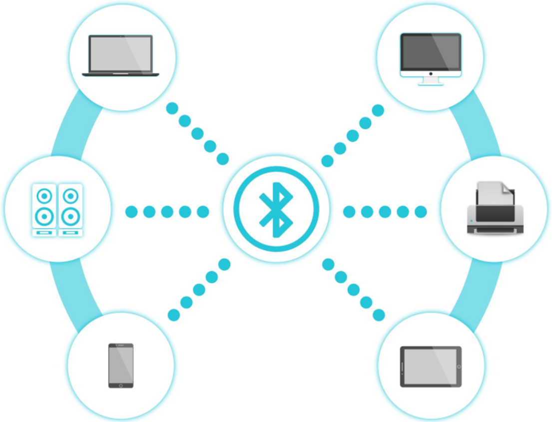

History of Bluetooth

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Dr. Jaap Haartsen started a project named Bluetooth.

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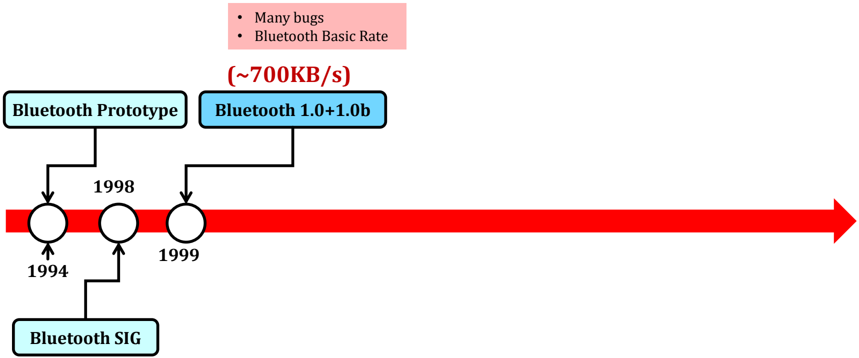

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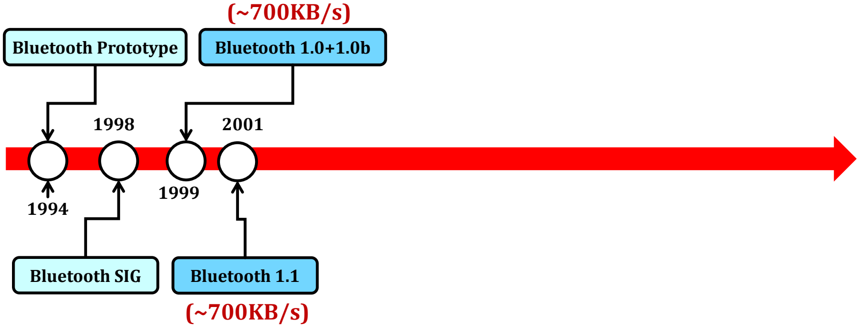
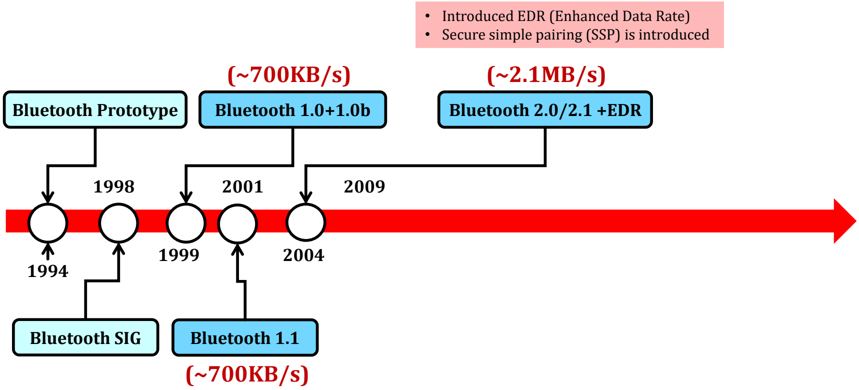


- Fixed security issues.
- First marketable product version.

History of Bluetooth



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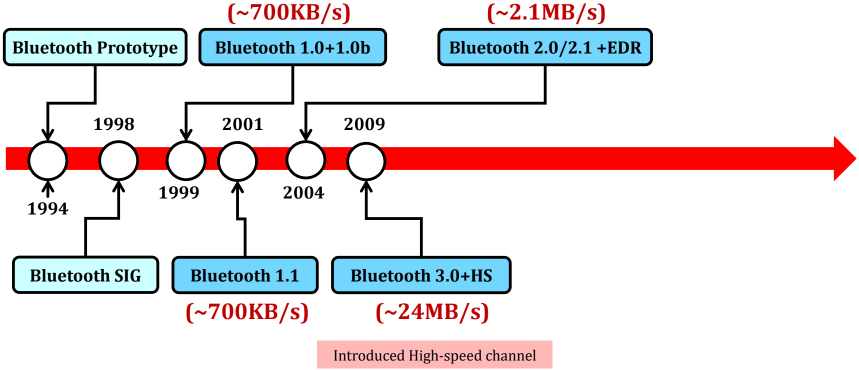

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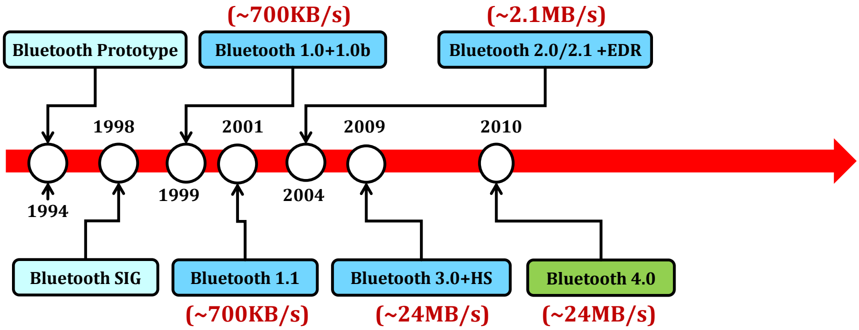
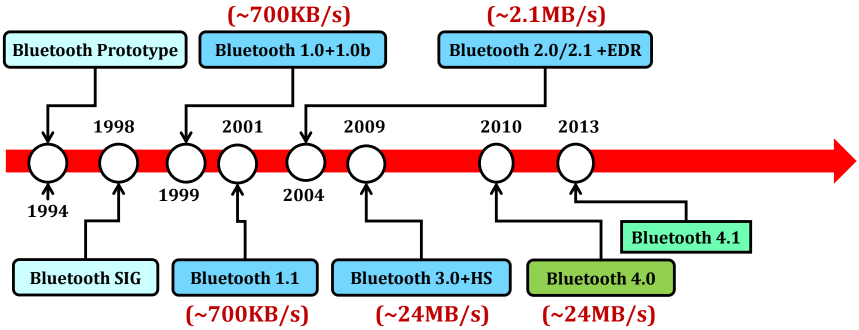


- Low energy (LE) protocol for IoT;
- 128-bit encryption/LE Privacy and Whitelisting

History of Bluetooth



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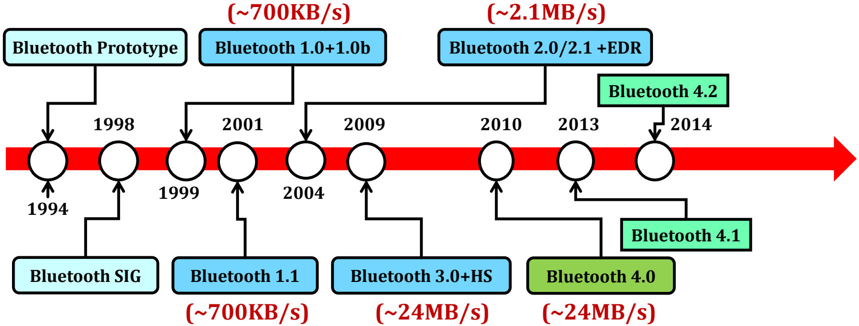

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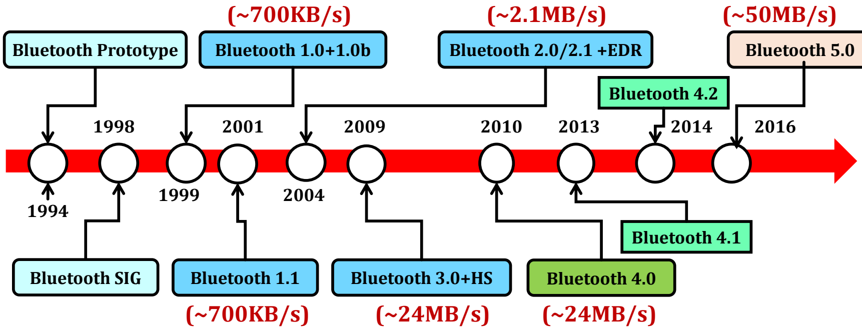
History of Bluetooth

Significant increase in range and data transfer rate



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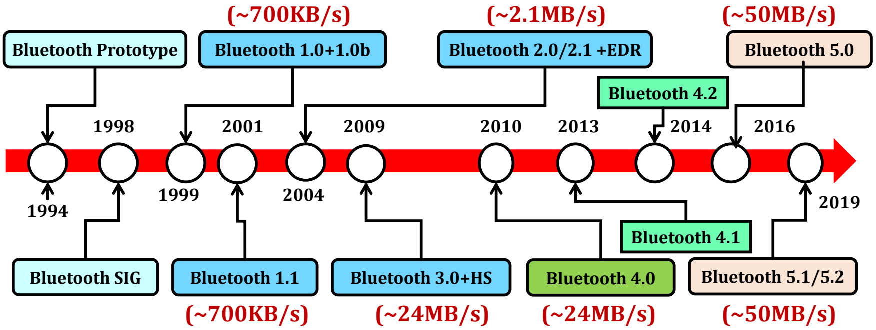

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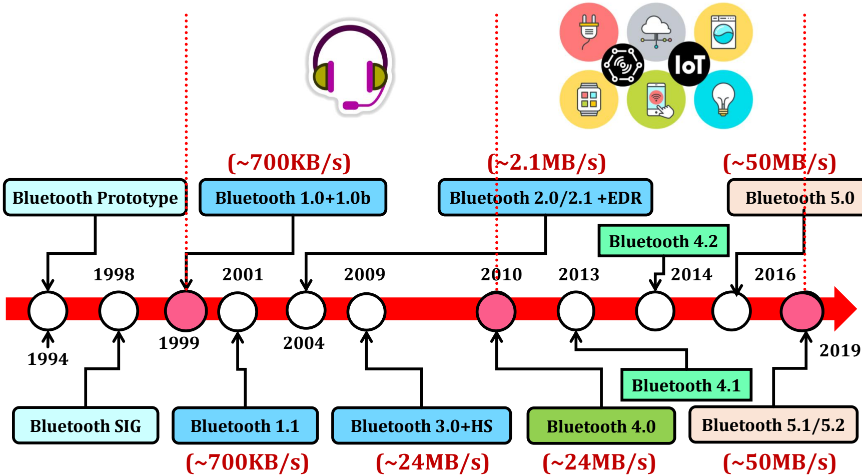
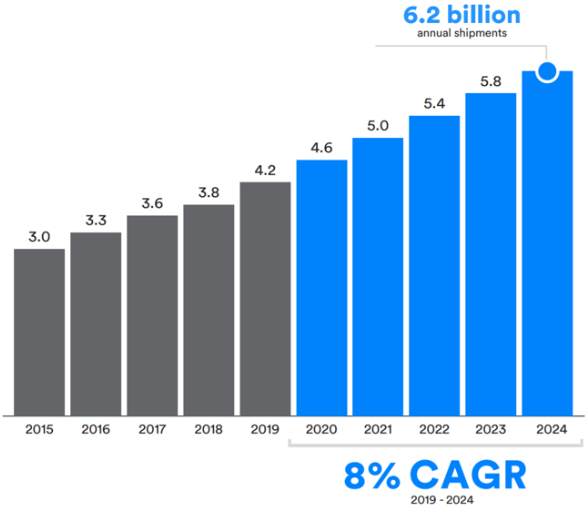


Total Annual Bluetooth Device Shipments [SIG20]



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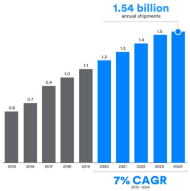
Annual Bluetooth Audio Streaming Device Shipments



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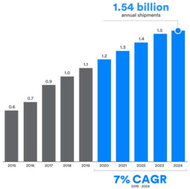
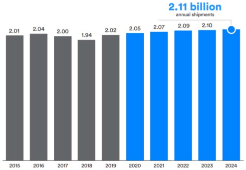


Annual Bluetooth Phone, Tablet & PC Shipments



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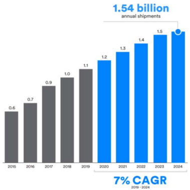

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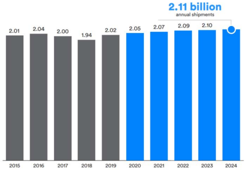
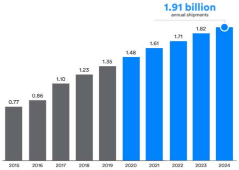


Annual Bluetooth Entertainments Shipments



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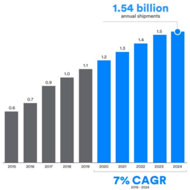

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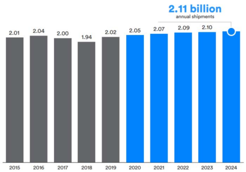

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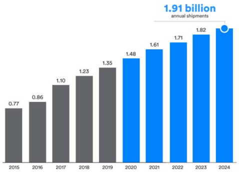
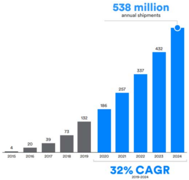


Annual Bluetooth Location Service Device Shipments



Bluetooth IoT Devices and Companion Apps

BLE IoT Devices

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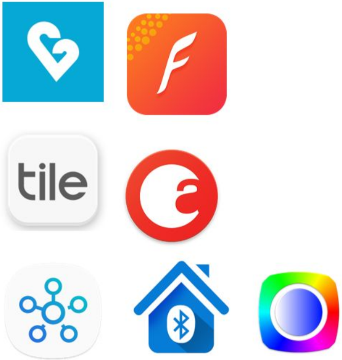
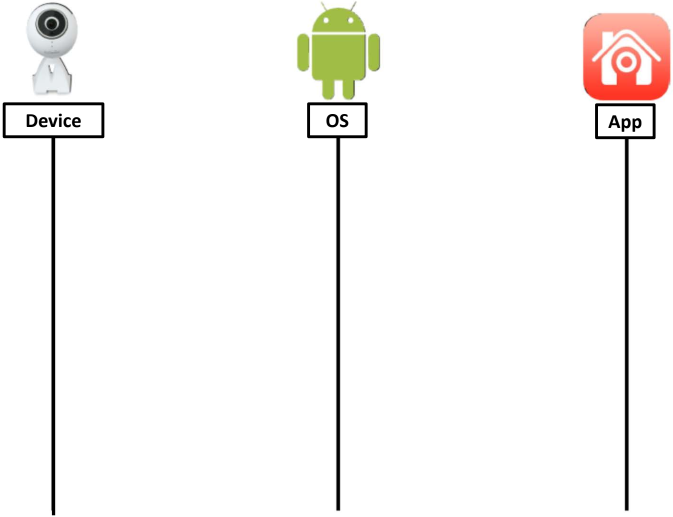


Companion Mobile Apps

The General Workflow of Device Communication in TCP/IP Setting



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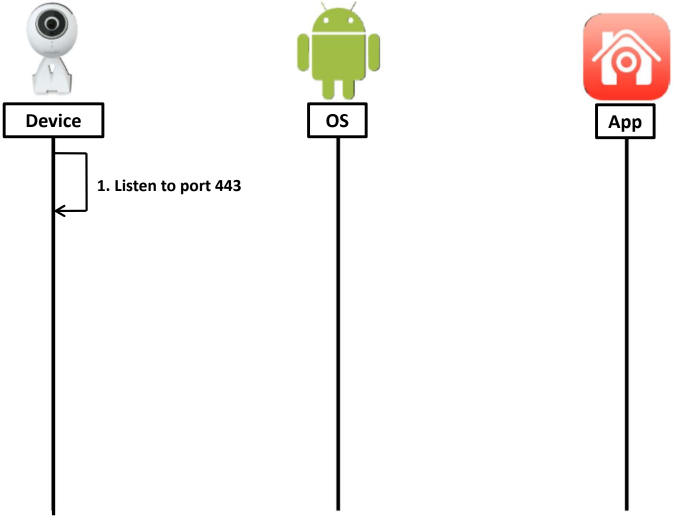

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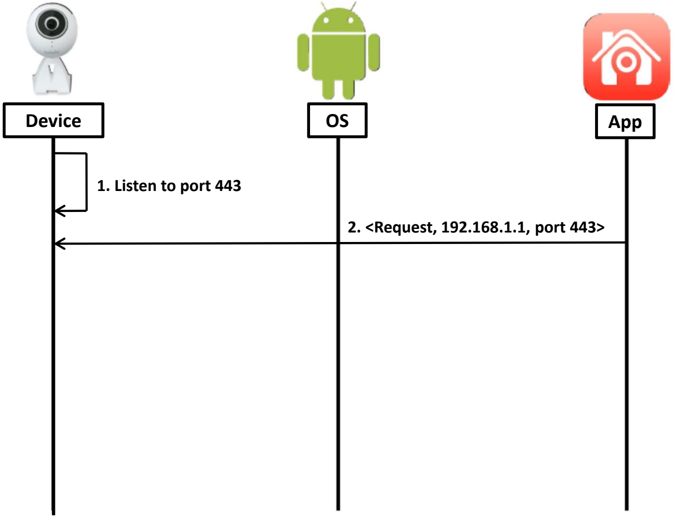

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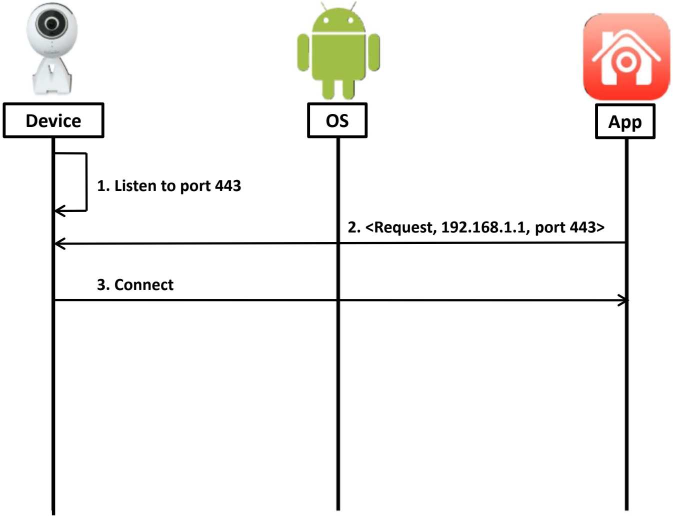

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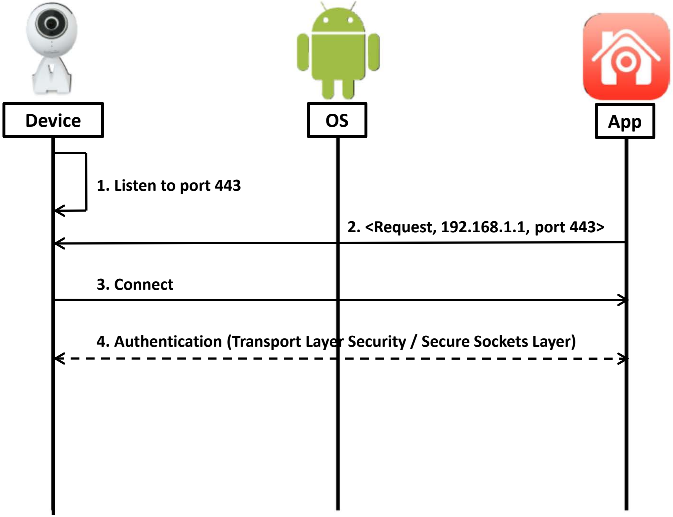

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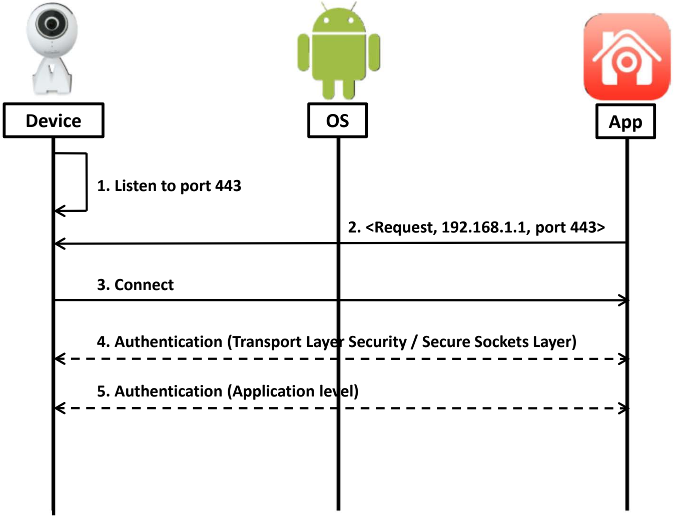

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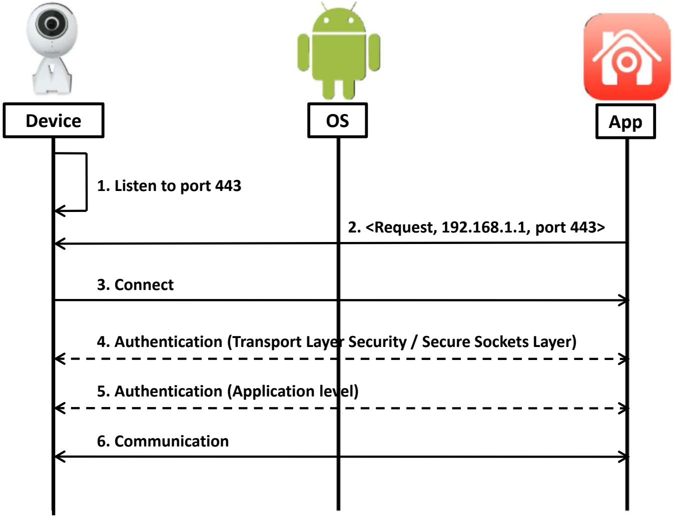
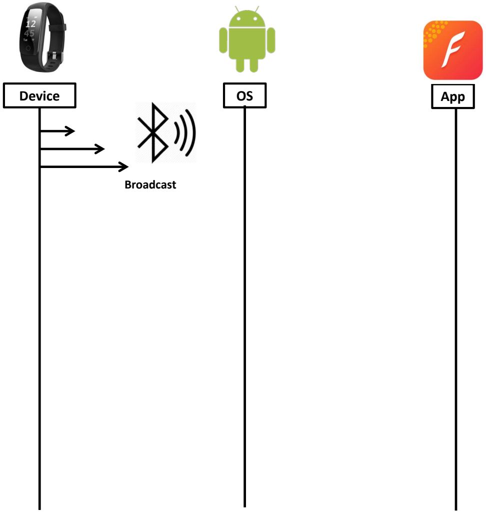


The General Workflow of BLE IoT Devices and Companion Apps



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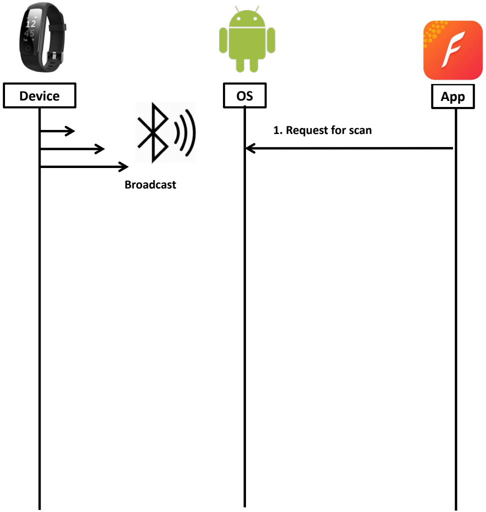

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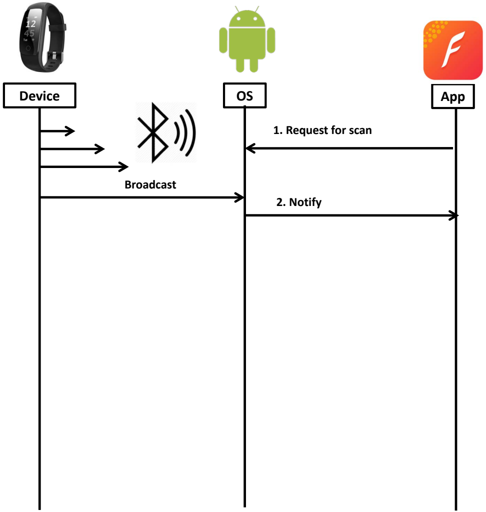

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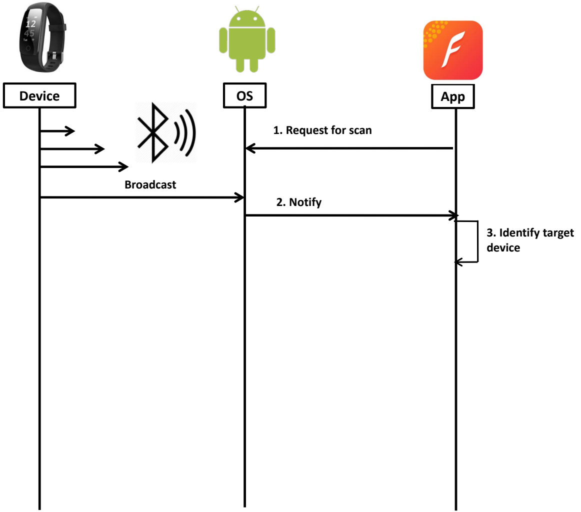

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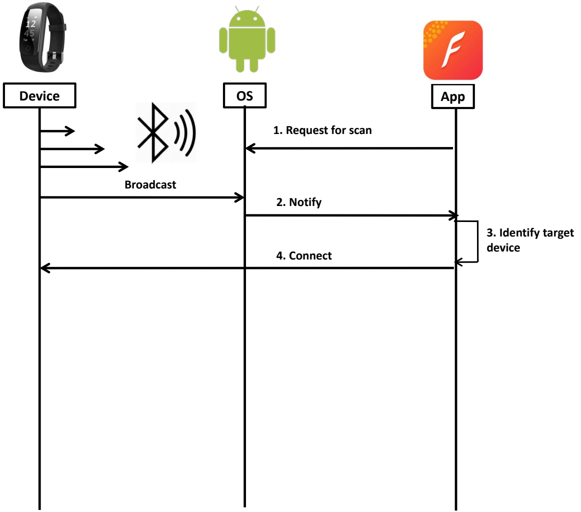

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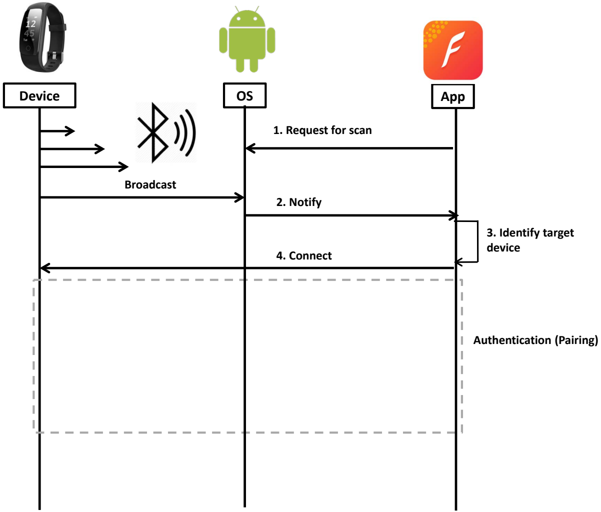

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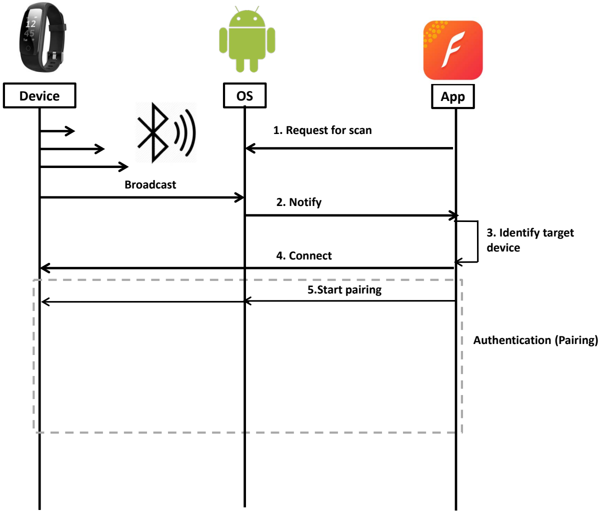

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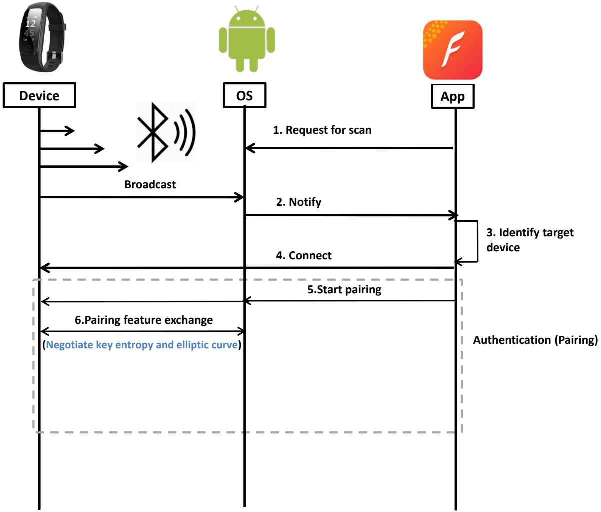

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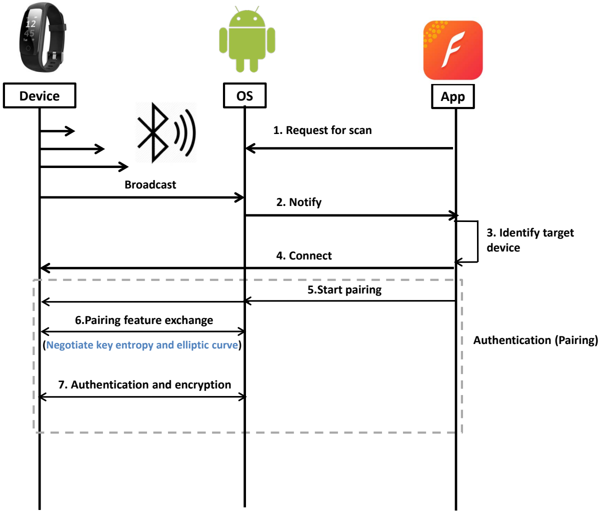

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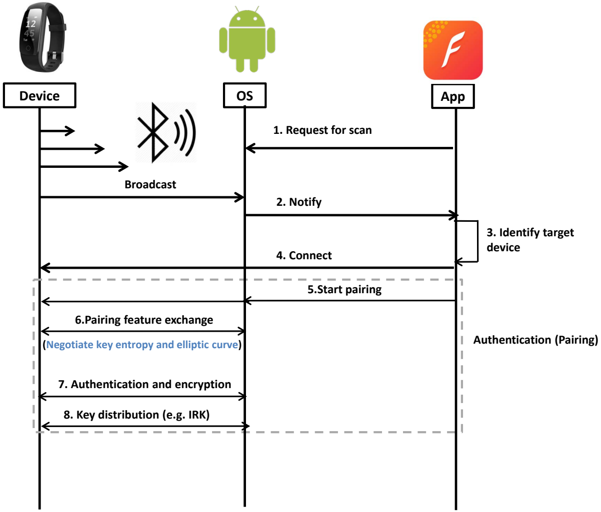

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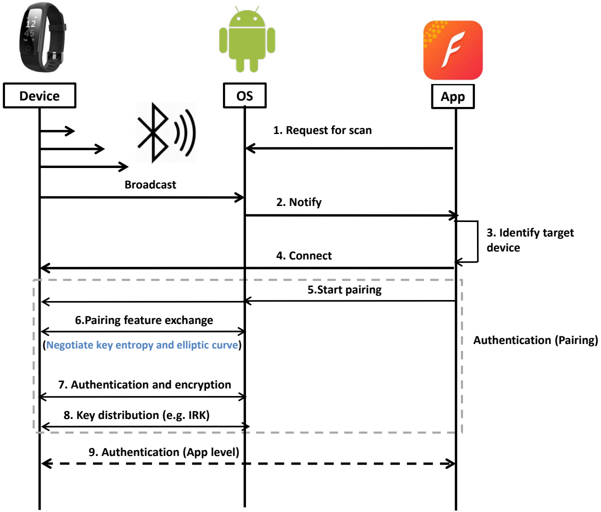

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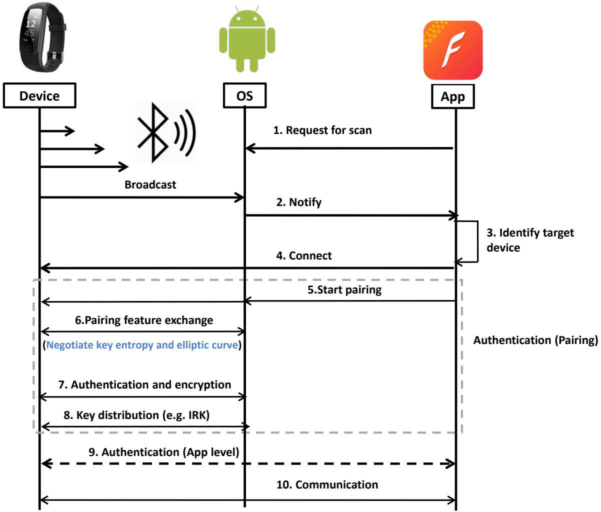

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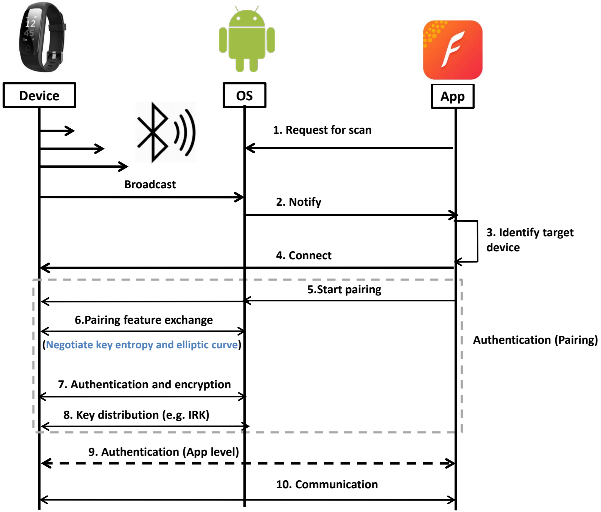
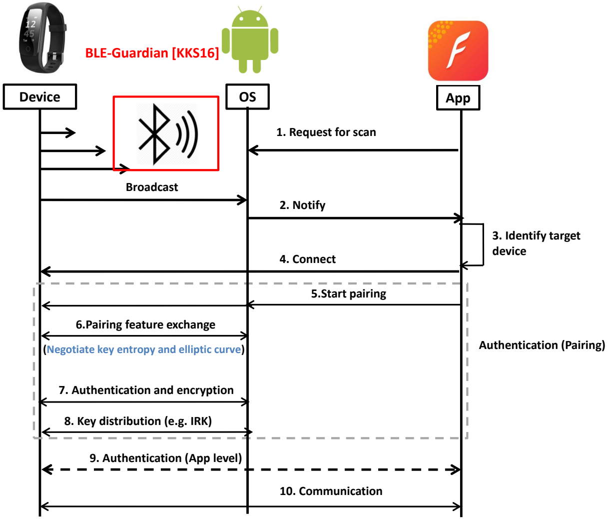


State-of-the-Art

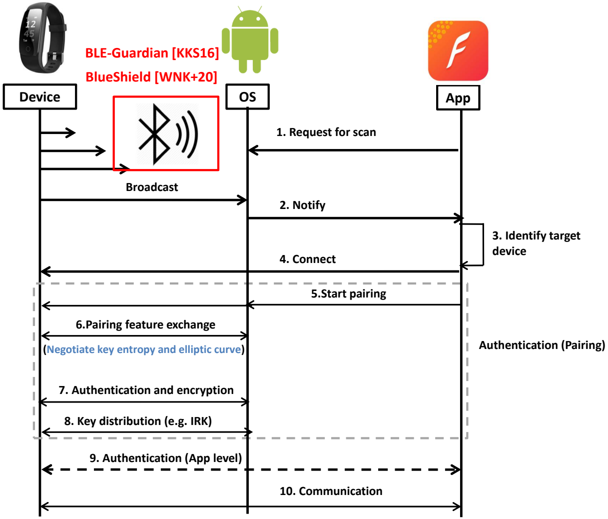


BLE-Guardian [KKS16]

Protecting Privacy of BLE Device Users. In USENIX Security 2016.

- Defending against sensitive information leakage during broadcasting

State-of-the-Art

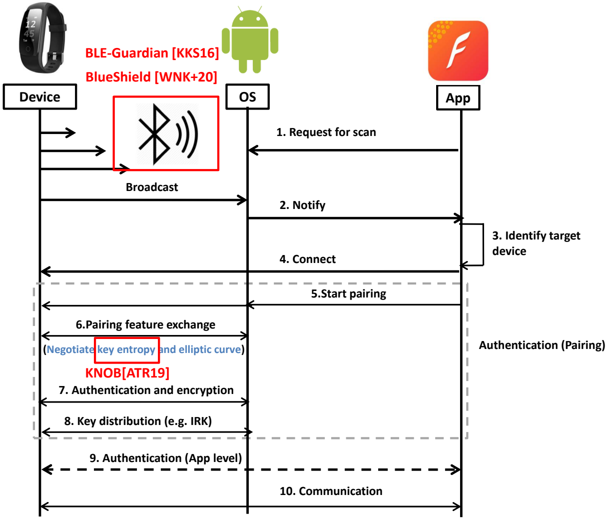


BlueShield [WNK+20a]

BlueShield: Detecting Spoofing Attacks in Bluetooth Low Energy Networks. In RAID 2020.

- Detecting spoofing BLE devices during broadcasting.

State-of-the-Art

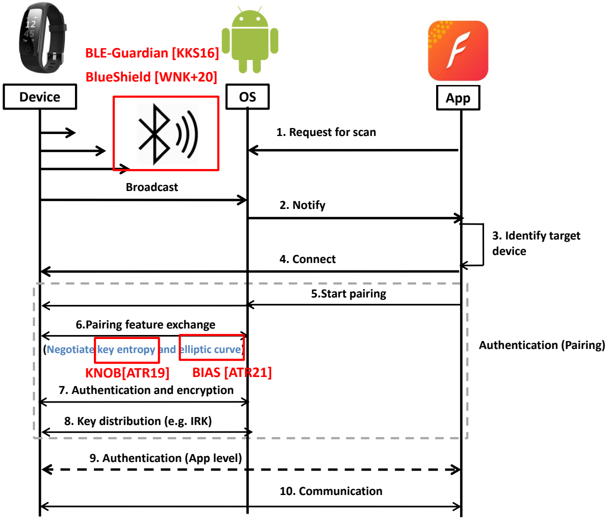


KNOB [ATR19]

The KNOB is Broken: Exploiting Low Entropy in the Encryption Key Negotiation Of Bluetooth BR/EDR. In USENIX Security 2019.

- An attacker forces victims to agree on an encryption key with only one byte of entropy.
- Windows/iOS have fixed it

State-of-the-Art

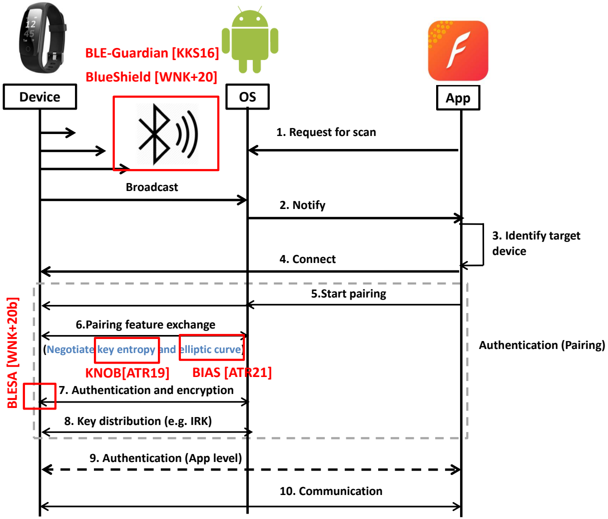


BIAS [ATR20]

BIAS: Bluetooth Impersonation AttackS. In Oakland 2020.

- An attacker forces victims to use P-192 curve instead of using P-256 curve.

State-of-the-Art

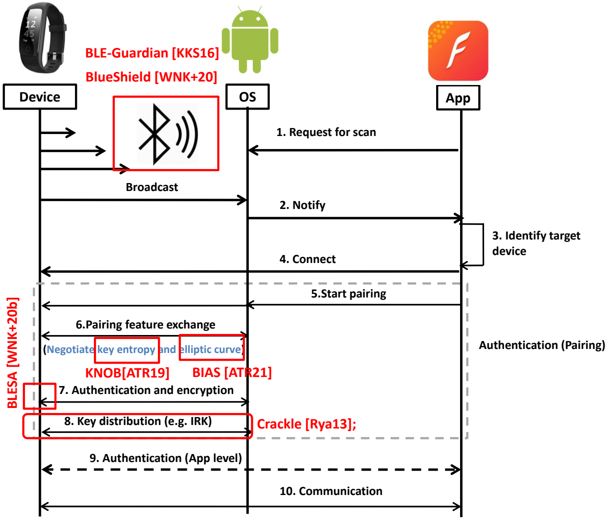


BLESA [WNK+20b]

BIESA: Spoofing Attacks against Reconnections in Bluetooth Low Energy. In WOOT 2020.

- Fake BLE device attacks against mobiles.
- Android and iOS have fixed it

State-of-the-Art

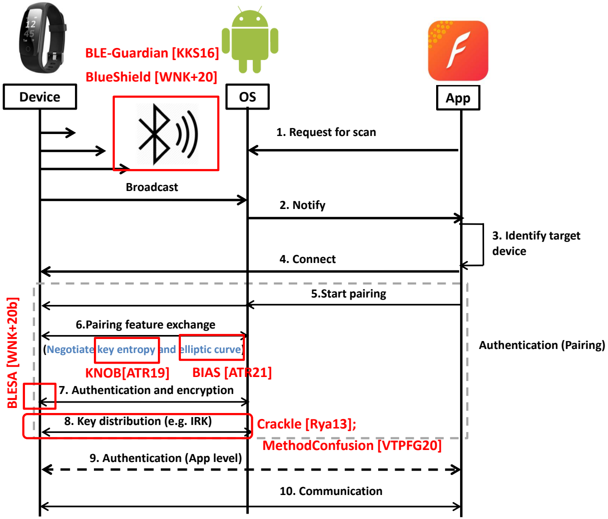


Crackle [Rya13]

With Low Energy Comes Low Security. In WOOT 2013.

- Brute force attacks against long term keys.
- Bluetooth after 4.1 is no longer vulnerable

State-of-the-Art

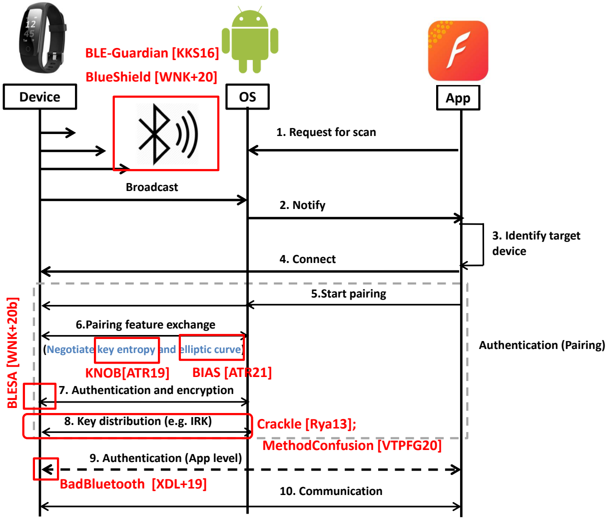


Bluetooth Method Confusion [VTPFG21]

Method Confusion Attack on Bluetooth Pairing. In Oakland 2021

- Man in the middle attack (similar to the active attacks against DH)
- Attackers manipulates the pairing methods and target the ECDH key exchange process.

State-of-the-Art

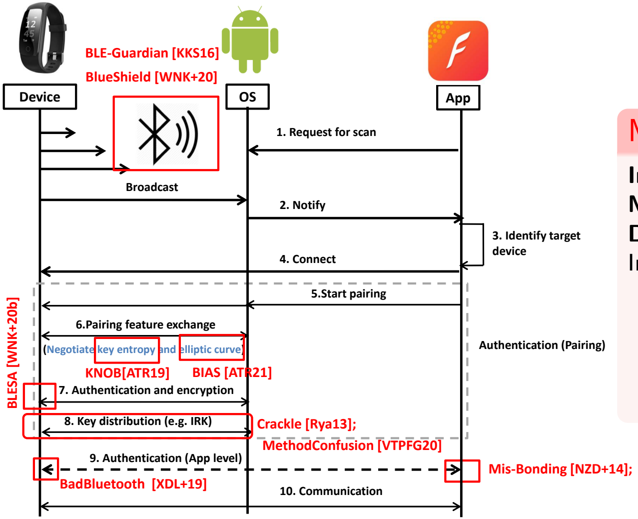


BadBluetooth [XDL+19]

Breaking Android Security Mechanisms via Malicious Bluetooth Peripherals. In NDSS 2019.

- Fake devices manipulate BLE communication due to the lack of app-level authentication.
- Defense is up to the apps

State-of-the-Art

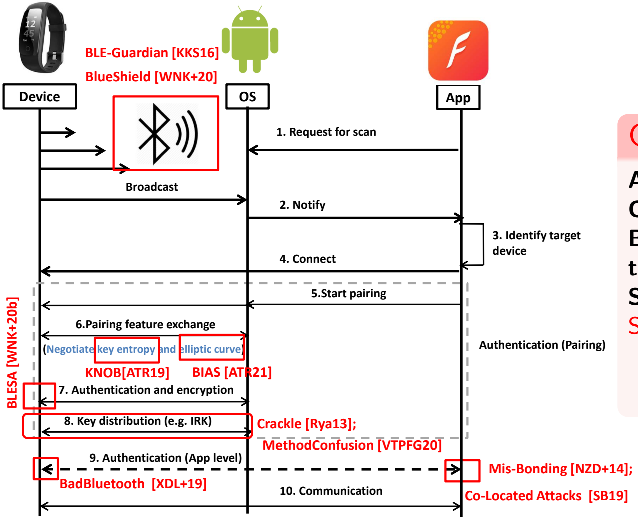


Mis-Bonding [NZD+14]

Inside Job: Understanding and Mitigating the Threat of External Device Mis-Bonding on Android.. In NDSS 2014.

- Malicious apps manipulate BLE communication due to lack of app-level authentication.
- Defense is up to the devices

State-of-the-Art

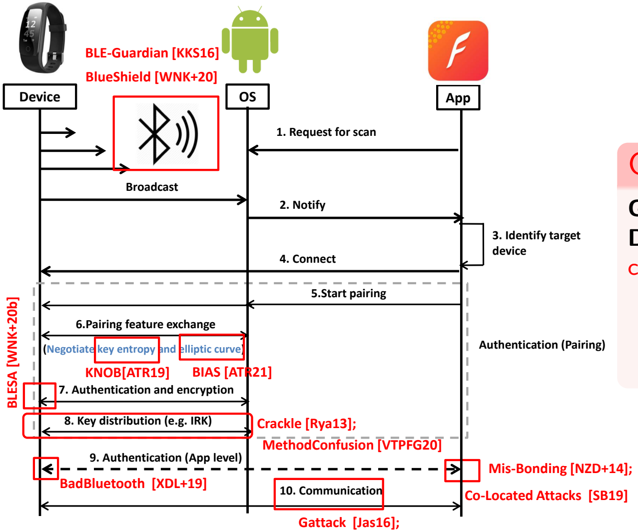


Co-Located Attacks [SB19]

A Study of the Feasibility of Co-located App Attacks against BLE and a Large-Scale Analysis of the Current Application-Layer Security Landscape. In USENIX Security 2019.

- Large-scale analysis of mis-bonding issues.

State-of-the-Art

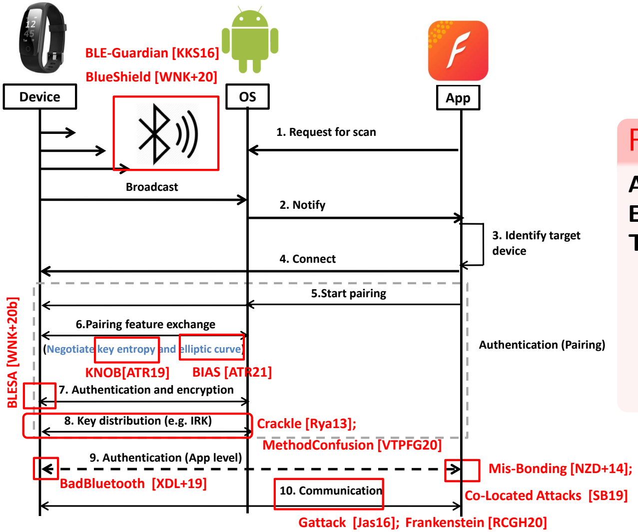


Gattacking [Jas16]

Gattacking Bluetooth Smart Devices. In Black hat USA conference 2016.

- Poorly designed communication protocols are subject to various attacks (e.g., replay attacks).

State-of-the-Art

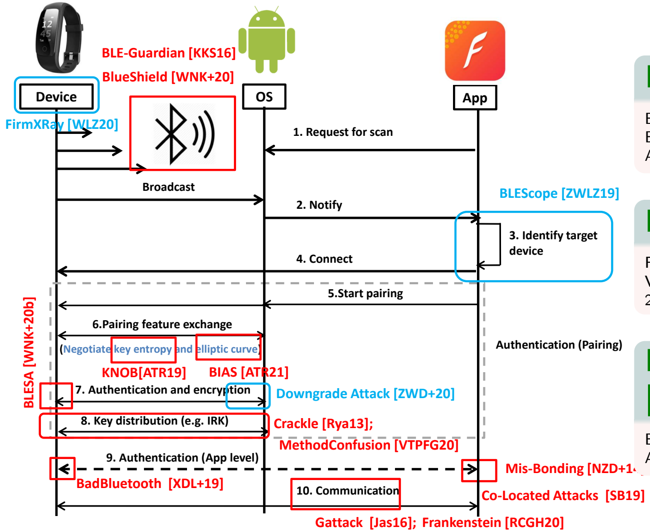


Frankenstein [RCGH20]

Advanced Wireless Fuzzing to Exploit New Bluetooth Escalation Targets. In USENIX Security 2020.

- BLE Fuzzing tool injects HCI traffic or Bluetooth frames into Bluetooth communication in order to uncover Remote Code Execution bugs.

Our Contributions



BLEScope [ZWLZ19]

BLEScope: Automatic Fingerprinting of Vulnerable BLE IoT Devices with Static UUIDs from Mobile Apps. In CCS 2019.

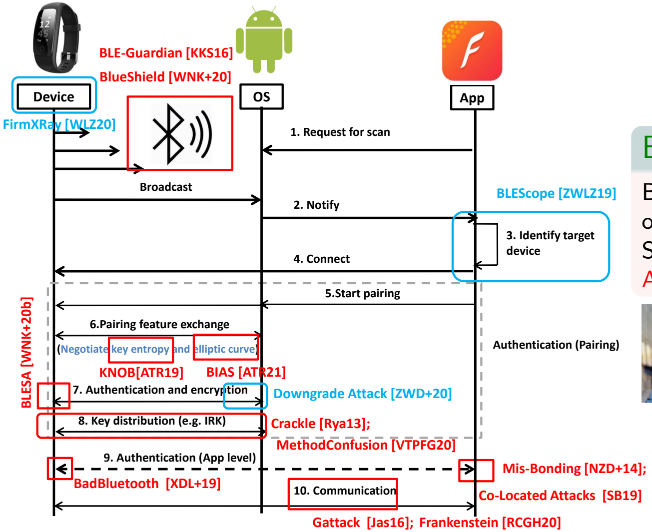
FirmXRay [WLZ20]

FirmXRay: Detecting Bluetooth Link Layer Vulnerabilities From Bare-Metal Firmware. In CCS 2020.

Downgrade Attacks [ZWD+20]

Breaking Secure Pairing of BLE Using Downgrade Attacks. In USENIX Security 2020.

Our BLEScope [ZWLZ19] Work



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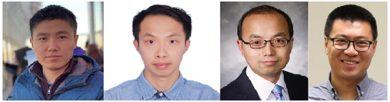
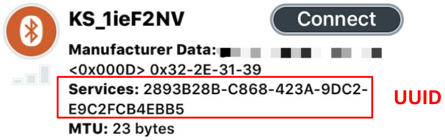
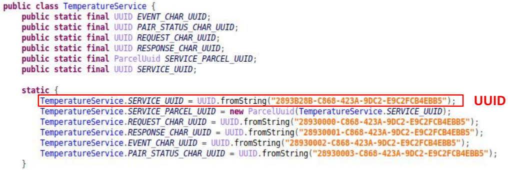


The Key Finding in BLEScope [ZWLZ19]

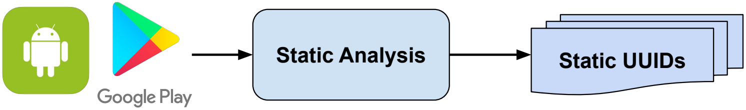




Key Observation

1. UUIDs are broadcasted by BLE IoT devices to nearby phones.
2. UUIDs are static.
3. Mobile apps contain UUIDs.
4. Mobile apps identify target BLE IoT devices based on their broadcasted UUIDs.

Attack: How to Fingerprint a BLE IoT Device with Static UUIDs



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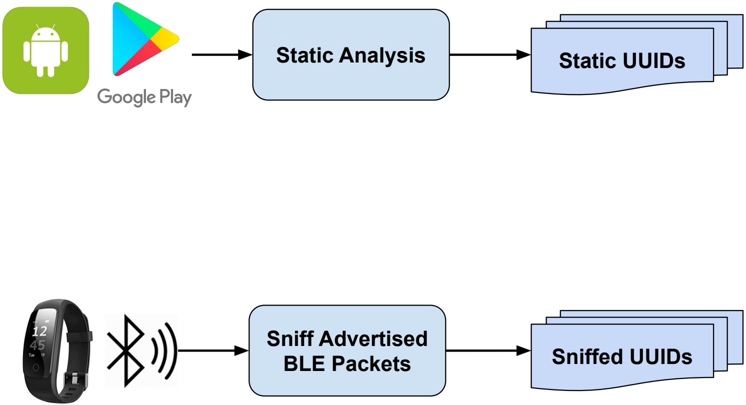

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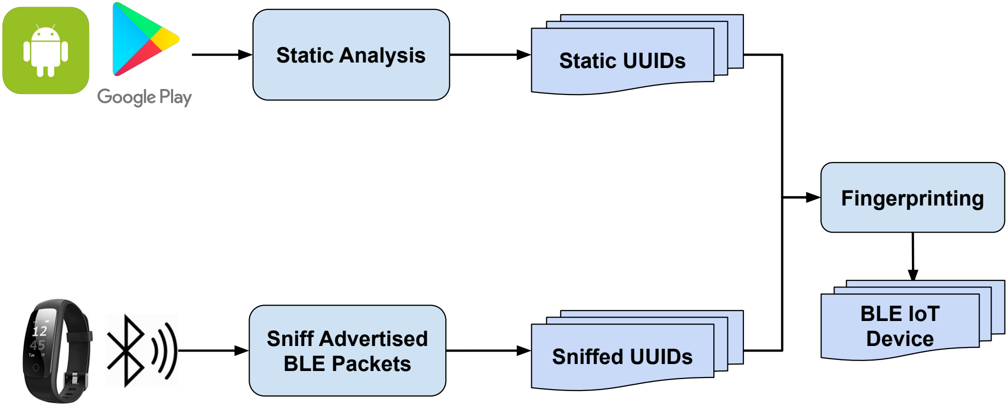

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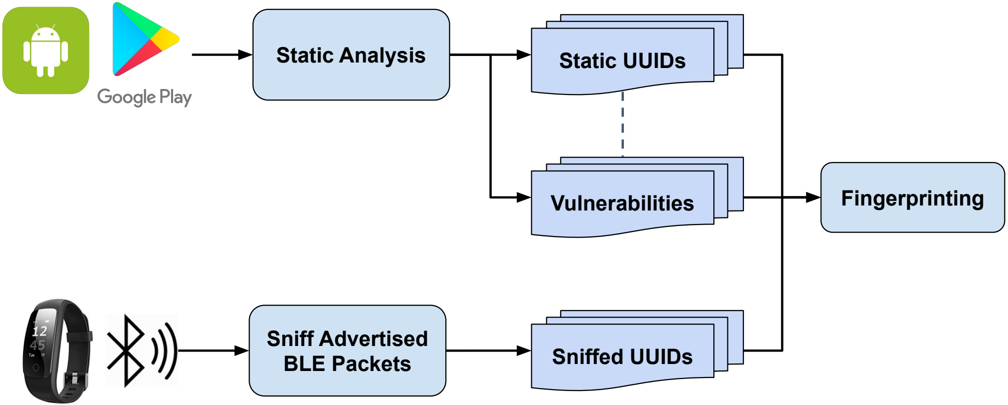

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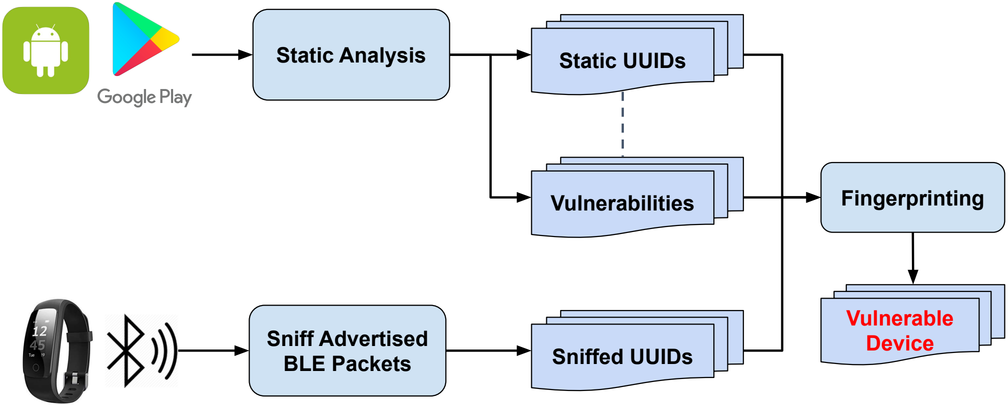


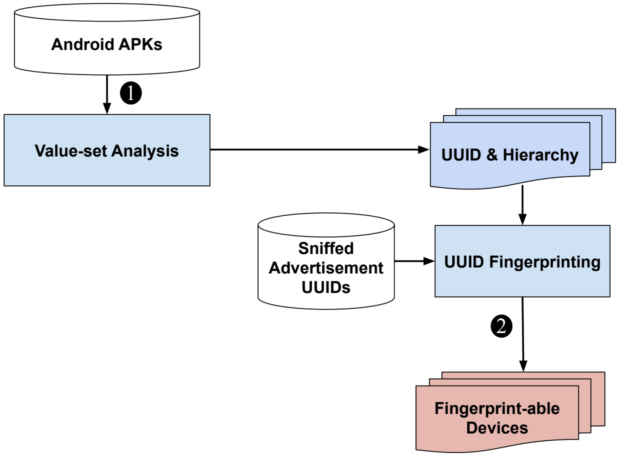
Introducing BLEScope

"**Automatic Fingerprinting of Vulnerable BLE IoT Devices with Static UUIDs from Mobile Apps**". Chaoshun Zuo, Haohuang Wen, Zhiqiang Lin, and Yinqian Zhang. In *Proceedings of the 26th ACM Conference on Computer and Communications Security (CCS'19)*, London, UK. November 2019

1. **Novel Discovery**. We are the *first* to discover BLE IoT devices can be fingerprinted with static UUIDs.
2. **Effective Techniques**. We have implemented an automatic tool BLEScope to harvest UUIDs and detect vulnerabilities from mobile apps.
3. **Evaluation**. We have tested our tool with 18,166 BLE mobile apps from Google Play store, and found 168,093 UUIDs and 1,757 vulnerable BLE IoT apps.
4. **Countermeasures.** We present channel-level protection, app-level protection, and protocol-level protection (with dynamic UUID generation).

Overview of BLEScope

Overview of BLEScope



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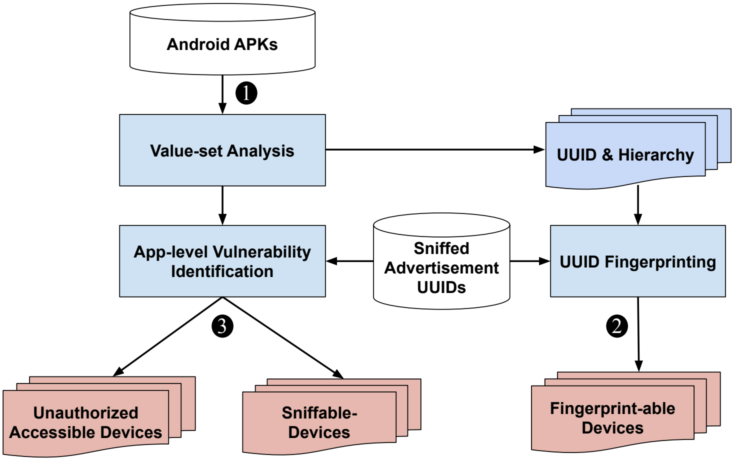

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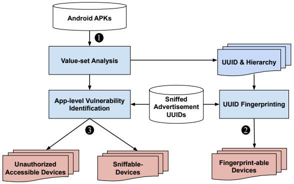

Challenges

1. How to extract UUIDs from mobile apps
2. How to reconstruct UUID hierarchy
3. How to identify flawed vulnerable authentication apps

Solutions: Using **Automated Program Analysis**

1. Resolving UUIDs using context and **value-set analysis**
2. Reconstructing UUID hierarchy with **control dependence**
3. Identifying flawed authentication with **data dependence**

Results from Google Play Store

IoT Mobile App Collection

1. We downloaded 2 million mobile apps from Google Play as of April 2019.
2. We identified BLE IoT apps by searching for after-connection BLE APIs.
3. 18,166 BLE IoT apps are found for our analysis

Results from Google Play Store

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Item	Value	%
# Apps Support BLE	18,166	100.0
# "Just Works" Pairing	11,141	61.3
# Vulnerable Apps	1,757	15.8
# Absent Cryptographic Usage	1,510	13.6
# Flawed Authentication	1,434	12.9

Table: Insecure app identification result.

Results from Google Play Store

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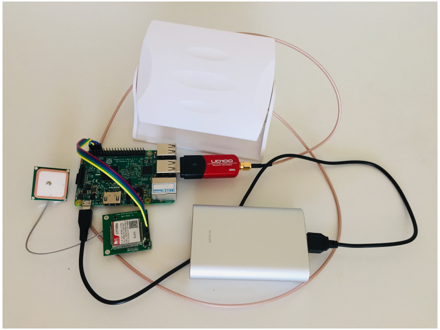
Table: Insecure app identification result.

Category	# App	"Just Works"	Absent Crypto	Flawed Auth.
Health & Fitness	3,849	2,639	221	207
Tools	2,833	1,895	385	362
Lifestyle	2,173	1,081	147	141
Business	1,660	972	90	85
Travel & Local	967	582	90	87

Table: Top 5 category of the IoT apps.

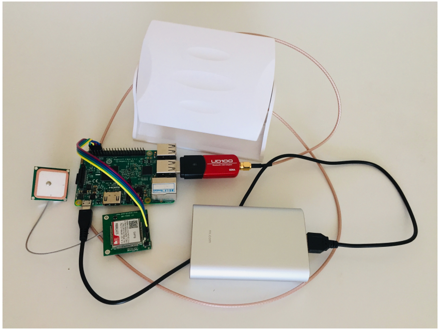
Results from Our Field Test



BLE Sniffer

- Raspberry-Pi
- Parani-UD100 (Bluetooth adapter)
- Antenna RP-SMA-R/A (**1km** range)
- SIM7000A GPS module (GPS sensor)

Results from Our Field Test



Results from Our Field Test

Item	Value	%
# Unique BLE Device	30,862	
# Unique BLE Device w. UUID	5,822	18.9
# Fingerprintable	5,509	94.6
# Vulnerable	431	7.4
# Sniffable	369	6.7
# Unauthorized Accessible	342	6.2

Table: Experimental result of our field test.

Results from Our Field Test

Company Name	# Devices
Google	2,436
Tile, Inc.	441
-	243
-	208
Logitech International SA	131
Nest Labs Inc.	114
Google	92
Hewlett-Packard Company	74
-	46
-	44
-	44

Table: Top 10 devices in the field test.

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Table: Top 10 devices in the field test.

Results from Our Field Test

Device Description	# Device
Digital Thermometer	7
Car Dongle	6
Key Finder A	6
Smart Lamp	5
Key Finder B	5
Smart Toy A	4
Smart VFD	4
Air Condition Sensor	4
Smart Toy B	4
Accessibility Device	4

Table: Top 10 **vulnerable** devices.

Results from Our Field Test

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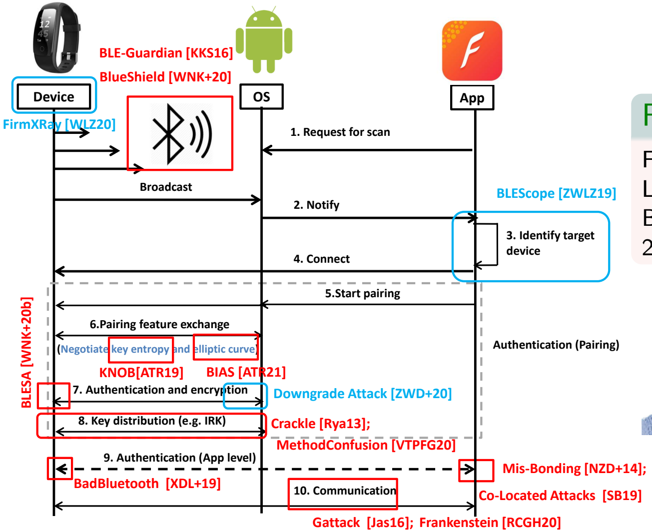
Table: Top 10 **vulnerable** devices.

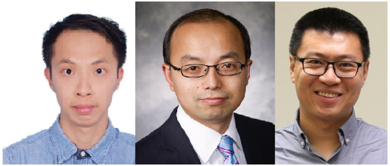
Results from Our Field Test

Our FirmXRay [WLZ20] Work

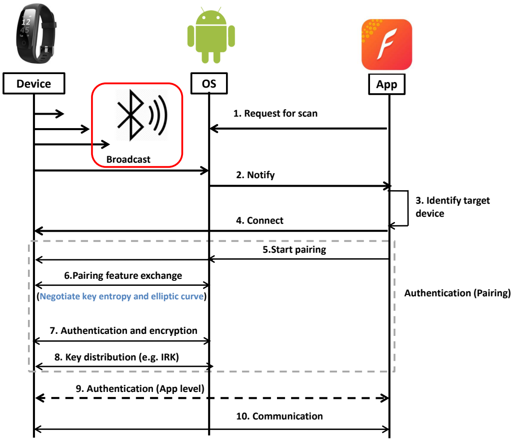


FirmXRay [WLZ20]

FirmXRay: Detecting Bluetooth Link Layer Vulnerabilities From Bare-Metal Firmware. In ACM CCS 2020.



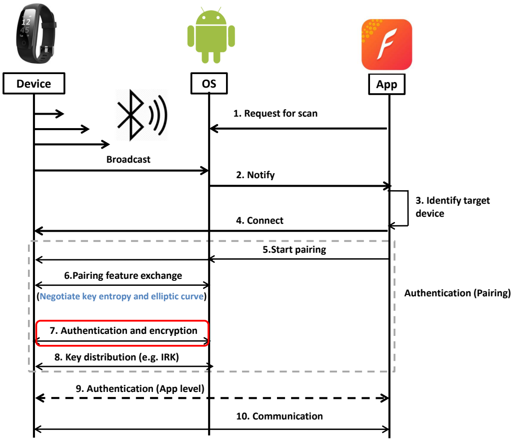
BLE Link Layer Vulnerabilities



Vulnerabilities

1. **Identity Tracking**. Configure static MAC address during broadcast [DPCM16].

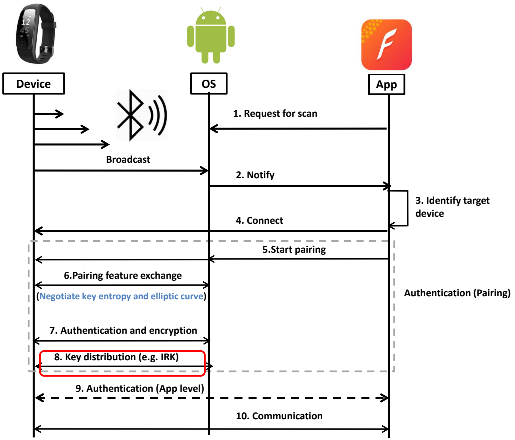
BLE Link Layer Vulnerabilities



Vulnerabilities

1. **Identity Tracking**. Configure static MAC address during broadcast [DPCM16].
2. **Active MITM**. Just Works is adopted as the pairing method.

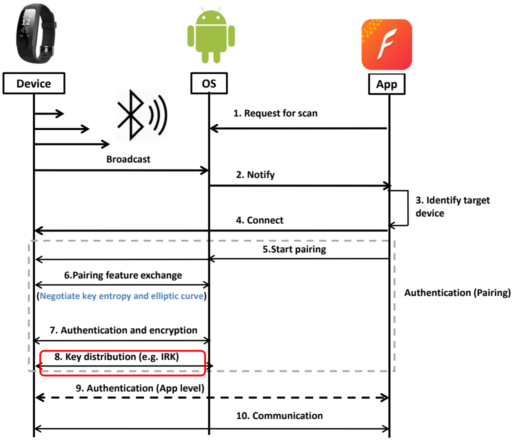
BLE Link Layer Vulnerabilities



Vulnerabilities

1. **Identity Tracking**. Configure static MAC address during broadcast [DPCM16].
2. **Active MITM**. Just Works is adopted as the pairing method.
3. **Passive MITM**. Legacy pairing is used during key exchange [ble14].

BLE Link Layer Vulnerabilities



Vulnerabilities

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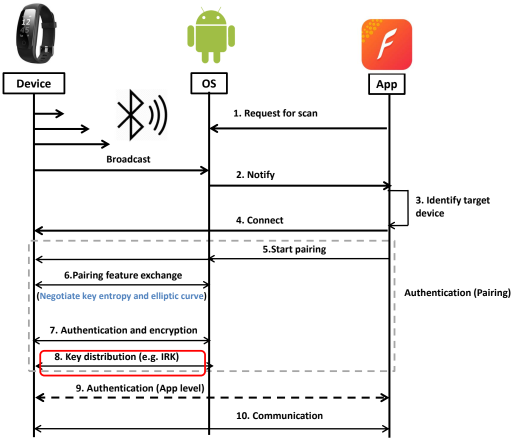
Identification

1. Traffic analysis
2. Mobile app analysis

BLE Link Layer Vulnerabilities



Vulnerabilities

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2. **Active MITM**. Just Works is adopted as the pairing method.
3. **Passive MITM**. Legacy pairing is used during key exchange [ble14].

Identification

1. Traffic analysis
2. Mobile app analysis
3. Firmware analysis

An Example of a Just Works Pairing Vulnerability

Read Only Memory

```
1  243a8   mov   r2, #0x0
2  243aa   orr   r2, #0x1
3  243ac   and   r2, #0xe1
4  243ae   add   r2, #0xc
5  243b0   and   r2, #0xdf
6  243b2   ldr   r1, [0x260c8]
7  243b4   str   r2, [r1,#0x0]
...
8  25f44   ldr   r2, [0x260c8]
9  25f46   mov   r1, #0x0
10 25f48   svc   0x7f
// SD_BLE_GAP_SEC_PARAMS_REPLY
...
11 260c8   0x20003268
           // ble_gap_sec_parms_t*
```

Register Values

```
r1 = 0x0
r2 = 0x0
```

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Register Values

```
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r2 = 0xD
```

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260c8   0x20003268
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```

Random Access Memory

Struct ble_gap_sec_params_t

```
20003268   uint8 pairing_feature

20003269   uint8 min_key_size
20003270   uint8 max_key_size
20003271   ble_gap_sec_kdist_t  kdist_own
20003275   ble_gap_sec_kdist_t  kdist_peer
```

Register Values

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           // IO   = 3, OOB  = 0
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An Example of a Just Works Pairing Vulnerability

Correct Firmware Disassembling

Read Only Memory

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Recognize data structures

Random Access Memory

Struct ble_gap_sec_params_t

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Register Values

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An Example of a Just Works Pairing Vulnerability

Correct Firmware Disassembling | Recognize data structures | Value computation

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Register Values

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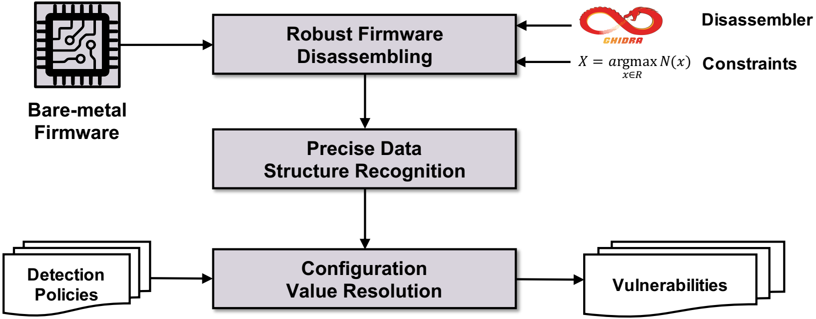
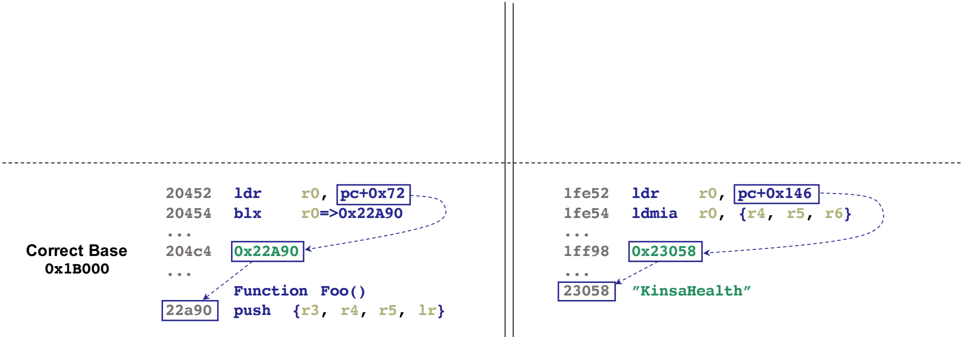
FirmXRay Overview



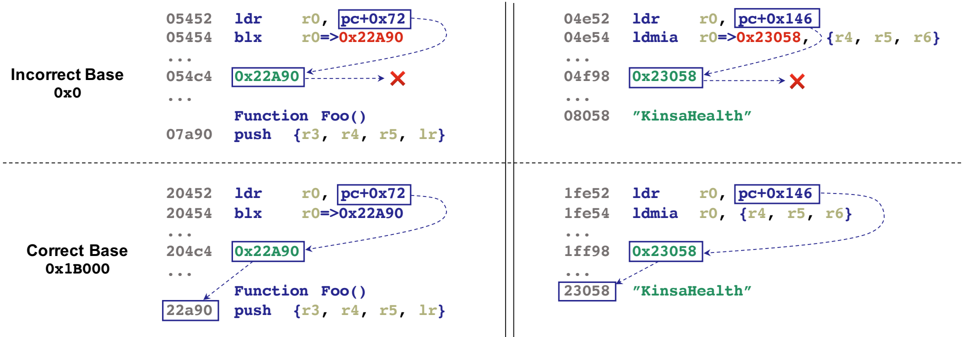
Robust Firmware Disassembling



(1) Absolute Function Pointer

(2) Absolute String Pointer

Robust Firmware Disassembling



(1) Absolute Function Pointer

(2) Absolute String Pointer

Robust Firmware Disassembling

Base
0x0

```
05452  ldr    r0, pc+0x72
05454  blx    r0=>0x22A90
...
054c4  0x22A90
...
       Function Foo()
07a90  push   {r3, r4, r5, lr}
```

```
04e52  ldr    r0, pc+0x146
04e54  ldmia  r0=>0x23058, {r4, r5, r6}
...
04f98  0x23058
...
08058  "KinsaHealth"
```

Robust Firmware Disassembling

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0x0

```
05452  ldr      r0, pc+0x72
05454  blx      r0=>0x22A90
...
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```

```
04e52  ldr      r0, pc+0x146
04e54  ldmia    r0=>0x23058, {r4, r5, r6}
...
04f98  0x23058
...
08058  "KinsaHealth"
```

Absolute Pointers: 0x22A90, 0x23058

Gadgets: 0x07A90, 0x08058

Robust Firmware Disassembling

Base
0x0

```
05452   ldr    r0, pc+0x72
05454   blx    r0=>0x22A90
...
054c4   0x22A90
...
        Function Foo()
07a90   push   {r3, r4, r5, lr}
```

```
04e52   ldr    r0, pc+0x146
04e54   ldmia  r0=>0x23058, {r4, r5, r6}
...
04f98   0x23058
...
08058   "KinsaHealth"
```

Absolute Pointers: 0x22A90, 0x23058

Gadgets: 0x07A90, 0x08058

N(0x1B000) = 2

Robust Firmware Disassembling

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0x0

```
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...
08058  "KinsaHealth"
```

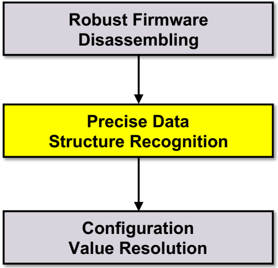
Absolute Pointers: 0x22A90, 0x23058

Gadgets: 0x07A90, 0x08058

0x1B000 = 0x22A90 − 0x07A90
= 0x23058 − 0x08058

N(0x1B000) = 2

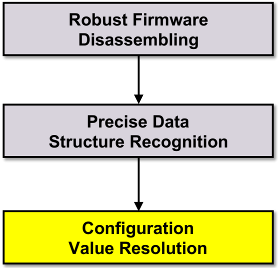
Precise Data Structure Recognition



Read Only Memory

```
243a8   mov   r2, #0x0
243aa   orr   r2, #0x1
243ac   and   r2, #0xe1
243ae   add   r2, #0xc
243b0   and   r2, #0xdf
243b2   ldr   r1, [0x260c8]
243b4   str   r2, [r1,#0x0]
...
25f44   ldr   r2, [0x260c8]
25f46   mov   r1, #0x0
25f48   svc   0x7f
// SD_BLE_GAP_SEC_PARAMS_REPLY(r0, r1, r2)
...
260c8   0x20003268
        // ble_gap_sec_parms_t*
```

Configuration Value Resolution

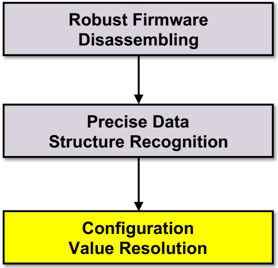


Read Only Memory

```
1  243a8   mov   r2, #0x0
2  243aa   orr   r2, #0x1
3  243ac   and   r2, #0xe1
4  243ae   add   r2, #0xc
5  243b0   and   r2, #0xdf
6  243b2   ldr   r1, [0x260c8]
7  243b4   str   r2, [r1,#0x0]
...
8  25f44   ldr   r2, [0x260c8]
9  25f46   mov   r1, #0x0
10 25f48   svc   0x7f
// SD_BLE_GAP_SEC_PARAMS_REPLY
...
11 260c8   0x20003268
           // ble_gap_sec_parms_t*
```

Program Path

Configuration Value Resolution



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25f48   svc   0x7f
// SD_BLE_GAP_SEC_PARAMS_REPLY
...
260c8   0x20003268
        // ble_gap_sec_parms_t*
```
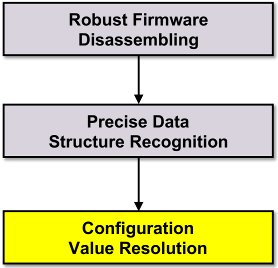

Program Path

```
ldr r2, [0x260c8]
str r2, [r1, #0x0]
```

Configuration Value Resolution



Read Only Memory

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// SD_BLE_GAP_SEC_PARAMS_REPLY
...
11 260c8   0x20003268
           // ble_gap_sec_parms_t*
```

Program Path

```
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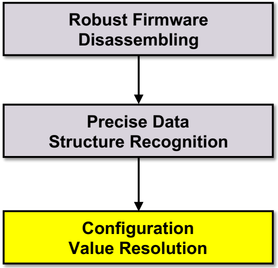
str r2, [r1, #0x0]
ldr r1, [0x260c8]
and r2, #0xdf
add r2, #0xc
and r2, #0xe1
orr r2, #0x1
mov r2, #0x0
```

Configuration Value Resolution



Read Only Memory

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// SD_BLE_GAP_SEC_PARAMS_REPLY
...
260c8    0x20003268
         // ble_gap_sec_parms_t*
```
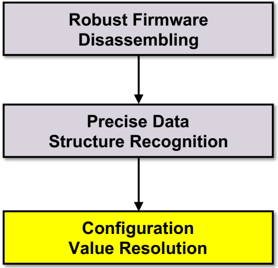

Program Path

```
ldr r2, [0x260c8]
str r2, [r1, #0x0]
ldr r1, [0x260c8]
and r2, #0xdf
add r2, #0xc
and r2, #0xe1
orr r2, #0x1
mov r2, #0x0
```

r2 = 0x20003268

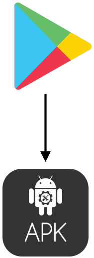
Configuration Value Resolution



Policy	SDK Function Name	Reg. Index	Description
(i)	SD_BLE_GAP_ADDR_SET	0	Configure the MAC address
	SD_BLE_GAP_APPEARANCE_SET	0	Set device description
	SD_BLE_GATTS_SERVICE_ADD	0, 1	Add a BLE GATT service
	SD_BLE_GATTS_CHARACTERISTIC_ADD	2	Add a BLE GATT characteristic
	SD_BLE_UUID_VS_ADD	0	Specify the UUID base
	GAP_ConfigDeviceAddr*	0	Setup the address type
	GATTServApp_RegisterService*	0	Register BLE GATT service
(ii)	SD_BLE_GAP_SEC_PARAMS_REPLY	2	Reply peripheral pairing features
	SD_BLE_GAP_AUTH	1	Reply central pairing features
	SD_BLE_GAP_AUTH_KEY_REPLY	1, 2	Reply with an authentication key
	SD_BLE_GATTS_CHARACTERISTIC_ADD	2	Add a BLE GATT characteristic
	GAPBondMgr_SetParameter*	2	Setup pairing parameters
	GATTServApp_RegisterService*	0	Register BLE GATT service
(iii)	SD_BLE_GAP_LESC_DHKEY_REPLY	0	Reply with a DH key
	GAPBondMgr_SetParameter*	2	Setup pairing parameters

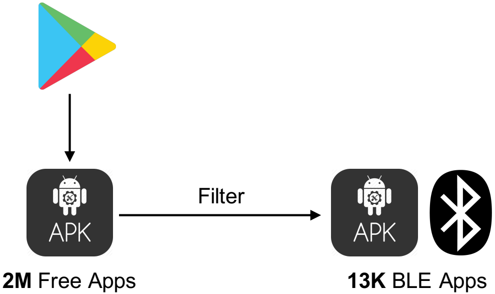
Firmware Collection

Firmware Collection

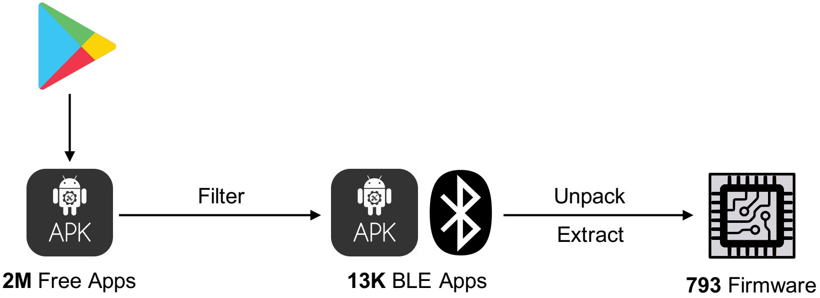


2M Free Apps

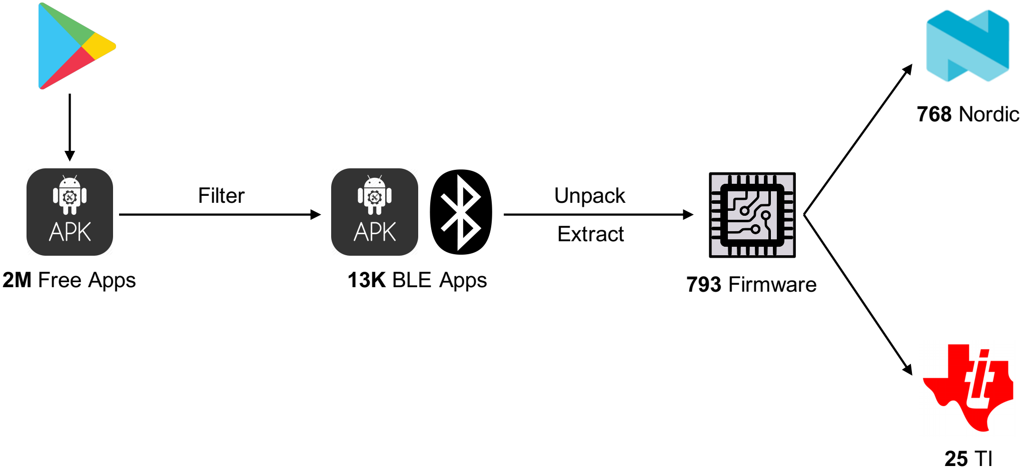
Firmware Collection



Firmware Collection



Firmware Collection



Firmware Categorization

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Category	# Firmware	# Device	Avg. Size (KB)
Nordic-based Firmware			
Wearable	204	138	98.2
Others	76	22	223.5
Sensor	67	51	80.9
Tag (Tracker)	58	41	84.2
Robot	41	21	117.7
Medical Devices	41	21	138.6
TI-based Firmware			
Sensor	19	19	132.9
Smart Lock	2	2	46.3
Smart Toy	2	2	47.8
Medical Devices	1	1	70.2
Others	1	1	76.7
Total	793	538	102.7

Table: Top categories of firmware.

Firmware Categorization

- Firmware categorization
  - Descriptive APIs (e.g., SD_BLE_GAP_APPEARANCE_SET)
  - Mobile app descriptions
- Firmware aggregation
  - Aggregate different versions of firmware of the same device
  - The 793 firmware represent 538 real devices

Category	# Firmware	# Device	Avg. Size (KB)
Nordic-based Firmware			
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Identity Tracking Vulnerability Identification

Among the 538 devices, nearly all of them (98.1%) have configured random static addresses that do not change periodically.

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Firmware Name	Mobile App	Category	# Device
cogobeacon	com.aegismobility.guardian	Car Accessory	4
sd_bl	fr.solem.solemwf	Agricultural Equip.	2
LRFL_nRF52	fr.solem.solemwf	Agricultural Equip.	2
orb	one.shade.app	Smart Light	1
sd_bl	com.rainbird	Agricultural Equip.	1

Table: Firmware using private MAC address.

Experiment Results

Active MITM Vulnerability Identification

385 (71.5%) devices use Just Works pairing, which essentially does not provide any protection against active MITM attacks at the BLE link layer.

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Item	N	T	Total	%
# Total Device	513	25	538	100
# Device w/ active MITM vulnerability	384	1	385	71.5
# Device w/ Just Works pairing only	317	1	318	59.1
# Device w/ flawed Passkey implementation	37	0	37	6.9
# Device w/ flawed OOB implementation	30	0	30	5.6
# Device w/ secure pairing	6	24	30	3.8
# Device w/ correct Passkey implementation	3	24	27	3.4
# Device w/ correct OOB implementation	3	0	3	0.4

Table: Pairing configurations of devices (N:Nordic, T:TI).

Experiment Results

Passive MITM Vulnerability Identification

98.5% of the devices fail to enforce LESC pairing, and thus they can be vulnerable to passive MITM attacks if there is no application-layer encryption.

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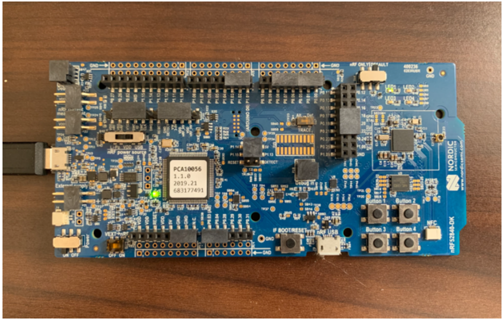
Firmware Name	**Mobile App**	**Category**	**# Version**
DogBodyBoard	com.wowwee.chip	Robot	16
BW_Pro	com.ecomm.smart_panel	Tag	1
Smart_Handle	com.exitec.smartlock	Smart Lock	1
Sma05	com.smalife.watch	Wearable	1
CPRmeter	com.laerdal.cprmeter2	Medical Device	4
WiJumpLE	com.wesssrl.wijumple	Sensor	1
nRF Beacon	no.nordicsemi.android.nrfbeacon	Beacon	1
Hoot Bank	com.qvivr.hoot	Debit Card	1

Table: Firmware that enforce LESC pairing.

Attack Case Studies



nRF52840 DK

Vulnerable BLE Devices

Attack Case Studies

Device Name	Category	Attacks		
		A1	A2	A3
Nuband Activ+	Wearable	✓		✓
Kinsa Smart	Thermometer			✓
Chipolo ONE	Tag	✓		
SwitchBot Button Pusher	Smart Home		✓	
XOSS Cycling Computer	Sensor	✓		✓

A1: User Tracking

Attack Case Studies

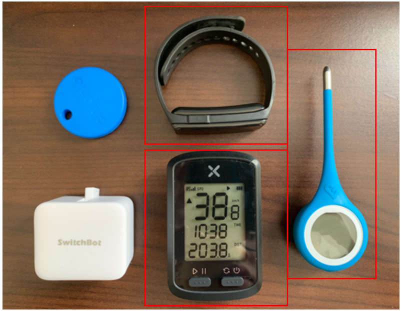
Device Name	Category	Attacks		
		A1	A2	A3
Nuband Activ+	Wearable	✓		✓
Kinsa Smart	Thermometer			✓
Chipolo ONE	Tag	✓		
SwitchBot Button Pusher	Smart Home		✓	
XOSS Cycling Computer	Sensor	✓		✓

A2: Unauthorized Control

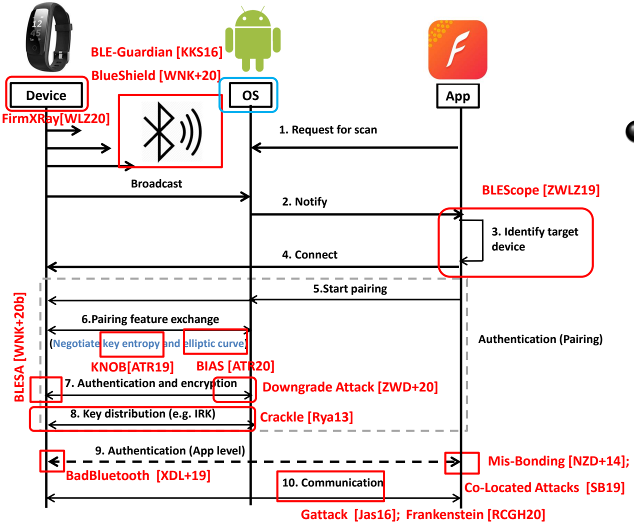
Attack Case Studies

Device Name	Category	Attacks		
		A1	A2	A3
Nuband Activ+	Wearable	✓		✓
Kinsa Smart	Thermometer			✓
Chipolo ONE	Tag	✓		
SwitchBot Button Pusher	Smart Home		✓	
XOSS Cycling Computer	Sensor	✓		✓

A3: Sensitive Data Eavesdropping

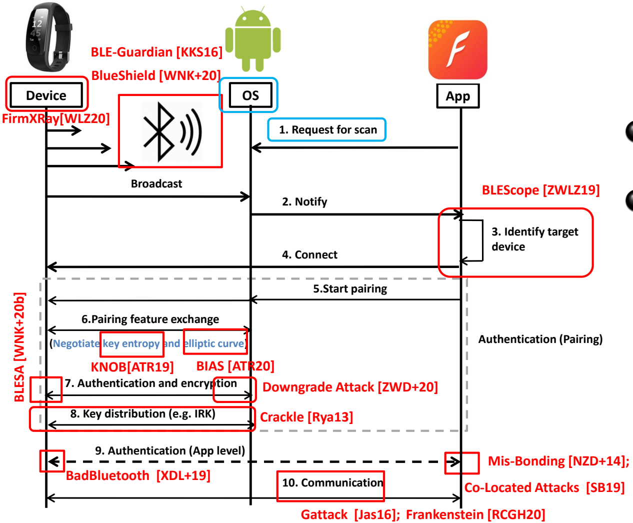


Near Term



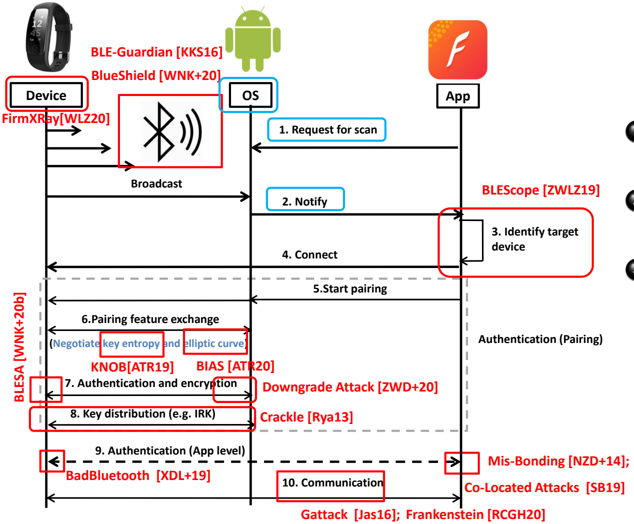
1. **OS Defense:** OS-level defense to patch multiple security issues.

Near Term



1. **OS Defense:** OS-level defense to patch multiple security issues.
2. **Scanning Defense:** Defending against malicious scanning.

Near Term



1. **OS Defense:** OS-level defense to patch multiple security issues.
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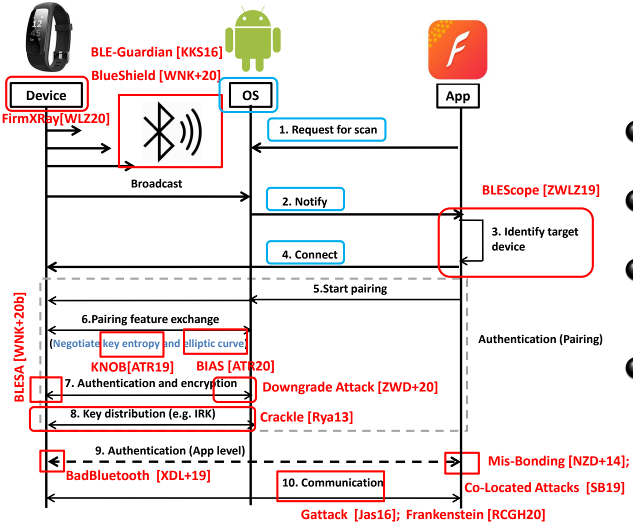
3. **Notification Fingerprinting:** Exploring notification fingerprinting against BLE devices.

Near Term



1. **OS Defense:** OS-level defense to patch multiple security issues.
2. **Scanning Defense:** Defending against malicious scanning.
3. **Notification Fingerprinting:** Exploring notification fingerprinting against BLE devices.
4. **Connection Security:** Exploring a defense for jamming attacks.

Other Directions

1. **Other New Security Features.** New security features (e.g., Cross-Transport Key Derivation) are keeping introducing, bringing new security attack surfaces.
2. **Privacy-preserving Protocols**. BLE Privacy-preserving protocols such as identity resolution protocol may be vulnerable, and further understanding is needed.

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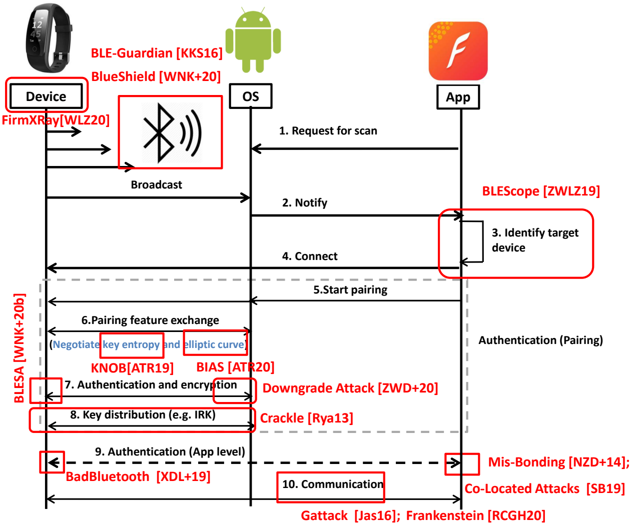
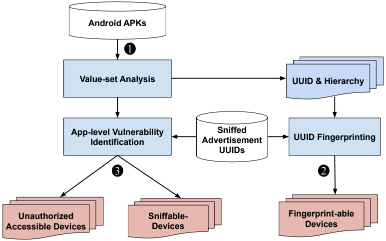
Recent Papers of Bluetooth Research with COVID-19

1. Qingchuan Zhao, Haohuang Wen, Zhiqiang Lin, Dong Xuan, and Ness Shroff. **On the Accuracy of Measured Distances of Bluetooth-based Contact Tracing** (short paper). In SECURECOMM'20, October 2020.
2. Haohuang Wen, Qingchuan Zhao, Zhiqiang Lin, Dong Xuan, and Ness Shroff. **A Study of the Privacy of COVID-19 Contact Tracing Apps**. In SECURECOMM'20, October 2020.

The Landscape of Bluetooth Security and Privacy



BLEScope [CCS 2019]



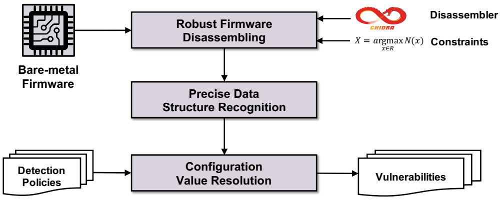
BLEScope

- Automatic UUID extraction and hierarchy reconstruction from mobile apps
- Identify app-level vulnerabilities by directly analyzing mobile apps

App Analysis and Field Test Result

- We analyzed 18,166 apps and discovered 168,093 UUIDs and 1,757 vulnerable apps
- 5,822 BLE devices were discovered in the field test, and 94.6% can be fingerprinted

FirmXRay [CCS 2020]

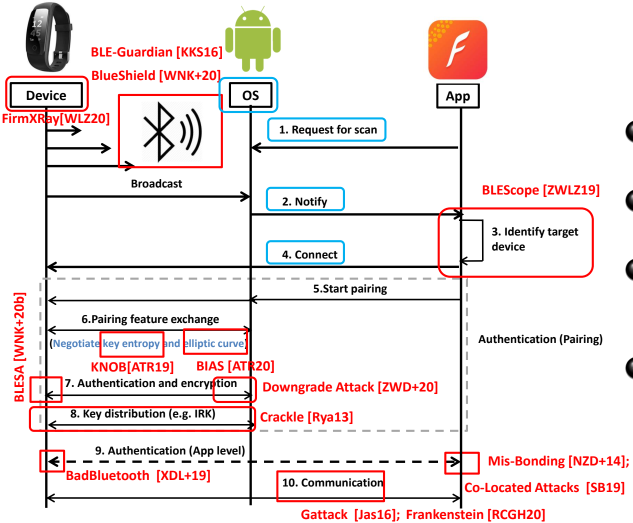


BLEScope

- A static analysis tool based on Ghidra for detecting BLE link layer vulnerabilities from bare-metal firmware.
- A scalable approach to efficiently collect bare-metal firmware images from only mobile apps.
- Vulnerability discovery and attack case studies.

The source code is available at https://github.com/OSUSecLab/FirmXRay.

Future Directions



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Thank You

Uncovering Vulnerabilities in Bluetooth Devices with Automated Binary Analysis

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03/26/2021

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Chaoshun Zuo, Haohuang Wen, Zhiqiang Lin, and Yinqian Zhang, *Automatic fingerprinting of vulnerable ble iot devices with static uuids from mobile apps*, Proceedings of the 2019 ACM SIGSAC Conference on Computer and Communications Security, 2019, pp. 1469–1483.