Rethinking the Security and Privacy of Bluetooth Low Energy

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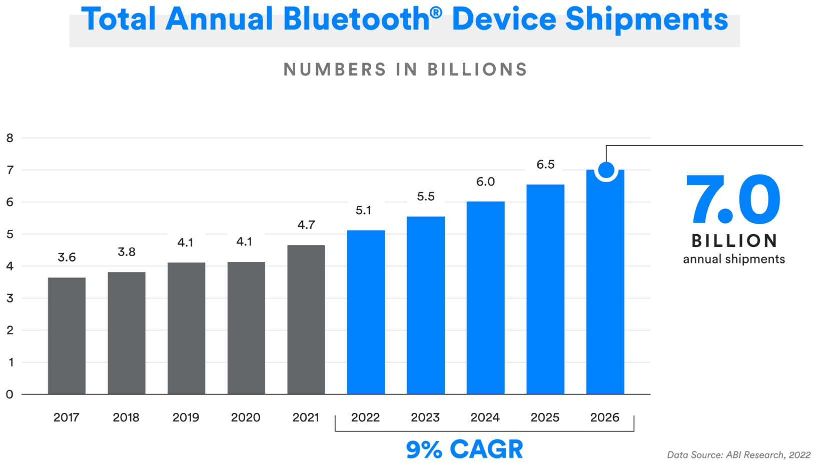
What is Bluetooth

What is Bluetooth



Total Annual Bluetooth® Device Shipments

NUMBERS IN BILLIONS

7.0 BILLION annual shipments

9% CAGR

Data Source: ABI Research, 2022

Why Named Bluetooth

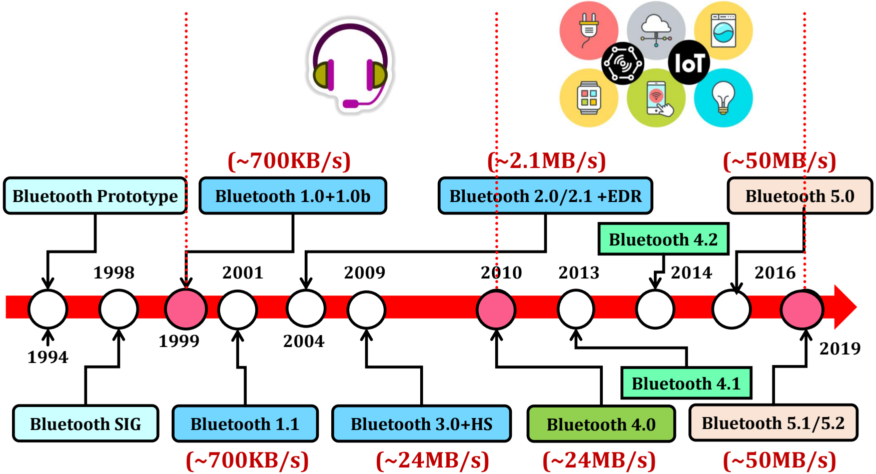
Harald “Bluetooth” Gormsson

- 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.

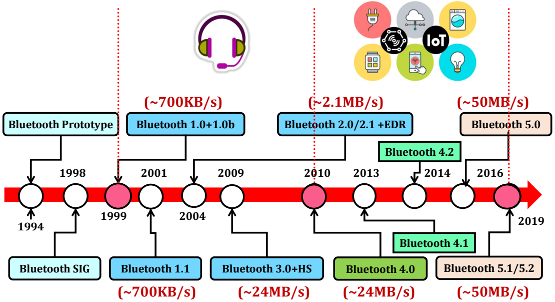
The technology was named after the king in 1997, based on an analogy **that the technology would unite devices the way Harald Bluetooth united the tribes of Denmark into a single kingdom**.

SAMI (LAPPS)
Halogaland
KVENLAND
JAMTLAND
FINNS
Trondelag
FAEROES
NORWAY
SHETLANDS
Halsingland
Vik
Rogaland
SWEDEN
LIVONIA
HEBRIDES
ORKNEYS
Gotaland
Agder
Smaland
KURLAND
SCOTLAND
Halland
LETTLAND
Scania
Jutland
DENMARK
Bornholm
Sjaelland
SAMLAND
Haithabu
Jomsborg (?)
WENDLAND
ENGLAND
POLES
HOLY ROMAN EMPIRE
NORMANDY
FRANCE
MAGYARS

History of Bluetooth



Our Recent Works on Bluetooth Security and Privacy



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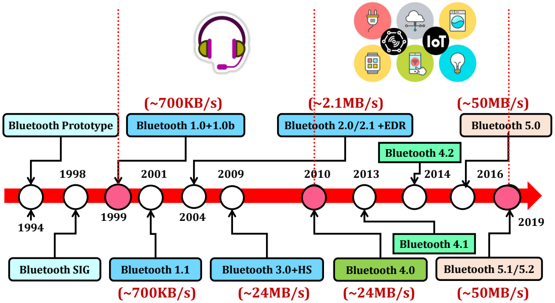

Bluetooth Prototype

1994

Bluetooth SIG

1998

1999

Bluetooth 1.0+1.0b (~700KB/s)

2001

Bluetooth 1.1 (~700KB/s)

2004

Bluetooth 2.0/2.1 +EDR (~2.1MB/s)

2009

Bluetooth 3.0+HS (~24MB/s)

2010

Bluetooth 4.0 (~24MB/s)

2013

Bluetooth 4.1

2014

Bluetooth 4.2

2016

Bluetooth 5.0 (~50MB/s)

2019

Bluetooth 5.1/5.2 (~50MB/s)

1. **BLEScope: Automatic Fingerprinting of Vulnerable BLE IoT Devices with Static UUIDs from Mobile Apps**. In ACM CCS 2019
2. **FirmXRay: Detecting Bluetooth Link Layer Vulnerabilities From Bare-Metal Firmware**. In ACM CCS 2020.
3. **Breaking Secure Pairing of Bluetooth Low Energy in Mobile Devices Using Downgrade Attacks**. In USENIX Security 2020
4. **On the Accuracy of Measured Proximity of Bluetooth-based Contact Tracing Apps**. In SECURECOMM. October 2020
5. **When Good Becomes Evil: Tracking Bluetooth Low Energy Devices via Allowlist-based Side Channel and Its Countermeasure"**. In ACM CCS 2022 (Best paper award honorable mention)
6. **Extrapolating Formal Analysis to Uncover Attacks in Bluetooth Passkey Entry Pairing**. In NDSS 2023

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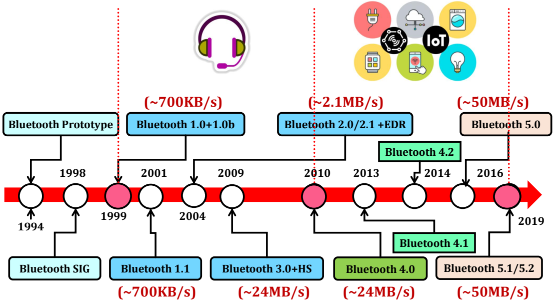

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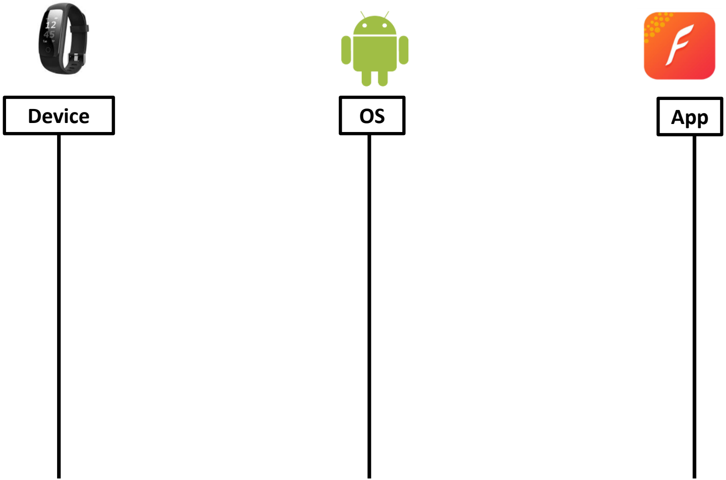
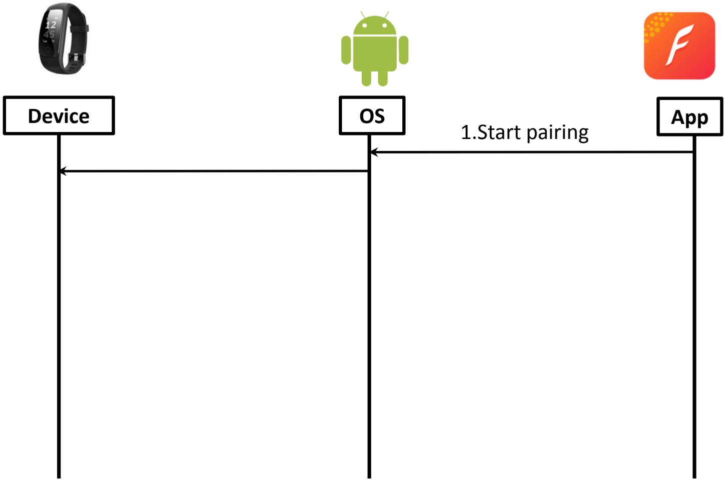
Pairing Workflow



Pairing Workflow



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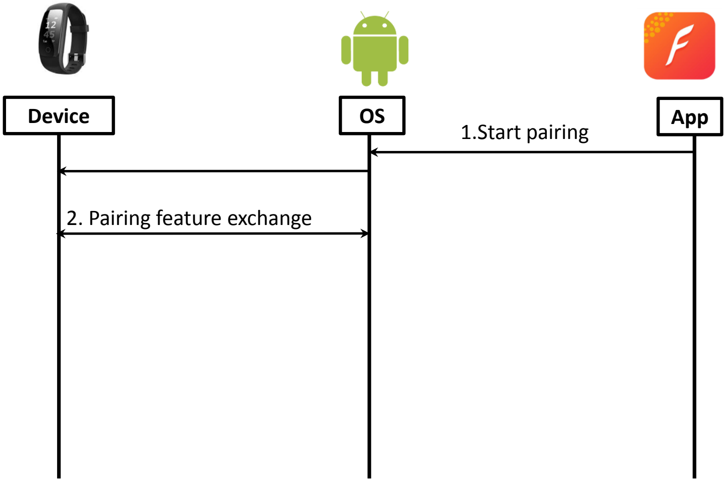
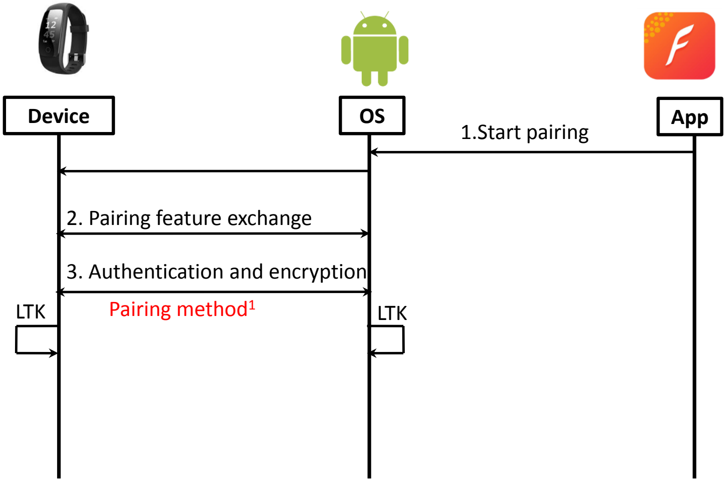


I/O Features

- Keypad
- Screen
- Out of band Channel

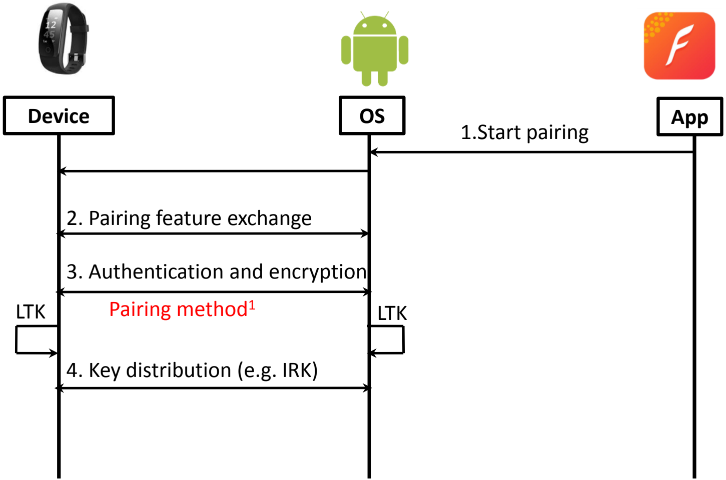
Pairing Workflow



Pairing Methods

- Just Works
- Passkey Entry
- Out of band
- Numeric Comparison

Pairing Workflow


Device
OS
App
1.Start pairing
2. Pairing feature exchange
3. Authentication and encryption
Pairing method[1]
LTK
LTK
4. Key distribution (e.g. IRK)

Pairing Methods

- Just Works
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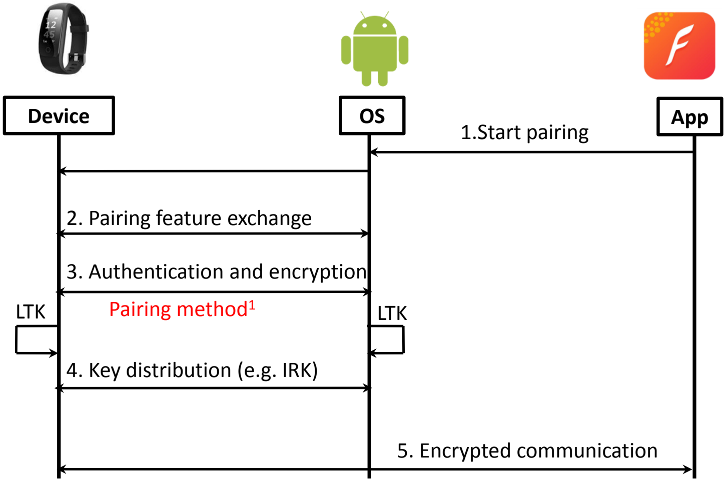
Pairing Workflow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App
1.Start pairing
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3. Authentication and encryption
Pairing method[1]
LTK
LTK
4. Key distribution (e.g. IRK)
5. Encrypted communication

Pairing Methods

- Just Works
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Workflow of Pairing: Elliptic Curve Diffie–Hellman (**ECDH**) Key Exchange

1. Alice generates a random ECC key pair: $\{Pri_A, PK_A = Pri_A * \mathsf{G}\}$

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1. Alice generates a random ECC key pair: $\{Pri_A, PK_A = Pri_A$ * G$\}$
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Workflow of Pairing: Elliptic Curve Diffie–Hellman (**ECDH**) Key Exchange

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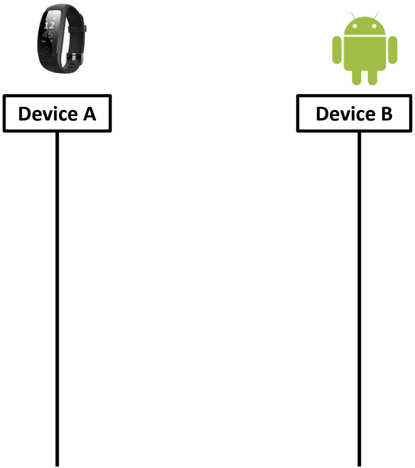
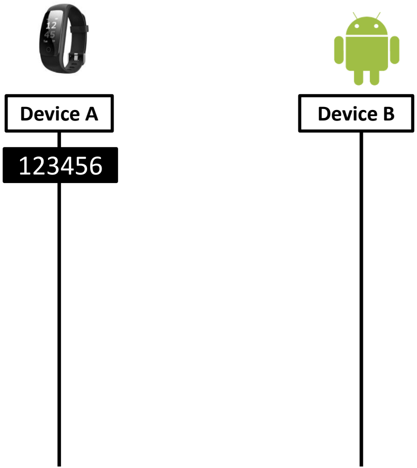
4. Alice calculates sharedKey: $K_A = Pri_A * PK_B$
5. Bob calculates sharedKey: $K_B = Pri_B * PK_A$

$$Pri_A * (Pri_B * G) = Pri_B * (Pri_A * G)$$

Workflow of Passkey Entry



Workflow of Passkey Entry

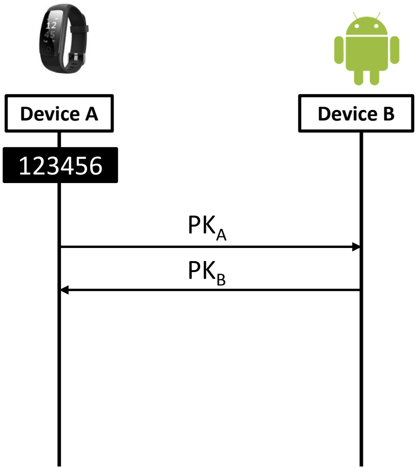


Device A

123456

Device B

Workflow of Passkey Entry



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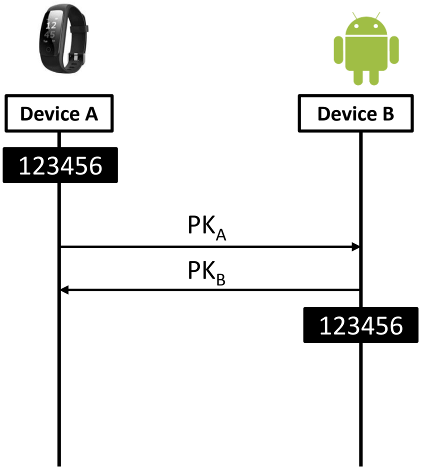


Device A

Device B

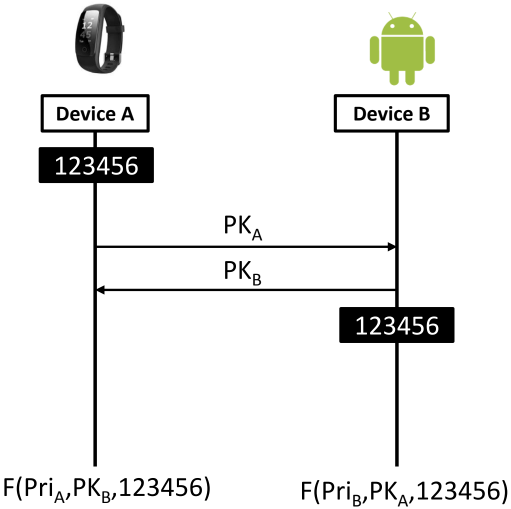
123456

PK_A

PK_B

123456

Workflow of Passkey Entry



Device A

Device B

123456

PK_A

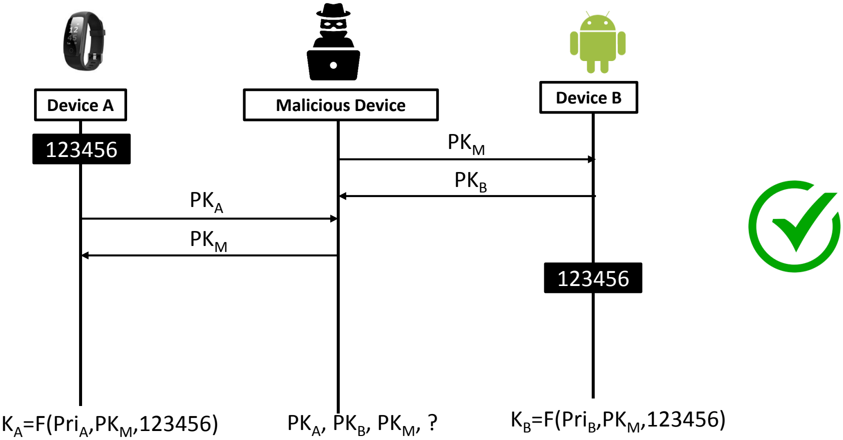
PK_B

123456

$F(Pri_A, PK_B, 123456)$

$F(Pri_B, PK_A, 123456)$

Workflow of Passkey Entry



Device A

Malicious Device

Device B

123456

PK_M

PK_B

PK_A

PK_M

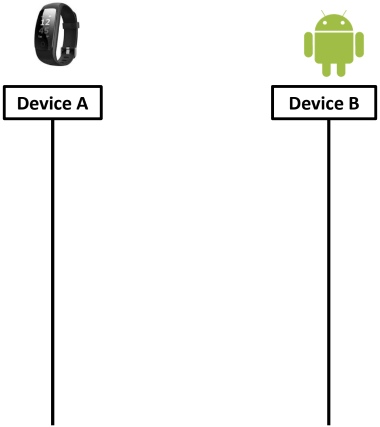
123456

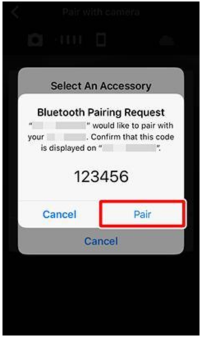
K_A=F(Pri_A,PK_M,123456)

PK_A, PK_B, PK_M, ?

K_B=F(Pri_B,PK_M,123456)

Workflow of Numeric Comparison




Pair with camera

Select An Accessory

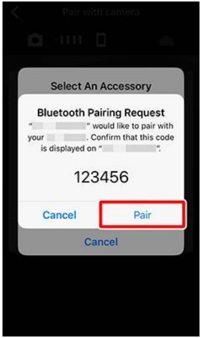
Bluetooth Pairing Request

“[redacted]” would like to pair with your [redacted]. Confirm that this code is displayed on “[redacted]”.

123456

Cancel Pair

Cancel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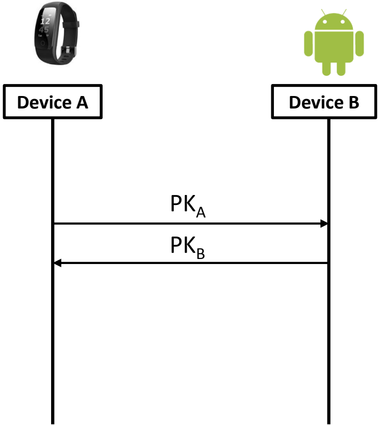

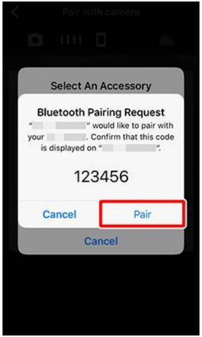

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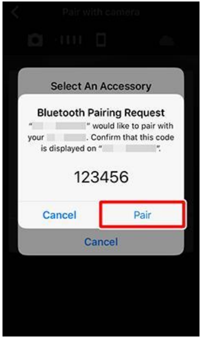

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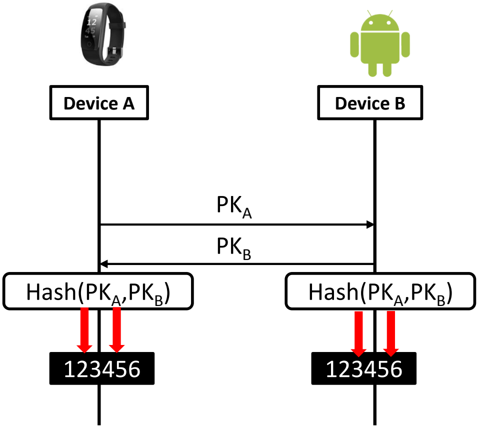


Device A

Device B

PK_A

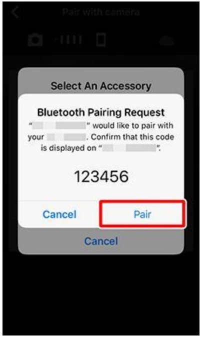
PK_B

Hash(PK_A,PK_B)

Hash(PK_A,PK_B)

123456

123456



Pair with camera

Select An Accessory

Bluetooth Pairing Request

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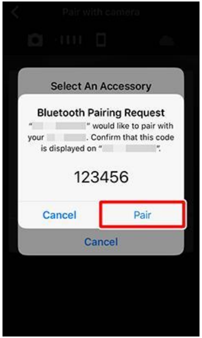
123456

Cancel | Pair

Cancel



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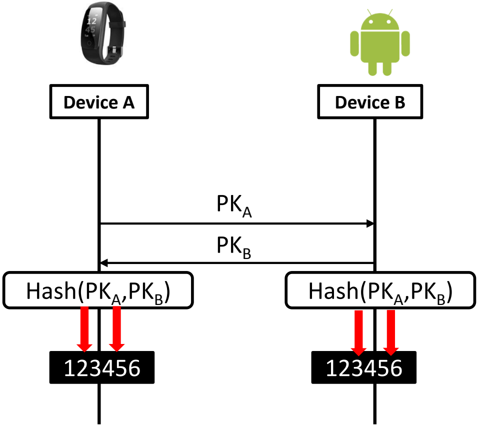

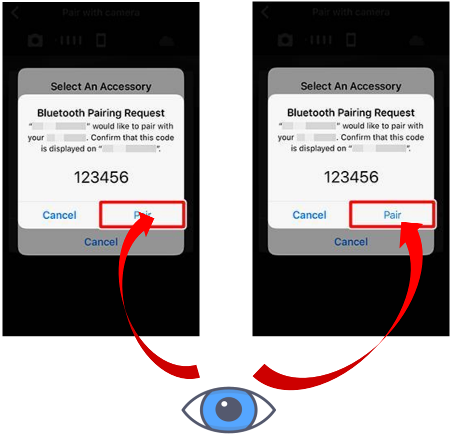
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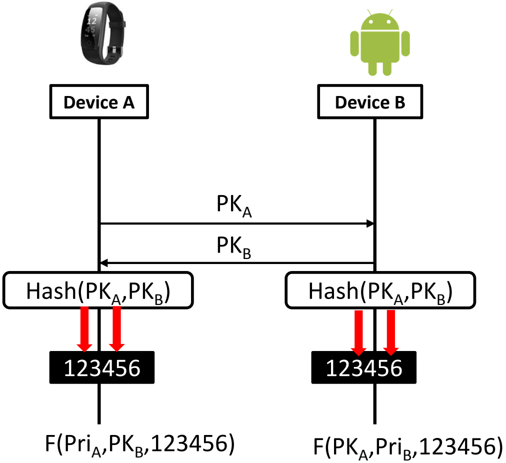

Device A

Device B

PK_A

PK_B

$Hash(PK_A,PK_B)$

$Hash(PK_A,PK_B)$

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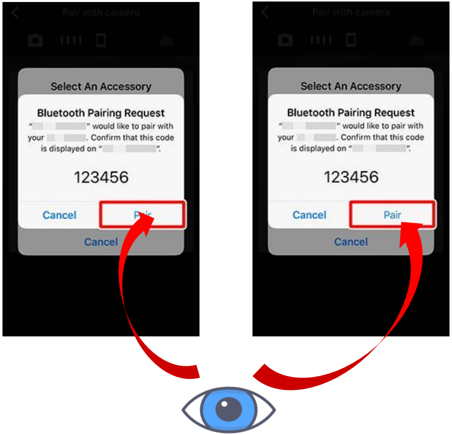
$F(Pri_A,PK_B,123456)$

$F(PK_A,Pri_B,123456)$



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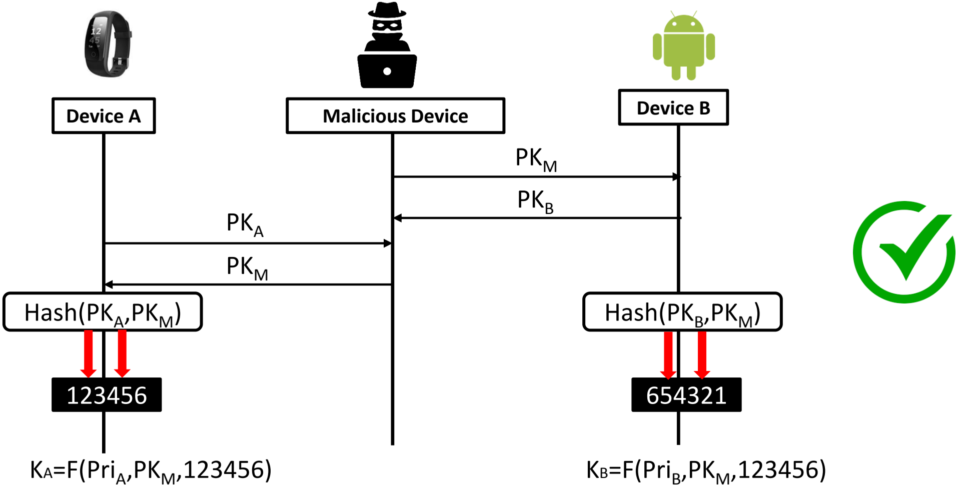
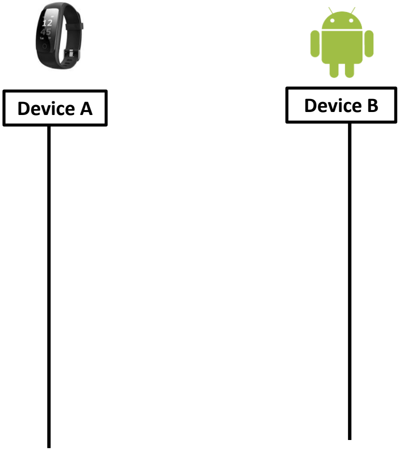


Workflow of Out of Band



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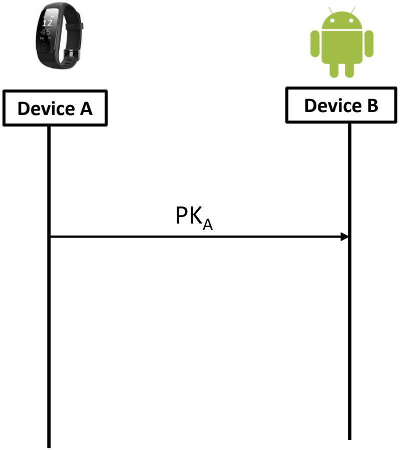

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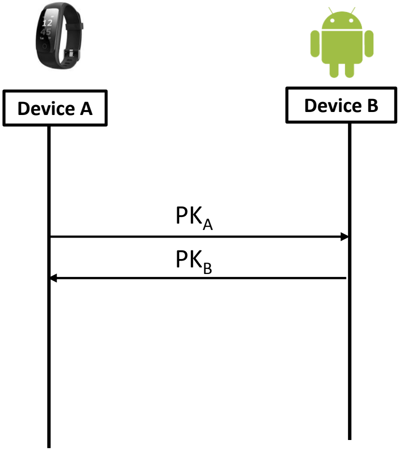

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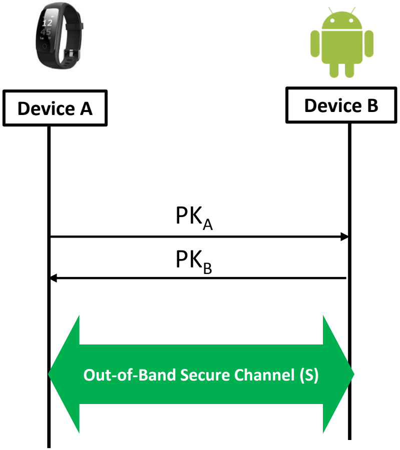

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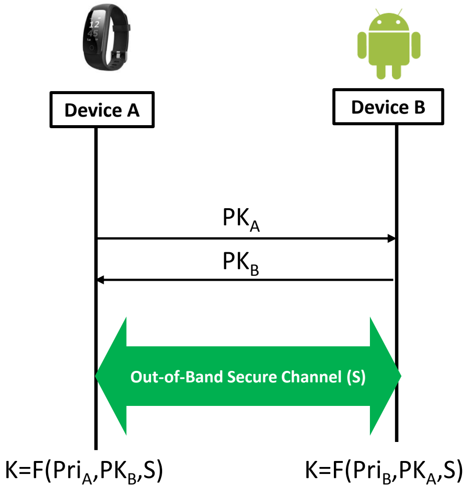

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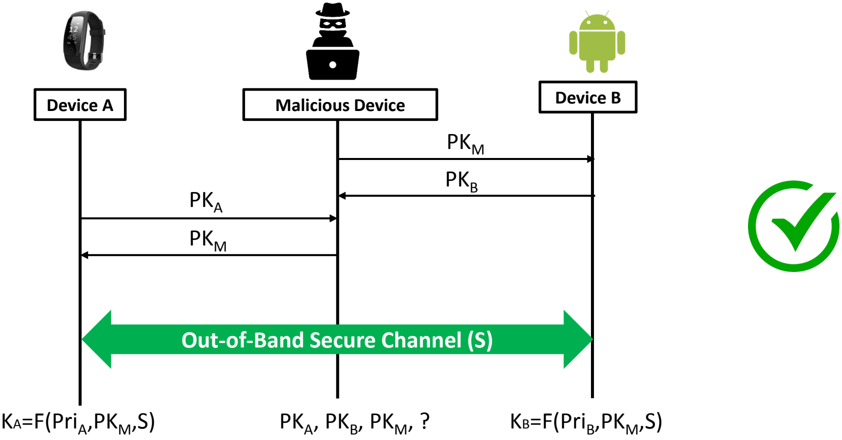
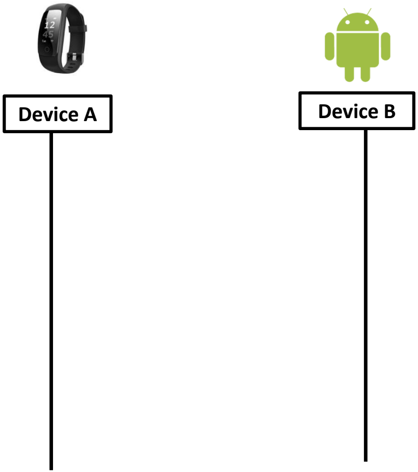


Workflow of Justworks



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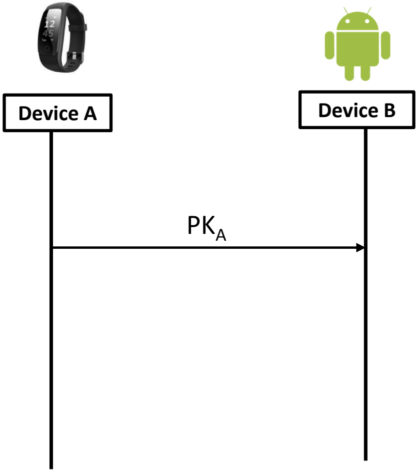

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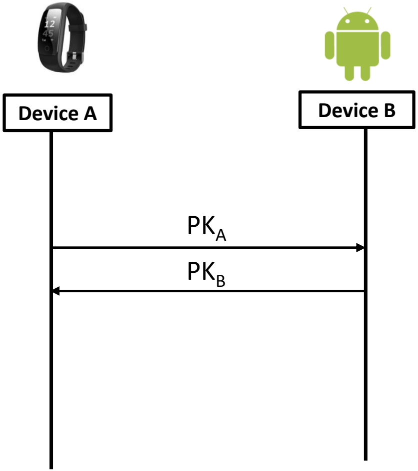

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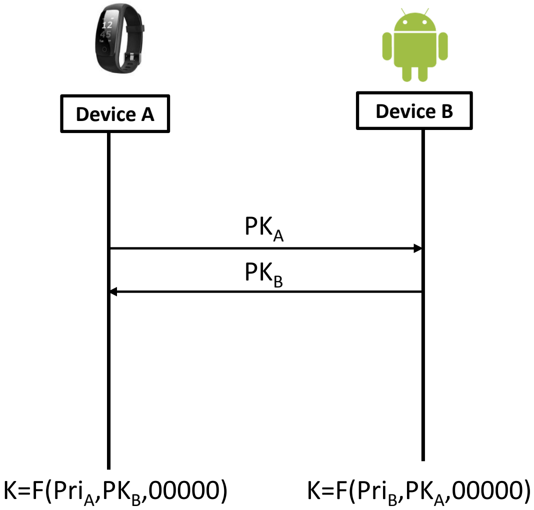


Device A

Device B

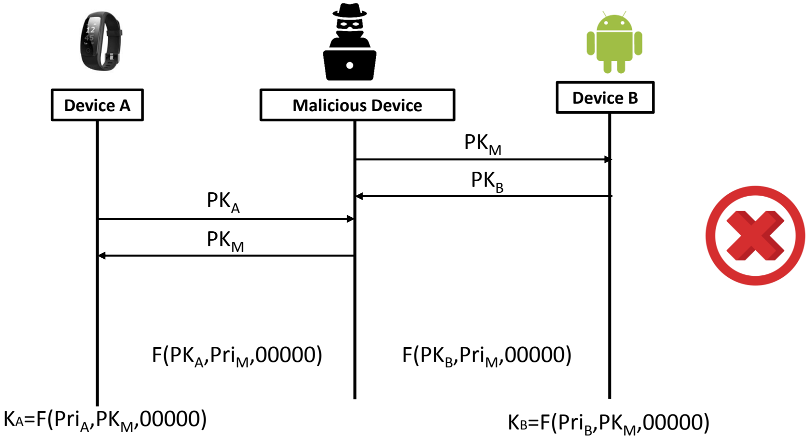
PK_A

PK_B

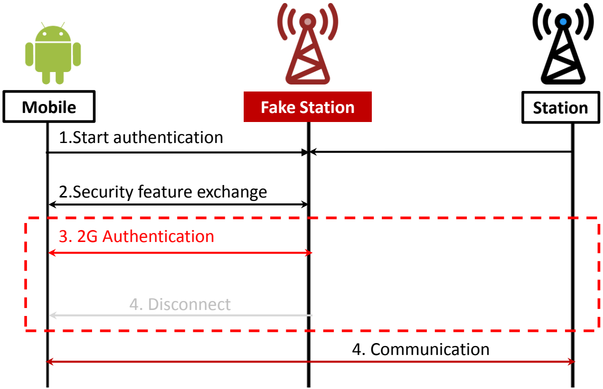
$K=F(Pri_A,PK_B,00000)$

$K=F(Pri_B,PK_A,00000)$

Workflow of Justworks



Our Downgrade Attacks against Bluetooth Low Energy



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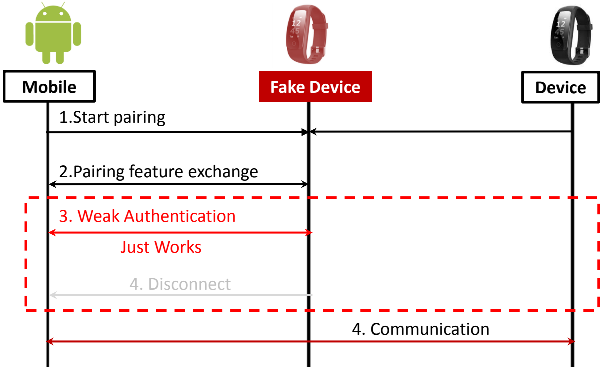

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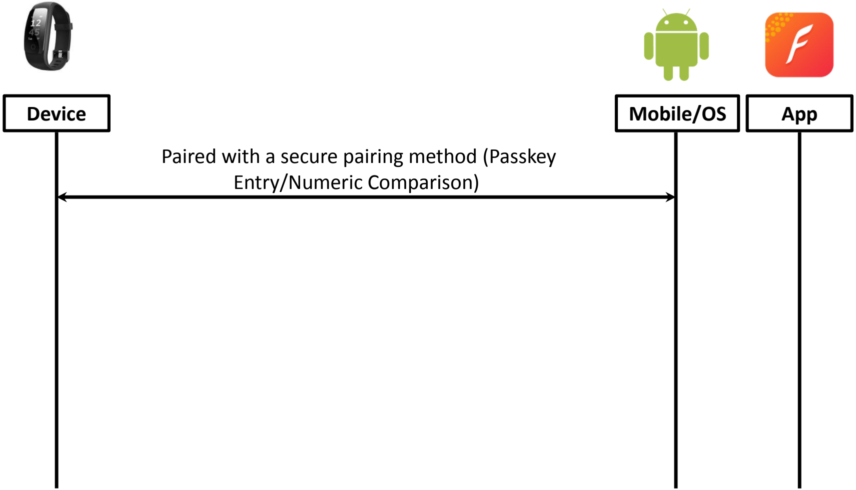


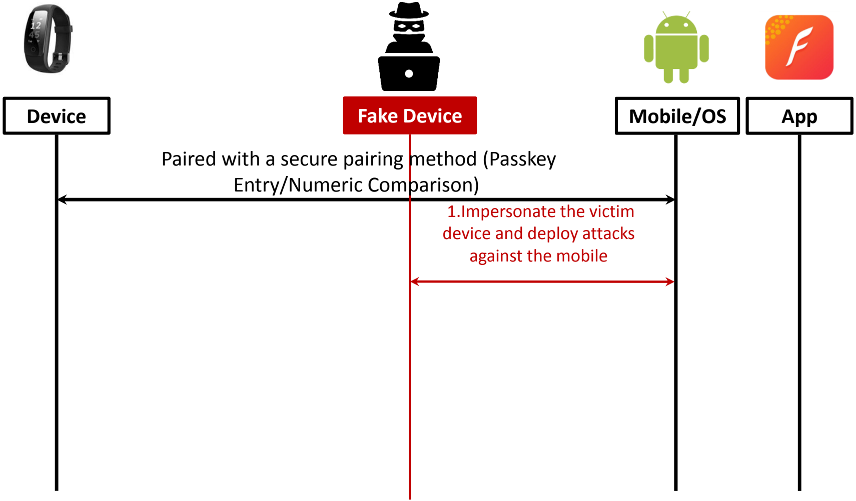
Device

Mobile/OS

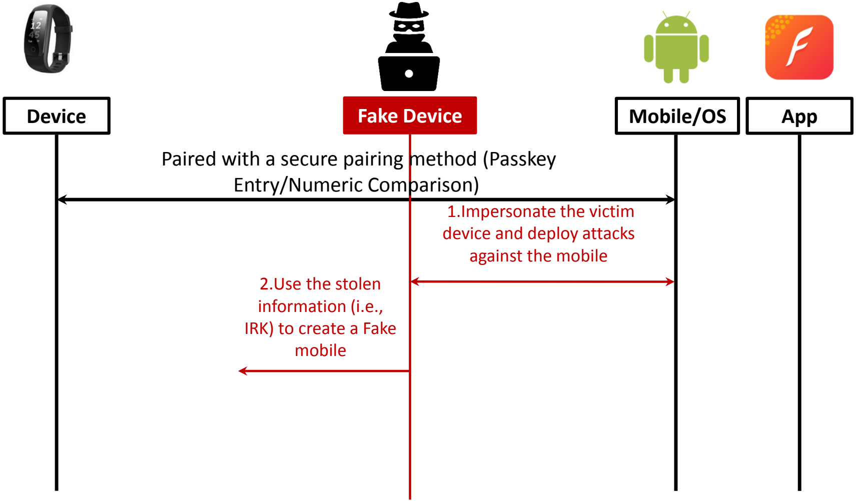
App

Paired with a secure pairing method (Passkey Entry/Numeric Comparison)

Our Downgrade Attacks against Bluetooth Low Energy


Device
Fake Device
Mobile/OS
App
Paired with a secure pairing method (Passkey Entry/Numeric Comparison)
1.Impersonate the victim device and deploy attacks against the mobile

Our Downgrade Attacks against Bluetooth Low Energy

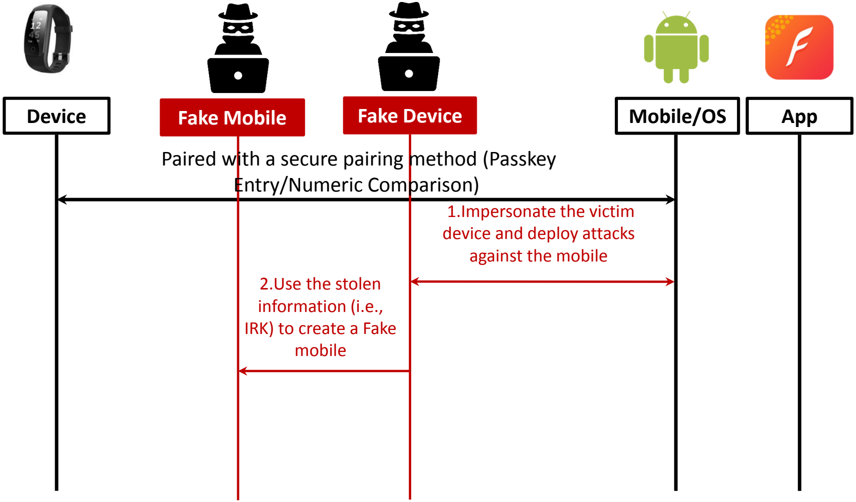


Paired with a secure pairing method (Passkey Entry/Numeric Comparison)

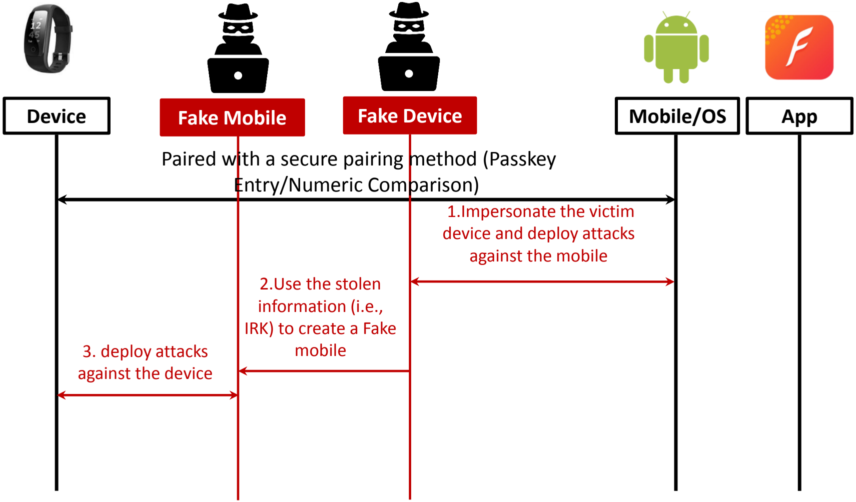
1.Impersonate the victim device and deploy attacks against the mobile

2.Use the stolen information (i.e., IRK) to create a Fake mobile

Our Downgrade Attacks against Bluetooth Low Energy


Device
Fake Mobile
Fake Device
Mobile/OS
App
Paired with a secure pairing method (Passkey Entry/Numeric Comparison)
1.Impersonate the victim device and deploy attacks against the mobile
2.Use the stolen information (i.e., IRK) to create a Fake mobile

Our Downgrade Attacks against Bluetooth Low Energy



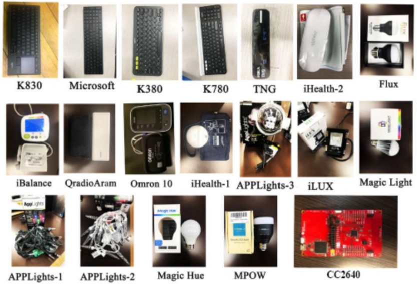
Paired with a secure pairing method (Passkey Entry/Numeric Comparison)

1.Impersonate the victim device and deploy attacks against the mobile

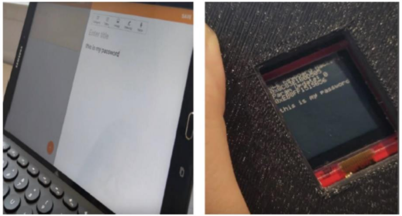
2.Use the stolen information (i.e., IRK) to create a Fake mobile

3. deploy attacks against the device

Our Downgrade Attacks against Bluetooth Low Energy



The Tested BLE devices



User

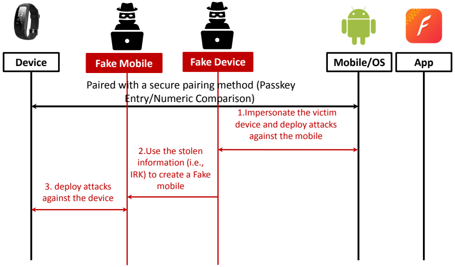
Attacker

MITM attack against BLE keyboards

Google

CVE-2020-9770

Our Downgrade Attacks against Bluetooth Low Energy



Device

Fake Mobile

Fake Device

Mobile/OS

App

Paired with a secure pairing method (Passkey Entry/Numeric Comparison)

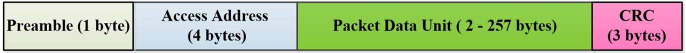
1.Impersonate the victim device and deploy attacks against the mobile

2.Use the stolen information (i.e., IRK) to create a Fake mobile

3. deploy attacks against the device

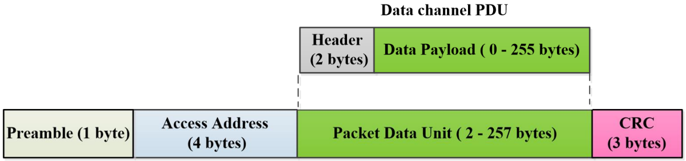
"Breaking Secure Pairing of Bluetooth Low Energy Using Downgrade Attacks", Yue Zhang, Jian Weng, Rajib Dey, Yier Jin, Zhiqiang Lin, and Xinwen Fu. *In Proceedings of the 29th USENIX Security Symposium*, Boston, MA. August 2020

The Format of A Bluetooth Packet

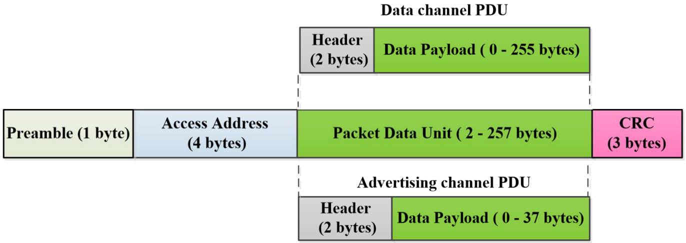


Preamble (1 byte)	Access Address (4 bytes)	Packet Data Unit (2 - 257 bytes)	CRC (3 bytes)

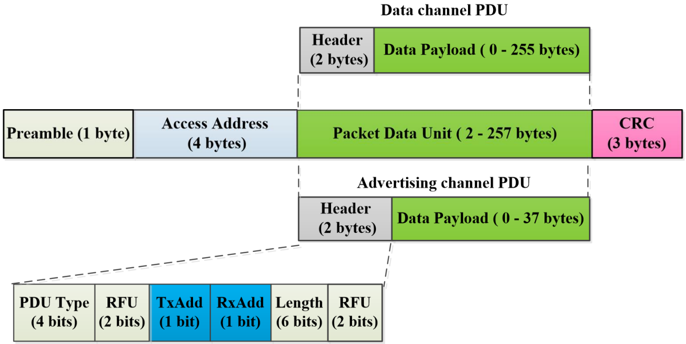
The Format of A Bluetooth Packet



The Format of A Bluetooth Packet



The Format of A Bluetooth Packet



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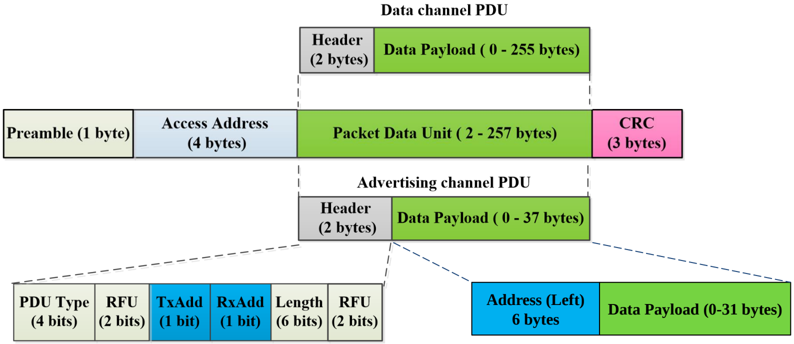
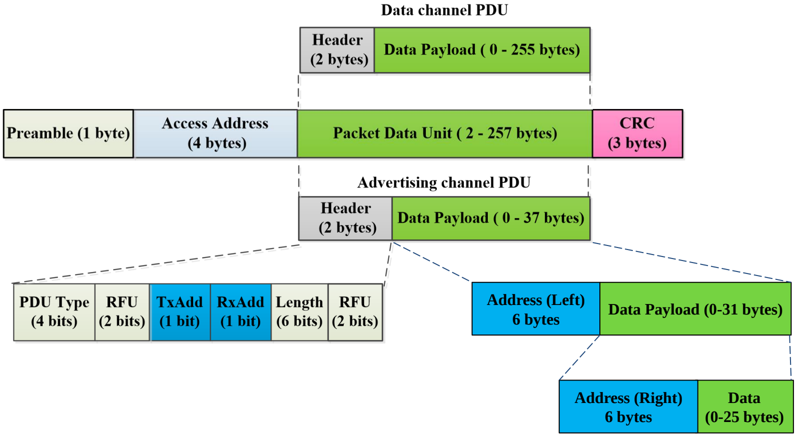


The Format of A Bluetooth Packet



Bluetooth Sniffers

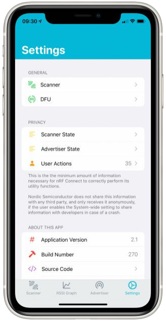
Ubertooth One Sniffer

125 USD

Adafruit LE sniffer

25 USD

nRF Connect 4+
The #1 Bluetooth LE utility
Nordic Semiconductor ASA
★★★★★ 4.4 • 77 Ratings
Free



09:30

Settings

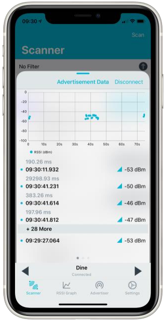
GENERAL
- Scanner >
- DFU >

PRIVACY
- Scanner State >
- Advertiser State >
- User Actions 35 >

This is the the minimum amount of information necessary for nRF Connect to correctly perform its utility functions.

Nordic Semiconductor does not share this information with any third party, and only receives it anonymously, if the user enables the System-wide setting to share information with developers in case of a crash.

ABOUT THIS APP
- Application Version 2.1
- Build Number 270
- Source Code >



09:30

Scan

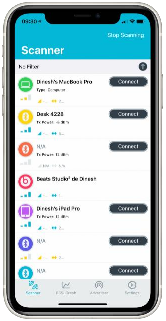
Scanner

No Filter

Advertisement Data Disconnect

190.26 ms
• 09:30:11.932 -53 dBm
29298.93 ms
• 09:30:41.231 -50 dBm
383.26 ms
• 09:30:41.614 -46 dBm
197.96 ms
• 09:30:41.812 -47 dBm
+ 28 More
• 09:29:27.064 -53 dBm

Dine
Connected



09:30

Stop Scanning

Scanner

No Filter

Dinesh's MacBook Pro — Connect
Type: Computer

Desk 4228 — Connect
Tx Power: -8 dBm

N/A — Connect
Tx Power: 12 dBm
N/A N/A

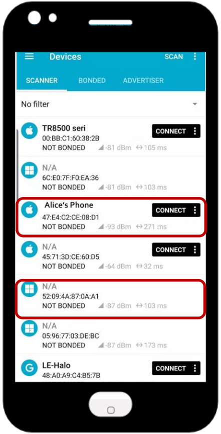
Beats Studio³ de Dinesh

Dinesh's iPad Pro — Connect
Tx Power: 12 dBm

N/A — Connect

N/A — Connect

Bluetooth Sniffers



Devices SCAN

SCANNER BONDED ADVERTISER

No filter

TR8500 seri
00:BB:C1:60:38:2B
NOT BONDED -81 dBm ↔105 ms
CONNECT

N/A
6C:E0:7F:F0:EA:36
NOT BONDED -81 dBm ↔103 ms

Alice's Phone
47:E4:C2:CE:08:D1
NOT BONDED -93 dBm ↔271 ms
CONNECT

N/A
45:71:3D:CE:60:D5
NOT BONDED -64 dBm ↔32 ms
CONNECT

N/A
52:09:4A:87:0A:A1
NOT BONDED -87 dBm ↔103 ms

N/A
05:96:77:03:DE:BC
NOT BONDED -87 dBm ↔173 ms

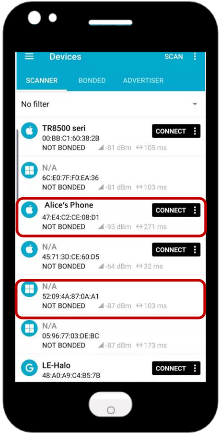
LE-Halo
48:A0:A9:C4:B5:7B
CONNECT

Alice's phone

Bob's phone

T1: 52:09:4A:87:0A:A1

Bluetooth Sniffers



Devices SCAN

SCANNER BONDED ADVERTISER

No filter

TR8500 seri
00:BB:C1:60:38:2B
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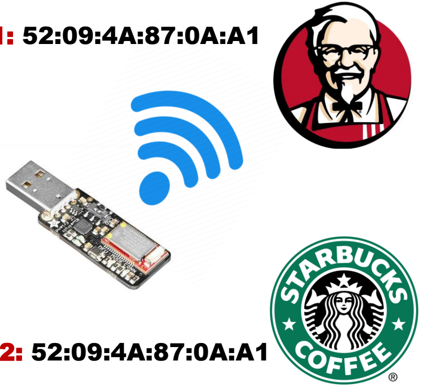
LE-Halo
48:A0:A9:C4:B5:7B CONNECT

Alice's phone

Bob's phone

T1: 52:09:4A:87:0A:A1

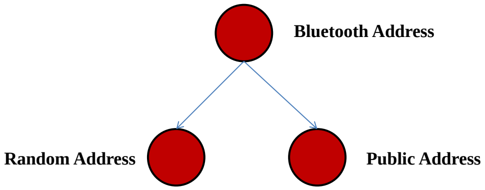


T2: 52:09:4A:87:0A:A1

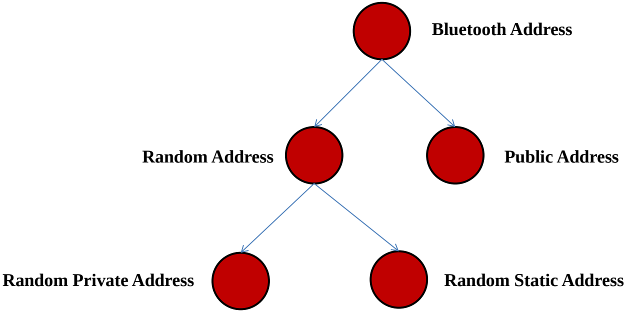
Bluetooth Address Types

Bluetooth Address

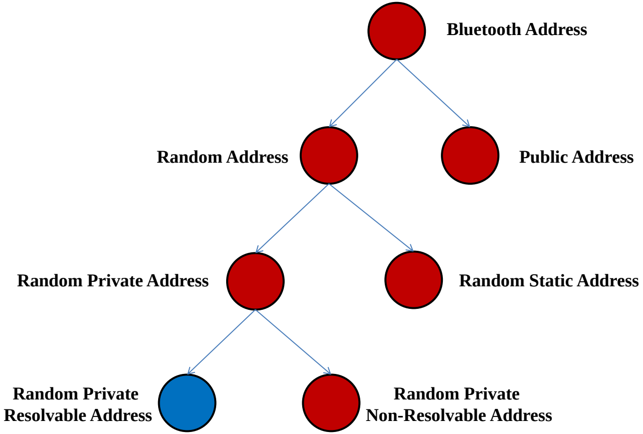
Bluetooth Address Types



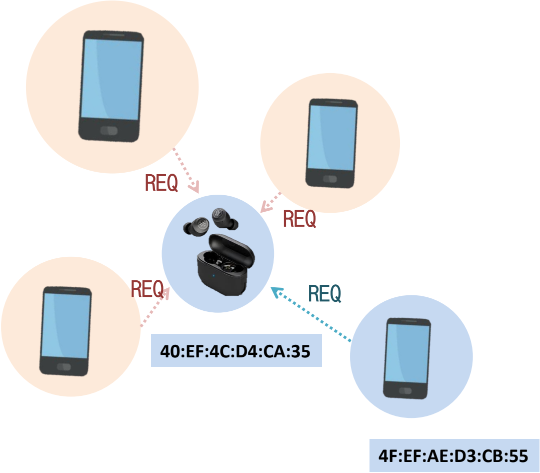
Bluetooth Address Types



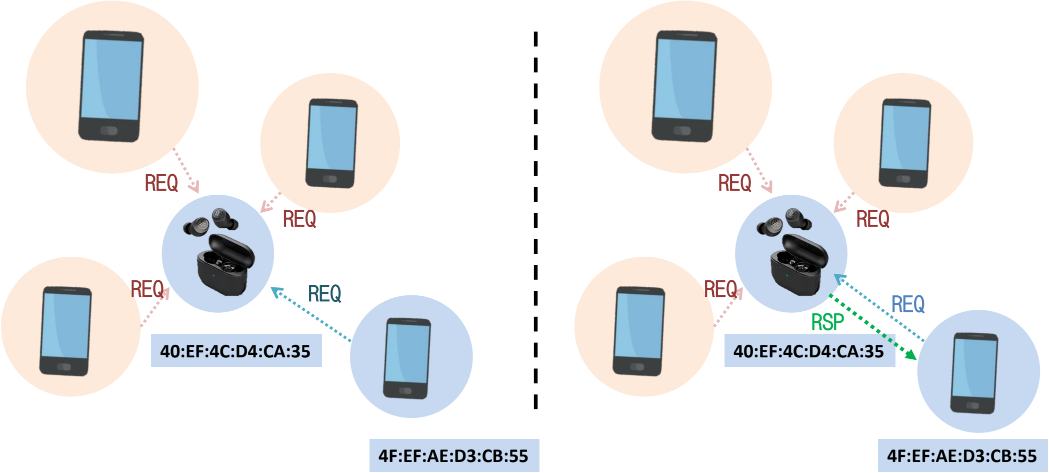
Bluetooth Address Types



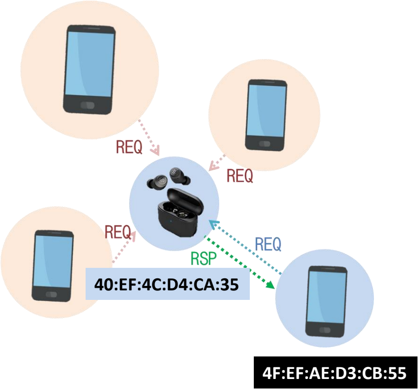
Our First Finding: Allowlist-based Side Channel



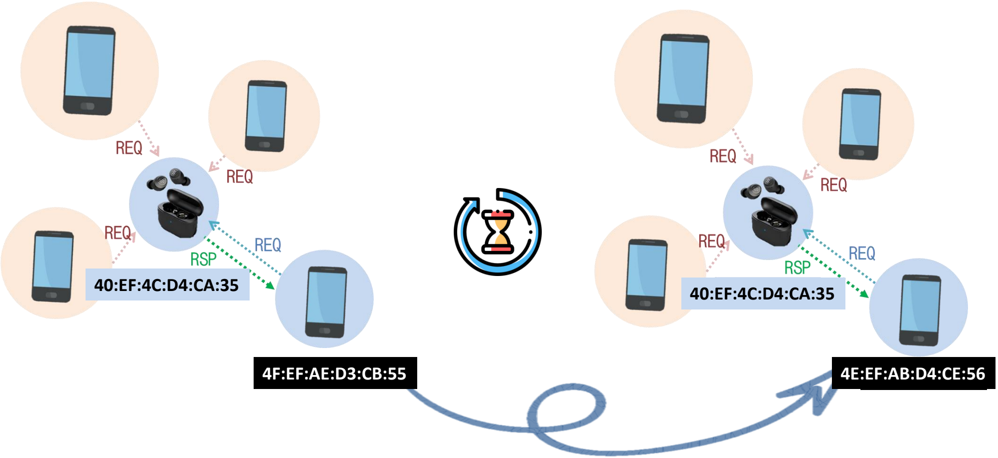
Our First Finding: Allowlist-based Side Channel



Our First Finding: Allowlist-based Side Channel



Our First Finding: Allowlist-based Side Channel



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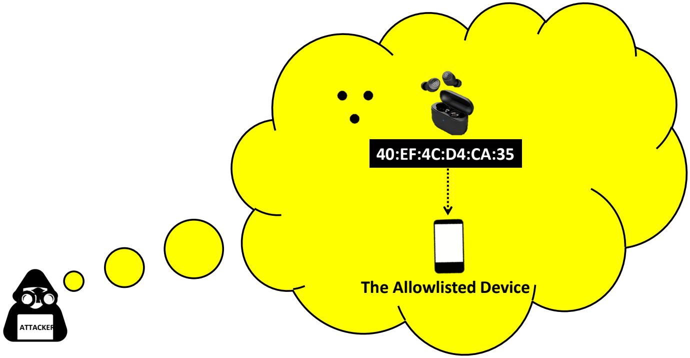

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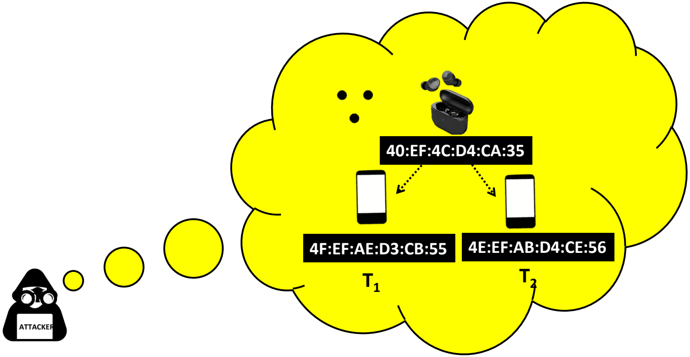
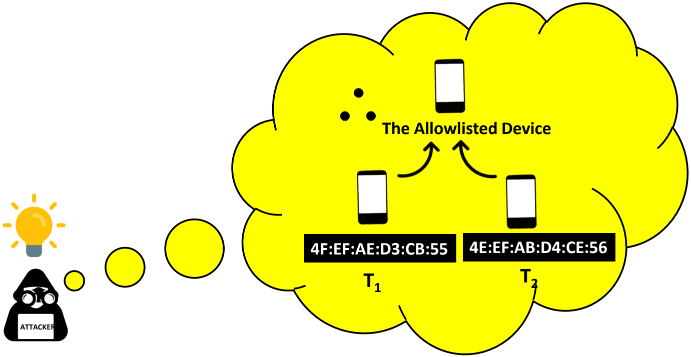
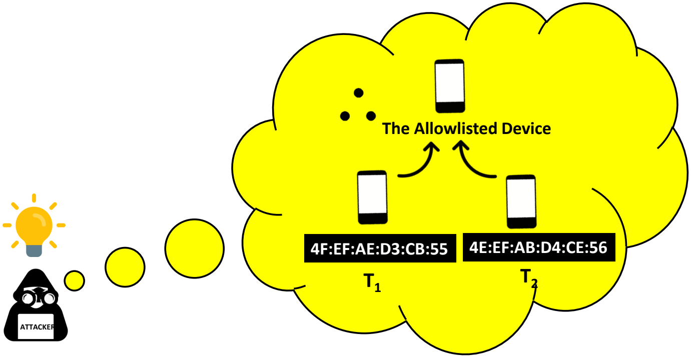


Our First Finding: Allowlist-based Side Channel

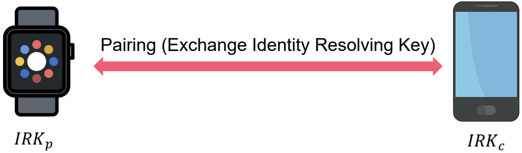


Our First Finding: Allowlist-based Side Channel



1. Cache
2. Timing
3. Power
4. Votage
5. Acoustic
6. **Allowlist**
7. ...

Our Second Finding: MAC Address Can be Replayed

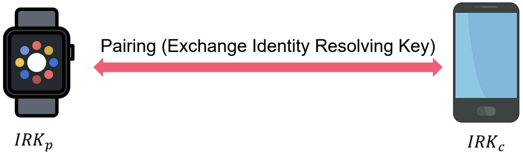


Pairing (Exchange Identity Resolving Key)

IRK_p

IRK_c

Our Second Finding: MAC Address Can be Replayed



Pairing (Exchange Identity Resolving Key)

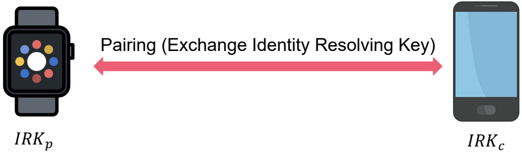
Random Address (RA) Generation

Random Address (RA) Resolution

$$RA_p = prand_{24} \,||\, H_{24}(prand_{24} \,||\, IRK_p)$$

47:2B:3C:6F:1C:DE

Our Second Finding: MAC Address Can be Replayed



Random Address (RA) Generation

$RA_p = prand_{24} \,||\, H_{24}(prand_{24} \,||\, IRK_p)$

47:2B:3C:6F:1C:DE

Random Address (RA) Resolution

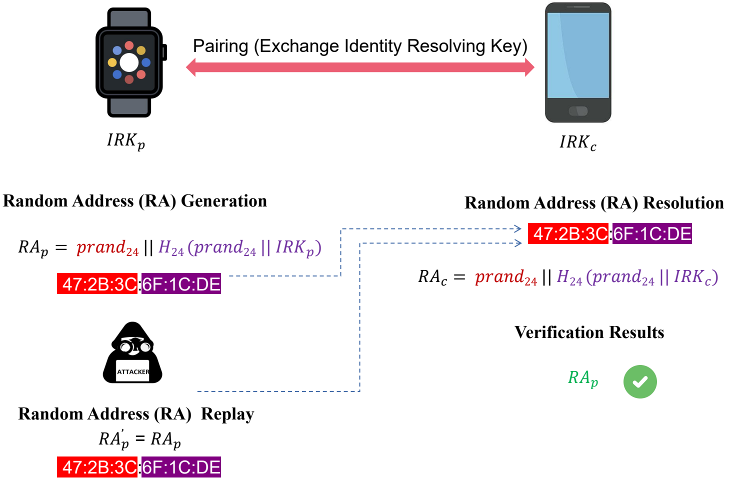
47:2B:3C:6F:1C:DE

$RA_c = prand_{24} \,||\, H_{24}(prand_{24} \,||\, IRK_c)$

Verification Results

RA_p ✓

Our Second Finding: MAC Address Can be Replayed



Pairing (Exchange Identity Resolving Key)

IRK_p

IRK_c

Random Address (RA) Generation

$RA_p = prand_{24} \,||\, H_{24}(prand_{24} \,||\, IRK_p)$

47:2B:3C:6F:1C:DE

Random Address (RA) Replay

$RA_p' = RA_p$

47:2B:3C:6F:1C:DE

Random Address (RA) Resolution

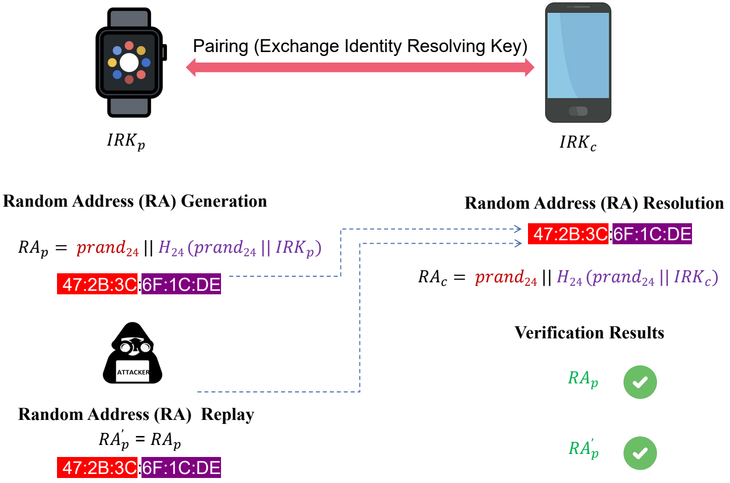
47:2B:3C:6F:1C:DE

$RA_c = prand_{24} \,||\, H_{24}(prand_{24} \,||\, IRK_c)$

Verification Results

RA_p ✓

Our Second Finding: MAC Address Can be Replayed



Pairing (Exchange Identity Resolving Key)

IRK_p

IRK_c

Random Address (RA) Generation

$RA_p = prand_{24} \,||\, H_{24}(prand_{24} \,||\, IRK_p)$

47:2B:3C:6F:1C:DE

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47:2B:3C:6F:1C:DE

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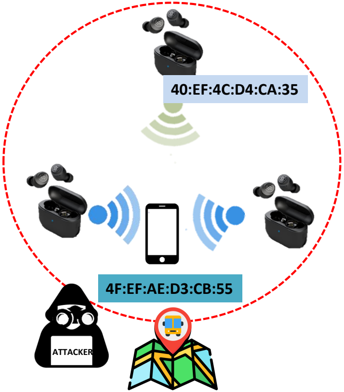
$RA_c = prand_{24} \,||\, H_{24}(prand_{24} \,||\, IRK_c)$

Verification Results

RA_p ✓

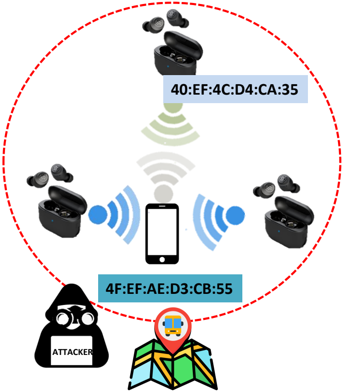
RA_p' ✓

Attack Example



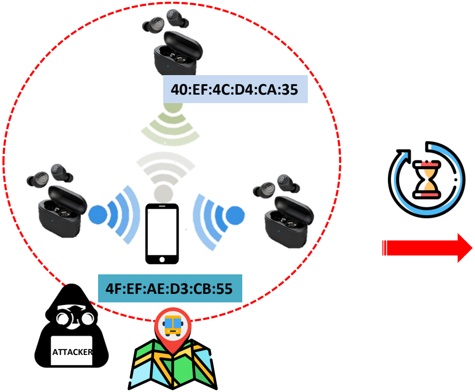
Tracking a Victim's Real-time Location

Attack Example



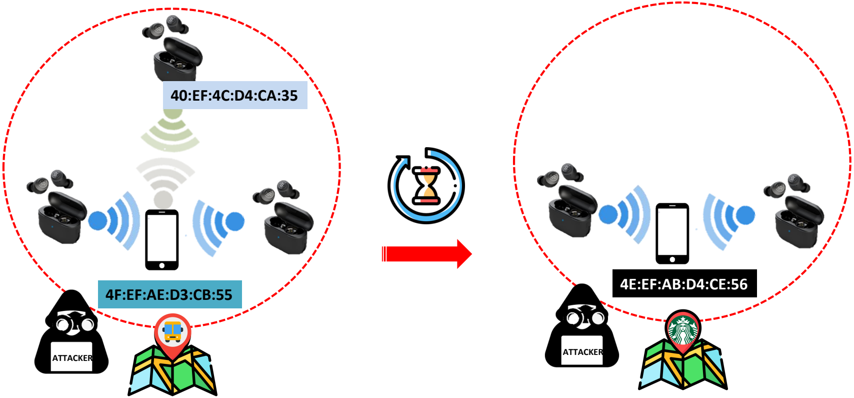
Tracking a Victim's Real-time Location

Attack Example



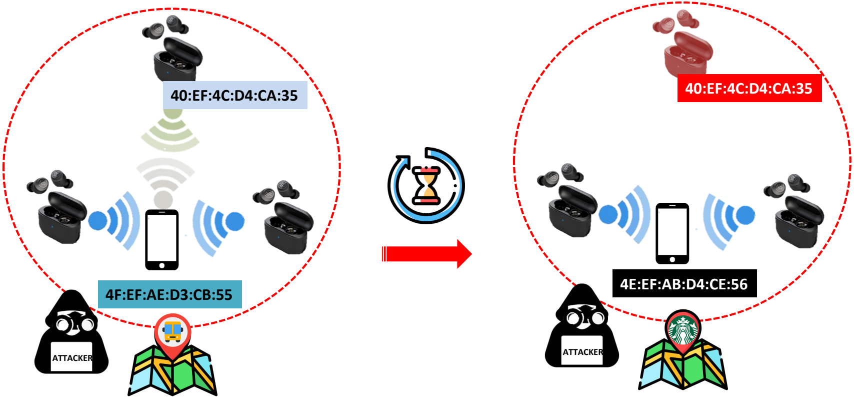
Tracking a Victim's Real-time Location

Attack Example



Tracking a Victim's Real-time Location

Attack Example



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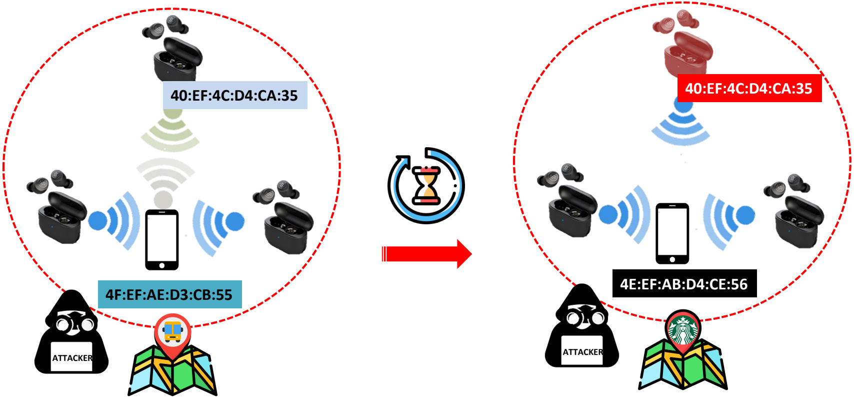
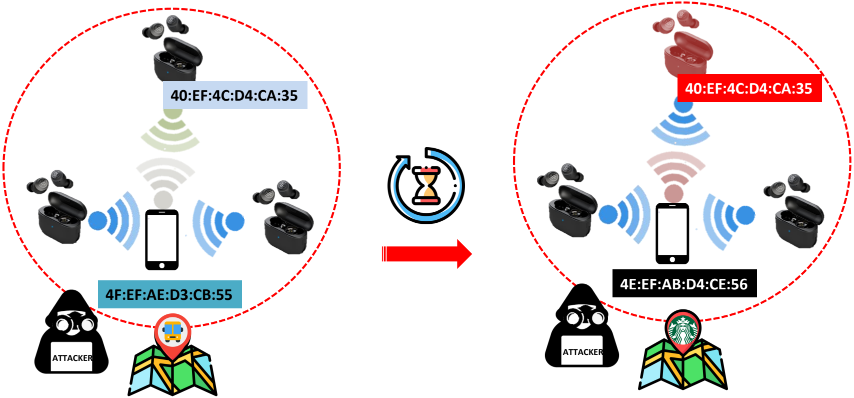


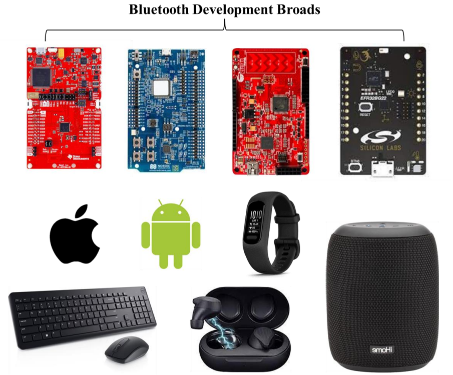
Tracking a Victim's Real-time Location

Attack Example



Tracking a Victim's Real-time Location

Devices That are Subject to BAT Attacks



CVE-2020-35473

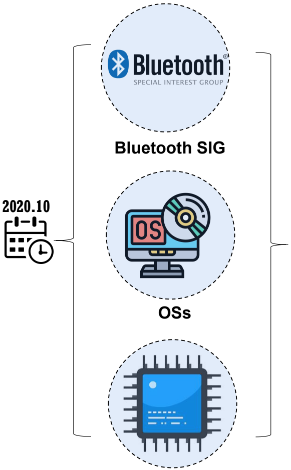
Peripherals & Development Boards

Brand & Model	Allowlist		Device Type	MAC Addr	Power Saving	Passive Attacks		Active Attacks			
								From Malicious Central		From Malicious Peripheral	
	Enabled by P	Used by C				TC	TP	TC	TP	TC	TP
DRACONIC	✓	✓	Keyboard	SRA	✓	✓	✓	✓	✓	✓	✓
JellyComb	✓	✓	Keyboard	SRA	✓	✓	✓	✓	✓	✓	✓
iClever	✓	✓	Keyboard	SRA	✓	✓	✓	✓	✓	✓	✓
Microsoft (V1)	✓	✓	Keyboard	SRA	✓	✓	✓	✓	✓	✓	✓
Microsoft (V2)	✓	✓	Keyboard	SRA	✓	✓	✓	✓	✓	✓	✓
byteblue	✓	✓	Keyboard	SRA	✓	✓	✓	✓	✓	✓	✓
Logitech K780	✓	✓	Keyboard	SRA	✓	✓	✓	✓	✓	✓	✓
Logitech K830	✓	✓	Keyboard	SRA	✓	✓	✓	✓	✓	✓	✓
Logitech K380	✓	✓	Keyboard	SRA	✓	✓	✓	✓	✓	✓	✓
SXWL	✓	✓	Keyboard	SRA	✓	✓	✓	✓	✓	✓	✓
SXWL	✓	✓	Mouse	SRA	✓	✓	✓	✓	✓	✓	✓
Inphic	✓	✓	Mouse	SRA	✓	✓	✓	✓	✓	✓	✓
Vogek	✓	✓	Mouse	SRA	✓	✓	✓	✓	✓	✓	✓
JellyComb (V1)	✓	✓	Mouse	SRA	✓	✓	✓	✓	✓	✓	✓
JellyComb (V2)	✓	✓	Mouse	SRA	✓	✓	✓	✓	✓	✓	✓
SEENDA	✓	✓	Mouse	SRA	✓	✓	✓	✓	✓	✓	✓
MiBand 4C	✓	✗	Wristband	PA	✗	✓	✓	✓	✓	✗	✓
i-Home Alexa	✗	✓	Speaker	PA	✓	✗	✓	✓	✓	✓	✓
TEZO	✗	✓	Earbuds	PA	✓	✗	✓	✓	✓	✓	✓
Boltune	✗	✓	Earbuds	PA	✓	✗	✓	✓	✓	✓	✓
SoundBot	✗	✓	Earbuds	PA	✓	✗	✓	✓	✓	✓	✓
Riitek	✗	✓	Keyboard	PA	✓	✗	✓	✗	✓	✓	✓
Cimetech	✗	✓	Mouse	SRA	✓	✗	✓	✗	✓	✓	✓
Ergonomic	✗	✓	Mouse	SRA	✓	✗	✓	✗	✓	✓	✓
TI CC2640R2F	✓	✓	Dev Board	RPA	-	✓	✓	✓	✓	✓	✓
Nordic NRF52	✓	✓	Dev Board	RPA	-	✓	✓	✓	✓	✓	✓
Silicon Labs 6101D	✗	✓	Dev Board	RPA	-	-	-	✗	✗	✓	✓
Crypess CY8kCIT	✗	✓	Dev Board	RPA	-	-	-	✗	✗	✓	✓

Centrals

Brand & Model	Allowlist		Type & OS	MAC Addr	Random Interval	Passive Attacks		Active Attacks			
								From Malicious Central		From Malicious Peripheral	
	Enabled by C	Used by P				TP	TC	TP	TC	TP	TC
Google Pixel 4	✓	✓	Phone (Android 11)	RPA	5-15	✓	✓	✓	✓	✓	✓
Google Pixel 2	✓	✓	Phone (Android 10)	RPA	5-15	✓	✓	✓	✓	✓	✓
Samsung S10	✓	✓	Phone (Android 10)	RPA	5-15	✓	✓	✓	✓	✓	✓
Google Piexl 4	✓	✓	Phone (Android 10)	RPA	5-15	✓	✓	✓	✓	✓	✓
iPhone 8	✓	✓	Phone (iOS 13.2)	RPA	15	✓	✓	✓	✓	✓	✓
iPhone 11	✓	✓	Phone (iOS 13.2)	RPA	15	✓	✓	✓	✓	✓	✓
iPad	✓	✓	Tablet (iOS 13.2)	RPA	15	✓	✓	✓	✓	✓	✓
Dell GD1H4KU	✓	✓	Laptop (Windows 10)	PA	$+\infty$	✓	✓	✓	✓	✓	✓
Dell	✓	✓	Laptop (Ubuntu 20.02)	PA	$+\infty$	✓	✓	✓	✓	✓	✓
Thinkpad T450s	✓	✓	Laptop (Windows 8)	PA	$+\infty$	✓	✓	✓	✓	✓	✓
Surface Pro	✓	✓	Tablet (Windows 10)	PA	$+\infty$	✓	✓	✓	✓	✓	✓

Responsible Disclosure



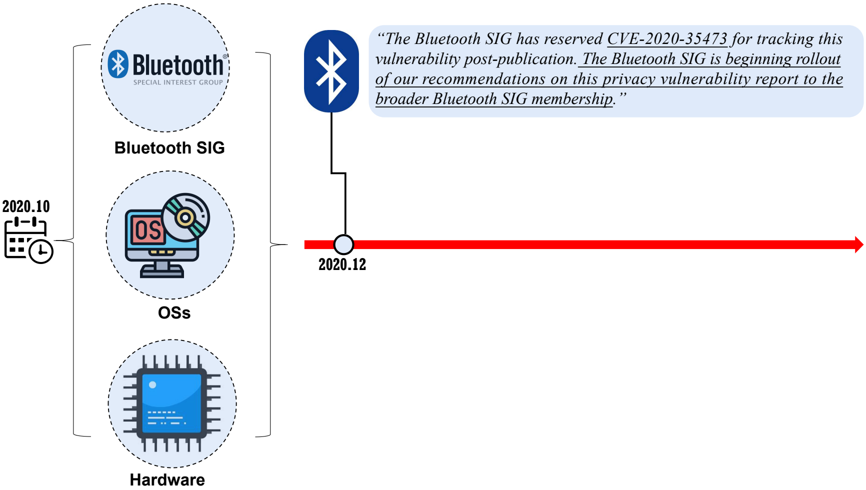
2020.10

Bluetooth SIG

OSs

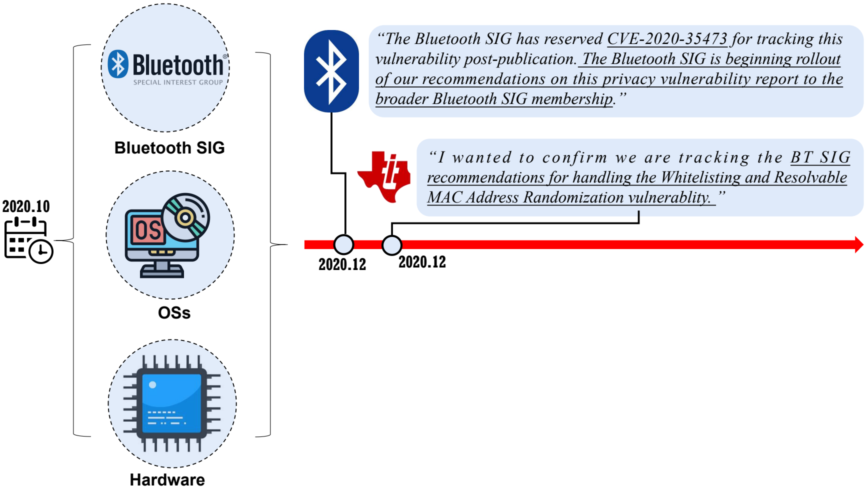
Hardware

Responsible Disclosure



"The Bluetooth SIG has reserved CVE-2020-35473 for tracking this vulnerability post-publication. The Bluetooth SIG is beginning rollout of our recommendations on this privacy vulnerability report to the broader Bluetooth SIG membership."

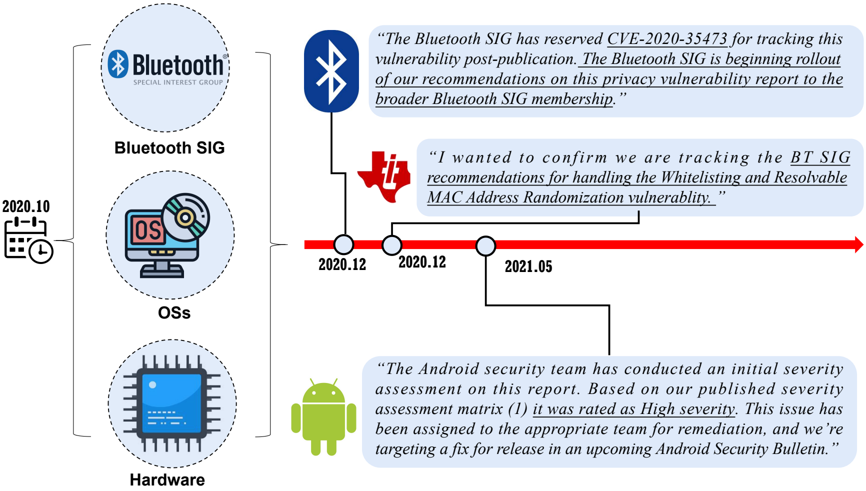
Responsible Disclosure



"The Bluetooth SIG has reserved CVE-2020-35473 for tracking this vulnerability post-publication. The Bluetooth SIG is beginning rollout of our recommendations on this privacy vulnerability report to the broader Bluetooth SIG membership."

"I wanted to confirm we are tracking the BT SIG recommendations for handling the Whitelisting and Resolvable MAC Address Randomization vulnerablity. "

Responsible Disclosure



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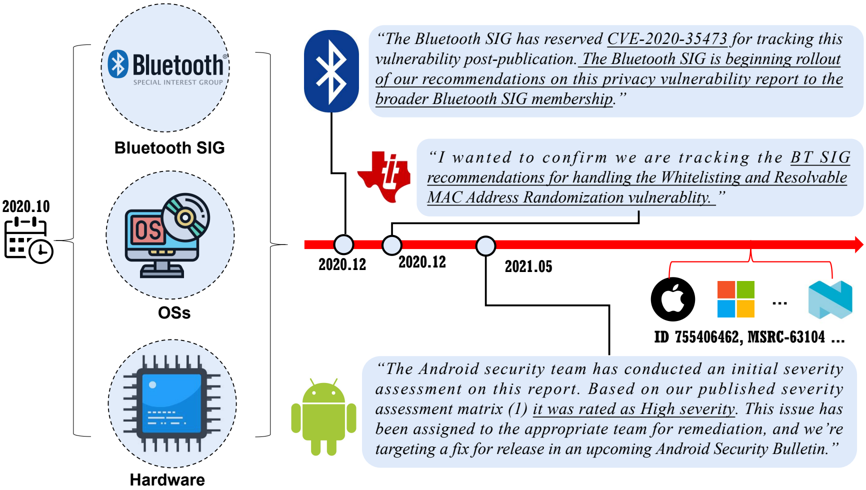
Responsible Disclosure


2020.10
Bluetooth SPECIAL INTEREST GROUP
Bluetooth SIG
OS
OSs
Hardware
2020.12
2020.12
2021.05
...
ID 755406462, MSRC-63104 ...

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Our Countermeasure: Securing Address of BLE (SABLE)

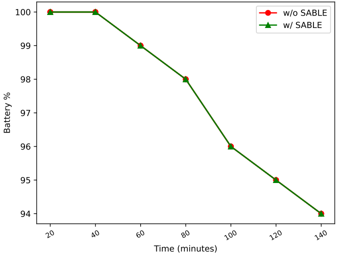
Allowlist Side Channel (Mitigation)

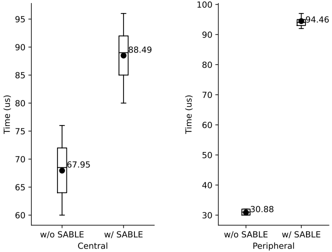
- We advocate the use of an interval unpredictable, central and peripheral synchronized RPA generation scheme to mitigate the side channel.

MAC Address Replay (Prevention)

- We propose adding a sequence number (which could be a timestamp) when generating the RPA to ensure that each MAC address can only be used once to prevent the replay attack.

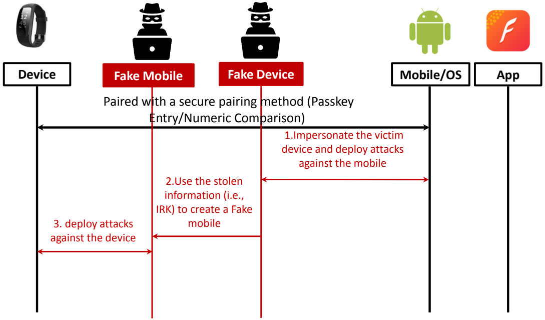
Performance of SABLE





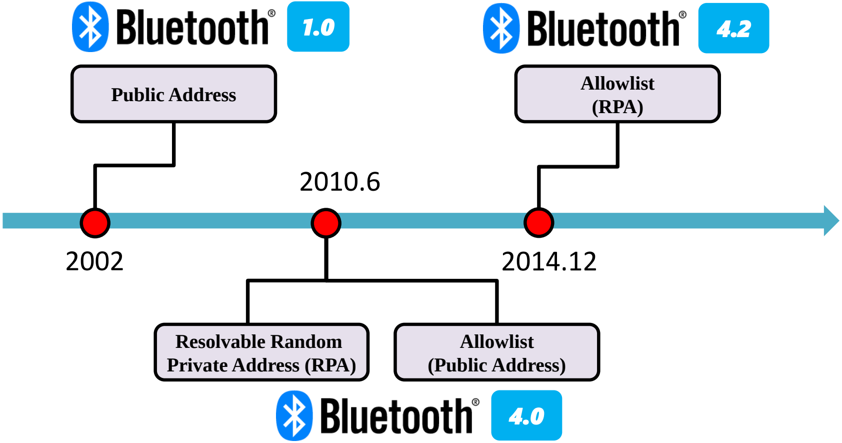
"When Good Becomes Evil: Tracking Bluetooth Low Energy Devices via Allowlist-based Side Channel and Its Countermeasure". Yue Zhang, and Zhiqiang Lin. *In Proceedings of the 29th ACM Conference on Computer and Communications Security (CCS 2022)*. November 2022 (Best Paper Award Honorable Mention)

Lesson Learned (1/3): BLE Communication Can Be Downgraded

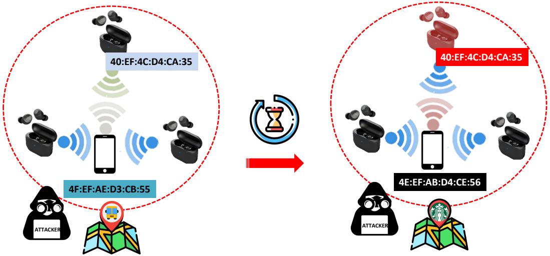

Device
Fake Mobile
Fake Device
Mobile/OS
App
Paired with a secure pairing method (Passkey Entry/Numeric Comparison)
1.Impersonate the victim device and deploy attacks against the mobile
2.Use the stolen information (i.e., IRK) to create a Fake mobile
3. deploy attacks against the device

- Bluetooth low energy (BLE) pairing can be **downgraded**
- There are many stages that are not part of the pairing process, but they are, in fact, closely related to pairing security.
- A systematic analysis of the pairing process, including the **error handling** of BLE communication, is needed.

Lesson Learned (2/3): New Features Need Re-examinations

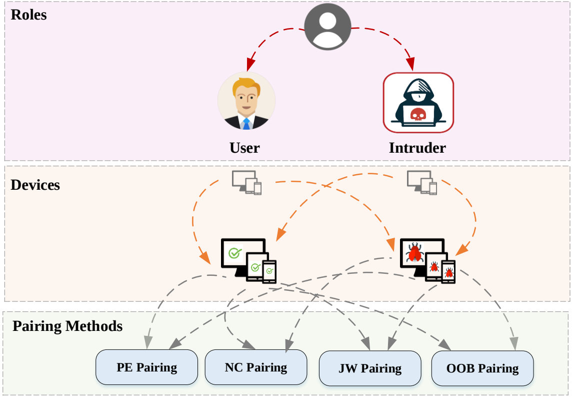


Lesson Learned (2/3): New Features Need Re-examinations



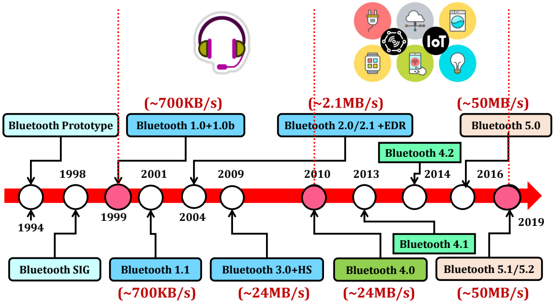
- BLE introduces multiple new features, some of which may **violate existing assumptions**
- Simliar to allowlist, those new features need to be **scrunitized**. For example, Cross-transport key derivation (CTKD); Authorization; The Connection Signature Resolving Key (CSRK).

Lesson Learned (3/3): Formal Method Can Help Improve BLE Security



- The specification (3,000+ pages) is often confusing and inconsistent across chapters.
- The confusion may lead to different vendors implement BLE protocols in quite different ways, for example, for error handling, and IRK use.
- Converting the Bluetooth specification to formal model, and formally verify the entire protocol would help.
- See our NDSS'23 paper.

Our Recent Work on Bluetooth Security and Privacy



1. ~~BLEScope: Automatic Fingerprinting of Vulnerable BLE IoT Devices with Static UUIDs from Mobile Apps. In ACM CCS 2019~~
2. ~~FirmXRay: Detecting Bluetooth Link Layer Vulnerabilities From Bare-Metal Firmware. In ACM CCS 2020.~~
3. **Breaking Secure Pairing of Bluetooth Low Energy in Mobile Devices Using Downgrade Attacks**. In USENIX Security 2020
4. ~~On the Accuracy of Measured Proximity of Bluetooth-based Contact Tracing Apps. In SECURECOMM. October 2020~~
5. **When Good Becomes Evil: Tracking Bluetooth Low Energy Devices via Allowlist-based Side Channel and Its Countermeasure"**. In ACM CCS 2022 (Best paper award honorable mention)
6. ~~Extrapolating Formal Analysis to Uncover Attacks in Bluetooth Passkey Entry Pairing. In NDSS 2023~~

Thank You

Rethinking the Security and Privacy of Bluetooth Low Energy

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06/01/2023