Automatic Fingerprinting Of Vulnerable BLE IoT Devices With Static UUIDs From Mobile Apps

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CCS 2019

Bluetooth Low Energy and IoT

Bluetooth™ 4.0

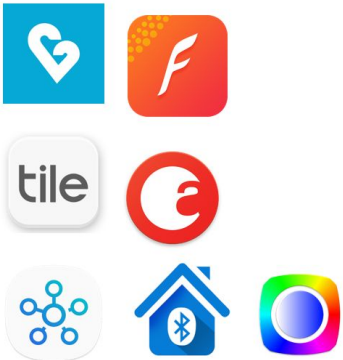
Low Energy

BLE IoT Devices and Companion Apps

BLE IoT Devices

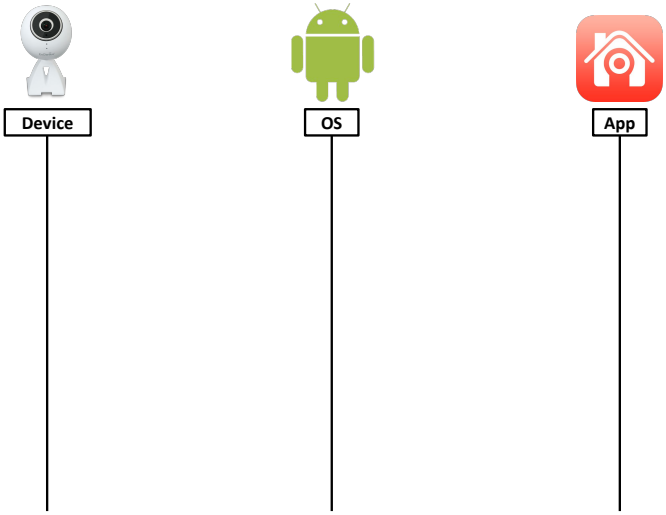
BLE IoT Devices and Companion Apps

BLE IoT Devices



Companion Mobile Apps

General Workflow of Device Communication in TCP/IP Setting



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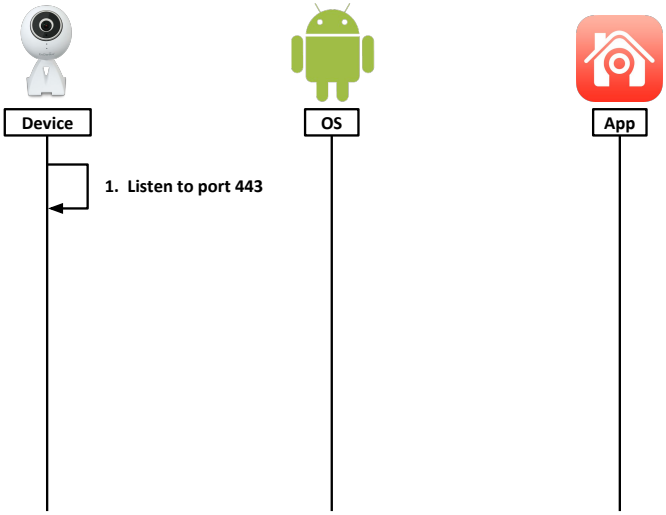

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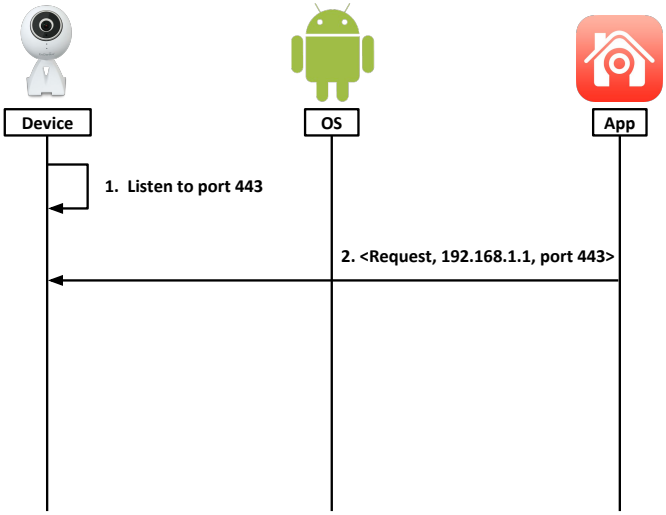

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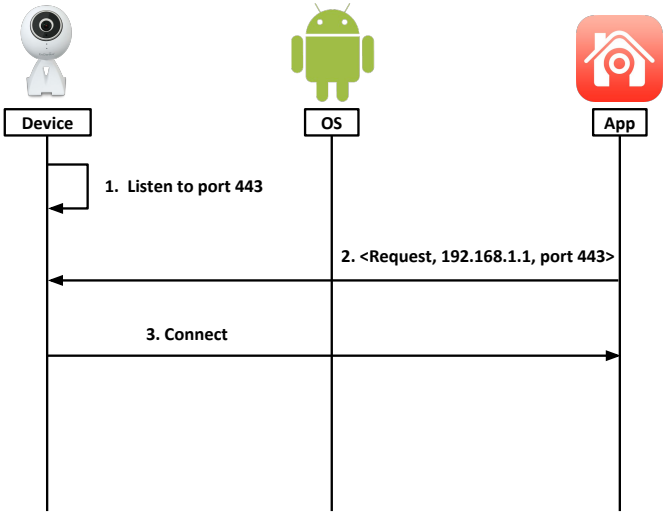

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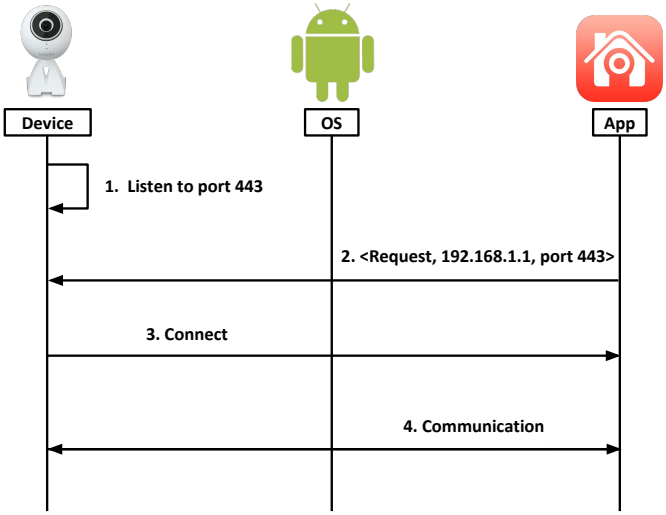

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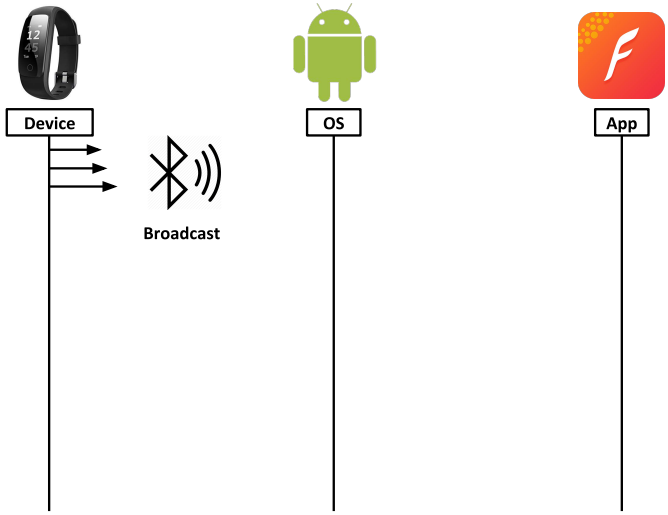

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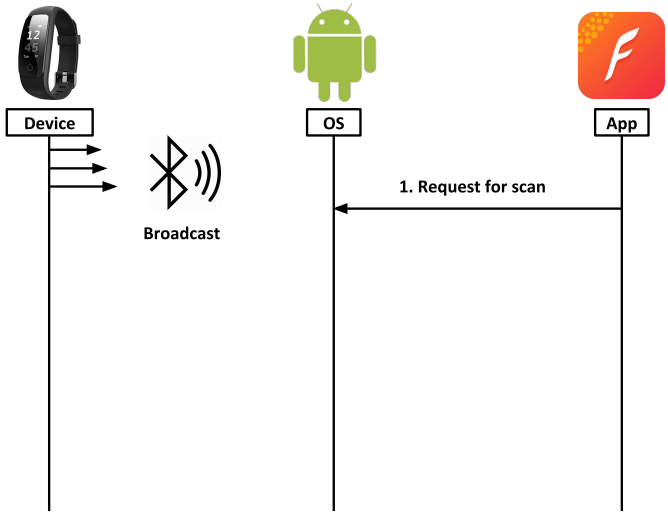

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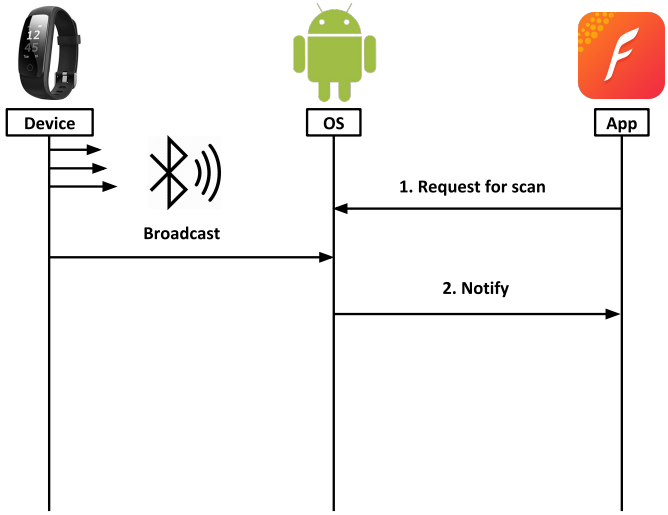

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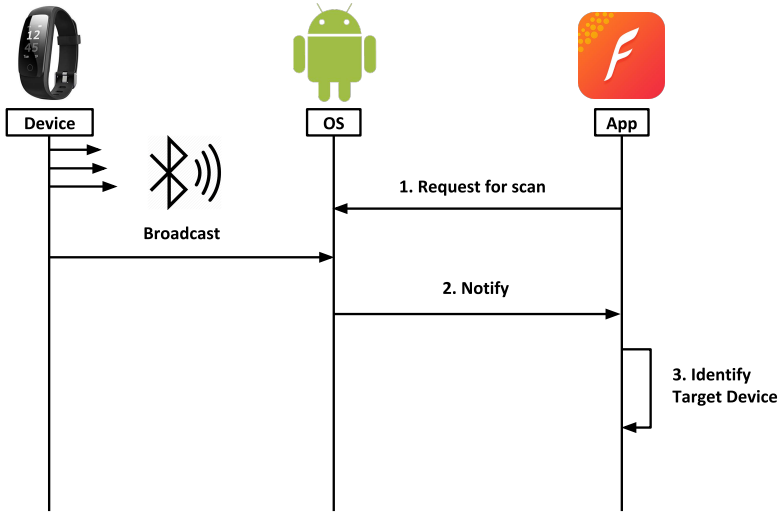

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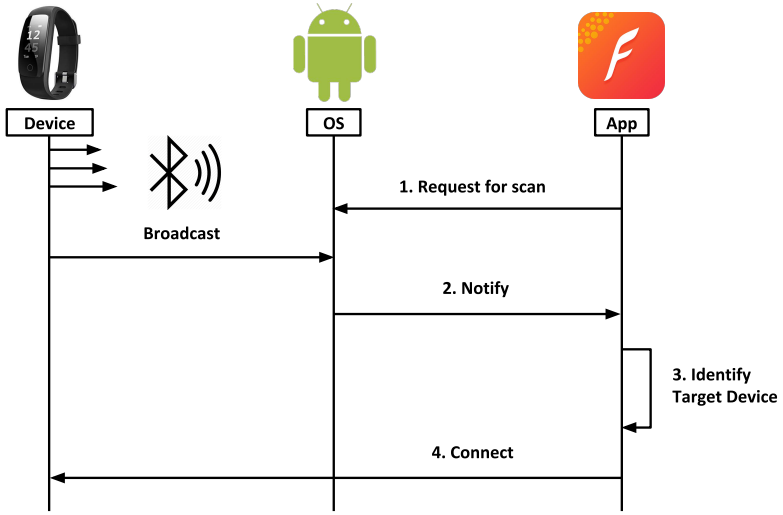

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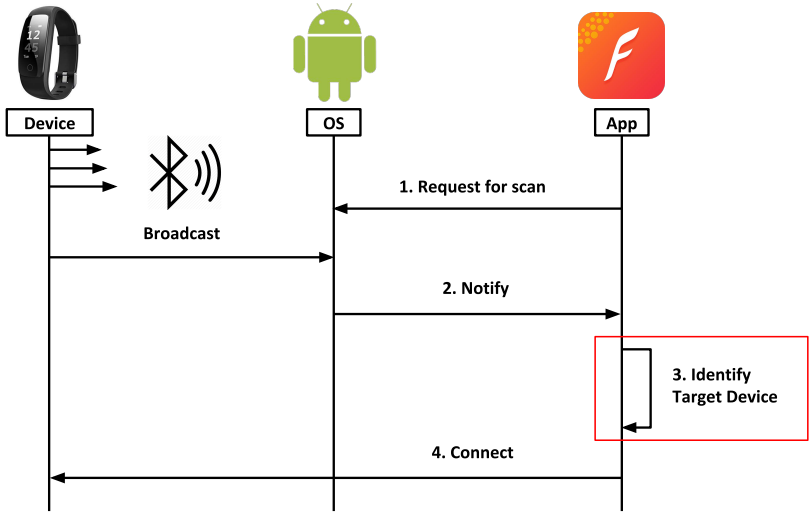

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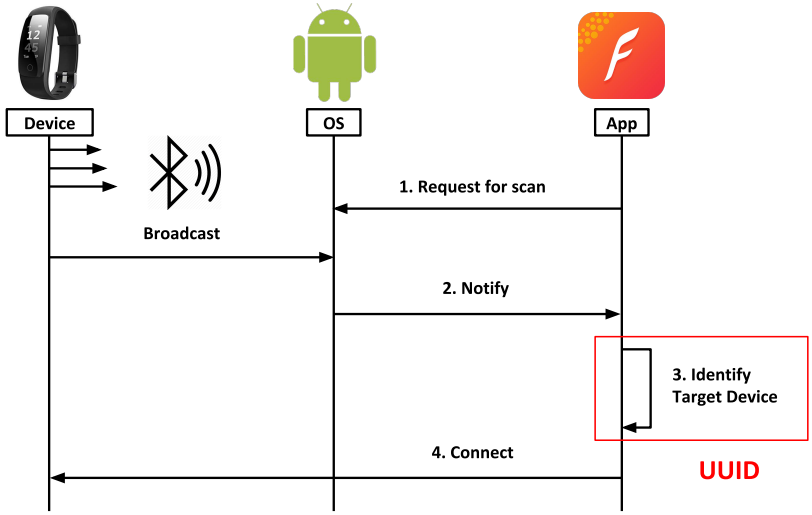
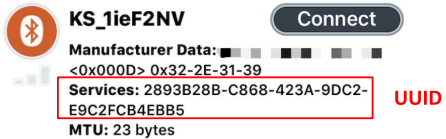
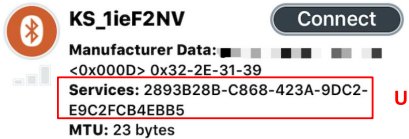


Our Observations



A BLE Broadcast Packet

Our Observations



A BLE Broadcast Packet

```
public class TemperatureService {
    public static final UUID EVENT_CHAR_UUID;
    public static final UUID PAIR_STATUS_CHAR_UUID;
    public static final UUID REQUEST_CHAR_UUID;
    public static final UUID RESPONSE_CHAR_UUID;
    public static final ParcelUuid SERVICE_PARCEL_UUID;
    public static final UUID SERVICE_UUID;

    static {
        TemperatureService.SERVICE_UUID = UUID.fromString("2893B28B-C868-423A-9DC2-E9C2FCB4EBB5");
        TemperatureService.SERVICE_PARCEL_UUID = new ParcelUuid(TemperatureService.SERVICE_UUID);
        TemperatureService.REQUEST_CHAR_UUID = UUID.fromString("28930000-C868-423A-9DC2-E9C2FCB4EBB5");
        TemperatureService.RESPONSE_CHAR_UUID = UUID.fromString("28930001-C868-423A-9DC2-E9C2FCB4EBB5");
        TemperatureService.EVENT_CHAR_UUID = UUID.fromString("28930002-C868-423A-9DC2-E9C2FCB4EBB5");
        TemperatureService.PAIR_STATUS_CHAR_UUID = UUID.fromString("28930003-C868-423A-9DC2-E9C2FCB4EBB5");
    }
```

UUID

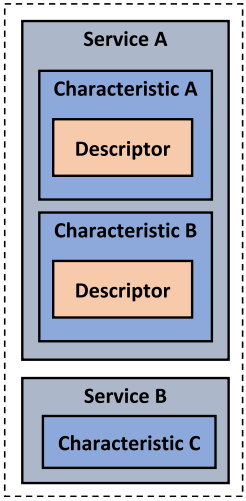
Decompiled Code in a Companion App

Our Observations

Key Insights

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

Hierarchy of UUIDs

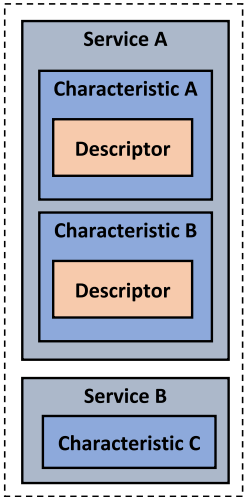



```
Service
    name: KINSA_SERVICE
    uuid: 00000000-006a-746c-6165…
    characteristics:
              name: REQUEST_CHARACTERISTIC
              uuid: 00000004-006a-746c-6165…
              descriptors: […]

              name: RESPONSE_CHARACTERISTIC
              uuid: 00000002-006a-746c-6165…
              descriptors: […]

Service
     name: BATTERY_SERVICE
     uuid: 180F
     characteristics: […]
      …
```

Hierarchy of UUIDs

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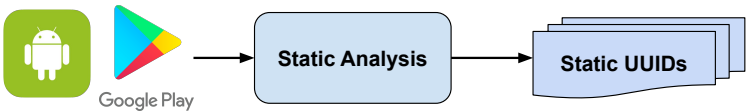
How to Fingerprint a BLE IoT Device with Static UUIDs



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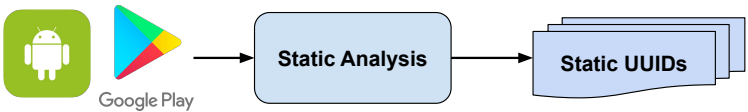

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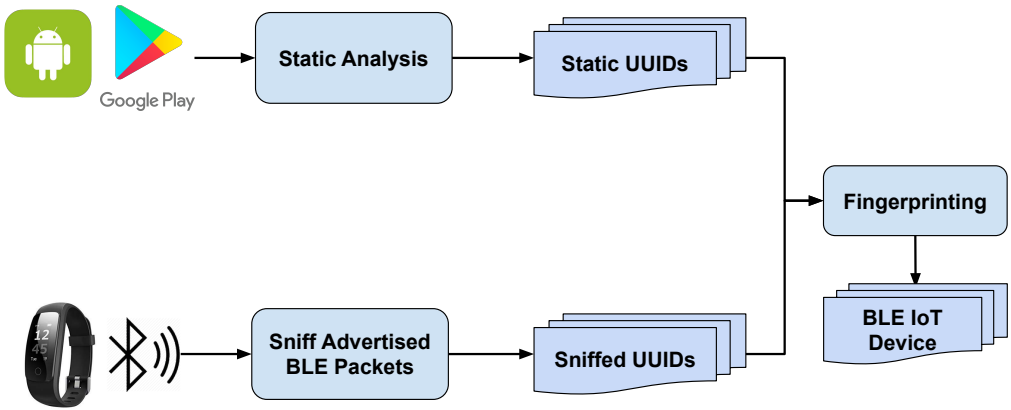
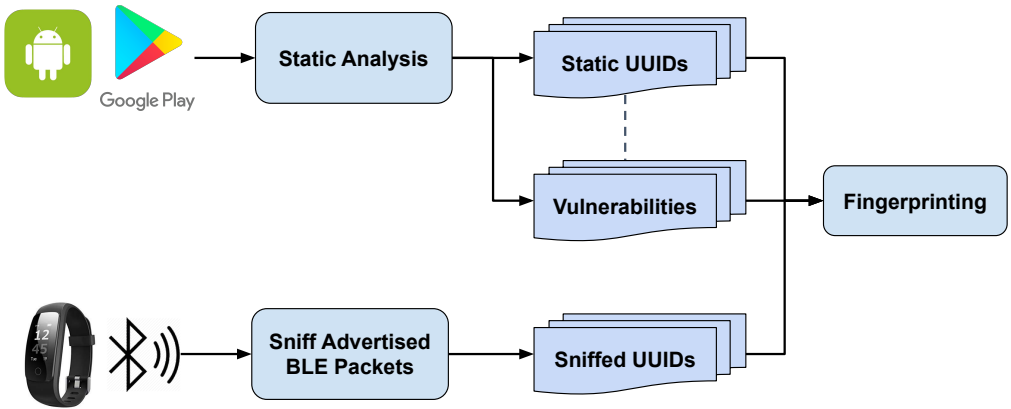


Application of BLE IoT Device Fingerprinting



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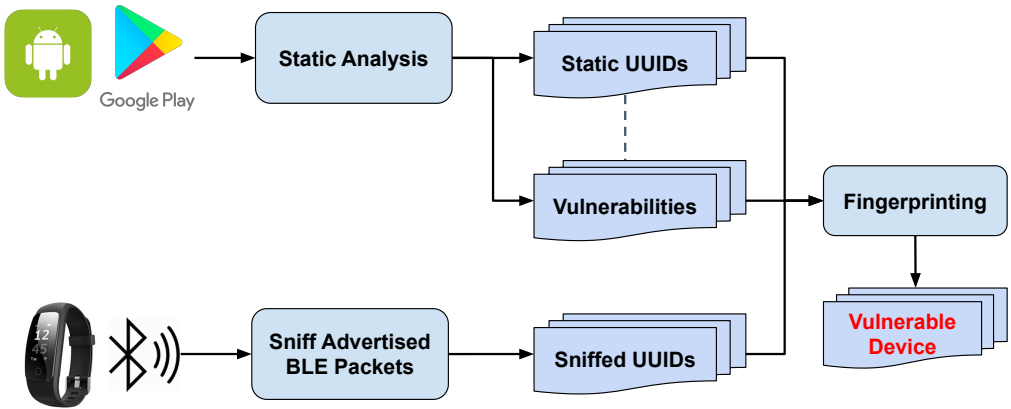

Our Contributions

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

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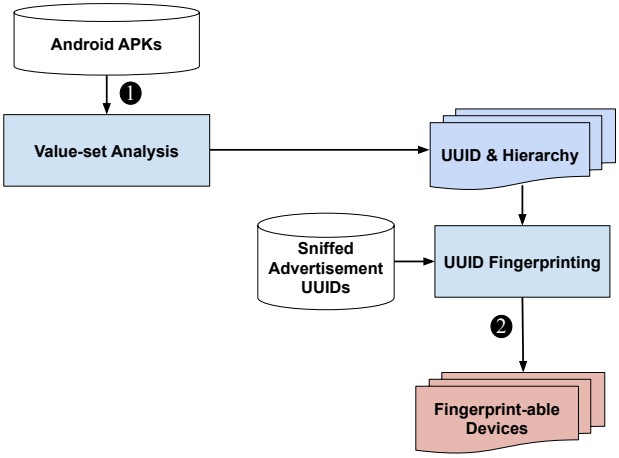

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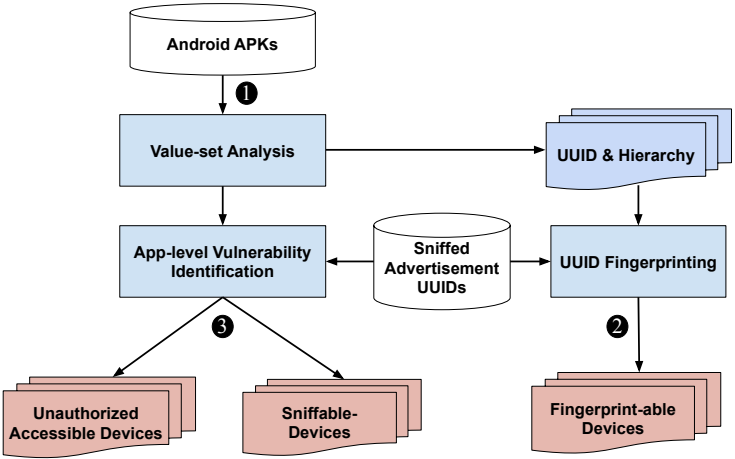

Challenges and Insights

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

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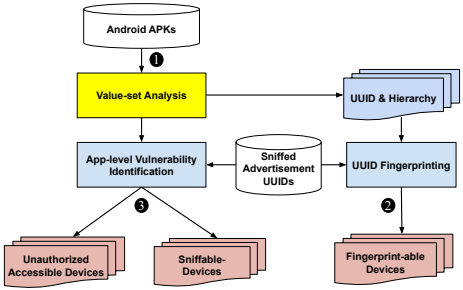
Solutions

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

Value Set Analysis



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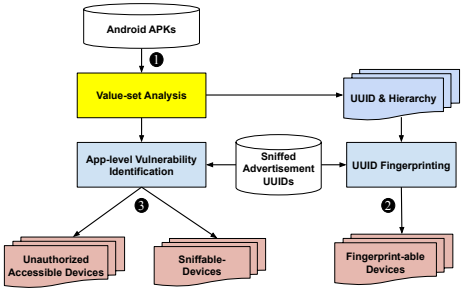

Category	API Name
UUID	BluetoothGatt: BluetoothGattService getService BluetoothGattService: BluetoothGattCharacteristic getCharacteristic BluetoothGattCharacteristic: BluetoothGattDescriptor getDescriptor ScanFilter.Builder: ScanFilter.Builder setServiceUuid ScanFilter.Builder: ScanFilter.Builder setServiceUuid ScanFilter.Builder: ScanFilter.Builder setServiceData ScanFilter.Builder: ScanFilter.Builder setServiceData

Table: APIs for UUID extraction and hierarchy reconstruction

UUID Extraction

```
1  public class KelvinDeviceProfile
2     private KelvinDeviceProfile(BlueToothLeGatt arg3)
3       super();
4       BluetoothGattService v0 = arg3.getService(KelvinGatt.KINSA_SERVICE);
5       if(v0!=null)
6         this.request = v0.getCharacteristic(KelvinGatt.REQUEST_CHARACTERISTICS);
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9
10      BluetoothGattService v3 = arg3.getService(KelvinGatt.BATTERY_SERVICE_UUID);
11      if(v3!=null)
12        this.batterylevel = v3.getCharacteristic(KelvinGatt.BATTERY_VALUE_CHAR_UUID);
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17 public class KelvinGatt
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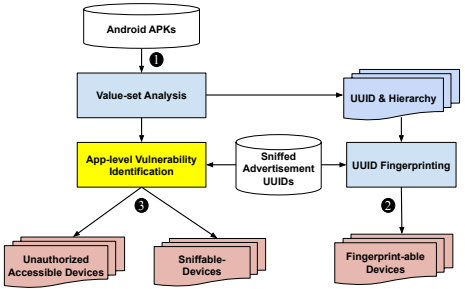
App-level Vulnerability Identification



Category	API Name
"Just Works"	BluetoothDevice: boolean createBond() BluetoothDevice.ACTION_BOND_STATE_CHANGED
Authentication	BluetoothGattCharacteristic: boolean setValue(String) BluetoothGattCharacteristic: boolean setValue(int,int,int) BluetoothGattCharacteristic: boolean setValue(byte[]) BluetoothGattCharacteristic: boolean setValue(int,int,int,int)
Cryptography	Cipher: byte[] doFinal(byte[]) Mac: byte[] doFinal(byte[]) MessageDigest: byte[] digest(byte[])

Table: APIs for app-level vulnerability identification

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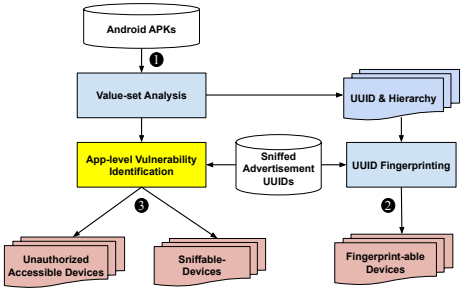

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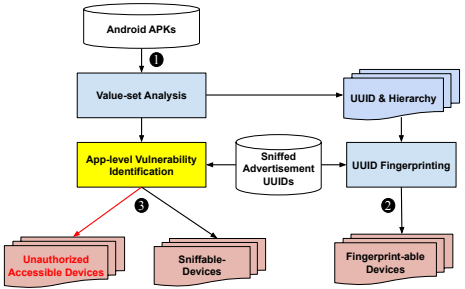

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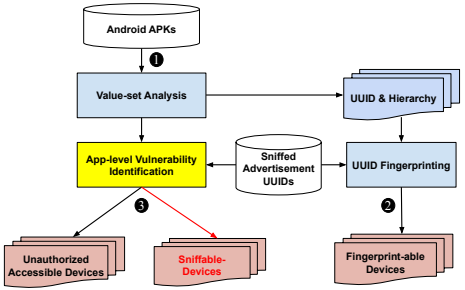

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API Name
BluetoothGatt: List getServices
BluetoothGatt: BluetoothGattService getService
BluetoothGattService: UUID getUuid
BluetoothGattService: BluetoothGattCharacteristic getCharacteristic
BluetoothGattCharacteristic: UUID getUuid

Table: APIs used to identify the BLE related IoT apps

Result of UUID Extraction and Hierarchy Reconstruction

Item	Value	%
# Apps Collected	18,166	
# UUID Identified	168,093	
# Unique UUID Identified	13,566	
# UUID Hierarchy Edges	540,797	100.0
# UUID Hierarchy Service Edges	316,379	58.5
# UUID Hierarchy Characteristics Edges	224,418	41.5

Table: Experimental result of UUID extraction and hierarchy reconstruction.

Result of UUID Extraction and Hierarchy Reconstruction

opcode	# operations	opcode	# operations
+	79,743	—	1,398
/	9,684	&	1,266
*	5,364	>>>	894
<<	1,860	^	462
-	1,775	>>	17

Table: Operations to resolve UUIDs.

Result of UUID Extraction and Hierarchy Reconstruction

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*	5,364	>>>	894
<<	1,860	^	462
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Table: Operations to resolve UUIDs.

# Apps Mapped to a Single UUID	Value	%
# 1	8,870	65.4
# 2	1,831	13.5
# 3	688	5.0
# 4	469	3.5
# 5	330	2.4
# ≥ 6	1,378	10.1

Table: Mapping between UUID and apps.

Result of App-level Vulnerability Identification

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.

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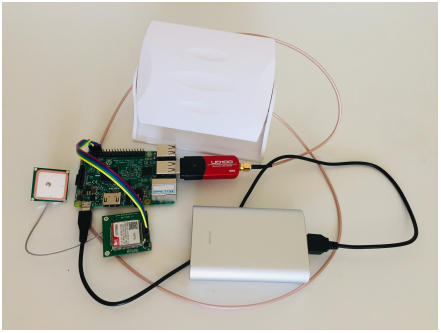
Table: Insecure app identification result.

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.

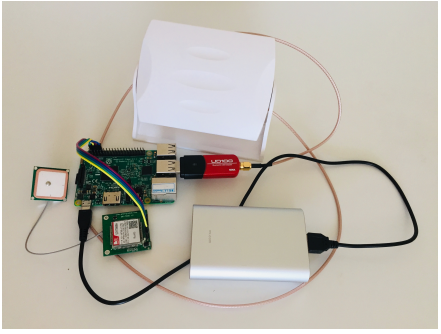
Field Test Environment Setup



BLE Sniffer

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

Field Test Environment Setup



Field Test Result

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.

Field Test Result

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.

Field Test Result

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.

Anti-UUID Fingerprinting

Countermeasures

1. **App-level protection**. Use obfuscation [HGM18], encoding, encryption, or cloud to hide UUIDs in mobile apps.
2. **Channel-level protection**. BLE-Guardian [FKS16]

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Drawbacks

1. UUIDs are statically constructed and can still be retrieved from apps.
2. Additional hardware support is required.
3. Not fundamental solutions.

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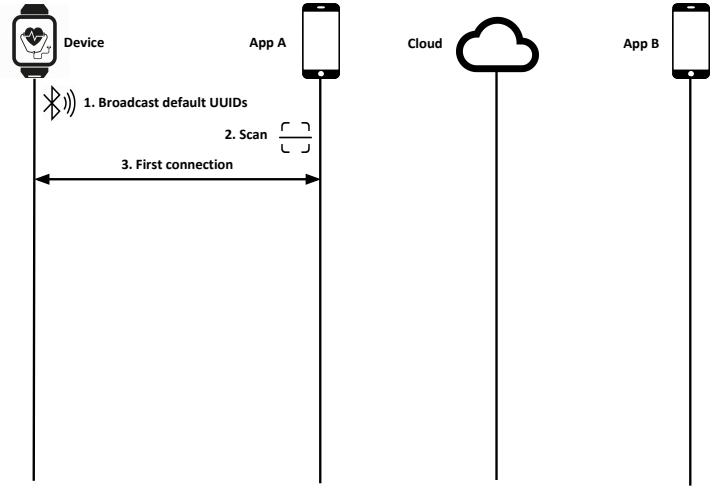
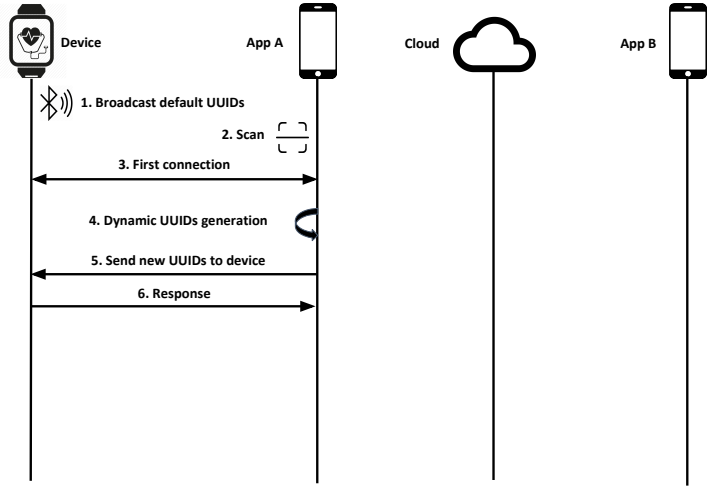
2. **Channel-level protection**. BLE-Guardian [FKS16]
3. **Protocol-level protection**. Construct one-time dynamic UUIDs for broadcast and communication.

Dynamic UUID Generation



Dynamic UUID Generation



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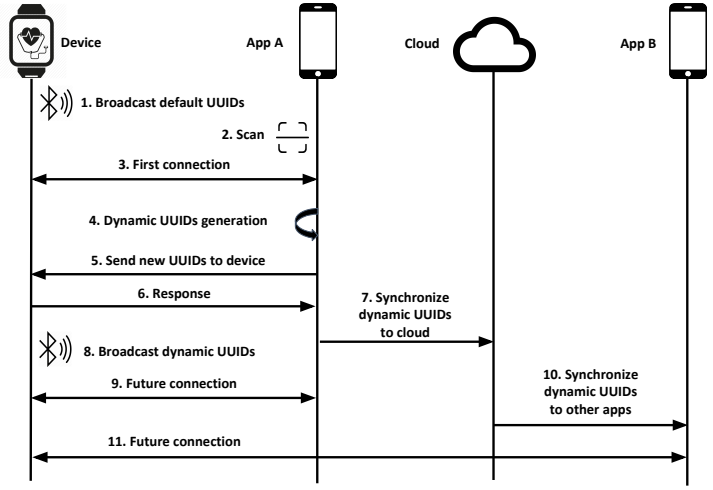
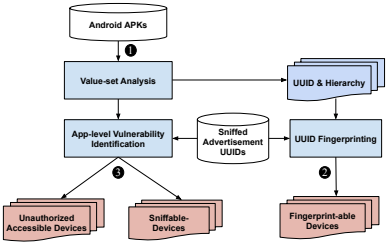
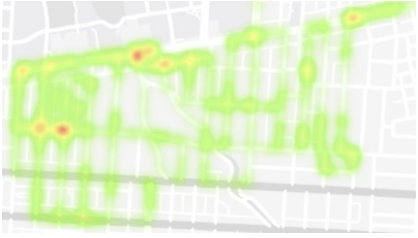


Related Work

1. **IoT Security**.
   - Vulnerability discovery of IoT devices. Credential leakage [CAWM17, CHMS14], unchanged address [BMI08, DPCM16], privilege misconfiguration [FJP16, HLM+16], unencrypted channel [ZL17a] and memory corruption [CDZ+18].
   - Defenses of vulnerabilities [FPR+16, DMK+12, TZL+17, FKS16].
2. **BLE Security**. Insecure pairing protocol and eavesdropping attack [Rya13]. MITM attacks [SBA18, SMS18], and brute force attack to break long term pairing key [Zeg15].
3. **Vulnerability discovery based on mobile apps analysis**.
   - Client Side: FlowDroid [ARF+14], Amandroid [WROR14], TaintDroid [EGC+10], PiOS [EKKV11], CHEX [LLW+12], SMV-Hunter [SSG+14].
   - Server Side: AutoForge [ZWWL16], SmartGen [ZL17b], AuthScope [ZZL17], LeakScope [ZLZ19], WARDroid [MG18].

BLEScope





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

Limitations and Future Work

1. **Fingerprinting precision**. We did not use the hierarchy UUIDs to fingerprint the device. This is due to ethical consideration, since it requires to fetch the data from the devices to construct the hierarchy of UUIDs (unauthorized access).

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2. **False negatives**. We applied a strict rule to detect flawed authentication in apps.
3. **Branch explosion**. The backward slicing attempts to exhaustively explore all possible branches. We will terminate our analysis for such apps.
4. **Optional UUIDs**. UUIDs do not always exist in BLE broadcast packets [BLS19]. No mobile apps, no need to broadcast UUIDs. (In our field test, we found 25k such BLE devices.)

Thank You

Automatic Fingerprinting Of Vulnerable BLE IoT Devices With Static UUIDs From Mobile Apps

Chaoshun Zuo, **Haohuang Wen**, Zhiqiang Lin, and Yinqian Zhang

Department of Computer Science and Engineering
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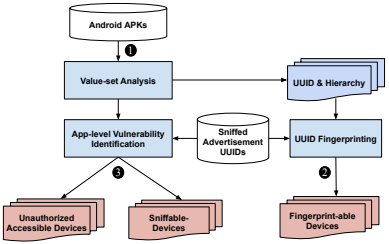
CCS 2019

Takeaway



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