Mobile Network Security

ACN / Mobile Security 2020

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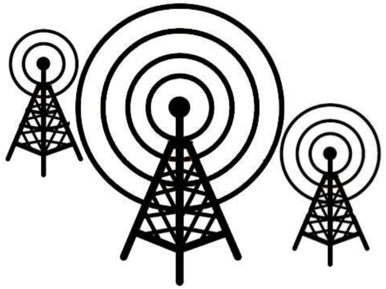
Outline

- Theory
  - Architecture of 2G / 3G networks, Evolution of 2G, 3G, 4G
  - GSM encryption
- Attacks
  - Active: IMSI Catchers, Passive: Cracking A5/1
  - Signaling System 7, LTE Security
- Protection Mechanisms
  - Are you protected? How to defend yourself?

Introduction



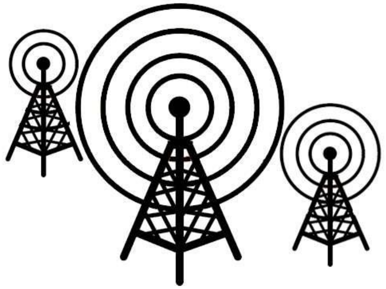
Goals

- Protect business models and operational services
- Privacy for user identity, data confidentiality
- Regulatory issues → legal interception

How to apply security?

- Minimize number of security threats
- Remember: Cost efficiency & high performance (load balancing)
- Interoperability with legacy systems (GSM <-> UMTS)
- Practical issues, e.g. end-to-end *vs.* hop-by-hop security?

Introduction



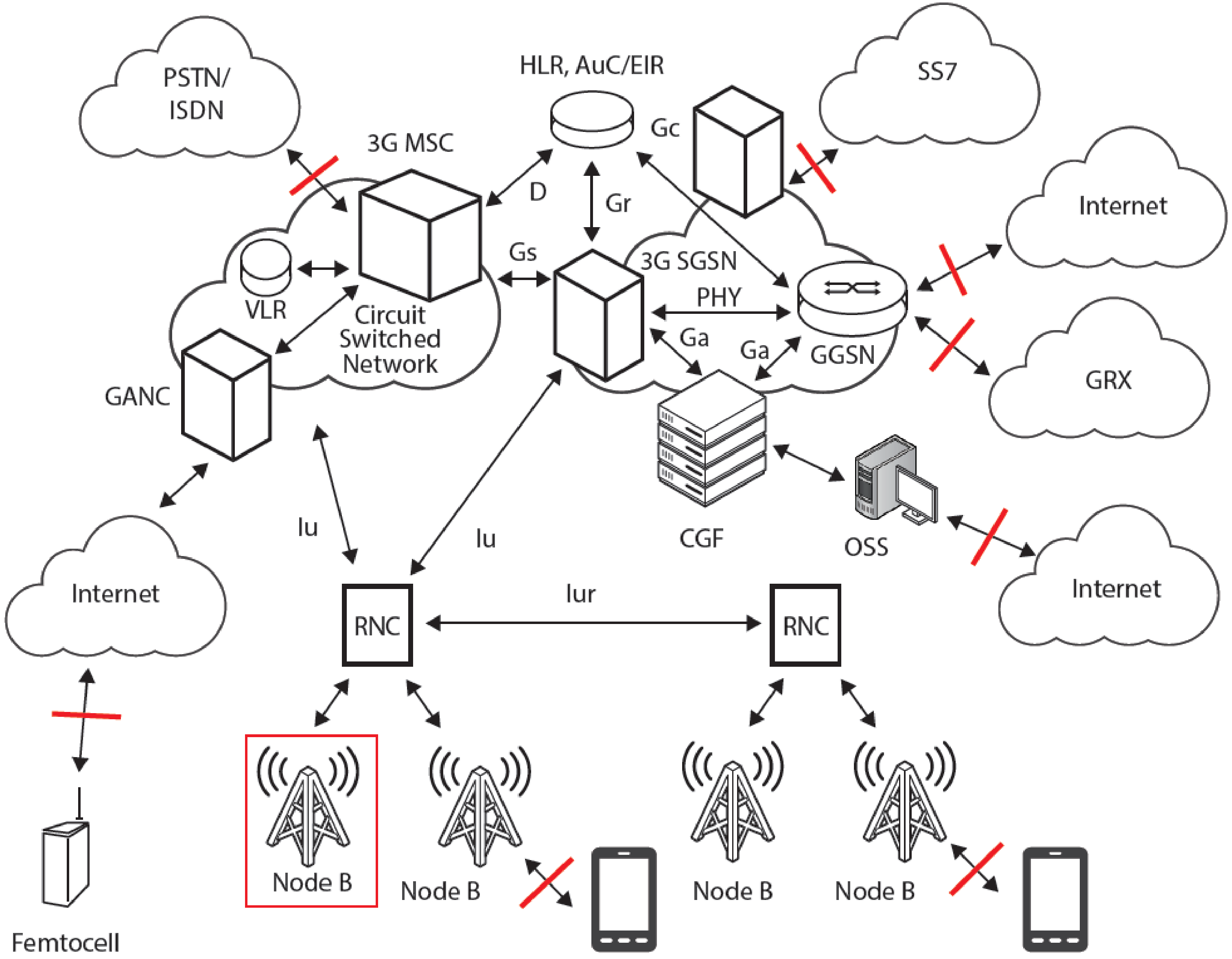
Technical objectives

- Authentication of user and network
- Confidentiality
  - User data & signaling data
  - User & device identity
  - User location
- Signaling data integrity
- User untraceability(?)

→ Need strong algorithms for enciphering and integrity,
→ Need algorithm extensibility for future proofness

Some theory...

3G/4G Network Structure



Source: https://goo.gl/V98GB5

Legend

- Node B
  UMTS Base Station
- RNC
  Radio Network Controller
- SGSN
  Serving GPRS Support Node
- GGSN
  Gateway GPRS Support Node
- MSC
  Mobile Switching Center

3G/4G Network Workflow

GSM equivalent: Base Transceiver Station (BTS)

1) Node B

- Minimum functionality base station in UMTS networks
- Typically located near the antenna (but not necessarily)
- Controlled by RNC using a „Iub“ interface

2) RNC

- Main task: Manage connected Node Bs and radio resources
  - Channels, signal strength (power), cell handover
- Can build Mesh networks with other RNCs

3a) Speech: MSC (Mobile Switching Centre) → routing voice / SMS

3b) Data: SGSN → routing data

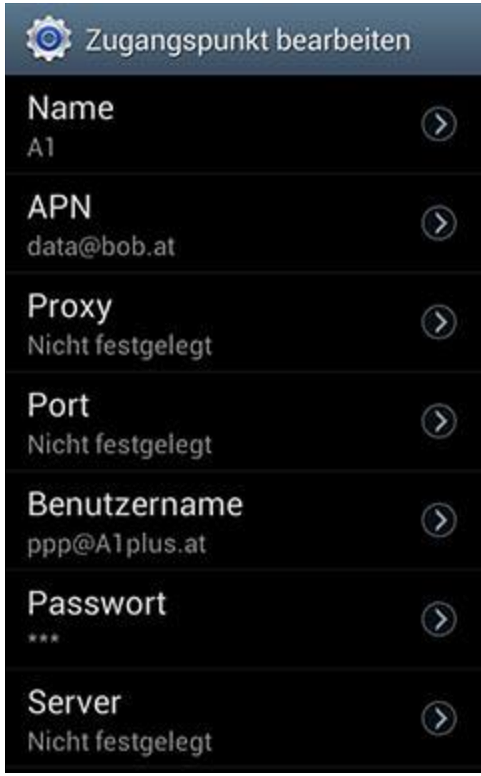
3G/4G Network Components

SGSN

- Data delivery from/to mobile station in defined geographical service area
- (*De-*)tunnel packets from/to GGSN (*Downlink*, Uplink)
- Handover → phone moves from Routing Area A to Routing area B
- User data billing

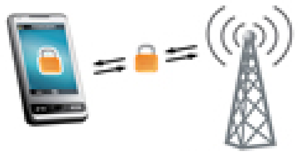
GGSN

- Inter-networking between internal network and external packet switched networks (Internet)
- Keeps your connections alive while moving around
- User authentication, IP pool management, QoS



GSM Encryption

How? Stream ciphers to encrypt traffic on air interface



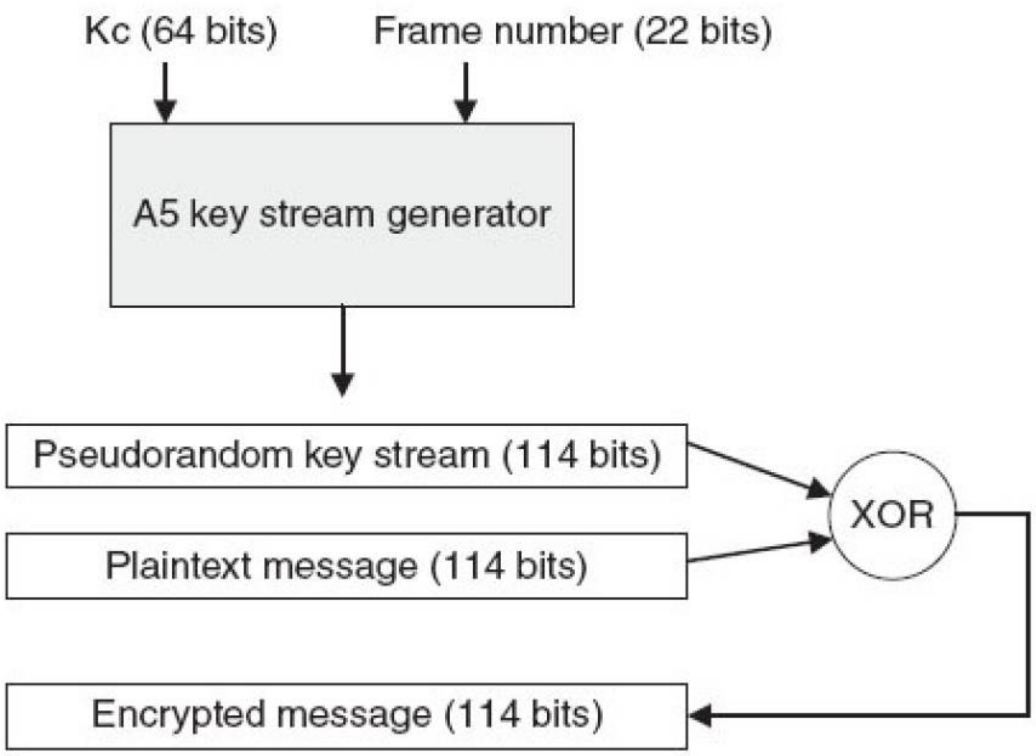
Set of algorithms

- A5/0: Unencrypted, no cracking needed ☺
  → broken (and partly banned, e.g. by T-Mobile Austria)
- A5/1: Combination of 3 linear feedback shift registers (LFSRs)
  → 64-bit key, broken using rainbow tables in 2009
- A5/2: export version of A5/1
  → broken in 1999, banned since 2006
- A5/3 + A5/4: Backport of Kasumi UMTS cipher (current standard)
  – 128-bit key, 64-bit input / output

GSM Encryption A5/1

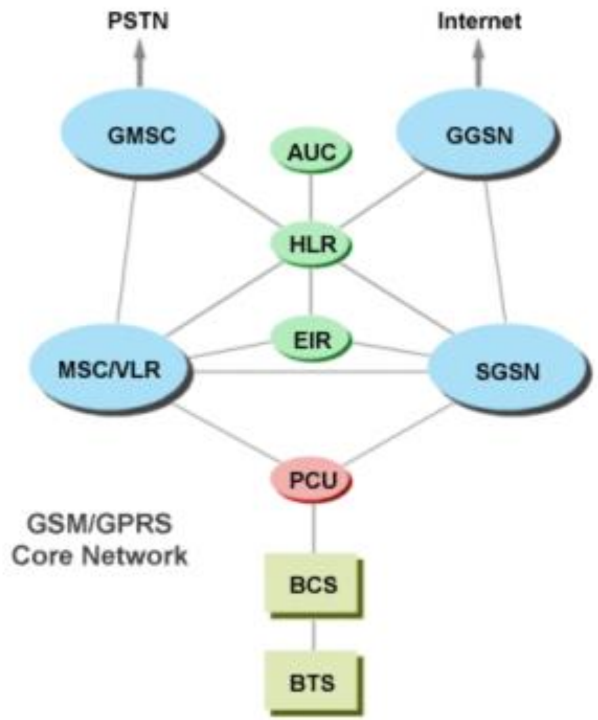
Key size: 64 bits(!!)

Avoid replay attacks



Evolution: 2G Networks

- Commerical launch in 1992
- User authentication based on per-subscriber secret key in SIM
- TDMA-based, circuit switching
  - „Time Division Multiple Access“
  - Share same frequency channel for multiple users by dividing signal into different time slots



Versions

- 2.5G: GPRS (added in 2000)
  - Theoretical speed: 171 kbps down, 40 kbps up
- 2.7G: EDGE
  - Theoretical speed: 384 kbps down, 108 kbps up

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Evolution: 3G Networks

Features

- Same core network as 2G
  - Still circuit-switched (GSM) & packet-switched hybrid (UMTS)
- No integrity protection (like LTE) → Downgrade attacks possible
- Almighty base station → Decides if, when, and how to authenticate / encrypt

Versions

3G	UMTS	max. 2 Mbps down, 384 kbps up
3.5G	HSDPA	max. 14.4 Mbps down, 2 Mbps up
3.6G	HSUPA	max. 14.4 Mbps down, 5.76 Mbps up
3.75G	HSPA+	max. 21 Mbps down, 5.8 Mbps up
3.8G	HSPA+ Enhanced	max. 84 Mbps down, 20 Mbps up
3.9G	LTE (**pre 4G!**)	max. 100 Mbps down, 50 Mbps up

Evolution: 4G Networks

Currently: LTE Advanced (LTE-A) max. 1 Gbit down, 500 Mbit up

Features

- Only IP-based communication (also voice → VoLTE), no more circuit switching
  - Fallback support for circuit-switched calls
- Mutual authentication between base station & mobiles
- Mandatory integrity protection for signaling messages
- IMEI ciphered to protect user equipment privacy

- New algorithms and extensibility
  - Word-oriented stream cipher (128 bit key): SNOW 3G
  - Integrity, confidentiality: AES-GCM

(Recent) Attacks

Scenarios

Intercept

- Adversary records calls & SMS
  - Decryption in real time or batch process (after recording)

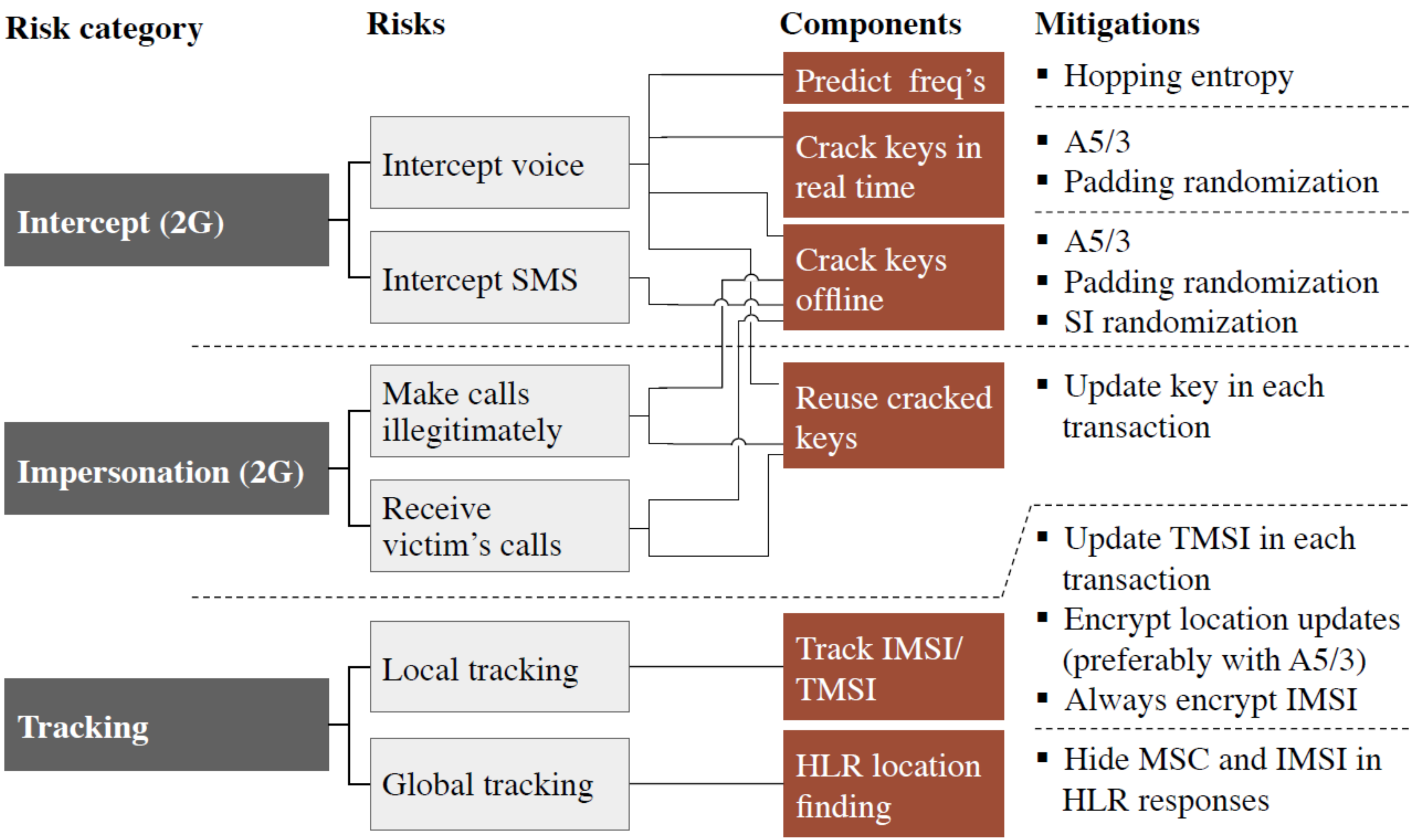
Impersonation

- Calls or SMS spoofed
- Received using stolen mobile identity

Tracking

- Tracing mobile subscribers
  - a) using Internet-leaked information
  - b) locally by repeated TMSI pagings

Scenarios & Mitigations



Source: https://goo.gl/15pRhE

Active Attack: Fake Base Stations

= IMSI Catchers

- Partially exploit weaknesses in GSM & 3G networks
- Used for
  - Tracking users (IMEI, IMSI, location)
  - Eavesdropping calls, data, SMS, etc.
  - Man-in-the-Middle
  - Attack phone using operator system messages,
    - e.g. Management Interface, re-program APN, HTTP proxy, SMS/WAP server, …
  - Attack SIM or phone baseband
  - Geo-targeting ads (SMS)
  - Intercept TAN, mobile phone authentication, …

Tracking,
Call & Data interception

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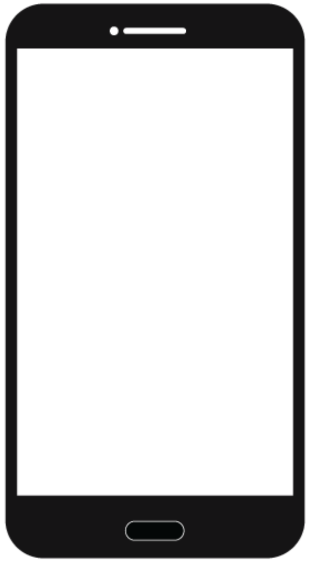
How does it work?



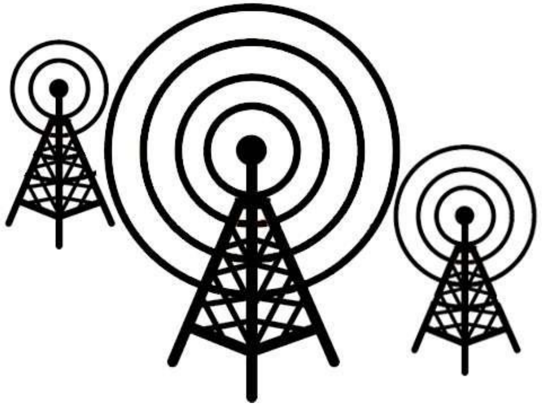
Advertise base station on beacon channel

Phone sends IMSI / TMSI (sort of secret)

MCC: Mobile Country Code (232 for .at)

MNC: Mobile Network Code

- Country-specific tuple with MCC, e.g. 232-01 for a1.net



→ Phones will connect to *any* base station with spoofed MNC/MCC

- If you claim it, they will come because strongest signal wins ☺
- Crypto optional (until 4G) and set by base station!

Terminal 1

Fichier Édition Affichage Rechercher Terminal Aide

```
$ sudo python simple_IMSI-catcher.py
WARNING: No route found for IPv6 destination :: (no default route?)
cpt ; IMSI ; country ; brand ; operator
1 ; 234 20 730143[redacted] ; Guernsey (United Kingdom) ; 3 ; Hutchison 3G UK Ltd
2 ; 208 20 154308[redacted] ; France ; Bouygues ; Bouygues Telecom
3 ; 208 20 029666[redacted] ; France ; Bouygues ; Bouygues Telecom
4 ; 208 20 085162[redacted] ; France ; Bouygues ; Bouygues Telecom
5 ; 208 20 031381[redacted] ; France ; Bouygues ; Bouygues Telecom
6 ; 208 20 031233[redacted] ; France ; Bouygues ; Bouygues Telecom
7 ; 208 20 031343[redacted] ; France ; Bouygues ; Bouygues Telecom
8 ; 208 20 171286[redacted] ; France ; Bouygues ; Bouygues Telecom
9 ; 208 20 090096[redacted] ; France ; Bouygues ; Bouygues Telecom
10 ; 208 20 100817[redacted] ; France ; Bouygues ; Bouygues Telecom
11 ; 208 20 144546[redacted] ; France ; Bouygues ; Bouygues Telecom
12 ; 208 20 220088[redacted] ; France ; Bouygues ; Bouygues Telecom
13 ; 208 20 171268[redacted] ; France ; Bouygues ; Bouygues Telecom
14 ; 208 20 154457[redacted] ; France ; Bouygues ; Bouygues Telecom
15 ; 208 20 144758[redacted] ; France ; Bouygues ; Bouygues Telecom
16 ; 208 20 031231[redacted] ; France ; Bouygues ; Bouygues Telecom
17 ; 208 25 001134[redacted] ; France ; LycaMobile ; LycaMobile
18 ; 208 20 171275[redacted] ; France ; Bouygues ; Bouygues Telecom
19 ; 208 20 031317[redacted] ; France ; Bouygues ; Bouygues Telecom
20 ; 208 20 154456[redacted] ; France ; Bouygues ; Bouygues Telecom
21 ; 208 20 144857[redacted] ; France ; Bouygues ; Bouygues Telecom
22 ; 208 20 031261[redacted] ; France ; Bouygues ; Bouygues Telecom
23 ; 208 20 144819[redacted] ; France ; Bouygues ; Bouygues Telecom
24 ; 208 20 100230[redacted] ; France ; Bouygues ; Bouygues Telecom
```

Terminal 2

Fichier Édition Affichage Rechercher Terminal Aide

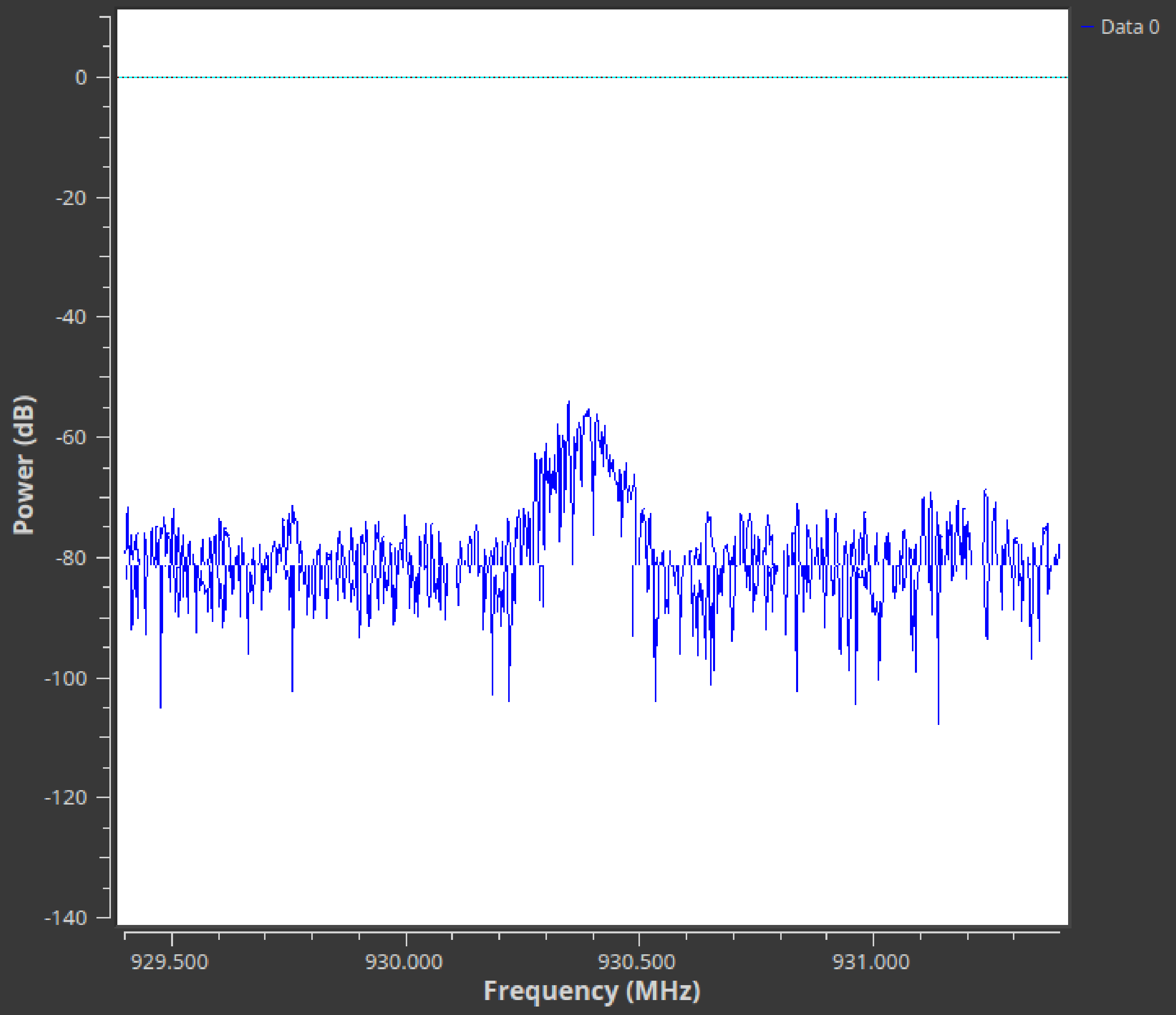
```
$ airprobe_rtlsdr.py
linux; GNU C++ version 5.3.1 20151219; Boost_105800; UHD_003.009.002-0-unknown

gr-osmosdr 0.1.4 (0.1.4) gnuradio 3.7.9
built-in source types: file osmosdr fcd rtl rtl_tcp uhd miri hackrf bladerf rfsp
ace airspy redpitaya
Using device #0 Realtek RTL2838UHIDIR SN: 00000001
Found Rafael Micro R820T tuner
[R82XX] PLL not locked!
Exact sample rate is: 2000000,052982 Hz
[R82XX] PLL not locked!
Using Volk machine: sse3_64_orc
 2d 06 22 00 d8 58 3a 30 a0 0d 25 b8 2b 2b 2b 2b 2b 2b 2b 2b 2b 2b 2b
 31 06 21 00 08 29 43 02 37 10 34 [redacted] 2b 2b 2b 2b 2b 2b 2b 2b 2b 2b
 15 06 21 00 01 f0 2b 2b 2b 2b 2b 2b 2b 2b 2b 2b 2b 2b 2b 2b 2b 2b 2b
 2d 06 22 00 ec 58 13 18 80 06 e3 b9 2b 2b 2b 2b 2b 2b 2b 2b 2b 2b 2b
 15 06 21 00 01 f0 2b 2b 2b 2b 2b 2b 2b 2b 2b 2b 2b 2b 2b 2b 2b 2b 2b
 15 06 21 00 01 f0 2b 2b 2b 2b 2b 2b 2b 2b 2b 2b 2b 2b 2b 2b 2b 2b 2b
 59 06 1a 8f e7 90 80 ad 1c 60 49 00 00 00 00 00 00 00 00 ff 79 00 00
 01 2b 2b 2b 2b 2b 2b 2b 2b 2b 2b 2b 2b 2b 2b 2b 2b 2b 2b 2b 2b 2b 2b
 2d 06 22 00 90 0e 42 fa cf 58 e5 08 2b 2b 2b 2b 2b 2b 2b 2b 2b 2b 2b
 59 06 21 00 08 29 80 02 51 34 80 [redacted] 17 08 29 80 02 20 69 66 [redacted]
 25 06 21 00 05 f4 d1 68 9f 28 23 2b 2b 2b 2b 2b 2b 2b 2b 2b 2b 2b 2b
 25 06 21 00 05 f4 ff 68 0f 60 23 2b 2b 2b 2b 2b 2b 2b 2b 2b 2b 2b 2b
```

Gr-gsm Livemon

PPM Offset: 0

Gain: 30,000

Frequency: 930400000



Source: https://goo.gl/5L29Ft

IMSI Catchers in Practice

User identification

- Retrieve IMSI / IMEI / TMSI
- Reject location update
- Tracking

Traffic Man-in-the-middle

- Hold user in cell
- Actively intercept traffic
  - Relay to real network
  - Active or passive decryption

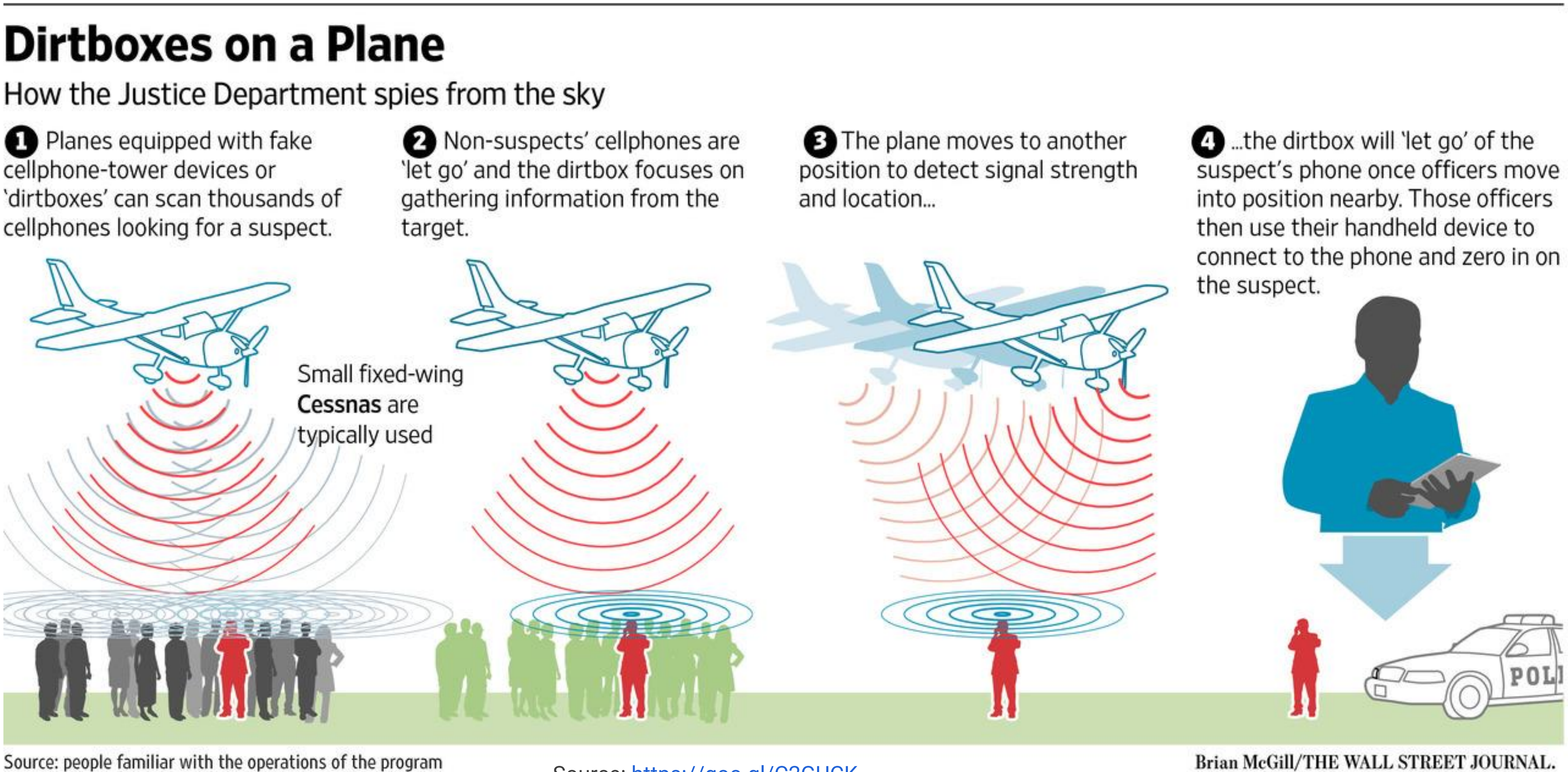
UMTS Downgrade

- Blocking UMTS transmission
- Spoofing system messages

Hold but intercept passively

- Imprison in cell
  → Phone not lost to neighbor cell

Fake Base Stations

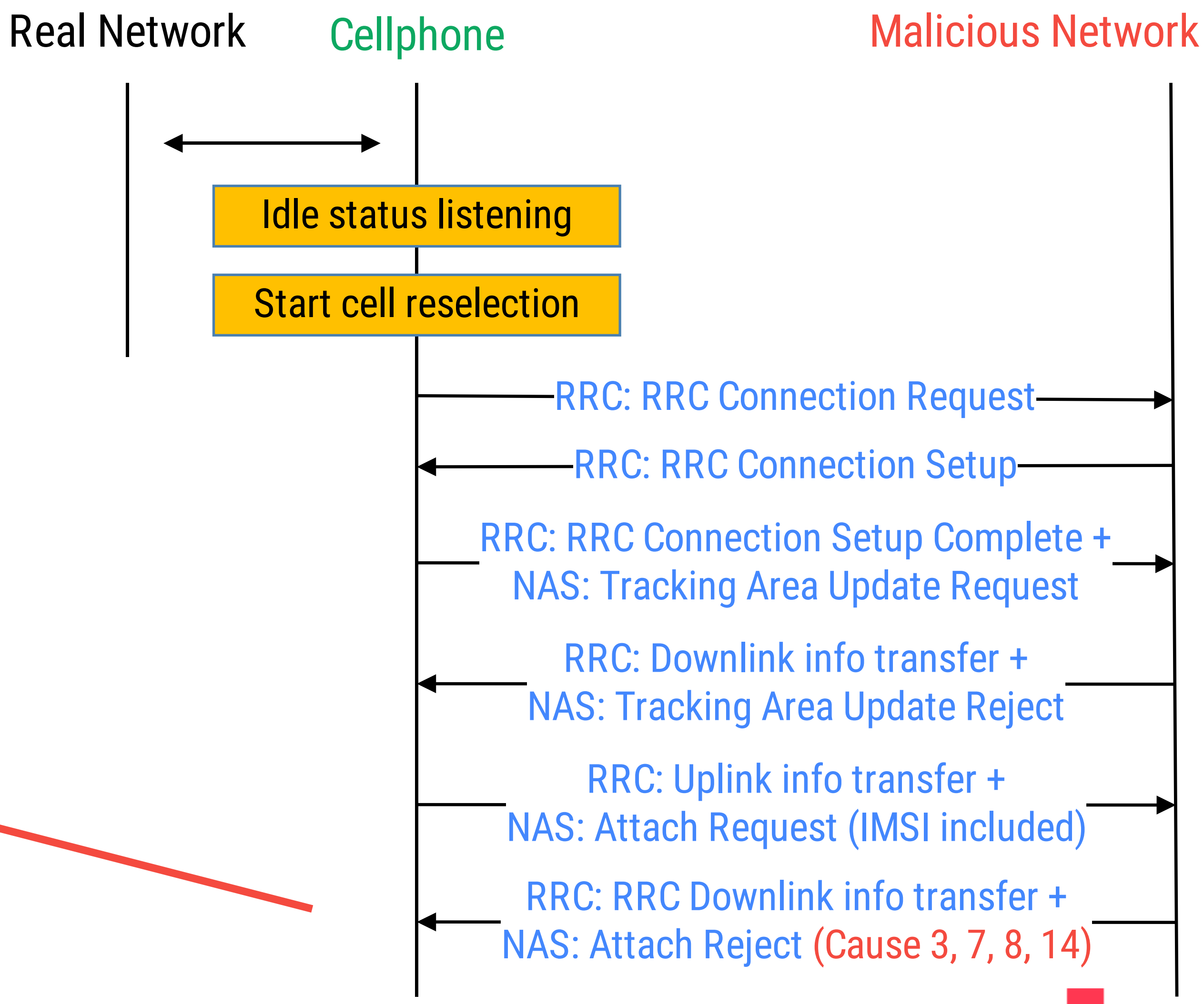


Source: https://goo.gl/C2GUCK

Active Attack: DoS

Fake base station sending messages

- „You are an illegal cellphone“
- „Here is no network available. You could shut down your 2G/3G/4G modem.“



Attach Request message can include cause for reject
→ Some special causes result in no service…

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Passive Attack: Key Cracking

- A5/1 vulnerable to generic pre-computation attacks
  - Goal: Break session key for communication between base station and phone

How to?

1. Intercept GSM call with reprogrammed 20 euro phone
   - Idea: Cluster multiple phones for wide-scale capture
2. Crack A5/1 session key using rainbow tables (1-2 TB)
   - Done in a few seconds using GPU power

Note: Also A5/3 uses only 64 bit key on SIM & USIM

→ According to „Intercept“ broken by NSA Source: https://goo.gl/mPluNH

→ GSM A5/4 and UMTS UEA/1 considered secure with USIM (128 bit key)

Signaling System 7

- Protocols used by most Telcos to identify network elements, clients, …
- Share session key in case of roaming (but works also without roaming!)

Problem:

- Walled-garden approach → we trust each other, need no auth
- Getting access is easy
  - Buy from telcos for < 1000 euro / month
  - Find equipment unsecured on internet (Shodan)

Attacker's playground

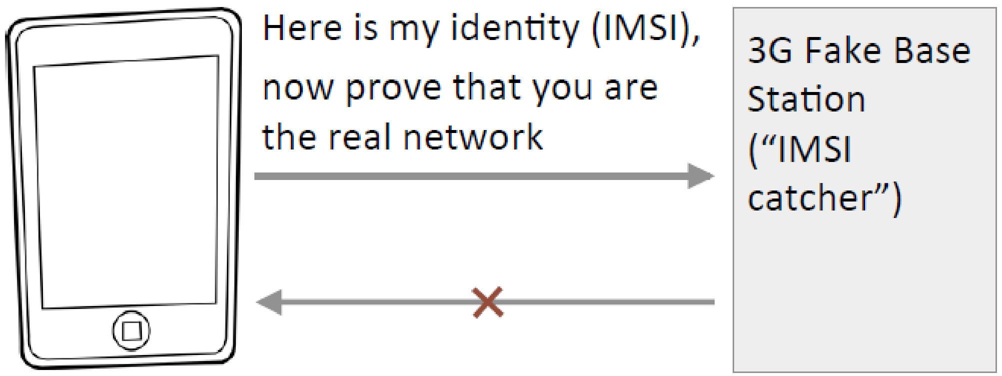
- Track any phone using a variety of signaling messages, e.g.
  - Phone number → `AnytimeInterrogation` → Get subscriber location (Cell ID)

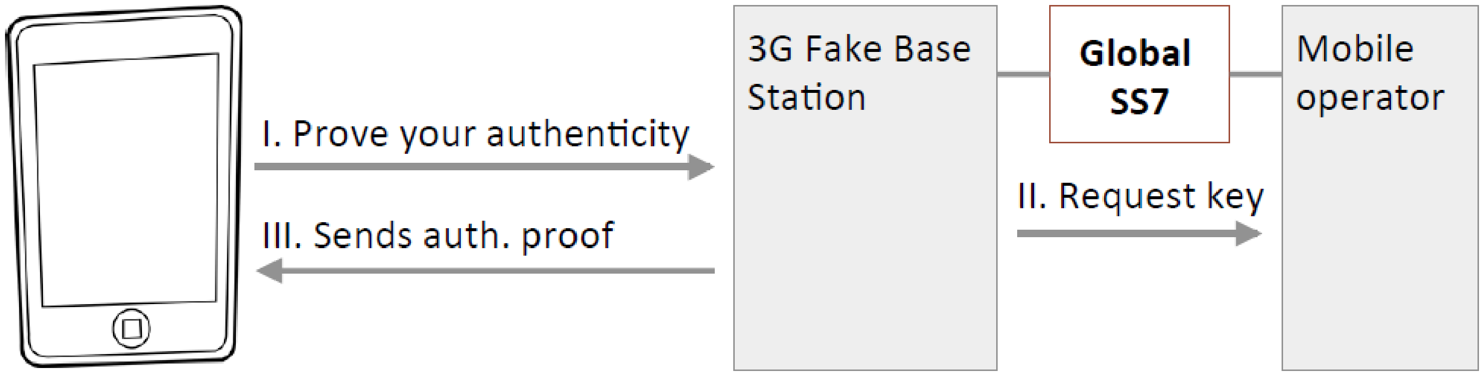
Signaling System 7

Send from any international SS7 inter-connection → abuse legitimate messages

Abuse Scenario

- Local passive intercept: `SendIdentification`
  → Easily blockable at network boundary
- 3G IMSI catcher: `SendAuthenticationInfo`
- Rerouting attacks: `UpdateLocation`
  → Message required for operations





Source: https://goo.gl/YBhvXw

Signaling System 7

How to intercept 3G (A5/3)?

1. Use software-defined radio (SDR) to capture 3G transactions
2. Query SS7 `SendIdentification` to get decryption key

Note: For many networks no SS7 needed for 3G interception!

Network	Encrypts	Authenticates calls / SMS	Protects integrity
	✗	✗	✔
	✗	✗	✔
	✗	✗	✔
	✗	✗	✔
	✗	✗	✔

Source: https://goo.gl/YBhvXw

LTE Security

Cipher & USIM improvements

→ No known ways to break used crypto, recover key from SIM, break authentication, encryption, or integrity protection

But…

- Not everything is encrypted
  - E.g. null encryption supported → Data is simply (unencrypted) plaintext
- Several messages allowed without integrity protection
  - E.g. null integrity for emergency calls, broadcast system, cell handover

Low-cost IMSI catcher for 4G/LTE networks tracks phones' precise locations

$1,400 device can track users for days with little indication anything is amiss.

The attacks target the LTE specification, which is expected to have a user base of about 1.37 billion people by the end of the year, and require about $1,400 worth of hardware that run freely available open source software. The equipment can cause all LTE-compliant phones to leak their location to within a 32- to 64-foot (about 10 to 20 meter) radius and in some cases their GPS coordinates,

Source: http://goo.gl/jlD7jQ

What?

Exploiting LTE *specification* flaws

Problems?

- RRC Protocol
  - – Measurement reports for handover
  - → Not authenticated, not encrypted
- EMM Protocol
  - – Control device mobility
  - → Not integrity protected

Attacker can

- Track user location / movements
- Downgrade to non-LTE

LimeSDR: Flexible, Next-generation, Open Source Software Defined Radio

Open Hardware
Technology

Home   Updates 40   Backers   History

Source: https://goo.gl/SD2ouo

$773,527 raised
of $500,000 goal

Funded!   **Order Now**

Jun 21	154%	3,175
funded on	funded	pledges

LimeSDR $289

The LimeSDR is based on Lime Microsystem's latest generation of field programmable RF transceiver technology, combined with FPGA and microcontroller chipsets. These connect to a computer via USB3. LimeSDR then delivers the wireless data and the CPU provides the computing power required to process the incoming signals, and to generate the data to be transmitted by the LimeSDR to all other devices.

Use with popular open source LTE projects

- OpenLTE See: https://goo.gl/GEUeHV
- Open Air Interface See: https://goo.gl/qSNrxk

Other Attack Vectors

- Branded mobile equipment
  - 3G/4G USB modems
  - Routers / Access points See: http://goo.gl/kIAJpe
  - Smartphones, femtocell, branded apps

- (U)SIM cards
  - Cracking SIM update keys, deploy SIM malware See: https://goo.gl/WYxUTq

- Radio / IP access network
  - Radio access network
  - IP access (GGSN, Routers, GRX) See: http://goo.gl/c3CNZ0

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Protection Mechanisms

Measures in Austria

- Numbers from 2014 (no LTE!)
- All 3G networks use A5/3 with encryption enabled
  - A1 & T-Mobile roll-out for 2G
- Unclear if networks would accept unencrypted transactions as well (subscriber-initiated)
- Call/SMS impersonation possible in all 2G networks

Attack vector		**Networks**		
		A1	T-Mobile	Three
2G Over-the-air protection				
- Encryption algorithm	A5/0	1%	0%	0%
	A5/1	8%	31%	35%
	A5/3	**91%**	**69%**	**65%**
- Require IMEI in CMC		○	◑	◕
- Hopping entropy		◔	◑	◔
- Authenticate calls (MO)		◔ 21%	◔ 23%	◔ 14%
- Authenticate SMS (MO)		○ 9%	◕ 67%	◔ 10%
- Authenticate paging (MT)		◔ 11%	◔ 16%	◔ 16%
- Authenticate LURs		◑ 40%	◑ 44%	◕ 61%
- Encrypt LURs		● 100%	● 100%	● 100%
- Update TMSI		◔ 32%	◕ 81%	◑ 44%
3G Over-the-air protection				
- Encryption		●	●	●
- Update TMSI		○ 1%	◕ 61%	○ 1%
HLR/VLR configuration				
- Mask MSC		●	●	●
- Mask IMSI		○	○	●

Source: https://goo.gl/fCqBZW

Abuse often detectable!

	Attack scenario	Detection heuristic
SMS Attacks	▪ **SIM OTA attacks** ▪ Semi-lawful **Tracking** through silent SMS	▪ Unsolicited binary SMS ▪ Silent SMS
SS7 Attacks	▪ SS7 abuse: **Tracking, Intercept**, etc.	▪ Empty paging
IMSI Catcher	▪ **Tracking** or **Intercept** through 2G or 3G fake base station	▪ Unusual cell configuration and cell behavior (detailed later in this chapter)
Network Security	▪ Insufficient encryption leads to **Intercept** and **Impersonation** ▪ Lack of TMSI updates enables **Tracking**	▪ Encryption level and key change frequency ▪ TMSI update frequency

Source: https://goo.gl/jFtXYu

SnoopSnitch

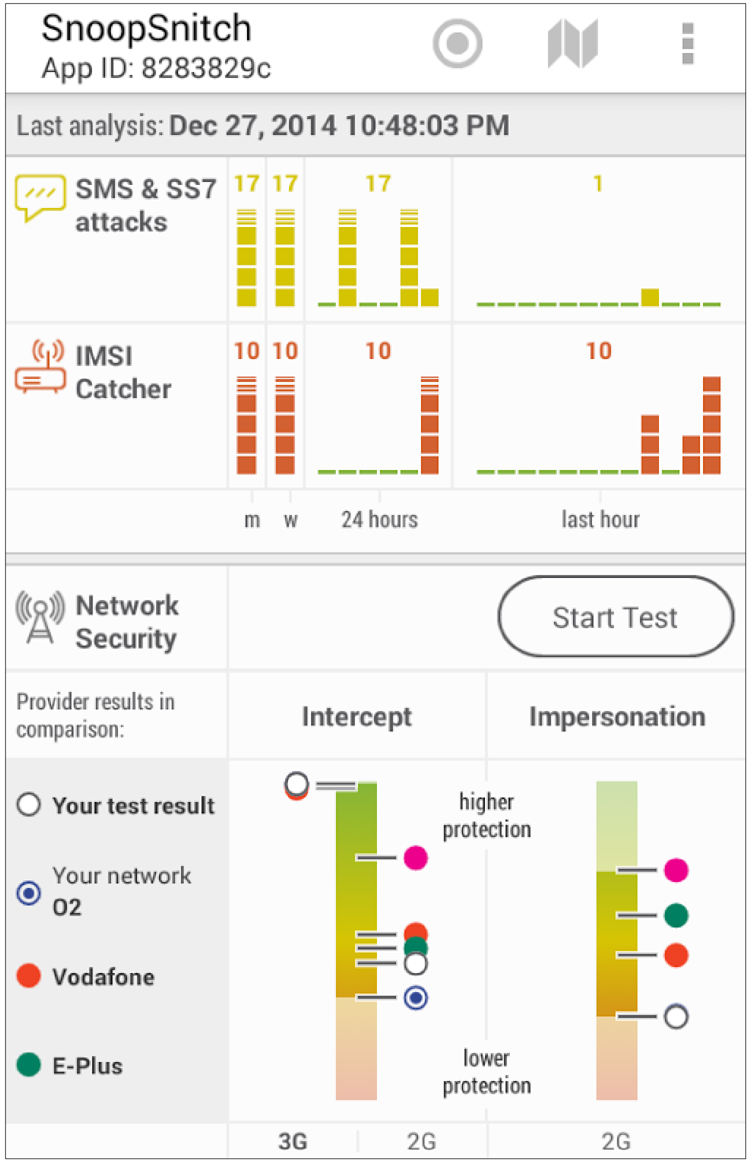
Collect network traces on Android → analyze for abuse

Features

- Detection of fake base station (IMSI catcher)
  - Suspicious cell configuration / behaviour
- User tracking
- SS7 attacks

Requirements

- Rooted phone with Android >= 4.1
- Qualcomm chipset
  - Samsung Galaxy S4/S5, Sony Z1, OnePlus 2, …



Source: https://goo.gl/KlhaZa

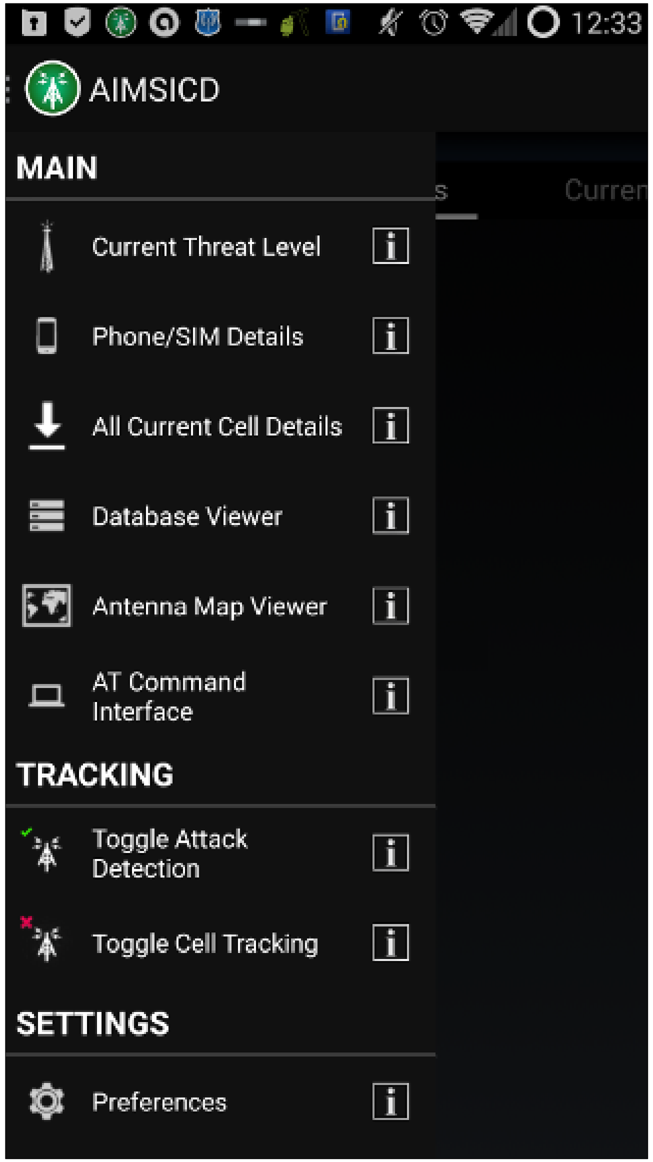
AIMSICD

Features

- Focus: Detecting IMSI catchers
- Check consistency of
  - Tower information
  - LAC / Cell ID
  - Signal strength
- Detect silent SMS (type 0 messages)
- Detect FemtoCells

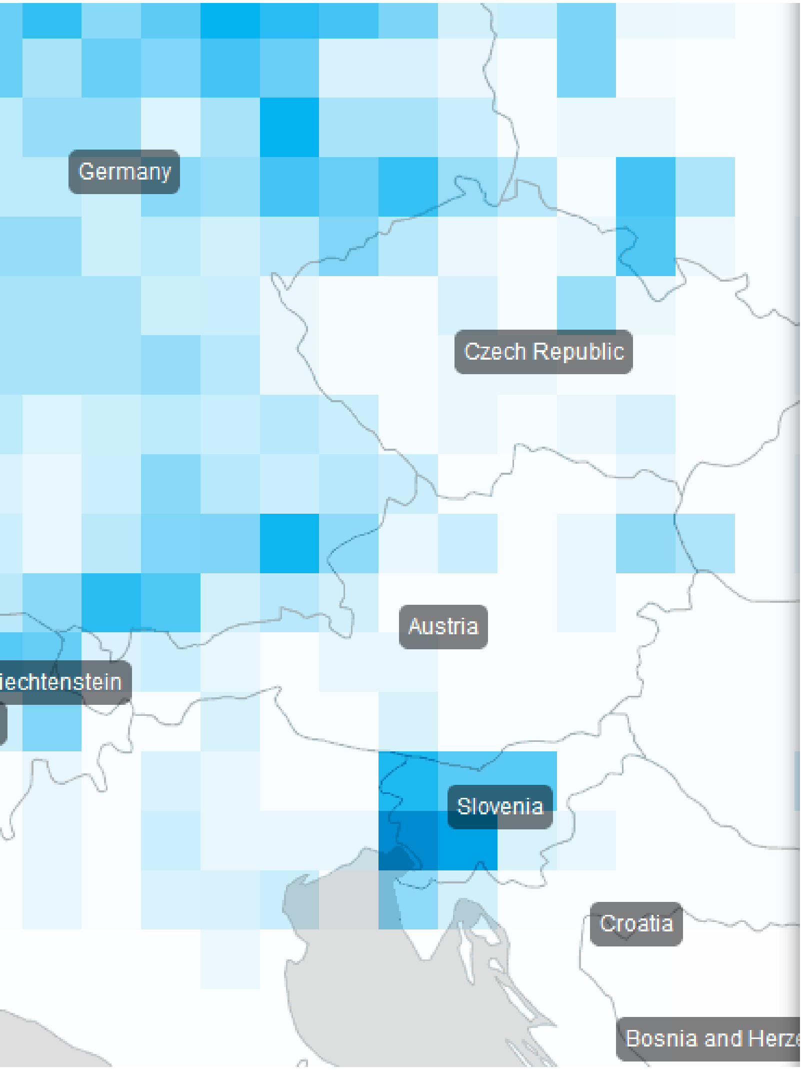
Requirements

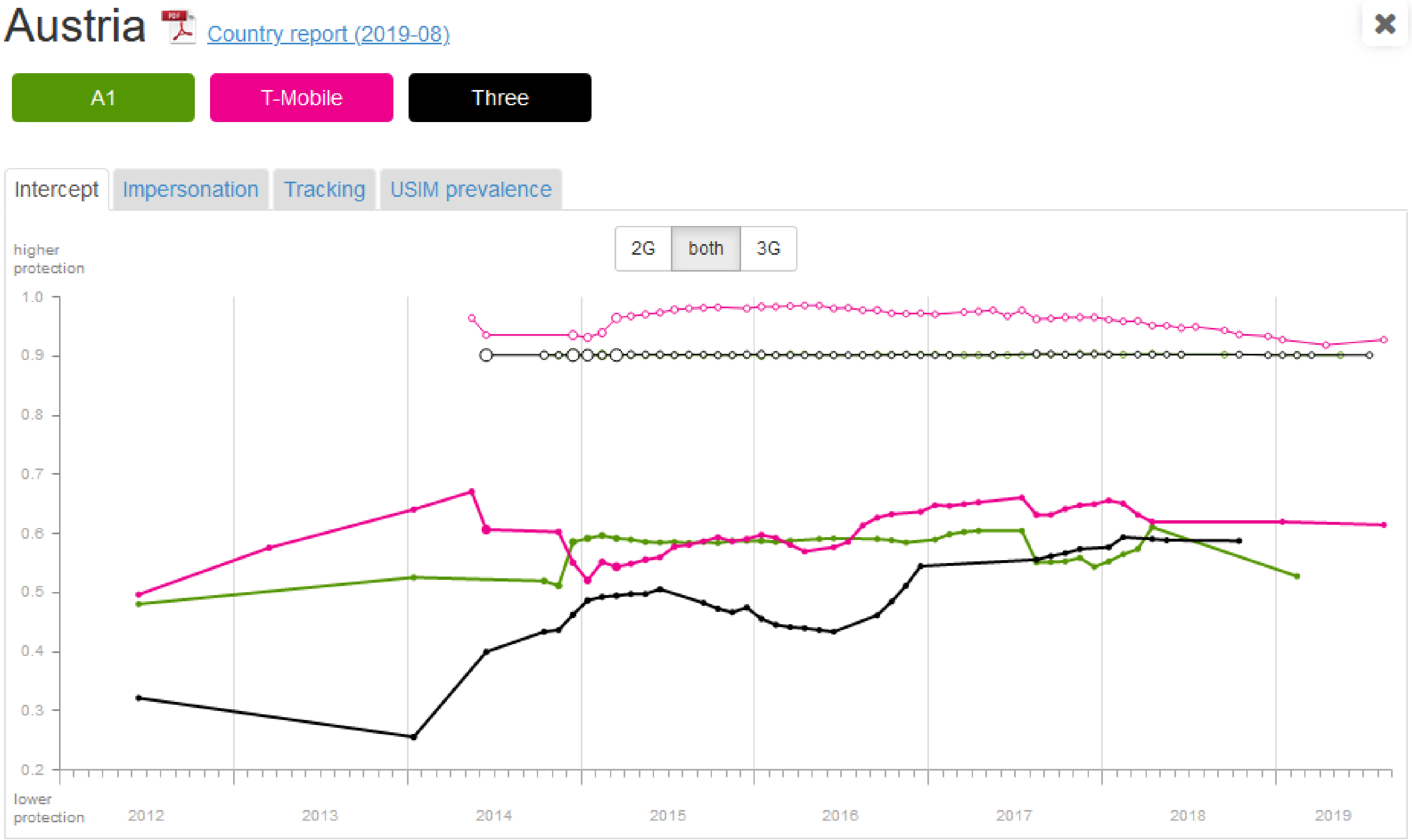
- Rooted Android
- Ability to send AT commands to modem



Source: https://goo.gl/mbZFgE

Network Protection Status





Source: http://gsmmap.org

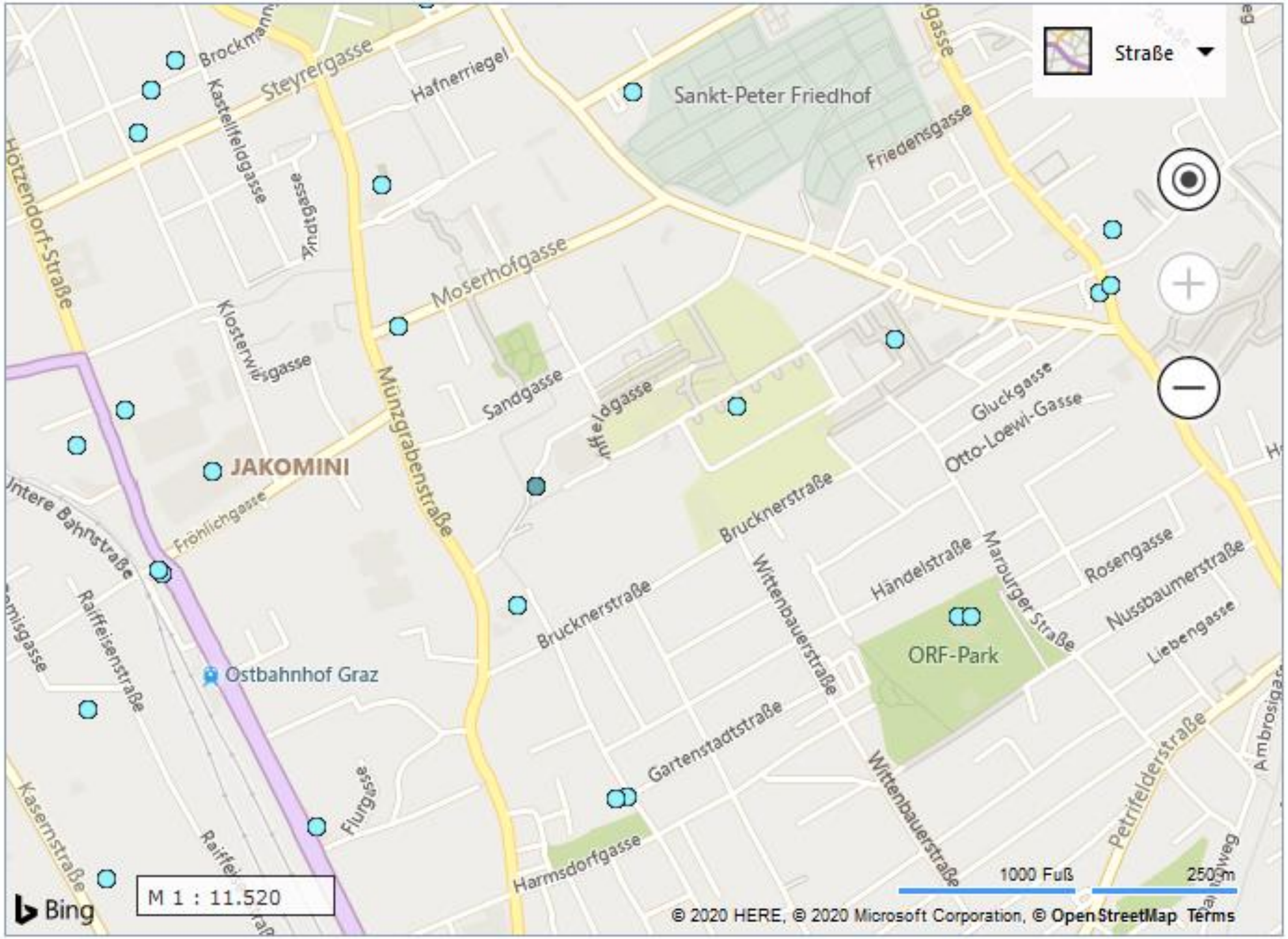
Physical Cell Locations

Tipp: Um Standorte in Ihrer Umgebung zu finden geben Sie im Feld "Adresse, Ort oder PLZ" die Postleitzahl bzw. den Namen der gesuchten Gemeinde ein und klicken Sie an- schließend auf die Taste "Suchen".

Allgemeine Daten

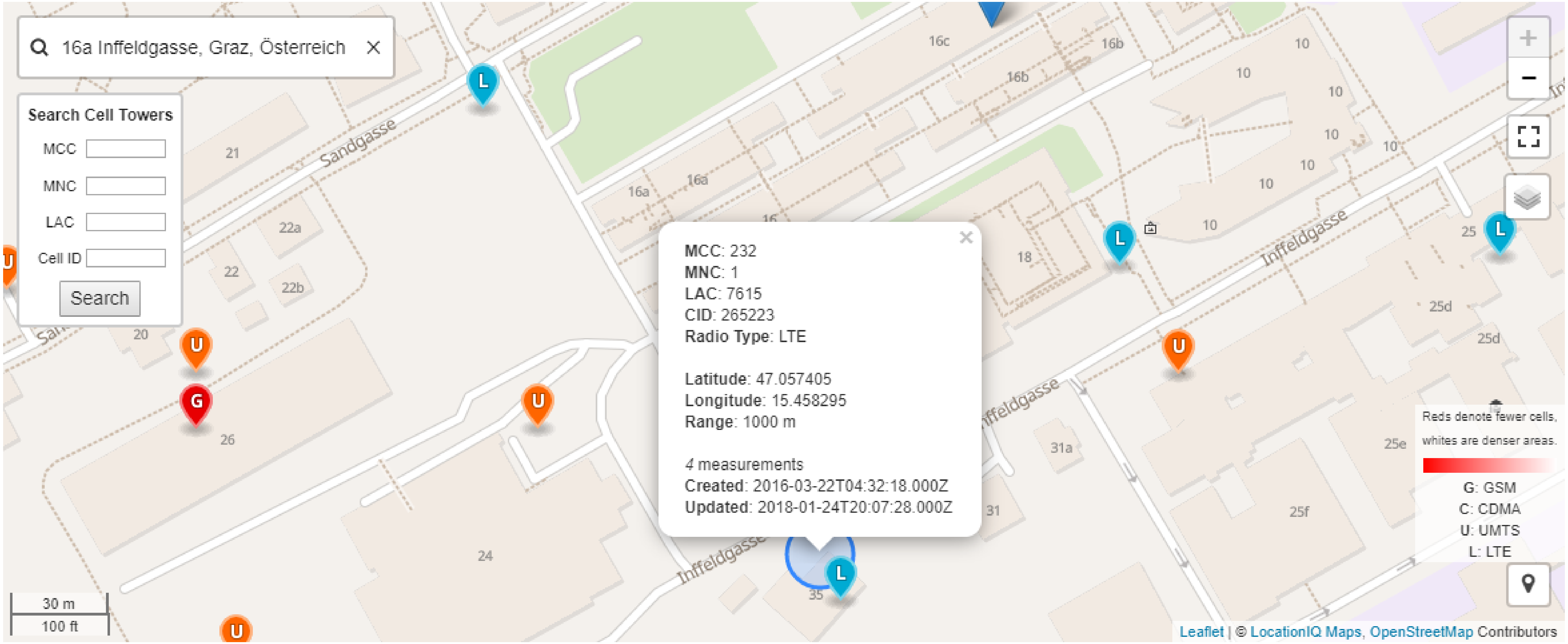
Standortanfrage versenden	
Funkdienst	Mobilfunk
Trägerstruktur	Mast
Gemeinsame Nutzung (Sharing)	Nein
Station1	
Protokoll(e)	GSM, UMTS, LTE, 5G
Sendeleistung	380-400 W

Mehr Informationen finden Sie im Kapitel **Erläuterungen** und **Technik**



Source: https://www.senderkataster.at

Physical Cell Locations



Source: https://opencellid.org

Outlook

- 18.06.2020
  - Presentation of your results of task 2