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MobileAtlas

Geographically Decoupled Measurements in Cellular Networks for Security and Privacy Research

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usenix THE ADVANCED COMPUTING SYSTEMS ASSOCIATION

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Problem and Motivation: Cellular Measurement Platforms

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- Cellular networks **differ** in terms of **measurement requirements**
  - (Fixed-line) Internet measurements: *RIPE Atlas*

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Problem and Motivation: Cellular Measurement Platforms

- **Lack** of **large-scale cellular measurement platforms**
- Cellular networks **differ** in terms of **measurement requirements**
  - (Fixed-line) Internet measurements: *RIPE Atlas*
- Mobile networks are complex
  - **(Legacy) protocols**: E.g., 2G, 3G, OTA updates, SMS, delivery reports, etc.
  - Complexity vs. **security**

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Cellular Measurement Approaches

- **Crowd-based** measurements
  - Smartphone App (e.g., *Wehe*)
  - Pros.: Low economic effort, easy to increase coverage
  - Cons.: Too little control/insights, background activity, user liable for roaming charges

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  - Pros.: Low economic effort, easy to increase coverage
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- **Dedicated test units**
  - Deployed and fully controlled by the test operator (e.g., *MONROE*)
  - Pros.: More control/insights, accurate measurement results
  - Cons.: High setup costs, **limited scaling**, cumbersome maintenance of test units

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Platform Requirements

- **Scalable, cost-efficient**
- **Flexible roaming** measurements
- **Controlled** measurement **environment**
- **Versatile** measurement **capabilities**, **low-level** insights
  - Internet measurements
  - Calling, SMS
  - Billing, APDU analysis

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MobileAtlas Measurement Platform

- **SIM card limits scaling**
  - For each operator **one SIM card per test unit** is needed
  - Physical remote **SIM card switching** is **cumbersome**

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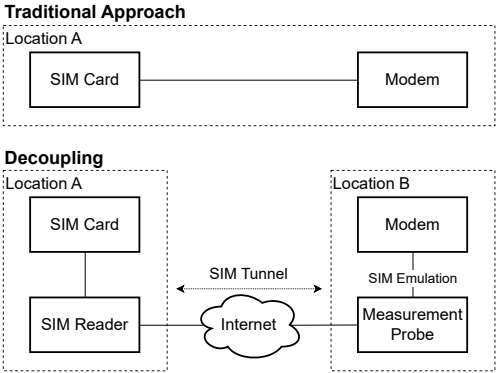
MobileAtlas Measurement Platform

- **SIM card limits scaling**
  - For each operator **one SIM card per test unit** is needed
  - Physical remote **SIM card switching** is **cumbersome**
- **Our approach**
  - Geographically **detach** the **SIM card from the modem**
    - **Tunneling** the SIM card's protocol over the Internet

Traditional Approach vs. SIM Tunnel



Traditional Approach vs. Decoupling

- Simple example:
  - Two countries, four SIM cards
  - Traditional: 2 x 4 = 8 SIMs
  - Decoupled: 4 SIMs
- Problem:
  - Increases rapidly
  - E.g., 10 countries => 40 SIMs

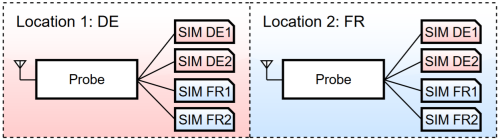


Figure 2: Traditional approach with poor scalability: Every new location needs a new set of all SIMs and mobile plans.

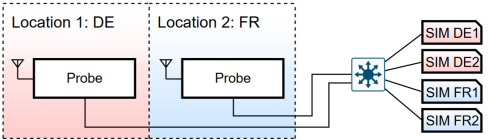
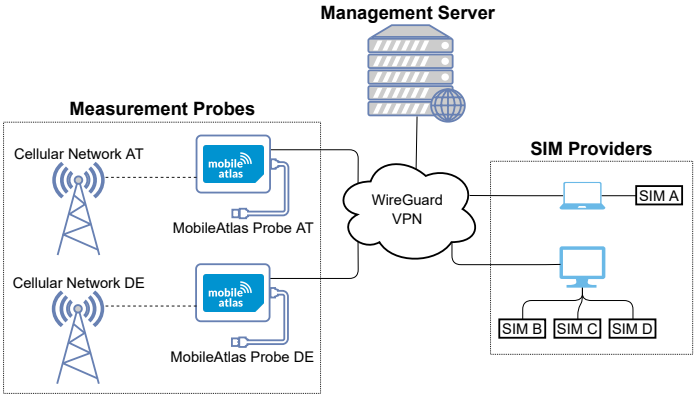


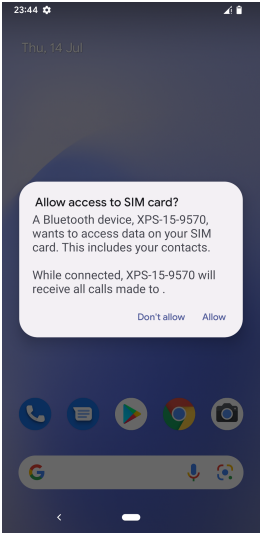
Figure 3: Decoupling the station from the SIM via tunneling requires only one set of SIMs.

MobileAtlas Measurement Platform: Components



MobileAtlas Components: SIM Provider

- SIM provider allows **remote sharing of SIM cards**
  - Measurement probes can **use** the shared cards **at remote locations**
- Various SIM reader types supported
  - PC/SC reader,
  - Serial based SIM card reader,
  - Bluetooth rSAP
    - **eSIM** support



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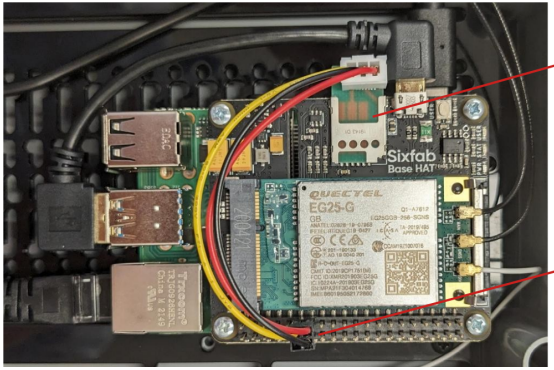
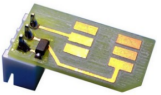
MobileAtlas Components: Measurement Probe

- Main components (revision 2)
  - Raspberry Pi 4
  - Modem adapter (mPCIe -> USB)
  - Quectel EG25G (same as PinePhone)
- **SIM tunneling**
  - **SIM pins** of **modem** are **connected** to Raspberry **GPIOs**
  - UART is used to **emulate** the **SIM**
- Ca. $200 hardware cost (+ $100 case)

MobileAtlas Components: Measurement Probe

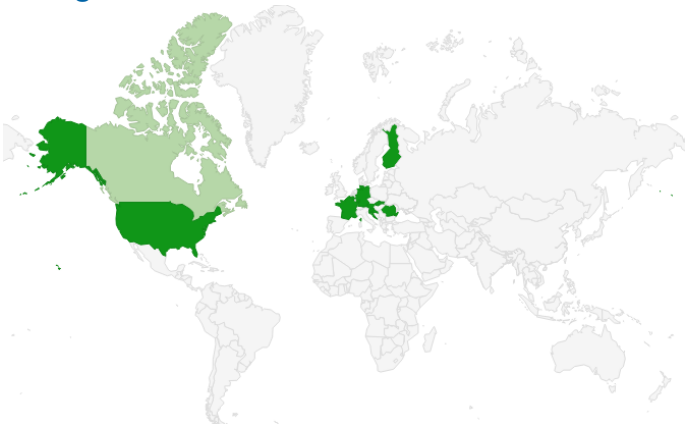


SIM Adapter



GPIO Ports (UART)

MobileAtlas Coverage



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Showcase Measurements (Selection)

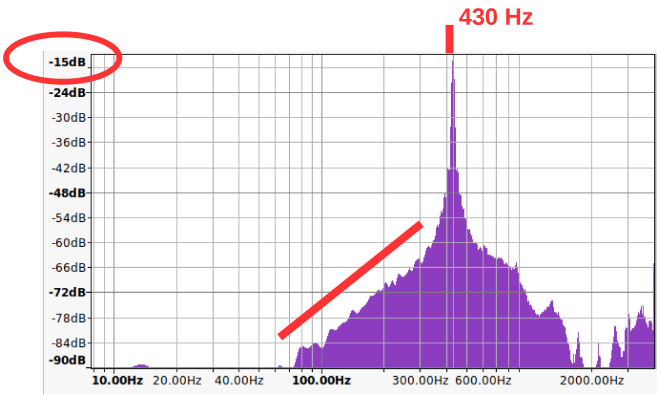
Platform Coverage and used SIMs

- We obtained SIMs from the major operators of five European countries
  - Austria, Croatia, Romania, Slovakia, Slovenia
  - Total: 14 SIM cards
  - Measured at all available countries and operators

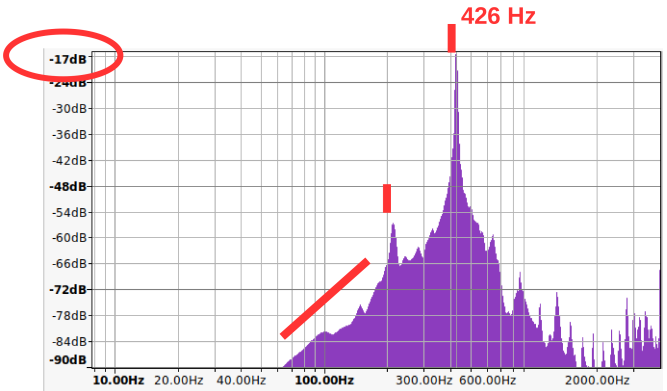
Showcase: Ringback Tone Fingerprinting

- Ringback tone is **issued by the operator** that is **terminating the call**
  - I.e., the **roaming partner**
- **Different ringback** tones in **different countries**
  - This can be abused to **deduce** the (country-level) **location** of the called person
  - Obvious differences between continents (e.g., US and EU), noticeable differences on country or operator levels
    - Can be used to identify the current operator
    - Potential abuse for SIM swapping attacks (within home country)

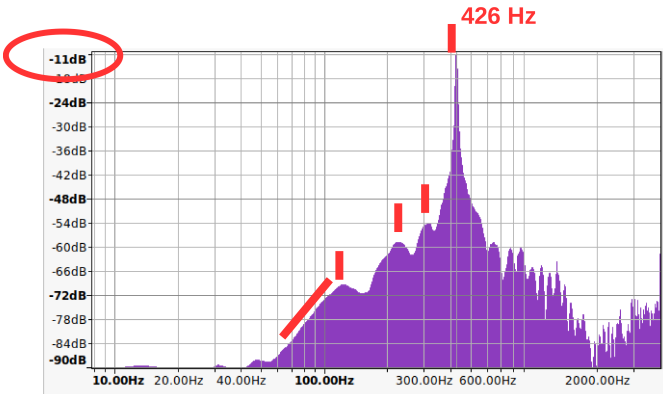
Ringback Tone Comparison: 1) RO Vodafone



Ringback Tone Comparison: 2) DE Telekom



Ringback Tone Comparison: 3) DE O2



Showcase: Ringback Tone Fingerprinting

- **Amplitude**
- **Base frequency**
- Overtones
- Duty cycle (on/off timing)

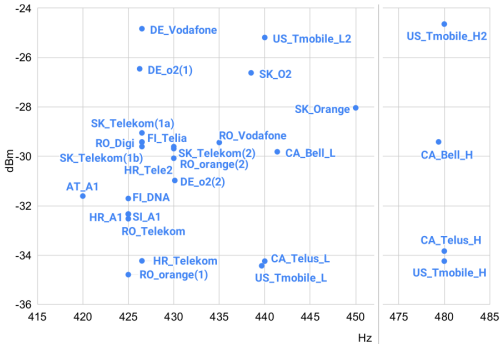
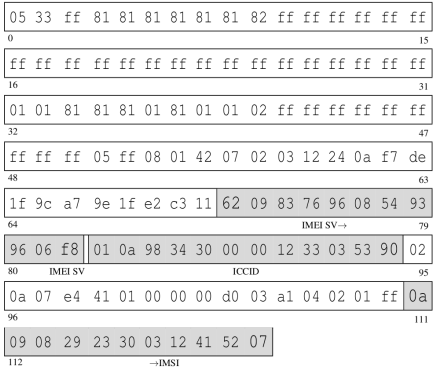


Figure 6: Fingerprinting ringback tones (without VoLTE).

Showcase: APDU Analysis

- **SIM card** is an often **underestimated** microprocessor
  - Can run *JAVA cardlets*
  - **Proactive** SIM commands: send SMS, display text, etc.
- We have **full insight** into **APDU traffic** between modem and SIM card
- We found two SIM cards that **covertly send binary SMS** messages to the operator
  - SMS sometimes is billed during roaming



Other Showcases: Internet Measurements

- Network- and Firewall Configuration
  - Home routing, local breakout, CGNAT
- **Billing mechanisms** in domestic and roaming environments
  - Identify **metrics** that are used for **zero-rating**
  - Some metrics (e.g., host/SNI header) can be used for free-riding
- More **detailed zero-rating analysis** can be found in **separate paper**:
  Zero-Rating, One Big Mess: Analyzing Differential Pricing Practices of European MNOs

Questions?

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mobileatlas.eu

github.com/sbaresearch/mobile-atlas

Ethical Considerations

- Legal
  - Radio regulatory
  - SIM registration
- Operator
  - Live network influence
  - Economic losses (free-riding tests)
- Probe hoster security

Ongoing Challenges and Future Steps

- Extending coverage
  - Finding probe locations (e.g., at other Universities)
- Extending codebase
  - Automatic measurement scheduling
  - Allowing other researchers to easily use our platform
- 5G probe version
- Probe maintenance
- Doing actual measurements :)