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Systems Security Lab

Firefly: Spoofing Earth Observation Satellites through Radio Overshadowing

Edd Salkield [1] Joshua Smailes [1] Sebastian Köhler [1]
Simon Birnbach [1] Richard Baker [1] Martin Strohmeier [2]
Ivan Martinovic [1]

[1] Systems Security Lab, University of Oxford

[2] Cyber-Defence Campus, armasuisse Science + Technology

Trinity Term 2022

Challenges of unauthenticated satellites

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  - Insecure cryptosystems [1]
  - Leaked keys [2]

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[2] GK-2A keys leaked in source code `https://vksdr.com/xrit-rx/`

Challenges of unauthenticated satellites

Insecure Earth Observation Satellites

Satellites with insecure downlinks include:

- **Fire detection and management**, e.g., Terra, Aqua

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- Geospatial intelligence, e.g., Landsat-7..9
- Weather monitoring, e.g., GOES-14..17, FengYun series
- Infrared sensing, e.g., Metop-A,B
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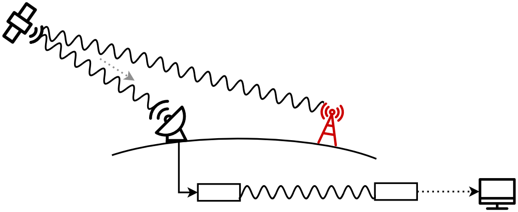
Further details available in the paper

Implications

Data secrecy



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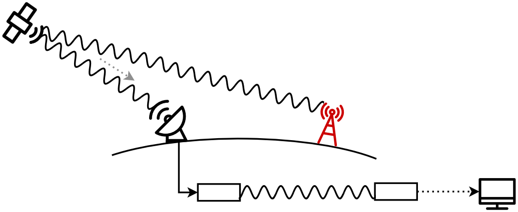

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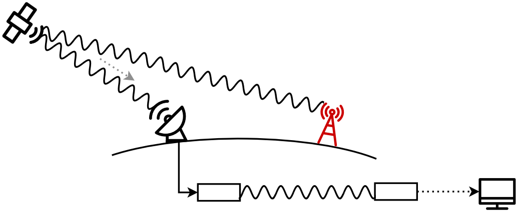

Using an SDR and open source software, attackers can:

- Read confidential maritime data[1] and internet traffic[2]

[1] Pavur et al. (2020) "*A Tale of Sea and Sky on the Security of Maritime VSAT Communications*"

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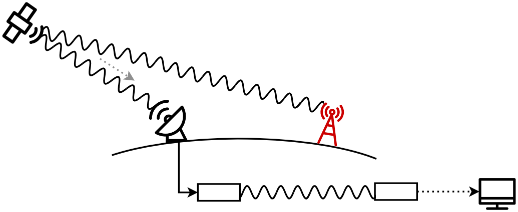

Using an SDR and open source software, attackers can:

- Read confidential maritime data[1] and internet traffic[2]
- Eavesdrop on Iridium traffic and calls [3]

---

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[3] muccc "*Iridium Toolkit*" `https://github.com/muccc/iridium-toolkit`

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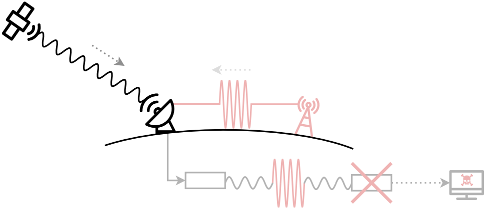
Data authenticity and integrity



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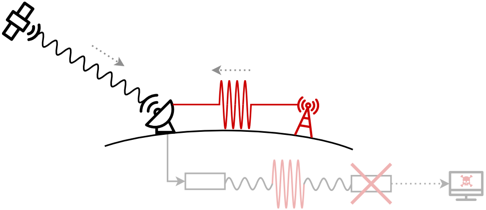

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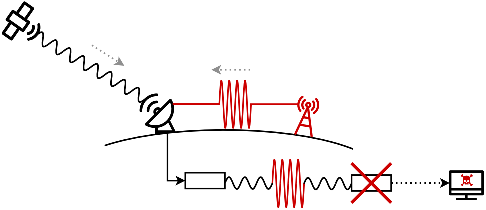

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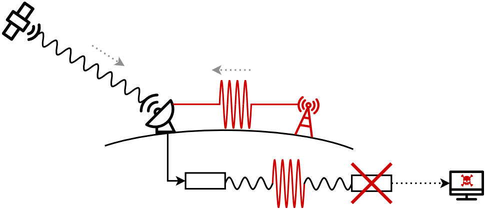

Spoofing attacks have been shown against:

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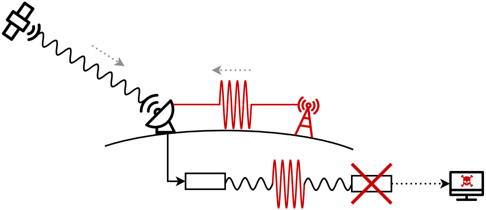

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- GNSS to manipulate calculated location[1]

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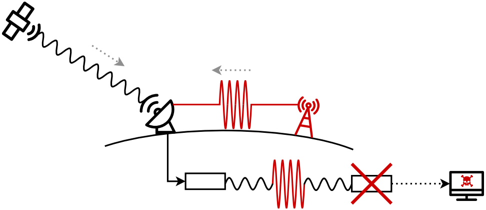

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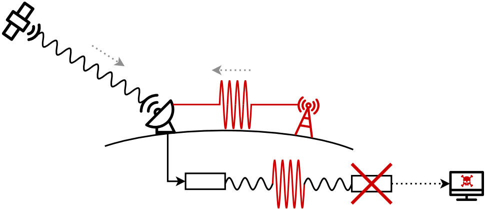

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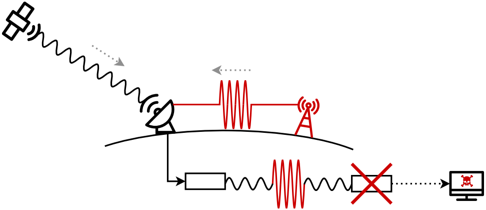

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RQ: What can the attacker achieve by exploiting the unauthenticated channel?

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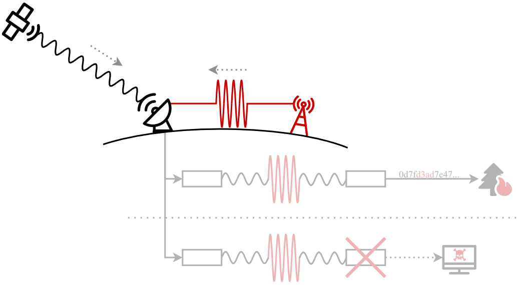
Threat model



Attacker transmits counterfeit signals in the vicinity of the receiver, to:

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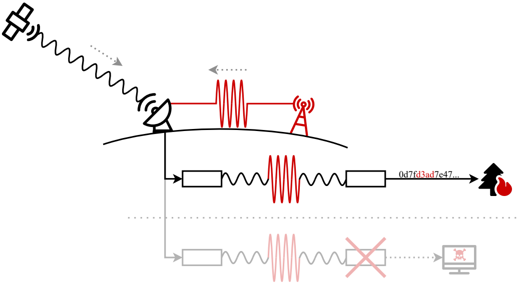

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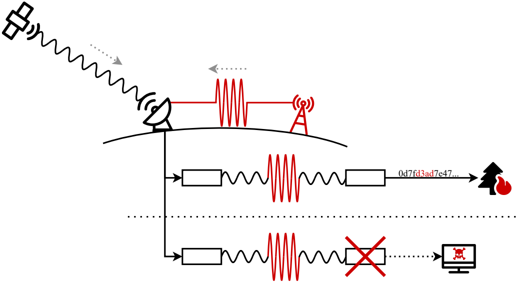

Attacker transmits counterfeit signals in the vicinity of the receiver, to:

- Affect the satellite-derived datasets
- Exploit or disrupt downlink processing stages

Attacker capabilities

Estimated cost

Hardware component	**Cost**
limeSDR	598 USD
X-Band upconverter	100 USD[1]
X-Band amplifier	1,638 USD
Compatible antenna	431 USD
Total	3,000 USD

[1] Estimated price from self-built amateur radio equipment

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Within the budget of a motivated hobbyist

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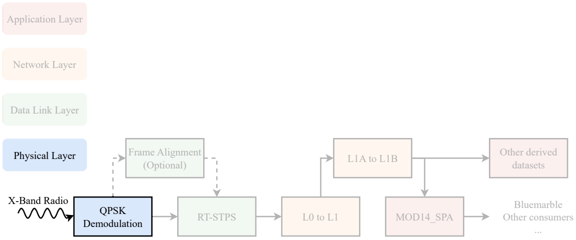
Case Study: Forest fire detection in FIRMS

NASA's global fire detection service

The 2019 Australia bushfires as seen from Aqua's MODIS instrument, annotated with the *Fires and Thermal Anomalies* dataset on NASA's worldview.

Case Study: Forest fire detection in FIRMS

Experiment setup



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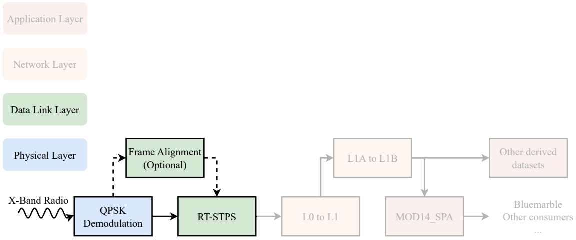

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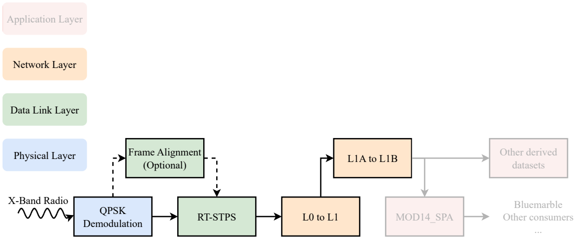

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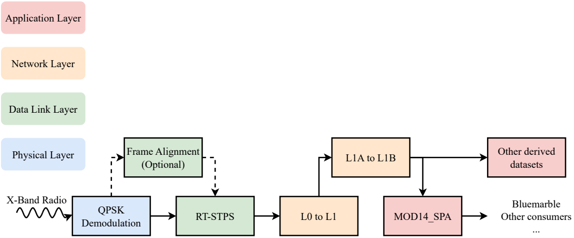

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  - Edit image format to insert fictitious data
  - Construct payload packet to trigger vulnerability chain

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Affecting the derived dataset

Packet structure

<table>
<tr><td colspan="2">Primary Header</td><td colspan="6">Secondary Header</td><td colspan="6">Data Zone</td></tr>
<tr><td>...</td><td>Packet Length</td><td>Time Tag</td><td>...</td><td>Packet Type</td><td>Scan Count</td><td>Mirror Side</td><td>...</td><td>Frame Count</td><td>...</td><td>Data Field</td><td>Checksum</td></tr>
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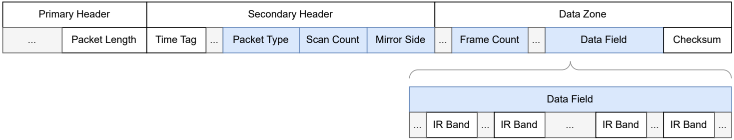

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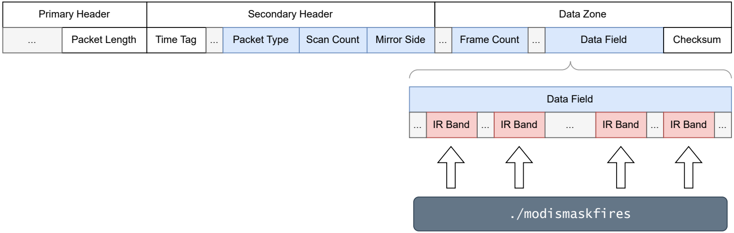

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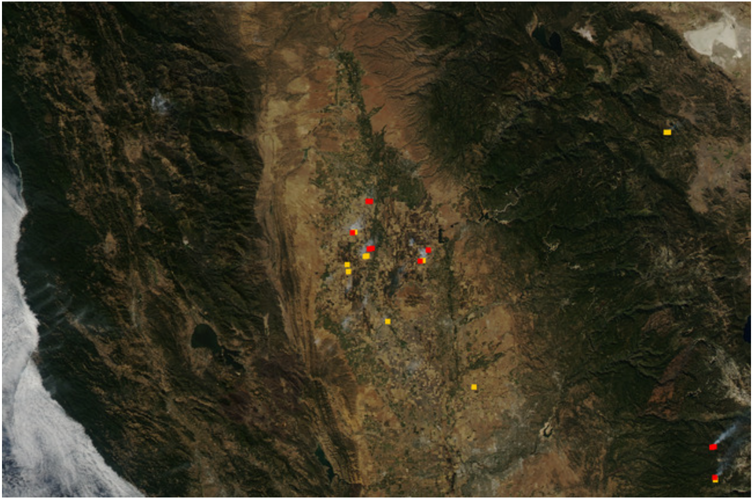
Affecting the derived dataset

Attack consequences



Original image.

Affecting the derived dataset

Attack consequences

Masking existing fires.

Affecting the derived dataset

Attack consequences

Fine-grained control over fire injection.

Exploiting the decoder

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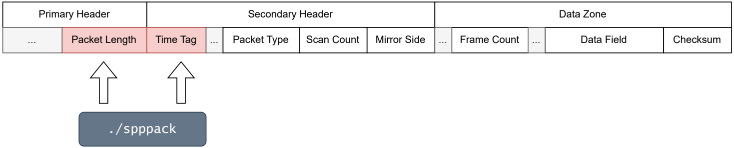

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$ ./run_all.sh ./data/
DATA_PATH: /mnt/data
CONTAINER_RUNTIME: docker
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### Processing new PDS:
  MYD00F.A2015299.2110.20152992235.001.PDS
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### Running modisl1db l1a-geo initial processing
l0fix_modis: Unrecoverable error in l0fix_modis!
```

Countermeasures

Cryptography should be required in future satellites

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Backwards-compatible countermeasures:

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Backwards-compatible countermeasures:

- Multi-receiver data comparison

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Backwards-compatible countermeasures:

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Comparative analysis presented in the paper

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- presents a demonstration of byte-level spoofing against NASA's forest fire detection system.
- provides the source code required to manipulate the packet data and structure.
- confirms that only a moderate budget is required to perform these attacks.
- identifies current countermeasures which significantly increase attack difficulty.

Thank you for your attention

Any questions?

Reach out to me at
edd.salkield@cs.ox.ac.uk