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Firefly: Spoofing Earth Observation Satellites through Radio Overshadowing

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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

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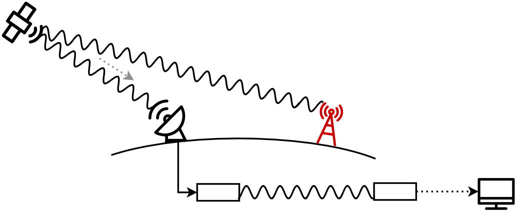
Implications

Data secrecy



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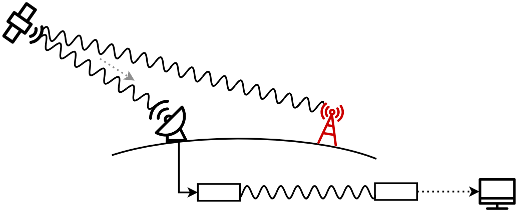

Using an SDR and open source software, attackers can:

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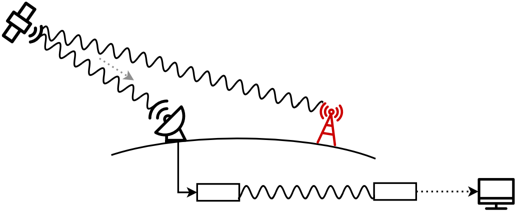

Using an SDR and open source software, attackers can:

- 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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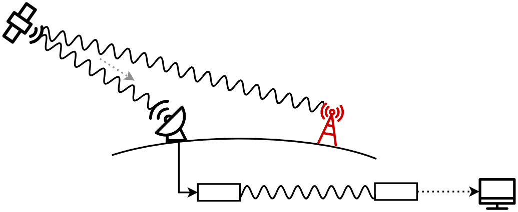

Using an SDR and open source software, attackers can:

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- 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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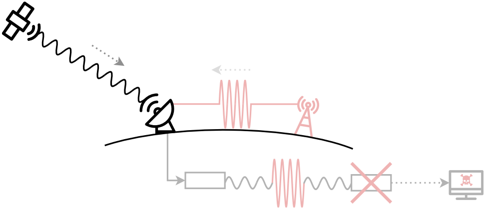
Implications

Data authenticity and integrity



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Implications

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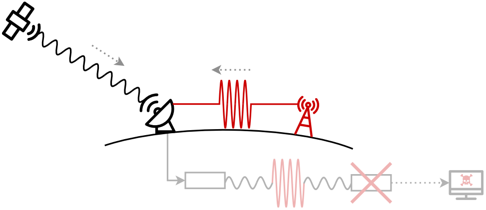

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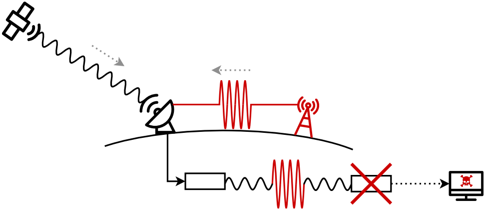

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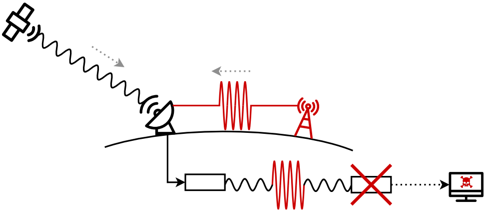

Spoofing attacks have been shown against:

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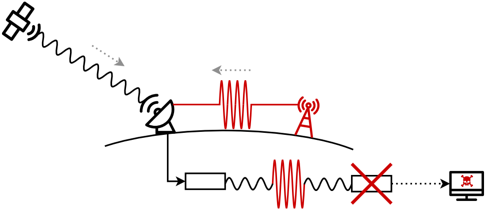

Spoofing attacks have been shown against:

- GNSS to manipulate calculated location[1]

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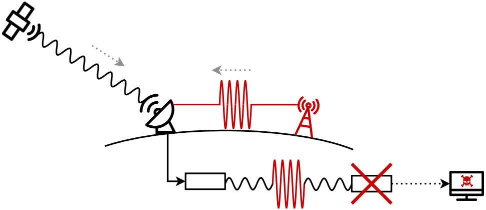

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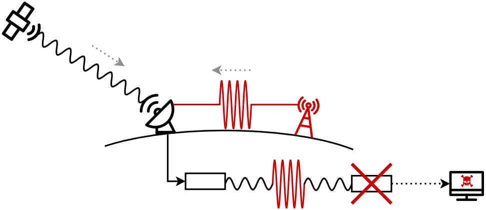

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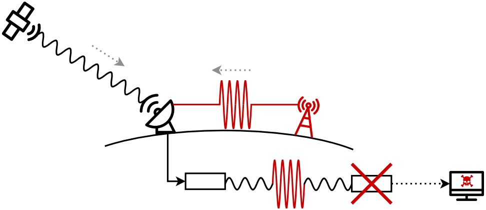

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RQ: What can the attacker achieve by exploiting the unauthenticated channel?

---

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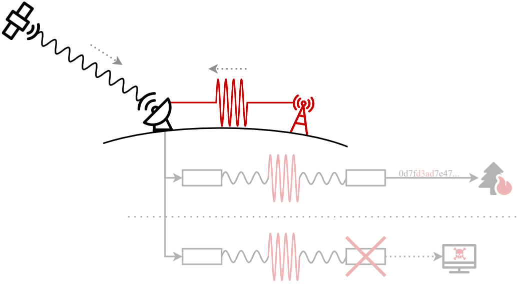
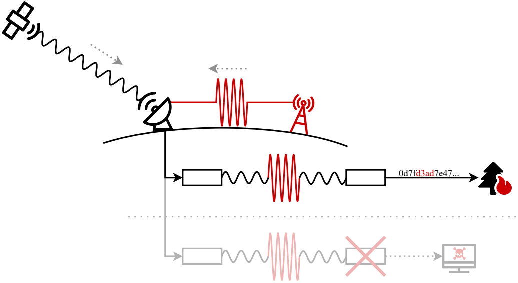
Threat model



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

Threat model



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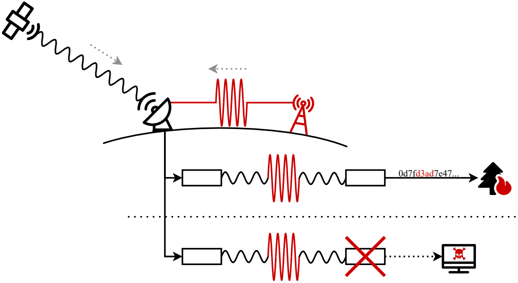

Attacker transmits counterfeit signals in the vicinity of the receiver, to:

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

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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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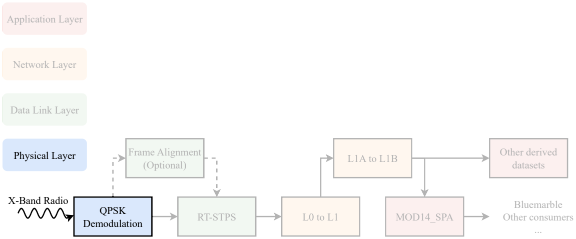
Case Study: Forest fire detection in FIRMS

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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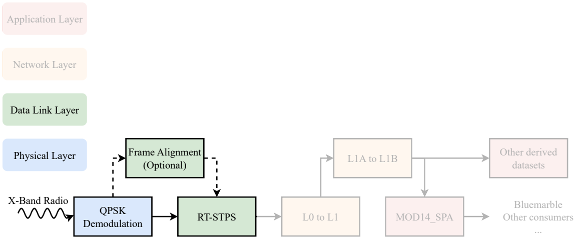

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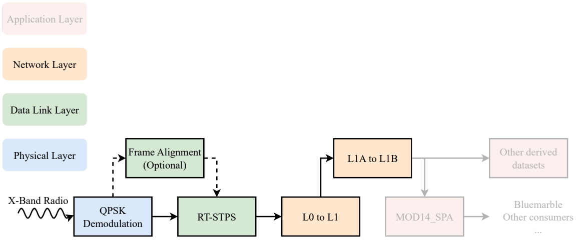

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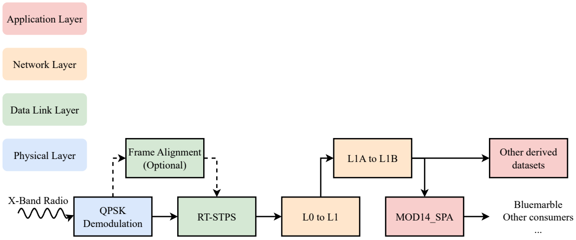

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Attack overview

- Obtain legitimate data from digital archive[1]

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Attack overview

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  - Construct payload packet to trigger vulnerability chain

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Affecting the derived dataset

Packet structure

Primary Header		Secondary Header					Data Zone					
...	Packet Length	Time Tag	...	Packet Type	Scan Count	Mirror Side	...	Frame Count	...	Data Field	Checksum

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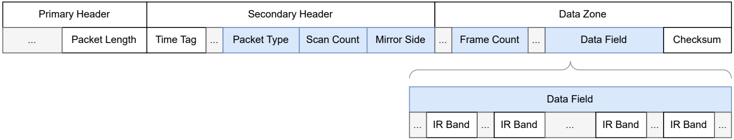

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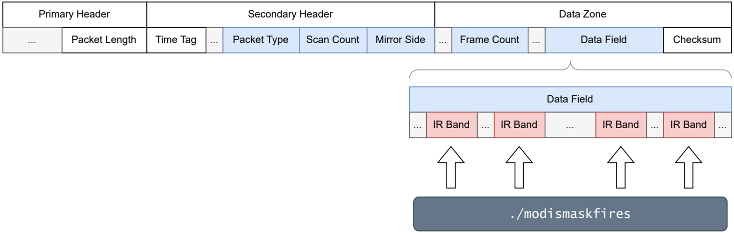

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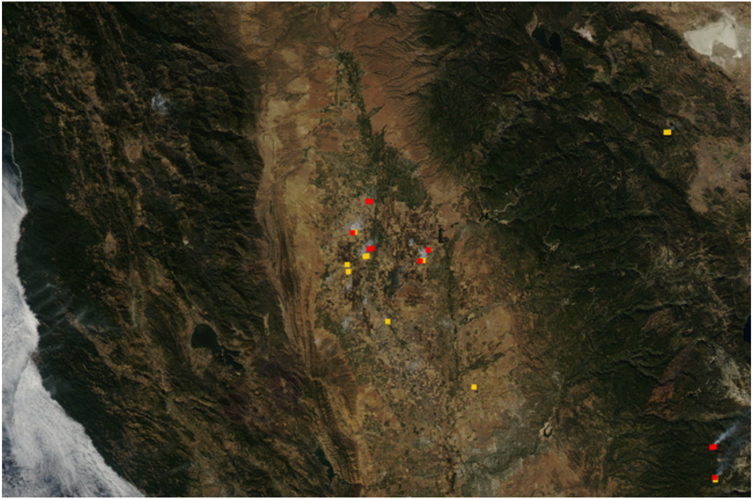
Affecting the derived dataset

Attack consequences



Original image.

Affecting the derived dataset

Attack consequences

Masking existing fires.

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Affecting the derived dataset

Attack consequences

Fine-grained control over fire injection.

Exploiting the decoder

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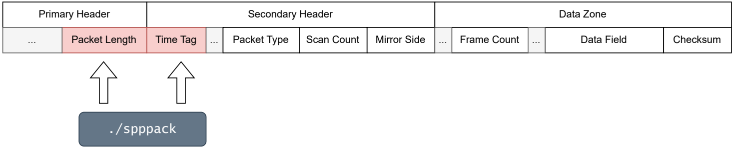

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DATA_PATH: /mnt/data
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### Processing new PDS:
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### Running modisl1db l1a-geo initial processing
l0fix_modis: Unrecoverable error in l0fix_modis!
```

Countermeasures

Cryptography should be required in future satellites

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Cryptography should be required in future satellites
But existing satellites can't be upgraded

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Countermeasures

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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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Backwards-compatible countermeasures:

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Comparative analysis presented in the paper

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- 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