

Authenticated Positioning Using GALILEO Open Service Navigation Message Authentication (OSNMA)

Semester Project

Lyubomir Kyorovski

Advisors:

Martin Kotuliak
Simon Erni

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Outline

1. GNSS and Problems with GNSS Security
2. Introduction to GALILEO OSNMA
3. OSNMA Receiver Implementation
4. Potential attacks against OSNMA
5. Further work

GNSS Basics

Allows us to know our geolocation, but what's behind it?

- Satellites in Space

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- Low data rate
- Provide navigational data
 - Almanac
 - Ephemeris

GNSS Security (or lack thereof)

Agencies Warn on Satellite Hacks & GPS Jamming Affecting Airplanes, Critical Infrastructure



Author

Sandra Erwin — February 25, 2022

MARITIME JOURNAL
COMMERCIAL MARINE BUSINESS

[MARITIME INSIGHTS](#) ▾

GPS vulnerability questioned after cyber attacks

30/05/2017

The recent spate of cyber attacks around the World has focussed attention on how vulnerable GPS could be from similar attacks. GPS is considered to be a public utility these days ranking alongside gas and electricity supplies and it is now a vital component of transport and financial markets.

LOCAL NEWS ▾

Experts Warn About Vulnerabilities of U.S. GPS System to Cyber Terrorists

BAY AREA

SEPTEMBER 13, 2021 / 7:07 PM / CBS SAN FRANCISCO



SPACE NEWS

NRO warns satellite operators of possible Russian attacks

by Sandra Erwin — February 25, 2022



Attempts at GNSS Security

Countermeasures based on:

- Signal Characteristics

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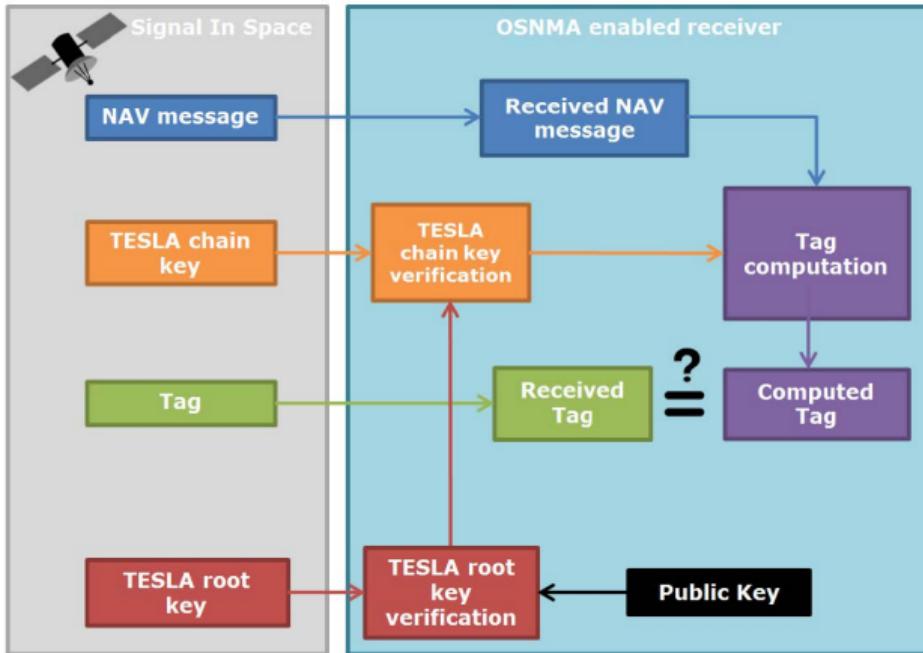
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- In Public Test phase since November 2021

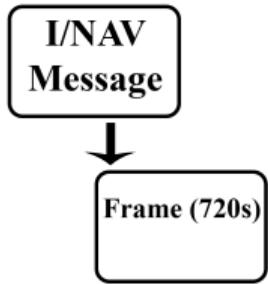
OSNMA Overview



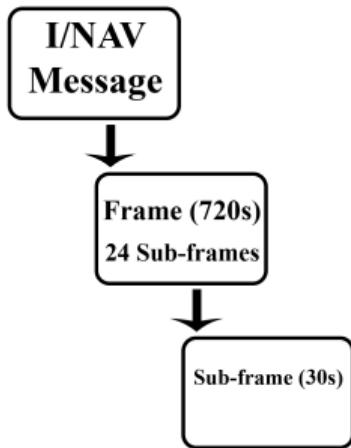
Where/What is the OSNMA Message?

I/NAV
Message

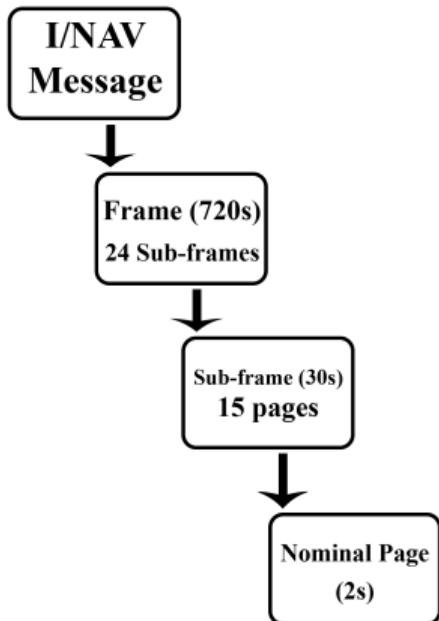
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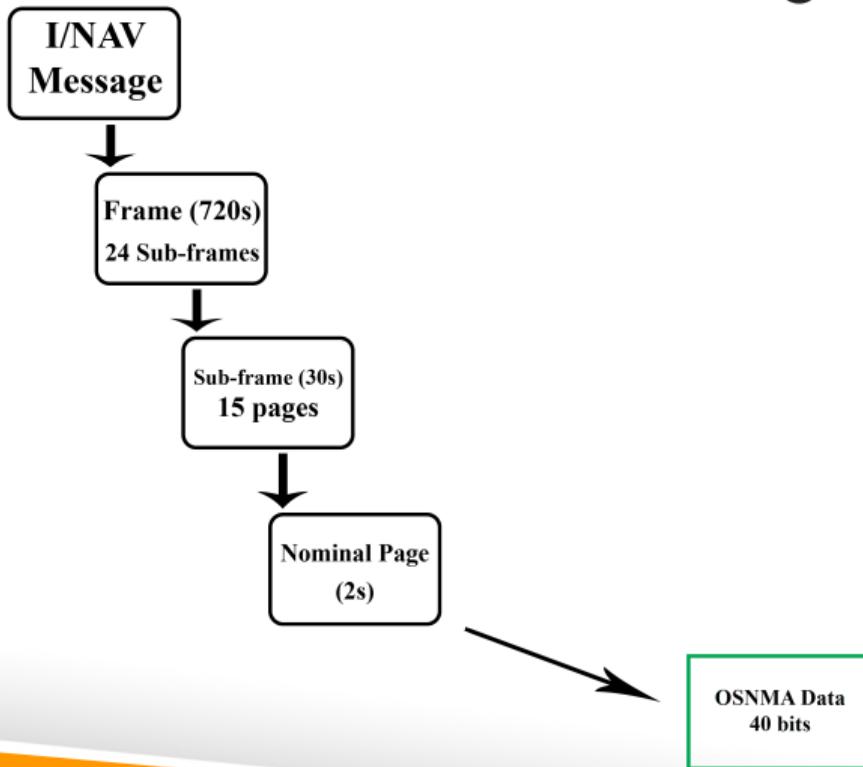
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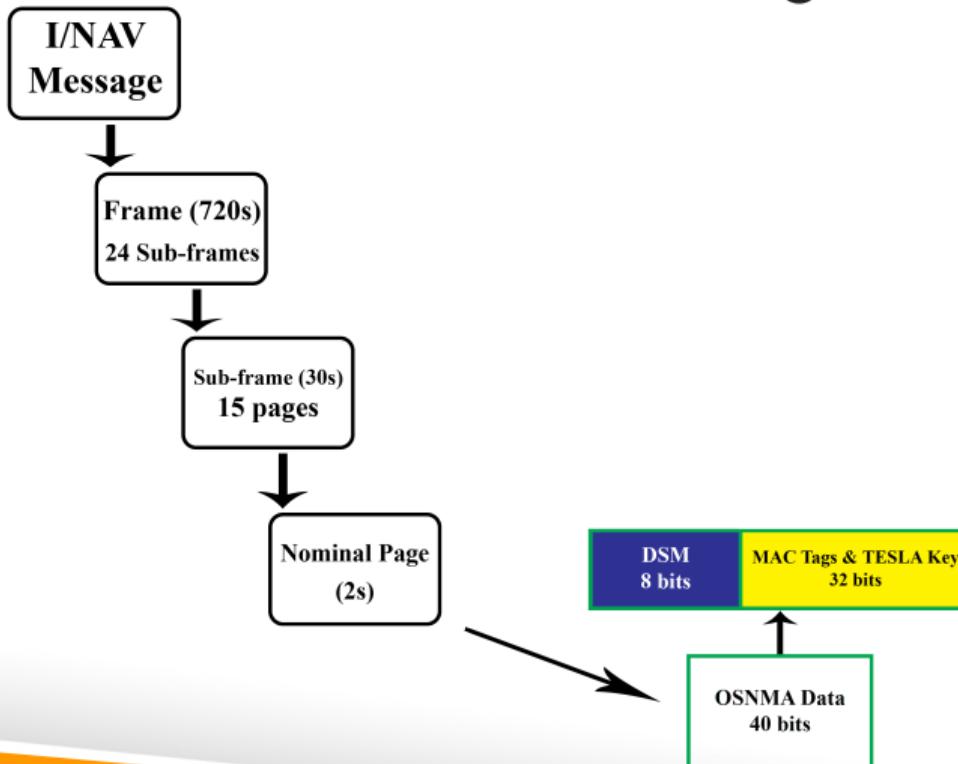
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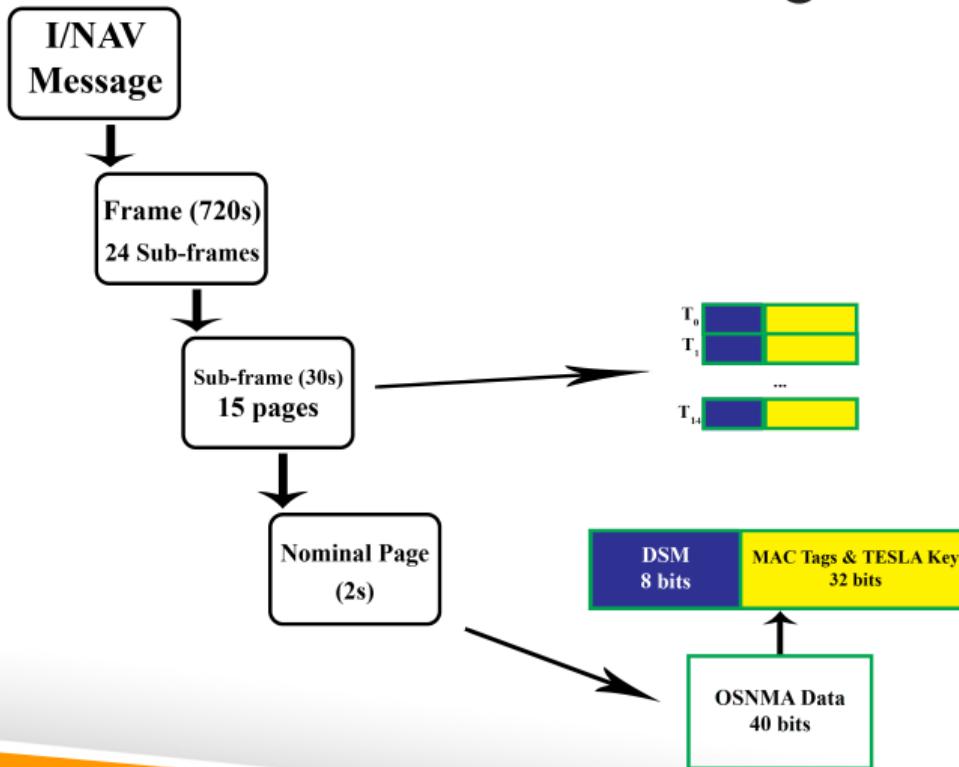
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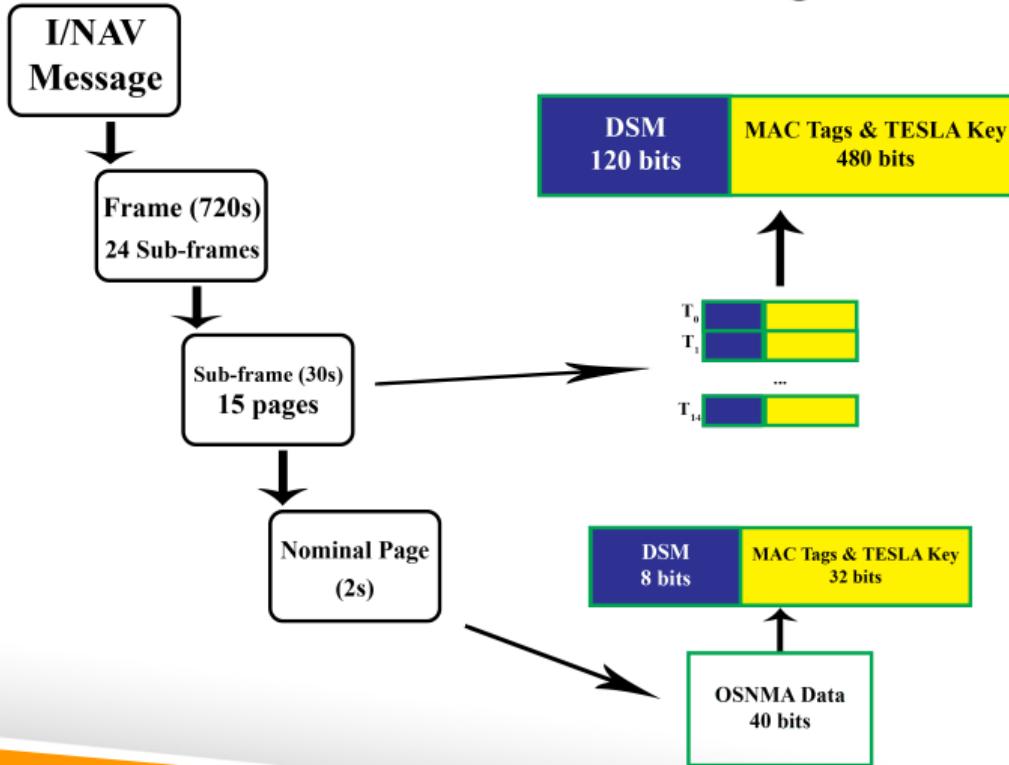
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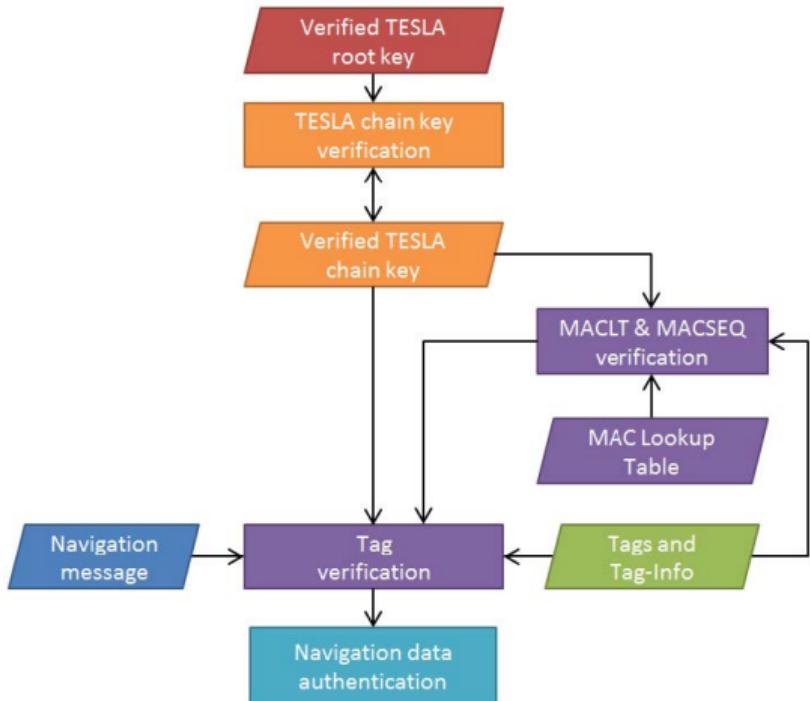
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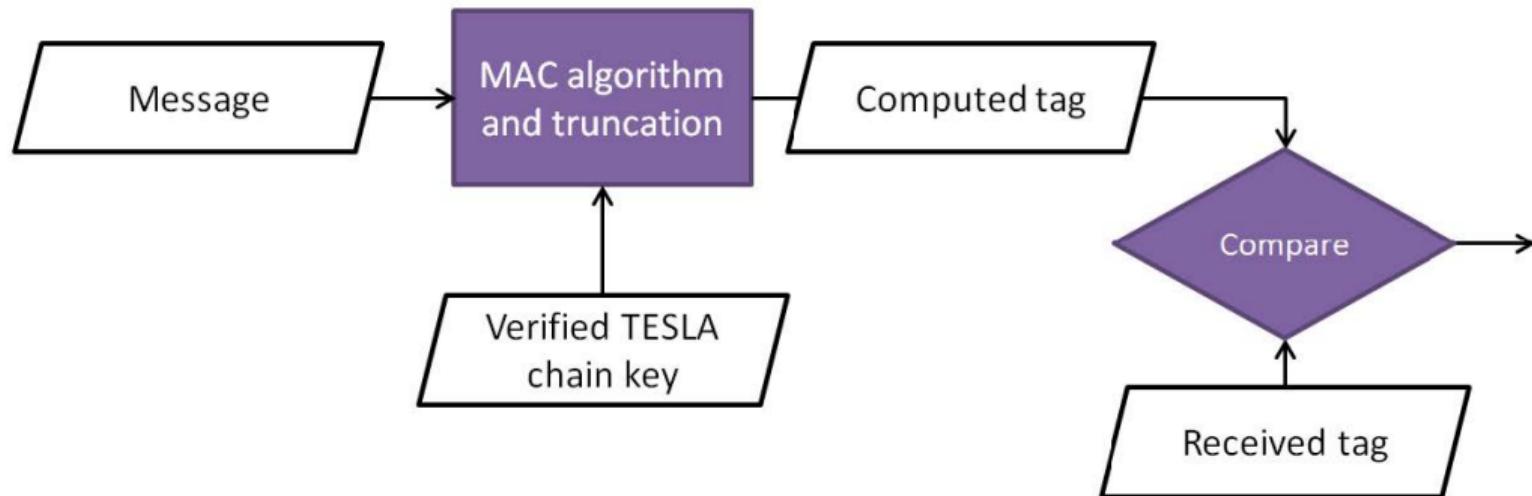
Where/What is the OSNMA Message?



OSNMA Overview



Tag Verification



Data for Tag Generation



Data for Tag Generation



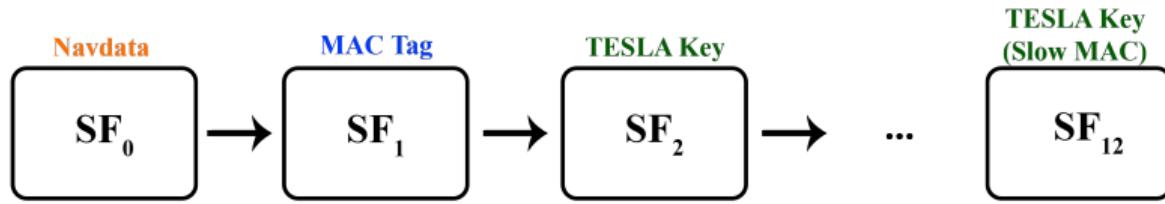
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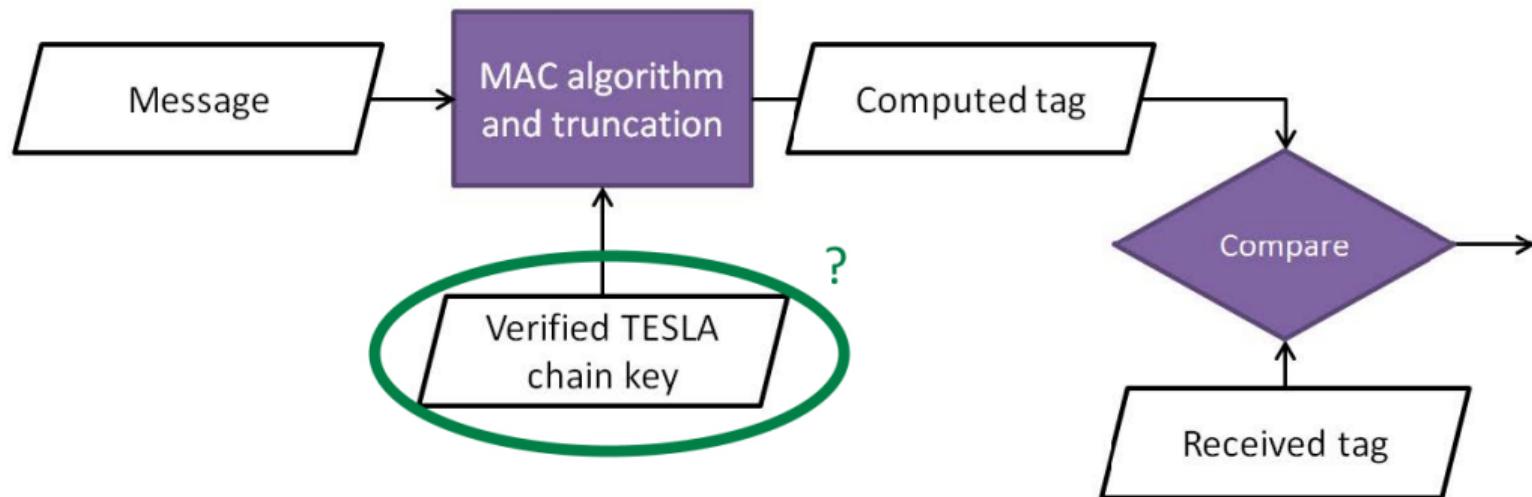
Data for Tag Generation



Data for Tag Generation



Tag Verification



TESLA Key Chain

K_N

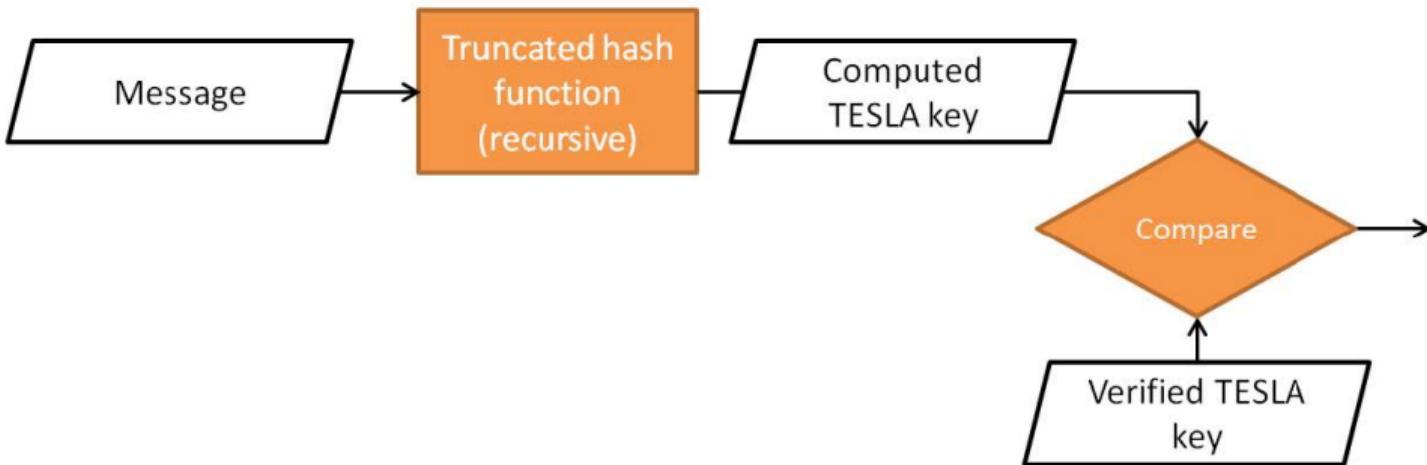
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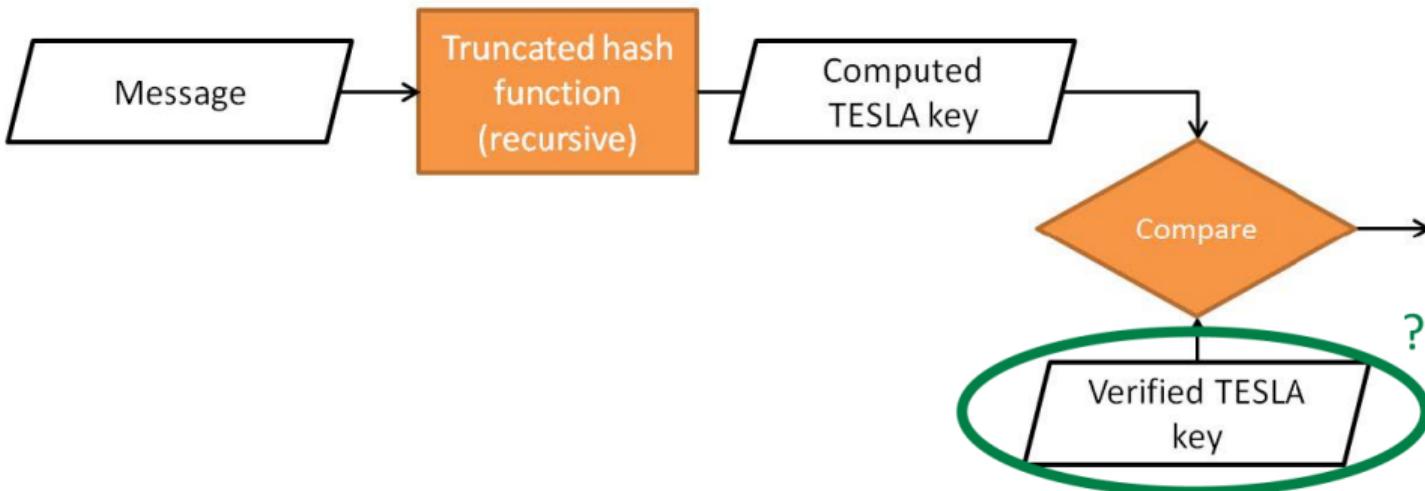
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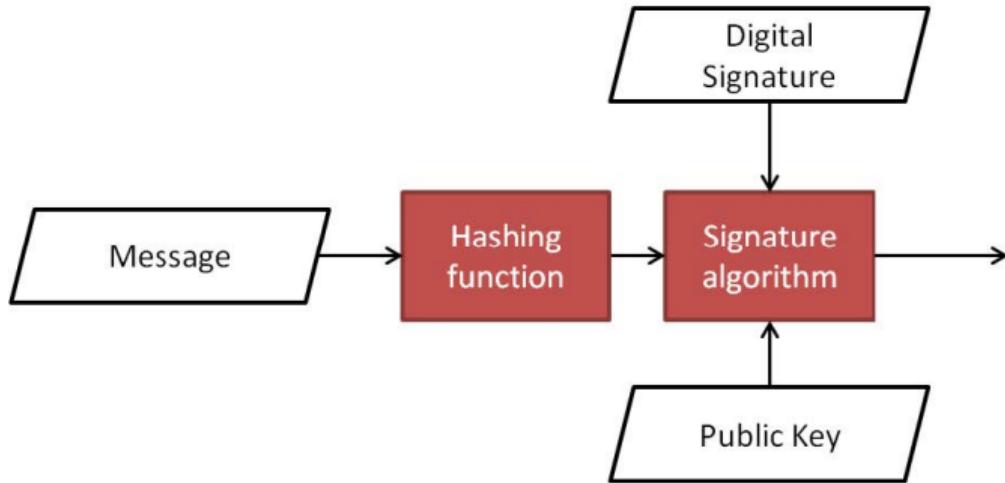
TESLA Chain Key Verification



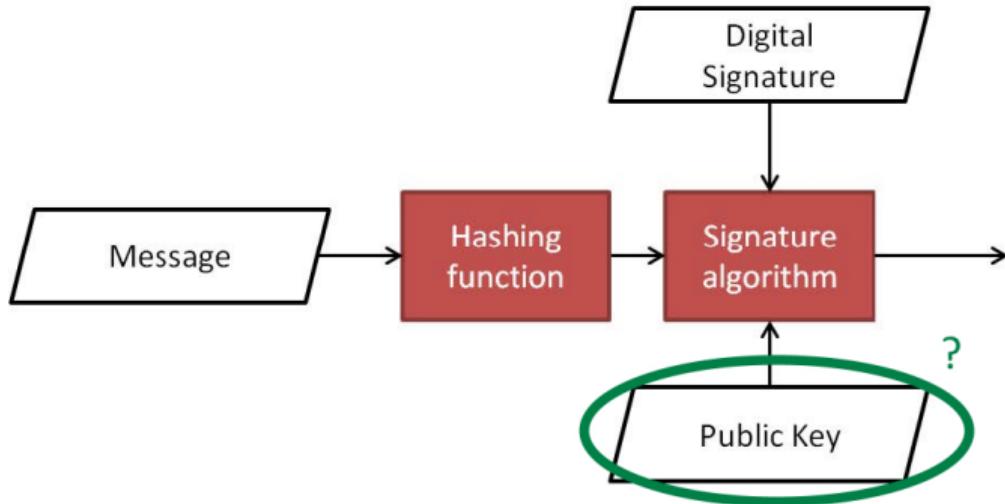
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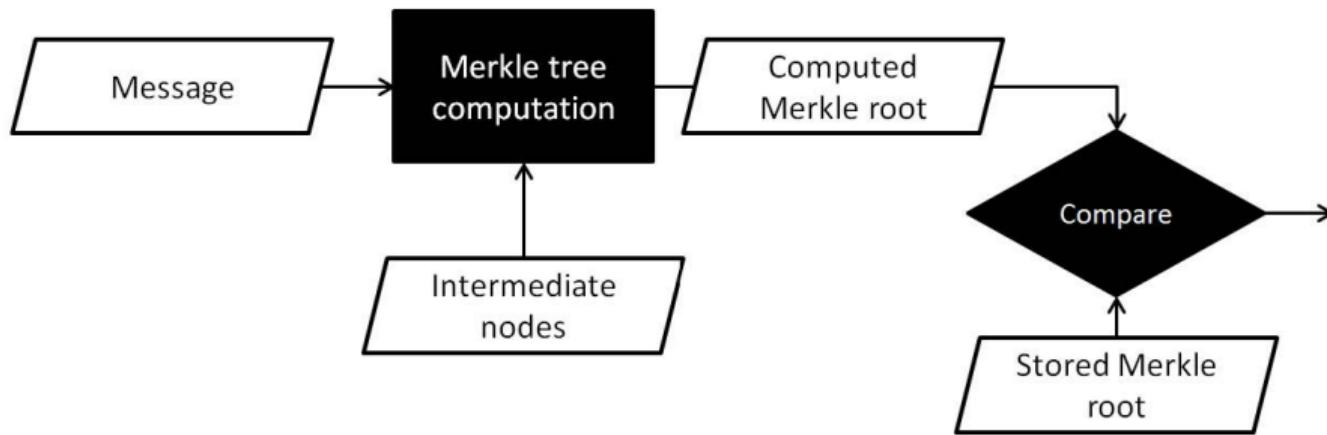
DSM-KROOT Verification



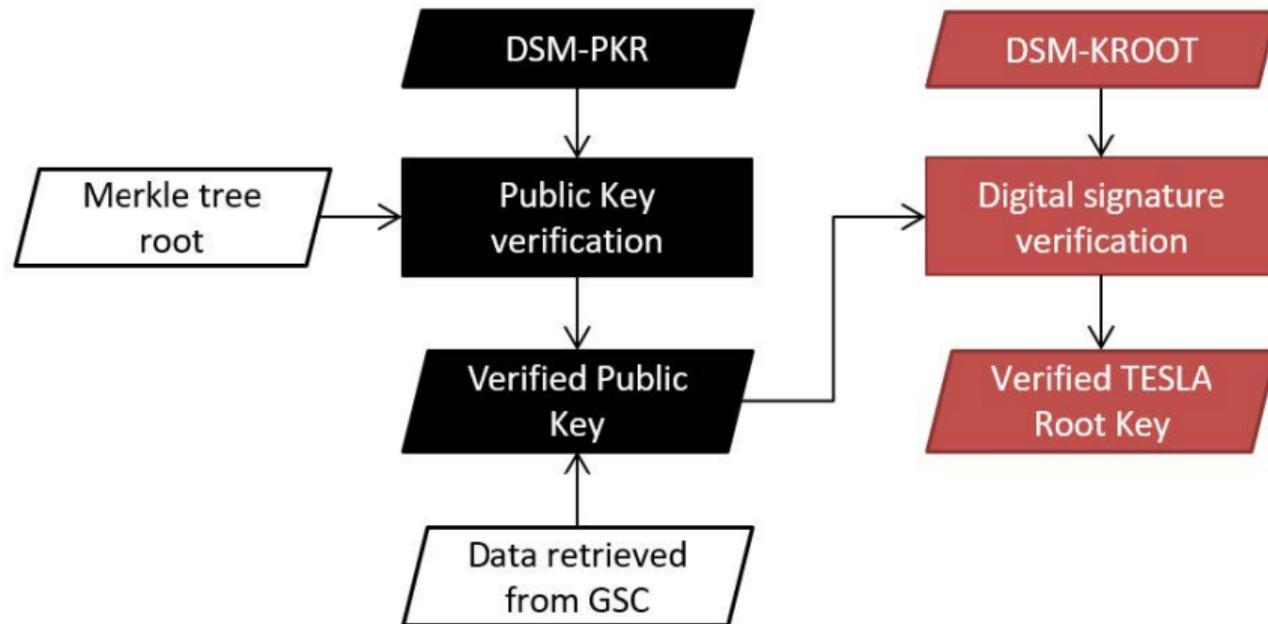
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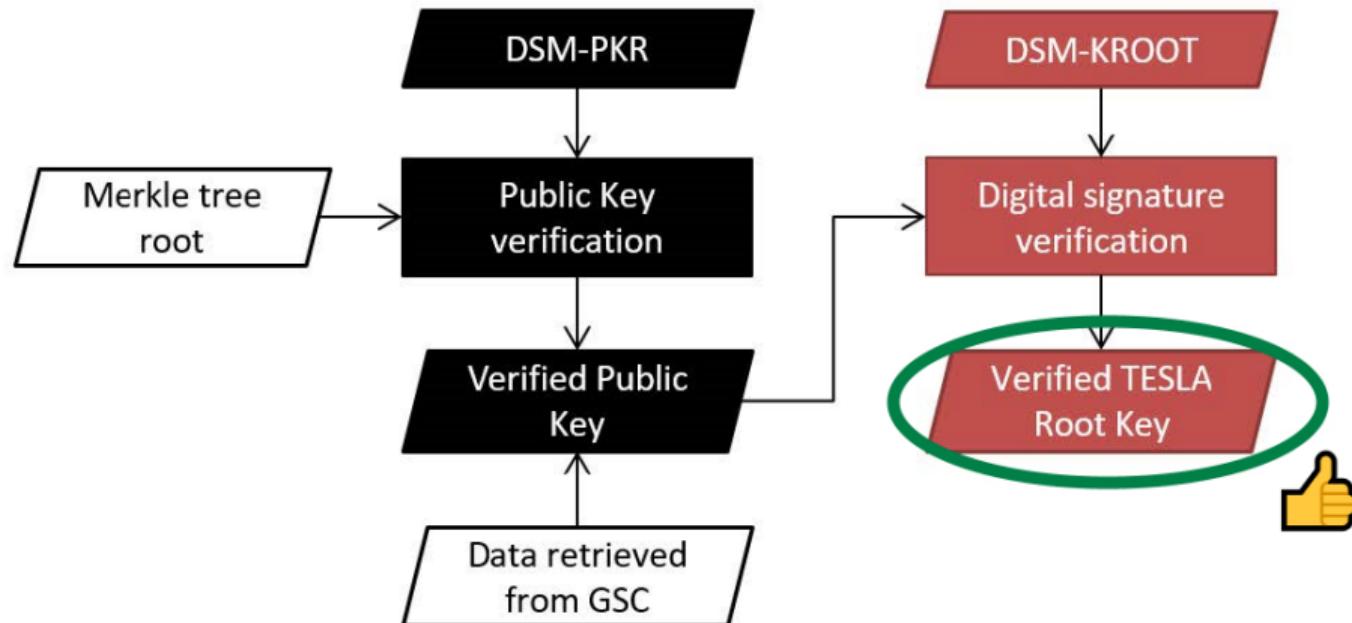
DSM-PKR Verification



DSM-* Verification



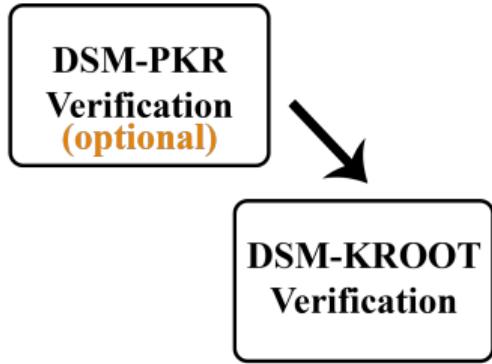
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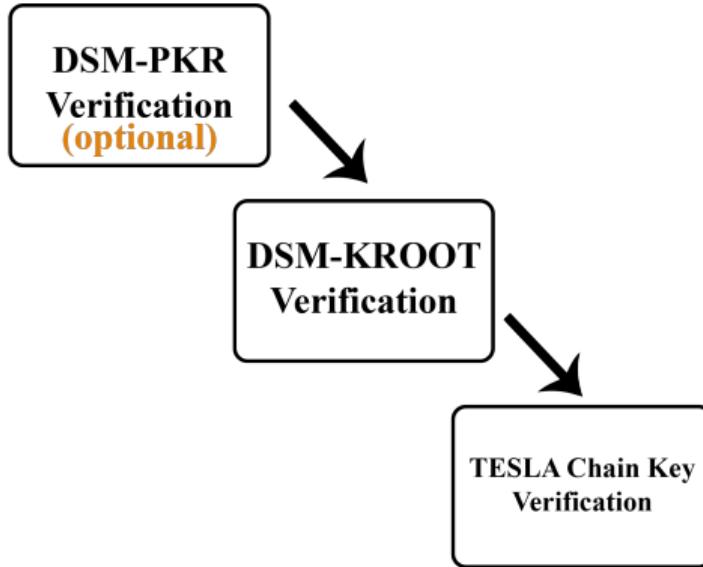
OSNMA Verification Summary

DSM-PKR
Verification
(optional)

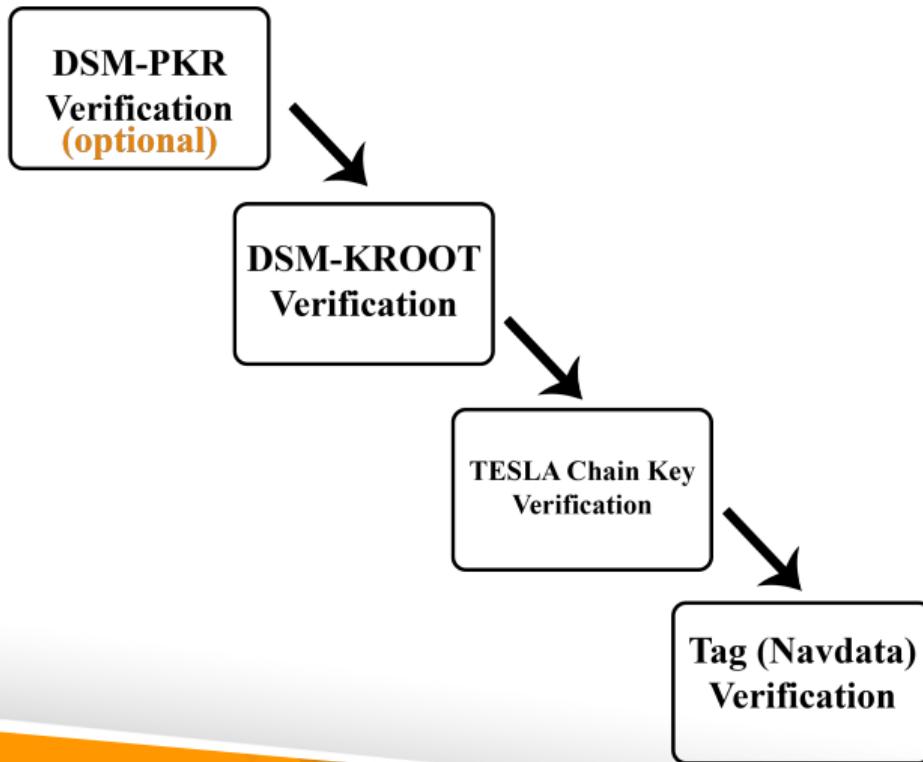
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OSNMA Receiver Implementation

- Python Parser for OSNMA data: **py-osnma-parser**

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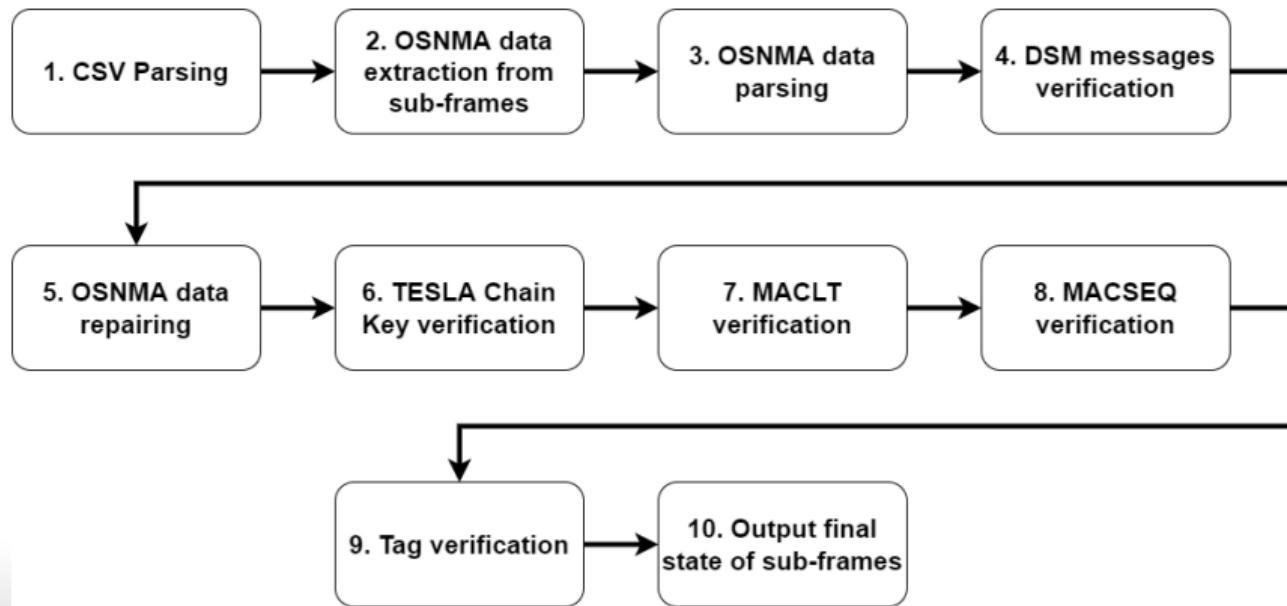
OSNMA Receiver Implementation

- Python Parser for OSNMA data: [py-osnma-parser](#)
- Processes stored OSNMA samples
 - Retrieved from GNSS-SDR and Galmon navfeed
- (Almost) Full OSNMA verification

OSNMA Receiver Implementation

- Python Parser for OSNMA data: [py-osnma-parser](#)
- Processes stored OSNMA samples
 - Retrieved from GNSS-SDR and Galmon navfeed
- (Almost) Full OSNMA verification
 - No DSM-PKR processing due to lack of test samples

py-osnma-parser Flow



py-osnma-parser Output

```
DSM-KROOT Verification:  
M(232 bits): 0x5250492104ac9e22967a3858080afad0590da613e6df39baea104f5598  
Sig(512 bits): 0x10cccad82a89ad0c32136fd4ed16a243e6cd97f4ae71bc05f2d48260...  
Root key(128 bits): 0xe0e845b091d32e27e882114457575e  
Pad(88 bits): 0xbddbdd06091e26a276fbac  
T88 bits: 0xbddbdd06091e26a276fbac  
Pad == ? True  
Signature correct? True  
DSM-KROOT Verification:  
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Root key(128 bits): 0x8afad6590da613e6df39baea104f5598  
Pad(88 bits): 0x9694d61ccbbe0220d4468  
T88 bits: 0x9694d61ccbbe0220d4468  
Pad == ? True  
Signature correct? True
```

DSM-KROOT Verification

TESLA Chain Key Verification

```
    M1: 3396, 7069348, Auth_7, Self-12 -> Computed tag: 0d999282c0, Reference: 0d9992d07e equal? - true  
    M1: 3396, 7069348, Auth_7, Self-Tag -> Computed tag: f0d7aa3935, Reference: f0d7aa3935 equal? - true  
No subordinate From PBR 9 at time M1 1196: T0d_ 569040 for Cross-0 authentication  
No subordinate From PBR 10 at time M1 1196: T0d_ 569041 for Cross-0 authentication  
No subordinate From PBR 11 at time M1 1196: T0d_ 569042 for Cross-0 authentication  
No subordinate From PBR 12 at time M1 1196: T0d_ 569043 for Cross-0 authentication  
M1: 3396, 7069348, Auth_1, Self-12 -> Computed tag: 30ab6f88, Reference: 30ab6f88 equal? - true  
M1: 3396, 7069348, Auth_1, Self-Tag -> Computed tag: a8a7d100, Reference: a8a7d100 equal? - true  
No subordinate From PBR 25 at time M1 1196: T0d_ 569091 for Cross-0 authentication  
No subordinate From PBR 26 at time M1 1196: T0d_ 569092 for Cross-0 authentication  
No subordinate From PBR 27 at time M1 1196: T0d_ 569093 for Cross-0 authentication  
M1: 3396, 7069348, Auth_13, Self-12 -> Computed tag: df1a5530, Reference: df1a5530 equal? - true  
M1: 3396, 7069348, Auth_13, Self-Tag -> Computed tag: f0d7a0d4, Reference: f0d7a0d4 equal? - true  
No subordinate From PBR 33 at time M1 1196: T0d_ 569099 for Cross-0 authentication  
No subordinate From PBR 34 at time M1 1196: T0d_ 569100 for Cross-0 authentication  
No subordinate From PBR 35 at time M1 1196: T0d_ 569101 for Cross-0 authentication  
M1: 3396, 7069348, Auth_4, Self-12 -> Computed tag: bcd343ba, Reference: bcd343ba equal? - true  
M1: 3396, 7069348, Auth_4, Self-Tag -> Computed tag: 0133d520fa, Reference: 0133d520fa equal? - true  
No subordinate From PBR 23 at time M1 1196: T0d_ 569109 for Cross-0 authentication  
No subordinate From PBR 24 at time M1 1196: T0d_ 569110 for Cross-0 authentication  
No subordinate From PBR 25 at time M1 1196: T0d_ 569111 for Cross-0 authentication  
M1: 3396, 7069348, Auth_5, Self-12 -> Computed tag: bdd098ca, Reference: bdd098ca equal? - true  
M1: 3396, 7069348, Auth_5, Self-Tag -> Computed tag: 0133d520fd, Reference: 0133d520fd equal? - true
```

Tag Verification

Verified Subframe



Attacks?

Attack 1

- Not all satellites transmit OSNMA data

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- OSNMA fields zeroed out

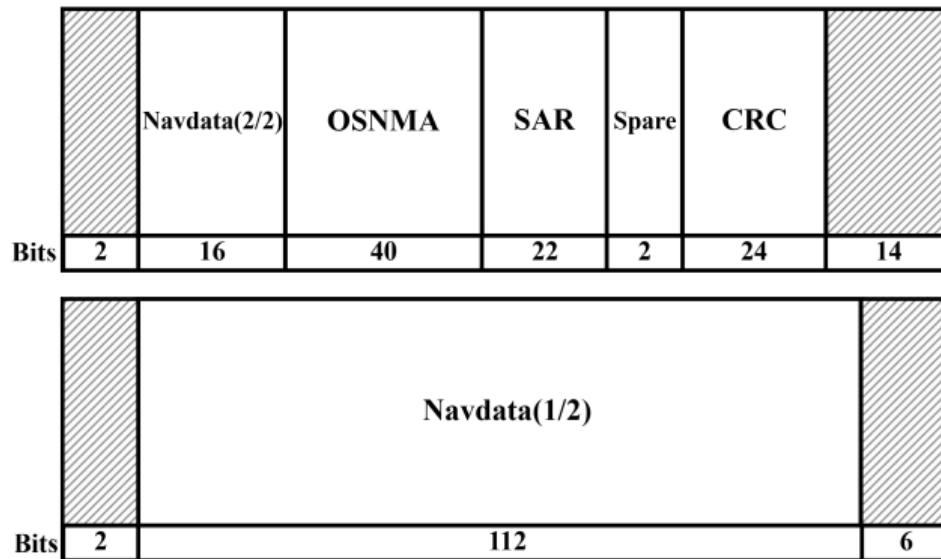
Attack 1

- Not all satellites transmit OSNMA data
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- Receivers should ignore 0-filled OSNMA field
 - Receiver guidelines mandate it

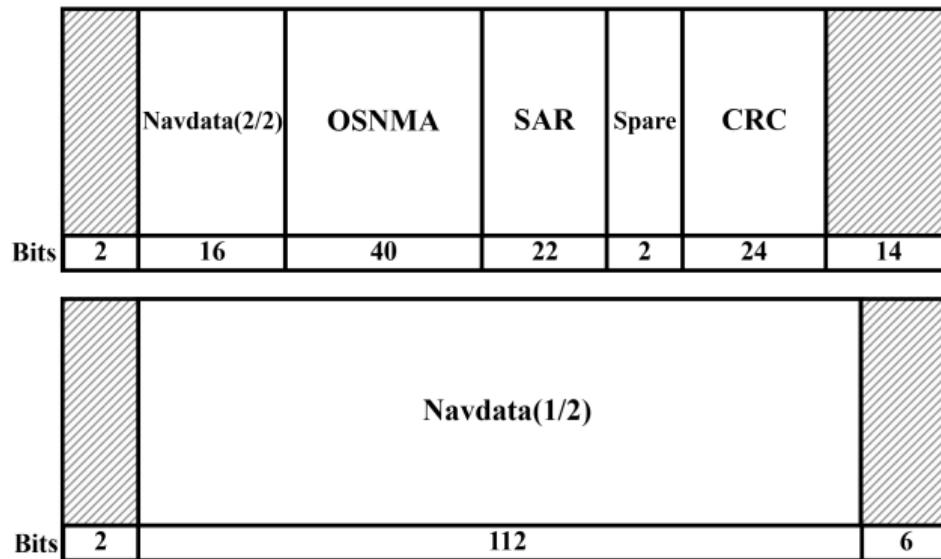
Attack 1

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- Downgrade attack?

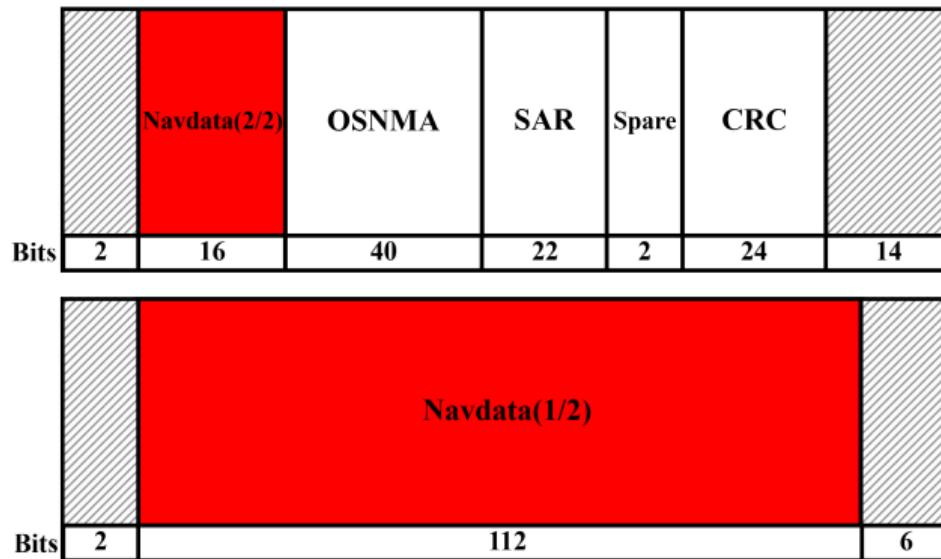
Downgrade Attack



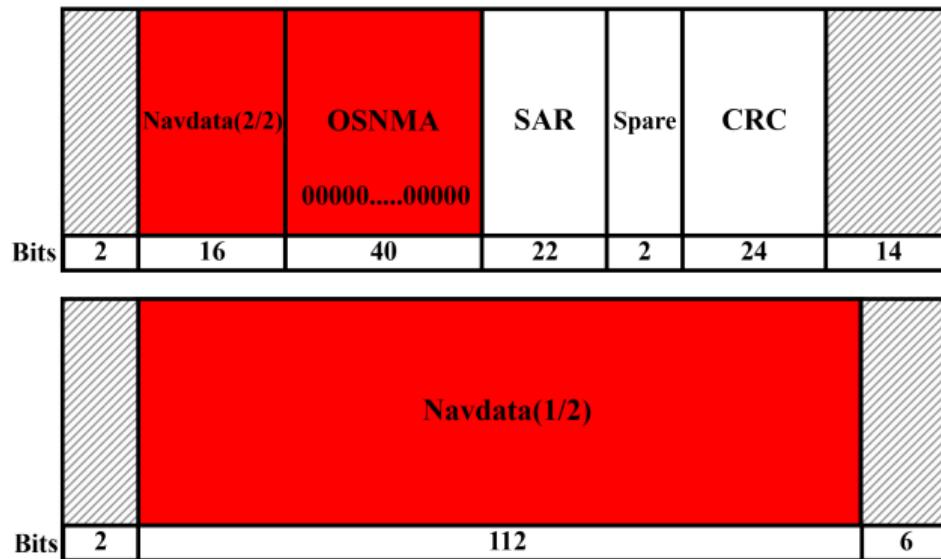
Downgrade Attack



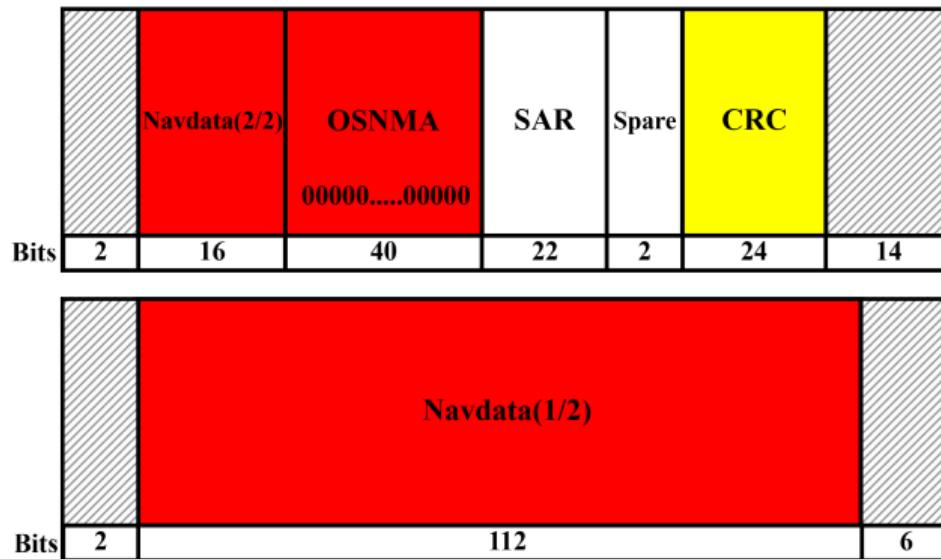
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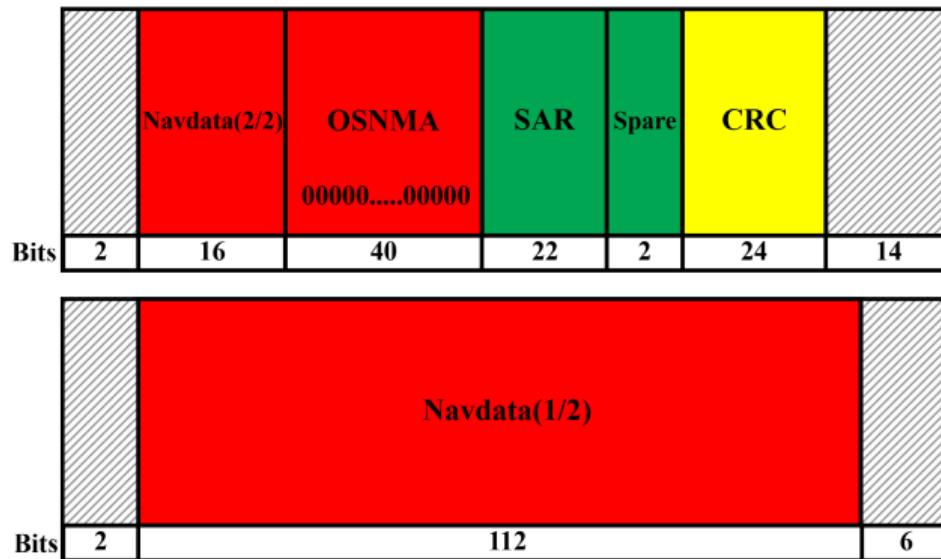
Downgrade Attack



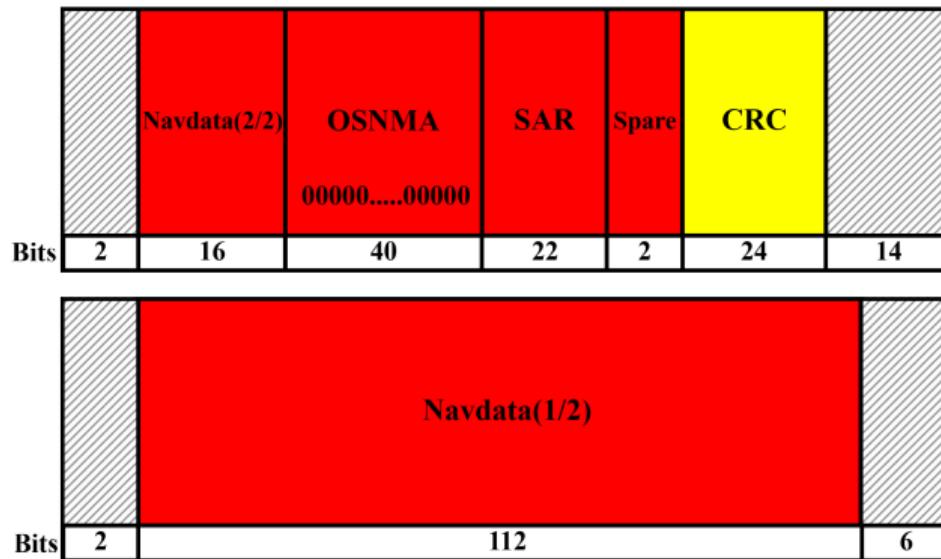
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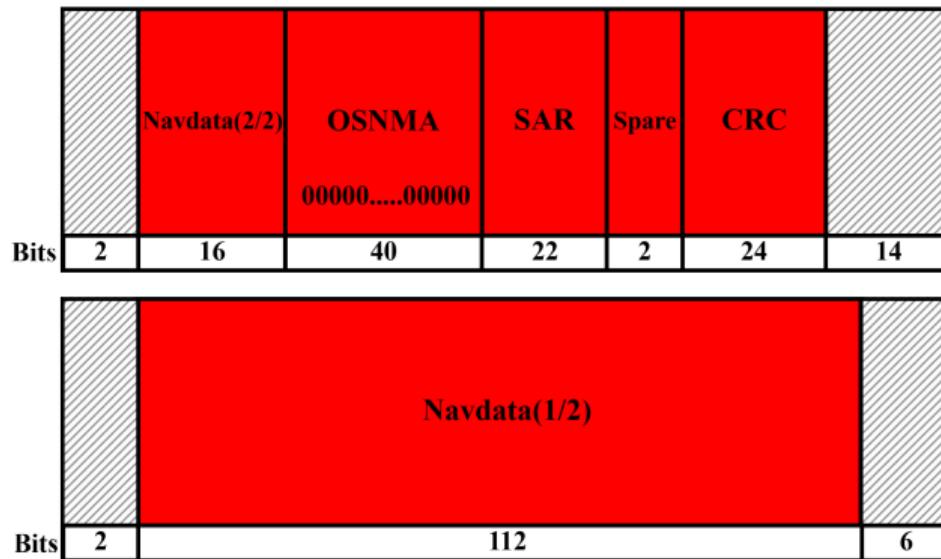
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Countermeasures

- Signal characteristics

Downgrade Attack

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Countermeasures

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Countermeasures

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 - No official API yet

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Countermeasures

- Signal characteristics
- Check whether OSNMA is enabled for a satellite via Internet
 - No official API yet
 - Use data from Galmon's website

Galmon Info Page

sv	iod	eph-age-m	orbit-disco	time-disco	sisa	health	alma-dist	osnma
E01@1	48	34 minutes ago	4.4 cm	0.0 ns	312 cm	ok/ok/NG/NG	0.8 km	
E03@1	43	84 minutes ago	13.7 cm	0.0 ns	312 cm	ok/ok/val/val	1.6 km	
E04@1	50	14 minutes ago	11.8 cm	0.4 ns	312 cm	ok/ok/val/val	2.1 km	✓
E05@1	50	14 minutes ago	20.1 cm	0.2 ns	312 cm	ok/ok/val/val	1.6 km	
E07@1	50	14 minutes ago	6.9 cm	0.0 ns	312 cm	ok/ok/val/val	1.3 km	✓
E08@1	50	14 minutes ago	2.1 cm	0.0 ns	312 cm	ok/ok/val/val	1.8 km	✓
E09@1	50	14 minutes ago	10.6 cm	-0.1 ns	312 cm	ok/ok/val/val	1.7 km	✓
E10@1	50	14 minutes ago	3.1 cm	0.0 ns	312 cm	ok/ok/val/val	1.0 km	✓
E11@1	50	14 minutes ago	7.9 cm	0.0 ns	312 cm	ok/ok/val/val	0.9 km	
E12@1	50	14 minutes ago	8.4 cm	0.1 ns	312 cm	ok/ok/val/val	1.2 km	✓
E13@1	50	14 minutes ago	5.6 cm	0.0 ns	312 cm	ok/ok/val/val	1.9 km	✓
E14@1	44	74 minutes ago	10.4 cm	-0.1 ns	312 cm	OUT/OUT/val/val		
E15@1	48	34 minutes ago	5.0 cm	0.0 ns	312 cm	ok/ok/val/val	0.6 km	
E18@1	50	14 minutes ago	16.6 cm	0.0 ns	312 cm	OUT/OUT/val/val		✓
E19@1	49	24 minutes ago	9.1 cm	-0.3 ns	312 cm	ok/ok/val/val	2.0 km	
E21@1	50	14 minutes ago	6.0 cm	0.1 ns	360 cm	ok/ok/val/val	1.9 km	✓
E24@1	50	14 minutes ago	4.3 cm	0.0 ns	312 cm	ok/ok/val/val	0.7 km	✓
E25@1	44	74 minutes ago	5.7 cm	0.0 ns	312 cm	ok/ok/val/val	1.1 km	

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 - "Fresh" data - $< 1s$ delay

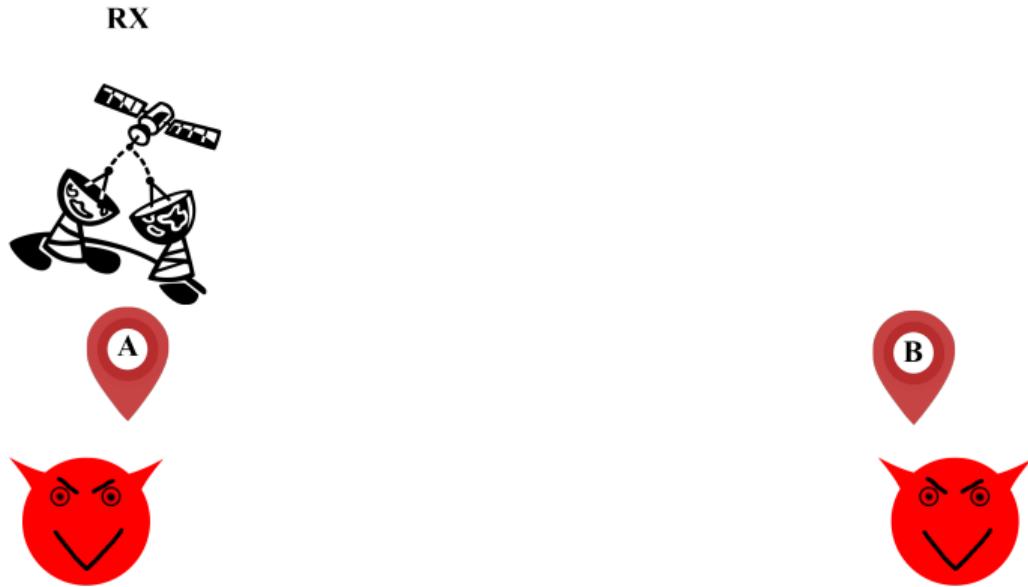
Attack 2

- OSNMA requires "fresh" messages
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 - "Fresh" data - $< 1s$ delay
 - Replayed data is inherently authentic

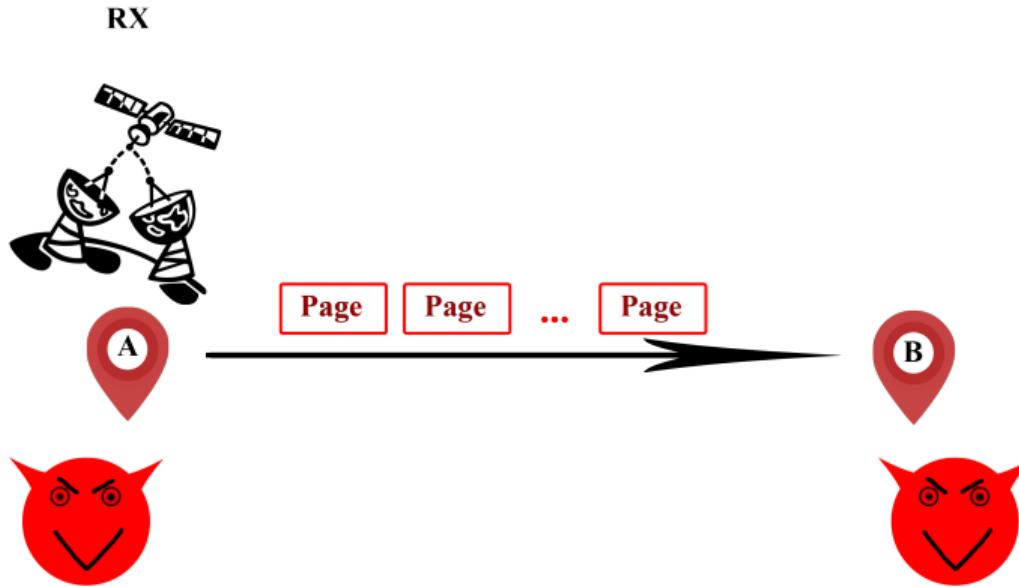
Relay Attack



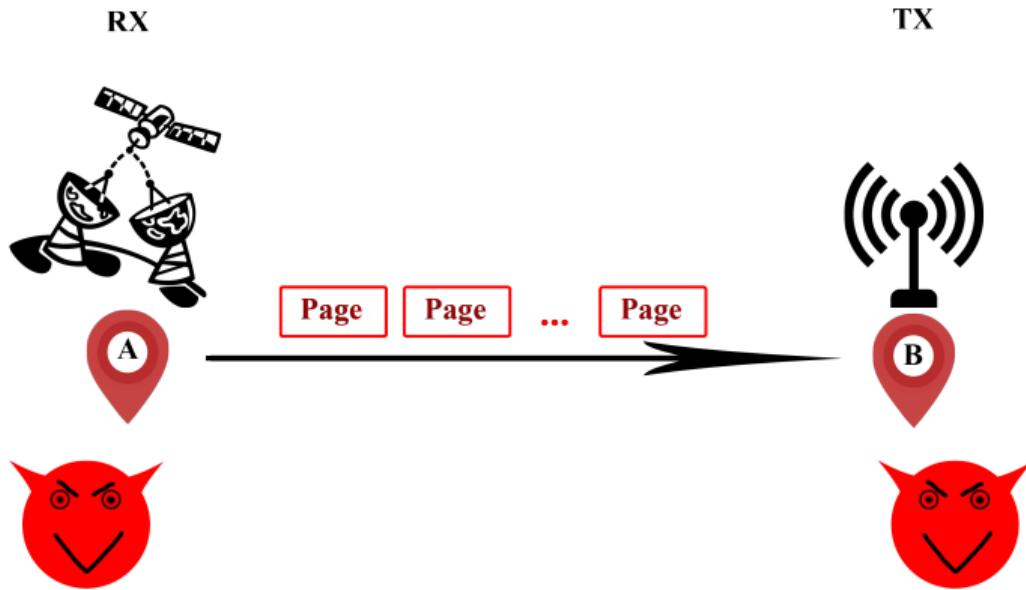
Relay Attack



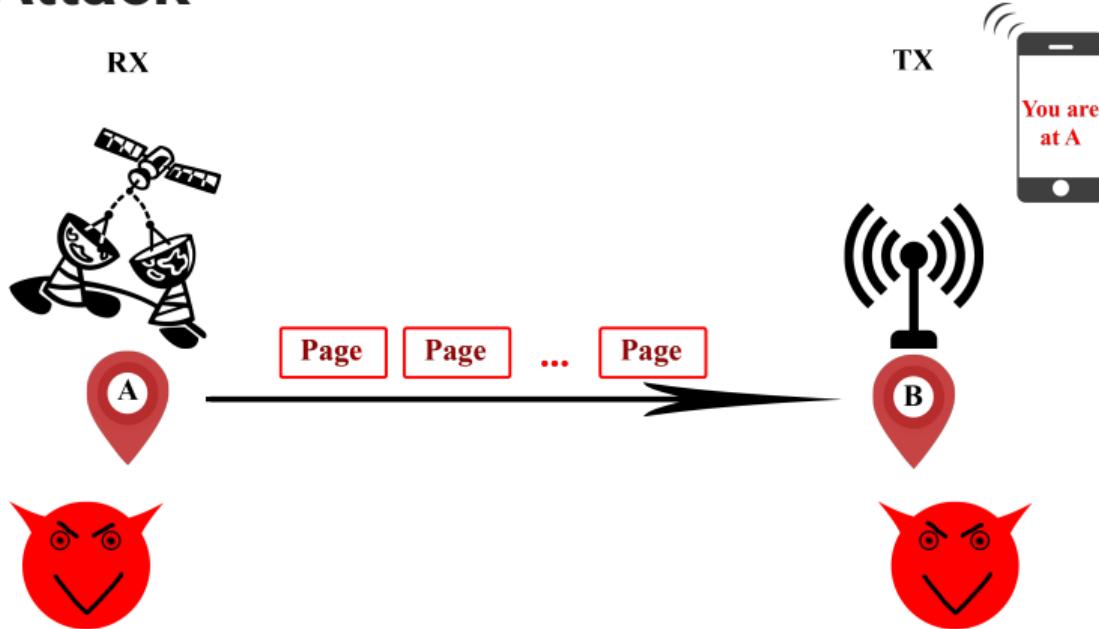
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 - "Fresh" data - < 1s delay
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*"Cryptography is not enough:
Relay attacks on authenticated GNSS signals"*

Countermeasures

- Signal characteristics

Attack 3

- Device cold-starts

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(\approx 4 minutes)

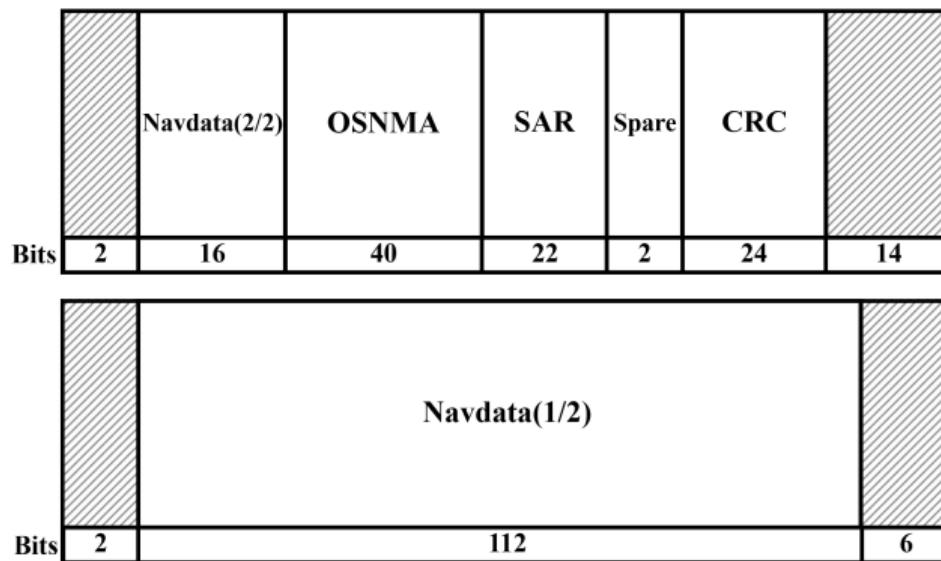
Attack 3

- Device cold-starts
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- Short-term spoofing?

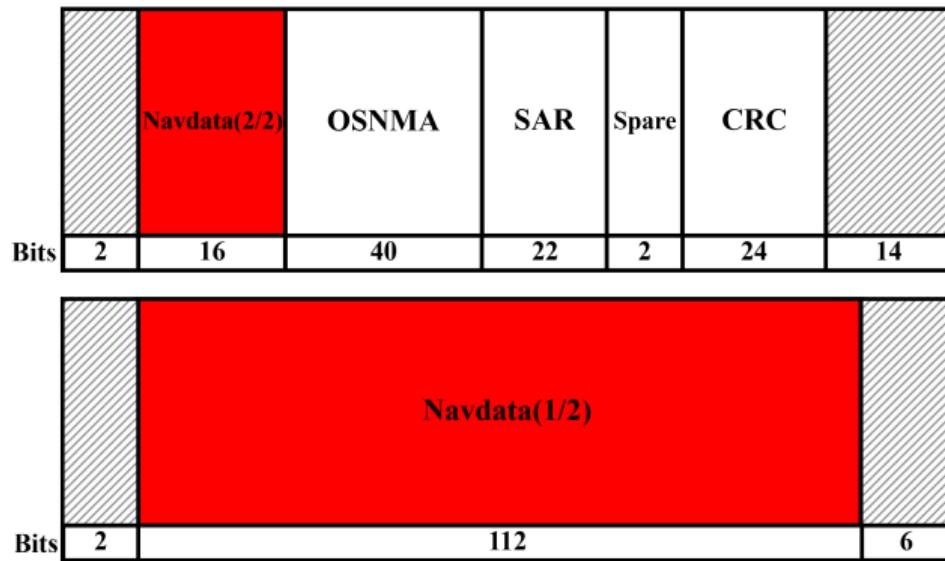
Attack 3

- Device cold-starts
 - No previous OSNMA data
- Must wait for KROOT verification
(\approx 4 minutes)
- **Short-term spoofing?**
 - Should go undetected until KROOT is received

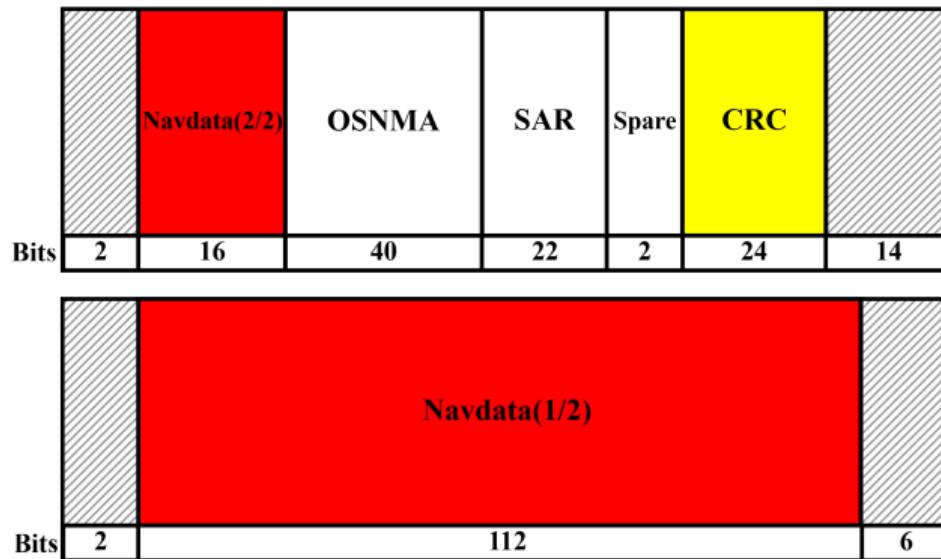
Cold Start Attack



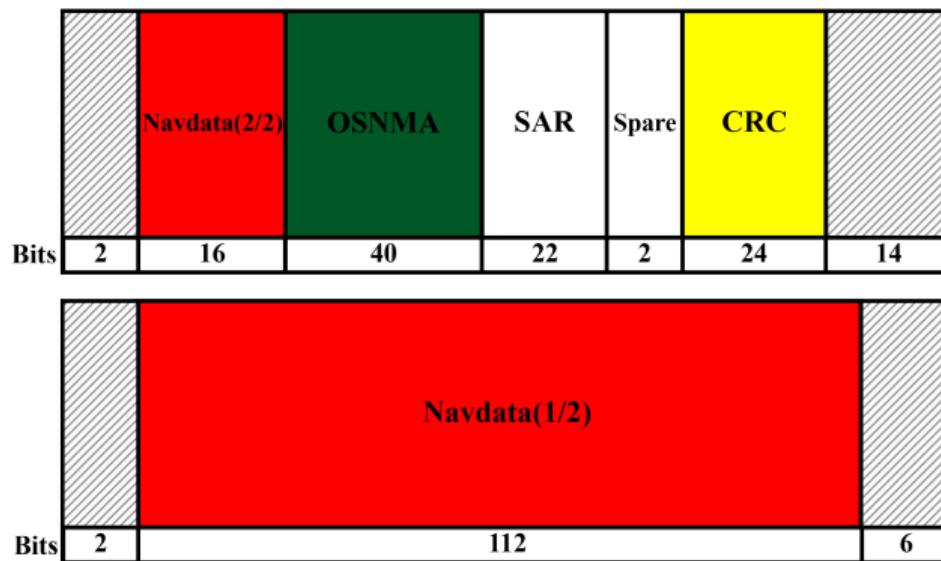
Cold Start Attack



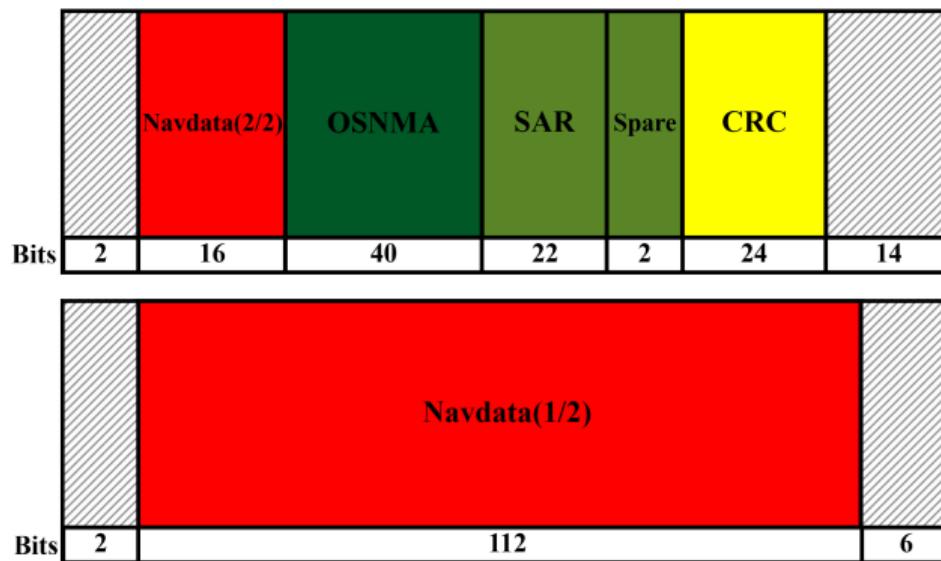
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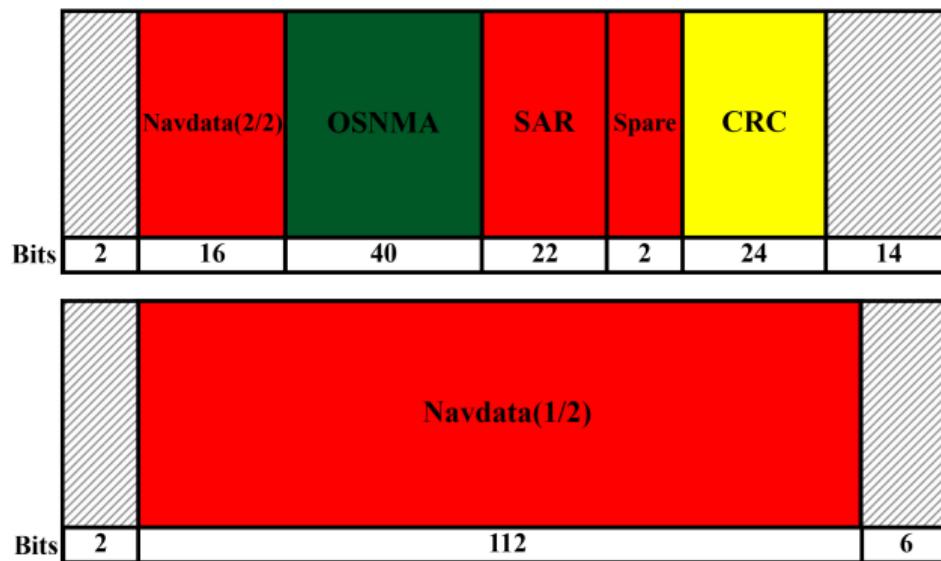
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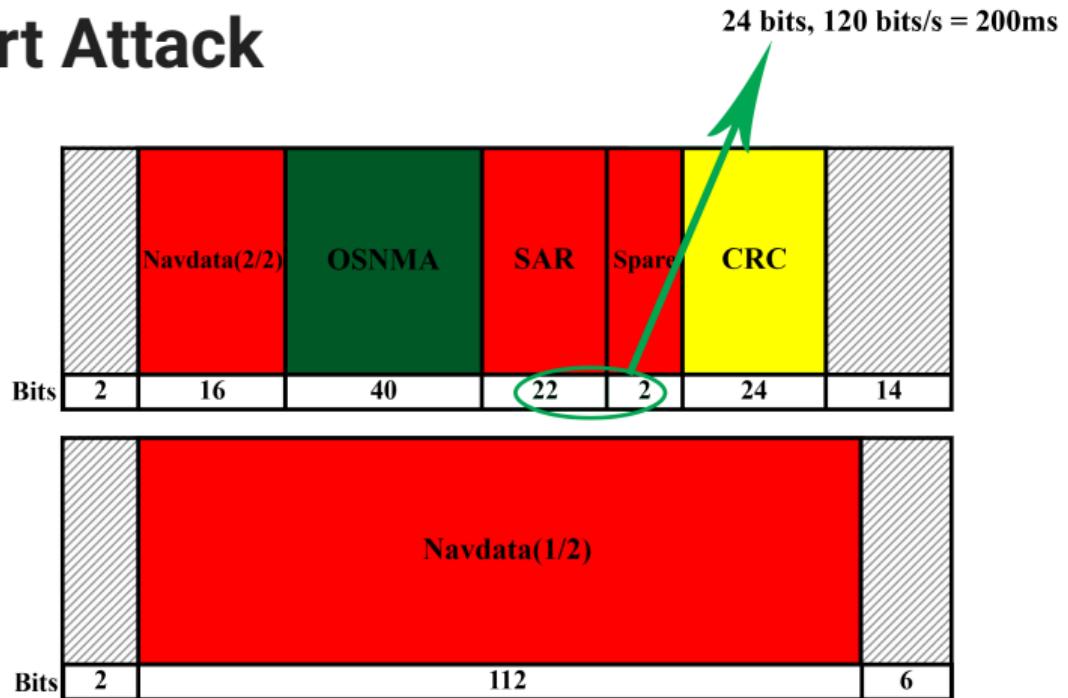
Cold Start Attack



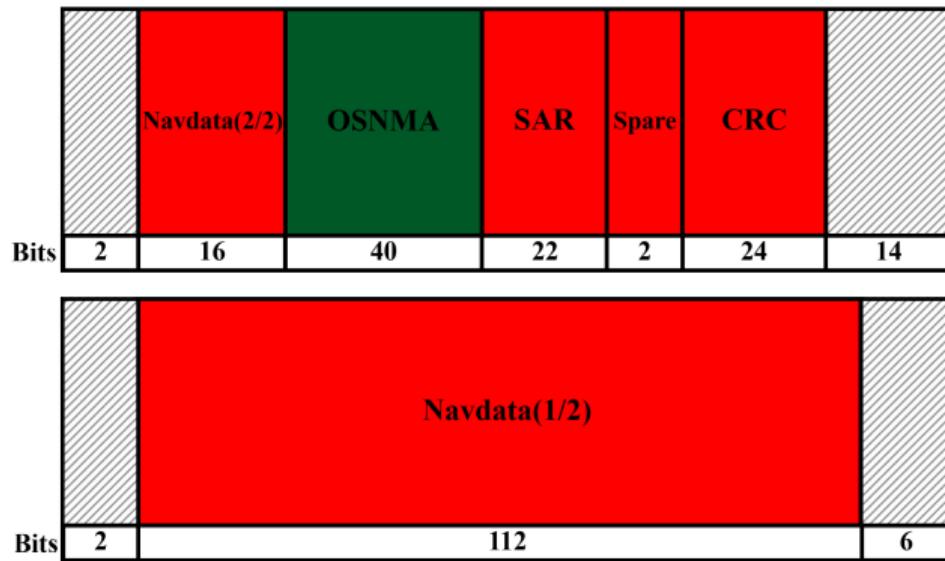
Cold Start Attack



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(\approx 4 minutes)
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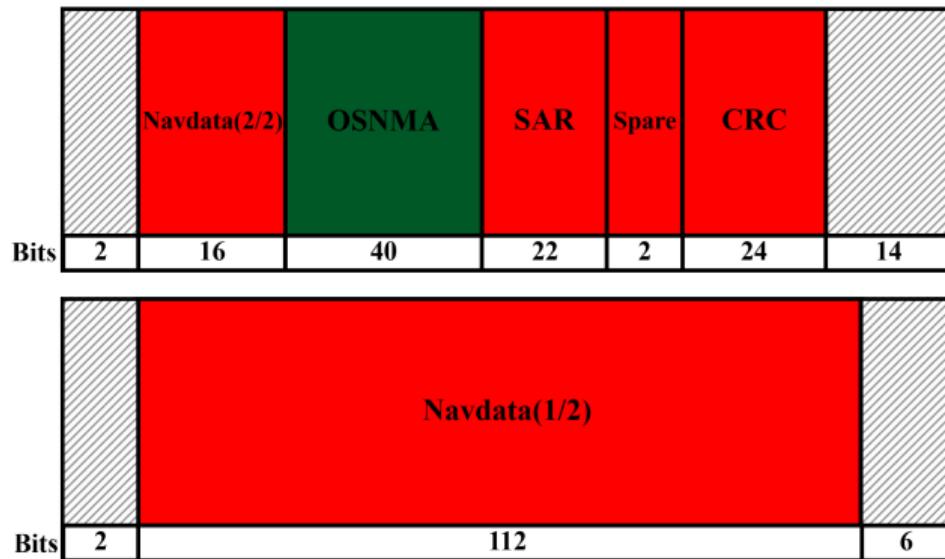
Temporal Authenticity



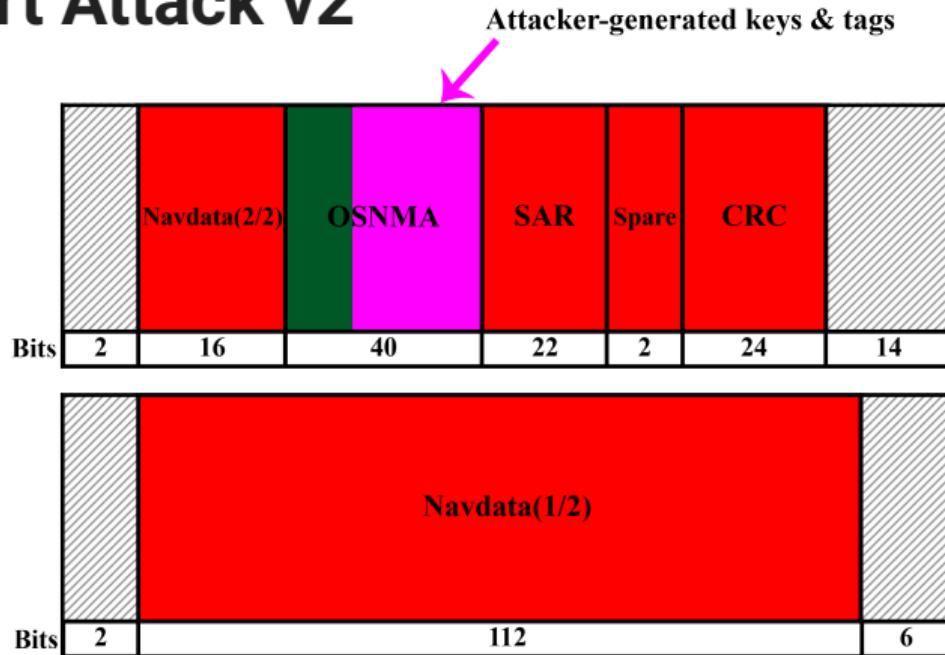
Temporal Authenticity



Cold Start Attack v2



Cold Start Attack v2



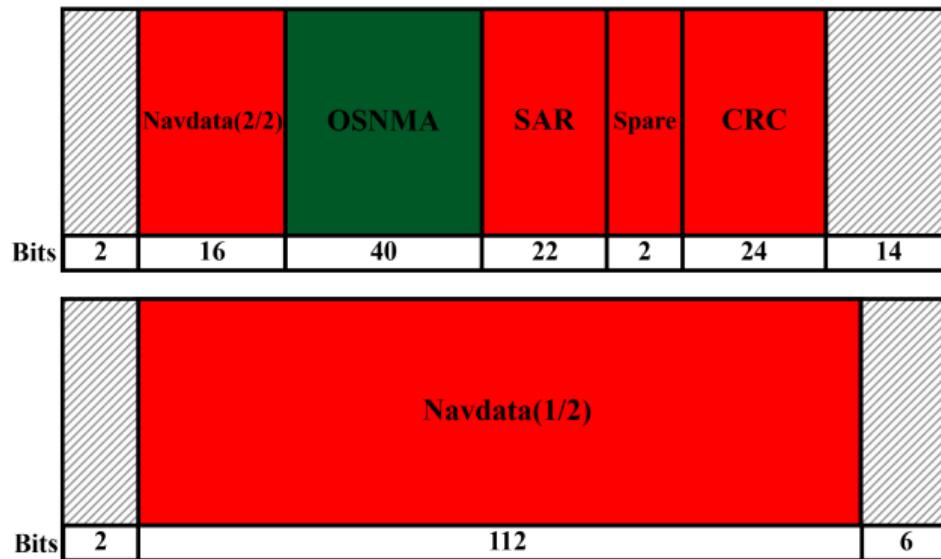
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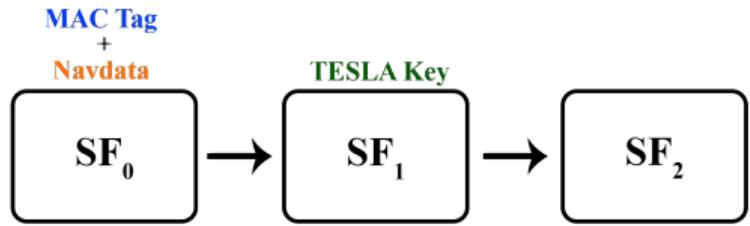
Countermeasures

- Signal characteristics
- Use Navdata only after it's verified
- Speed-up verification
 - Makes previous option more viable

Faster Verification?

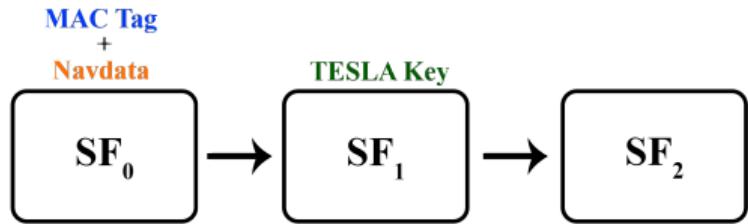


Faster Verification?



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Contradicts TESLA RFC!





What Now?

Ideal World: Official OSNMA Processing Library

- Open-Source

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- C/C++-based, for compatibility

More Tools: GNSS-SDR with OSNMA Support

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- Introduce OSNMA processing in it

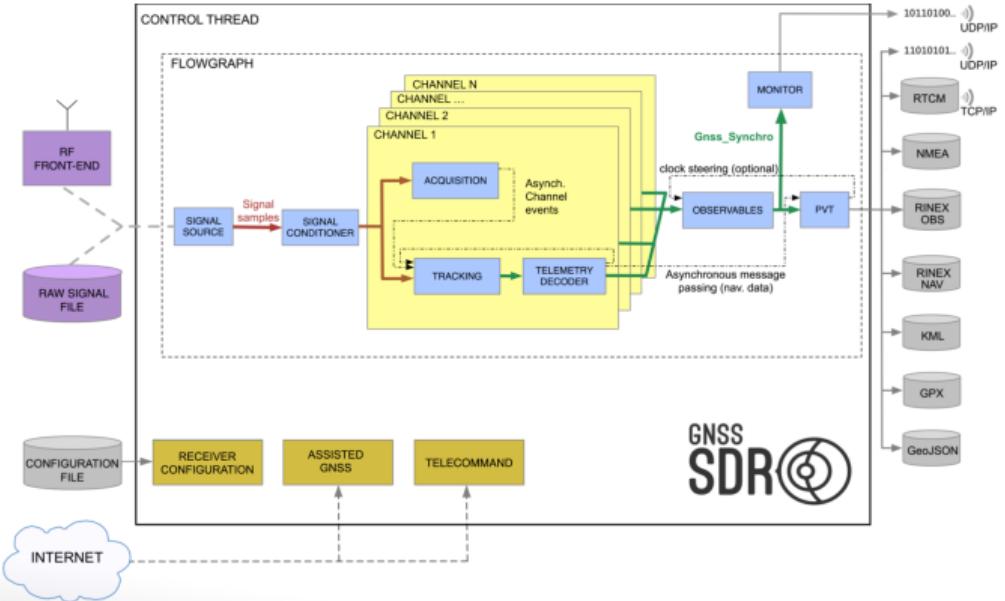
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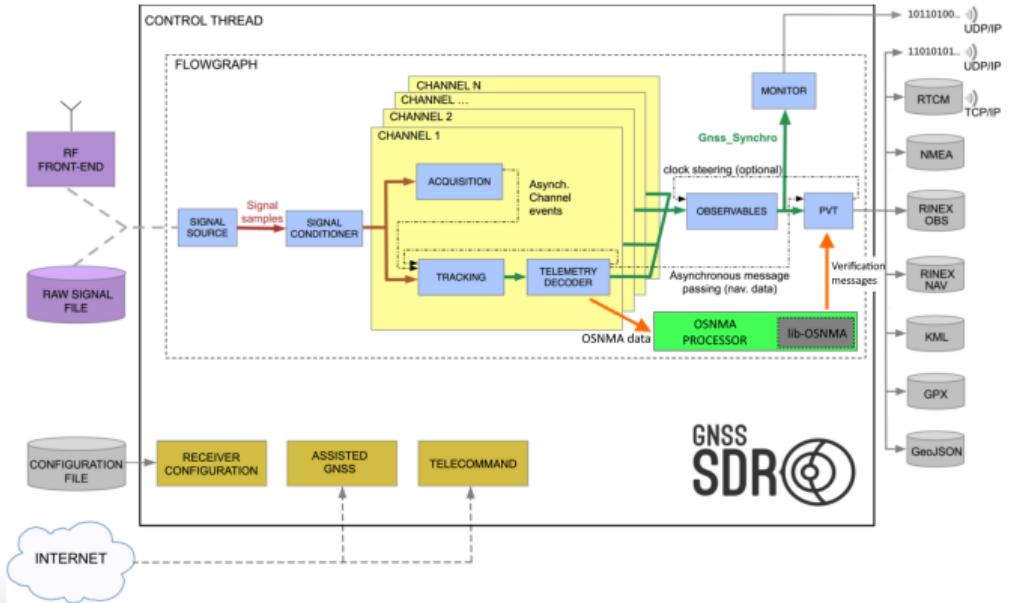
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 - Only DSM-KROOT verification

GNSS-SDR Block Diagram



GNSS-SDR-OSNMA Block Diagram



Conclusion

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OSNMA good, can be better



Live Demo + Q&A

Jim

For any further questions, feel free to contact me @
ikyorovski@ethz.ch

