GNSS Signal Authentication and It's Applications

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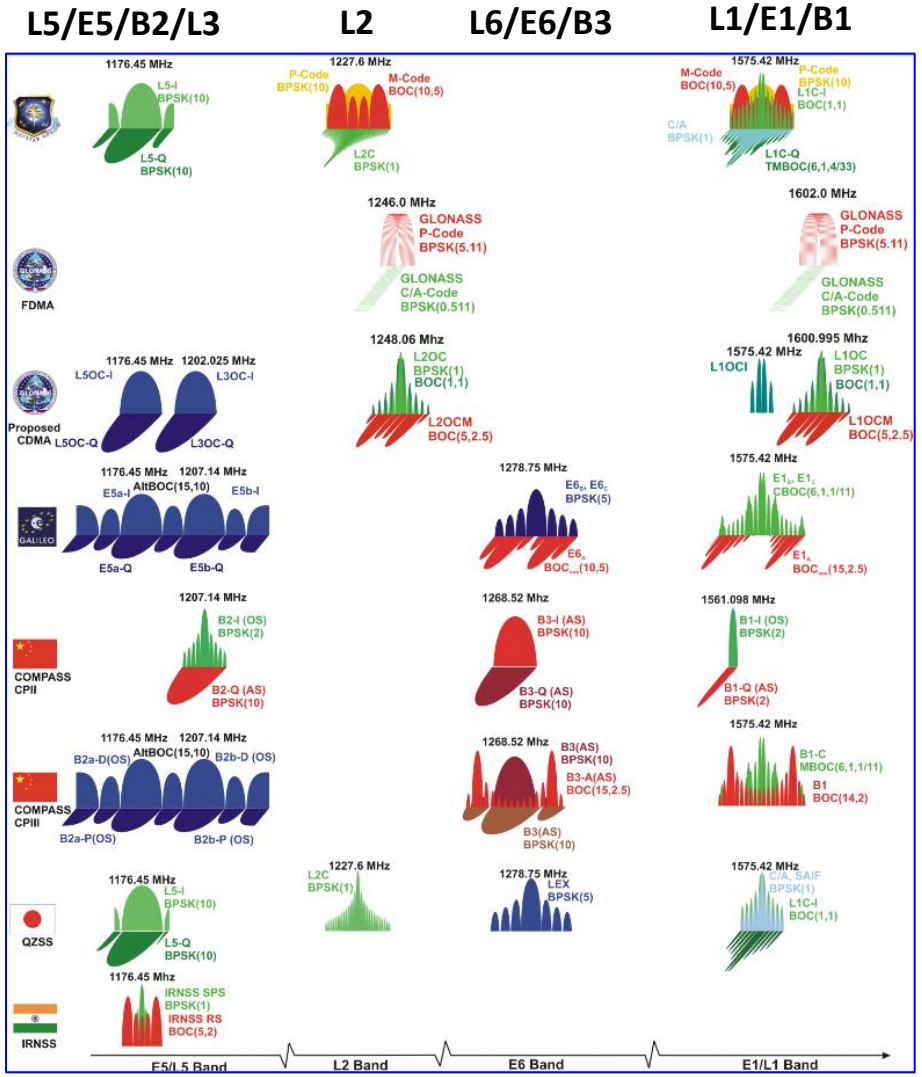
Contents

GNSS Signals

- GNSS (Global Navigation Satellite System) is an acronym used to represent all navigation satellite systems such as

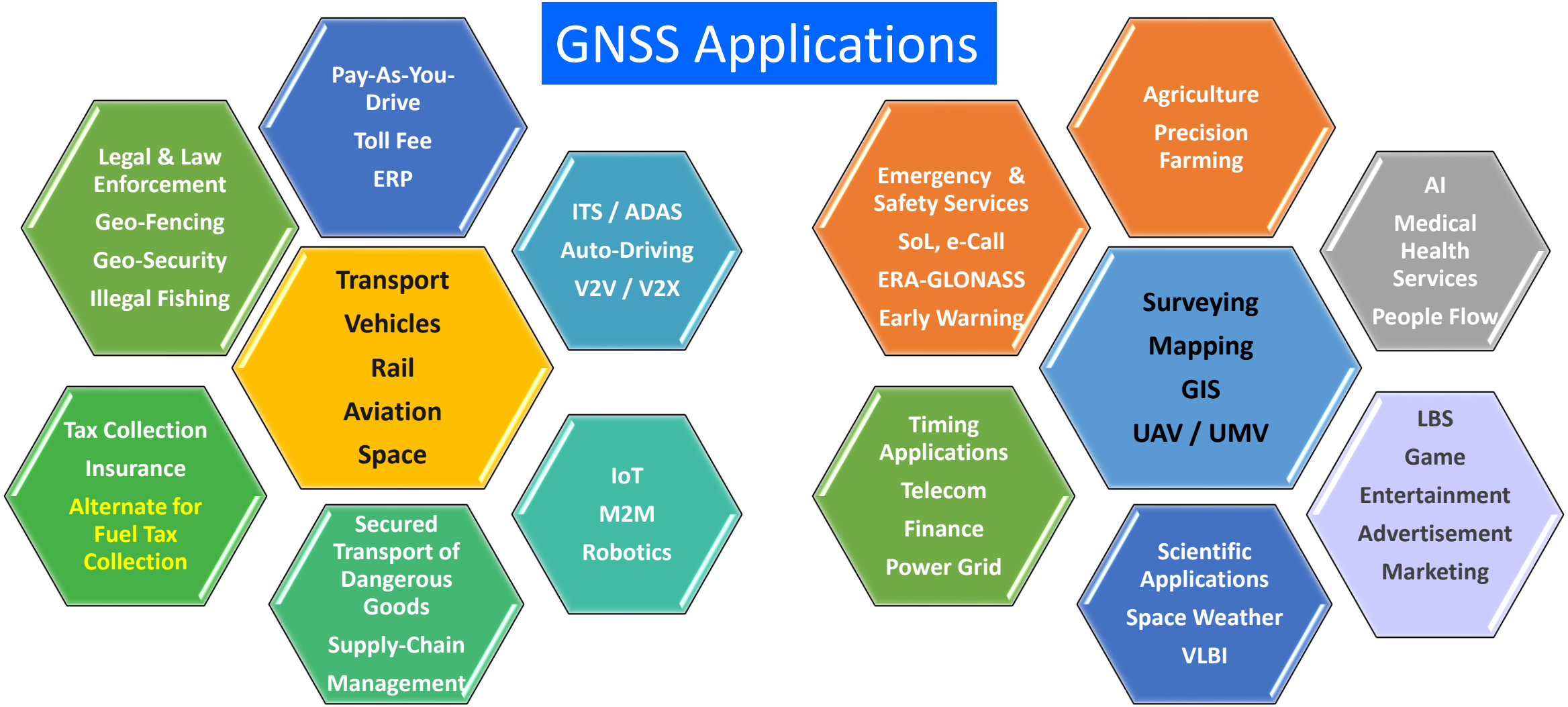
Satellite	Country	Coverage
GPS	USA	Global
GLONASS	Russia	Global
Galileo	Europe	Global
BeiDou (BDS)	China	Global
QZSS (Michibiki)	Japan	Regional
NavIC	India	Regional

- ✓ GPS and GLONASS have signals for civilian and military usage
  - ❖ Military signals are encrypted and not available for civilian use
- ✓ Galileo and BeiDou also have Open and Restricted Signals
- ✓ All civilian signals are freely available
- ✓ Technical information for civilian signals are made public
  - ❖ Necessary to develop a receiver
  - ❖ Its called ICD (Interface Control Document) or IS (Interface Specification) Document



https://gssc.esa.int/navipedia/images/c/cf/GNSS_All_Signals.png

Why GNSS Security is Important?

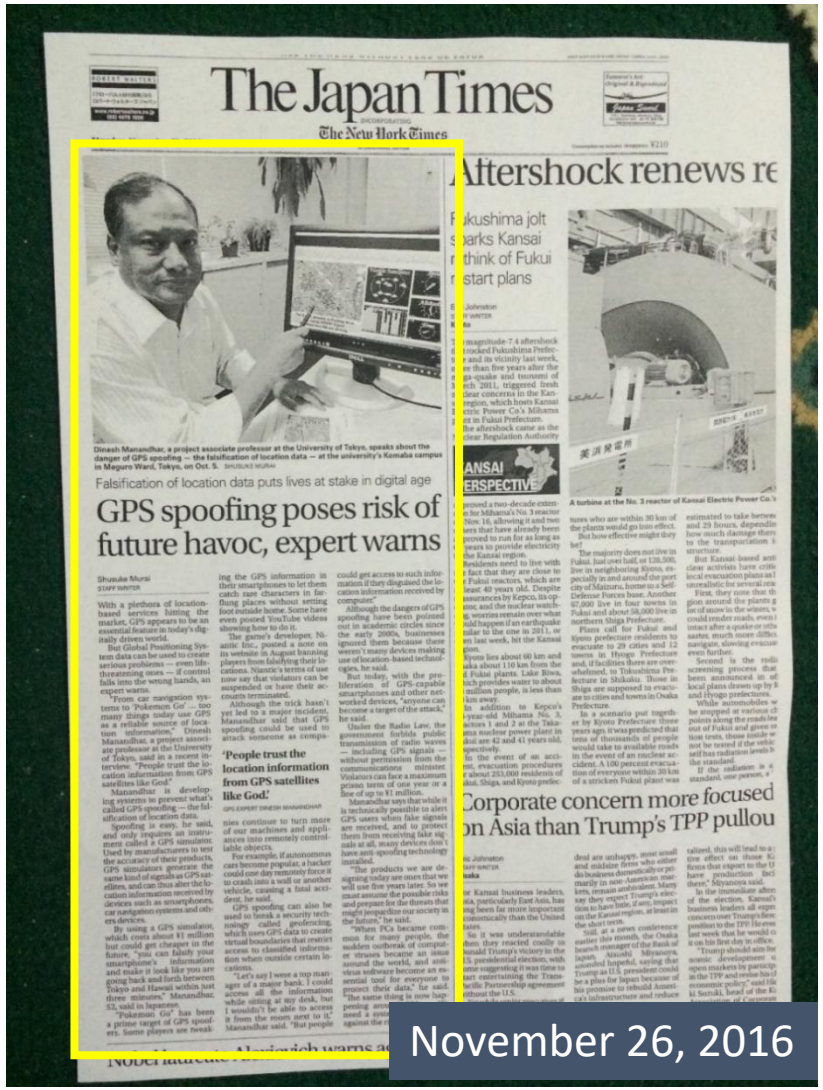


Main Issues of GNSS Signal Security: Jamming, Interference and Spoofing (JIS)

	Jamming	Interference	Spoofing
Attack Method	Intentional or Non-Intentional	Intentional or Non-Intentional	Intentional
Detection Possibility	It can be detected	Normally it can be detected Sometimes, non-detectable	Difficult to detect
Research and Studies	Many research and studies conducted	Many research and studies conducted	Limited research and studies
Existing Solutions	Limited solutions exist Not effective for mass-market receiver systems	Limited solutions exist Not effective for mass-market receiver systems	Recently, QZSS and Galileo are providing solutions for Spoofing detection
Severity Impact	Severe impact to deliver a service because the system may not work Non-availability of solutions	Severe impact to deliver quality service if the system is still working Non-reliable solutions	Severe and extremely dangerous impacts Spoofed solutions available as true solution

We will focus this talk mostly on Spoofing Issues

GPS Spoofing Poses Risk of Future Havoc


The Japan Times
The New York Times
Aftershock renews re
Falsification of location data puts lives at stake in digital age
GPS spoofing poses risk of future havoc, expert warns
Corporate concern more focused on Asia than Trump's TPP pullou
November 26, 2016

GPS 'Spoofing' is No Joke: Dangers of GPS Data Hacking Realized

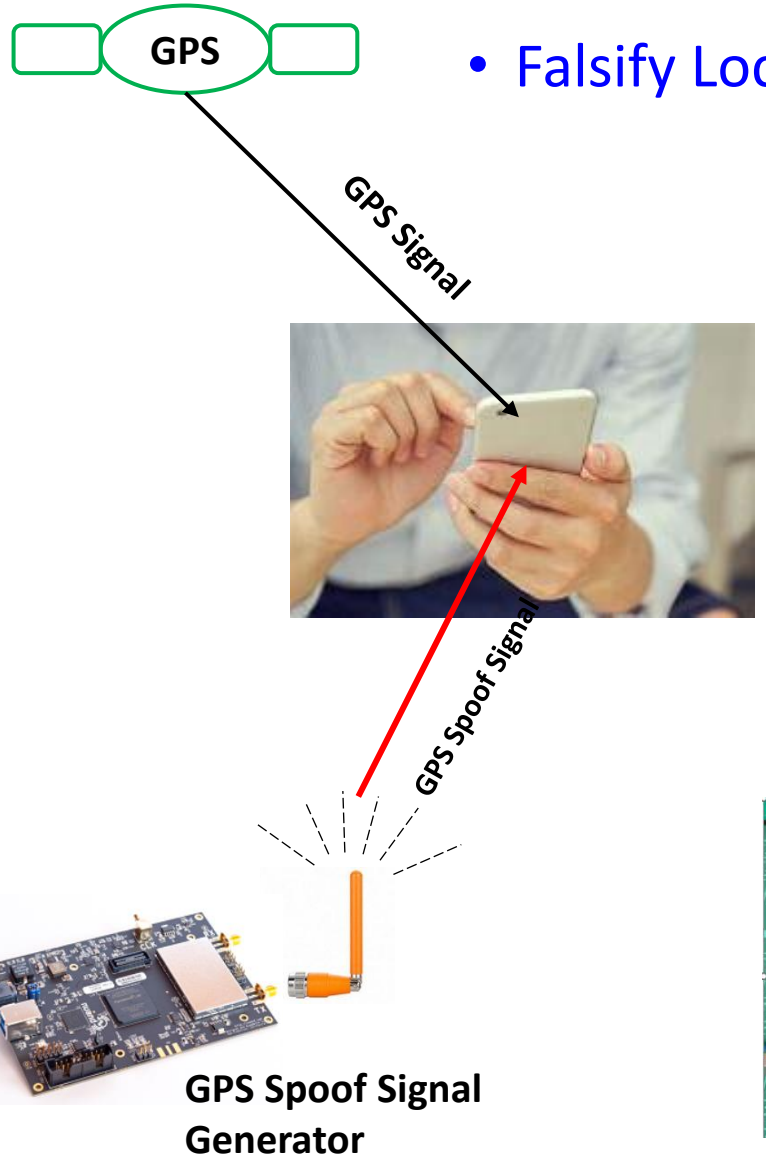
GNSS spoofing will attain virus status, warns expert – GPS World

Hacking Global Positioning System with GPS 'Spoofing' Can Lead To Fatalities
http://www.techworm.net/2016/11/gps-spoofing-dangers-gps-data-hacking.html

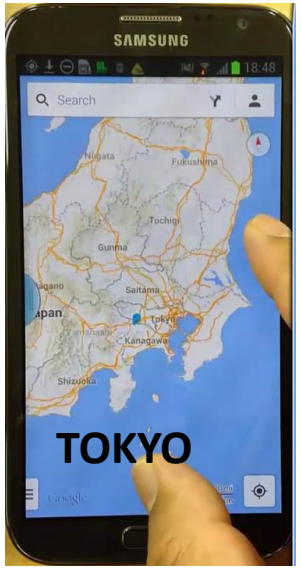
Dangers of GPS spoofing and hacking for location based services

Faking of GPS Data a growing and potentially lethal danger – The Japan Times, FB

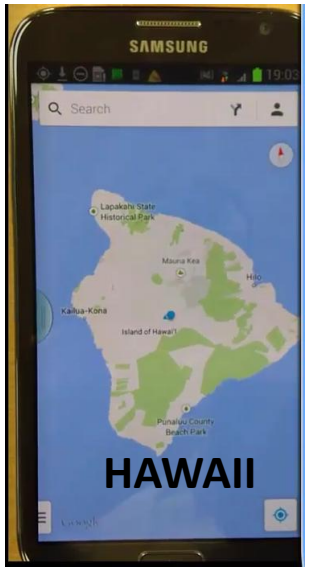
What is GNSS Signal Spoofing?



- Falsify Location and Time Data as If True Data



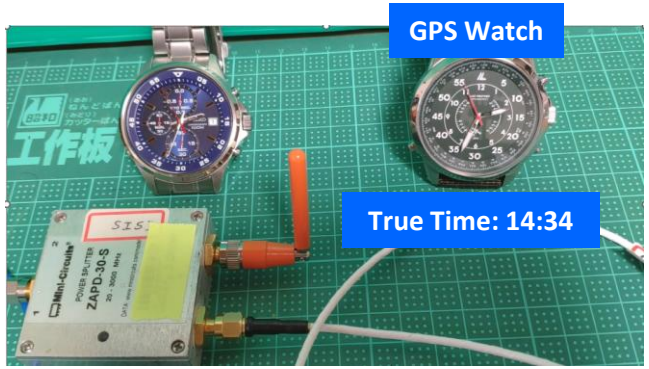
TOKYO
Or
Hawaii?



007

Tomorrow Never Dies

A movie based on GPS Signal Spoofing



Link to “Tomorrow Never Dies” Movie Clips

Bing Videos
https://www.bing.com/videos/riverview/relatedvideo?q=Tomorrow%20Never%20Dies%20Full%20Movie&mid=FB3A2EA6FBFDABC18121FB3A2EA6FBFDABC18121&ajaxhist=0
Watch at 1:44 – 2:05

- Looks like an American encoder.
- They use it to control their navigation satellites, the GPS system.

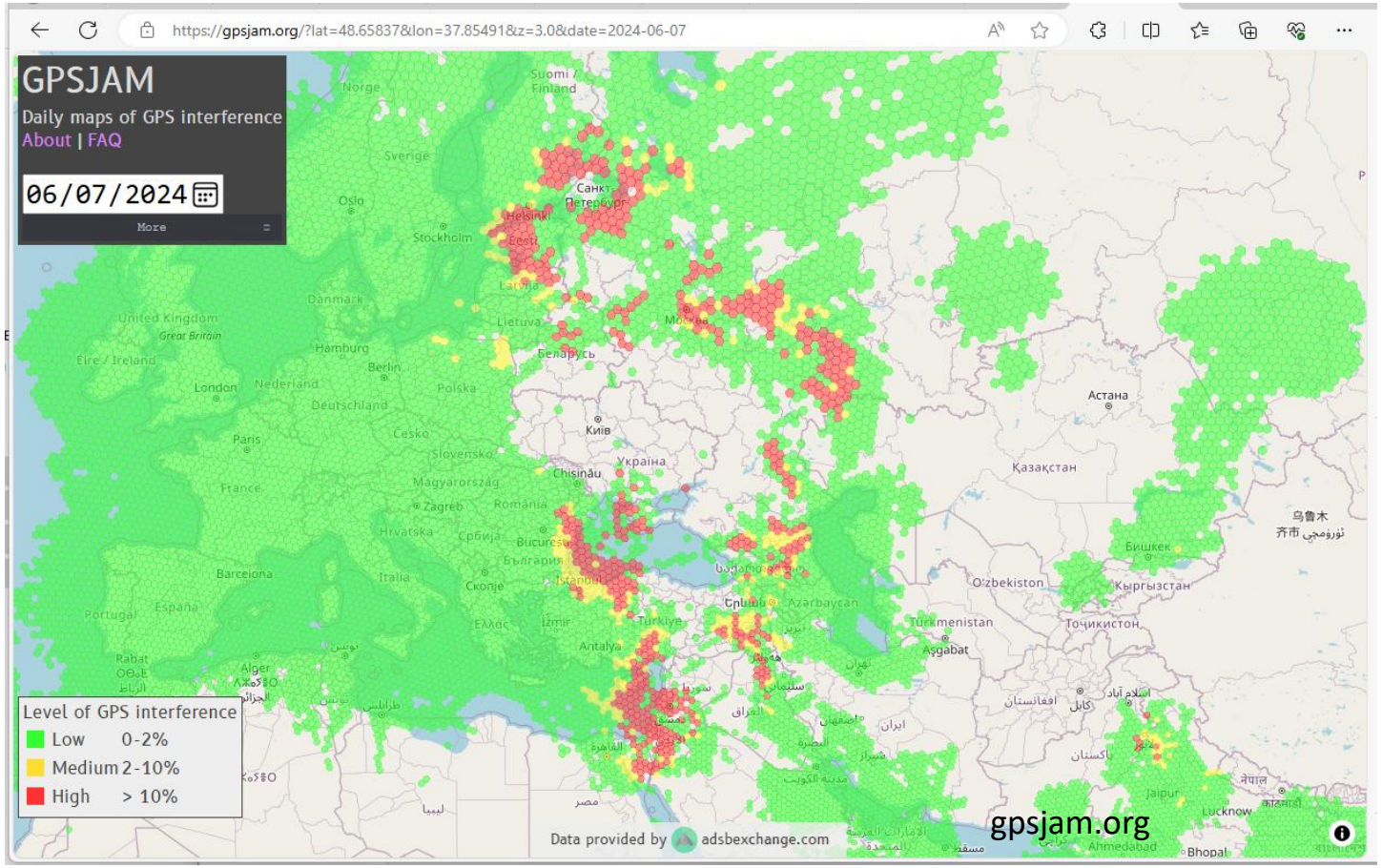
Bing Videos
https://www.bing.com/videos/riverview/relatedvideo?q=Tomorrow%20Never%20Dies%20Full%20Movie&mid=078335262EBCF0A56672078335262EBCF0A56672&ajaxhist=0
Watch 0:00 – 0:40

- GPS systems do not lie.
- But, our Singapore station picked up a mysterious signal on the GPS frequency at the time of the attack that sent our ship off the course
- Where exactly this mysterious GPS signal is coming from?

Bing Videos
https://www.bing.com/videos/riverview/relatedvideo?q=Tomorrow%20Never%20Dies%20Full%20Movie&mid=8D882D503274AF6410298D882D503274AF641029&ajaxhist=0
0:40 – 3:20

- It’s the missing encoder. How did you get it?
- Did somebody use it to send the ship off the-course? Kinda like putting a magnet beside a compass?
- Somebody tampered with your encoders

GPS Interference and Jamming Information



Finnair cancels flights to Tartu, Estonia citing GPS interference

The Finnish airline said it would be halting flights to the city over May as it developed an alternative approach method.

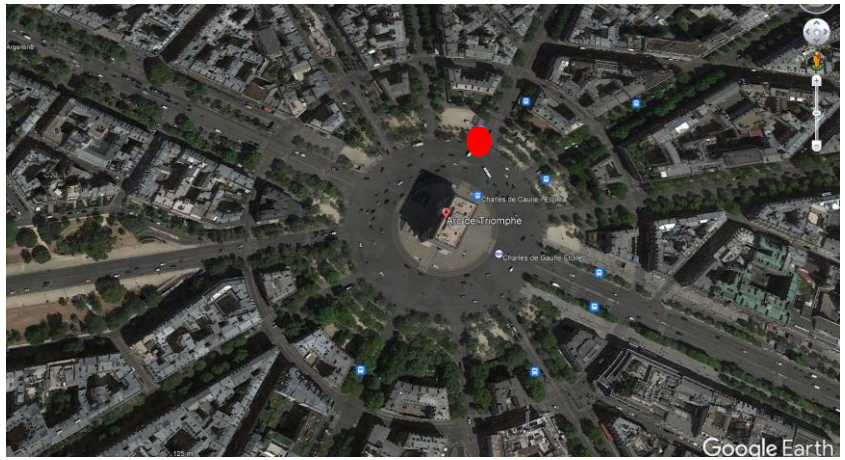
Noah Bovenizer | April 30, 2024

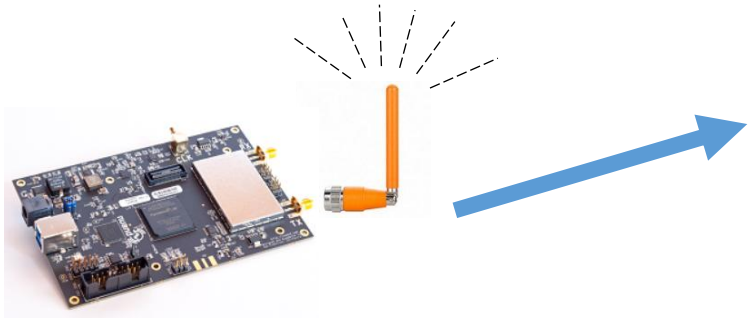
Share

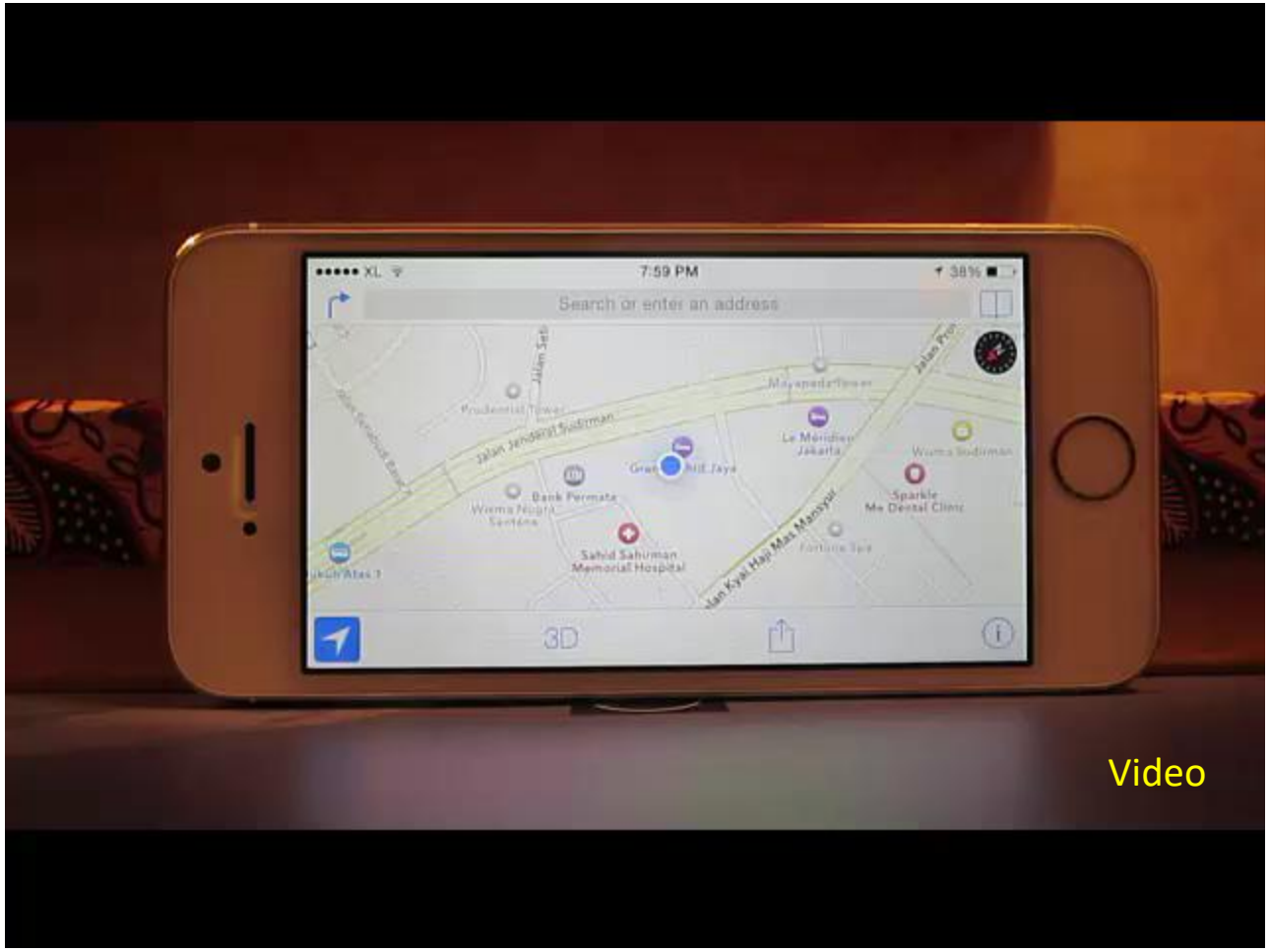
https://www.airport-technology.com/news/finnair-cancels-flights-tartu-gps-interference/

Spoofing a Car Navigation System

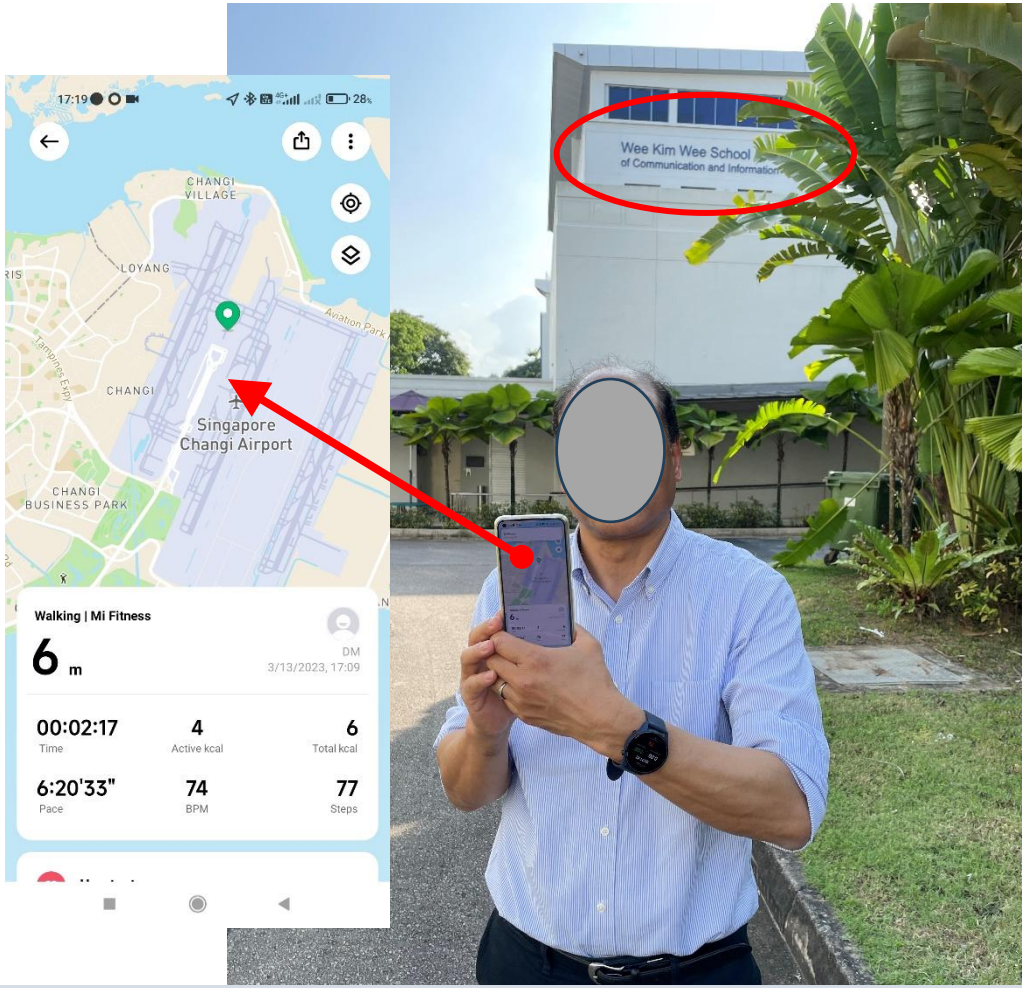
Mobile Phone Spoofing (Jakarta or Paris?)





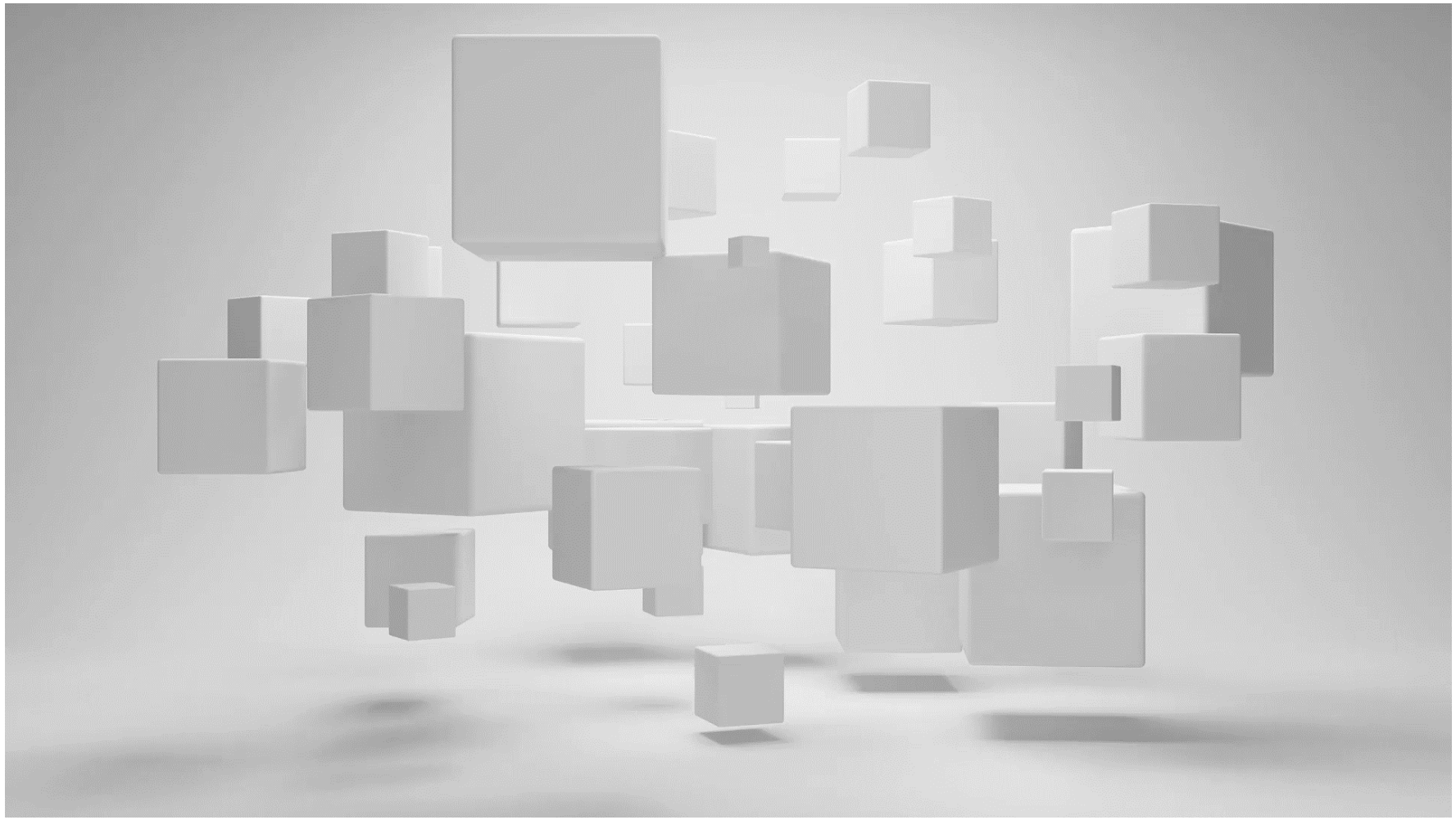


Spoofing Test at NTU



Source: From the Filed Test of GNSS Signal Authentication for Users of High Precision GNSS Positioning by Nanyang Technological University in collaboration with Singapore Land Authority, University of Glasgow, and The University of Tokyo

Spoofing a GPS Watch



How to Detect Spoofing Attacks?

E	D	C	B	A
Hardware Level	RF Level	Signal Monitoring	Signal Encryption	Navigation Message Authentication
➢ Multi Antenna ➢ Direction of Arrival	➢ AGC Monitoring ➢ RF Fingerprint	➢ P-Code Reference ➢ RAIM or ARAIM ➢ Signal Sanity Check ➢ Multi-Correlator	➢ PRN Code Encryption ➢ NAV Message Encryption	➢ **Broadcast Digital Signature of NAV Message**
➢ Impact on Receiver Hardware	➢ FW/SW Modification ➢ Less Impact on Hardware		➢ **FW/SW Modification** ➢ **No HW Modification**	
			➢ No PVT Solution until Decryption	➢ **PVT Solution available even if Authentication is not performed**
		➢ Fully Backward Compatible		➢ **Fully Backward Compatible**
		➢ Possible to Implement on Existing Signals		➢ **Possible to Implement on Existing Signals**
➢ Spoofing attacks may be identified but difficult to verify ➢ Authentication is not possible			➢ **Spoofing attacks can be detected and verified** ➢ **Authentication is possible**	

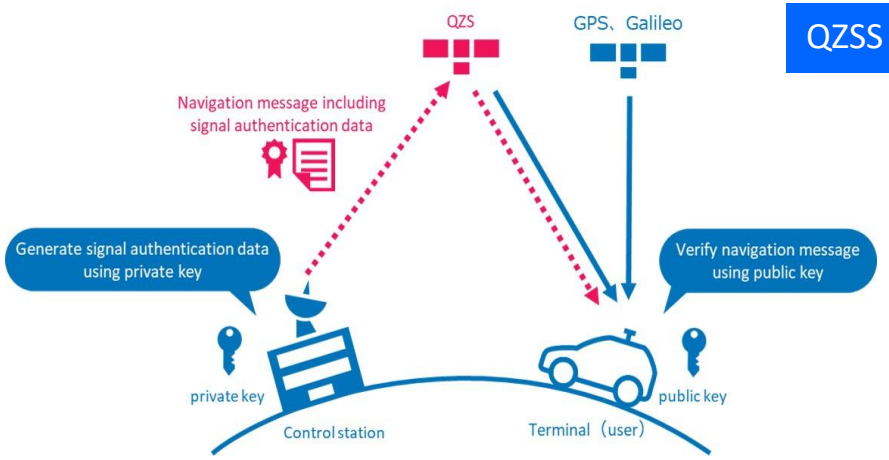
- A is the Minimum Necessary
- B is similar to P(Y) Code not Practical for Mass Market Receivers
- A+C+D? ➔ Increases Complexity in Signal Processing
- How about A + X?

Current Status on Signal Authentication

QZSS SAS

- Authentication of
  - QZSS Signals
    - QZSS L1C/A&B (LNAV)
    - QZSS L1C (CNAV-2)
    - QZSS L5 (CNAV)
  - GPS Signals
    - GPS L1C/A (LNAV)
    - GPS L1C (CNAV-2)
    - GPS L5 (CNAV)
  - GALILEO Signals
    - Galileo E1b (I/NAV)
    - Galileo E5a (F/NAV)
- Navigation Data Authentication
- Based on NMA, Digital Signature Verification
- Operational since 1st April 2024

QZSS SAS

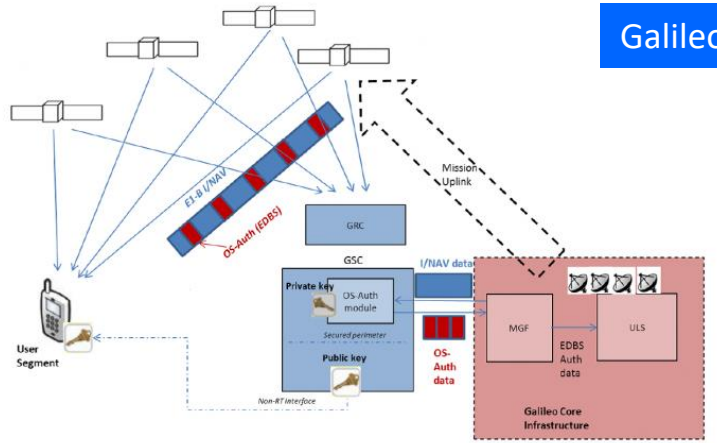


https://qzss.go.jp/en/overview/services/sv14_sas.html

Galileo OS NMA

- Authentication of OS E1b (I/NAV)
  - Probably other signals in future
- Navigation Data Authentication
- Based on NMA using TESLA
- Currently broadcasted as Test signal

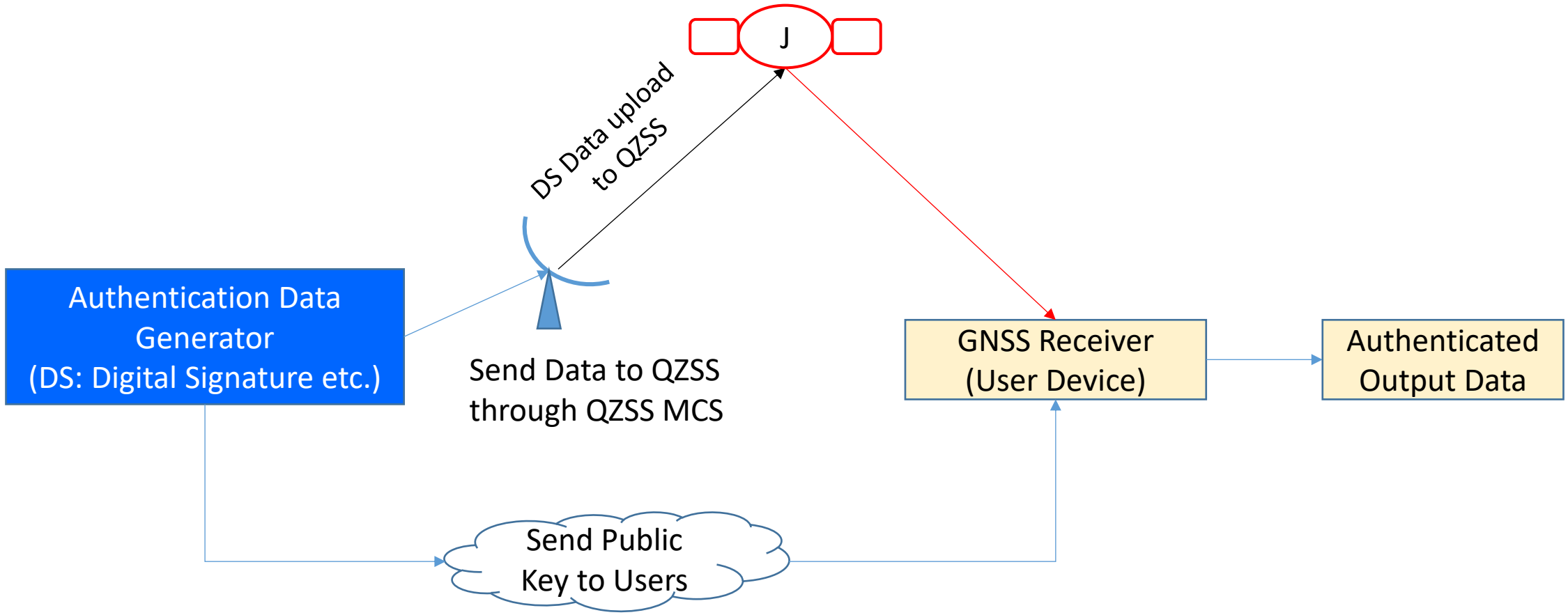
Galileo OS NMA



https://gssc.esa.int/navipedia/index.php/Galileo_Open_Service_Navigation_Message_Authentication

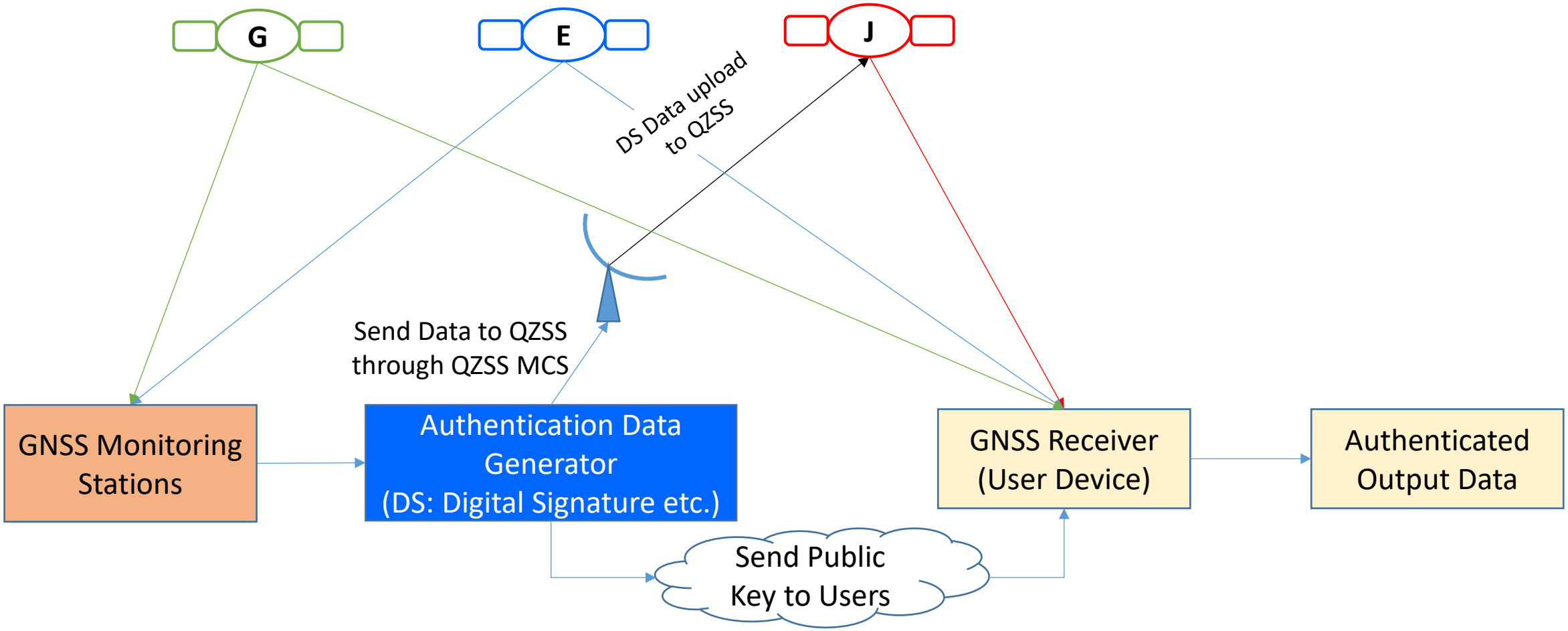
QZSS Signal Authentication by QZSS

- NMA (Navigation Message Authentication) based Signal Authentication.
- Broadcast Digital Signature of QZSS Navigation Message using one of the Navigation Messages of the QZSS Signals

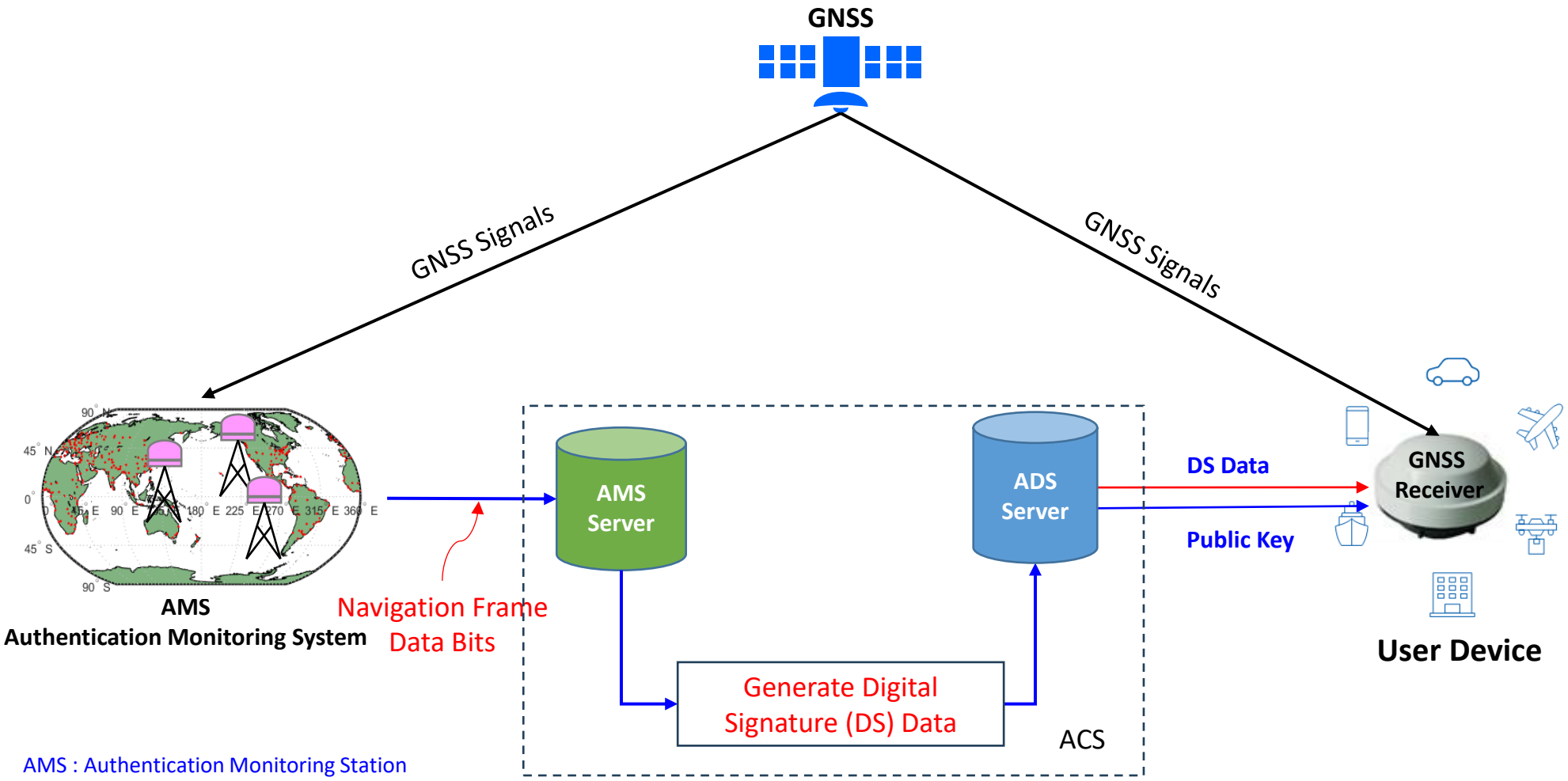


GPS and Galileo Signal Authentication by QZSS

- NMA (Navigation Message Authentication) based Signal Authentication.
- Broadcast Digital Signature of GPS and Galileo Navigation Message using **QZSS L6E Signal**.



Internet-based Authentication System Architecture



AMS : Authentication Monitoring Station
ADS : Authentication Database System Server
ACS : Authentication Control System
DS : Digital Signature
PUK : Public Key
PVK : Private Key

GNSS Authentication, Version: 202405-R005 Build: 20240531

QZSS SAS Test

Receiver: Septentrio PolaRx5 (L1/L2/L5/L6)
Satellites: QZSS & GPS (L1C/A, L5), Galileo (E1b/E5a)
Authentication Signals: LNAV, CNAV, INAV, FNAV

Lat: 35.90304467 GPS Week: 2316 TTFF: -
Lon: 139.93930950 GPS TOW: 485940 Active Time 0d 1h 7m 35s 35ms
Elv: 93.990 GAL Week: 1292
Device ID: 00 00 00 00 00 GAL TOW: 485935

Show All Satellites | Debug

Receiver Connection
RX: NTRIP
DX: OFF
Reset every 300 s
Setup RX | Setup DX | Reset | Stop

GPS Authenication Status

SV	MT	TOW	AZ	EL	CN0	Status
GP10	LNAV	485406	247	52	47	OK
GP10	CNAV	485406	247	52	47	OK
GP12	LNAV	485406	64	59	47	OK
GP15	LNAV	485406	129	6	35	OK
GP19	LNAV	485406	34	0	23	OK
GP23	LNAV	485406	198	35	44	OK
GP23	CNAV	485406	198	35	44	OK
GP24	LNAV	485406	68	26	40	OK
GP24	CNAV	485406	68	26	40	OK
GP25	LNAV	485406	153	76	47	OK
GP25	CNAV	485406	153	76	47	OK
GP29	LNAV	485406	153	7	38	OK
GP32	LNAV	485406	320	52	48	OK
GP32	CNAV	485406	320	52	48	OK

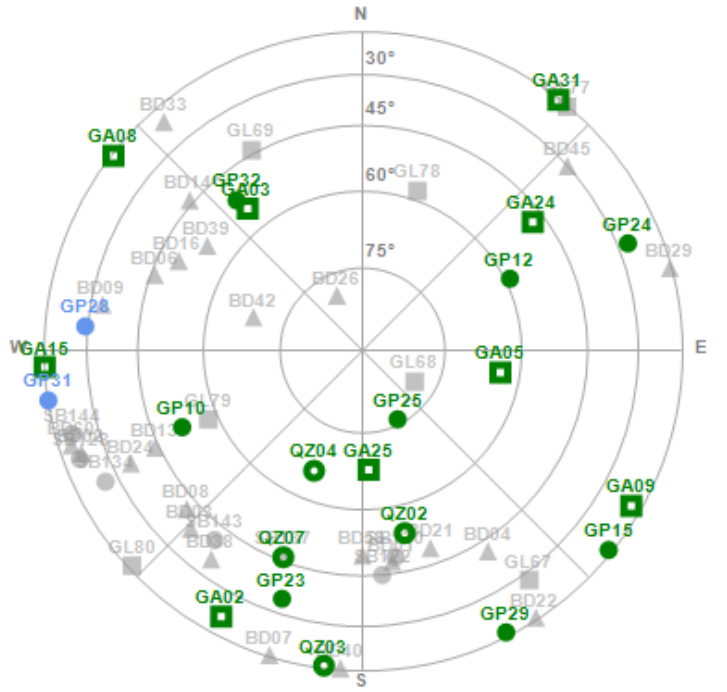
GALILEO Authenication Status

SV	MT	TOW	AZ	EL	CN0	Status
GA02	FNAV	485430	208	19	41	OK
GA02	INAV	485425	208	19	41	OK
GA03	FNAV	485430	321	55	45	OK
GA03	INAV	485425	321	55	45	OK
GA05	FNAV	485430	99	64	46	OK
GA05	INAV	485425	99	64	46	OK
GA08	FNAV	485430	308	7	35	OK
GA08	INAV	485425	308	7	35	OK
GA09	FNAV	485430	120	13	38	OK
GA09	INAV	485425	120	13	38	OK
GA13	FNAV	485430	315	0	35	OK
GA13	INAV	485425	315	0	35	OK
GA15	FNAV	485430	267	2	37	OK
GA15	INAV	485425	267	2	37	OK
GA24	FNAV	485430	53	48	45	OK
GA24	INAV	485425	53	48	45	OK
GA25	FNAV	485430	177	68	48	OK
GA25	INAV	485425	177	68	48	OK
GA31	FNAV	485430	38	2	34	OK
GA31	INAV	485425	38	2	34	OK

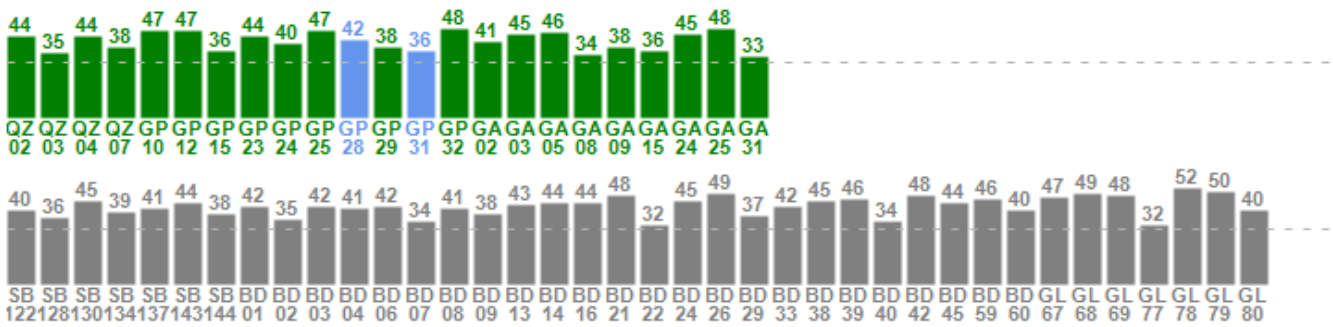
QZSS Authentication Status

SV	MT	TOW	AZ	EL	CN0	Status
QZ02	LNAV	485706	167	54	44	OK
QZ02	CNAV	485886	167	54	44	OK
QZ03	LNAV	485706	187	5	35	OK
QZ03	CNAV	485886	187	5	35	OK
QZ04	LNAV	485706	202	66	44	OK
QZ04	CNAV	485886	202	66	44	OK
QZ07	LNAV	485706	201	46	38	OK
QZ07	CNAV	485886	201	46	38	OK

Skyplot



Satellite Signal Details



Recording File: C:\SAS-DATA\KASHIWA\R005\202405_31_22_51_07.csv

RX: 13957B/s, DX: 0B/s

GNSS Authentication, Version: 202405-R005 Build: 20240531

QZSS SAS Test

Lat: 35.90305730 GPS Week: 2316 TTFF: -

Lon: 139.93931807 GPS TOW: 485946 Active Time 0d 0h 31m 37s 59ms

Elv: 94.917 GAL Week: 1292

Device ID: 00 00 00 00 00 GAL TOW: 485947

Show All Satellites | Debug

Receiver Connection

RX: NTRIP 1

DX: NTRIP 1

Reset every 300 s

Setup RX | Setup DX | Reset | Stop

Receiver: F9P (L1/L5)+ D9C (L6D/L6E)

Satellites: QZSS & GPS (L1C/A, L5), Galileo (E1b/E5a)

Authentication Signals: LNAV, CNAV, INAV, FNAV

GPS Authenication Status

SV	MT	TOW	AZ	EL	CN0	Status
GP10	LNAV	485406	247	52	46	OK
GP10	CNAV	485406	247	52	46	OK
GP12	LNAV	485406	64	59	47	OK
GP15	LNAV	485406	129	6	36	OK
GP19	LNAV	485406	32	0	21	OK
GP23	LNAV	485406	198	35	44	OK
GP23	CNAV	485406	198	35	44	OK
GP24	LNAV	485406	67	26	40	OK
GP24	CNAV	485406	67	26	40	OK
GP25	LNAV	485406	153	76	47	OK
GP25	CNAV	485406	153	76	47	OK
GP29	LNAV	485406	153	7	37	OK
GP32	LNAV	485406	320	52	47	OK
GP32	CNAV	485406	320	52	47	OK

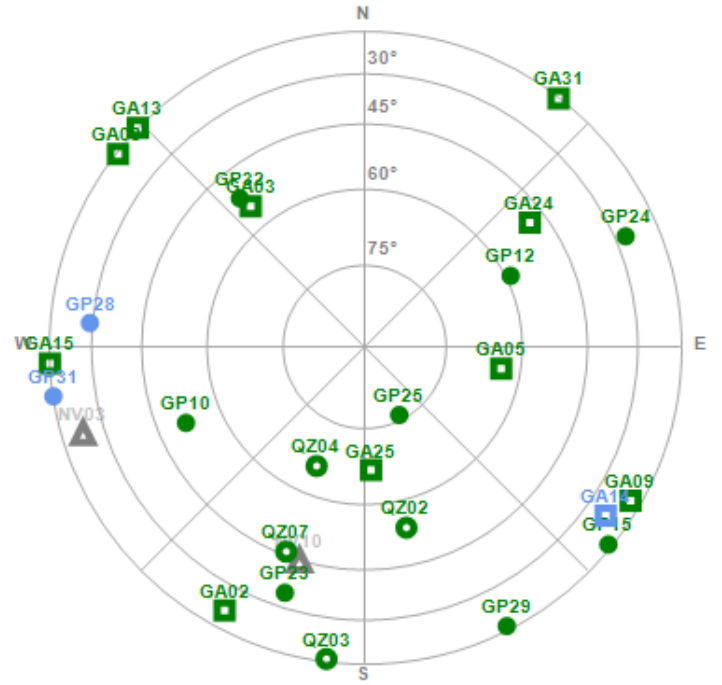
GALILEO Authenication Status

SV	MT	TOW	AZ	EL	CN0	Status
GA02	FNAV	485430	208	19	40	OK
GA02	INAV	485425	208	19	40	OK
GA03	FNAV	485430	321	55	44	OK
GA03	INAV	485425	321	55	44	OK
GA05	FNAV	485430	99	64	45	OK
GA05	INAV	485425	99	64	45	OK
GA08	FNAV	485430	308	7	36	OK
GA08	INAV	485425	308	7	36	OK
GA09	FNAV	485430	120	13	37	OK
GA09	INAV	485425	120	13	37	OK
GA13	FNAV	485430	314	0	20	OK
GA13	INAV	485425	314	0	20	OK
GA15	FNAV	485430	267	2	36	OK
GA15	INAV	485425	267	2	36	OK
GA24	FNAV	485430	53	49	44	OK
GA24	INAV	485425	53	49	44	OK
GA25	FNAV	485430	177	67	47	OK
GA25	INAV	485425	177	67	47	OK
GA31	FNAV	485130	38	2	36	OK
GA31	INAV	485425	38	2	36	OK

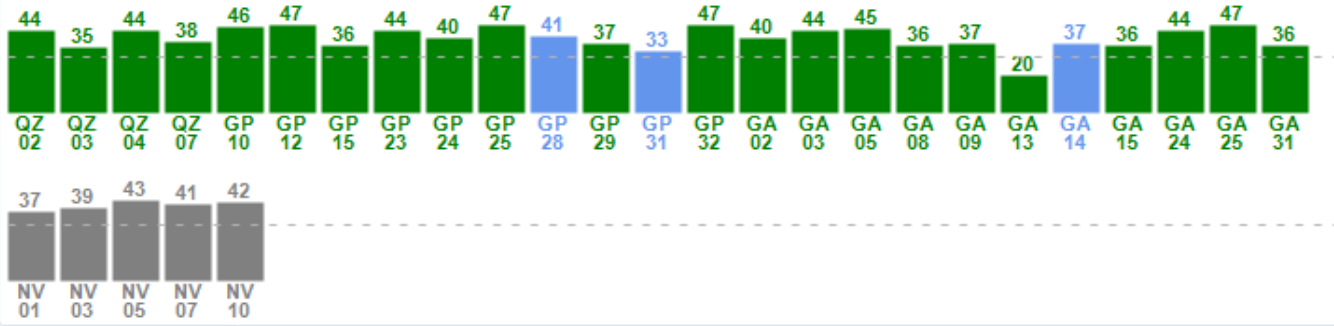
QZSS Authentication Status

SV	MT	TOW	AZ	EL	CN0	Status
QZ02	LNAV	485706	167	54	44	OK
QZ02	CNAV	485886	167	54	44	OK
QZ03	LNAV	485706	187	5	35	OK
QZ03	CNAV	485886	187	5	35	OK
QZ04	LNAV	485706	202	66	44	OK
QZ04	CNAV	485886	202	66	44	OK
QZ07	LNAV	485706	201	46	38	OK
QZ07	CNAV	485886	201	46	38	OK

Skyplot



Satellite Signal Details

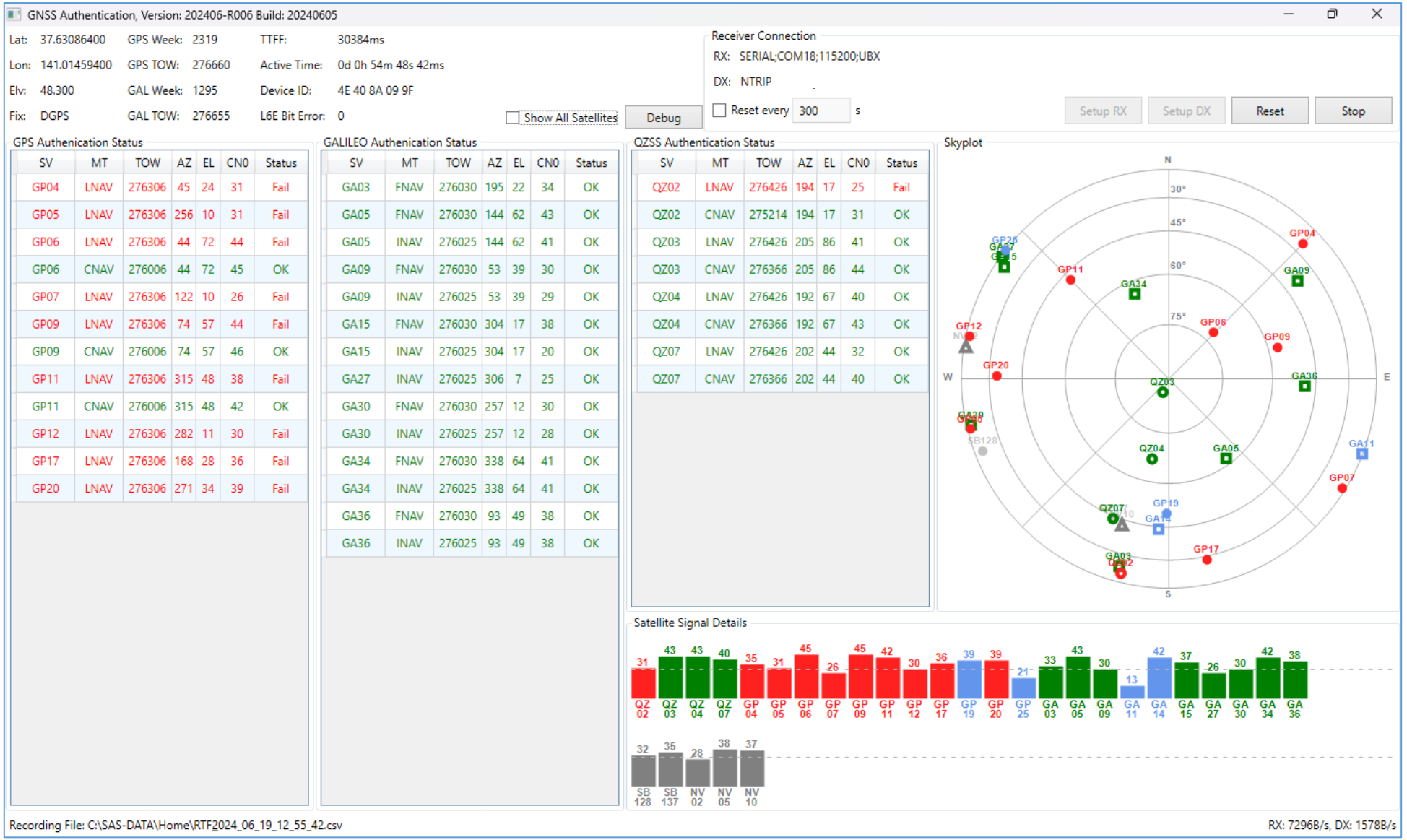


Recording File: C:\SAS-DATA\KASHIWA\R005\202405_31_23_26_50_UBX.csv

RX: 3782B/s, DX: 4612B/s

QZSS SAS Test with Spoof Signal

Spoof Signal: GPS L1C/A, LNAV, Receiver: F9P (L1/L5)



GPS Authenication Status

SV	MT	TOW	AZ	EL	CN0	Status
GP04	LNAV	276306	45	24	31	Fail
GP05	LNAV	276306	256	10	31	Fail
GP06	LNAV	276306	44	72	44	Fail
GP06	CNAV	276006	44	72	45	OK
GP07	LNAV	276306	122	10	26	Fail
GP09	LNAV	276306	74	57	44	Fail
GP09	CNAV	276006	74	57	46	OK
GP11	LNAV	276306	315	48	38	Fail
GP11	CNAV	276006	315	48	42	OK
GP12	LNAV	276306	282	11	30	Fail
GP17	LNAV	276306	168	28	36	Fail
GP20	LNAV	276306	271	34	39	Fail

GALILEO Authenication Status

SV	MT	TOW	AZ	EL	CN0	Status
GA03	FNAV	276030	195	22	34	OK
GA05	FNAV	276030	144	62	43	OK
GA05	INAV	276025	144	62	41	OK
GA09	FNAV	276030	53	39	30	OK
GA09	INAV	276025	53	39	29	OK
GA15	FNAV	276030	304	17	38	OK
GA15	INAV	276025	304	17	20	OK
GA27	INAV	276025	306	7	25	OK
GA30	FNAV	276030	257	12	30	OK
GA30	INAV	276025	257	12	28	OK
GA34	FNAV	276030	338	64	41	OK
GA34	INAV	276025	338	64	41	OK
GA36	FNAV	276030	93	49	38	OK
GA36	INAV	276025	93	49	38	OK

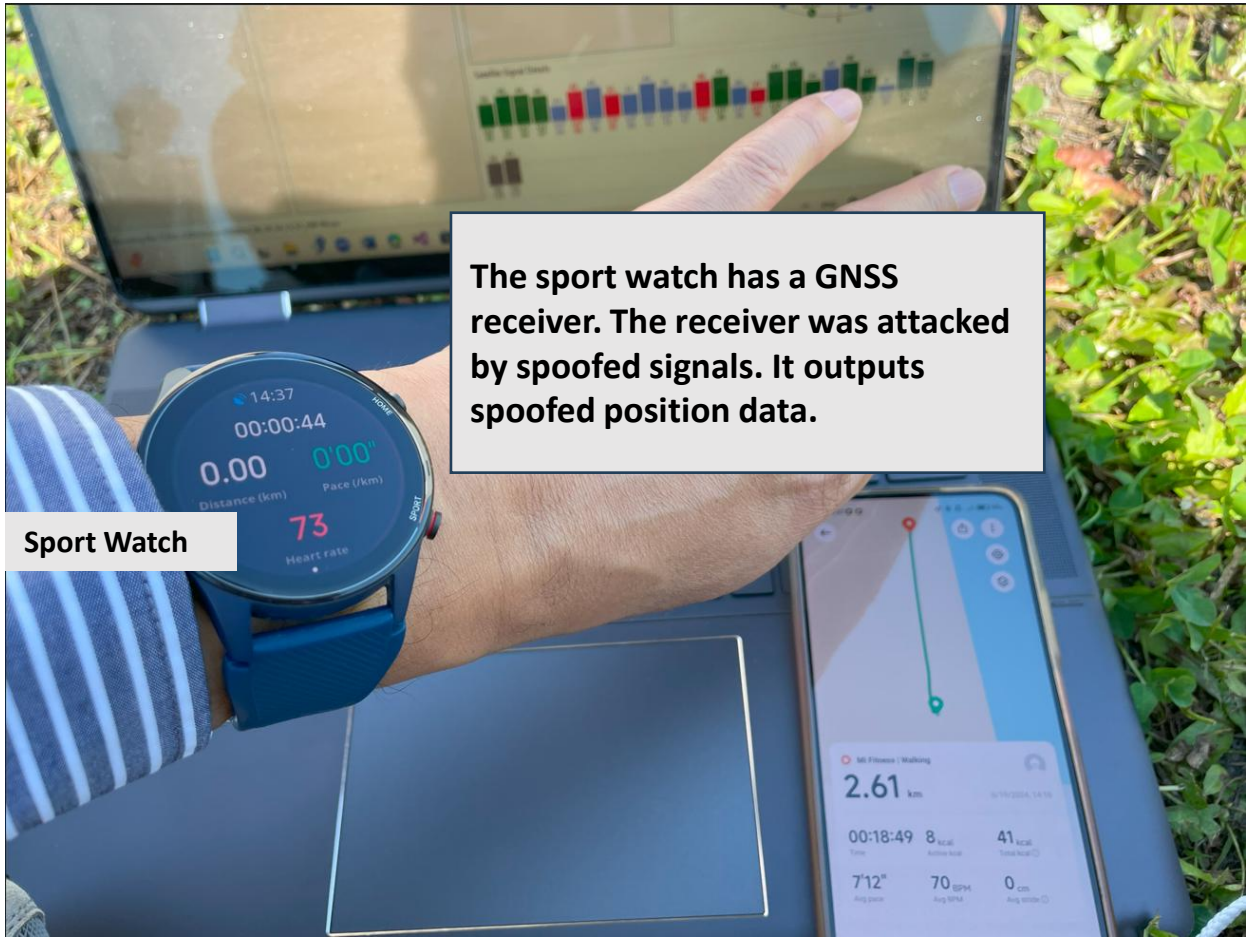
QZSS Authentication Status

SV	MT	TOW	AZ	EL	CN0	Status
QZ02	LNAV	276426	194	17	25	Fail
QZ02	CNAV	275214	194	17	31	OK
QZ03	LNAV	276426	205	86	41	OK
QZ03	CNAV	276366	205	86	44	OK
QZ04	LNAV	276426	192	67	40	OK
QZ04	CNAV	276366	192	67	43	OK
QZ07	LNAV	276426	202	44	32	OK
QZ07	CNAV	276366	202	44	40	OK

QZSS SAS Test with Spoof Signal

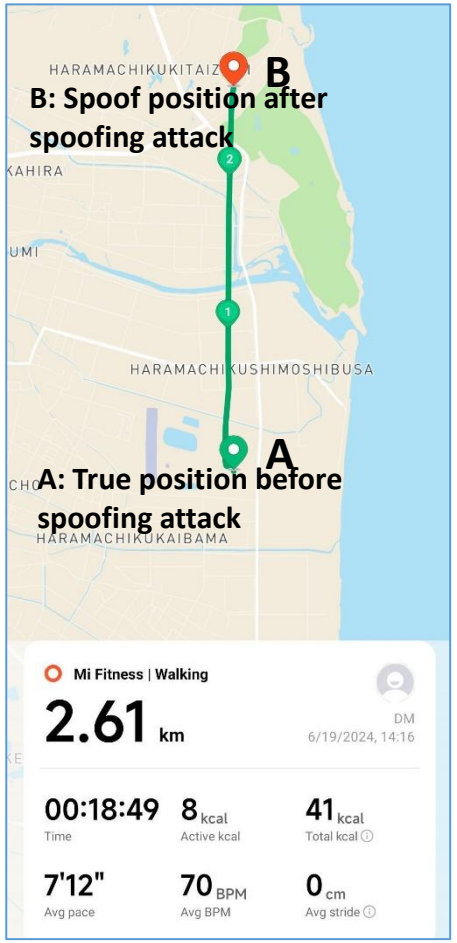
Spoof Signal: GPS L1C/A, LNAV, Receiver: Sport Watch with GNSS L1 Signals

The MiWatch data is exported to the Android device. It shows that the user has walked 2.6 Km from A to B



The sport watch has a GNSS receiver. The receiver was attacked by spoofed signals. It outputs spoofed position data.

Sport Watch

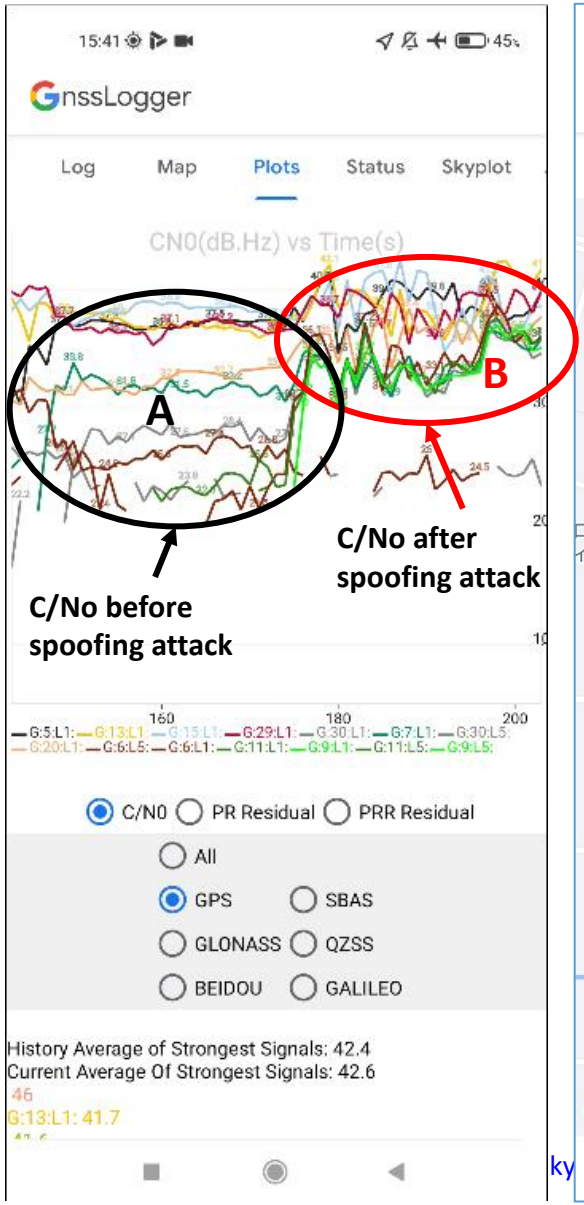


Distance is shown 0.0Km in the watch because the photo was taken after the spoofing attack.

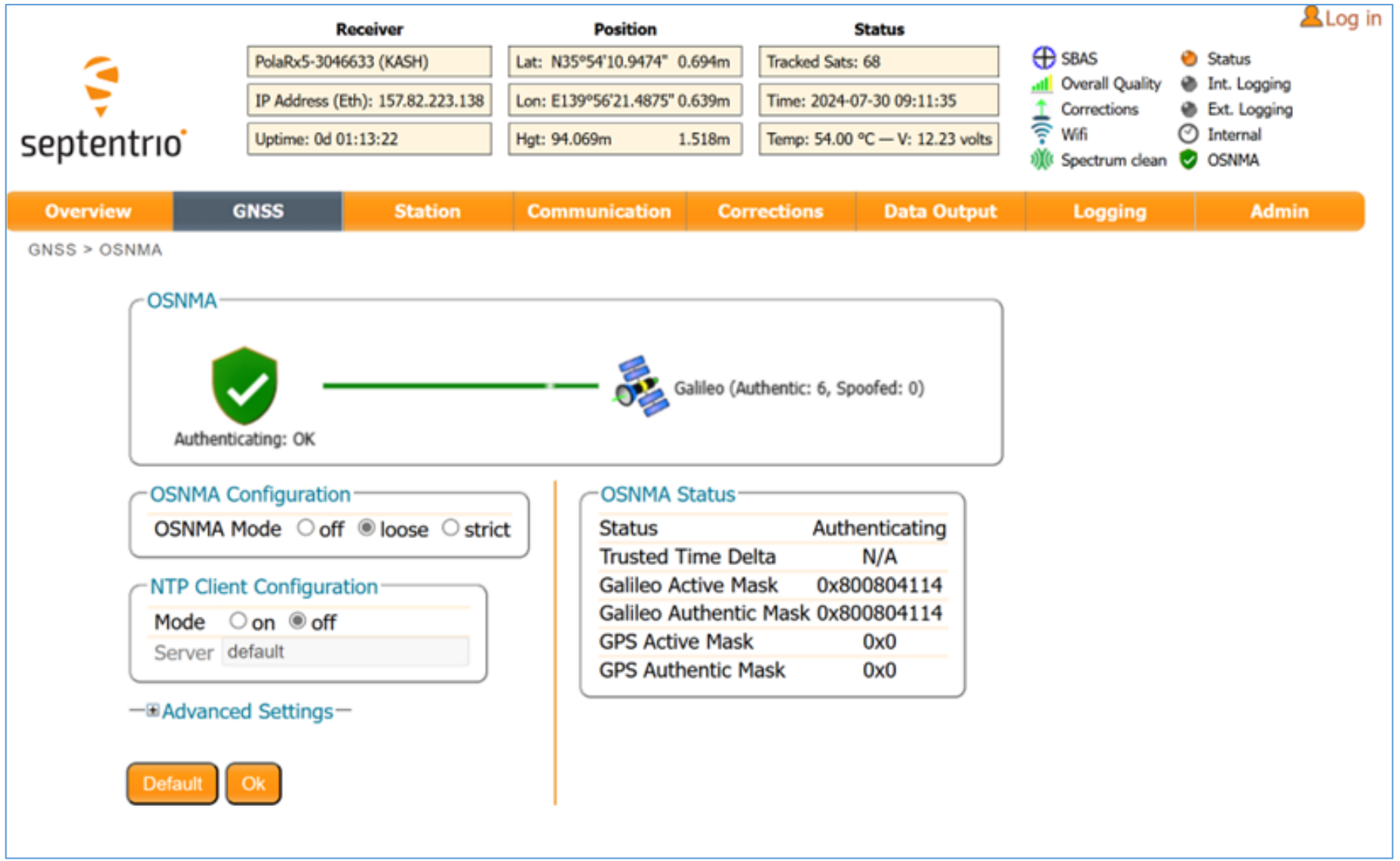
QZSS SAS Test with Spoof Signal

Spoof Signal: GPS L1C/A, LNAV, Receiver: Smart Phone with GNSS L1/L5 Signals

Spoof Signal : GPS L1C/A, LNAV
Receiver : Xiaomi Mi11Lite 5G
GNSS Signals: L1/L5 Signals
GPS, QZSS, GAL,
GLO, BDS



GALILEO OSNMA TEST (Septentrio Receiver)



GALILEO OSNMA TEST (U-Blox F9P Receiver)

COM13 @ 115200 - u-center 24.04 - [Messages - UBX - SEC (Security) - OSNMA (Galileo Open Service Navigation Message Authentication)]

File Edit View Player Receiver Tools Window Help

- SOL (Navigation Solution)
- STATUS (Navigation Status)
- SVIN (Survey-in)
- SVINFO (SV Information)
- TIMEBDS (BDS Time)
- TIMEGAL (Galileo Time)
- TIMEGLO (GLO Time)
- TIMEGPS (GPS Time)
- TIMELS (Leap Second Information)
- TIMENAVIC (NavIC Time)
- TIMEQZSS (QZSS Time)
- TIMETRUSTED (External trusted time information)
- TIMEUTC (UTC Time)
- VELECEF (Velocity ECEF)
- VELNED (Velocity WGS84)
- NAV2 (Navigation)
- RXM (Receiver Manager)
  - ALM (Almanac)
  - COR (Differential correction input status)
  - EPH (Ephemeris)
  - IMES (IMES Status)
  - MEASX (Measurement Data)
  - PMP (Point to Multipoint)
  - PMREQ (Power Mode Request)
  - QZSSL6 (QZSS L6 message)
  - RAW (Raw Measurement Data)
  - RAWX (Multi-GNSS Raw Measurement Data)
  - RLM (Return Link Message)
  - RTCM (RTCM input status)
  - SFRB (Subframe Data)
  - SFRBX (Subframe Data NG)
  - SPARTN (SPARTN input status)
  - SPARTNKEY (SPARTN key status)
  - SVSI (SV Status Info)
  - TM (Timestamps)
- SEC (Security)
  - OSNMA (Galileo Open Service Navigation Message Authentica
  - SIG (Signal Security)
  - SIGLOG (Signal Security Log)
  - UNIQID (Unique Chip ID)
- TIM (Timing)
- UPD (Firmware Update Messages)
- ??-?? (Unknown)
- ??-?? (Custom)
- UNKNOWN
- CUSTOM

UBX - SEC (Security) - OSNMA (Galileo Open Service Navigation Message Authentication) 0 s

Rx monitoring information
- OSNMA Enabled
- New NMA Header
- noOsnma
- wrongData
- FLX
- MACIt
- Collecting OSNMA data from 3 SVs

NMA Header
- NMA Status: Service in Test
- CPKS: Nominal
- TESLA chain in force (Id): 3
- NMA Header authenticated

Service configuration (only authenticated values)

Hash function	SHA-256	Key size [bits]	128
MAC function	HMAC-SHA-256	MAC size [bits]	40
MCLT Index	34	From NVS	No

Public Key and Merkle tree root

Current pub key ID	1	Source	From NVS
Future pub key ID		Source	
Current Merkle tree root source			From NVS
Future Merkle tree root source			

DSM-KROOT/DSM-PKR Authentication
- Authentication status
- Reason: No DSM authentication performed

Last subframe authentication results

The next sections show the results of the last TESLA key and MAC authentications, which took place 8 seconds ago

Time synchronization check
- TimSync Enabled
- Process Slow MACs
- TimSync Status: Time synchronization check not performed
- Time propagation diff [s] (GST-Trusted): 0.668

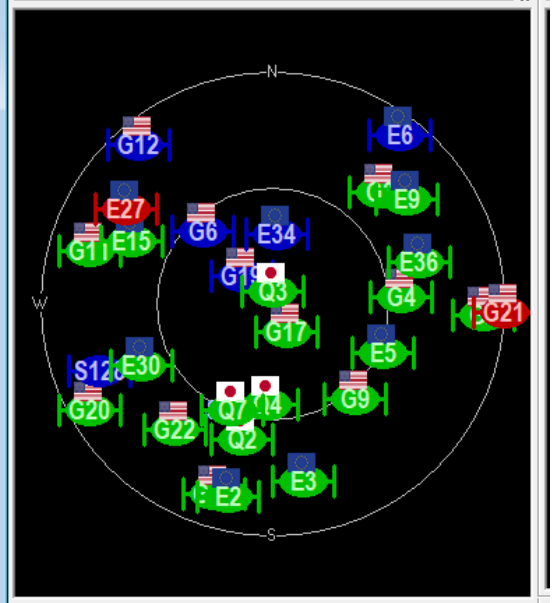
TESLA Key Authentication
- Authentication status: New TESLA key element successfully authenticated
- Chain Id: 3
- WNO (GST SF): 1301
- TOW [s] (GST SF): 346800

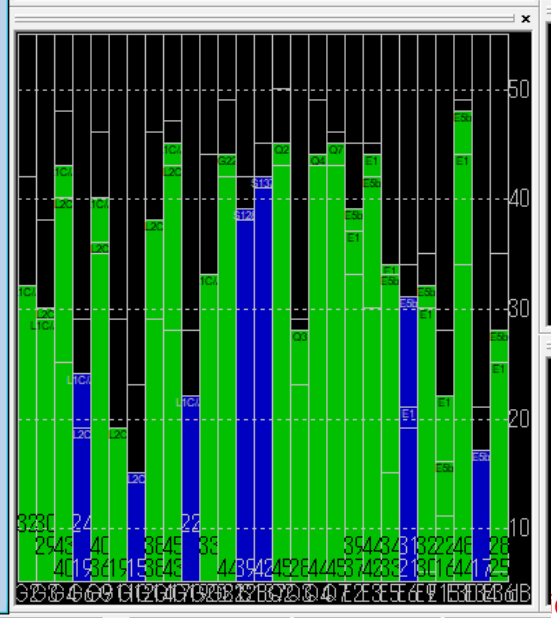
MAC Authentication

Num. Auth. SVs: 5

SVId	IODE	Auth. status	Num. auth	Comments
E2	68	Authenticated	1	
E3	67	Authenticated	2	
E5	68	Authenticated	1	
E9	65	Authenticated	1	
E36	68	Authenticated	1	

Timing parameters Authentication
- Authentication status
- Reason: Authentication not performed
- Number of authentications: 0



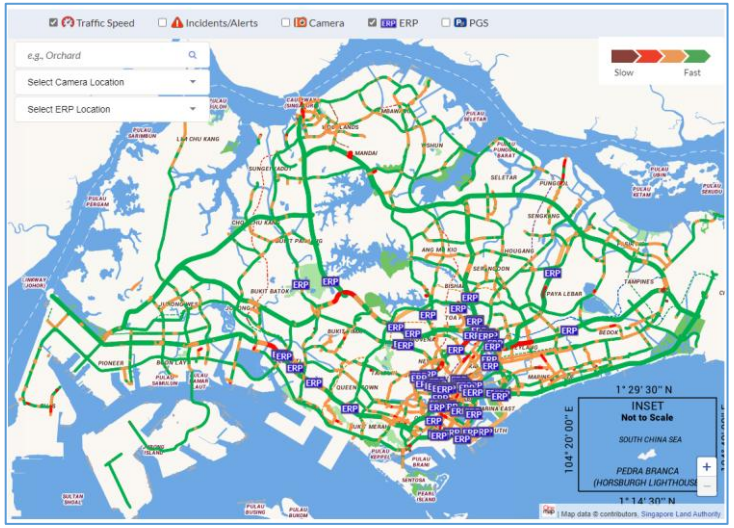


Send Poll

Ready | NTRIP client: Not connected | MQTT client: Not connected | u-blox Generation 9 | COM13 115200 | No file open

GNSS Signal Authentication Applications

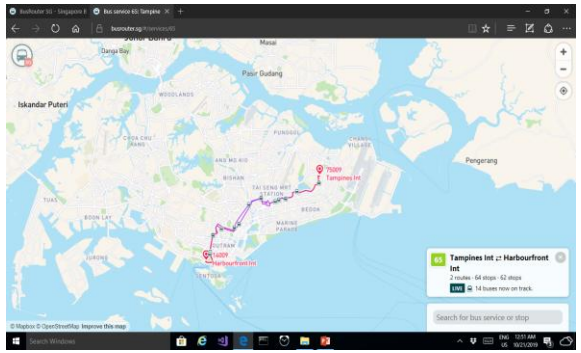
- Any applications that require secure and safety features
  - ITS, ADAS, UAV, UMV, Robotics etc.
  - Traffic Congestion Management
  - Illegal Traffic Monitoring (Road, Marine and Aviation)
  - Supply-chain management, Logistics
  - To make GNSS location data legal
- Any applications that require GNSS Time Synchronization
  - Telecom Network Systems, Banking Systems, Financial Transactions etc.
- Any payment/charging system that uses location and time data
  - *Toll system, Dynamic Road Pricing (DRP), Insurance etc.*
  - *Gateless Toll System, GNSS-based MLFF (Multi-Lane Free Flow)*
- *In the Context of Singapore*
  - Enhancement of SIRENT Services - Add a layer of security features
  - ERP 2.0 ➔ Further enhancement of the security system
    - Protection from Spoofing Attacks
- Monitoring of illegal marine activities

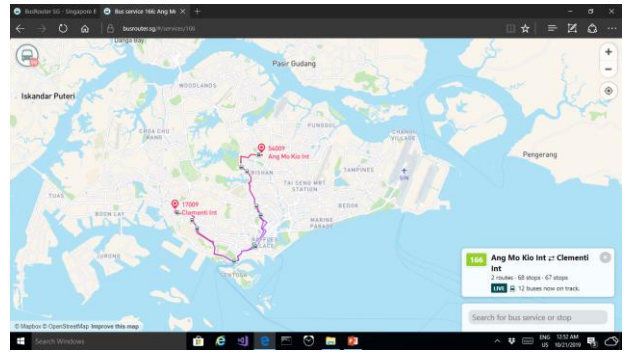


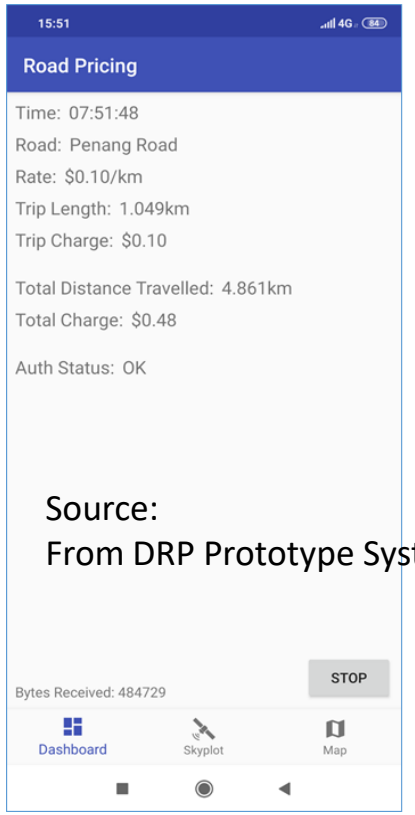
ERP 2.0:
https://onemotoring.lta.gov.sg/content/onemotoring/home/driving/ERP/erp-2-0.html

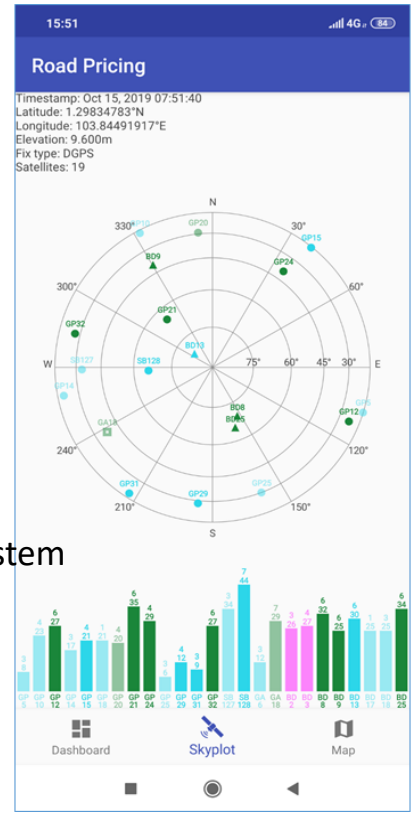
Dynamic Road Pricing (DRP) based on GNSS

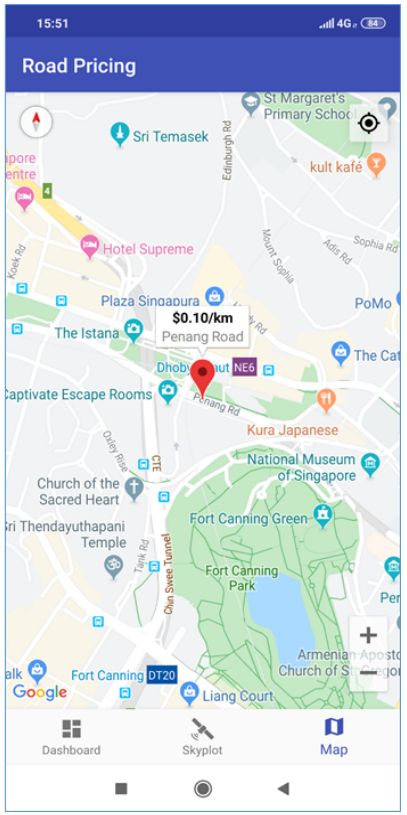
- No Physical Toll Gates
  - GPS-based system is used for Location, Distance, and Lane occupation
  - Multi-Lane Free Flow (MLFF)
  - Can be implemented on any road section
    - Not limited to only highways, expressways or toll roads
- Dynamically charge for road usage
  - Pricing is variable and based on
    - **Distance, time, location,**
    - **Vehicle type, lane, and occupancy**
    - **Traffic congestion condition**
- Reward road users for using alternate routes to avoid congested route
  - Payback the drivers who help to minimize traffic congestion
  - MaaS
- Global Seamless Implementation
  - Single system for smooth cross-border operation
    - Singapore ←→ Malaysia, ASEAN Countries, Europe
    - The same In-vehicle device can be used globally











Source:
From DRP Prototype System

Summary

- GNSS Service Providers and Users are aware of Spoofing Issues
  - Seeking Spoofing Detection Capabilities
- QZSS and GALILEO provide spoofing Detection Capabilities
  - QZSS SAS (Signal Authentication Services)
    - Already Operational and Provides QZSS, GPS and Galileo Signal Authentication
  - GALILEO OSNMA (Open Signal Navigation Message Authentication)
- Singapore has already implemented Satellite-based ERP
  - The services can be further enhanced by integrating Signal Authentication
- Other Asian Countries are moving towards Satellite-based Toll System
  - India, Indonesia
  - Thailand, Philippines, Malaysia, and Vietnam may be moving in this direction
- Singapore has always become a leader in implementing advanced technologies in the region
  - Creates Business Opportunities
- Let's explore the implementation of this technology in various applications and underlying business opportunities