Time-Spoofing of GNSS Receivers: Lessons Learned and Mitigation

By Guy Buesnel, CPhys, FRIN
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Real world threats to GNSS

Impacting Time and Position

Typical GNSS Vulnerabilities

- **Spoofing**
  - Covert
  - Deception

- **Interference**
  - Intentional
  - Unintentional

- **GNSS Segment Errors**
  - Erroneous upload data
  - SV Faults (E.g. SVN49)

- **Multipath Errors**

- **Cyber Attacks**
  - Non-RF

- **Atmosphere**
  - Scintillation
  - Solar Activity
GPS Spoofing – emergence as real threat

- Pokémon GO… When gamers discovered spoofing…..

**Six weeks from primitive to Sophisticated….**
GPS Spoofing – emergence as real threat

Reported in press 17th December 2015

- Highlighted attempts to jam and spoof drones patrolling US/Mexico border
- Attempted GPS spoofing in the real world reported for the very first time
- Criminals using technology to attempt to disrupt GNSS
Spoofing – Real world reports from 2017

DEFCON 25, August 2017, Caesar’s Palace

- How to spoof NTP using a programmed SDR
- Masterclass in Time based one time password (TOTP) manipulation using time spoofing
- Spoofing GPS signals indoors is easy
  - GPS enabled equipment will often acquire the first signals it receives
Spoofing – Real world reports from 2017

September 2017 – ION GNSS+, Portland Convention Centre, Oregon

- Thursday 28th September - Multiple incidents of smartphones erroneously indicating incorrect time and position as reported by numerous users

- **Time in the past**, position showing as somewhere in Europe

Logan Scott has published an analysis of the event – *Spoofing Incident Report: An Illustration of Cascading Security Failure* – in Inside GNSS
Spoofing – Real world reports from 2017

- One kind of phone more affected than other brands/types
- Carriers included all the majors
- Whilst there was no GPS signal in the exhibition hall, there was cellular coverage and many wi-fi points
- Clues to smart phones that the leaked signals were not authentic
  - Large date/time shift
  - Large location shift (several thousand miles)
- Relatively unsophisticated attack – but numerous devices affected
- Spoof date/time was 12 January 2014 – where devices accepted this data, this caused problems with data (email, text messages, etc)
Spoofing – Detection/Mitigation strategies

- Risk Assessment vital to identify most cost effective strategies based on quantitative data
- Improved Antenna Technologies can make a big difference

Processing (some of the ways to detect a spoofer)
  - Monitor power levels
  - Monitor own position
  - Look for code/carrier range changes or inconsistency
  - Navigation data analysis
  - Jump detection

Image courtesy of GPS World
Hackers talk about GPS spoofing…

GPS Spoofing “…so it is now party trick simple and cheap - This is the big game changer from the past” – “Karit”, Defcon 25, 2017

“…..NMEA is simply text over rs232. If you plug a terminal into your AIS transmitter you can tell people anything you like. A lot simpler than interfering with GPS.” - Unknown contributor, Schneier On Security blog…
Cyber-Security Considerations for GNSS

“Attack Surface”

- GNSS solutions utilise existing computing technologies
  - Many GNSS receivers run embedded operating systems (VxWorks, Linux etc.)
  - User interface, logging & alerting components run on “off the shelf” hardware & operating systems (embedded computers & processors, mobile devices, Windows, Android etc.)
  - Communication protocols such as TCP/IP, USB and RS232 move data between devices.
  - The Internet, Local & Wide Area Networks provide access to remote systems & data sources.
Real world threats to GNSS

7-Layer OSI Model

Transmit

Receive

Application Layer (7)
Presentation Layer (6)
Session Layer (5)
Transport Layer (4)
Network Layer (3)
Data Link Layer (2)
Physical Layer (1)

Link Channel
Cyber-Security Considerations for GNSS

Firmware Attacks

- Malicious modification of code running on embedded devices within GNSS components e.g. microcontrollers, Field Programable Gate Arrays (FPGAs) etc

- Applies to layers 1 & 2, but also other layers if the device is responsible for networking, user interfaces etc.

- Can be triggered in much the same way as Hardware Trojans.

- Difficult to detect, as firmware is usually inaccessible to the user

- Mitigations – code signing / secure boot features, code reviews and verification
Cyber-Security Considerations for GNSS

**Hardware Attacks**

- Attacking the low-level electronic components of a GNSS system (layers 1 & 2).
- “Hardware Trojan” - malicious modification of electronic components. Usually triggered once a pre-defined condition is reached, or a signal received.
  - Manipulation of data travelling on electrical busses i.e. spoofing, packet injection etc.
  - Preventing communication between legitimate components i.e. Denial of Service (DoS)
  - Leaking of sensitive information via radio or other signals.
- Difficult to detect – requires visual inspection or forensic analysis.
- Mitigation – tamper evident seals, sourcing electronic components and devices from reputable manufacturers, inspection of manufacturing processes.
Spoofing navigation data

NMEA

e.g., $GPGGA, 123519,4807.038,N,01131.000,E,1,08,0.9,545.4,M,46.9,M,*47

NMEA Sentence type

Time of fix

Checksum

Image courtesy Arduino online forum: https://forum.arduino.cc/index.php?topic=78774.0
Spoofing navigation data

Other NMEA Sentences include:-

- AAM - Waypoint Arrival Alarm
- ALM - Almanac data
- APA - Auto Pilot A sentence
- APB - Auto Pilot B sentence
- BOD - Bearing Origin to Destination
- BWC - Bearing using Great Circle route
- DTM - Datum being used.
- GGA - Fix information
- GLL - Lat/Lon data
- GRS - GPS Range Residuals
- GSA - Overall Satellite data
- GST - GPS Pseudorange Noise Statistics
- GSV - Detailed Satellite data
- RMB - recommended navigation data for gps
- RMC - recommended minimum data for gps
- RTE - route message
- TRF - Transit Fix Data
- STN - Multiple Data ID
- WCV - Waypoint closure velocity (Velocity Made Good)
- WPL - Waypoint Location information
- XTC - cross track error
- XTE - measured cross track error
- ZTG - Zulu (UTC) time and time to go (to destination)
- ZDA - Date and Time
Spirent experiences

Issues seen in user equipment

- Premature implementation of Leap Second Events
- Week Number Rollover - next one due in April 2019 (Modulo 1024 number)
- April 2014 GLONASS outage, corrupt ephemeris data
- Jan 2016 GPS timing errors due to incorrect ICD implementation in many GPS receivers (BBC DAB transmitters affected)
- Bit error events
- Sky obscuration
- Poor antenna installation
- Cross-over locations
- Dateline, equator, poles
- Spoofed signals (lack of detection, acceptance of incorrect pseudoranges and/or nav data)
- Interference (output of misleading data in band and out of band)
- Atmospherics – some effects in UK during event in 2015 affected telecoms transmitters

RF related
Non-RF related
Spirent Positioning and Timing Insights

- Often not enough testing is conducted up-front and with many scenarios, live sky testing is not sufficient..

- Risk Assessment and knowledge of your operating environment is essential

- Build security into the design of timing systems right from the start

- There is a need to responsibly create awareness in many application segments

- “GPS is more computer than radio”; “GPS Receivers lack cyber resilience. This is a National Issue.” - Harold (“Stormy”) Martin, National Co-ordination office for Space based PNT
Thank you for listening

guy.buesnel@spirent.com
http://www.spirent.com/Solutions/Robust-PNT

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Join the GNSS Vulnerabilities group on Linked In to find out more about GNSS jamming and spoofing