Secure, Resilient Time Distribution in Power Grids

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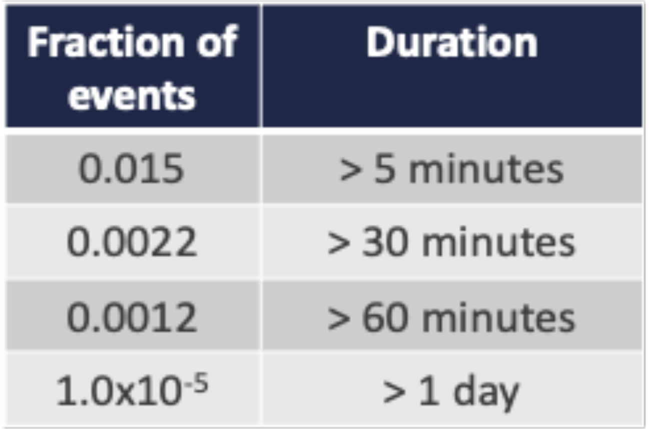
Herb Falk, Outside the Box Consulting Services
for help with network security graphics

Summary

- Threats to reliable time distribution
  - GNSS jamming
  - GNSS spoofing
  - PTP message injection
- Mitigations
  - Holdover
  - Timing source diversity
  - Algorithms
  - Network security

GNSS Jamming and Spoofing

L1 + L2 Jammer
In stock at
Amazon
$24



Fraction of events	Duration
0.015	> 5 minutes
0.0022	> 30 minutes
0.0012	> 60 minutes
1.0x10^{-5}	> 1 day

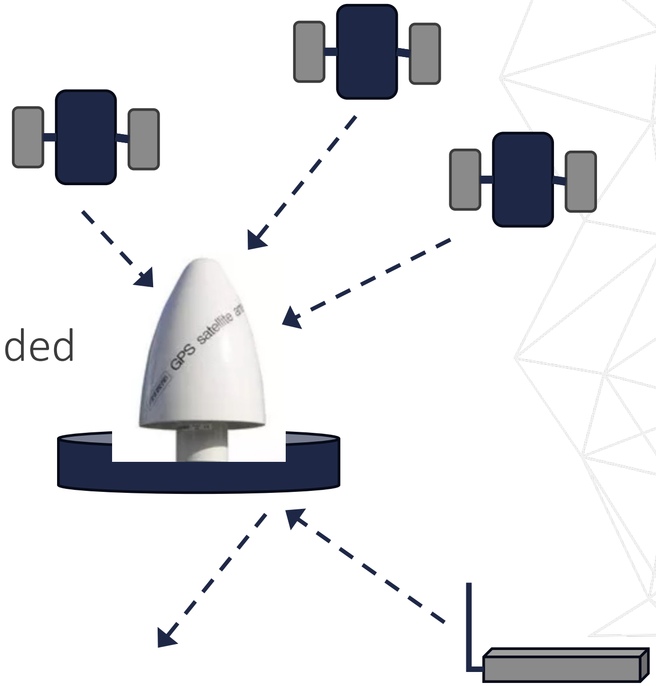
Data from STRIKE3 PROJECT
Most jamming short from vehicles
Long-term jamming rare in US

Amazon Prime
2-day delivery
< $350

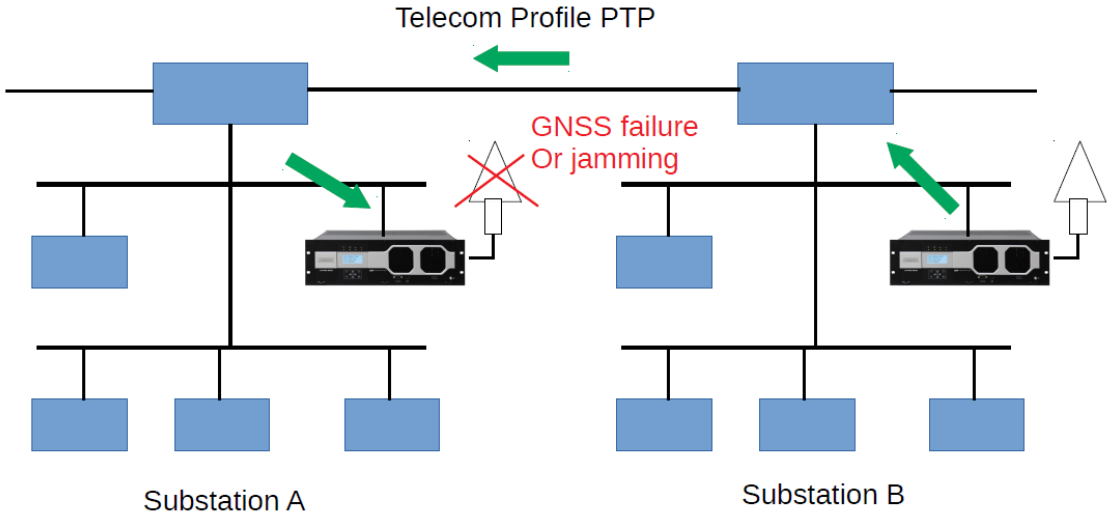
Software: free
gps-sdr-sim
at github

Jamming mitigations

- Holdover
  - PTP GMs typically have many oscillator choices
  - Substations are outside: **Temperature spec is the most important**
  - High end OCXOs often have better temperature specs than atomic clocks
- Source diversity
  - Time server with two GNSS receivers and separated antennas
  - PTP from next substation
  - Precise Time Network (ePTS in ITU-T)
  - Alt PNT (example: Iridium STL)
- Resistant GNSS antennas
  - Ground shielded
  - Phased array
    - Put Null in direction of jamming signal

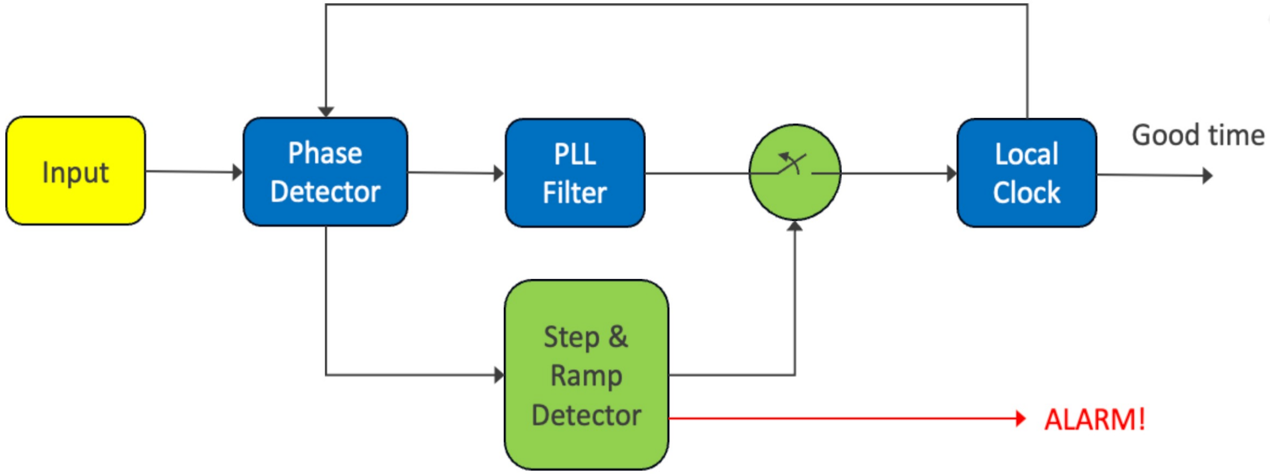


Ground shielded antenna



Spoofing mitigations

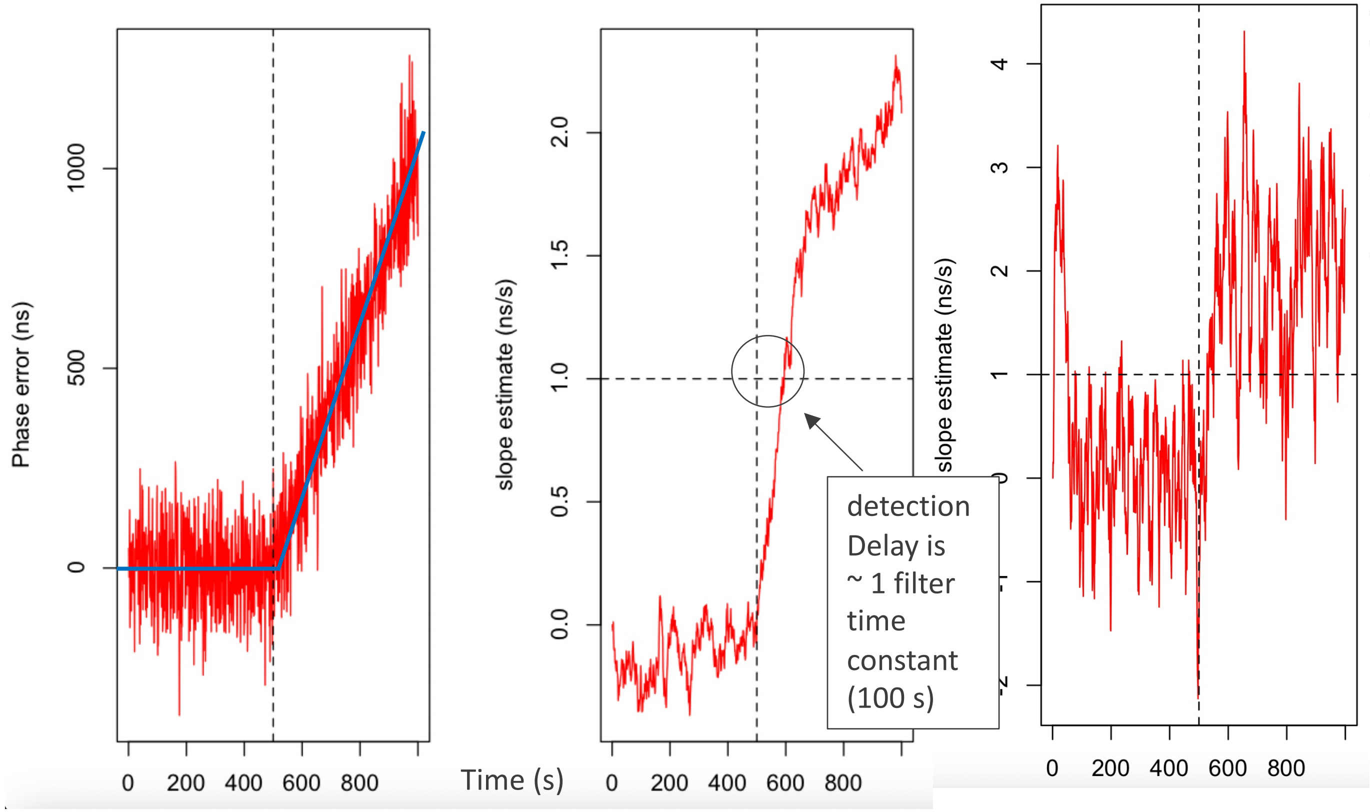
- Resistant GNSS antennas
  - Ground shielded
  - Phased array
    - Put Null in direction of jamming signal if spoofing detected
- Resistant GNSS receivers
  - Detect high signal level
  - Stationary receiver is moving
  - Multiple constellations and bands harder to spoof
- Satellites with encrypted messages
  - Iridium STL (LEO)
  - Atomicron
- Resistant Time servers
  - GNSS is jumping or steering my oscillator too fast



Using your local clock as a BS detector
The more stable the oscillator the more sensitive the detector

Step and Ramp Detection

- False alarms must be rare
- Monitored clock corrections will be noisy and must be filtered
  - Filtering takes time, so detection will be delayed
  - After detecting an error back out clock corrections from the filter delay interval
- Some spoofers jam first to get the receiver to reinitialize before acquiring the spoofed signal
  - The local clock PLL should perform a sanity check before reinitializing after holdover
- Complex algorithms vs simple algorithms
  - Complex algorithms can often out-perform simple ones, in most test cases
  - Complex algorithms are more likely to fail in unpredictable ways than simple ones



detection Delay is ~ 1 filter time constant (100 s)

white phase noise
dev = 100 ns

Slope estimator
Turns ramp into slope
But amplifies noise and requires filtering

filter time constant 30 s results faster detection,
but with false positives

PTP security

PTP Security Threats

- Compromised device in network
  - Compromised switch alters messages
  - Compromised switch delays messages
  - Compromised device injects messages
- False Grandmaster
  - With false Clock Quality values and/or low Priority1 value.
  - Wins BMCA
- Other PTP message injection
  - Replay attack
  - Messages with with forged GM clock Identity

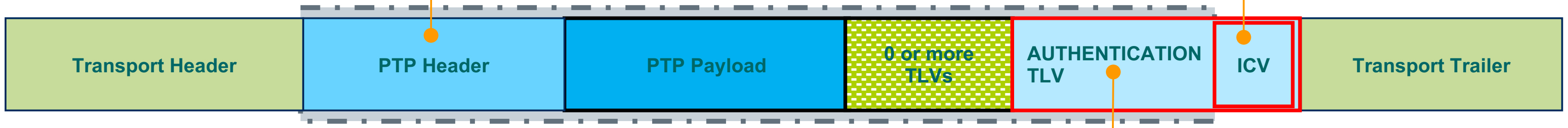
Easiest attack vector (switches have better security)

Aspects of PTP security

- Authenticate message integrity
- Authenticate and authorize security system users
- Automated key management
  - Needed for real (non-lab) networks

Utilized common header information:
- sourcePortIdentity
- sequenceNo

Integrity Check Value (ICV) providing integrity protection for marked PTP packet area



PTP Authentication TLV

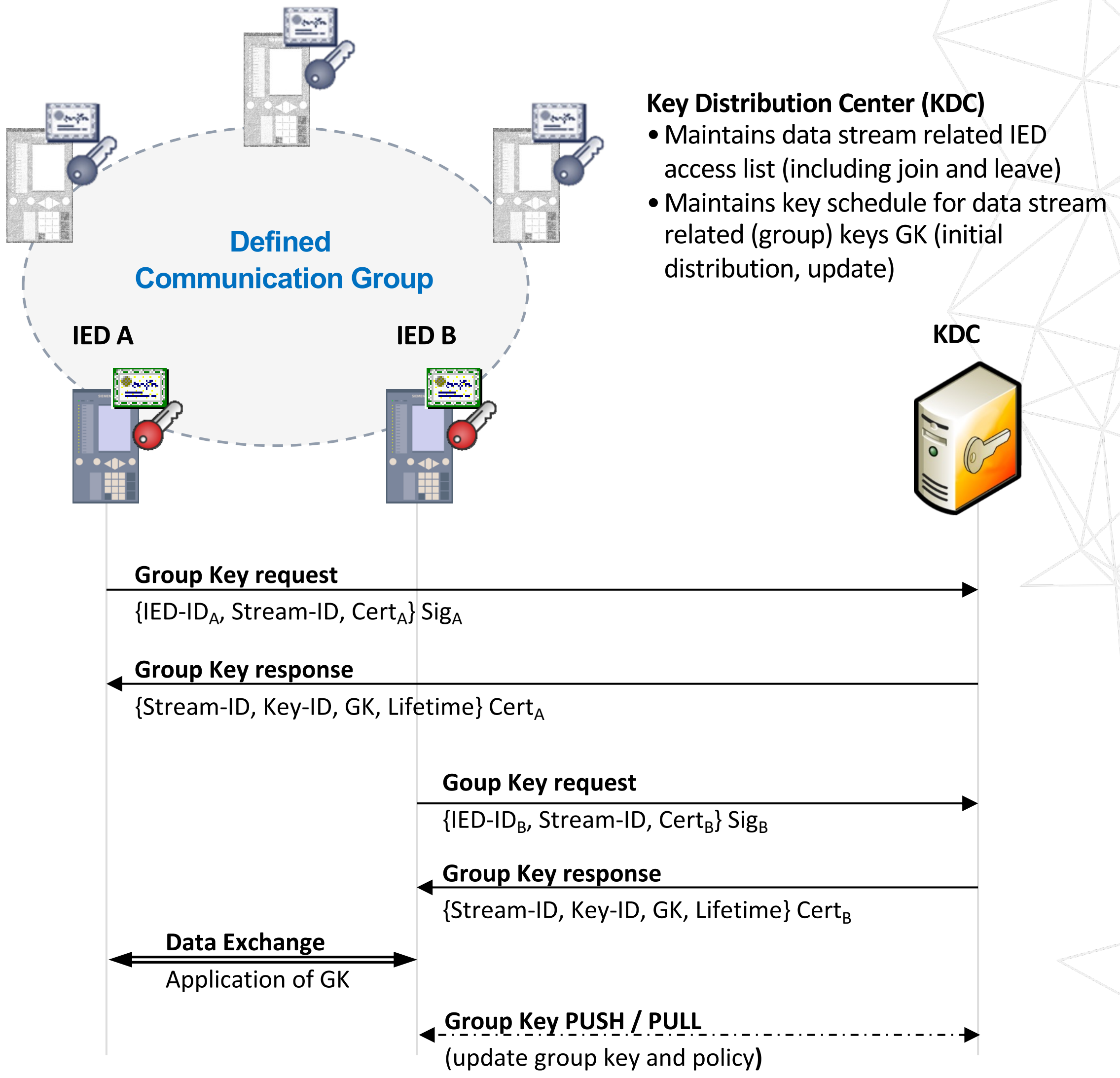
AUTHENTICATIONTLV, structured to support different key management options

Importance of ATHENTICATION TLV proven experimentally

- Research by Marist College and IBM
  - Experimentally demonstrated attacks with injected and manipulated messages in PTP networks
  - Tested both ptp4l (open source) and commercial PTP implementations
  - Both injected and manipulated messages were rejected when they did not have an AUTHENTIFICATION message with a correct ICV
  - See for example:
- L. McPadden, E. Herrera, C. Decusatis, P. Wojciak, C. Kaiser, S. Guendert, "Covert Channels and Data Injection Vulnerabilities for IEEE 1588 Precision Time Protocol using PTP4L," Proceedings of the 55th Annual Precise Time and Time Interval Systems and Applications Meeting, pp 77-86, Long Beach CA, January 2024.

PTP attack mitigations

- Delay Attacks
    - Can't be mitigated by cryptography
    - Compare time from multiple paths
        - PRP, HSR
    - Compare time from IRIG-B
- Injected message attacks
    - Boundary Clocks with Master-only ports
        - BC does not input time from downstream devices
    - MACsec
        - MACsec ASICS can have little jitter because they have to work at line rate
    - PTP Authentication TLV + GDOI key management
        - GDOI already can be used with GOOSE and SV
        - IEEE 1588d-2023 defines use with PTP



Key Distribution Center (KDC)

- Maintains data stream related IED access list (including join and leave)
- Maintains key schedule for data stream related (group) keys GK (initial distribution, update)

Group Key request
{IED-ID$_A$, Stream-ID, Cert$_A$} Sig$_A$

Group Key response
{Stream-ID, Key-ID, GK, Lifetime} Cert$_A$

Goup Key request
{IED-ID$_B$, Stream-ID, Cert$_B$} Sig$_B$

Group Key response
{Stream-ID, Key-ID, GK, Lifetime} Cert$_B$

Data Exchange
Application of GK

Group Key PUSH / PULL
(update group key and policy**)**

Summary

- Threats to reliable time distribution
  - GNSS jamming (mostly short term in North America)
  - GNSS spoofing (First you must detect it)
  - PTP message injection (BMCA makes PTP especially vulnerable)
- Mitigations
  - Holdover (OCXO might be best)
  - Timing source diversity (GNSS, Alt PNT, PTP, PTN)
  - Algorithms (Smart antennas, receivers, and time servers)
  - Network security (MACsec, GDOI)

Thank You!

I am happy to answer questions we didn't get to.

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