Robust and Secure GPS-based Timing for Power Systems

Algorithm and Validation of GPS-based Direct Timing Estimation for PMUs

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GOALS

- Develop a trustworthy GNSS-based timing source that is more jamming and spoofing-resilient than current GPS-based clocks.
- Investigate possible detection and mitigation schemes to harden PMUs against jamming, spoofing and receiver errors.
- Develop a hardware-based test-bed capable of investigating the resiliency of various PMUs to GPS jamming and spoofing attacks.

BACKGROUND ON GPS-BASED TIME TRANSFER

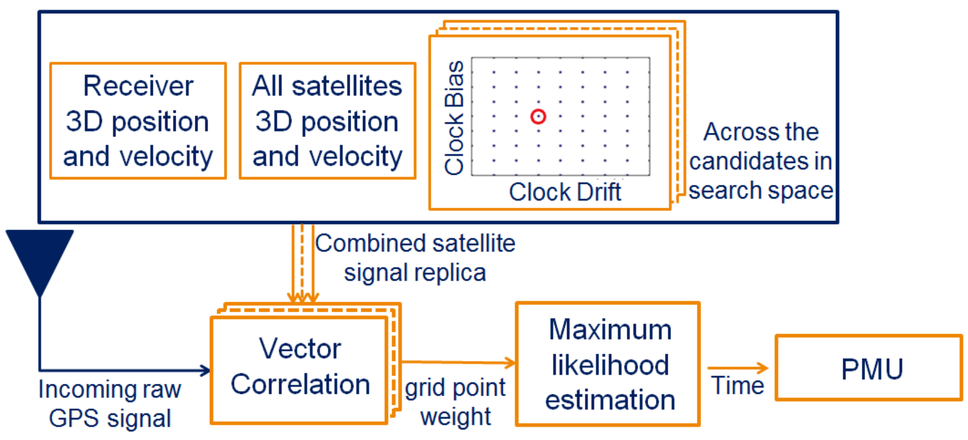
- GPS provides free accurate and precise time and frequency sources for power systems applications.
  - Time accuracy $\sim 100ns$, Frequency accuracy $\sim 1x10^{-12}$Hz.
- Civil GPS signals are susceptible to malicious attacks.
  - Civil GPS signals are weak and unencrypted, with their structures explicitly described in publicly available documents.
  - An attacker can broadcast counterfeit civil GPS signals and manipulate victim receivers' time and time drift solutions.
- Civil GPS-based timing equipment are not sufficiently robust to jamming, spoofing attacks and receiver errors.
  - Errors of up to 13 microseconds were observed for several hours during a GPS glitch on January 26 2016.
  - According to IEEE-C37.118.1, without other errors, maximum allowable phase angle error is $0.573°$ (~timing error of $26.5\ \mu s$).

OUR ROBUST GPS ALGORITHMS

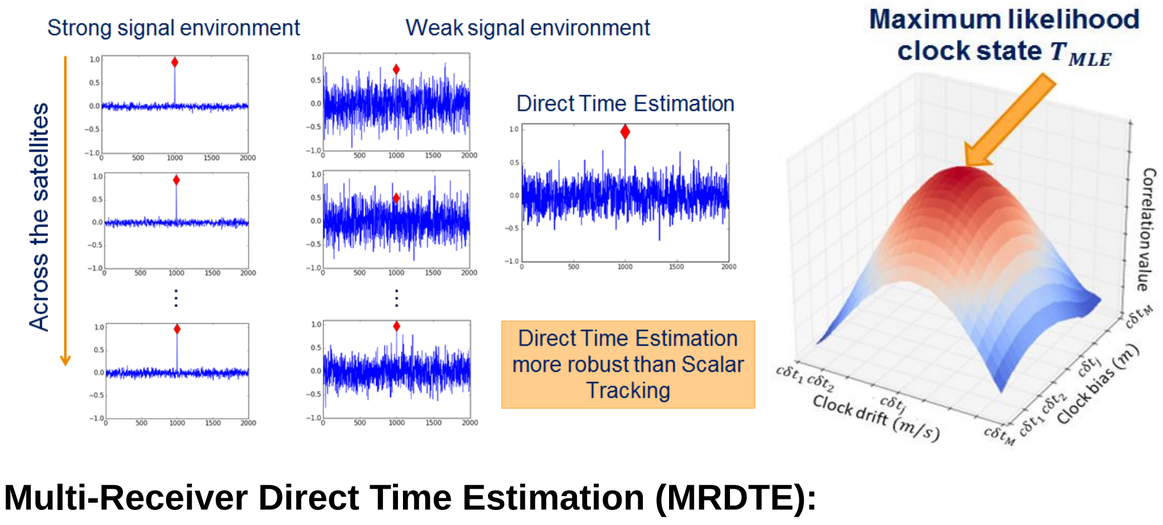
- Traditional GPS-based time transfer is a two-step process:
  - Acquire and track GPS signals per satellite individually to generate respective pseudorange and carrier phase.
  - Perform least-squares to obtain PVT solution from which UTC time is computed.
- The robust GPS algorithms developed in our lab:
  - No intermediate pseudorange measurements need to be estimated.
  - Leverage the static nature of the power grids to pre-determine 3D position an velocity of GPS receiver.
  - Works directly with timing parameters. Reduction in unknowns to be estimated from 8 $(x, y, z, c\delta t, \dot{x}, \dot{y}, \dot{z}, c\delta\dot{t})$ to 2 $(c\delta t, c\delta\dot{t})$.

Direct Time Estimation (DTE):

- Direct time estimation is a novel signal processing technique that evaluates a pre-generated set of clock candidates using the principle of maximum likelihood estimation.



- This algorithm computes non-coherent summation across satellites which improves the signal-to-noise ratio of the system.

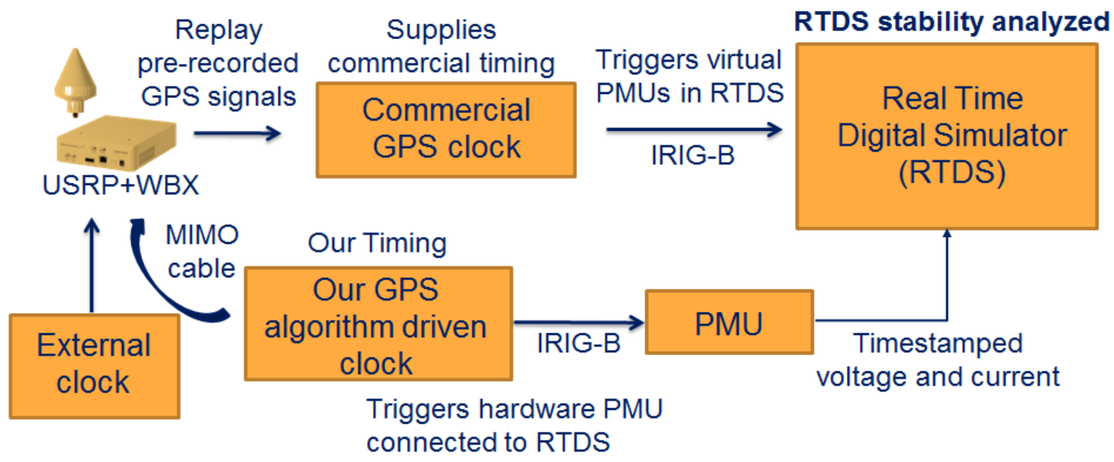


Multi-Receiver Direct Time Estimation (MRDTE):

- An extension of DTE known as Multi-Receiver Direct Time Estimation (MRDTE) is developed to incorporate multiple receivers.
  - Geographical diversity of multiple receivers is taken into account so as to further improve the robustness against timing attacks.
  - All the receivers are triggered by a common external clock.

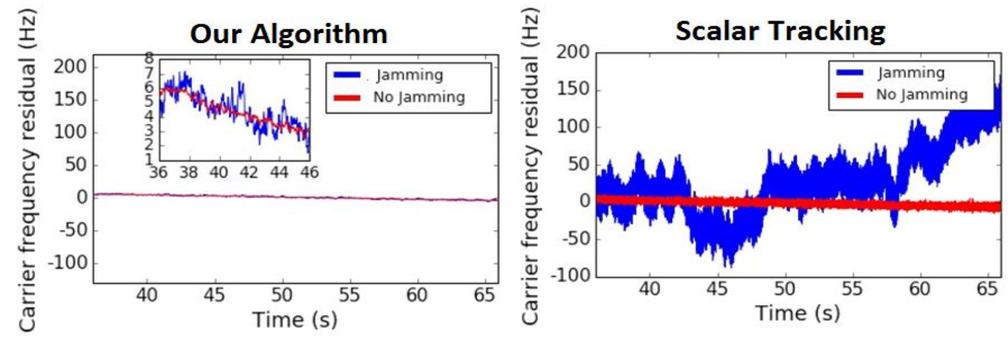
VALIDATION OF GPS-BASED TIMING FOR PMU

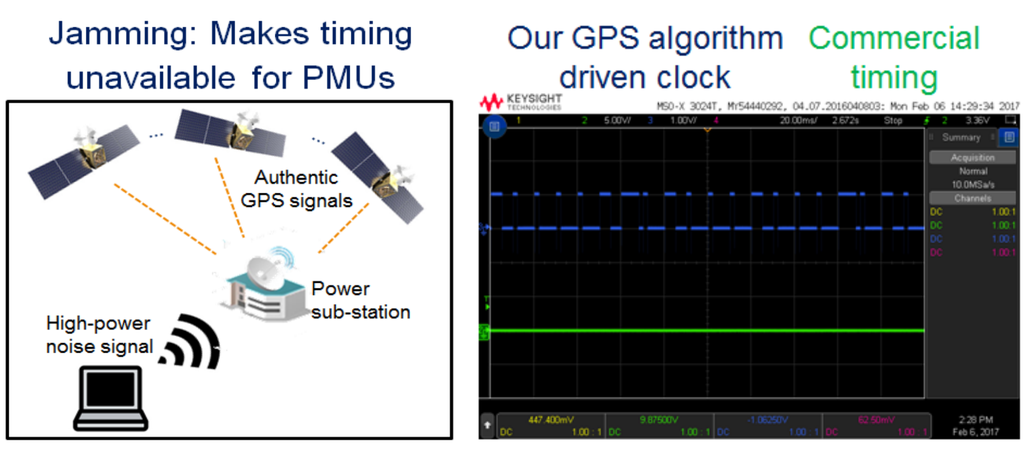
- Experimental validation of our robust GPS-based timing on PMUs involves two threads:
  - The GPS signals are given as input to the commercial clocks which supply IRIG-B timing signals to virtual PMUs in RTDS setup.
  - Our GPS algorithm driven clock takes the GPS signals to generate timing signals which are supplied to the hardware PMU connected to the RTDS setup.
- Synchronization of the threads is done using an external clock (Chip Scale Atomic Clock) and MIMO cable.



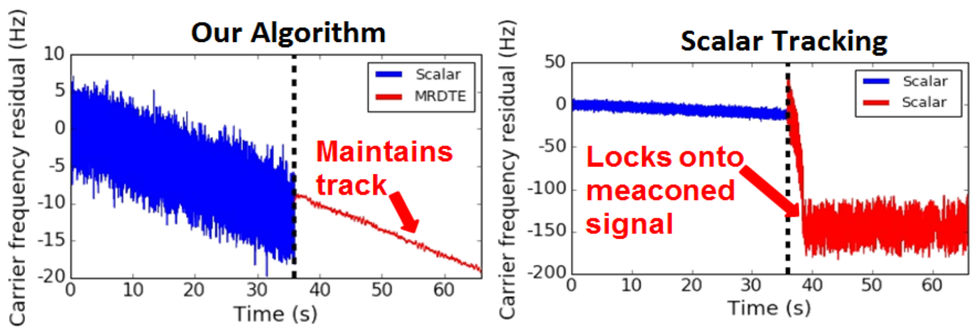
RESEARCH RESULTS

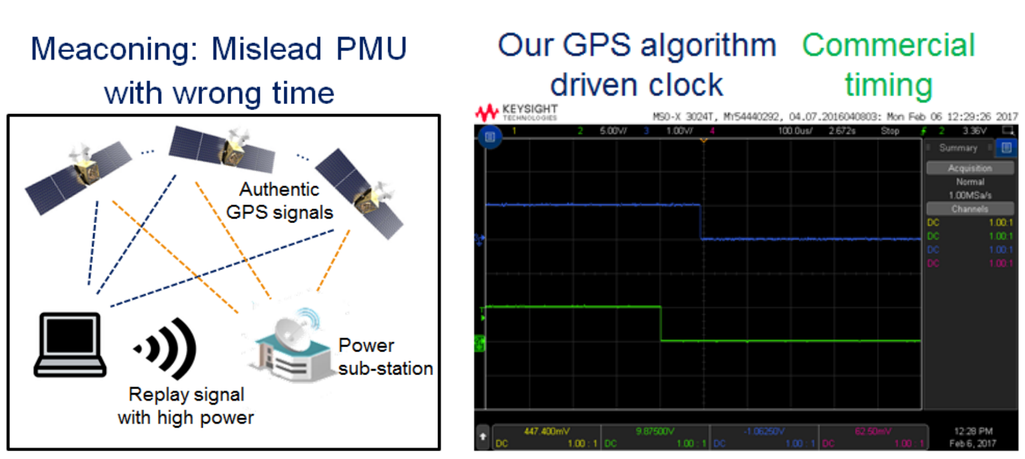
- Under $25dB$ of added Jamming above noise floor, the commercial clock lost track while our Direct Time Estimation driven clock is robust.





- Under Spoofing attack which broadcasts a meaconed signal of delay $100\mu s$ and $20db$ higher power, the commercial clock locks on spurious signal while Direct Time Estimation tracks the authentic signal.





CONCLUSION

- Our GPS algorithms utilize the entire information in the raw signal whereas the traditional methods discard the remaining information in raw signal after determining intermediate measurements.
- Experimental tests validate the increased robustness of our GPS algorithms against jamming, spoofing and receiver errors as compared to traditional GPS processing methods.

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