Session Architectures for Collaborative Orbit Determination using Ground Station Networks

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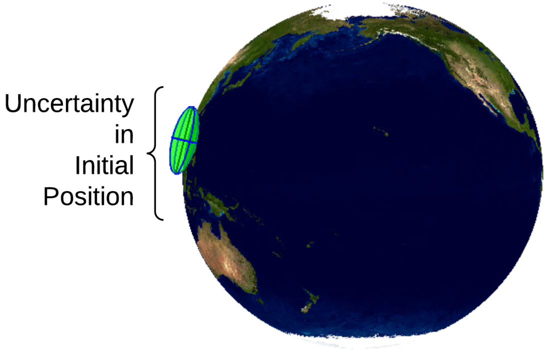
May 2, 2018

Initial acquisition with cluster launches is difficult

- There is increased access to space - cluster launches and TLE Lottery
- We can construct Autonomous Ground Station Networks (AGSNs).
- Initial acquisition through Doppler based OD.
- Deep space orbit determination

An ML Algorithm to do OD

- Orbital parameters Γ
- Uncertainty distribution P_Γ
- Observation interval $\mathcal{T}$
- Observed by ground station network
- Machine Learning Algorithm to estimate orbits [1]



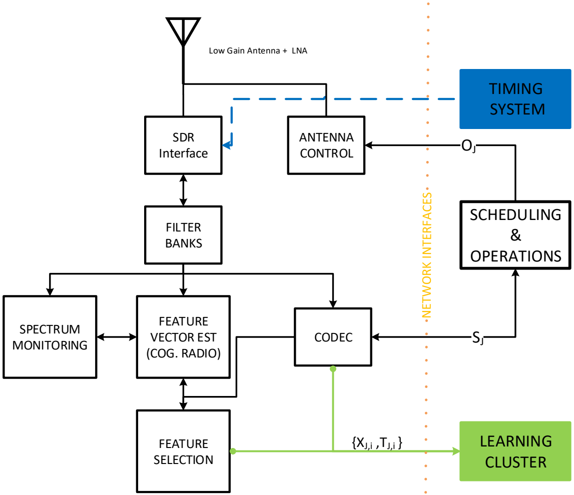
[1] Sharma et. al IPNPR 2015

Can a practial GSN satisfy Algorithmic Conditions?

The machine learning algorithm requires some conditions to be met

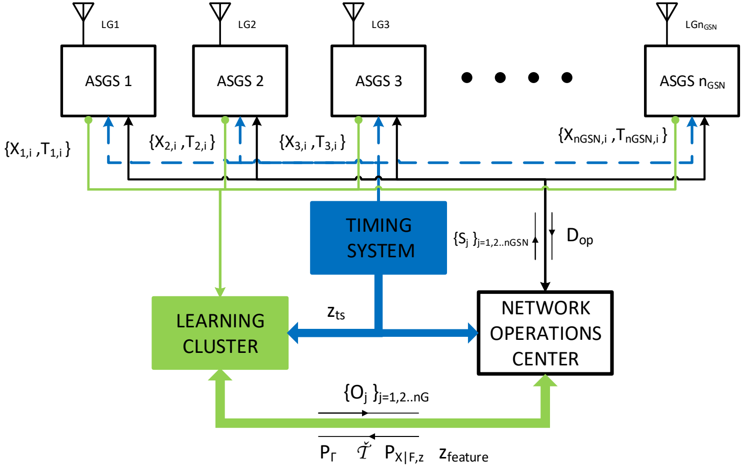
- Guaranteed observation of samples of any orbit from uncertainty distribution
- Observability
- Continuity of map

Spectrum analysis in a GS



Autonomous Software Ground Station

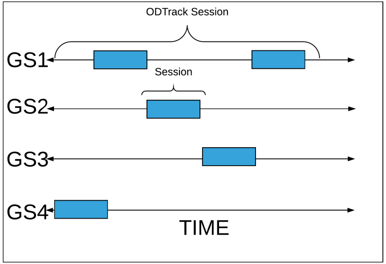
The global network has a learning cluster



Global Architecture

We can integrate OD into GSN Sessions

- GSNs work by reserving nodes (ground stations) through sessions.
- Orbit determination will be done inside of an “ODTrack Session”.
- The ODTrack Session is a group of GS Sessions.

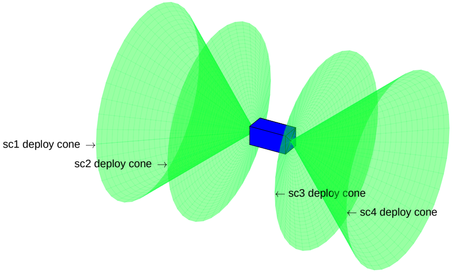


ODTrack Session

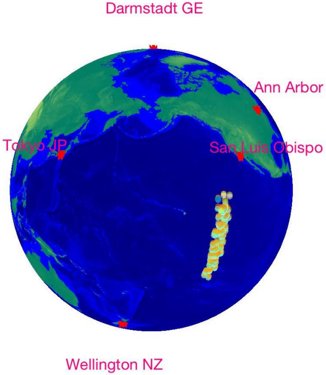
The learning cluster determines the OD session

- Learning Cluster samples the uncertainty distribution.
- Selects ground stations based on visibility.
- Coordinated antenna pointing.

Best explained by an example scenario



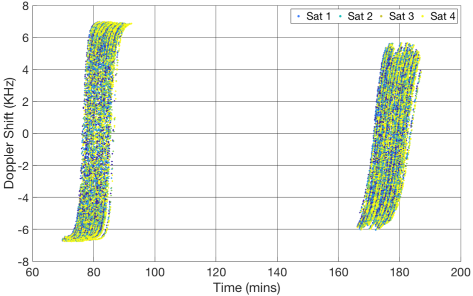
A simple model of random deployment



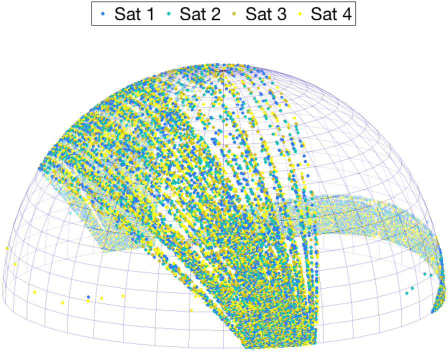
Samples of initial state deployment

Intervals of uncertain passes

- Break down OD into intervals of observation
- One pointing direction per interval

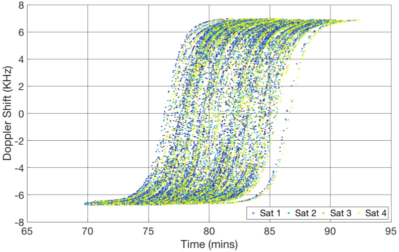


Wellington Doppler distribution has pass intervals

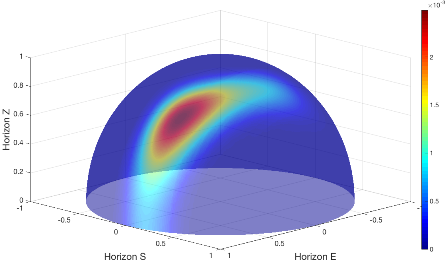


Wellington azimuth elevation distribution has bands

Point at the expected zero Doppler point

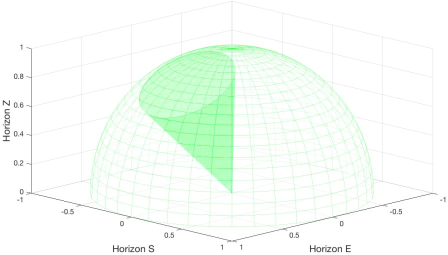


Collect zero Doppler time points



(Azim., elev.) probability of zero Doppler

- Antenna is approximated as a cone (cone angle: 3dB beamwidth)
- Antenna will point to the expected value of the azimuth elevation distribution

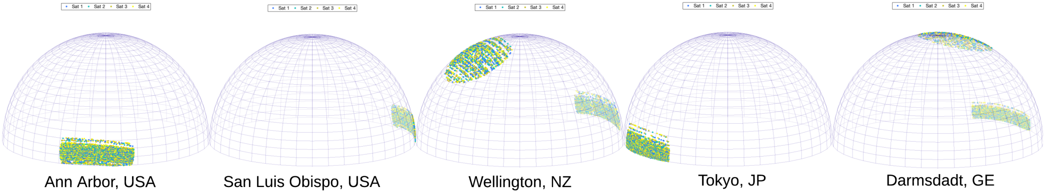


Antenna cone points along expected AzEl

(Sharma, Cutler, 2018)

A Pointing Profile

- Training Data is limited to learning with the profile information
- Profile + Interval information is sent to ASGS
- ODTrack Session is reserved for interval periods
- ASGS points antennas and examines spectrum during ODTrack intervals



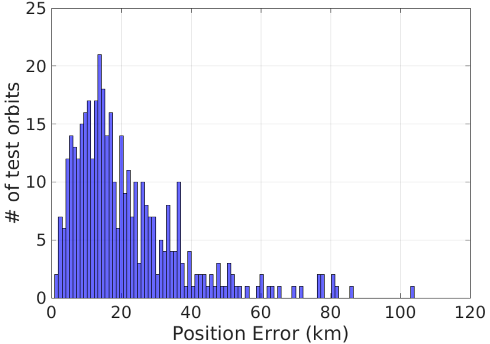
Azimuth and elevation of pruned training data

Simulated Scenario

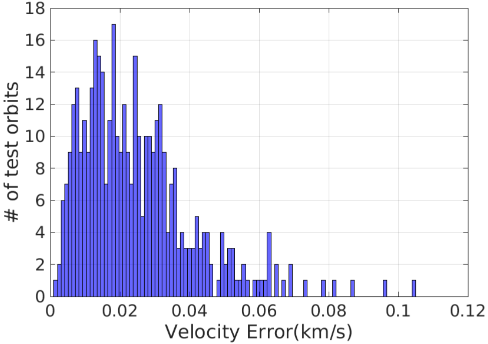
- Total Uncertainty in initial position of satellites: 863 km
- Observation Interval: 6 hours
- Deployment Interval: 200s
- Average Separation at initial state: 36km
- Noise in Doppler shift estimation: $2.5\%\Delta f_{maxDoppler}$
- Synchronization error between Ground stations: $\leq 1ms$
- Probability of transmission = 0.08 (1 in 10 seconds)

Results

Average error in initial position estimation: 21.44km



Histogram of position error



Histogram of velocity error

Conclusion and Future Work

- ODTrack Session Architecture for GSNs
- Algorithms for session instantiation for OD
- Coordinated Pointing Profiles for GSNs

Future Work

- Multiple antenna ground station nodes
- Integrating Learning with independent RADAR and Ground station based Doppler observations

Thanks

References

Sharma, S. and Cutler, J.W., 2015. Robust orbit determination and classification: A learning theoretic approach. Interplanetary Network Progress Report, JPL, 203, p.1.