TASKING SLR MEASUREMENTS TO THE GNSS SATELLITES:
PATH TOWARDS THE 1MM ACCURATE AND 0.1MM/YEAR TRF FRAME

International Technical Laser Workshop on
SLR Tracking of GNSS Constellations

September 14-19, 2009

Metsovo, Greece

Need for SLR measurements of the GNSS Constellations

- TRF Accuracy has been deemed necessary for a great many disciplines
- Accuracy at 1 mm and 0.1 mm/year is the goal
  - Validation metric needed for this level of accuracy
- SLR TRF to be defined using LAGEOS
- Accuracy of SLR used to:
  - Constrain the TRF
  - Constrain channel effects with multiple RF frequencies
  - Diagnosis systematic behavior between GNSS transmitters and receivers
  - Monitor clock performance and 1 cpr orbit errors
  - Augment force model validation and development
  - Monitor Eclipse behavior
  - Confirm attitude assumptions
- SLR is NOT required for use in routine / operational RF derived orbit and clock products

SLR Tasking Requirements

- Tasking schedule is well agreed upon in advance
  - SLR resources are finite
  - Only a few S/C of the Constellation use in any one week
  - Measurements not coordinated with the ILRS network are of little benefit to the global solutions
- SLR Observation Spans are fixed to Engineering Goals
  - Typically 1.5 to 2 Days for Constellation Revisit Tasking
  - Tied explicitly to GPS weeks
  - Repeat at specific Beta Prime Seasons
  - Focus on specific achievable observations and comparisons and constraints to the RF products
  - Weather outages are handled via redundancy built in to plan – no abnormal scheduling needed
- SLR measurements are driven by ability to achieve a Normal Point
  - Routinely achieve at Elevations above 20 degrees requested (low as practical)
  - Must not adversely impact the ILRS tasking on LEO and LAGEOS commitments
  - More frequent than one normal point per half hour is not a strong driver to global solution accuracy
- SLR sites local ties to GNSS
  - Routinely revisited with ACCURACY and Repeatability better than 1 mm
  - Observe all the future RF frequencies

Implementation

- Constellation is revisited periodically
- Each Plane (of 6 for GPS and of 3 for Galileo) is Tasked for one week
- S/C in a Plane are chosen for specific days
  - Anchor S/C is selected based on maximum night observing and local weather probability over the whole network
  - Anchor is used for first and last days with 1.5 to 2.0 day observation spans
  - Non-Adjacent s/c are selected to task remaining days with 1.5 day observation spans
    - Permits overlap as half the network is redundant with respect to one plane
    - Permits the observation of 6 s/c in one week
- Between dedicated weeks long arc single s/c observations are planned
  - Similar to today's tasking of GPS 35/36, Glonass (only 3 of many) and the Several Week campaigns on GVA and GVB
  - Driven by measurement data needed (ie. clock characterization needs at least 10 days of obs)

GNSS Documentation Provided to ILRS and Analysts

- Documentation for each Retroreflector equipped S/C
  - SLR tray center of mass to the Optical Phase Center Model as a function of Incident Angle
  - SLR Tray center of mass to S/C center of mass
  - RF phase centers to S/C center of mass
  - Retroreflector optical coatings are known

Scheduling Goals: Short and Long Observations

- Short Observation Span Goals
  - Less than 2 day duration
  - Validation of within a Plane at same Beta Prime
    - Choose same geometry for each member of the plane
  - Validation of RF transmitter location
    - May require intra plane tasking
  - Validation of Clock performance across members of constellation
  - RF Channel Effects
    - Direct measurements may require observations denser than 0.5 hr
  - Validation across Planes
    - Revisit the SLR network geometry the same
    - Exploit different Beta Prime orbits at same epoch
- Multi-Week Observation Span Goals
  - Long (>7 day) duration requires coordinated scheduling
  - Clock characterization
  - Non Conservative Force Model Tuning
  - Eclipse Monitoring
    - SLR raw data desirable

Intensive Tracking: Regional Model Validation

- Regional Model Validation using intensive regional tracking is likely unnecessary
  - Benefits:
    - Revisit all S/C in constellation – possible use for ionospheric mapping?
    - Achieves Closure on all models
  - Tradeoffs:
    - Difficult to coordinate with other satellite taskings
    - Combination with other datasets will give similar results
    - Impacts resource commitments
  - Recommendation: Follow short duration tasking and multiweek tasking as stated on previous chart

Sample ILRS GNSS Ranging Schedule:

Six plane constellation example

Week in Solar Season

Week 1-6	Week 7-13	Week 14-19	Week 20-26	Week 27-32	Week 33-39	Week 40-45	Week 46-52
GNSS SLR		GNSS SLR		GNSS SLR		GNSS SLR	

		Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Week 1	Plane 1	P1SV1	P1SV2	P1SV3	P1SV4	P1SV5	P1SV1	
Week 2	Plane 2	P2SV1	P2SV2	P2SV3	P2SV4	P2SV5	P2SV1	
Week 3	Plane 3	P3SV1	P3SV2	P3SV3	P3SV4	P3SV5	P3SV1	
Week 4	Plane 4	P4SV1	P4SV2	P4SV3	P4SV4	P4SV5	P4SV1	
Week 5	Plane 5	P5SV1	P5SV2	P5SV3	P5SV4	P5SV5	P5SV1	
Week 6	Plane 6	P6SV1	P6SV2	P6SV3	P6SV4	P6SV5	P6SV1	

Note: SV1 for each plane is chosen by optimizing the weekly schedule for the SV with the most nighttime availability

Analysis Drives Schedule

- GPS repeat Ground Track induces systematics in the SLR site overflights
  - Requires sampling across multiple planes to confirm no trends / biases
    - Minimum of 2/3 of planes in constellation
  - Day and Night ranging required to sample various beta prime seasons for a plane
  - Intra Plane validation:
    - Requires a minimum of 2 s/c in a *balanced* constellation
    - Temporal sampling may require more than 2 per plane - real constellations are not balanced
    - Recommend minimum of 4 s/c per plane in a realistic, *unbalanced* constellation
- Asymmetric ground network can bias collection on sub-orbit basis
  - Susceptible to the GPS repeat ground track
- Galileo ground track varies and longer fit span needed to constrain cross track component

Additional Thoughts

- Retroreflector array will provide greater response to current GPS satellites.
  - Current consideration is same design as ETS-VIII, performing nominally
  - ETS-VIII at GEOStationary orbit, ~36,000 km orbit
  - GPS significantly lower, thus greater response.
  - Other solutions being considered.
- Constellation will be populated over a period of years
  - To achieve most benefit, need to get retroreflector-equipped S/C launched in early part of constellation population
  - High likelihood that constellation will not be symmetric (implementation unlikely to adhere to baseline)