Beyond GPS II and Galileo I

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Q: What is coming after Galileo and GPS?

A: A New Era that begins now...

- Global Adoption - Greater International Cooperation
- Technical Improvements - Better Performance
  - Space Segment
  - Ground Segment
  - User Segment
- New Frontiers - GNSS & Space Exploration
US PNT Policy

• The 1996 policy introduced GPS as a dual-use system, and presented a strategic vision for management and use of GPS.

• The 2004 US Space-Based Positioning, Navigation, and Timing (PNT) policy responds to changing international conditions and the worldwide growth of GPS applications.

– emerging navigation systems, and related augmentations, should be compatible with GPS – in short, no interference from future signals and ideally, interoperable with civil GPS services and their augmentations.
Global Adoption and Greater International Cooperation

- Long cooperative relationship with Japan on GPS and the US is looking forward to their progress on a GPS-compatible augmentation known as QZSS.
- On-going consultations with Russia on potential cooperation, as well as compatibility and interoperability, between GPS and GLONASS.
- On-going consultations with India on their development of the WAAS-like aviation augmentation system known as GAGAN.
- The agreement in 2004 between the US and the European Union (EU) on GPS and Galileo recognized the benefits of interoperable systems for both parties.
- The EU and US agreed to implement a common, open, civil signal on both Galileo and future GPS III satellites.

June 26 Press Conference at US-EU Summit in Shannon, Ireland (left to right: US Sec. of State Colin Powell, Irish Foreign Minister Brian Cowen, EU Vice-President Loyola De-Palacio)

Space-based PNT services must serve global users and should have transparent interfaces and standards
Technical Improvements for Better Performance

• **Space Segment**
  - Constellation Configurations
    - More Satellites, Additional Signals, Longer lifecycles
  - Signal Enhancements
    - Higher Power, More Robust Codes, Anti-Jam, Anti-Spoof, Flex-Power
  - Integrity Alerting
  - Signal Authentication
  - Higher Data Rate
    - Search & Rescue, Value-Added Services
  - Greater System Accuracy, Availability, Continuity, and Utility

• **Ground Segment**
  - Satellite Tracking & Maintenance
  - Civil Signal Monitoring

• **User Applications**
  - Augmentations - Dissemination and use of PNT data
  - Receiver design - Ultra-sensitive, software-defined radios

Integration of Technology Advances in Space, Ground, and User Segments will enable GNSS for Space Exploration!
• January 14, 2004, the US President announced a new vision for NASA
  – Implement a sustained and affordable human and robotic program to explore the solar system and beyond;
  – Extend human presence across the solar system, starting with a human return to the Moon by the year 2020, in preparation for human exploration of Mars and other destinations;
  – Develop the innovative technologies, knowledge, and infrastructures both to explore and to support decisions about the destinations for human exploration; and
  – Promote international and commercial participation in exploration to further U.S. scientific, security, and economic interests.
Challenges for GPS use in Space

- Many emerging space users of GPS beyond Low Earth Orbit
  - Not just Geostationary Orbits
- Space users above the terrestrial service volume (>3000 km altitude) share unique GPS signal challenges
- GPS space flight experiments in high orbits have shown that existing signal availability becomes more limited due to:
  - Geometry between the SV and the space user
  - Vast signal strength changes due to signal path length variations (near/far problem)
- Robust GPS signals in the space service volume:
  - Needed to support future civil and military space requirements
  - Will open unprecedented science opportunities for 21st century space vehicles
High Accuracy Monitoring and Augmentation with the Global Differential GPS System (GDGPS)

The GDGPS System tracks each GPS satellite by at least 12 sites, and by 25 sites on average, enabling robust, real-time GPS performance monitoring with 4 sec to alarm.

Current real-time GPS products and services from the GDGPS System:

- High-accuracy (10 cm) global differential corrections
- Global ionospheric (TEC) maps
- Earth orientation
- Broadcast and almanac service
- Precise orbit and clock states
- Performance monitor (broadcast quality and signal metrics, alarms)
- Predicted orbit and clock states
- Assisted-GPS data
- Time transfer service

For more information see: http://www.gdgps.net
NASA’s Global Differential GPS System

Fully operational since 2000

For more information see: http://gipsy.jpl.nasa.gov/igdg

NASA’s global real time network

Terrestrial and airborne users

Land lines

Inmarsat

Iridium

Uplink

Frame

Internet

NASA’s GDGPS Operations Center

TDRS

Space users

Broadcast

Terrestrial and airborne users

Iridium

Inmarsat

Frame

Internet

NASA’s GDGPS Operations Center

TDRS

Space users
• Tracking and Data Relay Satellite System (TDRSS) Augmentation Service for Satellites (TASS) provides Global Differential GPS (GDGPS) corrections via TDRSS satellites
• Integrates NASA’s Ground and Space Infrastructures
• Provides user navigational data needed to locate the orbit and position of NASA user satellites
GPS and Planetary Navigation: Navigation Options

Lunar Mission Tracking Options:
- Earth based tracking
- Satellite laser ranging stations
- Earth based relay (TDRSS and follow-on)
- GPS
  - Signals can be tracked to the surface of the Moon.
  - Signals effective up to approx. 322,000 km / L1 Lagrange Point (4/5 the distance to the Moon).
  - Probably will be used to support the 1st Translunar Correction Maneuver (TCM) at 12-20 hours after Trans Lunar Injection (TLI)
- Lunar based relay

Range of Earth GPS Reception
- MEO (GPS)
- GEO
- LEO
- Trans-lunar CEV/EDS

Effective Outer Limit of GPS Space Service Volume
- L1 Lagrange Point

Range of Lunar NavSat Reception
- HLO (Lunar NavSat)
- LLO

To Outer Planets
The Vision for Space Exploration: Support Infrastructure - ‘another GPS?’

Lunar and Mars Network
- Integrated Navigation and Telecommunications
- Develop a communications capability to provide a substantial increase in data rates and connectivity
- Develop an in situ navigation capability to enable more precise targeting and location information.
Three relativistic effects contribute to different “times”: 
(1) Velocity (time dilation) 
(2) Gravitational Potential (red shift) 
(3) Sagnac Effect (rotating frame of reference) 
These effects need to be taken into account when adjusting from one time reference to another (Earth to Mars, Mars to Earth, etc.)

- GPS provides a model for timekeeping and time dissemination
- GPS timekeeping paradigm can be extended to support NASA space exploration objectives
- With appropriate relativistic transformations can provide a common reference system

Objective: Integrated Interplanetary Navigation and Communications
Vision For Space Exploration: A New Era that begins now

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- Ground Segment
- User Segment

New Frontiers - GNSS & Space Exploration
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