Orbit Determination using Two way measurements and Extended Ephemeris of NavIC Satellites

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Introduction To NavIC System

• Measurements System:

➢ One-way Range measurement from IRIMS has Receiver /Satellite clock and other errors

➢ Two-way Range measurement from IRCDR, which is independent of clock errors
NavIC Two-Way Data And Processing

• Two-way Data: Range and Ground Station calibration data from four Two-way Ranging stations (IRCDR) for each operational NavIC s/c is used.

➢ For each NavIC S/c, data arc of 10-12 min/2 hr is available from each IRCDR station.

➢ Ground station zero range calibration data of 5 min/2 hr is available
NavIC Two-Way Data Availability

IRNSS-1B-IRCDR STN(BHOP)

IRNSS-1B-IRCDR STN(HASS)

IRNSS-1B-IRCDR STN(JODH)

IRNSS-1B-IRCDR STN(SHLG)
NavIC Two-Way Data Processing

- Measurement Processing:
  - Removal of Outliers
  - IRCDR Station Delay Correction
  - Iono-delay Correction
  - Tropo-delay Correction

- Processed Range availability for OD
NavIC Orbit Determination Using Two-Way Data

- Dynamic Orbit Determination in NavIC Navigation Software

- Estimation:
  - Estimator: Least square
  - Mode: Batch processing
  - Span of data used: 3 days
  - Number of parameters: X, Y, Z, Xdot, Ydot, Zdot + 9 empirical Accelerations

- Measurement models:
  - Satellite Antenna Phase Centre Correction
  - IRCDR Antenna Phase Centre Correction
  - Station Bias estimation: Arc-wise station bias estimation
NavIC Orbit Determination Using Two-Way Data

• Dynamic Orbit Model:
  ➢ Earth Gravity: EGM 2008(21X21)
  ➢ N-body gravitation: JPL DE405 (Sun, Moon and Other planets)
  ➢ Solid Earth tide and Earth pole tide: IERS Conventions 2010
  ➢ Ocean Tide and Ocean pole tide: IERS Conventions 2010
  ➢ Relativistic effects: IERS Conventions 2010
  ➢ Atmosphere drag: Not Considered

• Reference Frame:
  ➢ Coordinate system: WGS 84
  ➢ Precession/Nutation: IAU 2006/IAU2006A model
  ➢ Earth rotation parameters: IERS final EOP products
NavIC OD Using Two-Way Data – Results

**ORBIT OVERLAP ERROR**

RSS Pos Error (m) with $\sigma = 2m$

RSS Vel Error (mm/s) with $\sigma = 0.1mm/s$
Typical Navigation Performance – Results

BLR-IRIMS: USER EQUIVALENT RANGE ERROR

BLR-IRIMS: POSITION ERROR
Extended Ephemeris of NavIC satellites

- To generate and disseminate extended ephemeris for NavIC satellites with longer usage period for SPS users of NavIC

**Benefits**

- To Provide Faster Time To First Fix (TTFF) through Extended (Longer Validity) Ephemeris under Following Adverse Conditions
  - Frequent Loss of Lock leads to loss of Broadcast Ephemerides (Poor signal Environments)
  - Cold Start of the receiver
- Faster TTFF under nominal Conditions with reasonable accuracy (20 to 100 meters in position)
Navigation parameters

- NavIC satellites Broadcast Navigation Data and PRN codes to users to enable PVT fix.

- Navigation Data of SPS users Consists of
  - Ephemerides (Orbital State + Clock Coefficients + URA + TGD.. etc)
  - Almanac, Iono-Grid Parameters/ Klobaucher Coefficients, EOP (Earth-Orientation Parameters), Inter-Signal Corrections, and IRNWT offset etc.

- Ephemerides (Also called Primary Navigation Parameters) are broadcast at an interval of 48 seconds and valid for short duration of 2 hours

- Acquisition and Tracking takes about 3 seconds

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Message ID</th>
<th>Broadcast Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iono-Grid Parameters</td>
<td>MT5</td>
<td>5mins</td>
</tr>
<tr>
<td>Klobaucher &amp; EOP</td>
<td>MT11</td>
<td>10mins</td>
</tr>
<tr>
<td>Almanac</td>
<td>MT7</td>
<td>20mins</td>
</tr>
<tr>
<td>IRNWT offsets</td>
<td>MT26</td>
<td>20mins</td>
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</table>
PVT

TTFF - Components

• Inputs for PVT
  \[ T = T_{acq} + T_{track} + T_{eph} + T_{sol}. \]
• Ephemerides
  \[ T_{acq} \quad \text{– Acquisition} \]
• Pseudo-Range
  \[ T_{track} \quad \text{– Tracking} \]
  \[ T_{eph} \quad \text{– Ephemerides Collection Time} \]
  \[ T_{sol} \quad \text{– Solution computation duration} \]

**Teph is about 90% of Total TTFF**

<table>
<thead>
<tr>
<th>Nav. Data</th>
<th>Tinit sec</th>
<th>Tacq Sec</th>
<th>Tbsyn sec</th>
<th>Tvitb sec</th>
<th>Teph sec</th>
<th>Tpos sec</th>
<th>Total TTFF (T) (sec)</th>
<th>Tnav/T</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broadcast</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>0.5</td>
<td>48</td>
<td>1</td>
<td>54.5</td>
<td>88%</td>
</tr>
</tbody>
</table>
Extended Ephemeris Generation

• Least square Fit
• Fit Interval – 8 Hours (3 sets per day)
• Two Types of Informations
  • Ephemeris
  • Events data
• Ephemeris Types

<table>
<thead>
<tr>
<th>Ephemeris Type</th>
<th>Prediction Period</th>
<th>Update Interval</th>
<th>No. of sets</th>
<th>Size of data/satellite</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>24 Hours</td>
<td>Everyday</td>
<td>3</td>
<td>0.2KB</td>
</tr>
<tr>
<td>2</td>
<td>7 days</td>
<td>Once / week</td>
<td>21</td>
<td>1KB</td>
</tr>
<tr>
<td>3</td>
<td>21 days</td>
<td>Once /Week</td>
<td>84</td>
<td>4.2KB</td>
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</tbody>
</table>
Extended Ephemeris Generation

- Event Data
  - S/C Manoeuvre info.
  - Clock Jump info.
  - Planned S/C Maintenance, if any

Enhancement with Additional New Parameters

Extended Ephemeris includes all parameters of Subframes 1 and 2 with the following additional parameters to provide enhanced performance.
### Additional Parameters

<table>
<thead>
<tr>
<th>S.NO</th>
<th>SUB-FRAME Data</th>
<th>Notation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ephemerides Validity Period</td>
<td>E_VP</td>
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<tr>
<td>2</td>
<td>Time Of Differential Corrections</td>
<td>$t_{od}$</td>
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<tr>
<td>3</td>
<td>Diff. Cor. Validity Period</td>
<td>DC_VP</td>
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<tr>
<td>4</td>
<td>Issue of data Differential Correction</td>
<td>IODDC</td>
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<tr>
<td>5</td>
<td>Issue of data Differential Cor. and Ephemeris</td>
<td>IODDE</td>
</tr>
<tr>
<td>6</td>
<td>Alpha correction to ephemeris parameters</td>
<td>$\Delta \alpha$</td>
</tr>
<tr>
<td>7</td>
<td>Beta correction to ephemeris parameters</td>
<td>$\Delta \beta$</td>
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<tr>
<td>8</td>
<td>Gamma correction to ephemeris parameters</td>
<td>$\Delta \gamma$</td>
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<tr>
<td>9</td>
<td>Angle of inclination correction</td>
<td>$\Delta i$</td>
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<tr>
<td>10</td>
<td>Events Data</td>
<td>ED_MSG</td>
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</tbody>
</table>
# Expected Performance of Extended Ephemeris-TTFF

## BEST CASE

<table>
<thead>
<tr>
<th>Nav. Data</th>
<th>Tinit (sec)</th>
<th>Tacq Sec</th>
<th>Tbsyn sec</th>
<th>Tvitb (sec)</th>
<th>Teph sec</th>
<th>Tpos sec</th>
<th>Total TTFF (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broadcast</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>0.5</td>
<td>48</td>
<td>1</td>
<td>54.5</td>
</tr>
<tr>
<td>Ext. Eph.</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>0.5</td>
<td>0</td>
<td>1</td>
<td>6.5</td>
</tr>
</tbody>
</table>

## WORST CASE

<table>
<thead>
<tr>
<th>Nav. Data</th>
<th>Tinit (sec)</th>
<th>Tacq Sec</th>
<th>Tbsyn sec</th>
<th>Tvitb (sec)</th>
<th>Teph sec</th>
<th>Tpos sec</th>
<th>Total TTFF (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broadcast</td>
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<td>3</td>
<td>1</td>
<td>0.5</td>
<td>60</td>
<td>1</td>
<td>66.5</td>
</tr>
<tr>
<td>Ext. Eph.</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>0.5</td>
<td>0</td>
<td>1</td>
<td>6.5</td>
</tr>
</tbody>
</table>
Conclusion

➢ Two-way range measurements accuracy ~0.3m (2σ)
➢ Achieved orbit accuracy is ~ 8m-12m (3σ RSS) over a day based on the overlap analysis

➢ Utilization:
  ➢ Estimated orbital parameters from Two-way measurements are used to generate the NavIC navigation parameters

➢ Additional data with long base line is expected to improve the orbit accuracy

➢ Using Extended ephemeris 90% reduction in TTFF w.r.t broadcast under Initial Position Fix

➢ Lot of new applications possible
  • Mobile Phones
  • Activity trackers and eHealth
  • Wearables Technologies
Thank You