Precision Improvement in GNSS Time Synchronization by Mitigating the Effect of Multipath Signals from NLOS Satellites

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TD-LTE Mobile Communication Services in Japan

- 3.5GHz band (band 42) licenses assignment for TD-LTE mobile communication services in Japan

High speed mobile communication services with up to 788 Mbps downlink has already been provided with the inter-band carrier aggregation based on C-RAN (Centralized RAN) architectures.
Inter Cells Interferences in TD-LTE Systems

- Inter cells interferences in the TD-LTE Systems include inter BSs (Base stations) interferences and inter UE (User Equipment) interferences.
- High precision time synchronization within mobile base stations is required to avoid interferences.

![Diagram of Inter BS and Inter UE interference]

If

Guard Period (GP)

\[ \text{Time Error} \leq (2 \times 3.3 \times \text{Cell Radius}[m])[-\mu s] \]

Then,
Interference occurs

Time synchronization between mobile base stations is required to be within \( \pm 1.5 \, \mu s \)

BS : Base station  UE : User Equipment

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Problems in High Precision GNSS Time Synchronization

Standardized budget assignment of time errors in mobile communication systems

Time Error
- NOT predictable
- ±50ns ~ > 1μs

Time Error
- Predictable
- < # of IFs x tens of ns

ITU-T Recommendations G.8271.1/G.8272

Difficult to estimate the time error in actual GNSS systems in advance

PTP : Precision Time Protocol (IEEE1588v2)
Time Error Causes in GNSS Time Synchronization Systems

1. Satellite Orbit Error
2. Satellite Clock Error
3. Ionosphere delay (Scintillation error)
4. Troposphere delay
5. Open air space condition
6. Multipath
7. Antenna
8. Cable delay compensation error
9. GNSS receiver
10. Interferences/Jamming/Spoofing

Ionosphere
250km ~ 400km high

Troposphere
~ 12km high

Most of the Error occurs around close to the ground
Time Synchronization with GNSS

- By receiving more than four satellite signals simultaneously by GNSS receivers, four unknown parameters, three-dimensional position and time, can be calculated.
- In that sense, positioning and time synchronization in GNSS receivers are a set of the processing.

![Diagram of GNSS satellites and receiver](image_url)

- **GNSS Satellite #1** $(X_1, Y_1, Z_1, T_1)$
- **GNSS Satellite #2** $(X_2, Y_2, Z_2, T_2)$
- **GNSS Satellite #3** $(X_3, Y_3, Z_3, T_3)$
- **GNSS Satellite #4** $(X_4, Y_4, Z_4, T_4)$

**GNSS Receiver**

**Antenna** $(x, y, z, t)$

**Blue**: Already known
**Red**: Unknown

Four parameters, the coordinate (latitude, longitude, altitude) and the time difference from satellite clock, are calculated in GNSS receivers.
Reduction of Number of LOS satellites with Restriction of Open Air Spaces

Decrease of the number of LOS satellites with limitation of open air spaces

DOP (Dilution Of Precision) degrades
Furthermore, accuracy of positioning and time synchronization degrade with reception of multipath signals which are formed by reflection and diffraction of GNSS satellites signals at peripheral buildings.
Effect of Multipath Signals on the Accuracy in GNSS Time Synchronization

Influence of multipath signals on the time-sync accuracy is different between **LOS satellites and NLOS satellites**. Effect of LOS multipath signals can be removed effectively in correlators, but that of NLOS multipath signals can only be removed by not using (filtering out) NLOS satellite signals.

(A) Multipath signals of LOS satellite accompanying direct wave

(B) Multipath signals of NLOS satellite Not accompanying direct wave

Main cause of degradation of the time sync accuracy is from NLOS multipath signals.

Effectively removing mutipath signals of NLOS satellites is ESSENTIAL.
Statistical Satellites Selection Algorithm (1)

- Signal processing in conventional GNSS receivers

  - GNSS Satellite Signals Detection
  - Ranging
  - Positioning & Time Sync

- Signal processing in GNSS receivers with statistical satellite selection

  - GNSS Satellite Signals Detection
  - Ranging
  - Statistical Satellite Selection
  - Positioning & Time Sync

Select appropriate GNSS satellite signals through statistical satellite selection algorithms
Statistical Satellites Selection Algorithm (2)

- Our contrived algorithms select few LOS satellites for sure in urban canyon reception environments where open air spaces are limited and number of LOS satellites is reduced.
- If number of LOS satellites is less than four, the algorithm select minimum “good” NLOS satellites signal complementally with LOS satellite signals. In this case, “good” means suffering from less propagation delays.

An example of reception environments with open air spaces severely restricted by structures close to antenna

NLOS satellite signals reflected at structures nearby antenna which suffers from less propagation delay have less effect on the time error.

In these environments, “good” NLOS satellites should be positively utilized along with LOS satellites signals

⇒ This is the point of our algorithm
Model Environments of Multipath Reception for Experimental Evaluation

- Multipath Reception Point A (Outdoor)
- Multipath Reception Point B (Indoor)
- Reference Reception Point (Open sky)

Reference

20m
Experimental setup for the performance evaluation

Reference timing signal

- Antenna
- Clear Open-sky reception environment

Timing signal under test

- Coaxial cable
- Splitter
- Multipath signal reception environment

**Equipment #1**

- "Golden" GPS receiver
- 1PPS ref
- 10MHz ref
- Time error measurement equipment #1

**Equipment #2**

- GPS receiver w/ statistical satellite selection
- GPS receiver w/o statistical satellite selection
- 1PPS
- 10MHz ref
- 1PPS ref
- 1PPS ref

**Reference timing signal**

- Reference timing signal
- Timing signal under test

**"Golden" GPS receiver**

- "Golden" GPS receiver

**Multipath signal reception environment**

- Multipath signal reception environment

**Clear Open-sky reception environment**

- Clear Open-sky reception environment
Estimation of LOS Satellites Reception Characteristics with Sky Plot Images Taken by Fish-Eye Lens Camera

Estimated # of LOS satellites over time
GPS Satellites Signals Reception Characteristics @ Multipath Signals Reception Point A

- Received Satellites
- Estimated LOS Satellites (Open sky)
- Estimated LOS Satellites (With structures)

Number of received satellite signals vs Time Epoch

Estimated number of LOS satellites

#: GPS satellite number, figure in parentheses: CNR(dB-Hz)
Measured Time Error Comparison @ Multipath Reception Point A

Time Errors measured with commercial GNSS receiver modules with the reception of GPS satellites without elevation nor SNR mask

Receiver module A

Receiver module B

Receiver module C

Max|TE| = 208 ns

Max|TE| = 422 ns

Max|TE| = 365 ns
Performance Evaluation Results with the Contrived Algorithm @ Multipath Reception Point A

Multipath reception environments with surroundings of structures

Measured time synchronization accuracy

WITH Statistical Satellite Selection

WITHOUT Statistical Satellite Selection

Improved

Measured accuracy of two dimensional positioning

Position of the antenna
The Condition of GPS Satellite Selection with the Contrived Algorithm @ Multipath Reception Point A

(a) 2017/1/10 10:18:14 JST

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#: GPS satellite number, figure in parentheses: CNR(dB-Hz)

(a) (b) (c)

\[ \text{Selected four GPS satellites} \]
GPS Satellites Signals Reception Characteristics @ Multipath Signals Reception Point B

Multipath reception environment with an antenna inside the window

![Image of antenna inside window]

- **Received Satellites**
- **Estimated LOS Satellites (Open sky)**
- **Estimated LOS Satellites (With structures)**

![Graph showing number of received satellite signals over time]

Time Epoch
0:00 - 5:00 - 18:30 - 24:00

(a)  (b)

- #: GPS satellite number, figure in parentheses: CNR(dB-Hz)
Performance Evaluation Results with the Contrived Algorithm @ Multipath Reception Point B

Multipath reception environment with an antenna inside the window

Measured time synchronization accuracy

WITH Statistical Satellite Selection

WITHOUT Statistical Satellite Selection

Improved

Time Error (ns)

Elapsed Time(h)

Measured accuracy of two dimensional positioning

Position of the antenna
GPS Satellites Signals Reception Characteristics @ Multipath Signals Reception Point C

Multipath reception environment with an antenna inside the window

#: GPS satellite number, figure in parentheses: CNR(dB-Hz)
Performance Evaluation Results with the Contrived Algorithm @ Multipath Reception Point C

Multipath reception environment with an antenna inside the window

Max|TE| = 146ns
TE Improvement with the reduction of PLL Loop Bandwidth

Improvement of Max|TE| from 146 ns to 85 ns by drastic reduction of PLL Loop bandwidth from 99 mHz to 0.49 mHz in GNSS DO with high precision OCXO (H/O : ±1.5μ@24h)

QZSS will be expected to complement the reduction of the number of receivable GPS LOS satellites signals
Why We Need Multipath Simulation of GNSS?

1. “True” reference time is required to measure the time error but it cannot be available at urban canyon environment (with no full-open-sky reception point nearby).

2. By “editing” simulated multipath signals, independent test of LOS multipath, NLOS multipath and DOP effects can be conducted, differently from the real GNSS signal.
Multipath Simulation @ Actual Signal Reception Environment

3D Map

Measured building height data is added as attribute data to 2D map

Radio Propagation Analysis

Multipath estimation with three dimensional ray-trace simulation

GNSS Signal Simulator

More closely real multipath signal generation with SDR (Software-Defined Radio) architecture through digital I/Q data
Visualization of Simulated GPS Multipath Signals

All of the multipath signal can be regenerated with SDR-based GNSS Signal Simulator
Edit Multipath Signals

Los Satellites

Nlos Satellites

Sky map from GNSS signal simulator

Direct wave

Multipath signal

Path loss: 10dB

Delay: 300ns
(Approx. 100m propagation delay)

Direct wave

Multipath signal

Path loss: 10dB

Delay: 300ns
Performance Evaluation Results with Edited Multipath signals (1)

- **LOS Satellites**
- **NLOS Satellites**

**Without Statistical Satellite selection**

- **Relative Position (in meters)**
- **Satellite Elevations**

**With Statistical Satellite selection Algorithm**

- **Relative Position (in meters)**
- **Satellite Elevations**

- **Delay**: 300ns (Approx. 100m propagation delay)
- **Path loss**: 10dB

- **Path loss**: 10dB

**Selected satellites**

**Unselected Satellites**
Performance Evaluation Results with Edited Multipath signals (2)

Time synchronization characteristics

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WITH Statistical Satellite selection

WITHOUT Satellite Signal selection

Improved
Domain of Applicability of GNSS Positioning and Time-sync Improvement

Conventional measures proposed so far to suppress effect of multipath signals of NLOS satellites and this technology are mapped together on a two-dimensional diagram with number of LOS satellites and moving speed assuming application to positioning segments.

Conventional measures are only applicable to the condition with reception of more than four LOS satellites. So, have problems in applications with moving antennas in which reception condition change dynamically.
Thank you for your attention.
Any questions?