Innovative R&D by NTT

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

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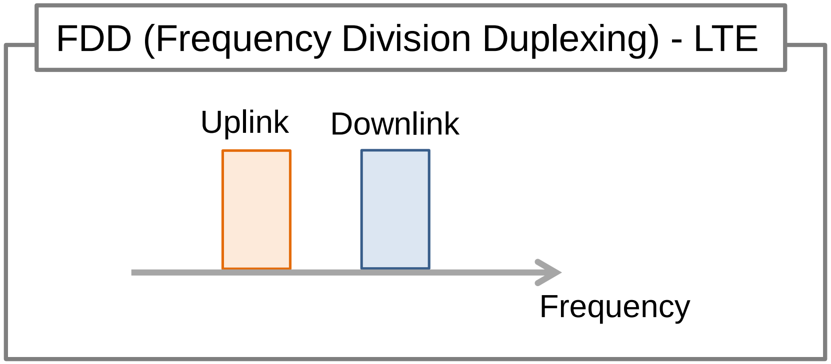
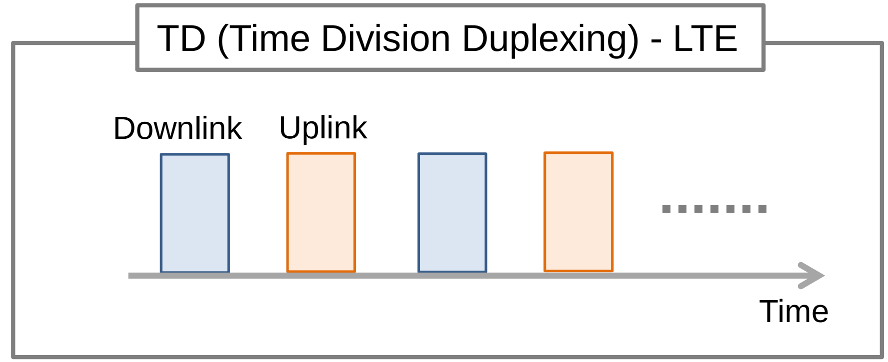
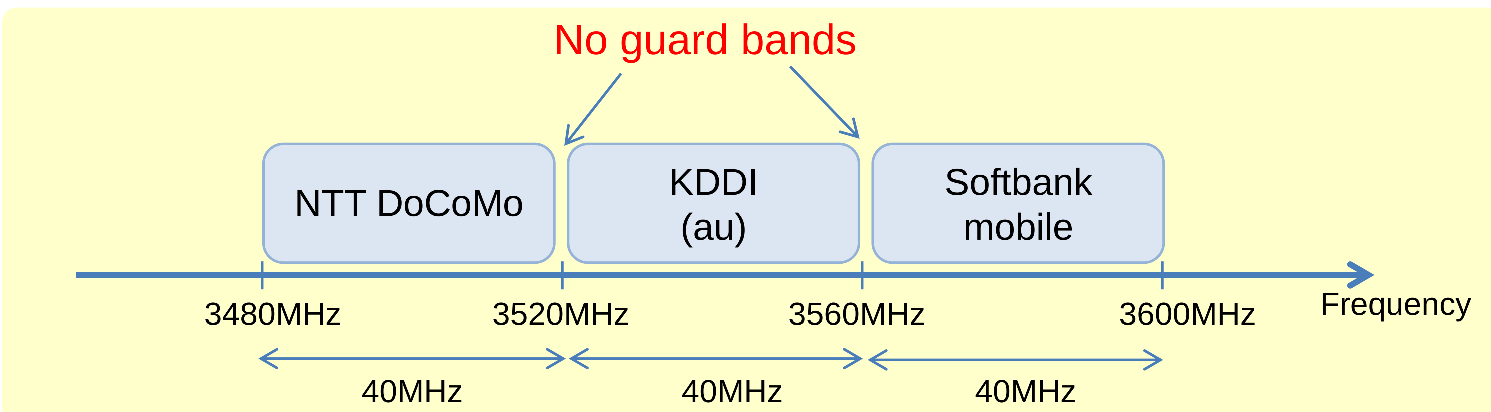
# TD-LTE Mobile Communication Services in Japan






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

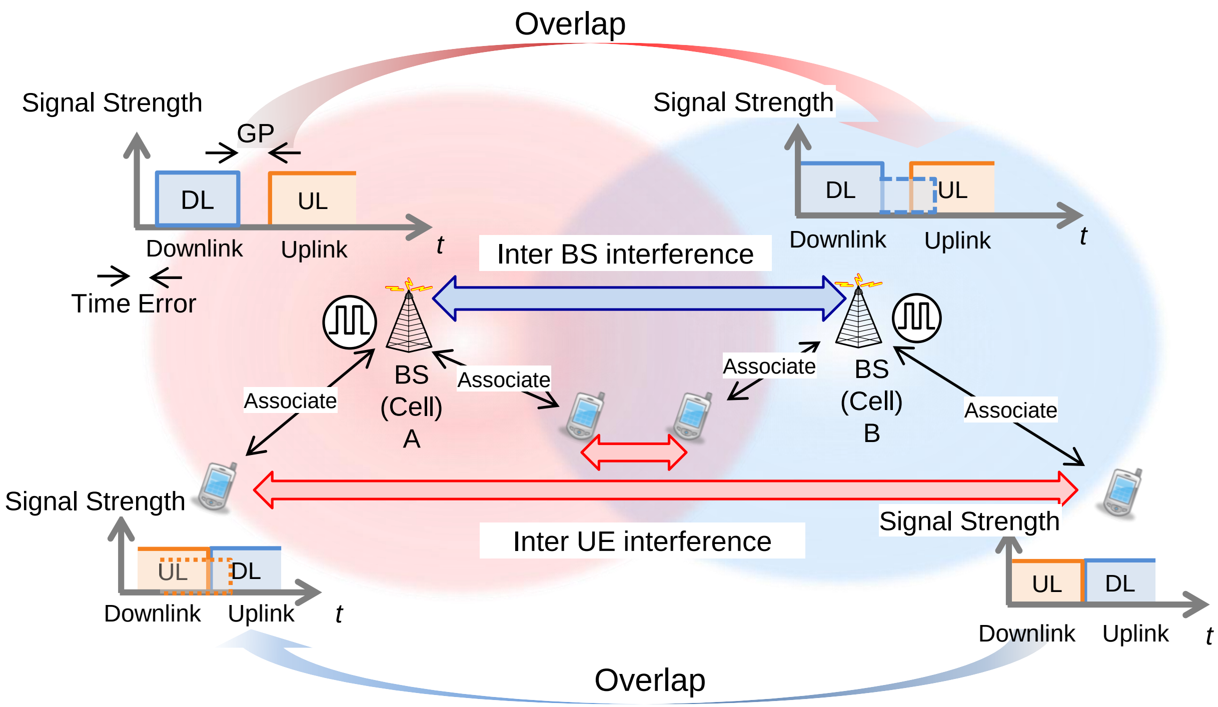



High speed mobile communication services with up to 788 Mbps downlink has already been provided with the inter-band carrier aggregation based on C-RAN (Centralized RAN) architectures.

# 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




Inter BS interference    Inter UE interference

BS : Base station   UE : User Equipment

If

Guard Period (GP) < Time Error + Transmission Delay

(2 x 3.3 x Cell Radius[m])[ns]

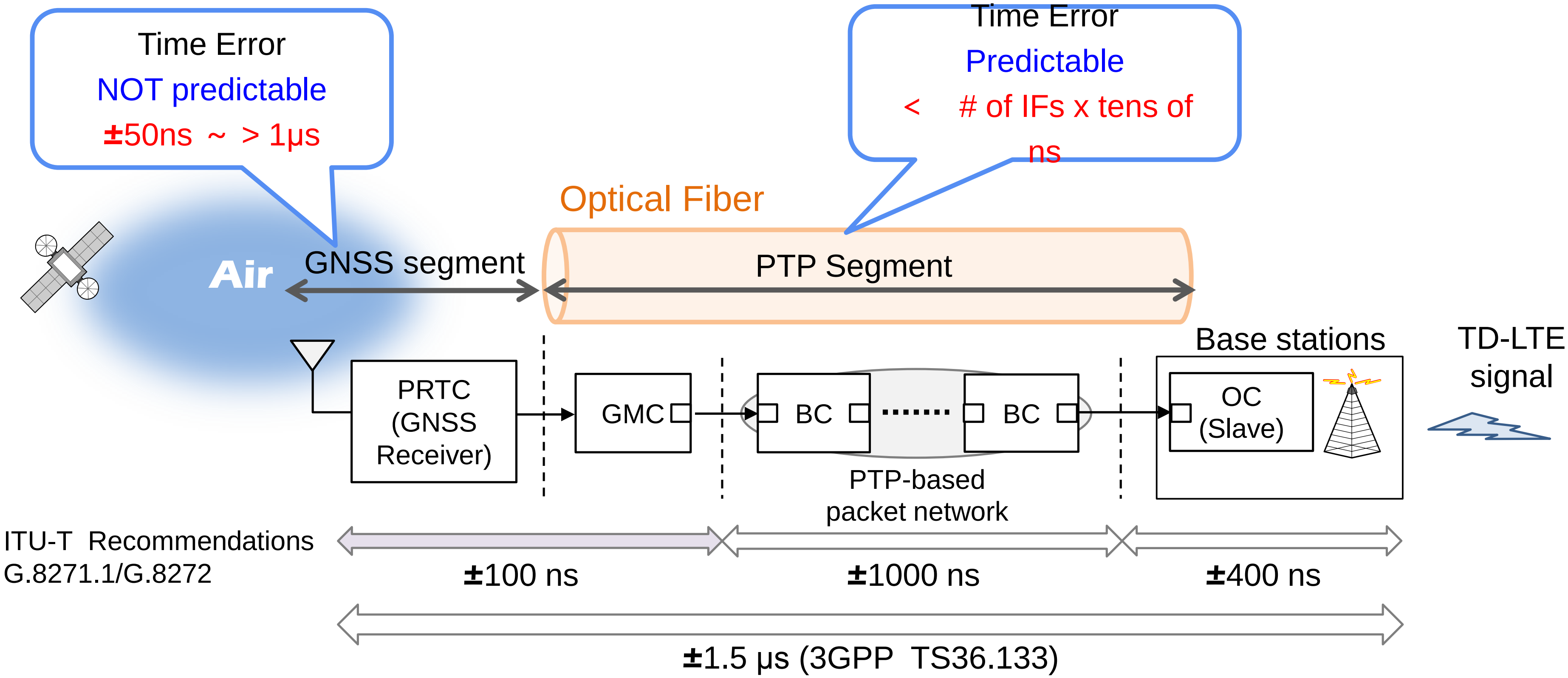
Then,
Interference occurs

Time synchronization between mobile base stations is required to be within ±1.5 μs

# Problems in High Precision GNSS Time Synchronization



Standardized budget assignment of time errors in mobile communication systems




**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

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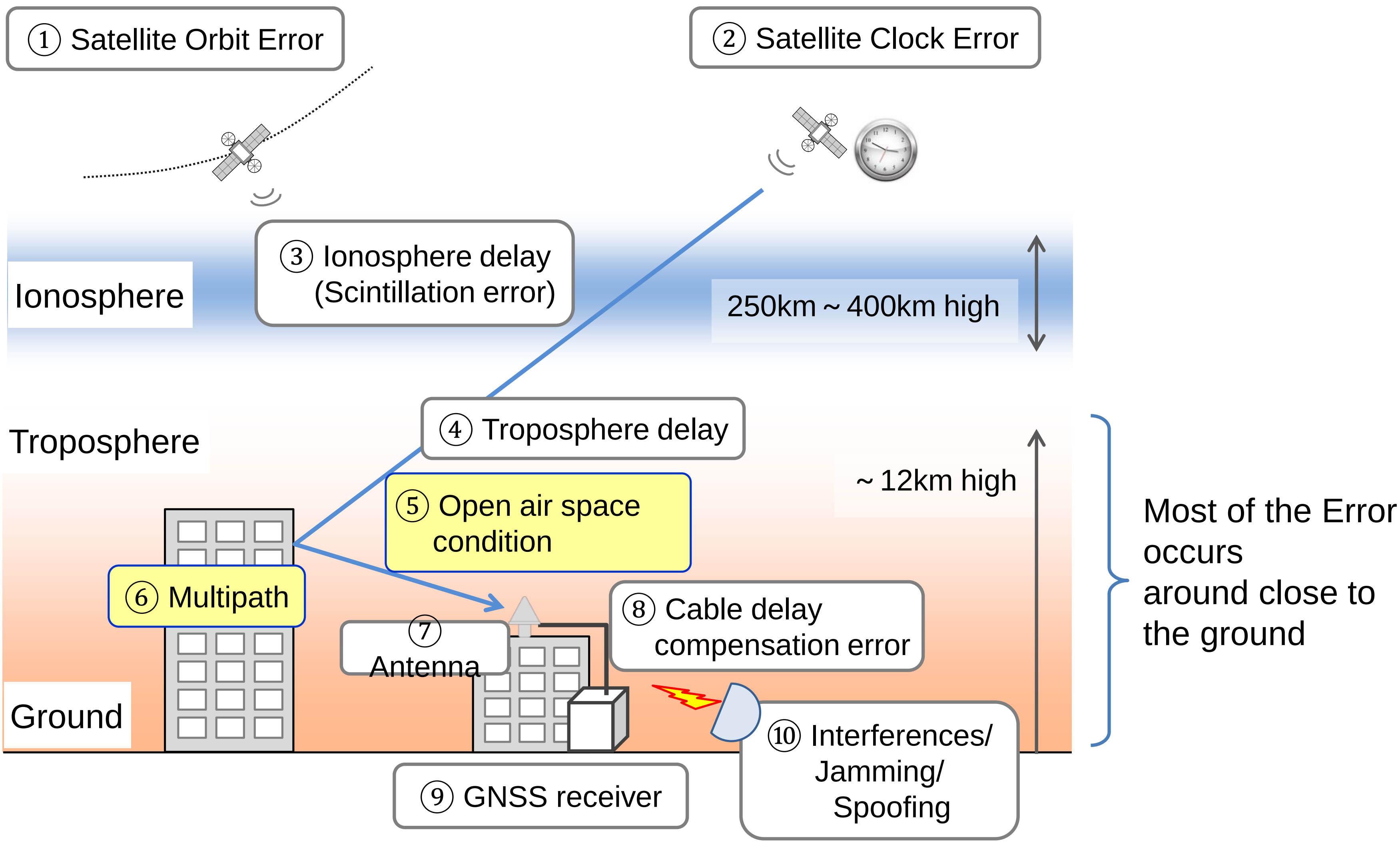
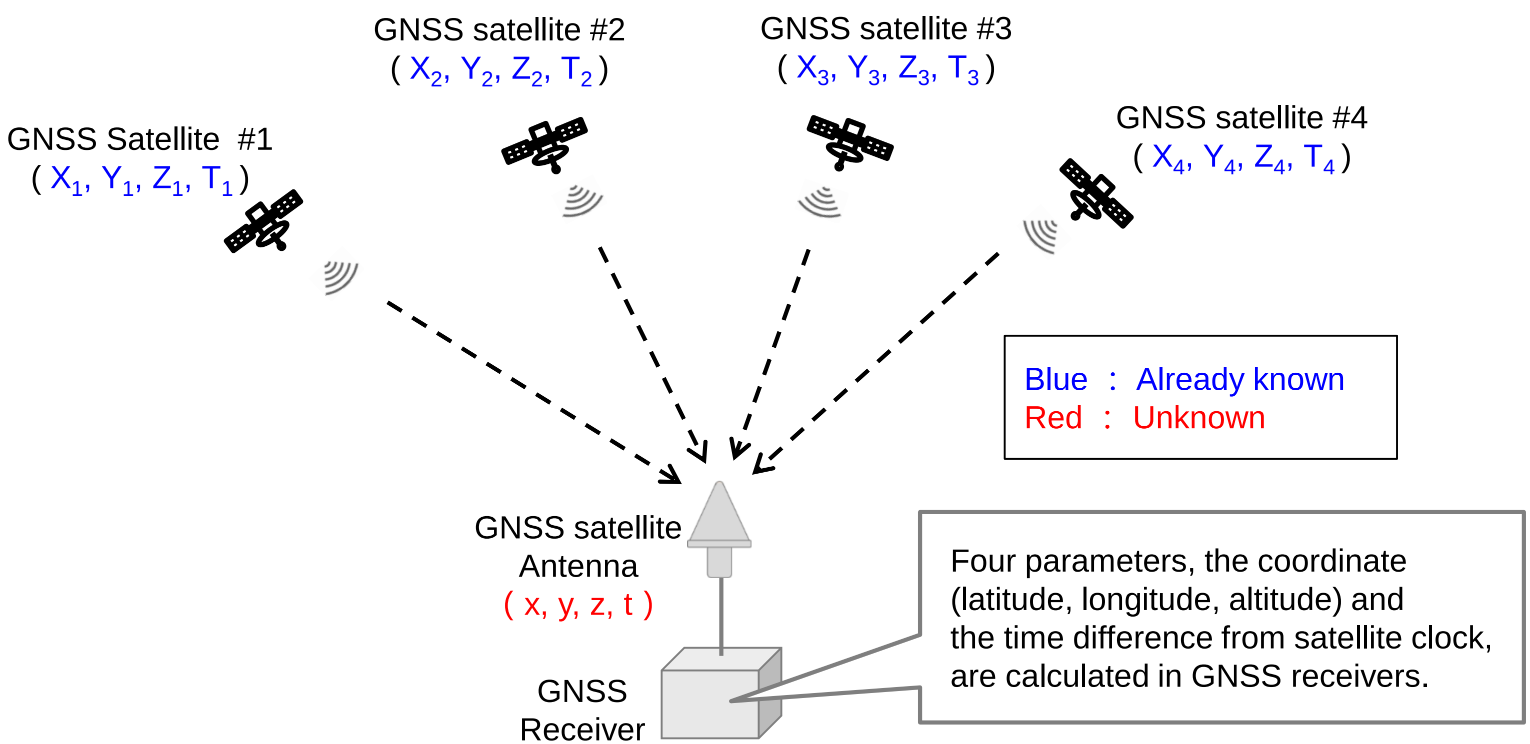


# Time Synchronization with GNSS

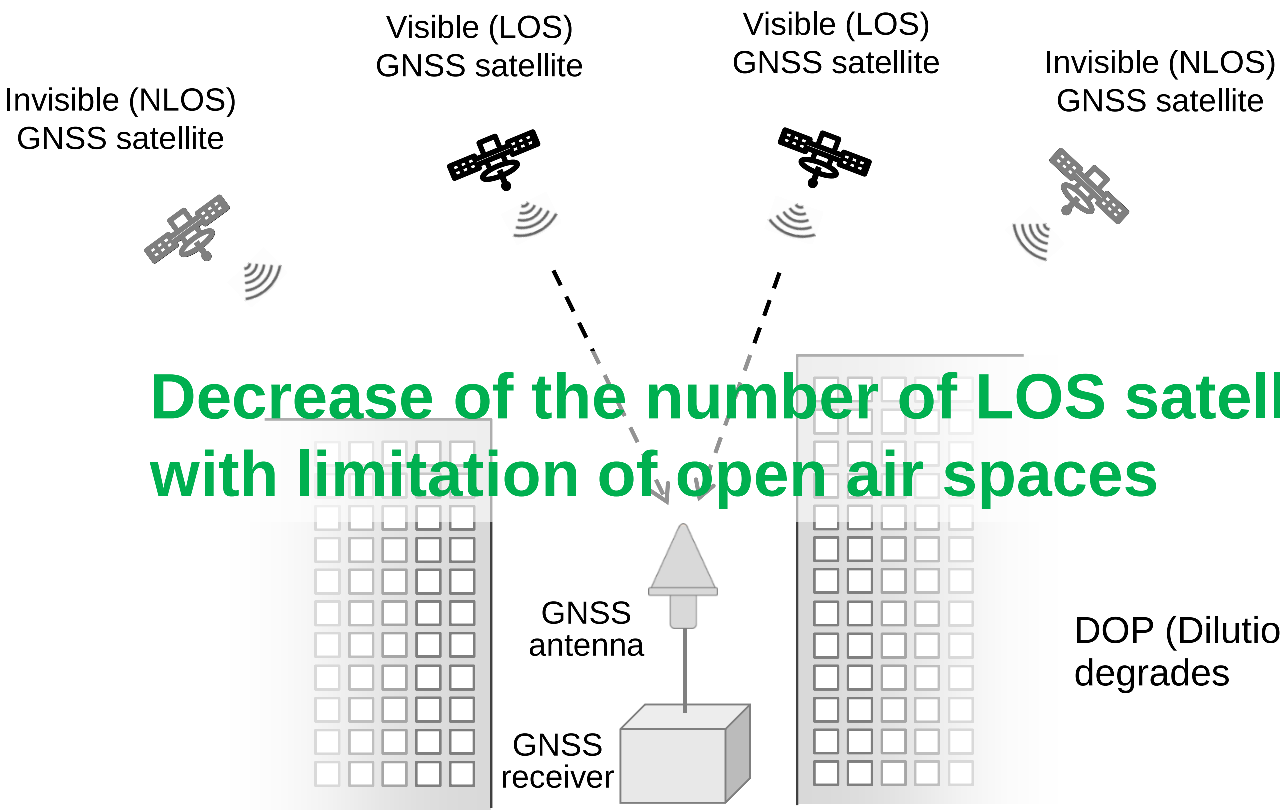


- By receiving more than four satellite signals simultaneously by GNSS receivers, four unknown parameters, three-dimensional position and time, can be calculated.
- In that sense, positioning and time synchronization in GNSS receivers are a set of the processing.



# Reduction of Number of LOS satellites with Restriction of Open Air Spaces





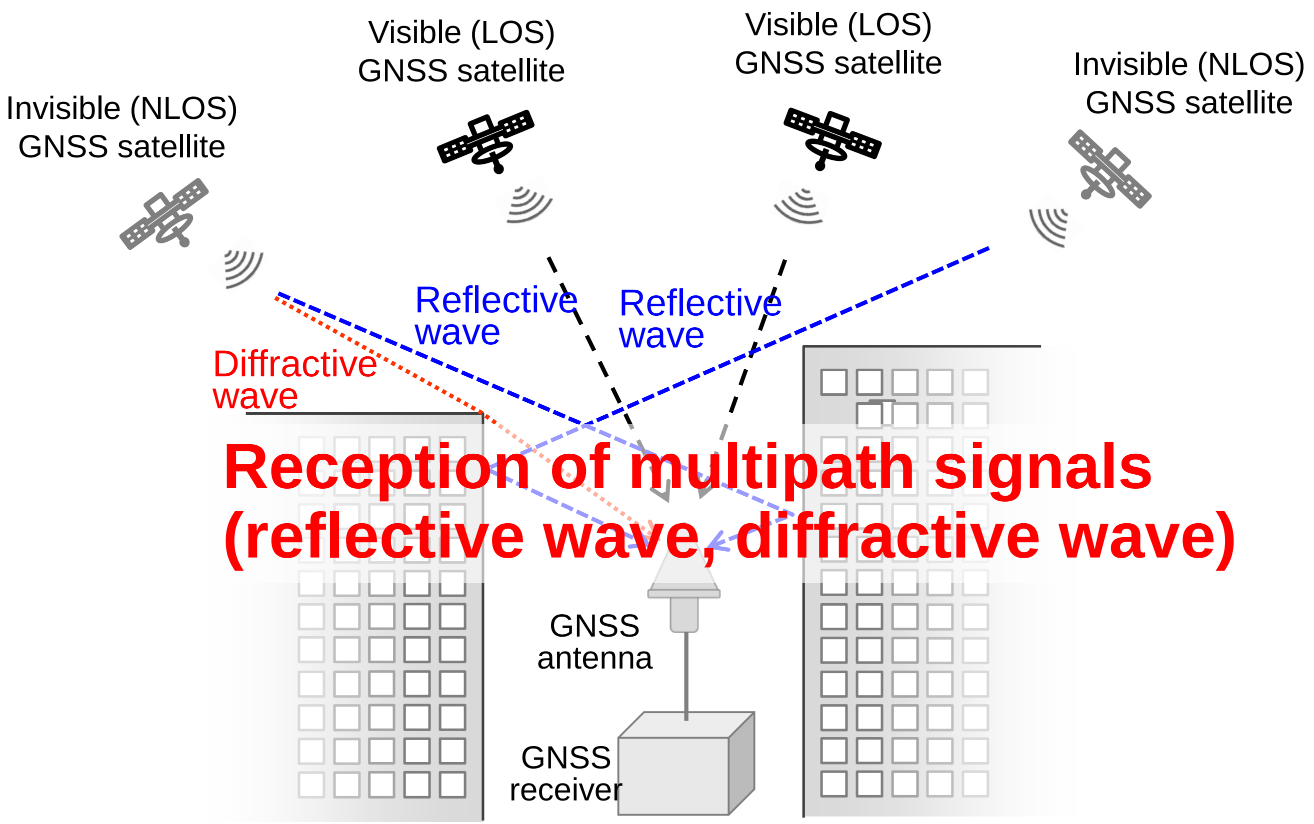

**Decrease of the number of LOS satellites with limitation of open air spaces**

DOP (Dilution Of Precision) degrades

# Reception of Multipath Signals



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.



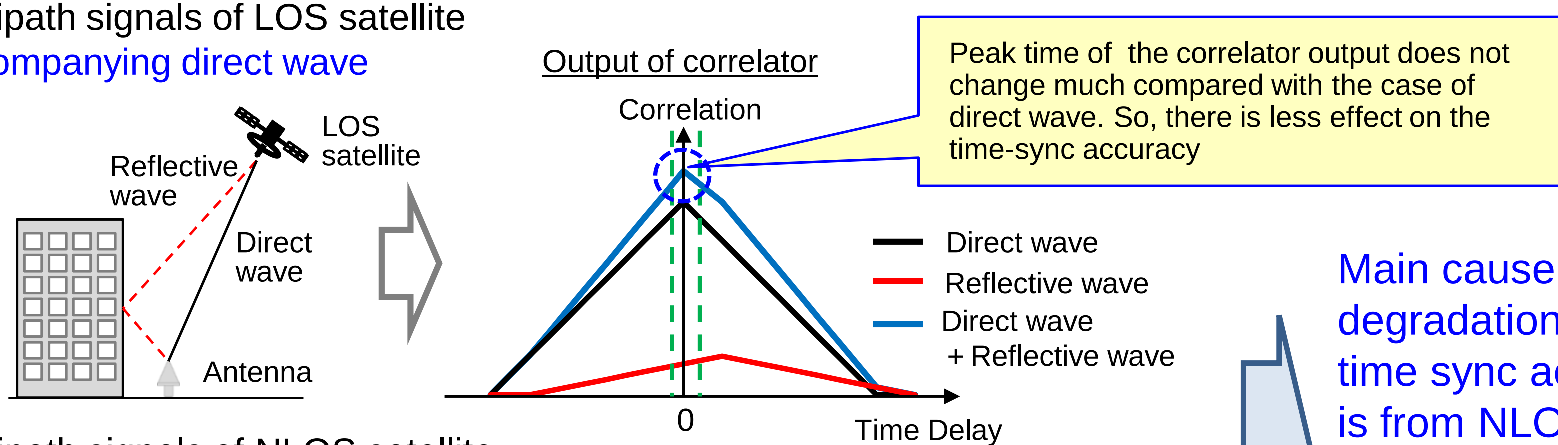
# Effect of Multipath Signals on the Accuracy in GNSS Time Synchronization



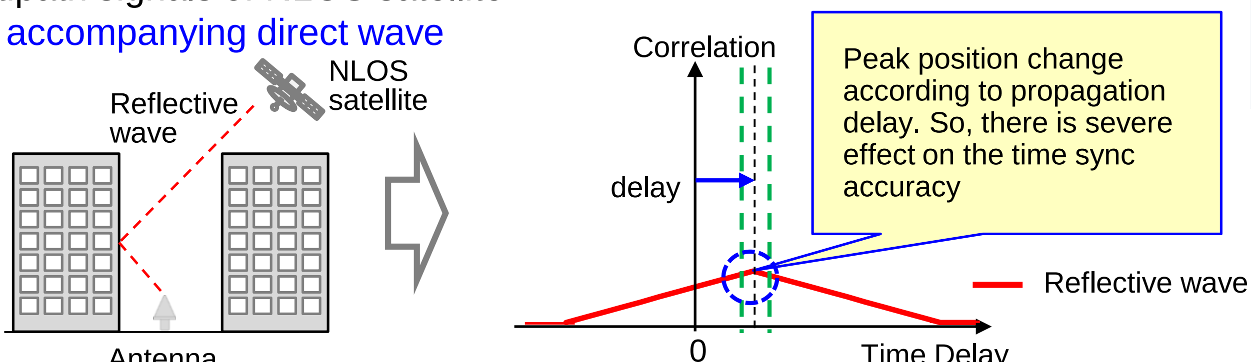


Influence of multipath signals on the time-sync accuracy is different between LOS satellites and NLOS satellites. Effect of LOS multipath signals can be removed effectively in correlators, but that of NLOS multipath signals can only be removed by not using (filtering out) NLOS satellite signals.

(A) Multipath signals of LOS satellite
accompanying direct wave




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



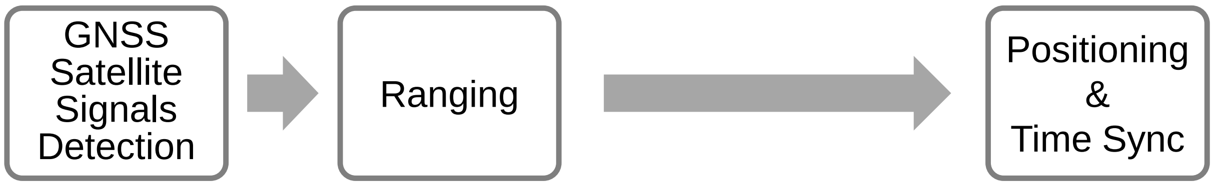

Main cause of degradation of the time sync accuracy is from NLOS multipath signals.

Effectively removing mutipath signals of NLOS satellites is ESSENTIAL.

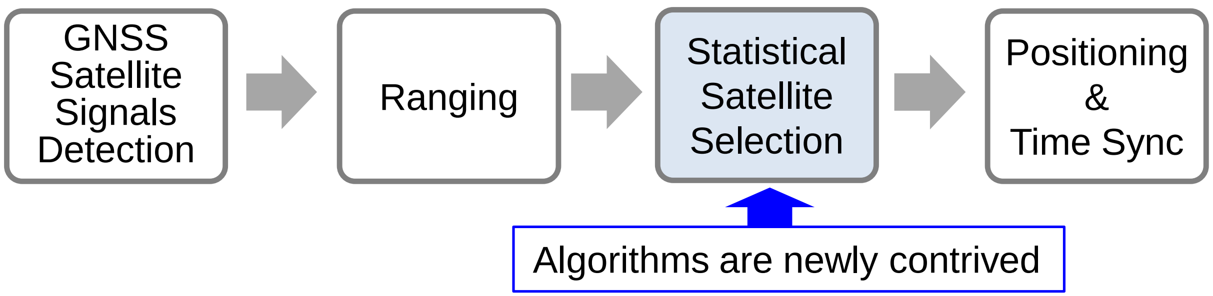
# Statistical Satellites Selection Algorithm (1)



- Signal processing in conventional GNSS receivers




- Signal processing in GNSS receivers with statistical satellite selection




**Select appropriate GNSS satellite signals through statistical satellite selection algorithms**

# Statistical Satellites Selection Algorithm (2)

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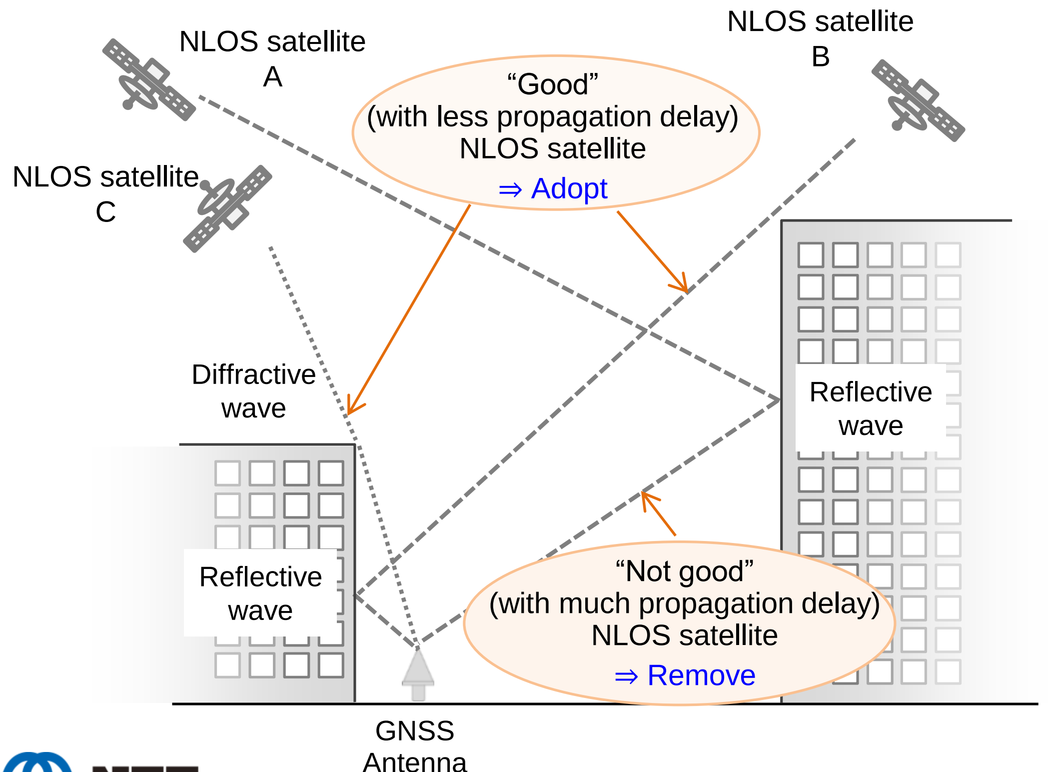
- Our contrived algorithms select few LOS satellites for sure in urban canyon reception environments where open air spaces are limited and number of LOS satellites is reduced.
- If number of LOS satellites is less than four, the algorithm select minimum “good” NLOS satellites signal complementally with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

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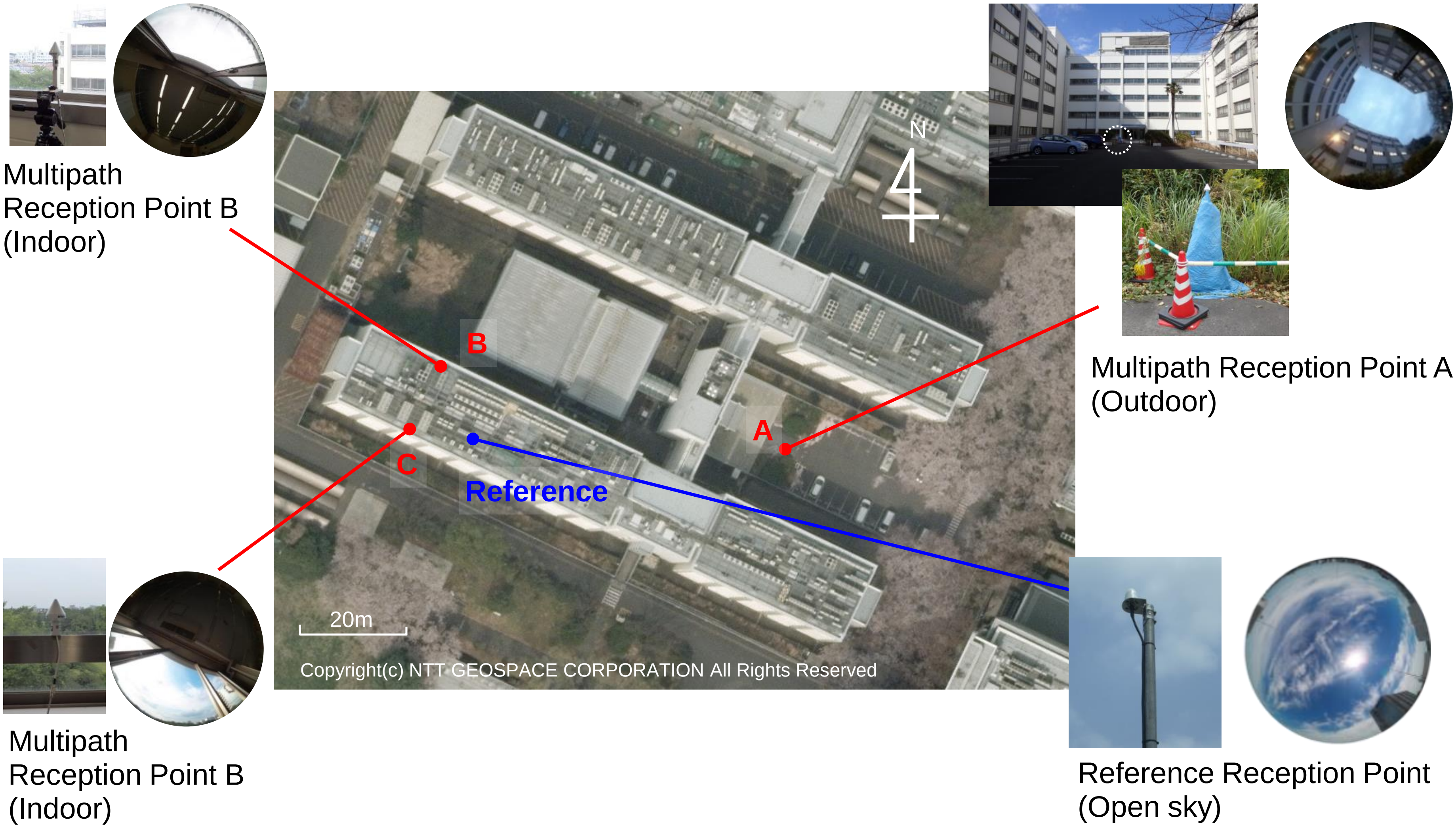
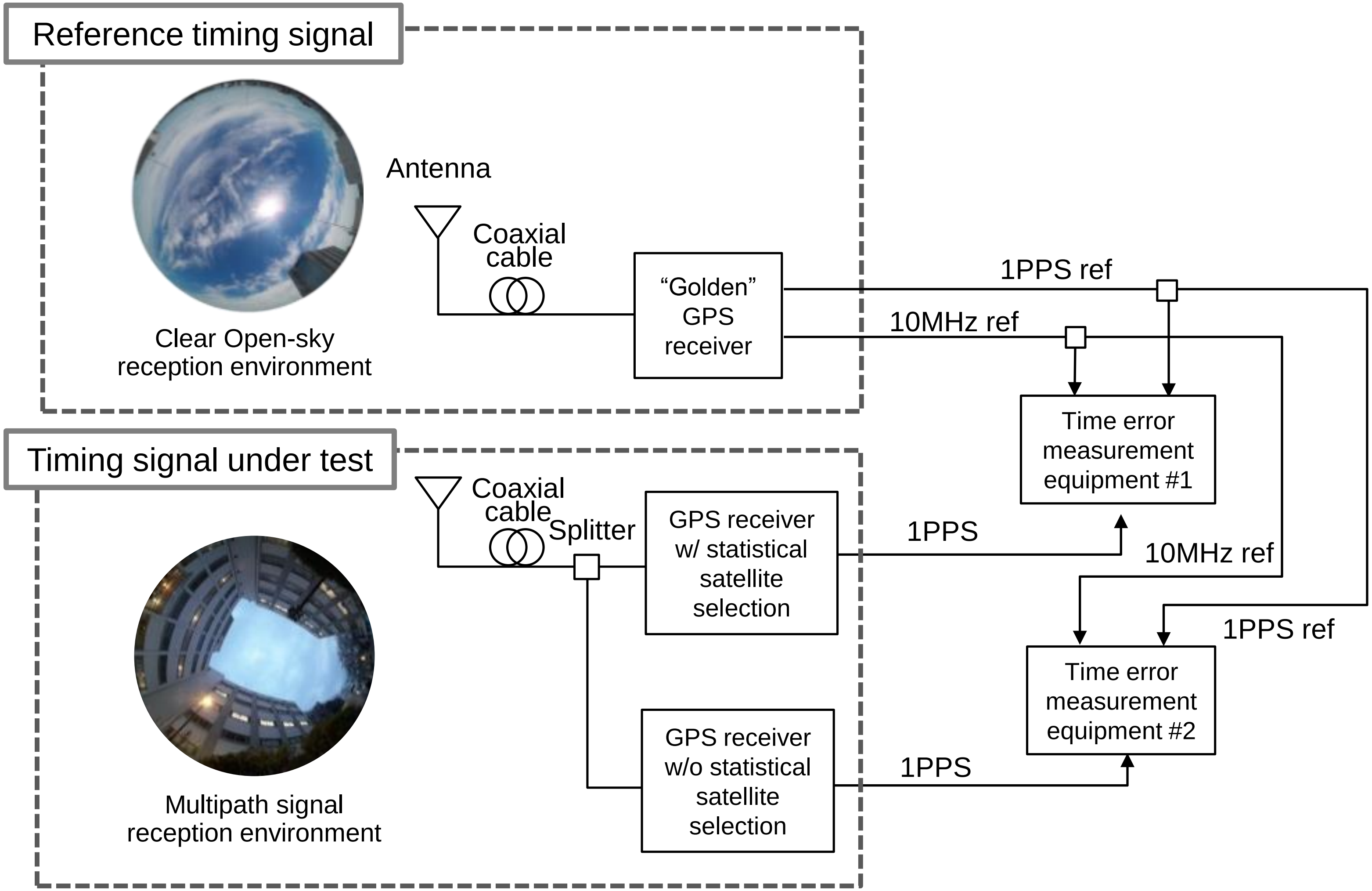
# Model Environments of Multipath Reception for Experimental Evaluation





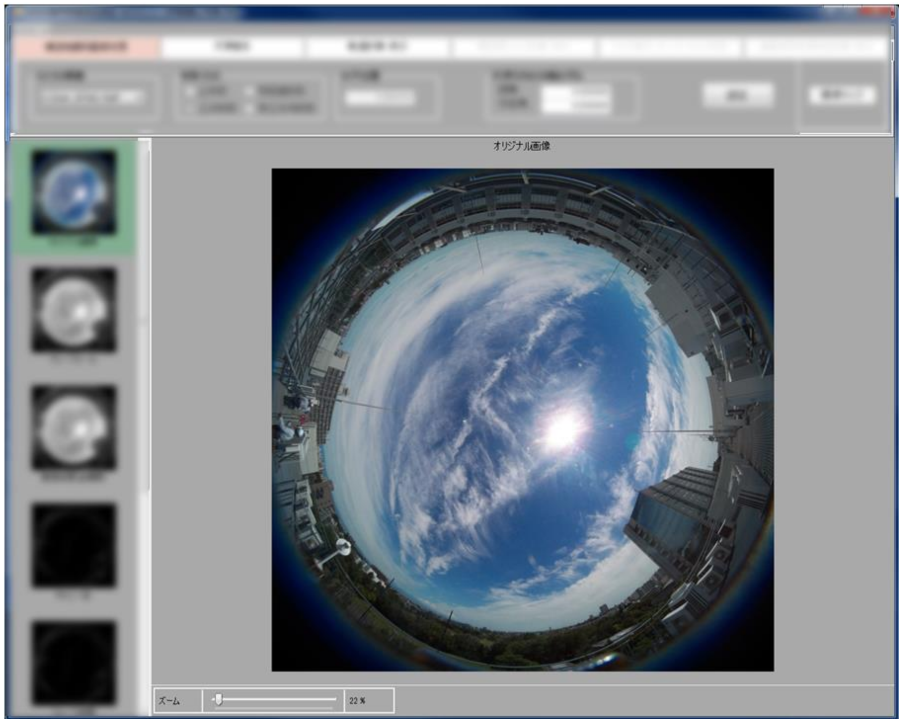
# Experimental setup for the performance evaluation

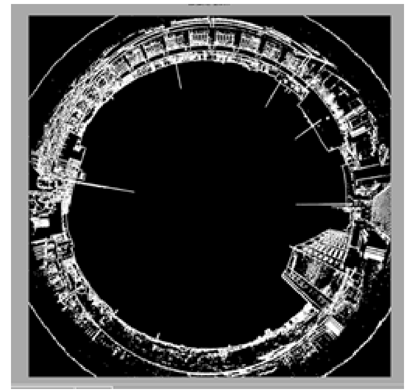


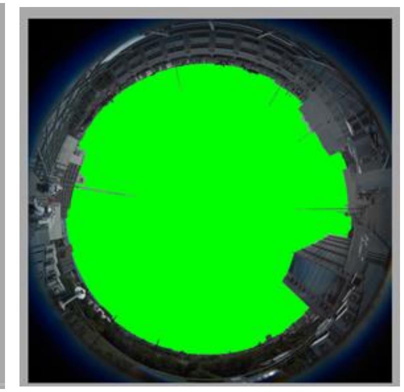


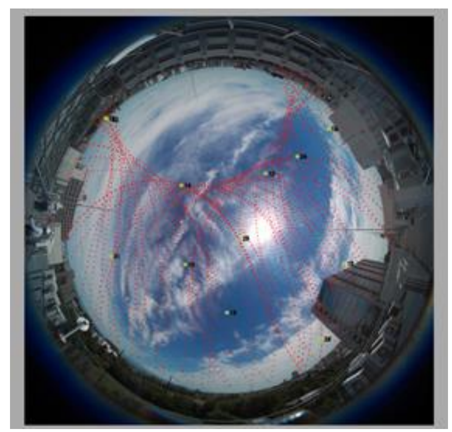
# Estimation of LOS Satellites Reception Characteristics with Sky Plot Images Taken by Fish-Eye Lens Camera

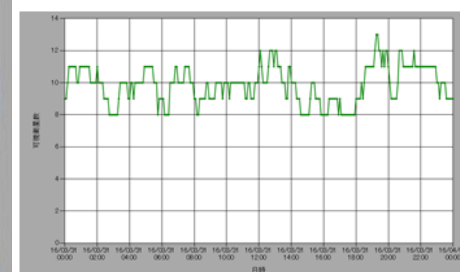






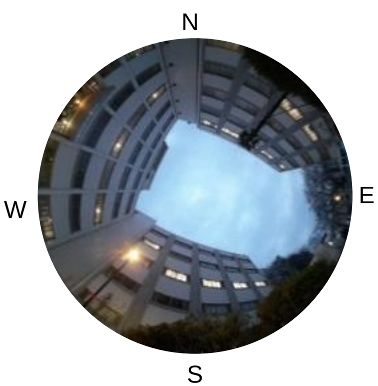


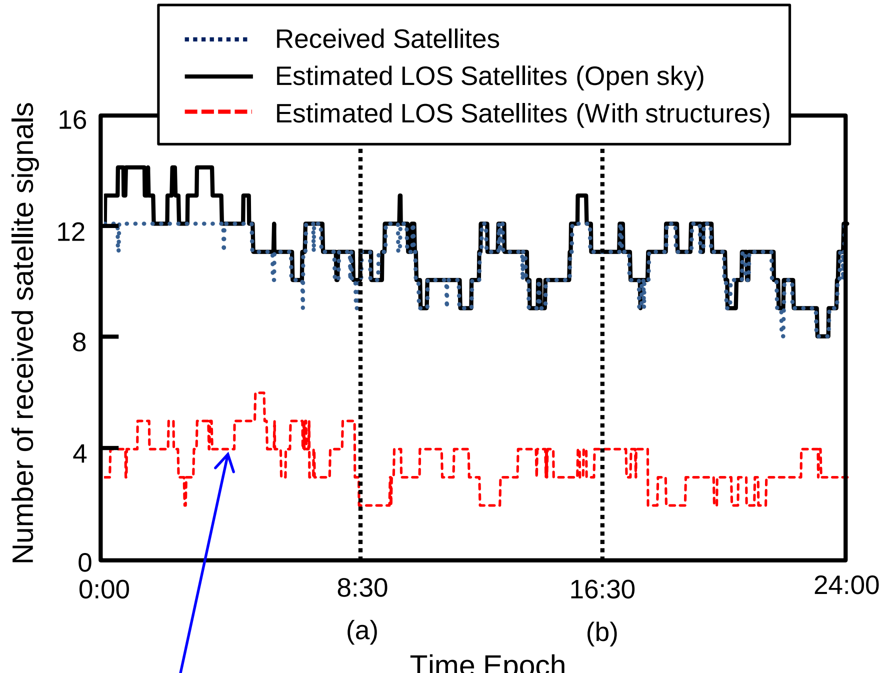


Estimated # of LOS satellites over time

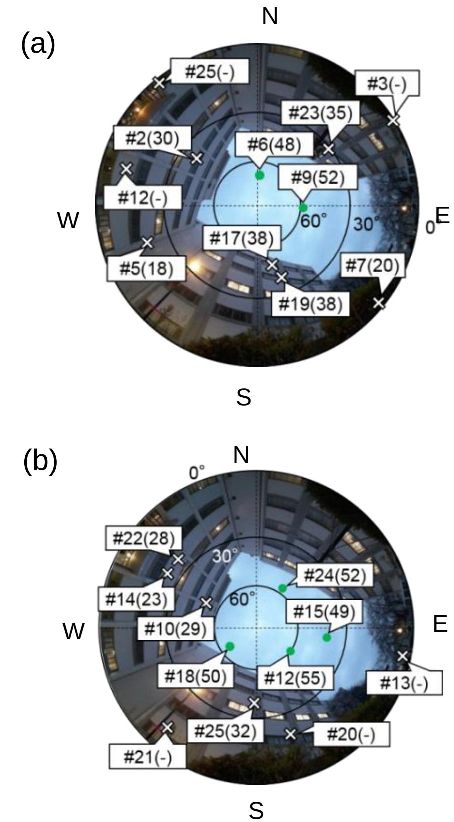
# GPS Satellites Signals Reception Characteristics @ Multipath Signals Reception Point A






Estimated number of LOS satellites




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

# Measured Time Error Comparison @ Multipath Reception Point A

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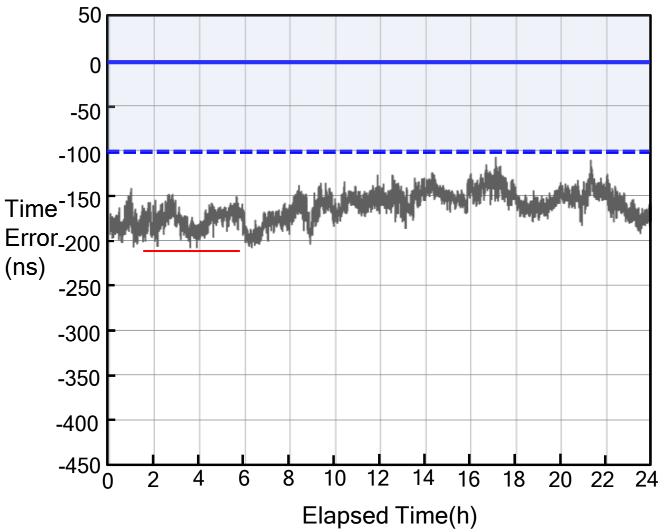
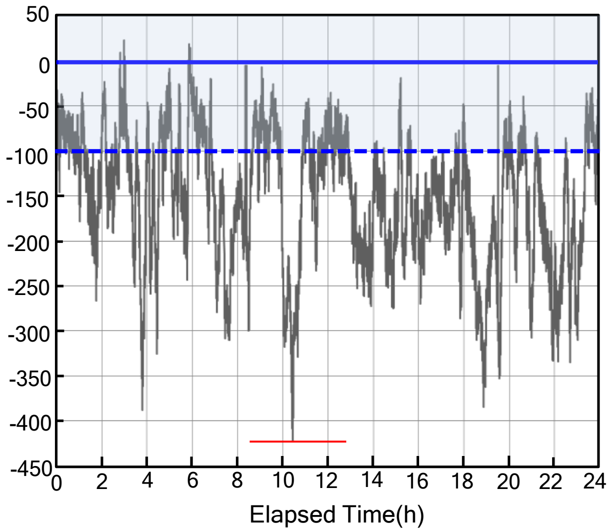
Time Errors measured with commercial GNSS receiver modules with the reception of GPS satellites without elevation nor SNR mask

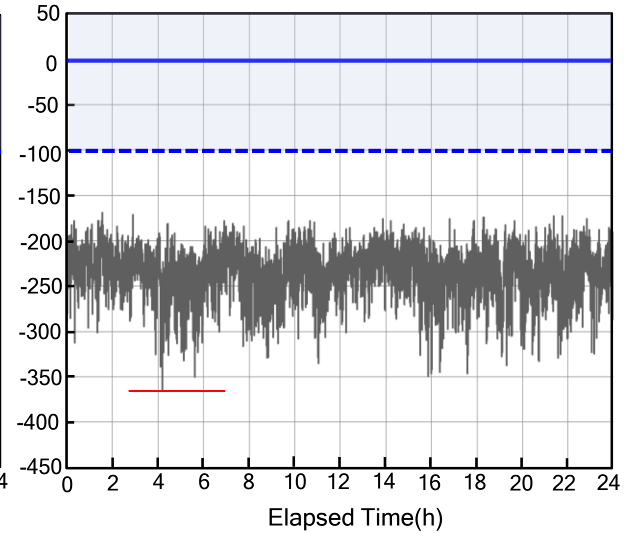
Receiver module A




Receiver module B




Receiver module C




Max|TE| = 208 ns

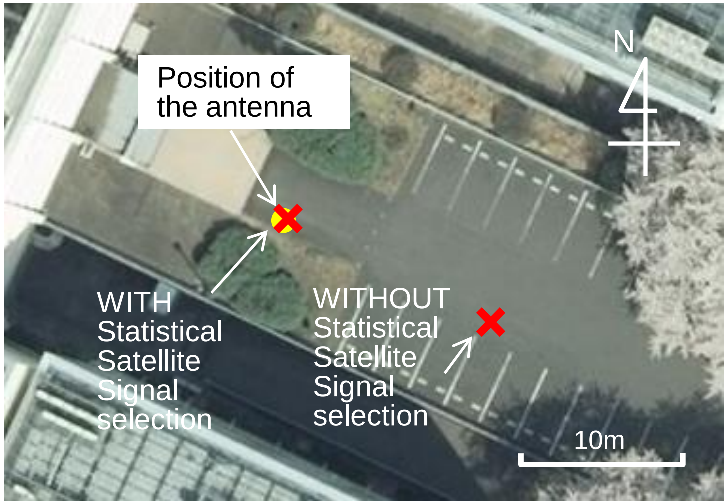
Max|TE| = 422 ns

Max|TE| = 365 ns

# Performance Evaluation Results with the Contrived Algorithm @ Multipath Reception Point A

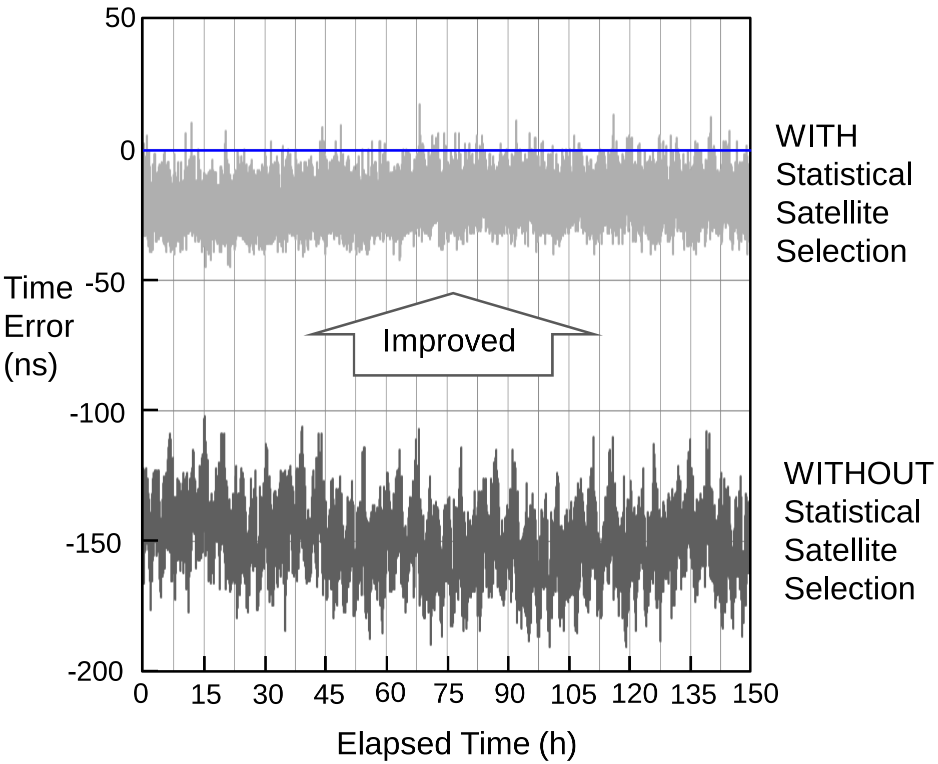


Multipath reception environments with surroundings of structures


Measured accuracy of two dimensional positioning

Measured time synchronization accuracy



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

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

| | | | |
|---|---|---|---|
| #2(48) | #5(50) | #6(19) | #7(35) |
| #13(52) | #15(26) | #29(25) | #30(49) |

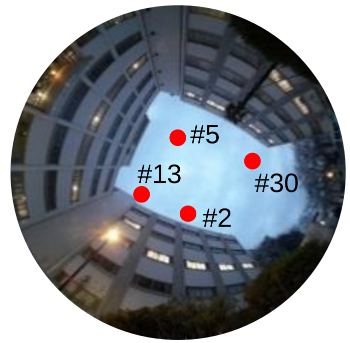
(b) 2017/1/10 15 : 29 : 57 JST

| | | | |
|---|---|---|---|
| #10(37) | #12(53) | #13(26) | #14(24) |
| #15(48) | #18(49) | #19(27) | #20(20) |
| #21(14) | #24(48) | #25(28) | #32(28) |

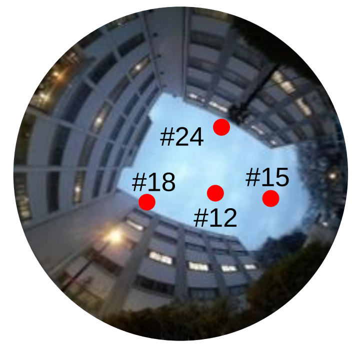
(c) 2017/1/10 20 : 50 : 31 JST

| | | | |
|---|---|---|---|
| #14(30) | #16(34) | #21(43) | #23(33) |
| #26(52) | #27(37) | #29(27) | #31(51) |

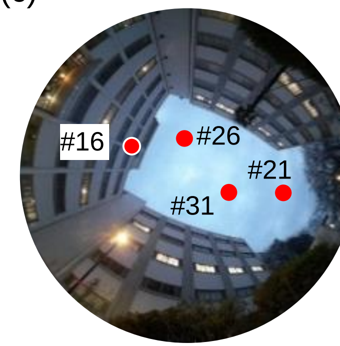
(a)




(b)




(c)




● : Selected four GPS satellites

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

# GPS Satellites Signals Reception Characteristics @ Multipath Signals Reception Point B

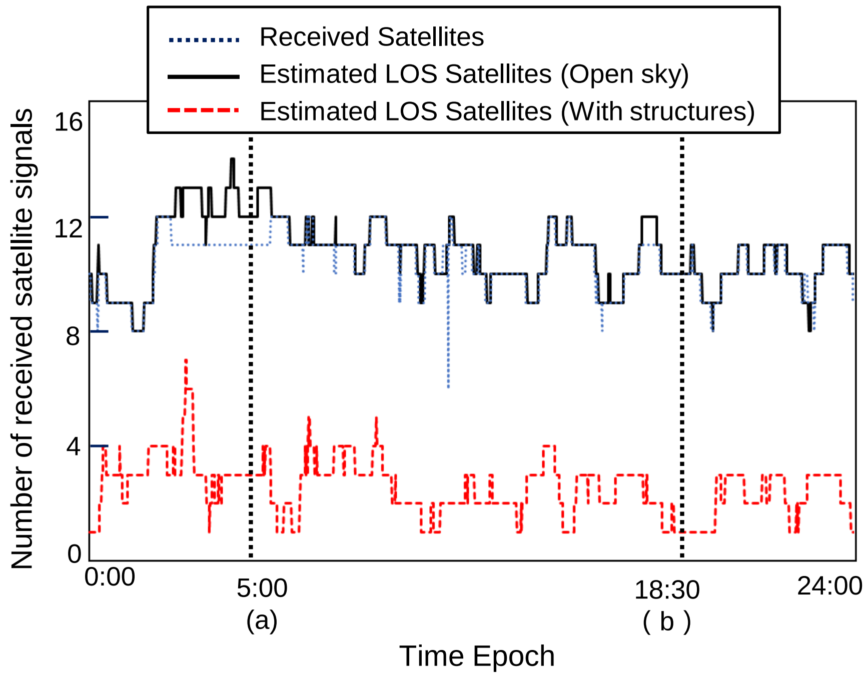
Multipath reception environment with an antenna inside the window

N

W

E

S



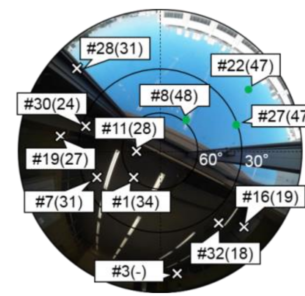

(a)

N

W

E

S



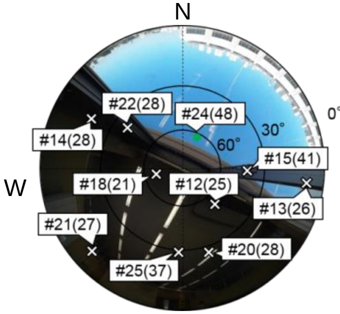

(b)

N

W

E

S

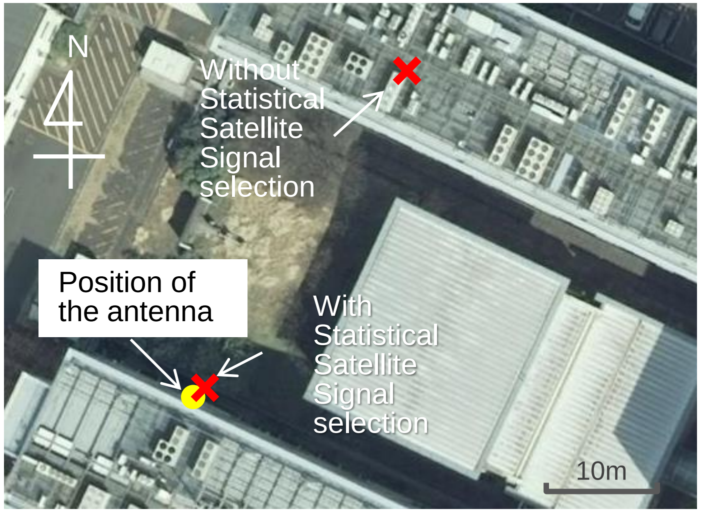



#: GPS satellite number, figure in parentheses: CNR(dB-Hz)

# Performance Evaluation Results with the Contrived Algorithm @ Multipath Reception Point B

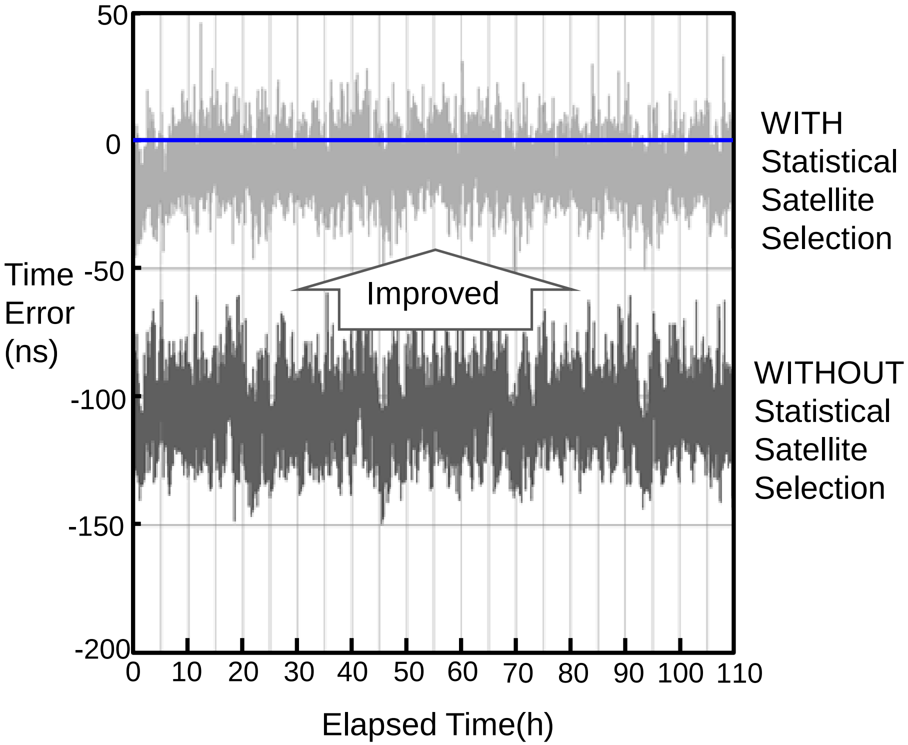


Multipath reception environment with an antenna inside the window




Measured accuracy of two dimensional positioning

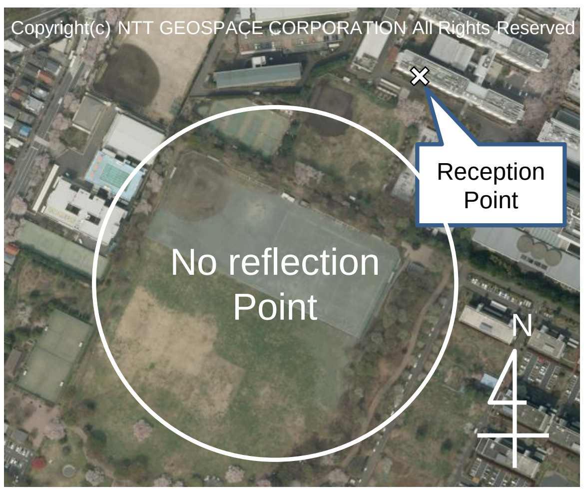
Measured time synchronization accuracy

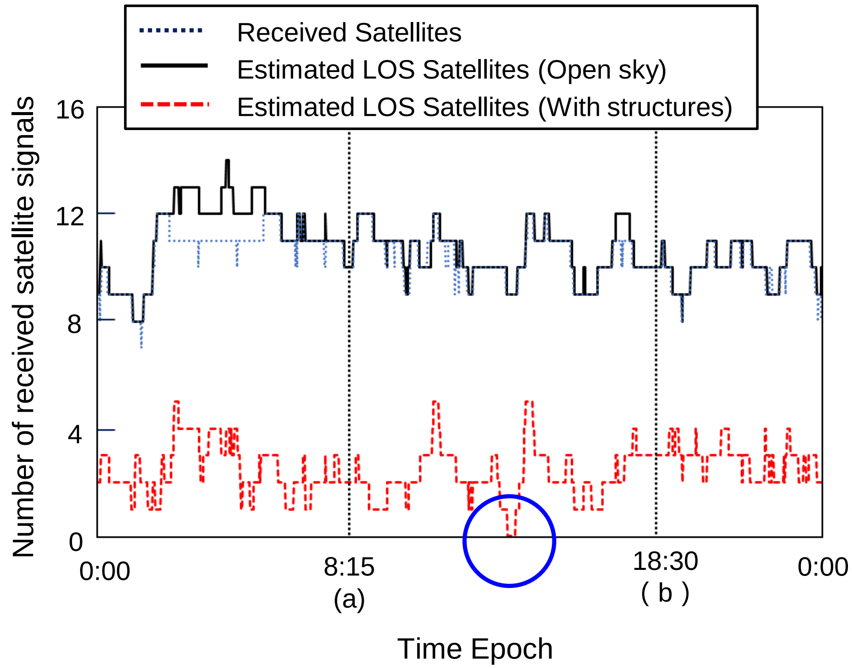


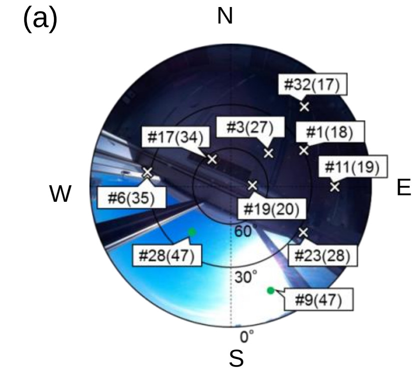
# GPS Satellites Signals Reception Characteristics @ Multipath Signals Reception Point C

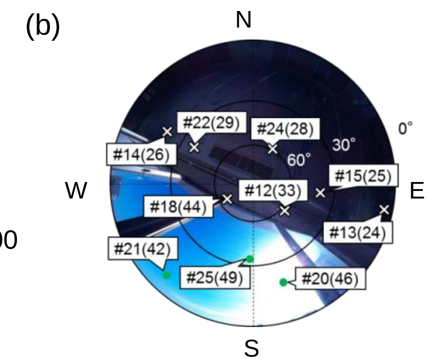


Multipath reception environment with an antenna inside the window

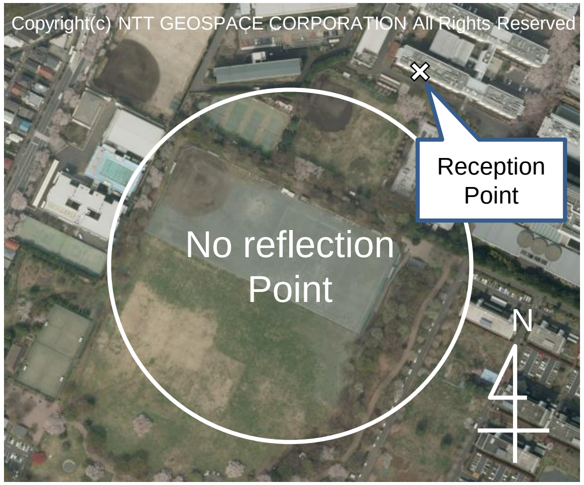



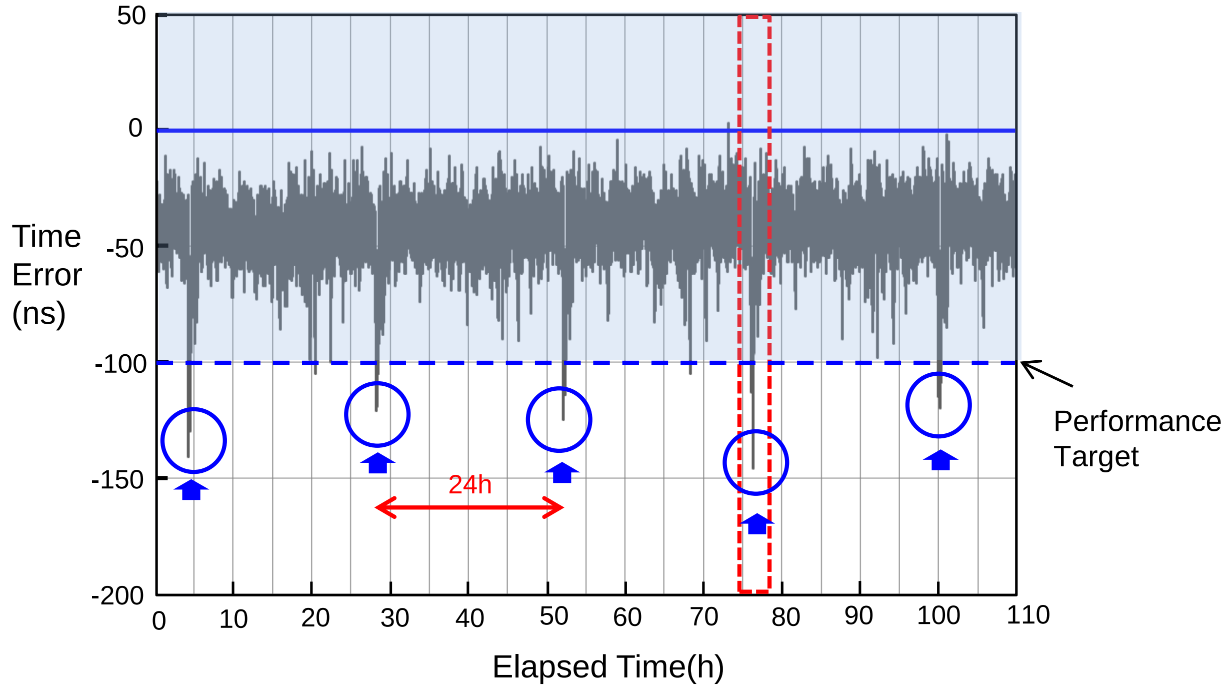

#: GPS satellite number, figure in parentheses: CNR(dB-Hz)

# Performance Evaluation Results with the Contrived Algorithm @ Multipath Reception Point C



Multipath reception environment with an antenna inside the window

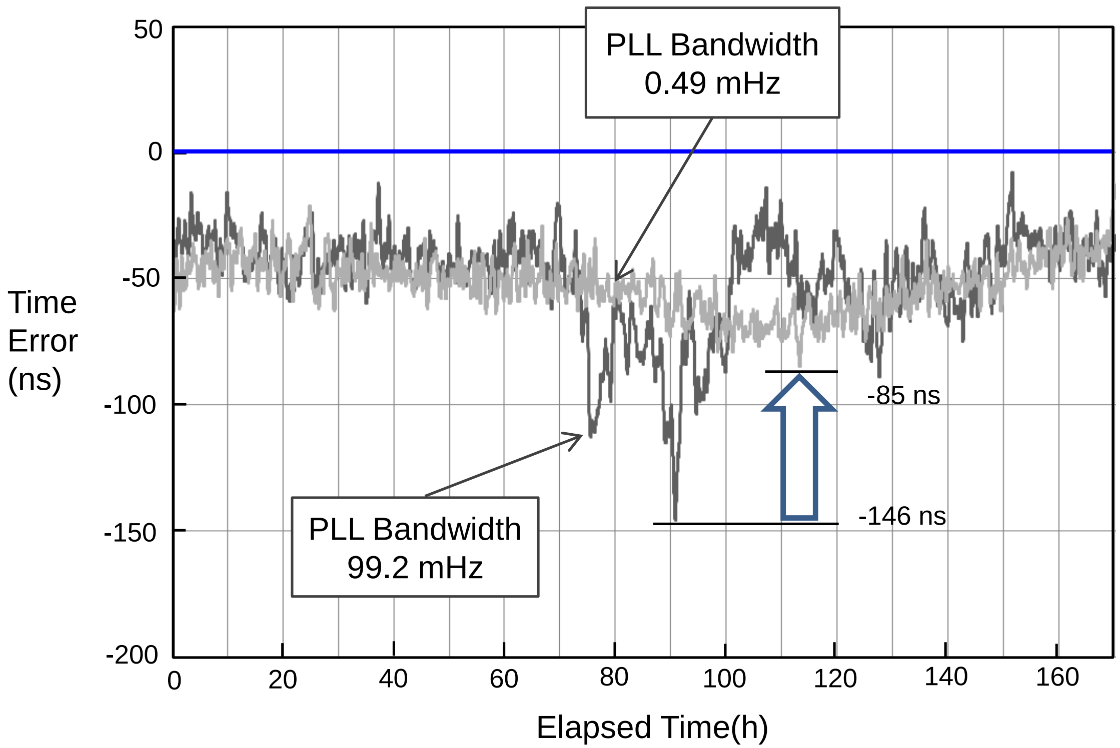



Max|TE| = 146ns

# 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 ?

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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.

Urban canyon environment

# Multipath Simulation @ Actual Signal Reception Environment

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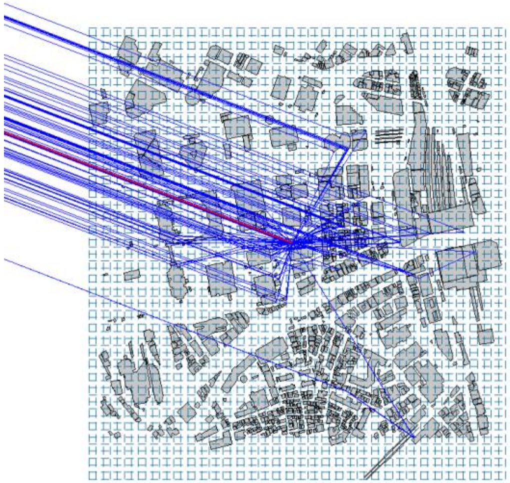
3D Map

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

Radio Propagation Analysis



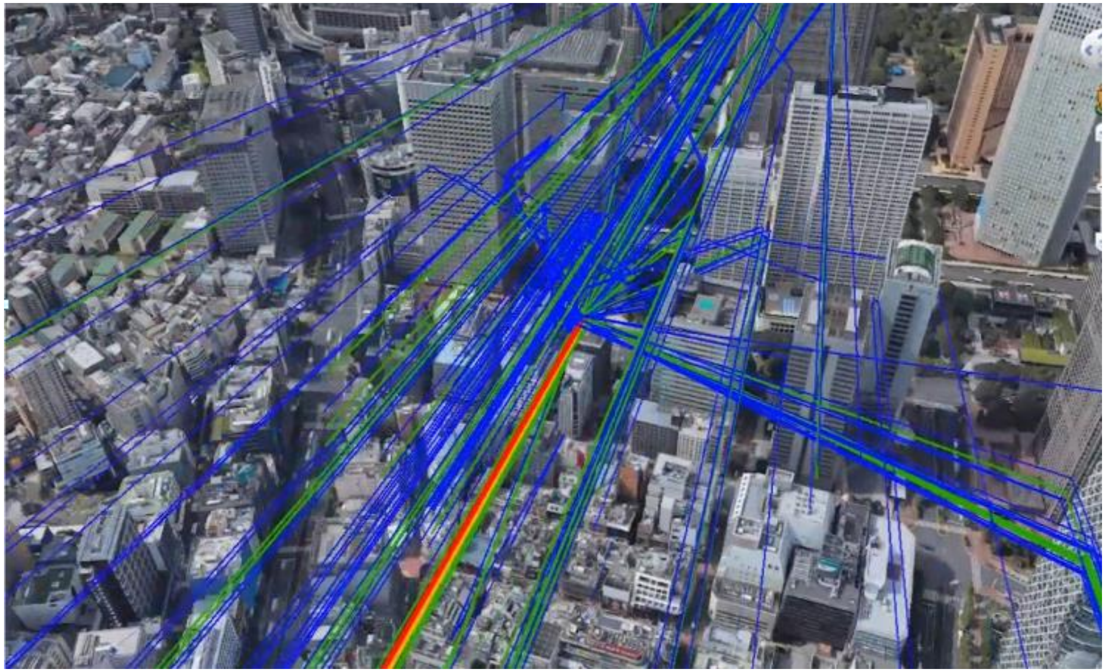
Multipath estimation with three dimensional ray-trace simulation

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

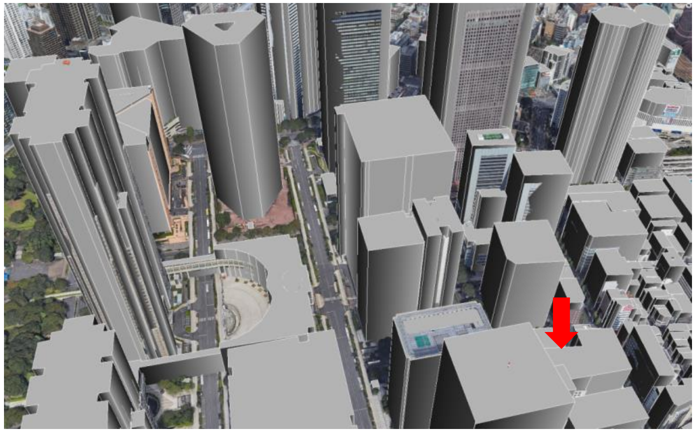




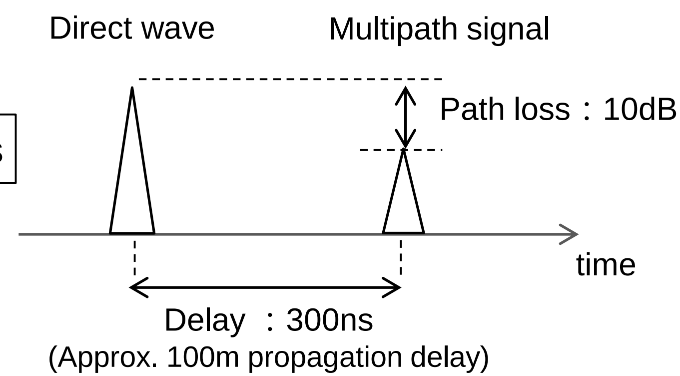
- Direct wave (red)
- Once reflected wave (orange)
- Once diffracted wave (green)
- Once reflected & once diffracted wave (blue)

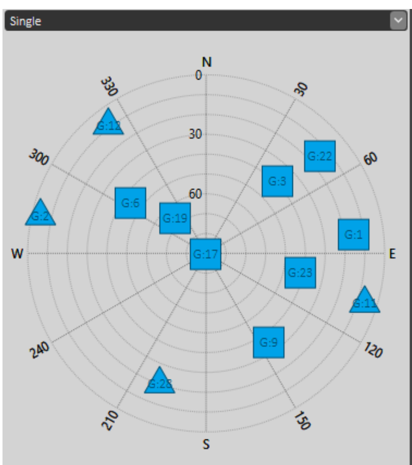
All of the multipath signal can be regenerated with SDR-based GNSS Signal Simulator

# Edit Multipath Signals



LOS Satellites



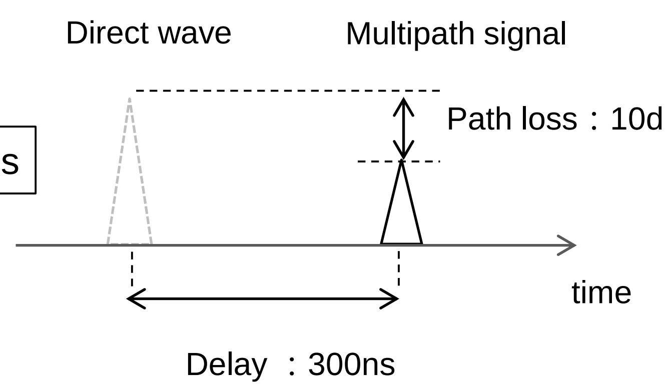




← Sky map from GNSS signal simulator

LOS Satellites

NLOS Satellites

NLOS Satellites



# Performance Evaluation Results with Edited Multipath signals (1)

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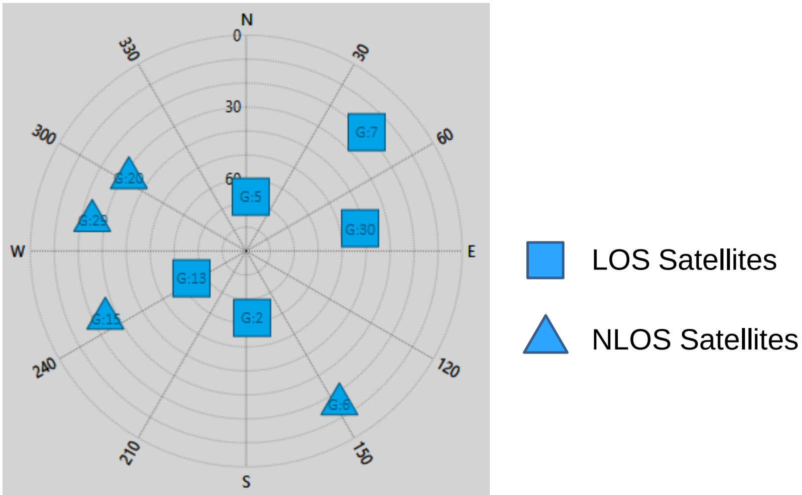
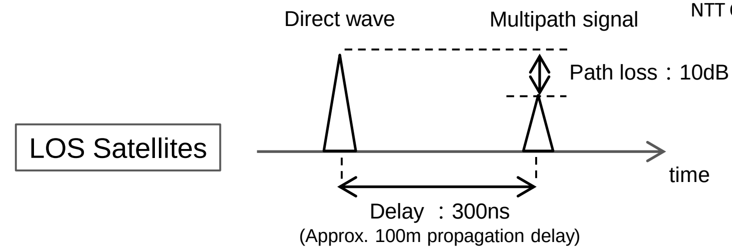
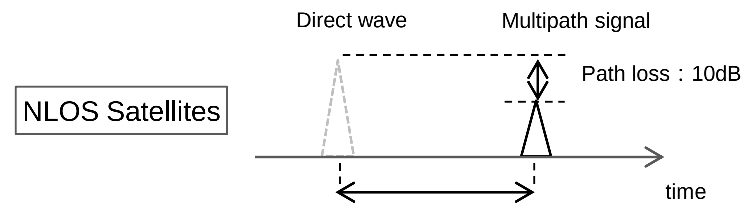
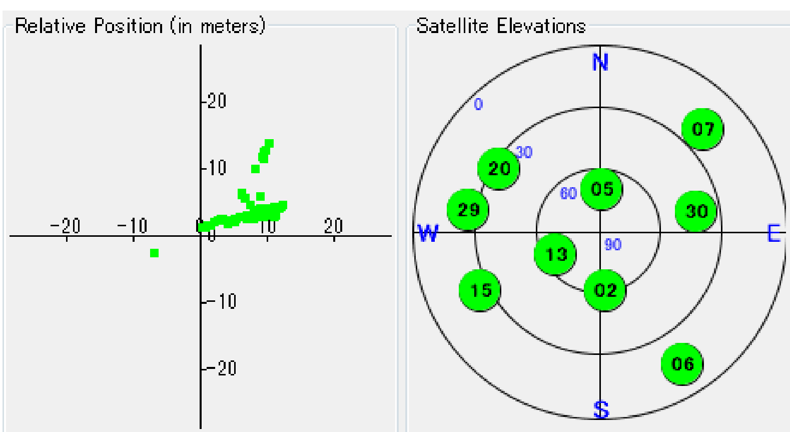
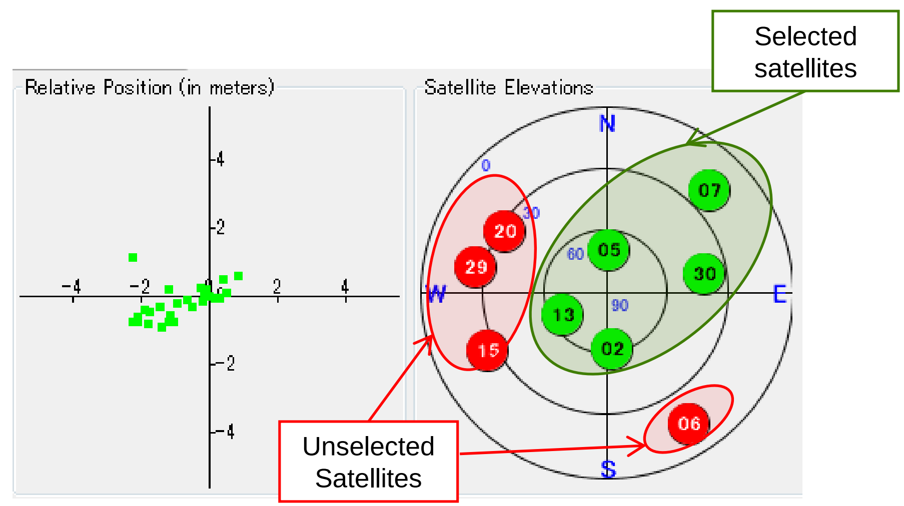


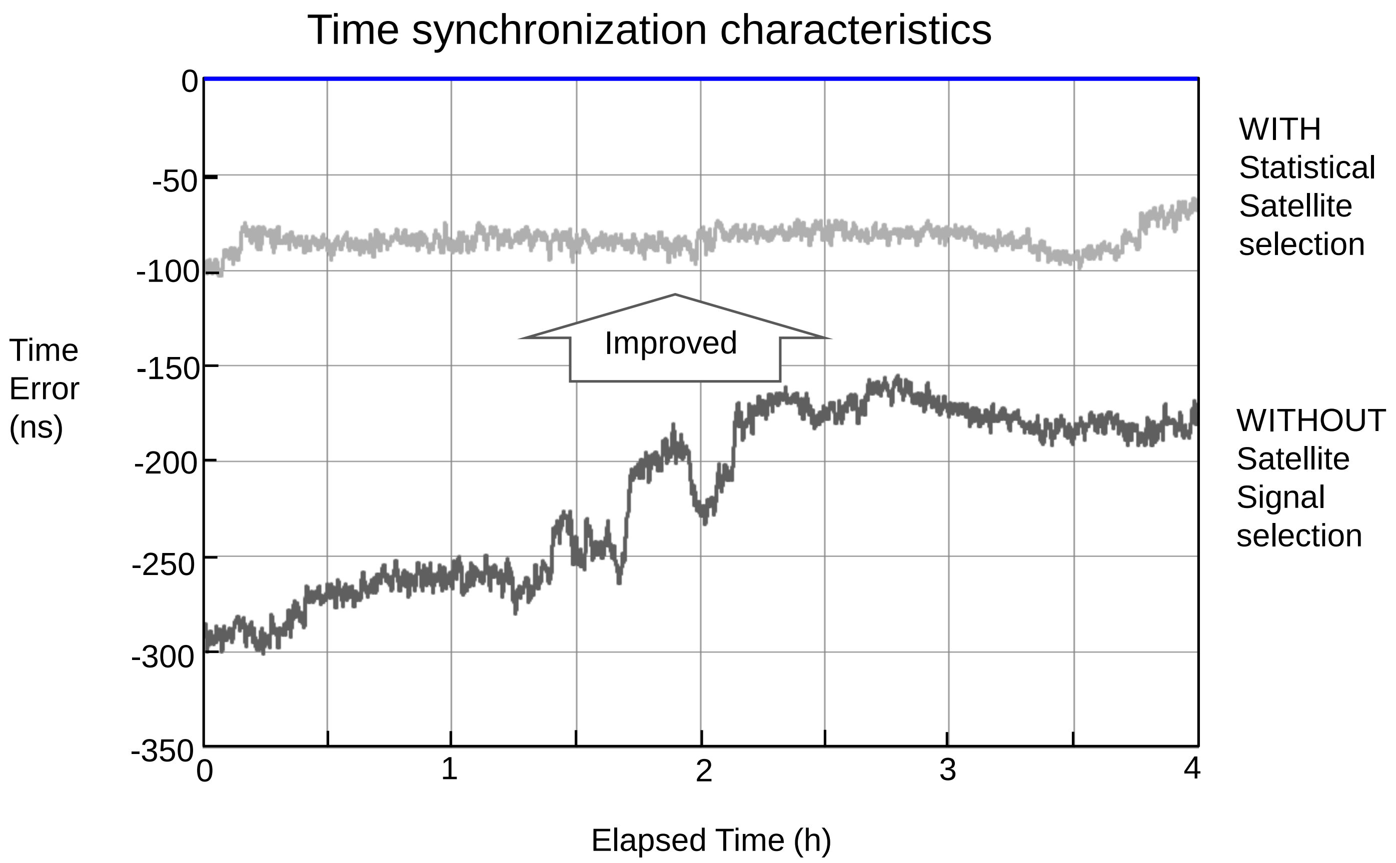

Without Statistical Satellite selection




With Statistical Satellite selection Algorithm

# Performance Evaluation Results with Edited Multipath signals (2)

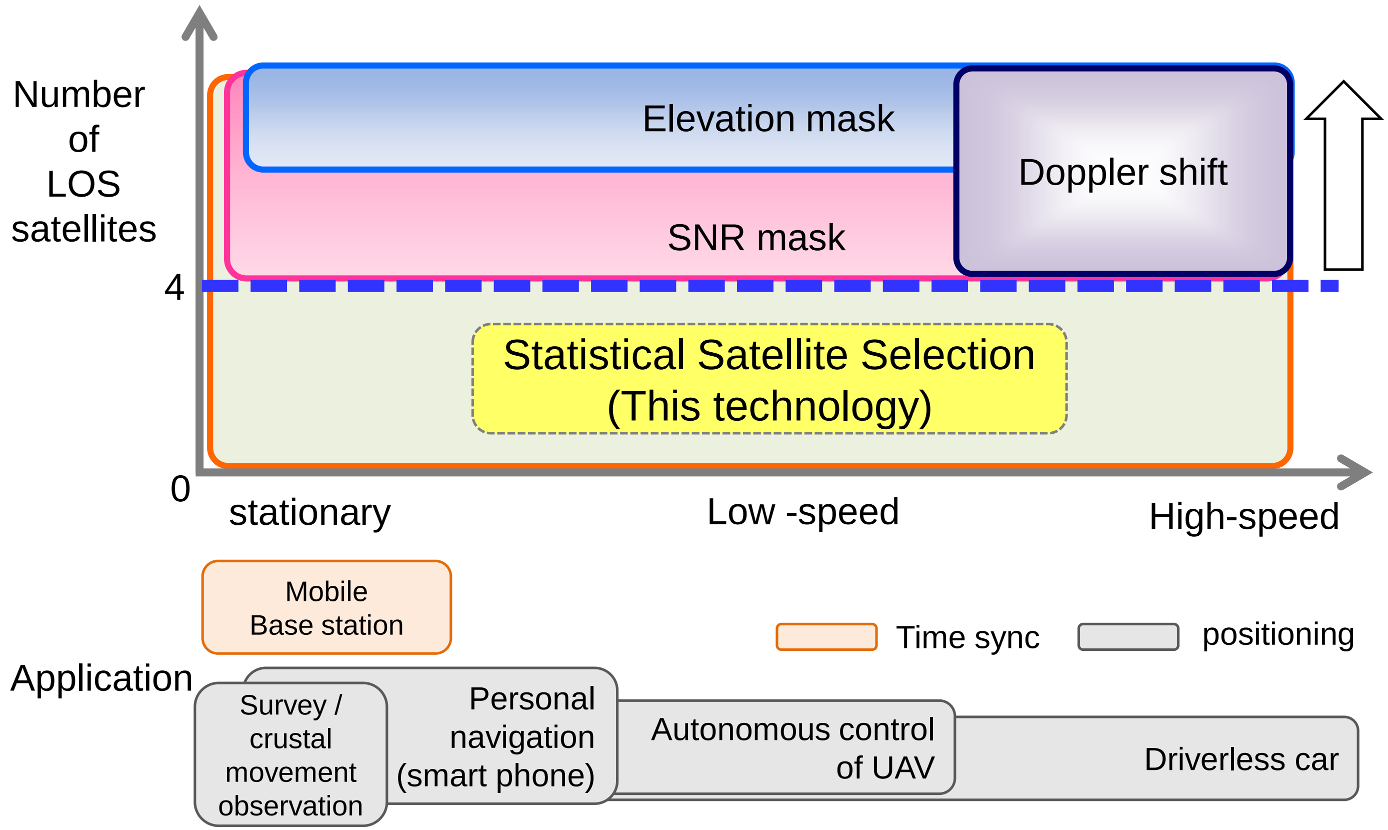




# Domain of Applicability of GNSS Positioning and Time-sync Improvement



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?*