Innovative R&D by NTT

Improvement of GNSS Time Synchronization Accuracy with NLOS Multipath Mitigation Algorithms Applied in GNSS Receivers

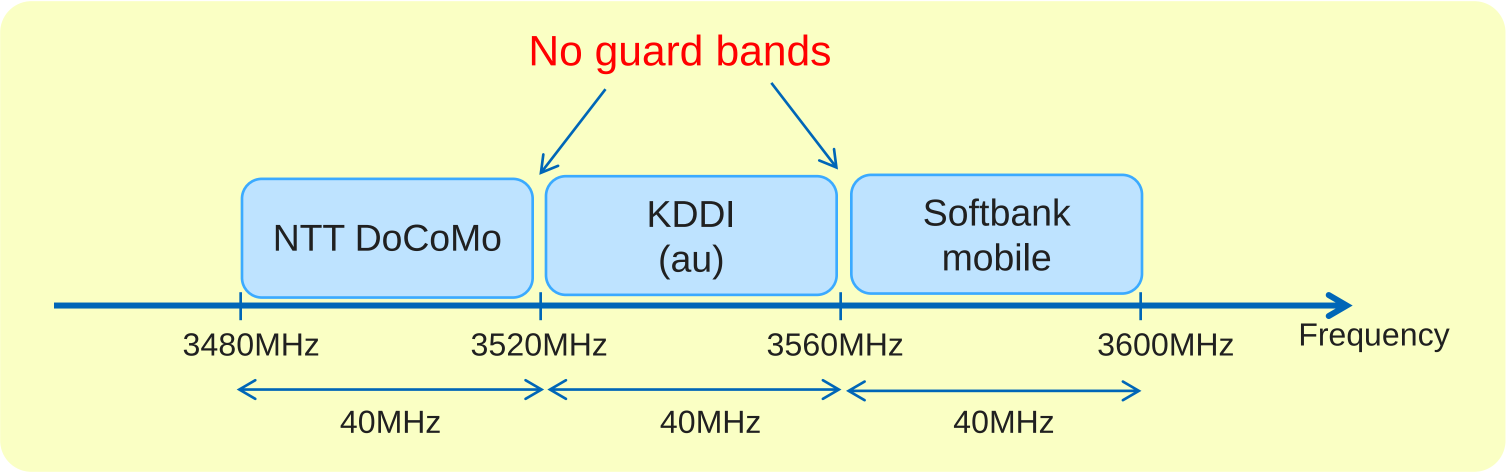
Nov 8, 2017

Seiji Yoshida, Katsunori Noritake
NTT Network Technology Laboratories

Copyright©2017 NTT Corp. All Rights Reserved.

TD-LTE Mobile Communication Services in Japan

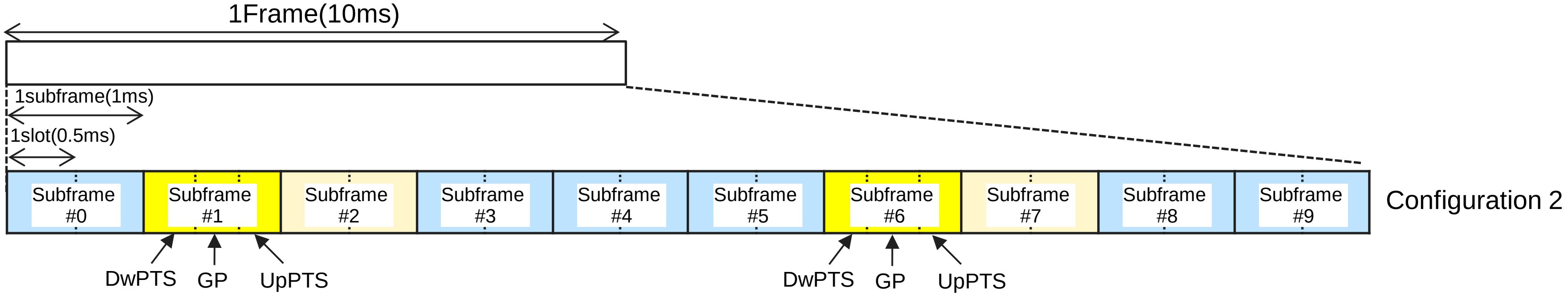
3.5GHz band (band 42) licenses assignment for TD-LTE mobile communication services in Japan



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

Copyright©2017 NTT Corp. All Rights Reserved.

TD-LTE Frame Format (3GPP TS36.211)



Uplink-downlink configuration	Downlink-to-Uplink Switch-point periodicity	Subframe number									
		0	1	2	3	4	5	6	7	8	9
0	5ms	D	S	U	U	U	D	S	U	U	U
1	5ms	D	S	U	U	D	D	S	U	U	D
2	5ms	D	S	U	D	D	D	S	U	D	D
3	10ms	D	S	U	U	U	D	D	D	D	D
4	10ms	D	S	U	U	D	D	D	D	D	D
5	10ms	D	S	U	D	D	D	D	D	D	D
6	5ms	D	S	U	U	U	D	S	U	U	D

Select any one of seven frame configurations within / among mobile operators

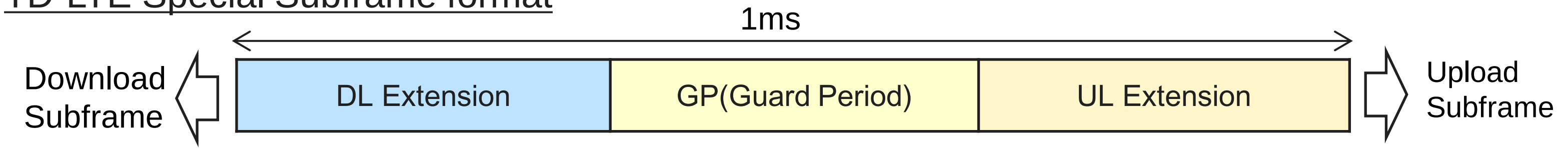
GP : Guard Period DwPTS : Downlink Pilot Time Slot UpPTS : Uplink Pilot Time Slot
U : Upload Subframe D : Download Subframe S : Special Subframe

Copyright©2017 NTT Corp. All Rights Reserved.

TD-LTE Frame Format (3GPP TS36.211)

Innovative R&D by NTT

TD-LTE Special Subframe format



Special subframe configuration	Normal Cyclic Prefix(CP)					
	DwPTS [ms]	GP [ms]	UpPTS [ms]	DwPTS (Symbol)	GP (Symbol)	UpPTS (Symbol)
0	0.2142	0.7146		3	10	
1	0.6422	0.2866		9	4	
2	0.7134	0.2154	0.0712	10	3	1
3	0.7847	0.1441		11	2	
4	0.8559	0.0729		12	1	
5	0.2142	0.6433		3	9	
6	0.6422	0.2153		9	3	
7	0.7134	0.1441	0.1425	10	2	2
8	0.7847	0.0728		11	1	
9	0.4280	0.4295		6	6	

Select any one of Ten subframe configurations within / among mobile operators

DwPTS : Downlink Pilot Time Slot UpPTS : Uplink Pilot Time Slot GP : Guard Period

Minimum Value of GP is 72.8μs

Example) Cell Radius : 10km、Cell Phase difference : 10μs
⇒ Transmission delay + Phase difference ≒ 76μs

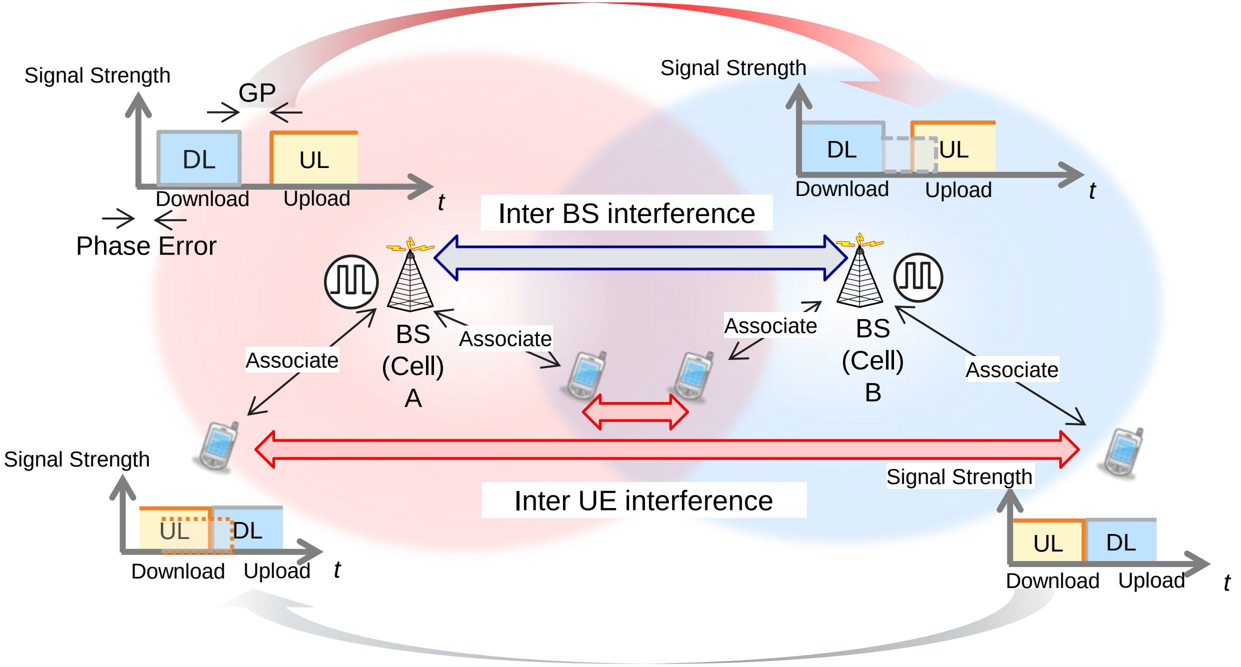
NTT

Copyright©2017 NTT Corp. All Rights Reserved.

Inter Cells Interferences in TD-LTE Systems

Innovative R&D by NTT

Inter Cells Interferences in the TD-LTE Systems include inter BSs(Base stations) interferences and inter UEs (User Equipments) interferences.



If

GP

∧

Phase Error | Transmission Delay

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

Then,
Interference Occurs

Inter BS interference

Inter UE interference

BS : Base station
UE : User Equipment

NTT

Copyright©2017 NTT Corp. All Rights Reserved.

Phase Synchronization Requirements in 3GPP TS36.133

Innovative R&D by NTT

7.4 Cell phase synchronization accuracy (TDD)

7.4.1 Definition

Cell phase synchronization accuracy is defined as the maximum absolute deviation in frame start timing between any pair of cells on the same frequency that have overlapping coverage areas.

7.4.2 Minimum requirements

※ Defining phase error at the BS antenna connector point

For Wide Area BS, the cell phase synchronization accuracy measured at BS antenna connectors shall be better than the requirement specified in table 7.4.2-1. If a cell's coverage area overlaps with another cell with different cell radius then the cell phase synchronization accuracy corresponding to the larger of the two cell sizes applies to the overlapping cells with different radii.

Table 7.4.2-1 Cell phase synchronization requirement for wide area BS (TDD)

Cell Type	Cell Radius	Requirement
Small cell	≤ 3 km	≤ 3 μs
Large cell	> 3 km	≤ 10 μs

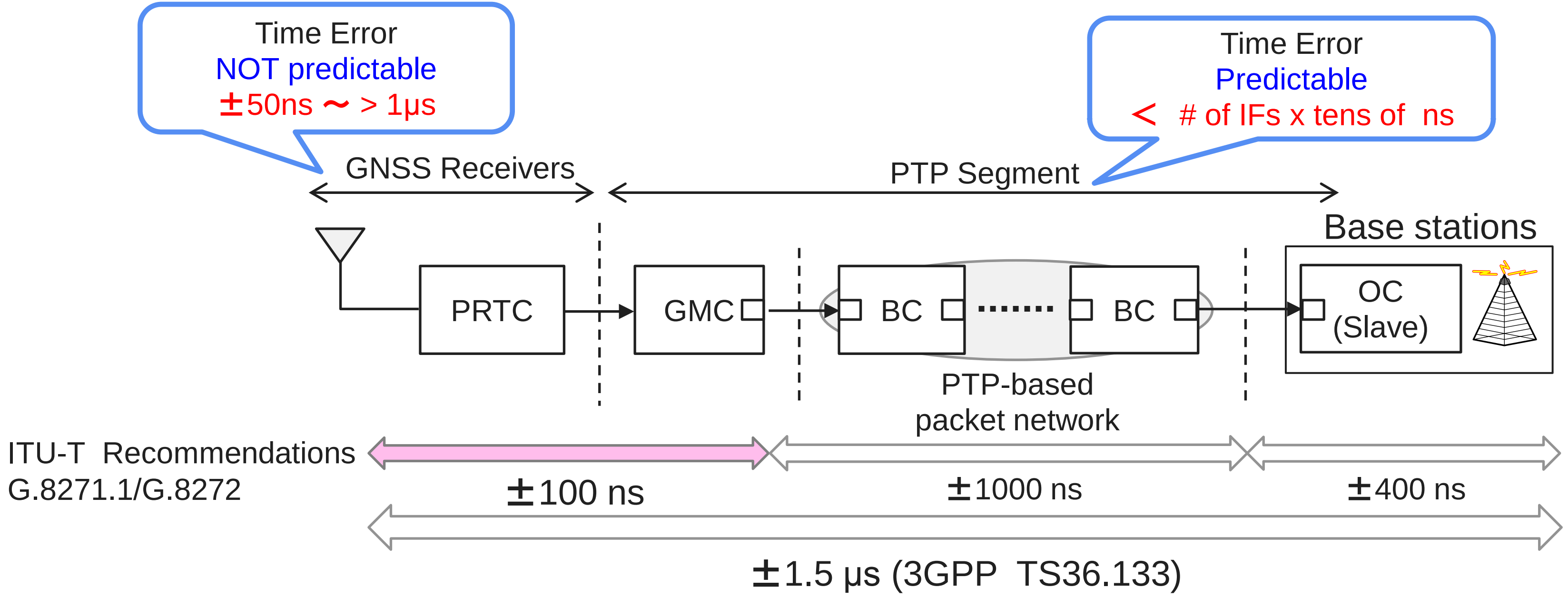
Requirement of Phase Synchronization between Small Cells : ≤ 3μs

Time (Phase) Sync Requirement for TD-LTE is defined as ≤ ±1.5μs apart from GNSS time

Copyright©2017 NTT Corp. All Rights Reserved.

Problems in High Precision GNSS Time Synchronization

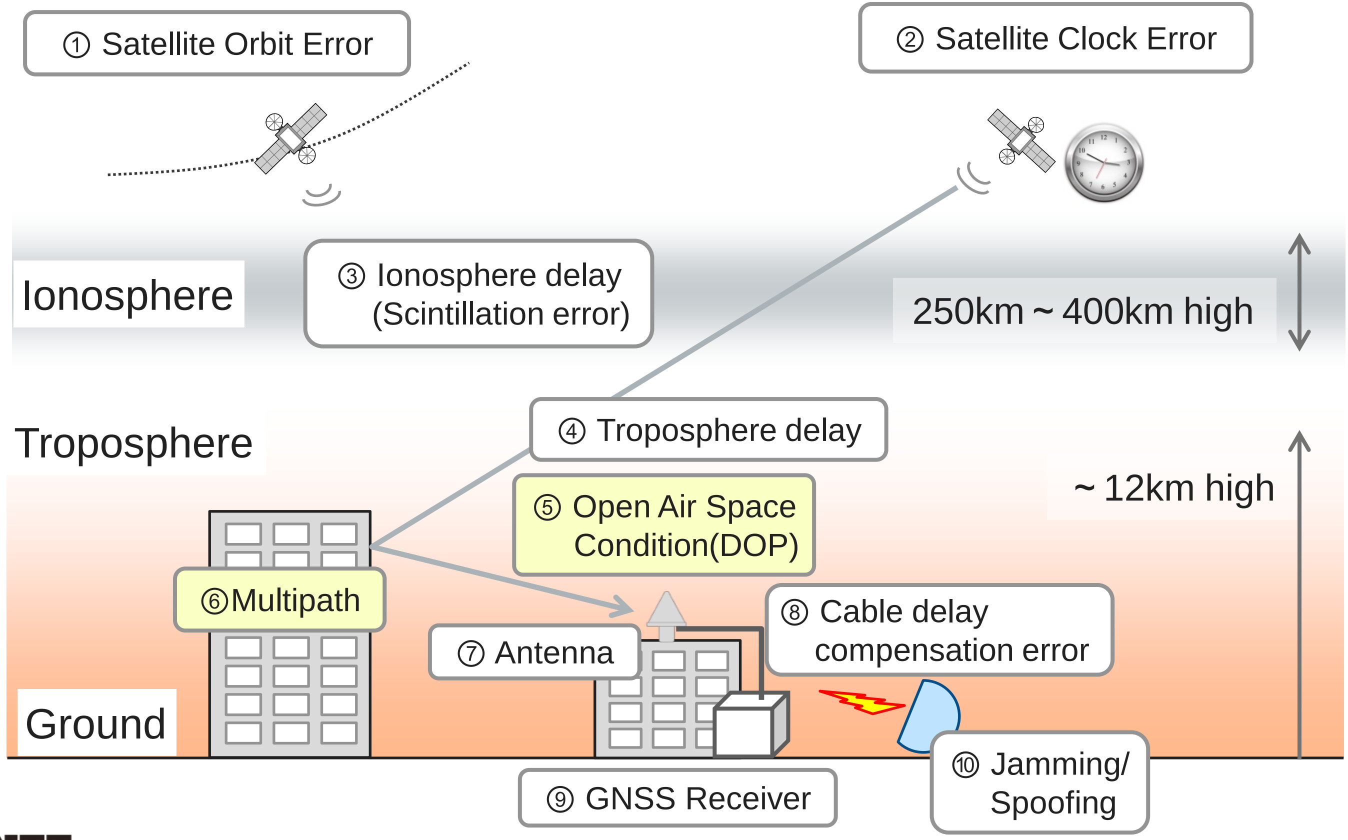
Standardized budget assignment of time errors in mobile communication systems



Difficult to estimate the time error in actual systems in advance

Copyright©2017 NTT Corp. All Rights Reserved.

Time Error Causes in GNSS Time Synchronization Systems

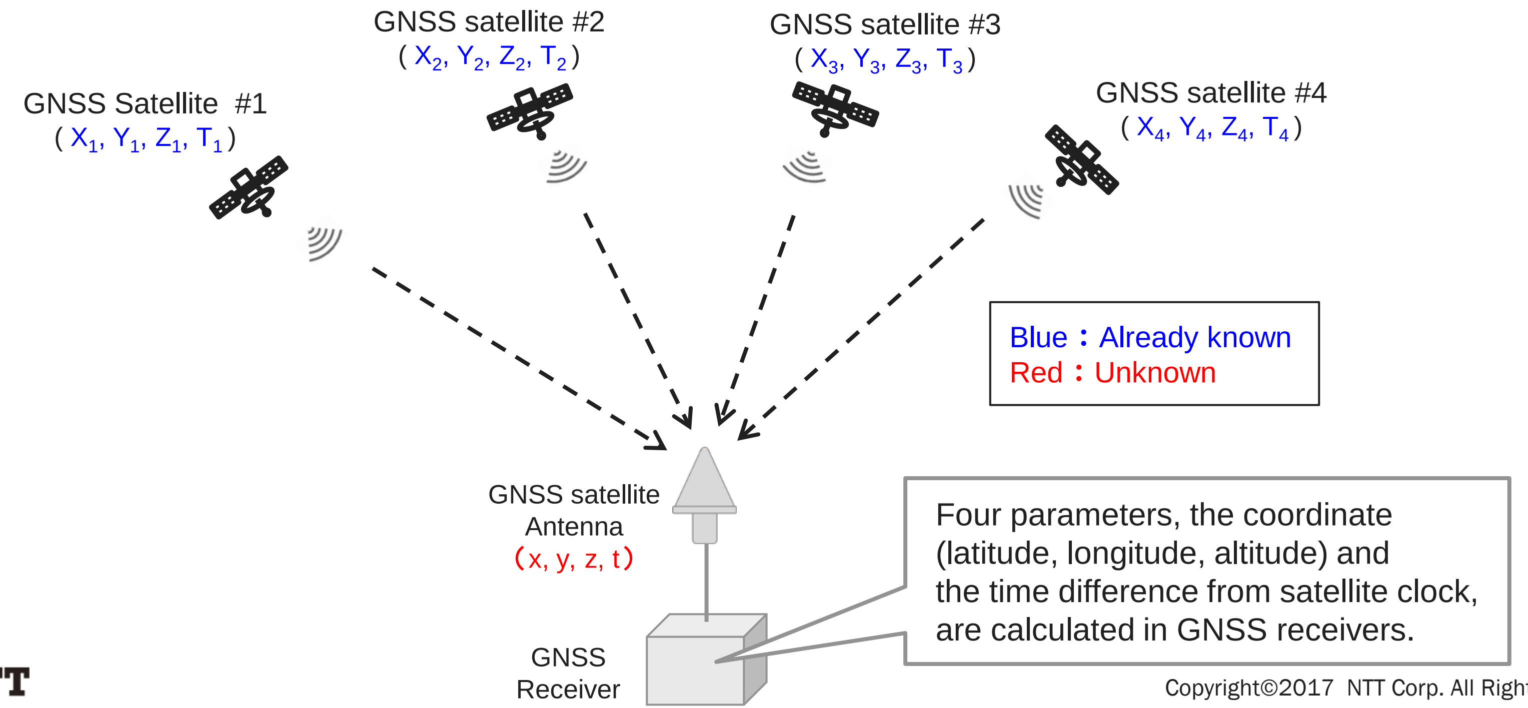


Most of the Error occurs around close to the ground

Copyright©2017 NTT Corp. All Rights Reserved.

Positioning and Time Sync with GNSS

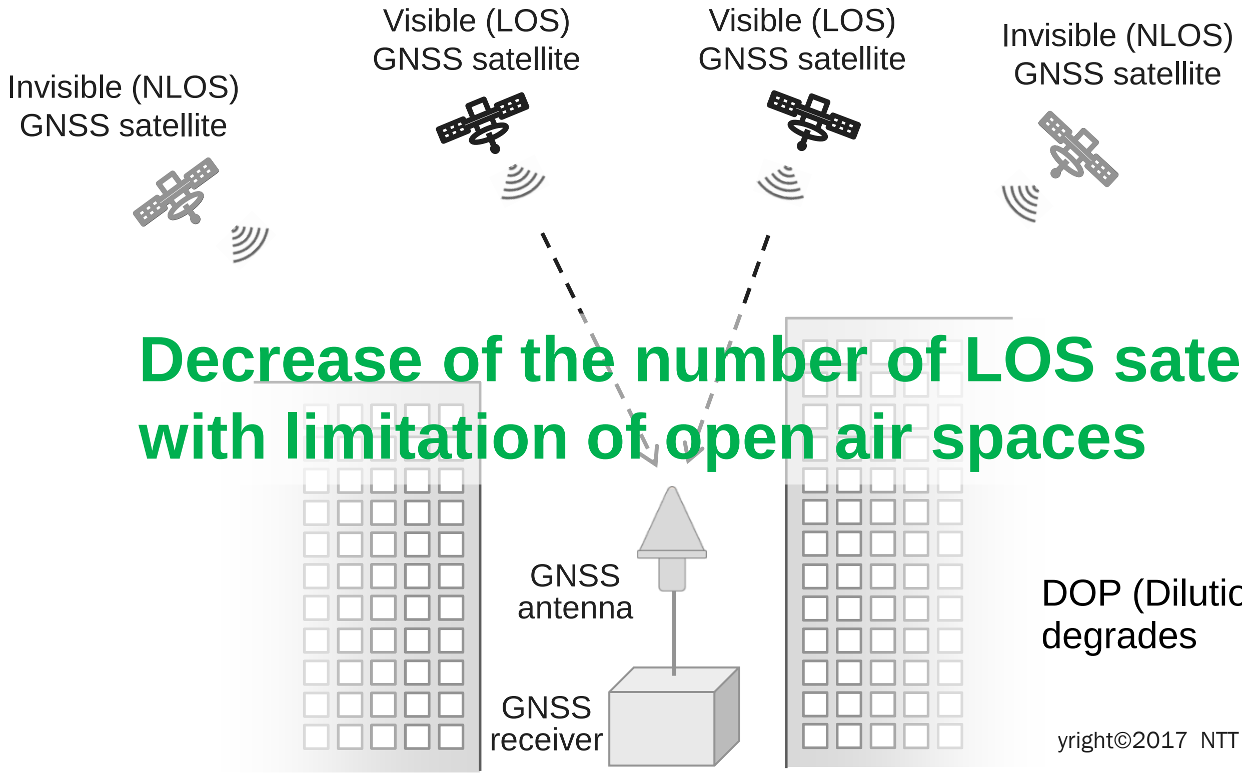
By receiving more than four satellite signals simultaneously by GNSS receivers, four unknown parameters, three-dimensional position and time, can be calculated. In that sense, positioning and time synchronization in GNSS receivers are a set of the processing.



Copyright©2017 NTT Corp. All Rights Reserved.

Reduction of Number of LOS satellites with restriction of open air spaces

In “urban-canyon” environments seen at urban areas where antennas are surrounded with buildings, number of LOS (visible) satellites decreases as open air spaces are restricted with surrounding buildings.



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

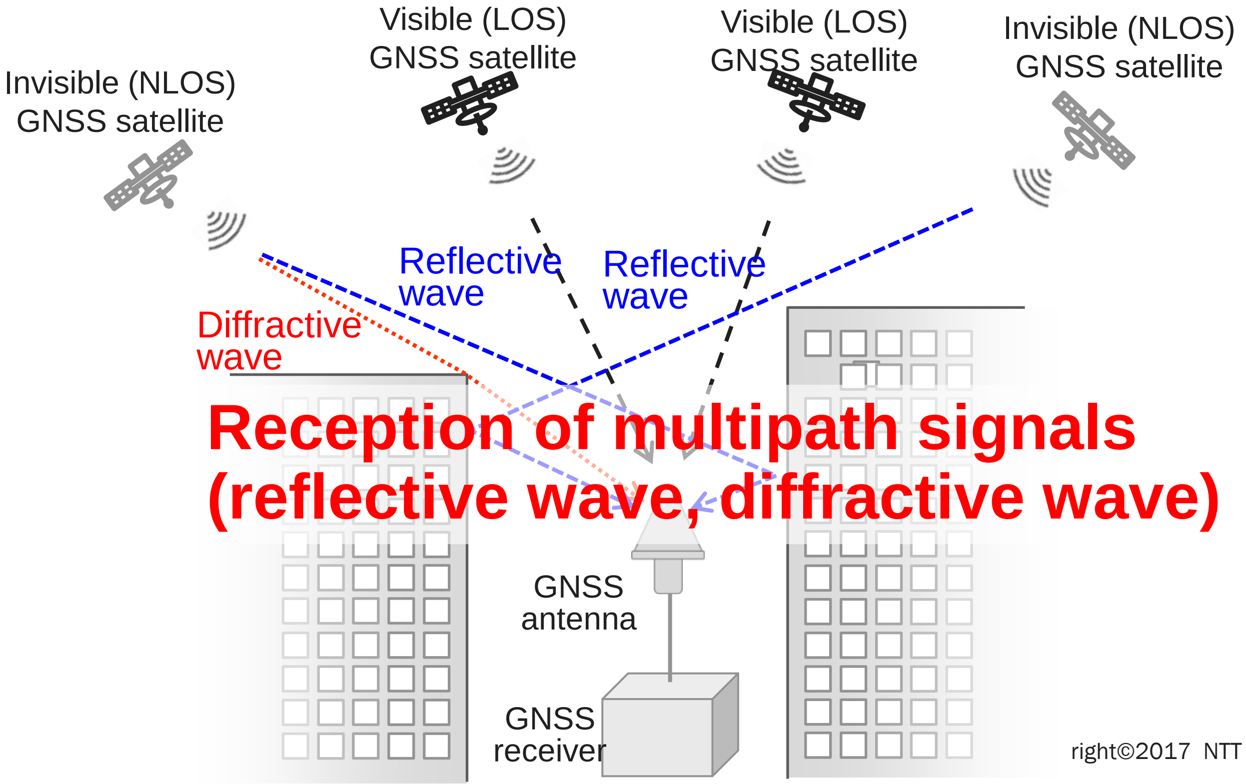
DOP (Dilution Of Precision) degrades

NTT

yright©2017 NTT Corp. All Rights Reserved.

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 satellites signals at surrounding buildings.

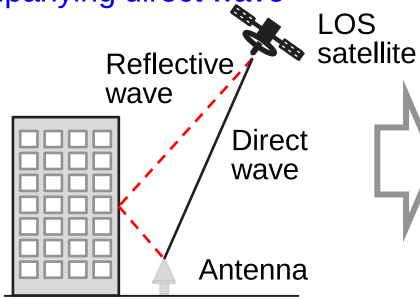


right©2017 NTT Corp. All Rights Reserved.

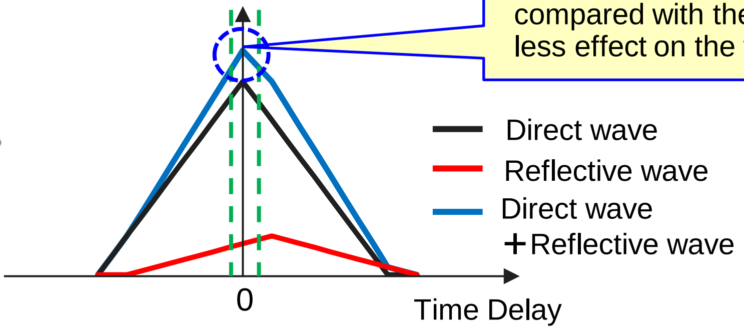
Effect of Multipath Signals on the Accuracy of GNSS Time Synchronization

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) NLOS satellite signals.

(A) Multipath signals of LOS satellite
accompanying direct wave

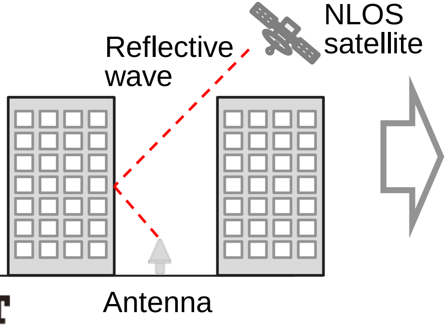


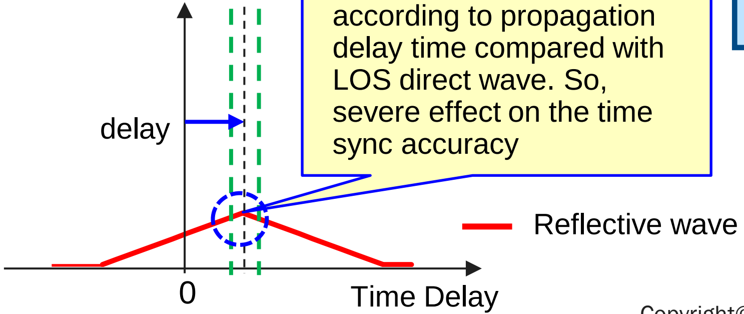
Output of correlator



Peak time of the correlator output does not change compared with the case with only direct wave. So, less effect on the time-sync accuracy

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





Peak position change according to propagation delay time compared with LOS direct wave. So, severe effect on the time sync accuracy

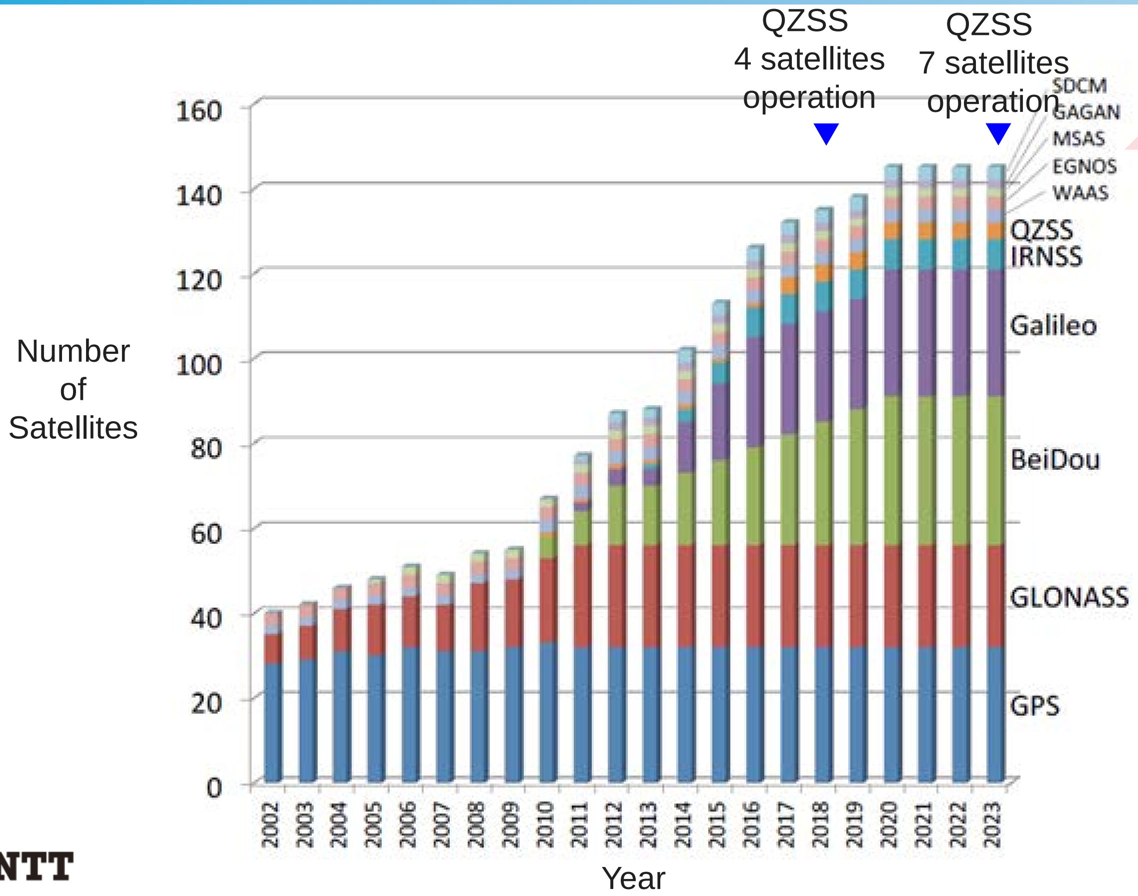
Main cause of degradation of the time sync accuracy is from NLOS multipath signals.

Effectively removing mutipath signals of NLOS satellites is ESSENTIAL!

NTT

Copyright©2017 NTT Corp. All Rights Reserved.

Perspective of Available Satellites Enhancement with Multi-GNSS



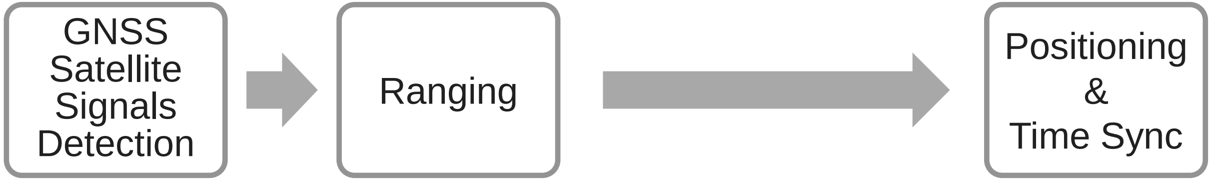
Total number of available satellites will be tripled from 2009 to 2020

Cited from JAXA presentation

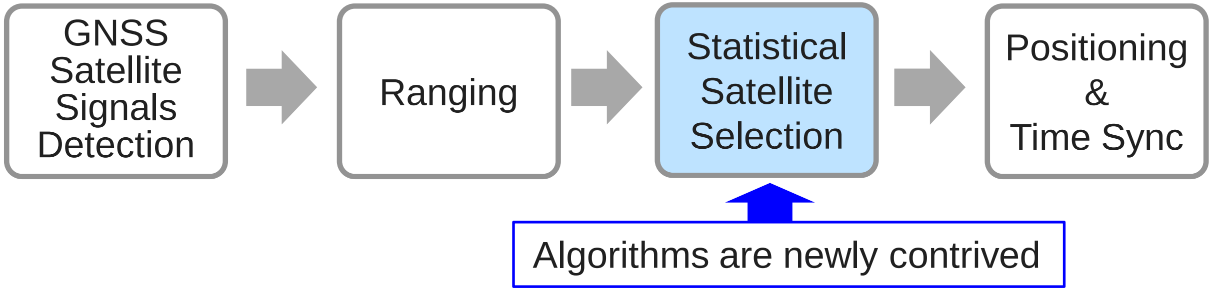
Copyright©2017 NTT Corp. All Rights Reserved.

Statistical Satellites Selection Algorithm (1)

- Signal processing in conventional GNSS receivers



- Signal processing in GNSS receivers with statistical satellite selection

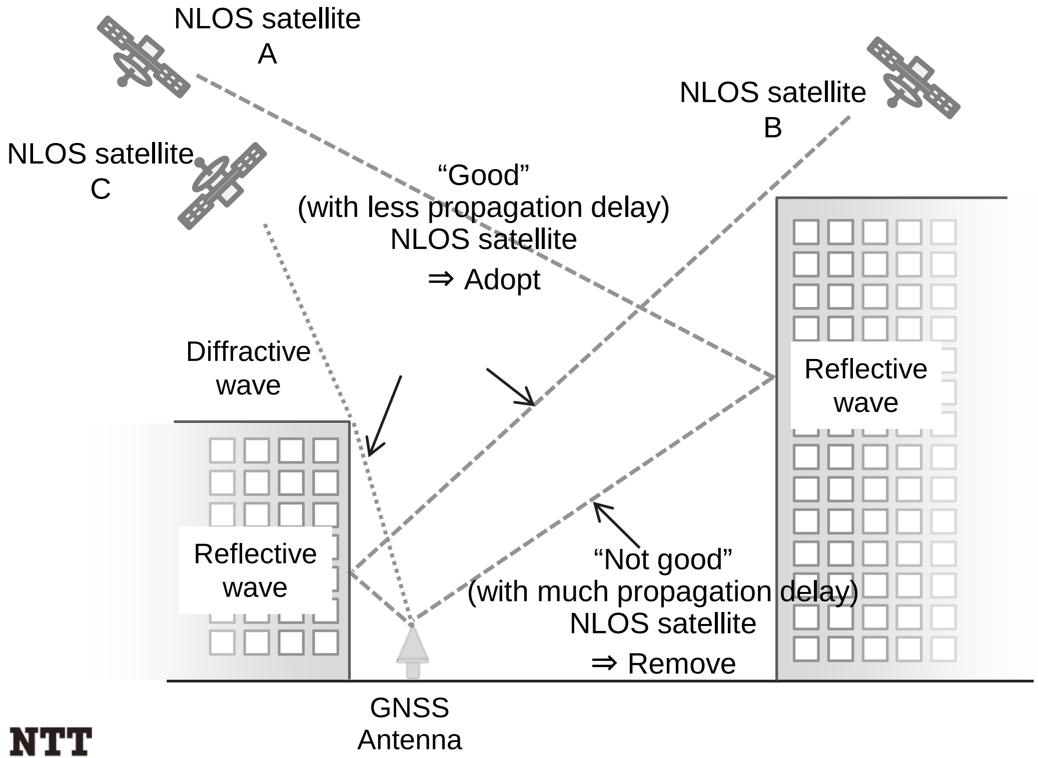


Select appropriate GNSS satellite signals through statistical satellite selection algorithms

Copyright©2017 NTT Corp. All Rights Reserved.

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

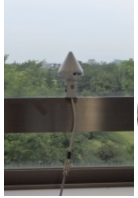
⇒ This is the point of our algorithm

NTT

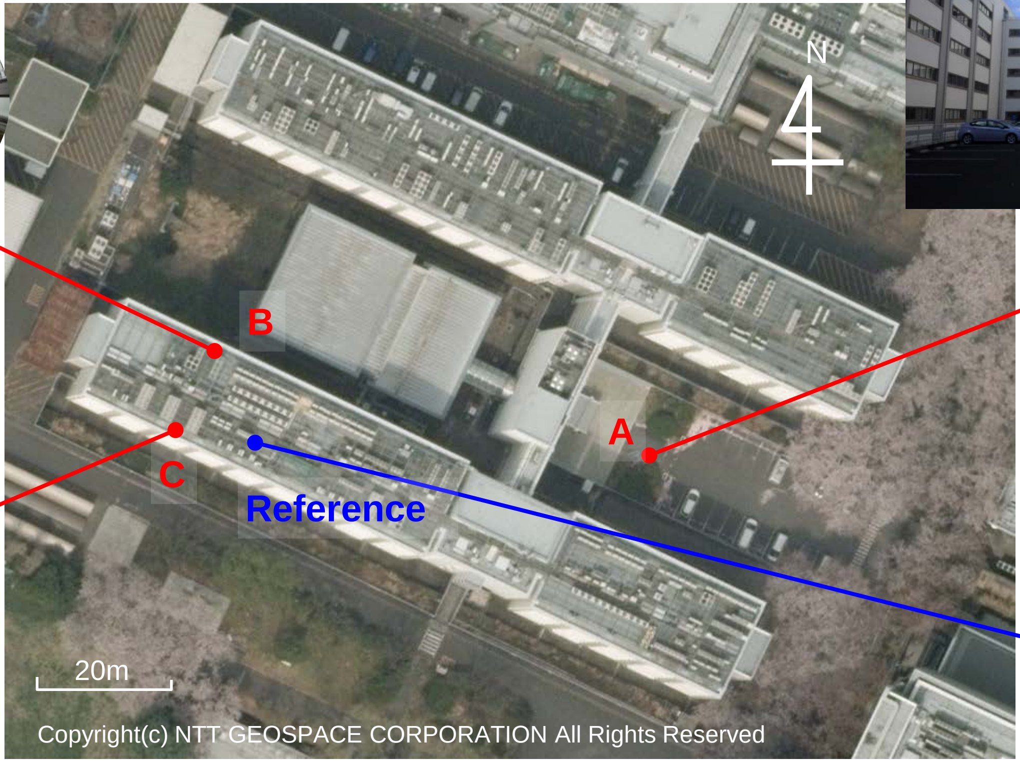
Copyright©2017 NTT Corp. All Rights Reserved.

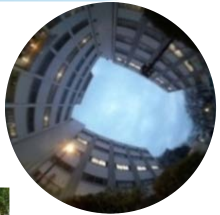
Multipath Reception Environments for Experimental Evaluation


Multipath Reception Point B (Indoor)




Multipath Reception Point B (Indoor)



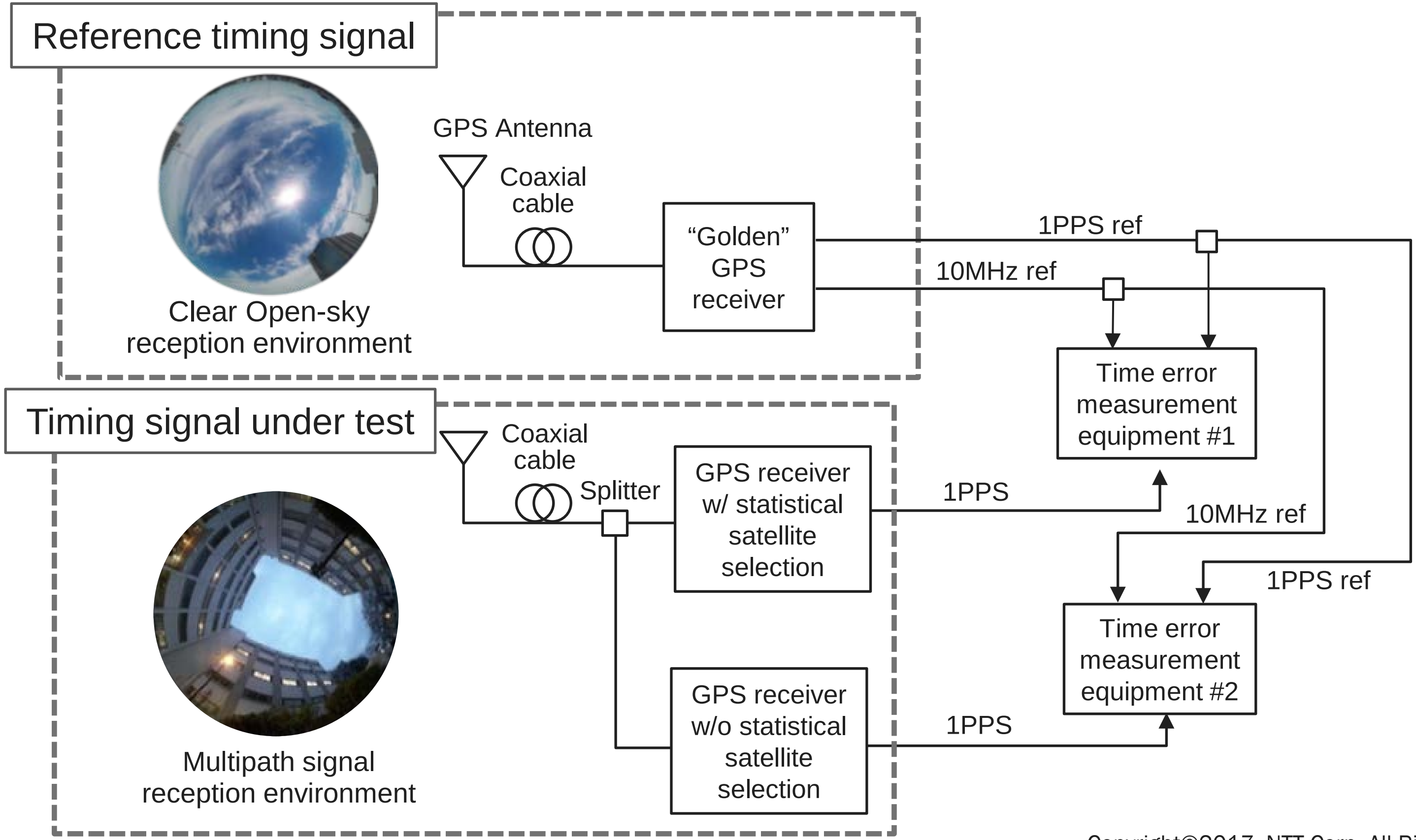




Multipath Reception Point A (Outdoor)


Reference Reception Point (Open sky)

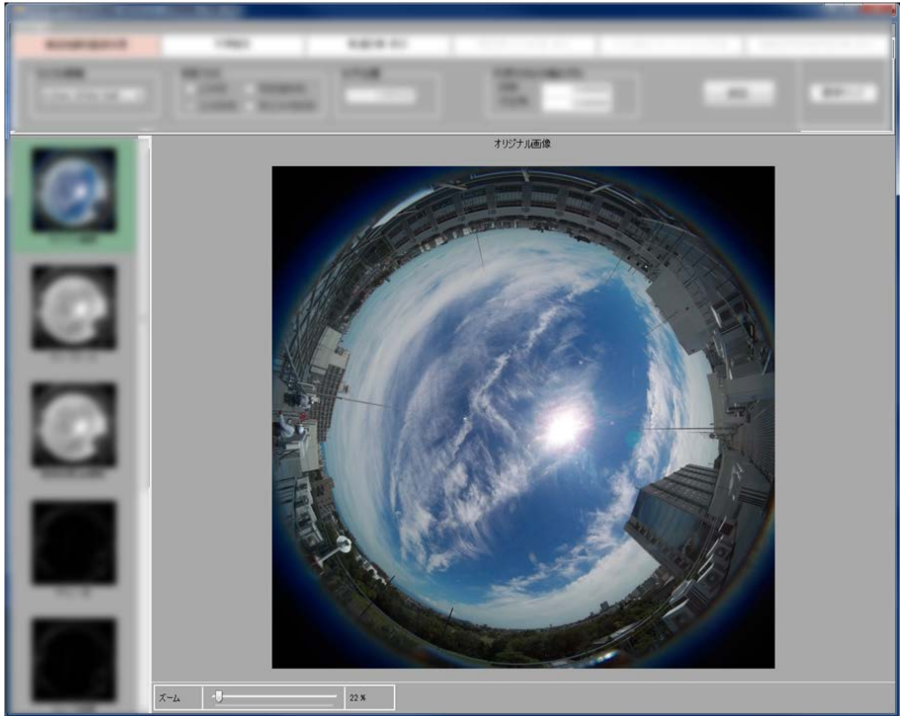
Copyright©2017 NTT Corp. All Rights Reserved.

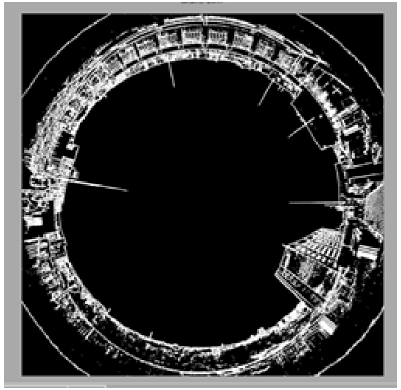
Experimental setup for the performance evaluation

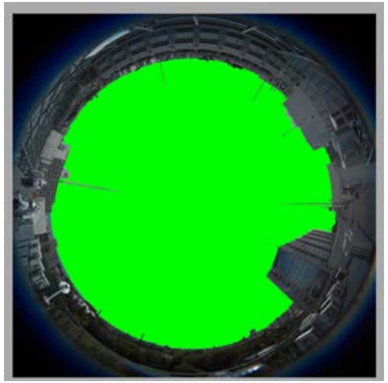


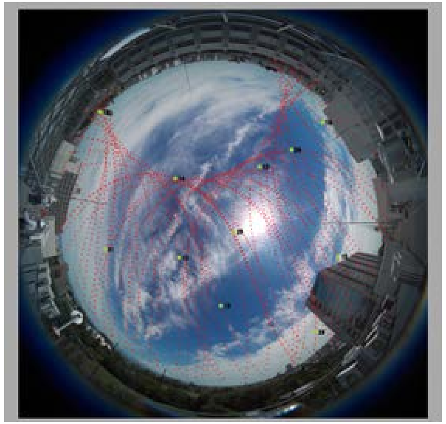
Copyright©2017 NTT Corp. All Rights Reserved.

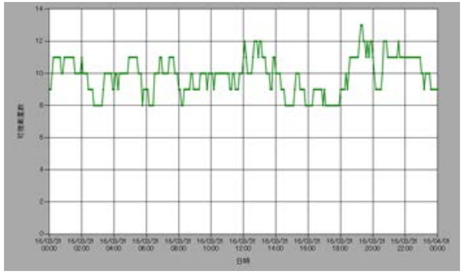
Estimation of LOS Satellites Reception Characteristics with Sky Plot Images Taken by Fish-Eye Lens Camera







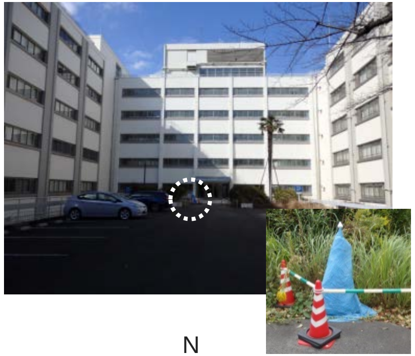


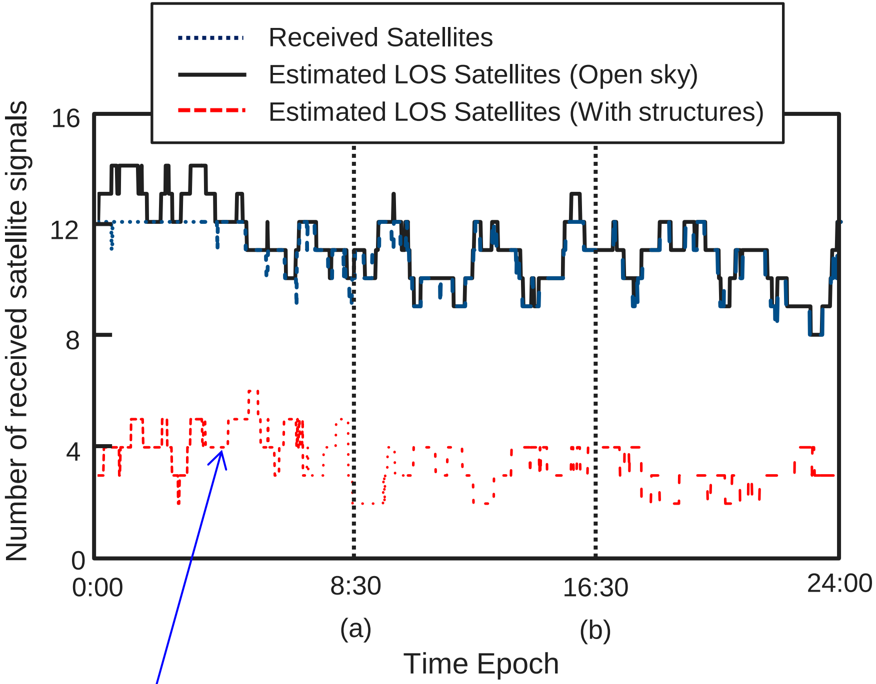


Estimated # of LOS satellites over time

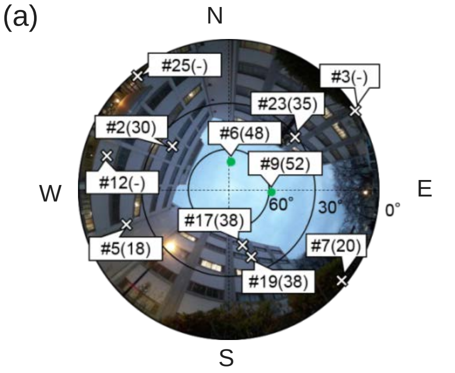
Copyright©2017 NTT Corp. All Rights Reserved.

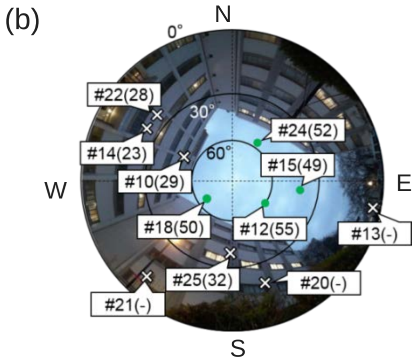
GPS Satellites Signals Reception Characteristics @ Multipath Signals Reception Point A





Estimated number of LOS satellites



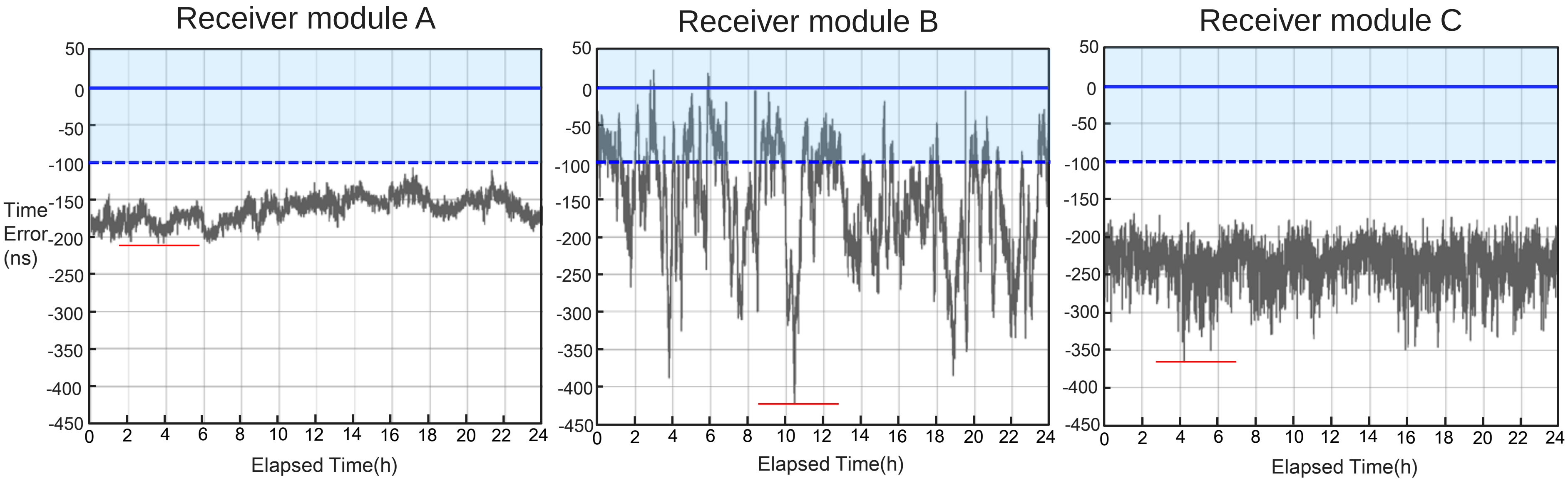


#: GPS satellite number, figure in parentheses: CNR(dB-Hz)

Copyright©2017 NTT Corp. All Rights Reserved.

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



Max|TE| = 208 ns

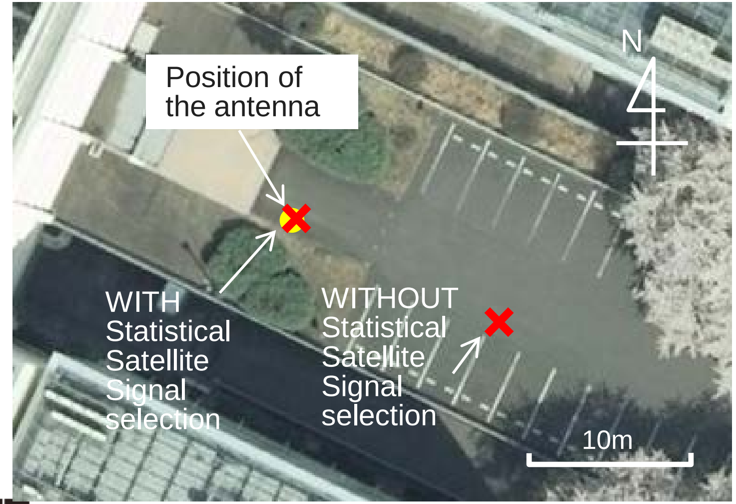
Max|TE| = 422 ns

Max|TE| = 365 ns

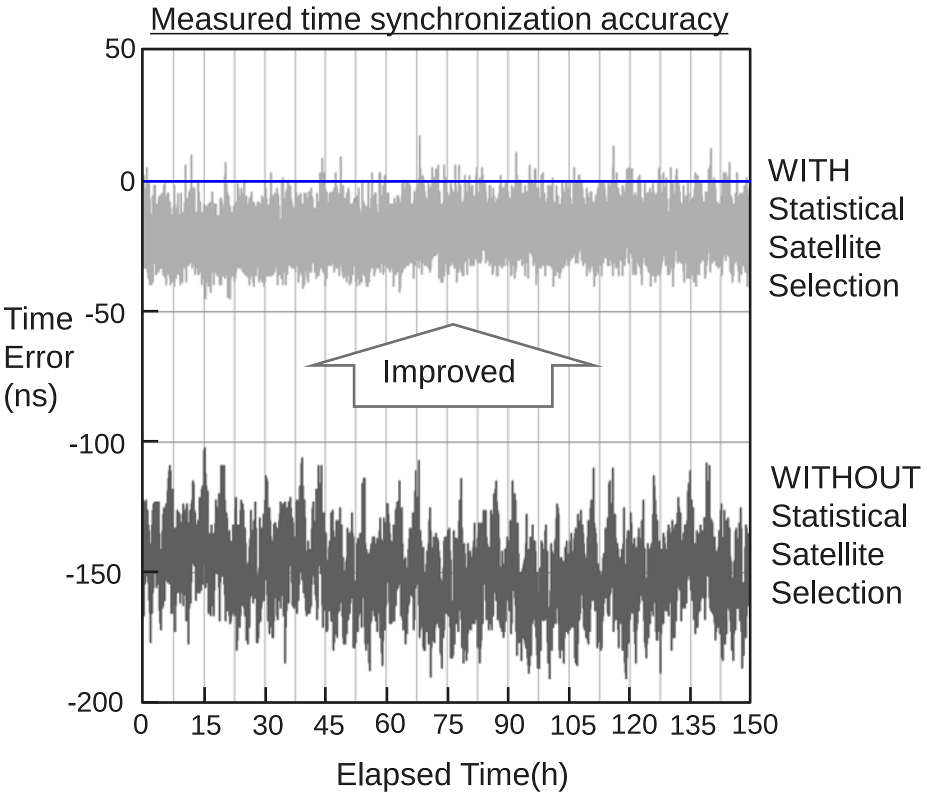
Copyright©2017 NTT Corp. All Rights Reserved.

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

Multipath reception environments with surroundings of structures



Measured accuracy of two dimensional positioning



Copyright©2017 NTT Corp. All Rights Reserved.

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)

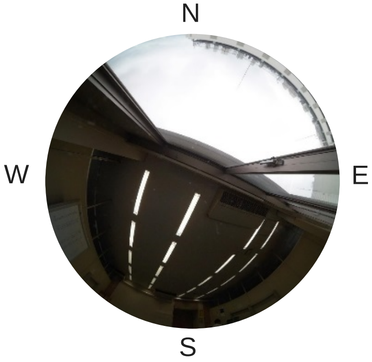
● : Selected four GPS satellites

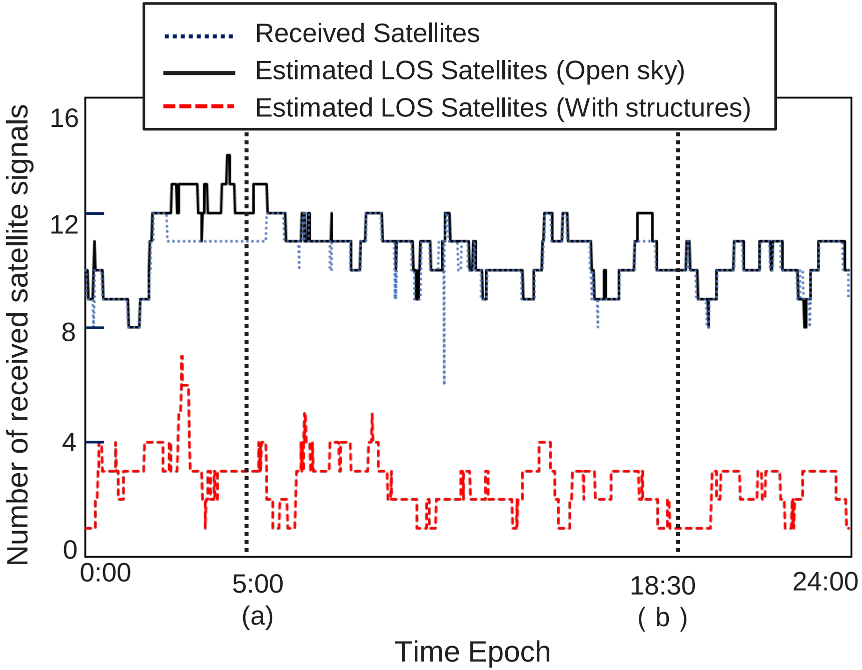
#: GPS satellite number, figure in parentheses: CNR(dB-Hz)

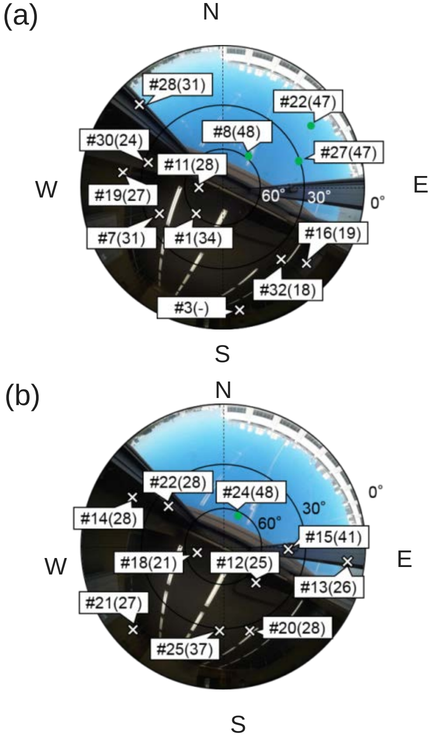
NTT
Copyright©2017 NTT Corp. All Rights Reserved.

GPS Satellites Signals Reception Characteristics @ Multipath Signals Reception Point B

Multipath reception environment with an antenna inside the window







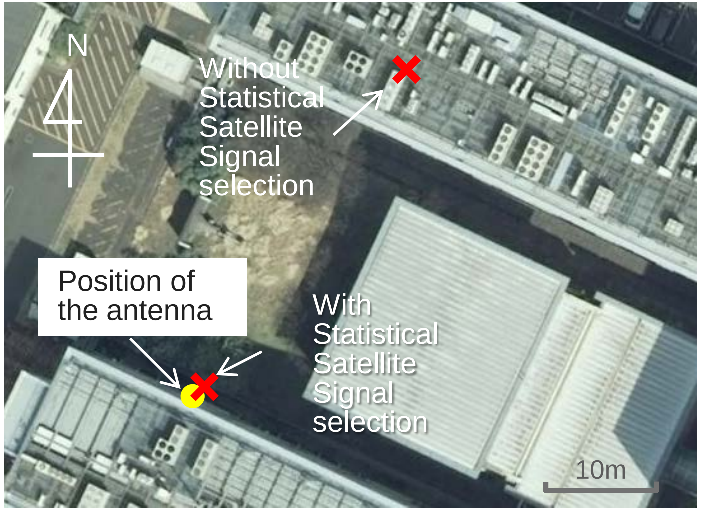
#: GPS satellite number, figure in parentheses: CNR(dB-Hz)

NTT

Copyright©2017 NTT Corp. All Rights Reserved.

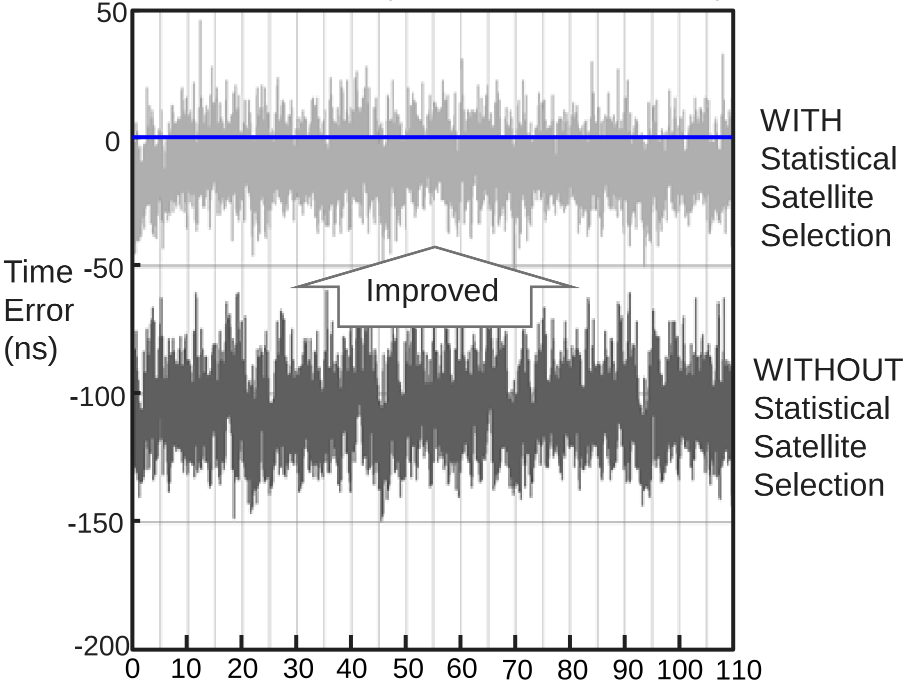
Performance Evaluation Results with the Contrived Algorithm @ Multipath Reception Point B

Multipath reception environment with an antenna inside the window



Measured accuracy of two dimensional positioning

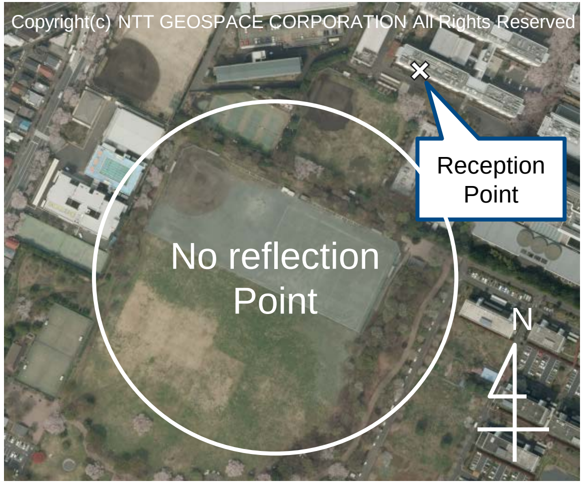
Measured time synchronization accuracy

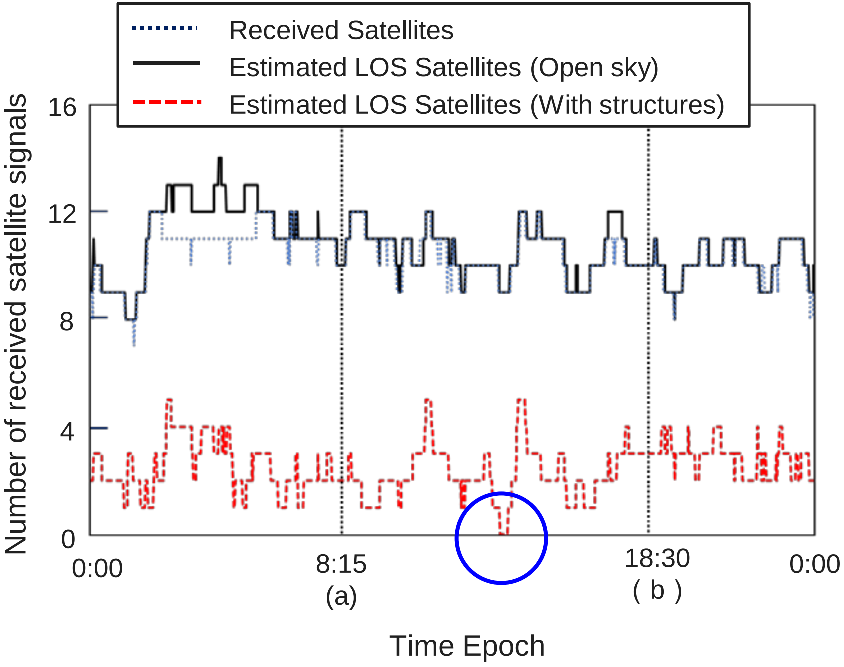


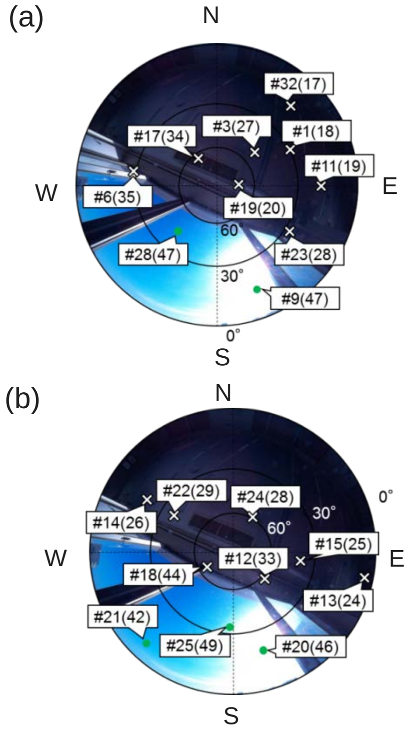
Copyright©2017 NTT Corp. All Rights Reserved.

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)

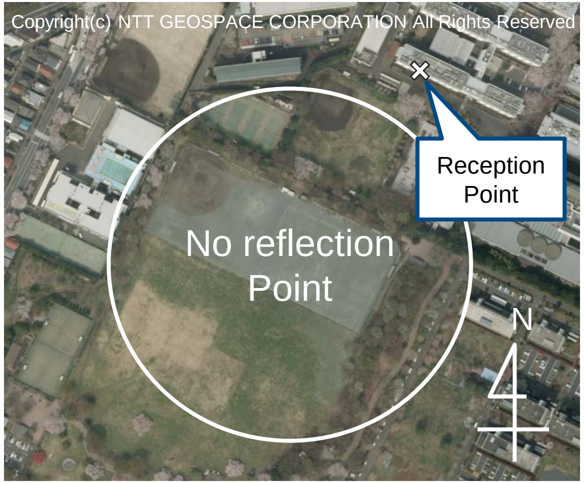
Innovative R&D by NTT

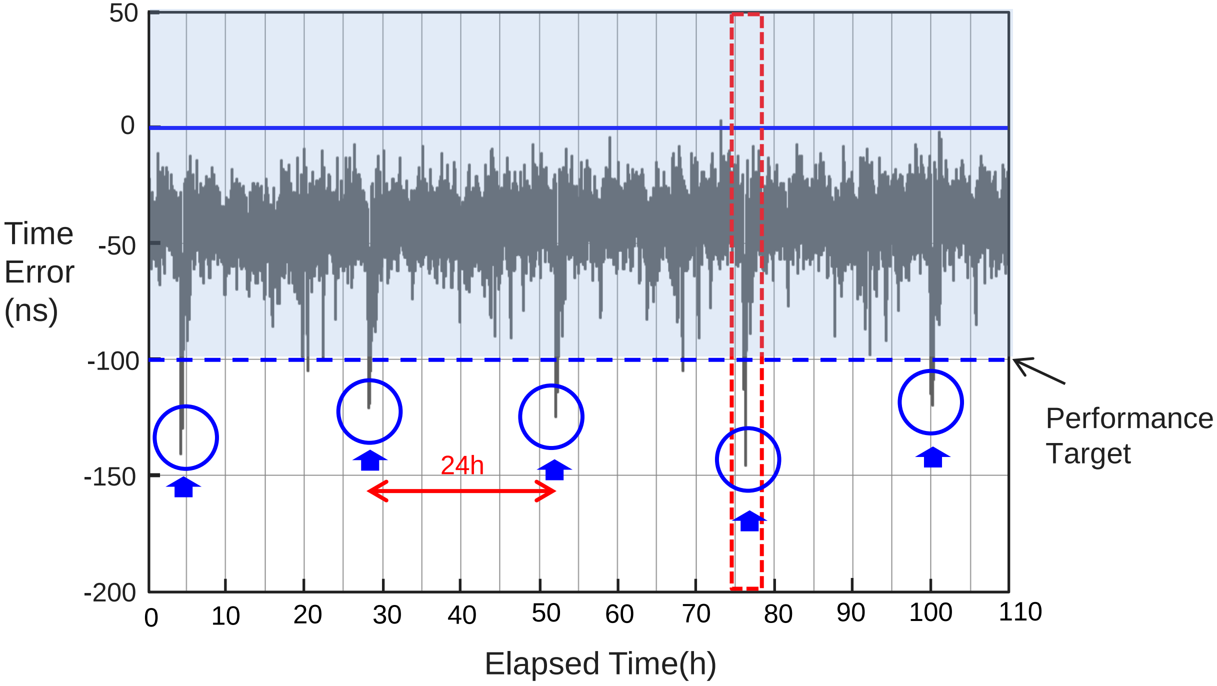
NTT

Copyright©2017 NTT Corp. All Rights Reserved.

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

Multipath reception environment with an antenna inside the window

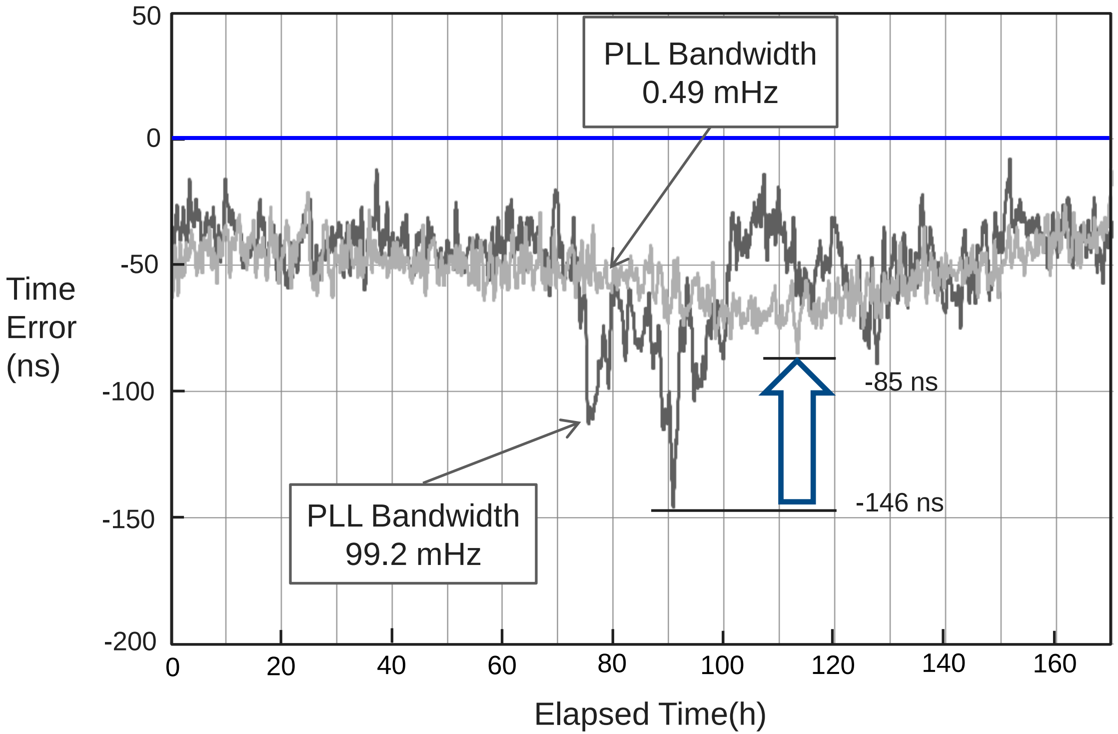




Max|TE| = 146ns

Copyright©2017 NTT Corp. All Rights Reserved.

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)

Copyright©2017 NTT Corp. All Rights Reserved.

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.

Urban canyon environment

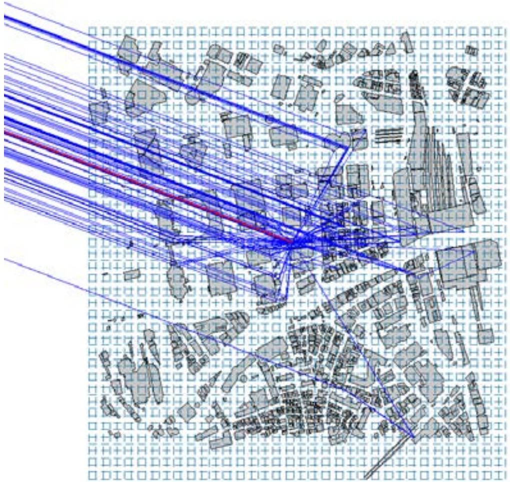
Copyright©2017 NTT Corp. All Rights Reserved.

Multipath Simulation @ Actual Signal Reception Environment

3D Map

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

Radio Propagation Analysis



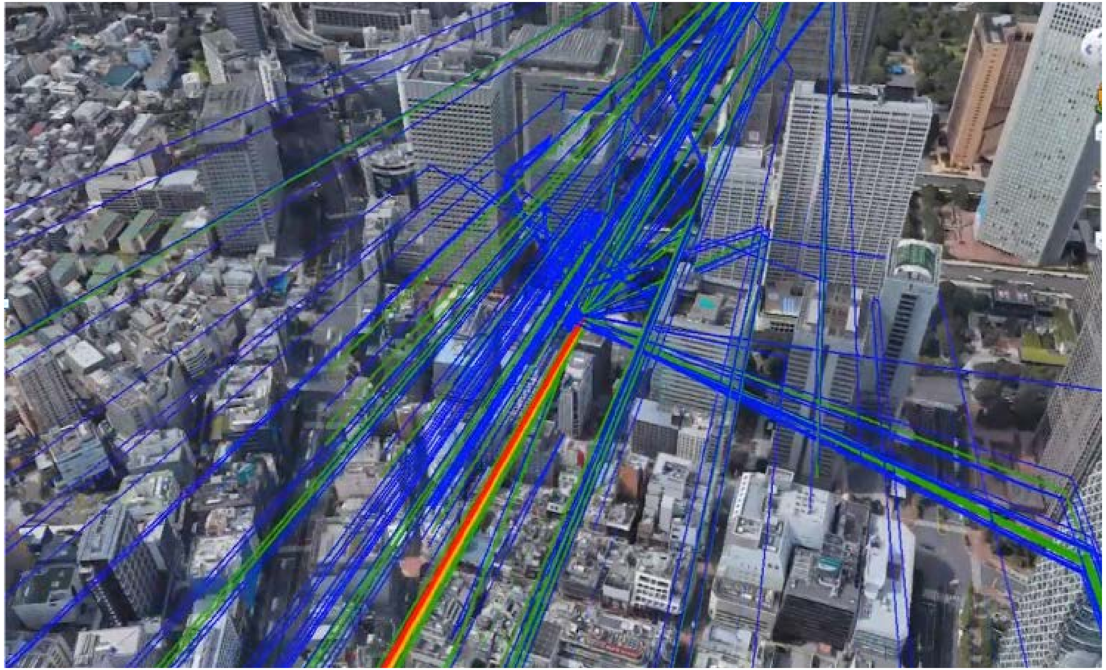
Multipath estimation with three dimensional ray-trace simulation

GNSS Signal Simulator

More closely real multipath signal generation with SDR (Software-Defined Radio) architecture through digital I/Q data

Copyright©2017 NTT Corp. All Rights Reserved.

Visualization of Simulated Multipath Signals

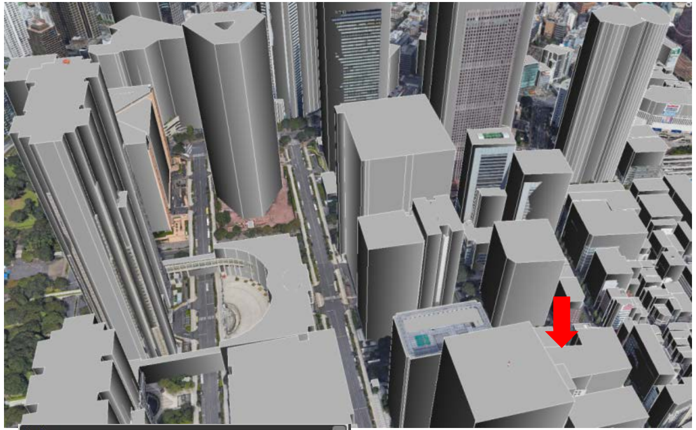


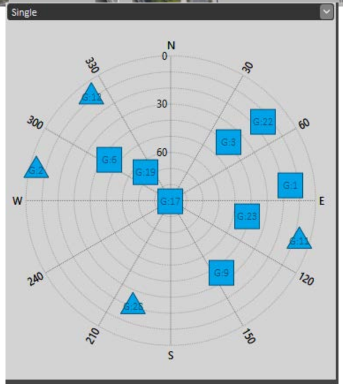
Red line	Direct wave
Orange line	Once reflected wave
Green line	Once diffracted wave
Blue line	Once reflected & once diffracted wave

Almost all of the multipath signal Can be regenerated with SDR-based GNSS Signal Simulator

Copyright©2017 NTT Corp. All Rights Reserved.

Edit Multipath Signals



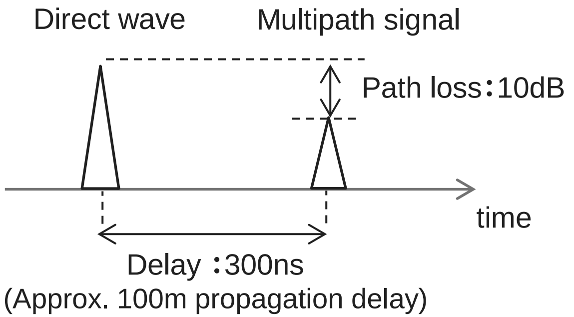


← Sky map of GNSS signal simulator

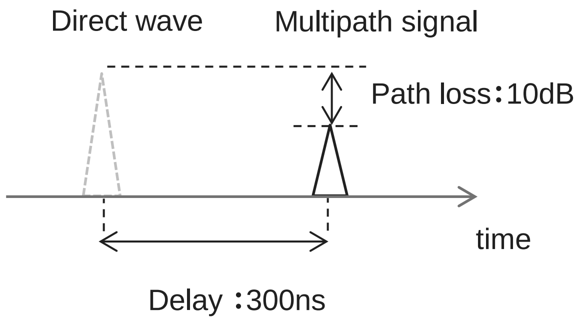
LOS Satellites

NLOS Satellites

LOS Satellites



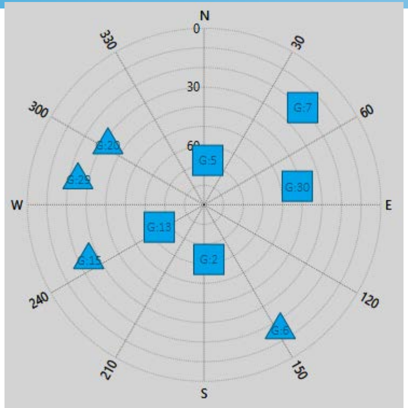
NLOS Satellites

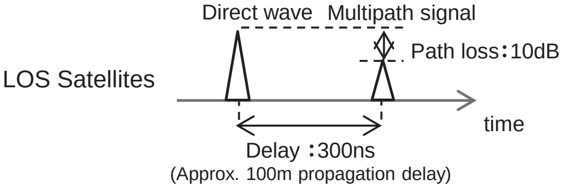


Copyright©2017 NTT Corp. All Rights Reserved.

Performance Evaluation Results with Edited Multipath signals (1)

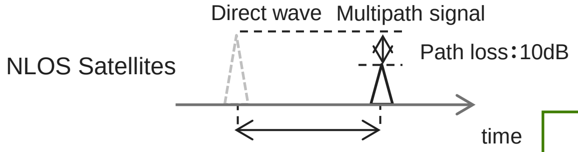
Innovative R&D by NTT

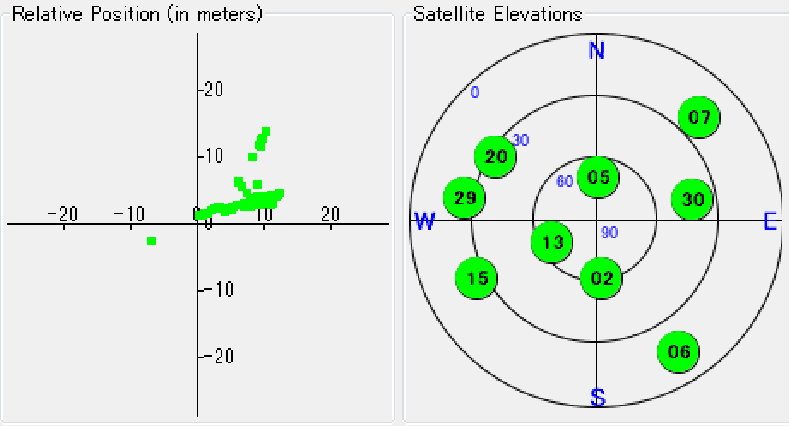




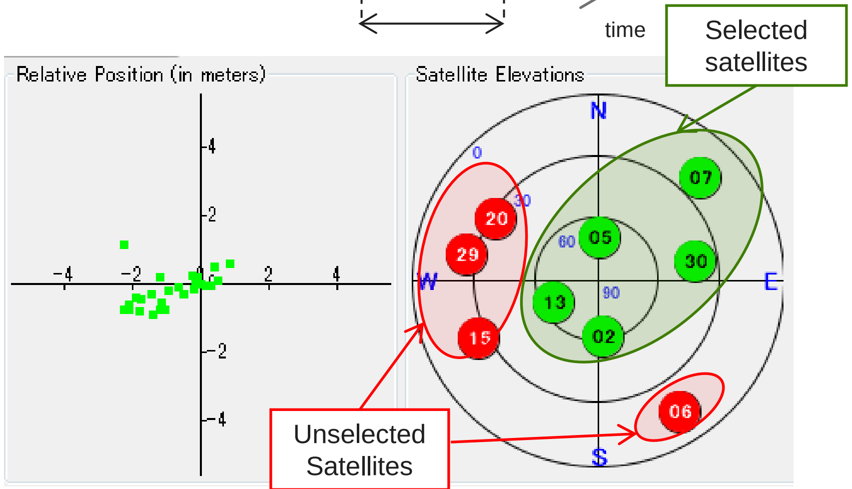
LOS Satellites

NLOS Satellites





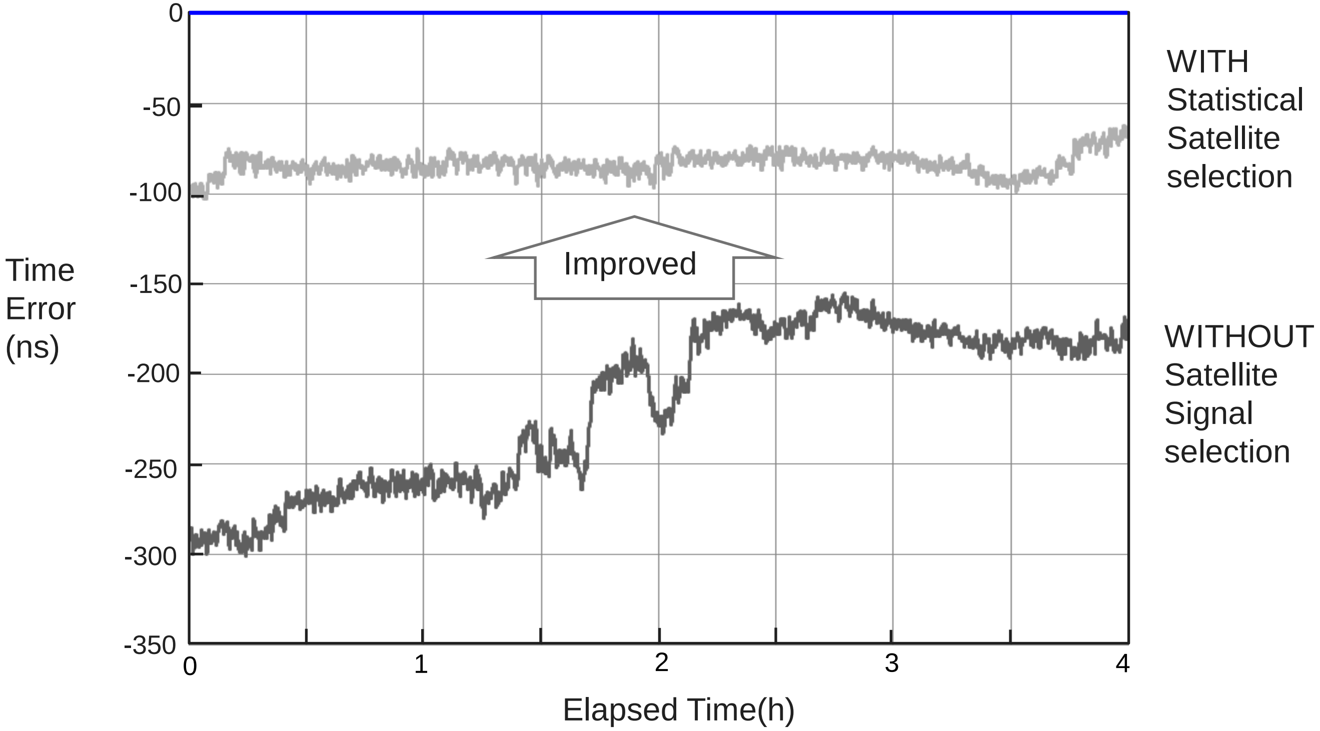
Without Statistical Satellite selection



With Statistical Satellite selection Algorithm

Copyright©2017 NTT Corp. All Rights Reserved.

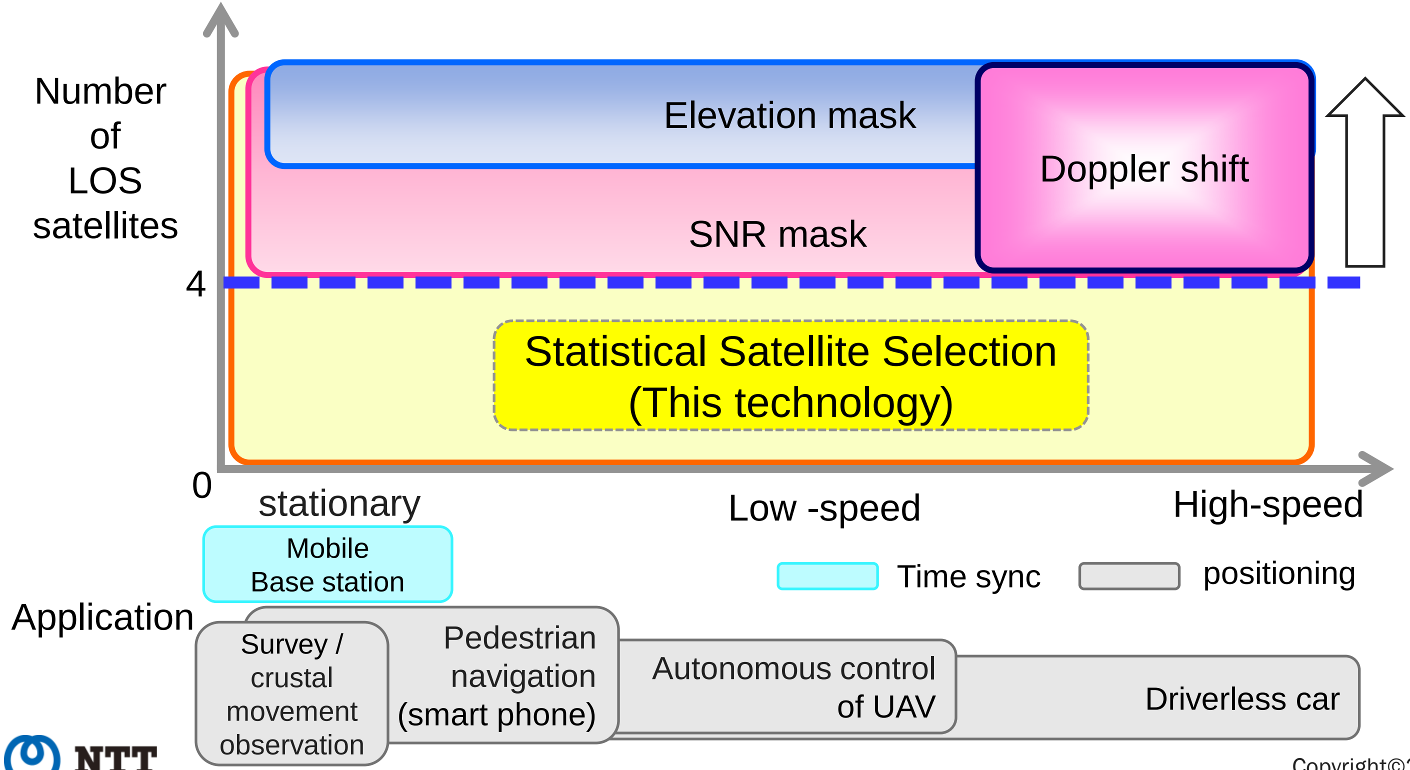
Performance Evaluation Results with Edited Multipath signals (2)



Copyright©2017 NTT Corp. All Rights Reserved.

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

NTT
Copyright©2017 NTT Corp. All Rights Reserved.

Thank you for your attention.
Questions?

Copyright©2017 NTT Corp. All Rights Reserved.