Effective Satellite Selection Methods for RTK-GNSS NLOS Exclusion in Dense Urban Environments

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Hiroko Tokura, Nobuaki Kubo (TUMSAT)

Hitachi Zosen Corporation

Geospatial Information Authority of Japan

The Geographical Survey Institute carried out this study as a general technology development project of the Ministry of Land, Infrastructure and Transport minister's secretariat technology Security Research Division.

Outline

1. Background and objective
2. Conventional satellite selection methods
3. Testing and results
4. Weakness of SNR and SNR based new method
5. Testing and results
6. Conclusions

Background

Multipath effects in dense urban environment

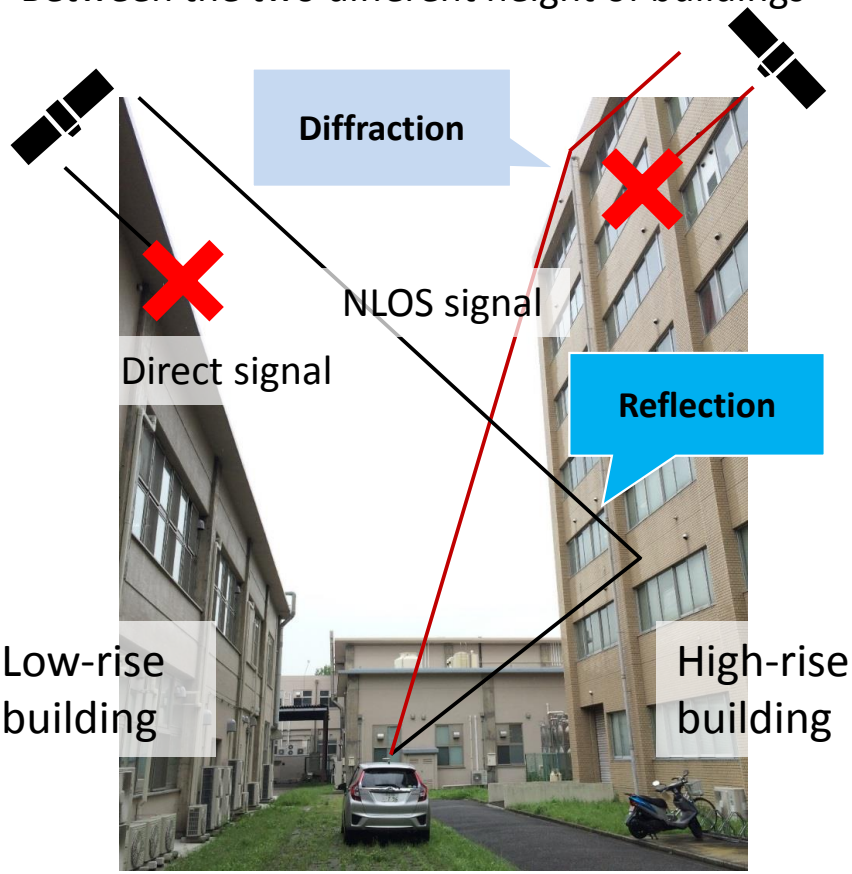
Huge errors

Caused by high-rise buildings

Multipath effects are problem for GNSS positioning
In dense urban environments

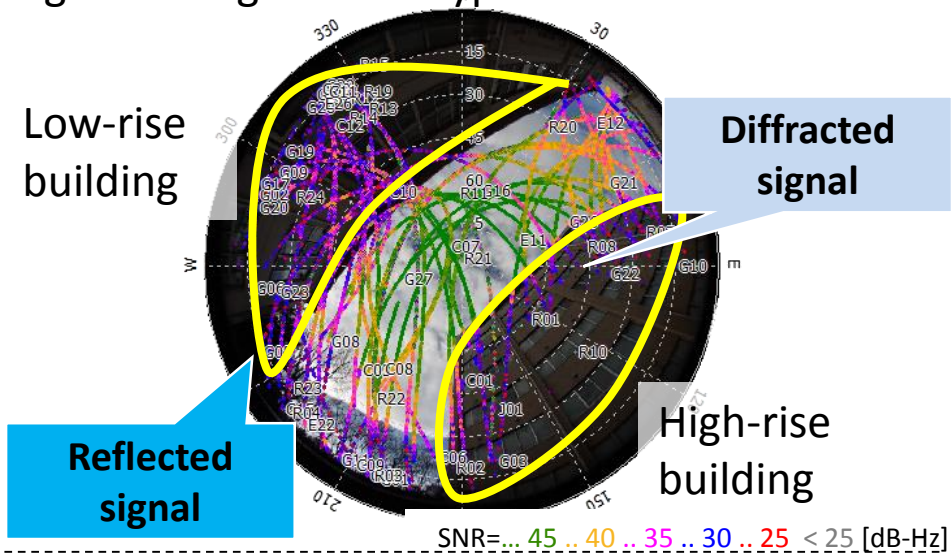
Two types of multipath effects by NLOS satellites

Between the two different height of buildings



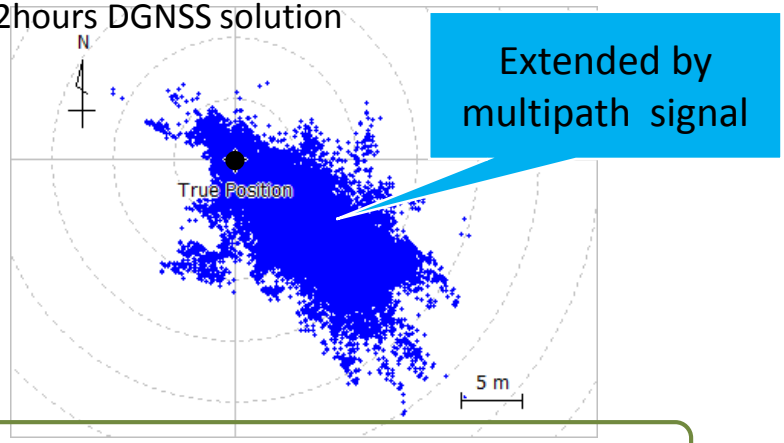
NLOS signal occurs Multipath errors (Non-line of sight)

Signal strength with skyplot



Results of DGNSS

12hours DGNSS solution



Mitigate the multipath errors by satellite selection methods

Background

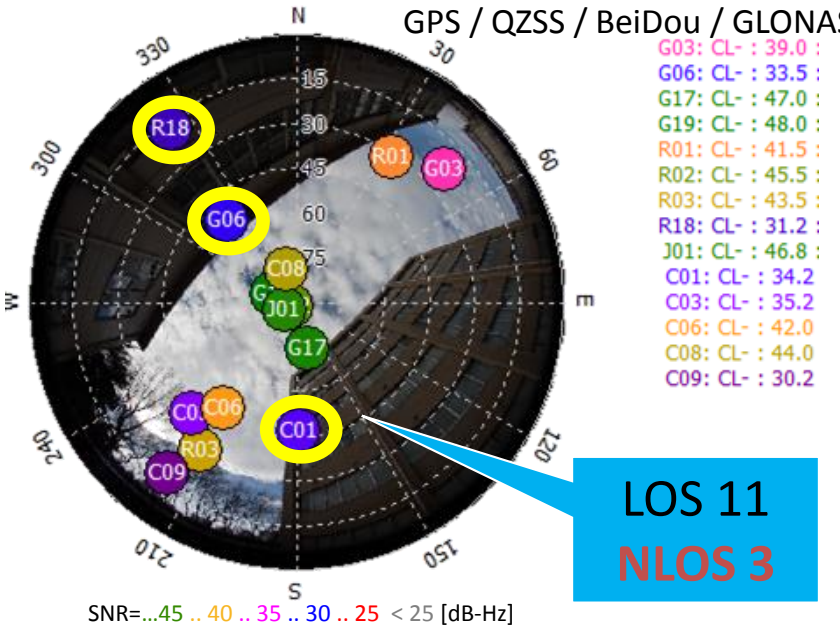
Increasing number of operational GNSS satellites

Increase the number of received satellites by multiple constellation

Satellite selection to exclude NLOS satellite

Improvement of positioning performance

Received satellites by observation data



One epoch of actual received signals
By the results of experiment

Chance to improve positioning performance using satellite selection method

Background

Conventional satellite selection methods

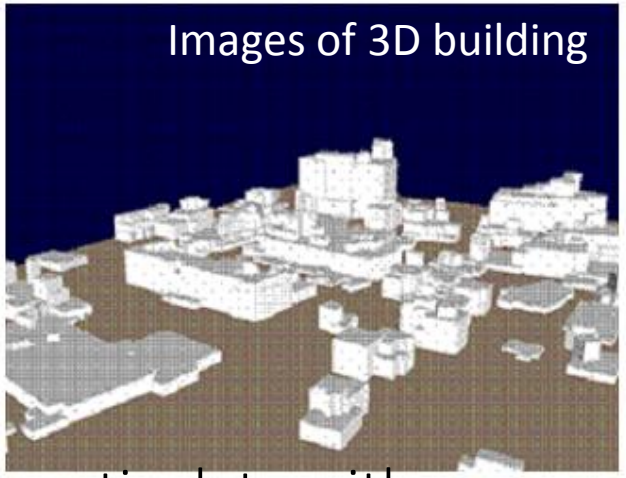
- The fisheye view image has been used for several researches

  Suzuki, T., Kitamura, M., Amano, Y., and Hashizume. High-accuracy GPS and GLONASS positioning by multipath mitigation using omnidirectional infrared camera. ICRA 2011

- Precise 3D building maps are being developed by companies and used for multipath mitigation

  Hsu, L. T., GU, Y., and Kamijo, S., 3D building model-based pedestrian positioning method using GPS/GLONASS/QZSS and its reliability calculation. GPS Solutions, 1-16.ISO 690

  Groves, Paul D., et al. Intelligent urban positioning using multi-constellation GNSS with 3D mapping and nlos signal detection. 2012



  - These methods are mainly discussed for kinematic data with code based positioning

    → We try to apply these methods for RTK-GNSS

- Signal strength observation to detect the multipath signal

  Suzuki, T., Kubo, N., and Yasuda, A., The possibility of the precise positioning and multipath error mitigation in the real-time. In The 2004 International Symposium on GNSS/GPS

Objective

Performance improvement for surveying

Target: Multipath mitigation for **surveying**

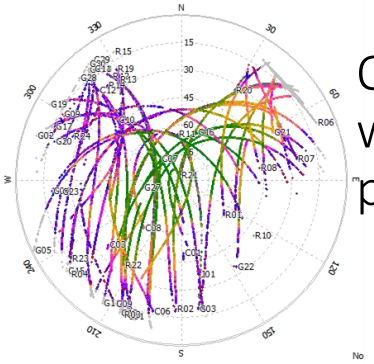
- cm-level positioning (RTK-GNSS)
- Use of Multi-GNSS
- Static positioning

Evaluation of conventional study of satellite selection method for RTK-GNSS

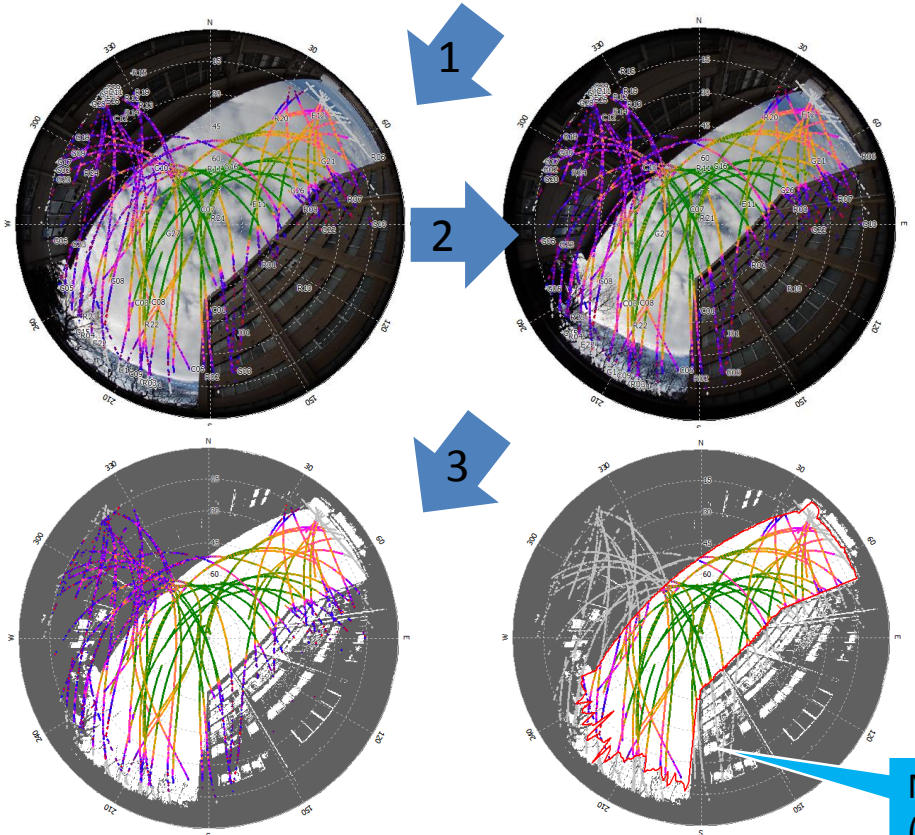
1. Mask based on fisheye view image
2. Mask based on precise 3D-map
3. Mask based on SNR measurements

Conventional satellite selection methods

1. Fisheye view images based mask



Observed signal strength with equidistant projection



SNR=... 45 .. 40 .. 35 .. 30 .. 25 < 25 [dB-Hz]

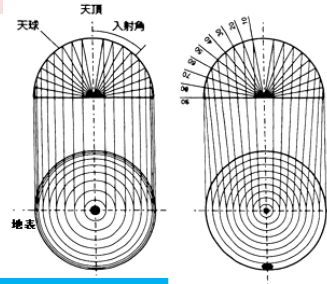
Procedure for making mask

1. **Azimuth adjustment**
2. **Projection adjustment**
   checkerboard calibrating tools for the initialization
3. **Mask Making**
   Binaries the image

RTKLIB
2.4.3 b5~

Open source software to make a mask with the fisheye view image

Projection



Mask: Red line
(Expressed by elevation for every 1 deg. Of azimuth)

Conventional satellite selection methods

2. Precise 3D-map based mask

Input data

- Precise 3D map (10cm accuracy)
- Estimated position by SPP
  (Several metres)

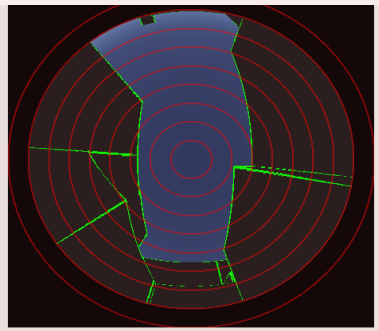
Output data

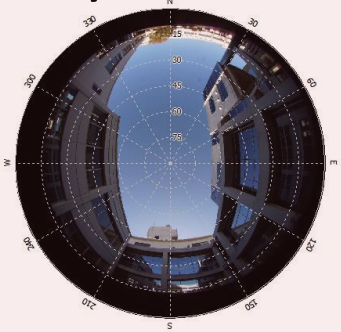
- Sky obstacles mask

Sky obstacles comparisons

By 3D map

By Fisheye view image





Software Screen shot

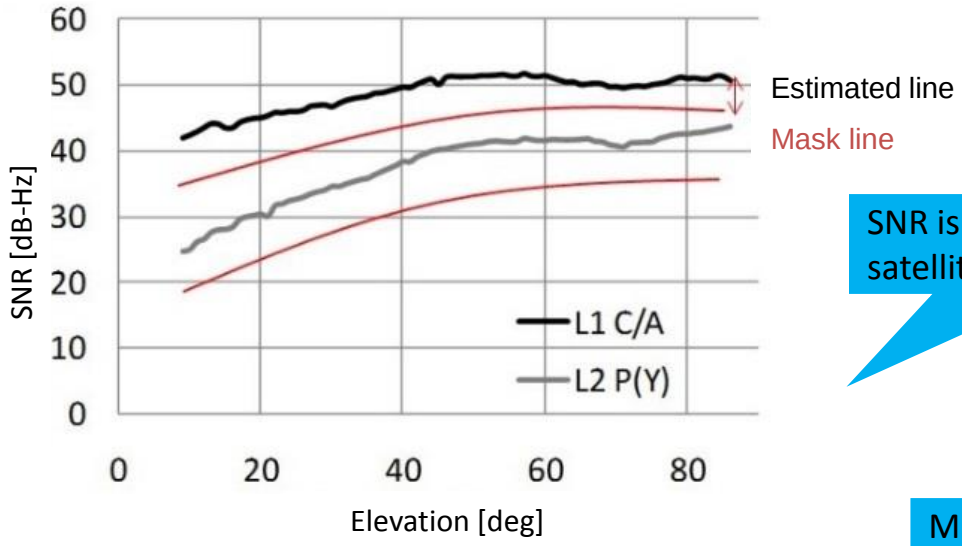
Expressed same tendency

By Dr. Suzuki of Waseda Institute for Advanced Study

Conventional satellite selection methods

3. SNR measurement quality check based mask

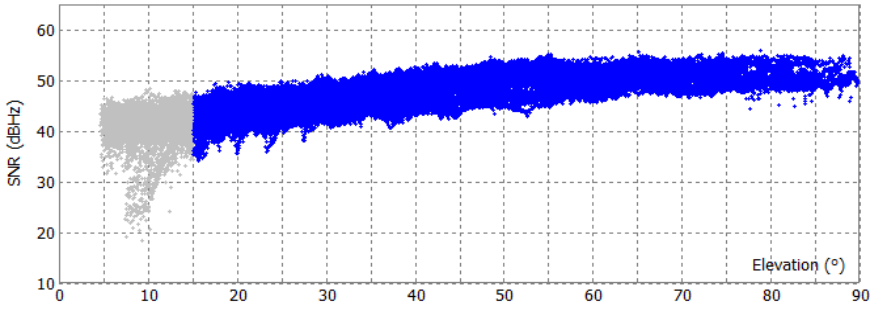
Elevation-SNR estimated line and Threshold line



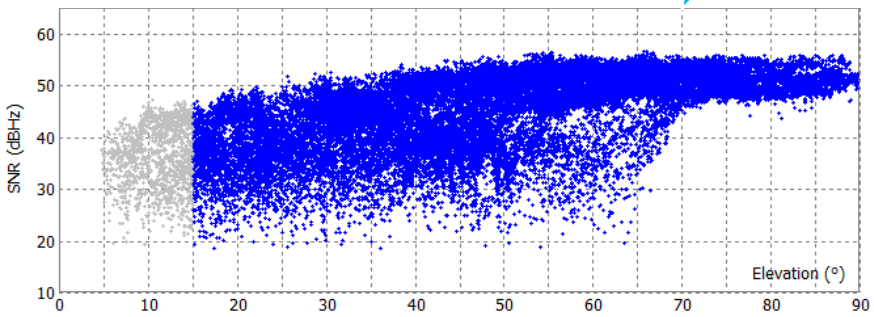
SNR is basically related to the satellite elevation angle

Multipath signal causes a reflection loss

24-hours SNR at base station (Open sky)



24-hours SNR at rover (Multipath environment)

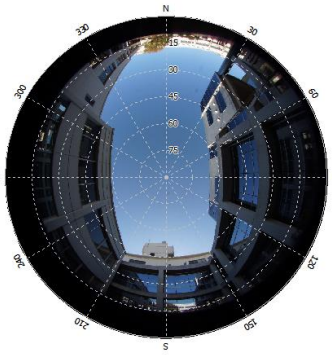


Testing and results

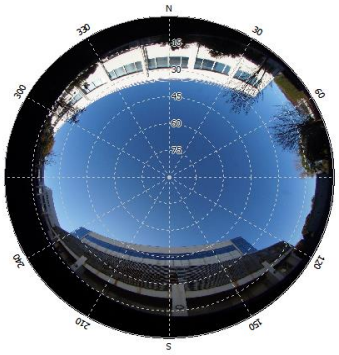
Outline of experiments

Fisheye view pictures of each testing environment

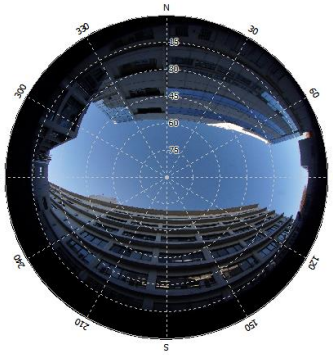
Point A



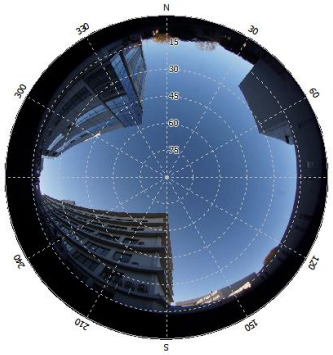
Point B



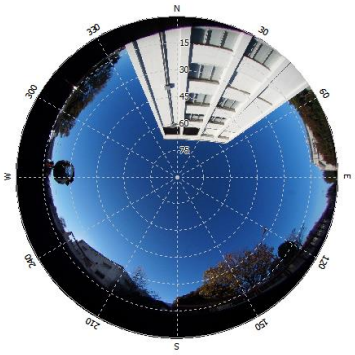
Point C



Point D



Point E



＊North side up

- Instantaneous RTK-GNSS

(Without any filter, hold technique)

- Double frequency observations
- GPS/QZSS/BeiDou

Analyse conditions

AR: LAMBDA Methods with Ratio test
(Fixed threshold for over 3)

Elevation mask: Over 15 degrees

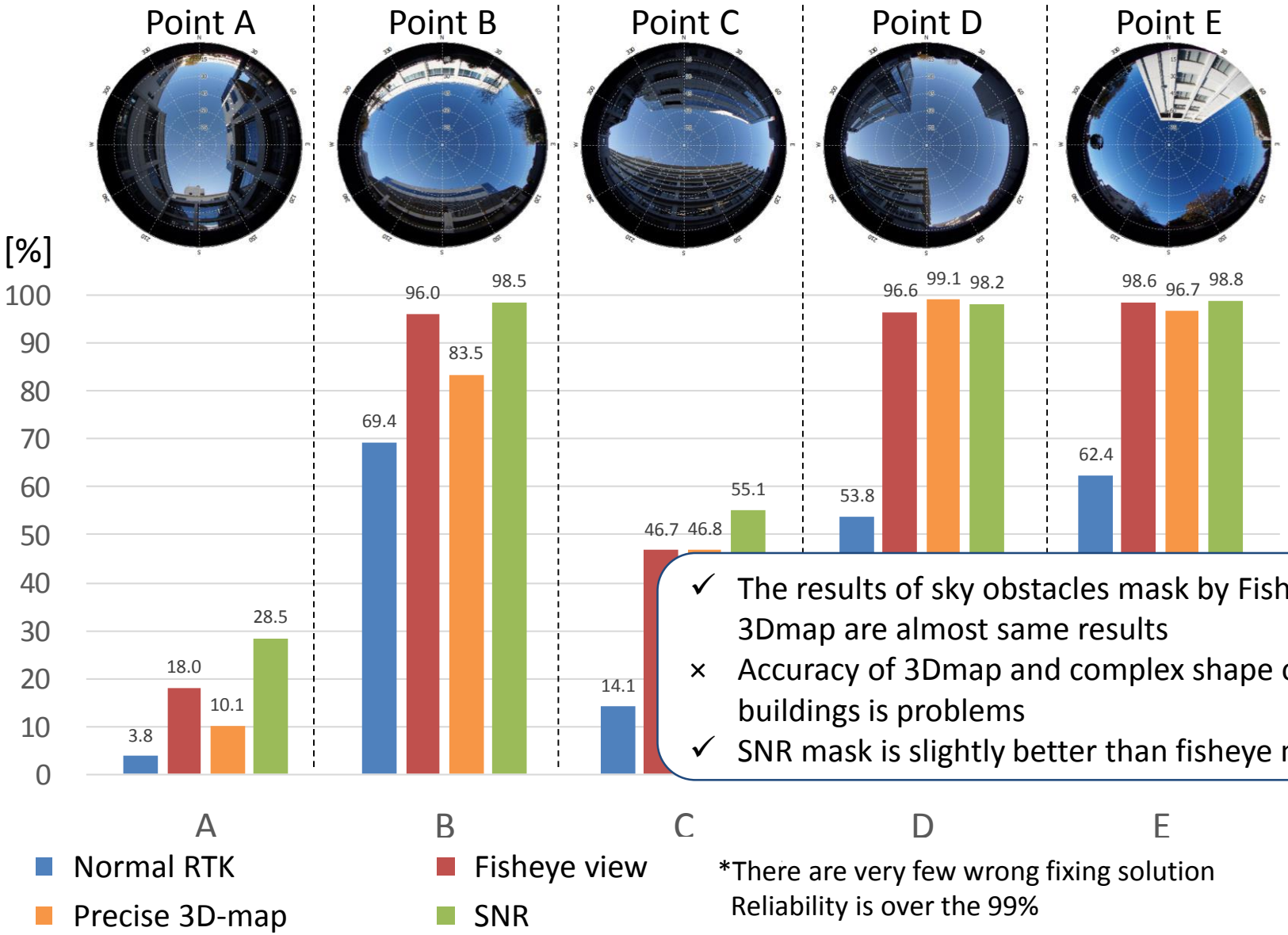
Short baseline (within 1 Km)

	24hours data at each point
Period	A 2015-12-09 07:09:30～ 12-10 07:05:30
	B 2015-12-22 07:53:30～ 12-23 07:53:00
	C 2015-12-09 07:09:30～ 12-10 07:09:00
	D 2015-12-21 06:54:00～ 12-22 06:53:30
	E 2015-12-21 06:54:00～ 12-22 06:53:30
Receivers	Base / Rover : JAVAD DELTA
Antenna	JAVAD GrAnt-G3T

Testing and results

Availability results of each point

$$\text{Availabitliy} = \frac{Fix\ solution}{Total\ epoch}$$



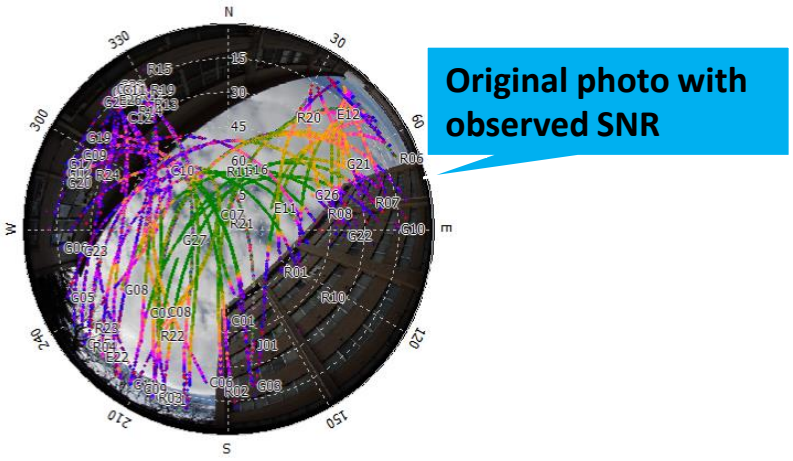
- ✓ The results of sky obstacles mask by Fisheye and 3Dmap are almost same results
- × Accuracy of 3Dmap and complex shape of the buildings is problems
- ✓ SNR mask is slightly better than fisheye mask

*There are very few wrong fixing solution
Reliability is over the 99%

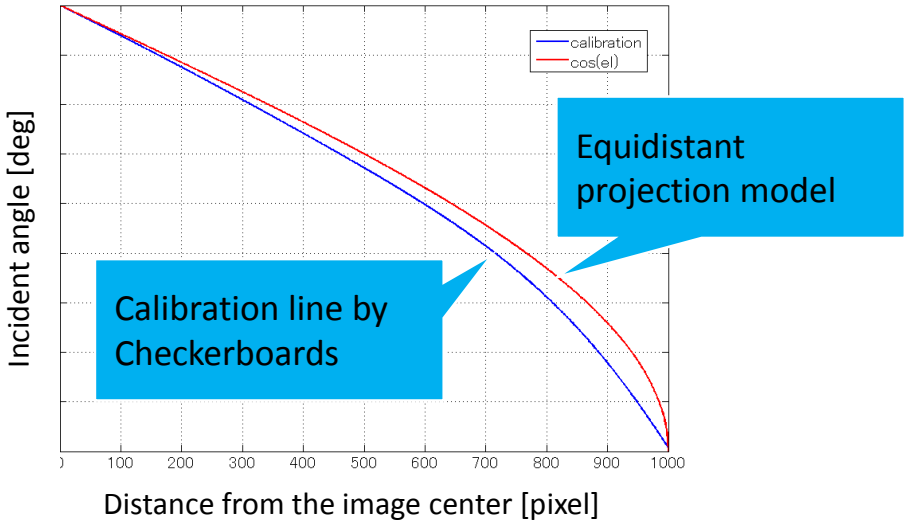
Fisheye view mask

The important point to make a mask with fisheye view image

- Lens calibration
  - Checkerboard is used to obtain the Initial calibration value
- Important points to take a photo
  - Using the camera is difficult to set up to the true north
  - The camera has to be set up at the same place as the antenna with same posture



Original photo with observed SNR



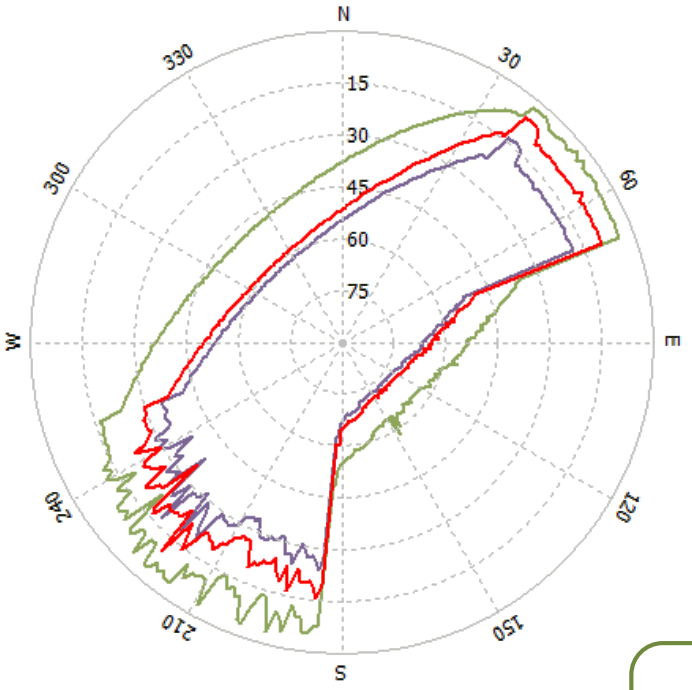
Equidistant projection model

Calibration line by Checkerboards

Fisheye view mask

Effects of lens calibration

- 12hours static data
- GPS/QZSS/BeiDou/GLONASS
- Instantaneous RTK-GNSS

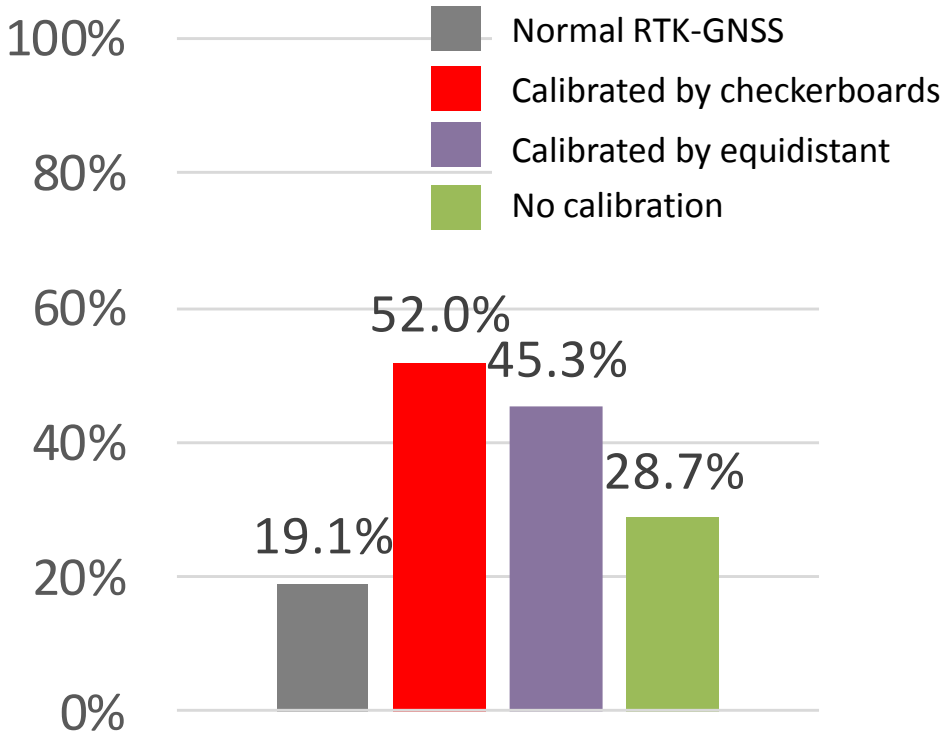


No calibration

Calibrated by equidistant

Calibrated by Checkerboards

The results of each calibration model



NLOS exclusion by fisheye view required precise calibration

Testing and results

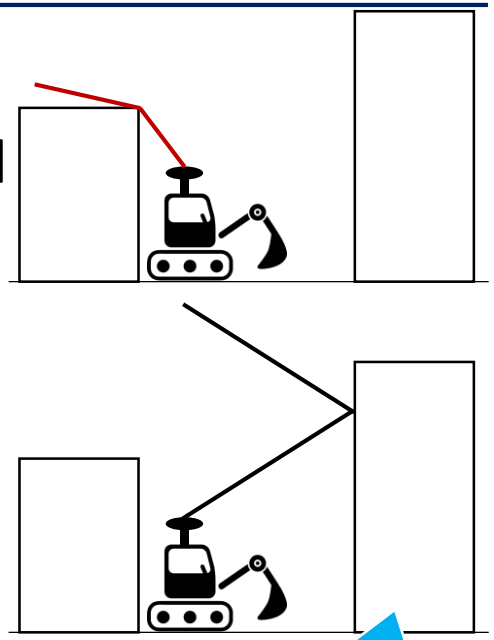
Characteristic for the methods

1. Fisheye view mask
   - ✓ Density of sky obstacles for both buildings and trees
   - ✓ More realistic: same environment as antenna
   - × Making mask procedure is manually
   - × Initial correction for each lens to adjust projection
   - × Not realistic
2. Precise 3D map mask
   - ✓ Making masks automatically in advance
   - × Trees, distant buildings and complicated shape buildings
   - × Depends on accuracy of input position and 3Dmap
   - × Limited to the place that exist of precise 3Dmap
3. SNR mask
   - ✓ No need for external data
   - × Preparation for each estimated line of receiver and satellite systems

Testing and results

How is the effect of mitigating for two types of multipath?

- Diffracted signals by NLOS
  - As a result of previous experiments, diffracted signals can be excluded correctly.
- Reflected signals by NLOS
  - Because of the building height is almost same, the effect of reflected signal is relatively low.
  - However, there is the situation that received strong reflected signals by NLOS
  - SNR mask is difficult to detect these reflected signals

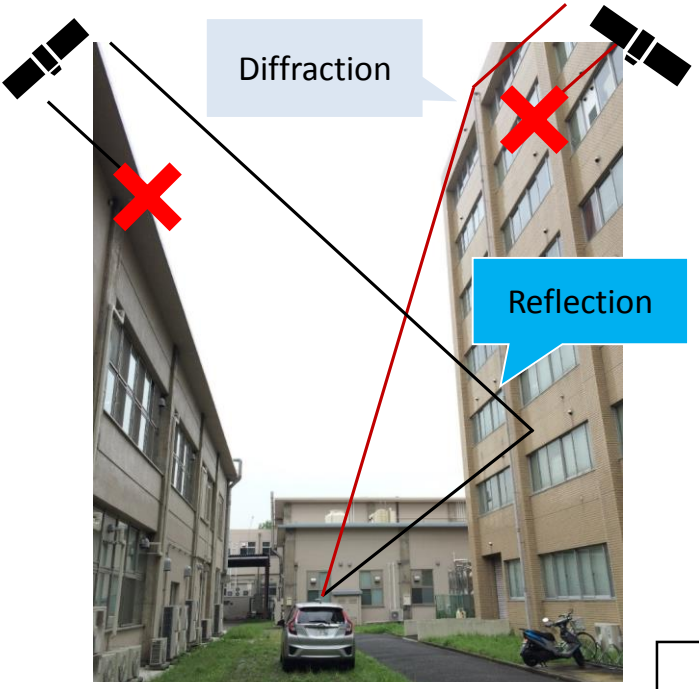


Strong reflected signals are difficult to mitigate

- We investigated to know the proper performance under this situation
- Additional experiments were performed

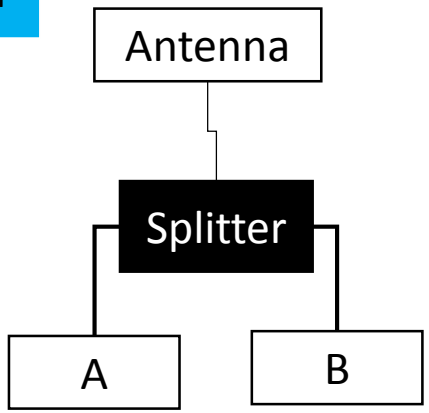
Testing and results at NLOS environments

Outline of new experiments



Testing environment

Specific environment that the receivers force to receive strong reflected signal by NLOS satellites



Conditions

- Instantaneous RTK-GNSS

(Without any filter, hold technique)

- Double frequency observations for GPS/QZSS/BeiDou/GLONASS

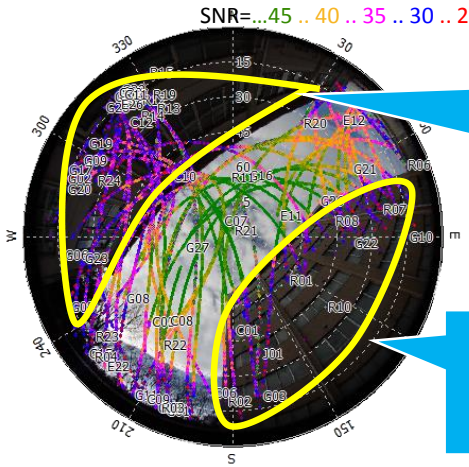
Analyse conditions

AR: LAMBDA Methods with Ratio test (Fixed threshold for over 3)

Elevation mask: Over 15 degrees

Short baseline (within 1 Km)

Receiver Base/Rover: A, B



Powerful reflected signals were contentiously received

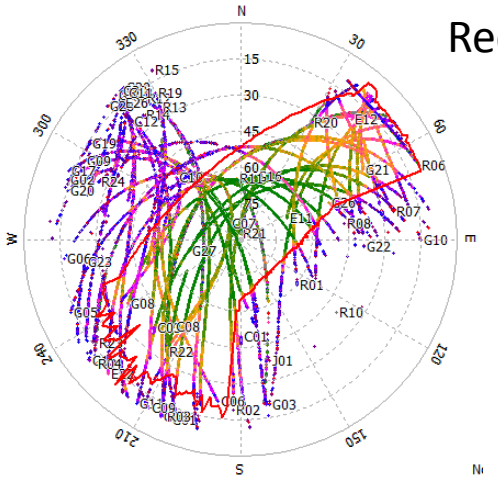
Diffracted signals are relatively few

Satellite selection methods

1. Fisheye view mask
2. SNR mask

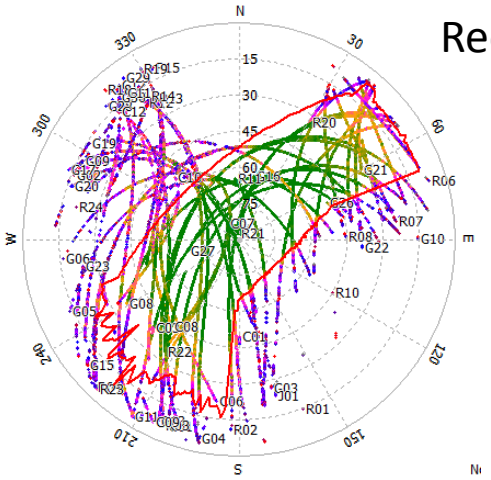
Testing and results at NLOS environments

Availability results of both receivers



Receiver A

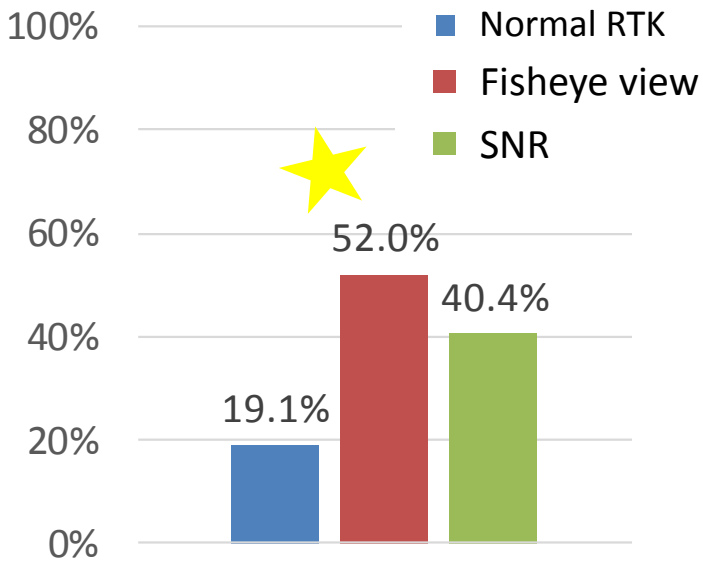
Ave SV
All 11.4
GJ 4.3
C 3.8
R 3.3

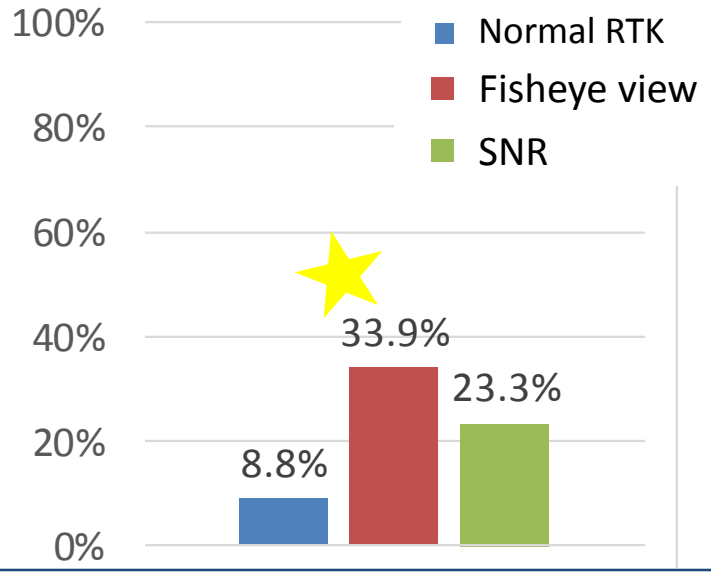


Receiver B

Ave SV
All 12.4
GJ 4.7
C 3.8
R 3.8

SNR=... 45 .. 40 .. 35 .. 30 .. 25 < 25 [dB-Hz]

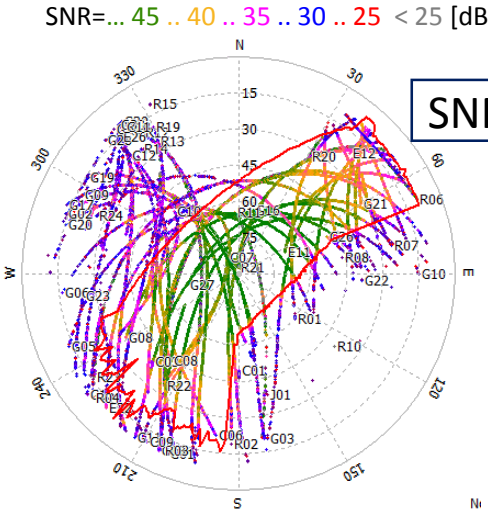




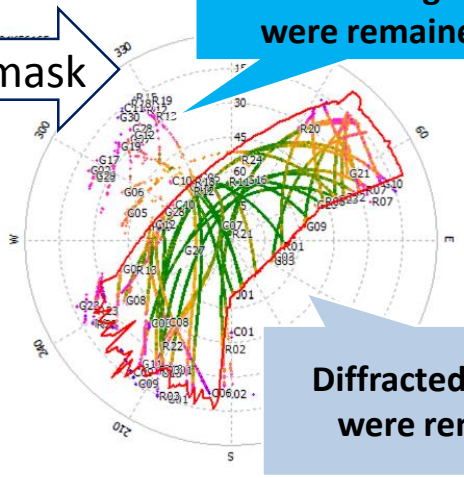
✓ As expected, Fisheye view mask is more efficient to exclude multipath signal
We improved SNR mask based on the fisheye view mask..

Testing and results at NLOS environments

Remaining SNR observations of reflected signal



SNR mask

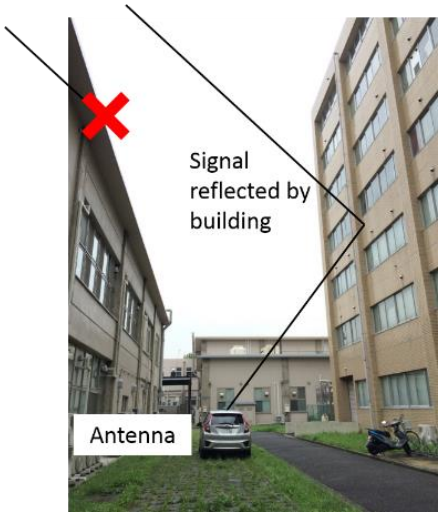


Lots of strong reflected signals were remained

Diffracted signals were removed

Observed SNR

Applying SNR mask

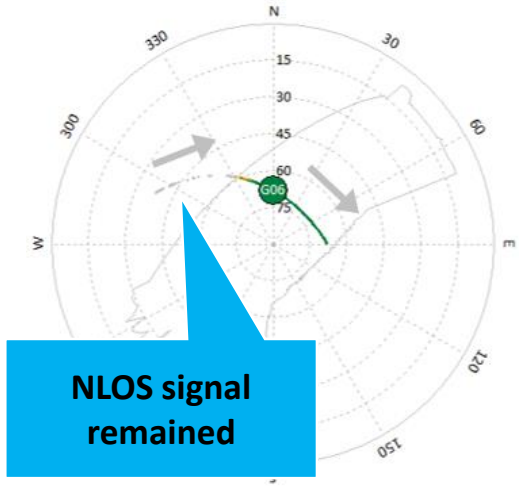


The remaining SNR was analyzed based on fisheye view mask

- Conventional SNR mask cut off lower SNR below the line

Improved satellite selection method focused on variation

Strong reflection signal

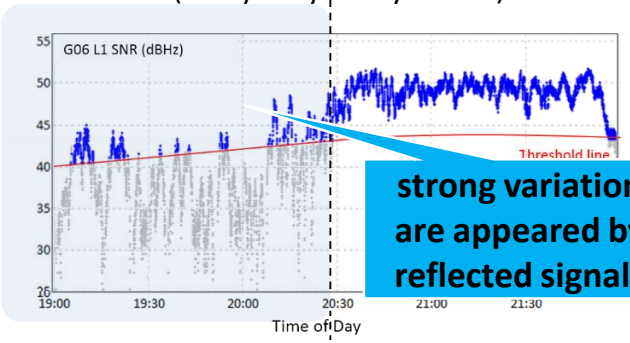


NLOS signal remained

Time series of SNR

NLOS LOS

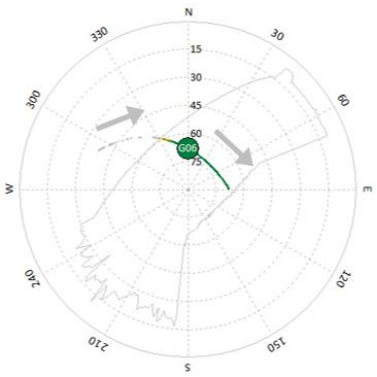
(Analyse by fisheye mask)



strong variation are appeared by reflected signals

Testing and results at NLOS environments

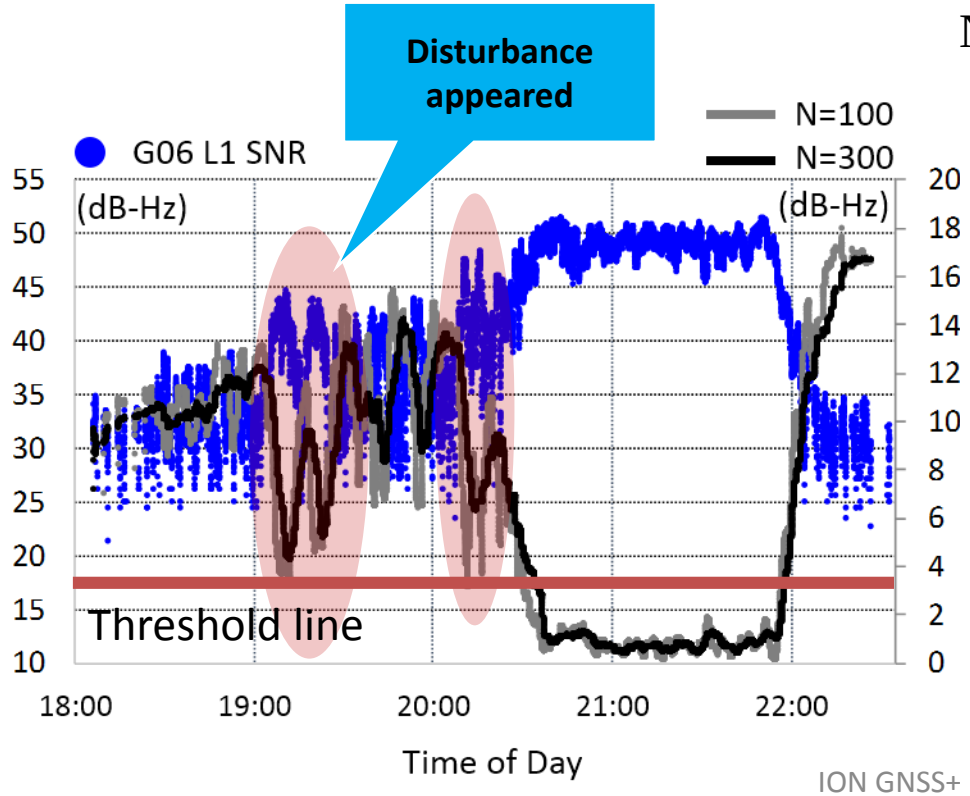
Proposed new SNR based satellite selection methods



$$v(t_i) = SNR(t_i)_{ele} - SNR(ele) \qquad (1)$$

$$V(t_i) = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(v(t_i))^2} \qquad (2)$$

N is the averaging window size.



1. Take the difference between Estimated SNR line and observed SNR (1)
2. Calculate the backward moving average over the N epoch (2)

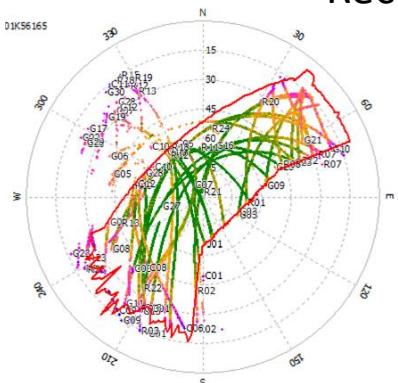
- ✓ Huge SNR degradation is able to be distinguished
- ✓ Effectively for continuously received reflected signal

Testing and results at NLOS environments

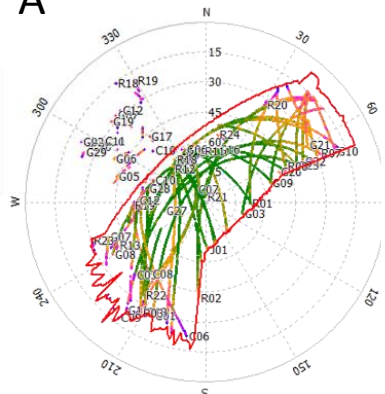
New results of proposed method

SNR=... 45 .. 40 .. 35 .. 30 .. 25 < 25 [dB-Hz]

Receiver A

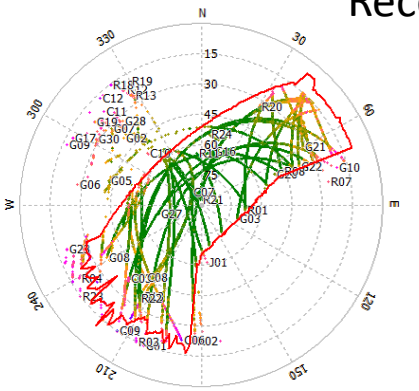


SNR mask



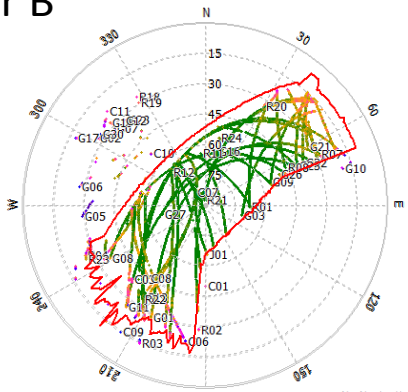
New SNR mask

Receiver B



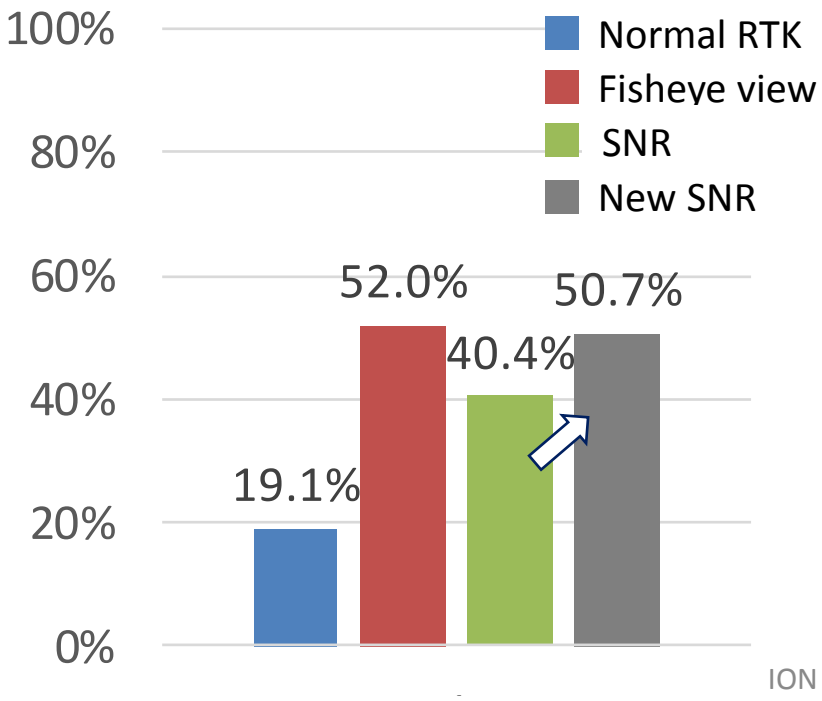
SNR mask

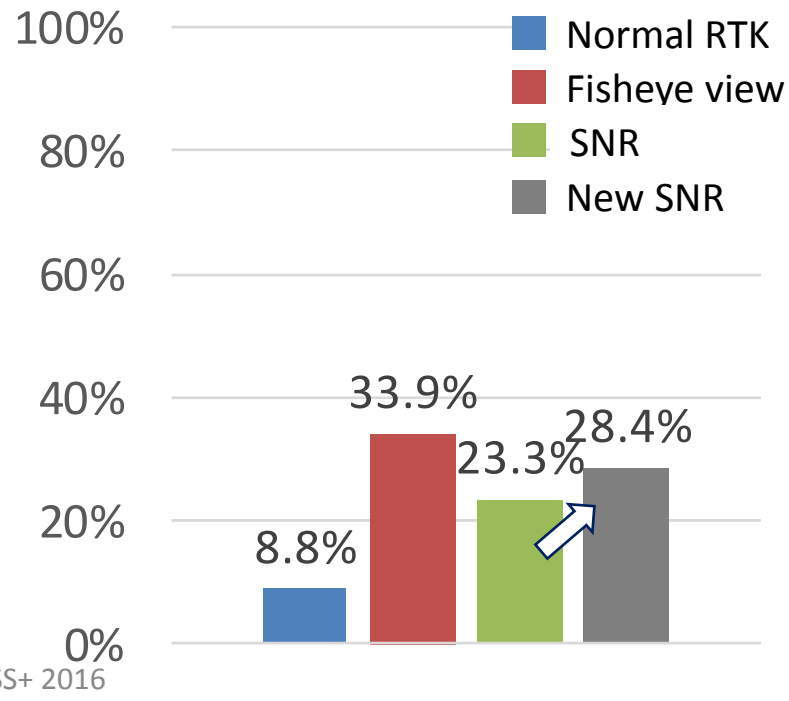
No Navigation Data



New SNR mask

No Navigation Data





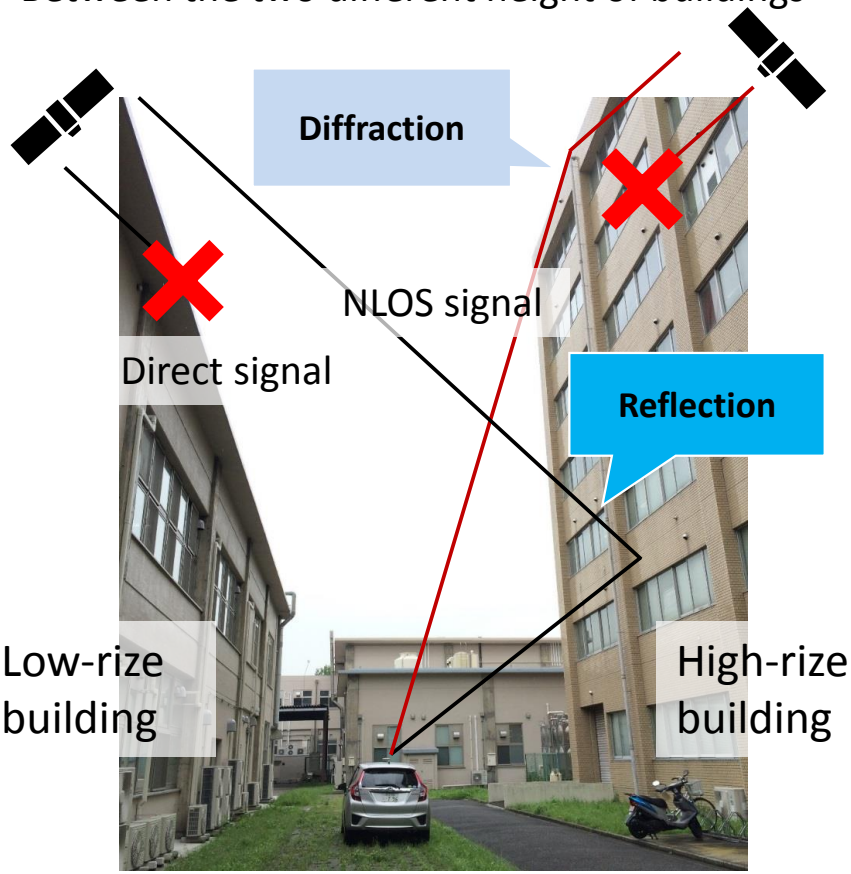
Conclusion

- 3 methods were evaluated at the static positioning
  - Sky obstacles mask by precise 3D-map showed almost the same performance as a fisheye view mask
  - The SNR based mask is the powerful and effective method to remove the quality deterioration signal
  - Availably results of applying conventional methods are improved more than 2 times
- Additional experiments for the strong reflected signal
  - As expected, fisheye view exclusion improved powerfully than SNR
  - New SNR mask was proposed to refer the fisheye view mask
  - The proposed SNR mask is able to be excluded strong reflected signal

Thank you for your attention!

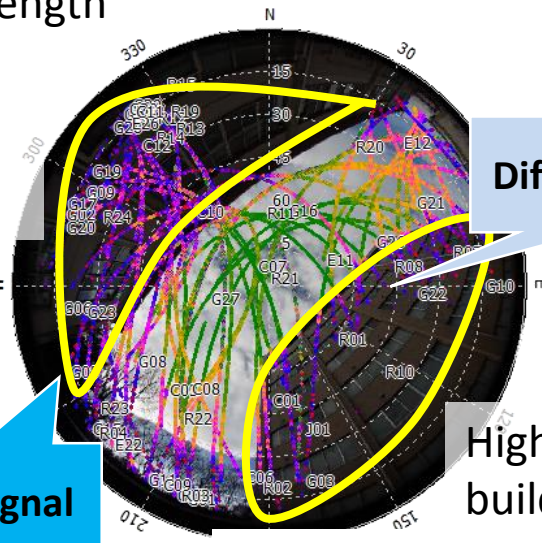
Two types of multipath effects by NLOS satellites

Between the two different height of buildings



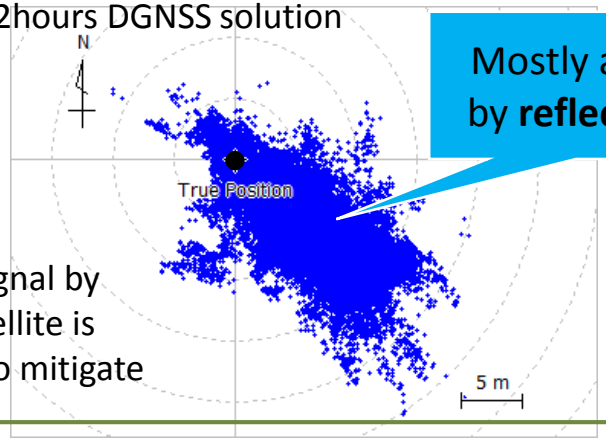
Multipath occurs by NLOS signal (Non-line of sight)

Signal strength



Multipath errors in Pseudorange

12hours DGNSS solution

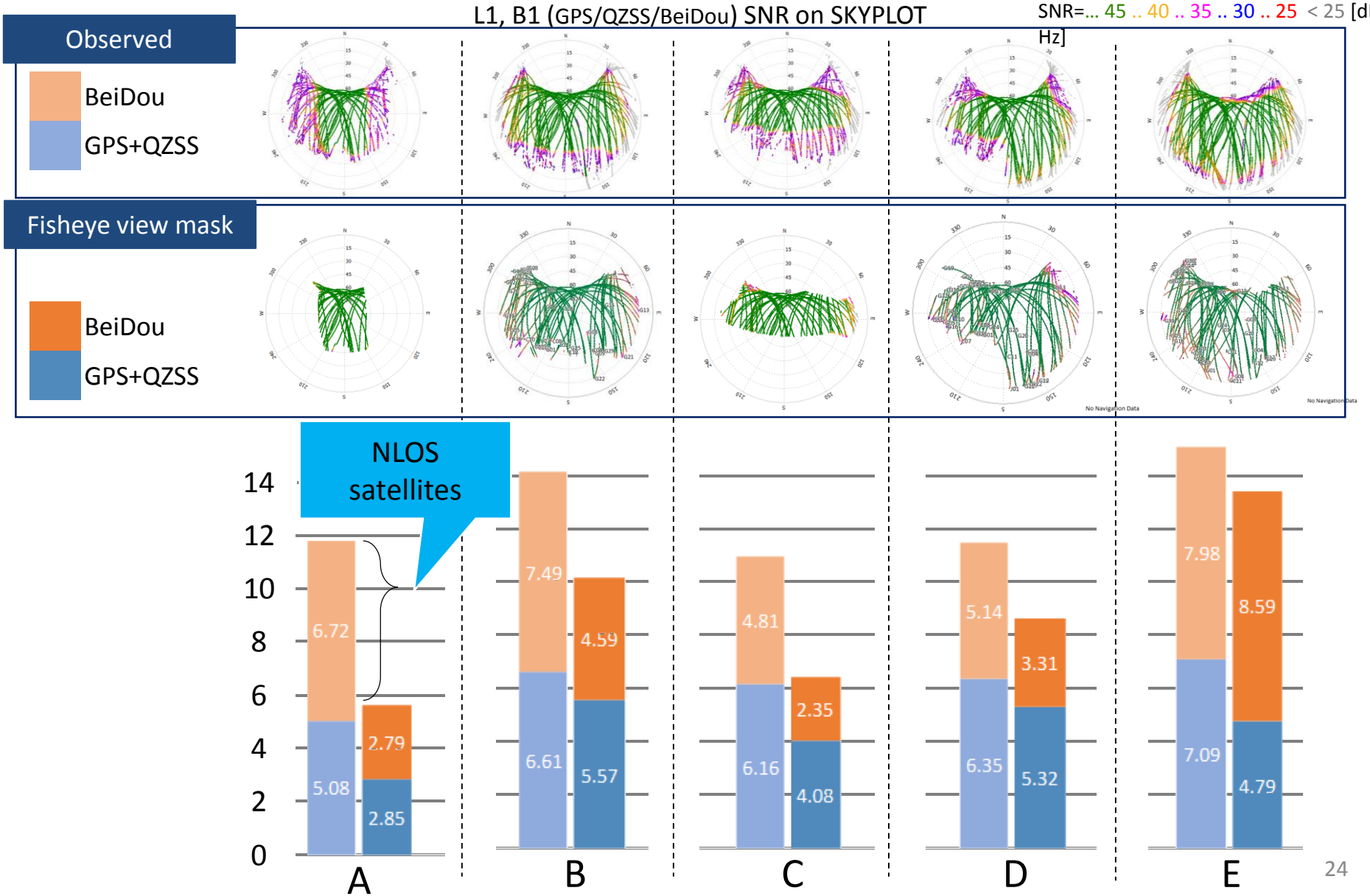


Reflect signal by NLOS satellite is difficult to mitigate

Satellite selection to exclude NLOS is effective

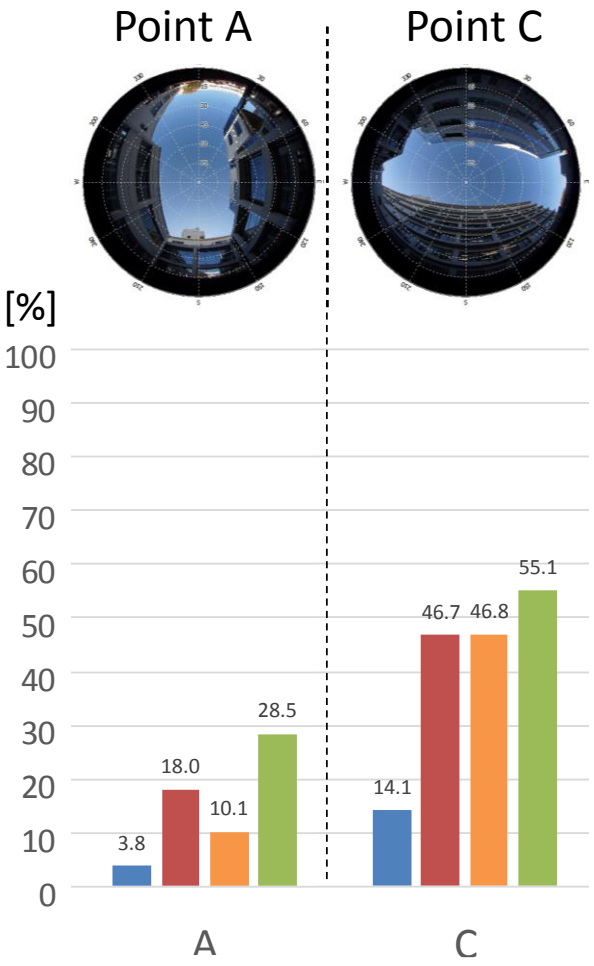
Testing and results

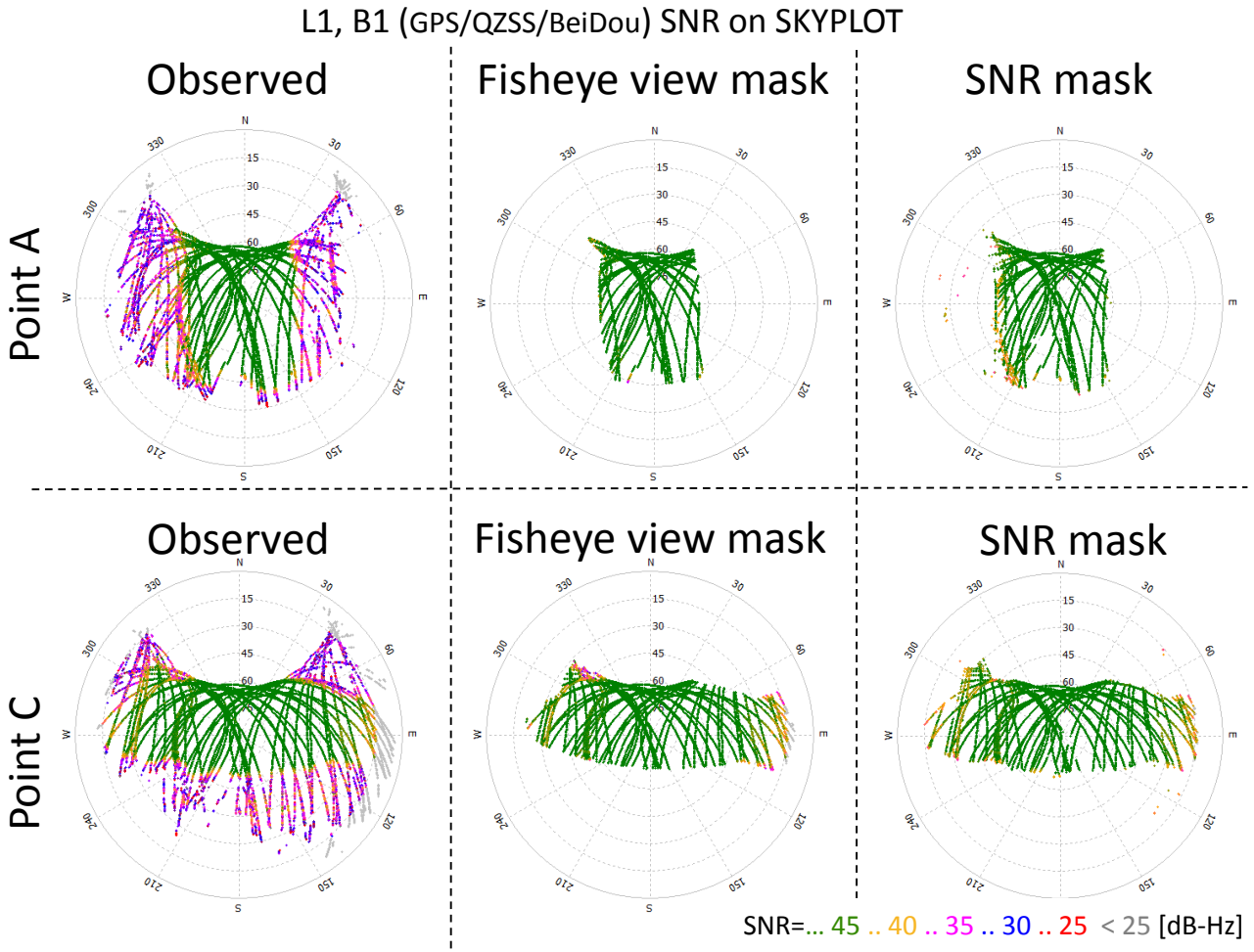
Number of satellite comparison



Testing and results

Fisheye mask and SNR mask comparison (L1, B1)





✓ Clearly degraded SNR was removed by SNR mask under this situation