POSITIONING SIMULATION USING A 3D MAP AND VERIFICATION OF POSITIONAL ESTIMATION ACCURACY IN URBAN AREAS USING ACTUAL MEASUREMENT

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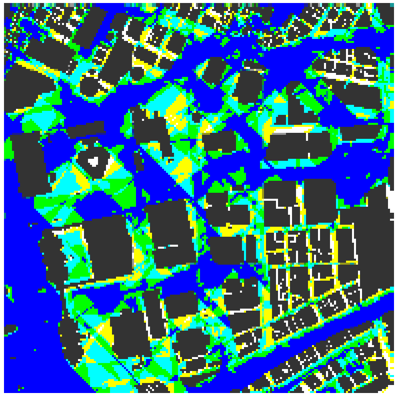
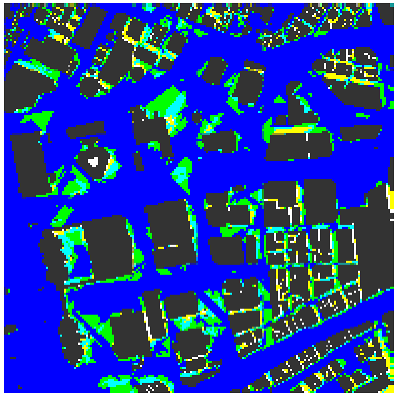
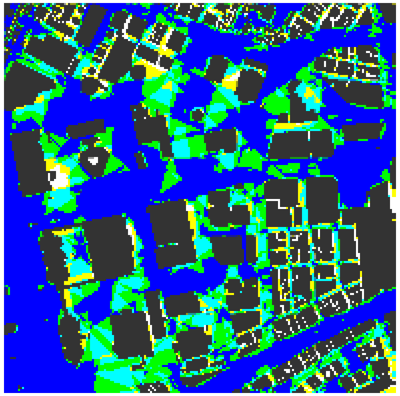
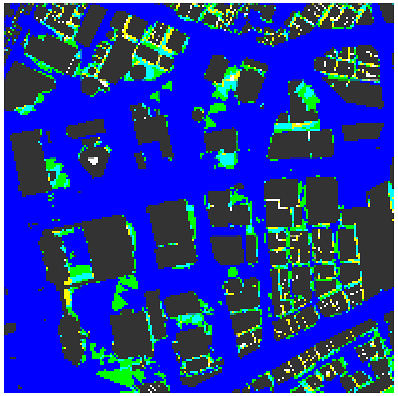
INTERNATIONAL

Motivation

- GPS/GNSS is one of the candidates of positioning sensors for ITS applications.
- Position accuracy of GPS/GNSS has been evaluated for many players under various conditions for a long time.
- However, it is difficult to conduct 24 hours actual running tests and the results strongly depend on the measurement time and location.
- If we could simulate the performance of GPS/GNSS as correctly as possible, it is significantly helpful for R&D in GPS/GNSS

How Japanese 3 QZS s contribute the availability of GNSS ?

Map of the Number of Visible Satellites

Time	GPS - only	GPS + QZSS
00:00		
03:00		

Shinjuku in Tokyo
(very dense urban areas)

Ph.D thesis by Dr. Suh at the University of Tokyo (2004)

Contents

1. Error sources and positioning of GNSS

2. Test vehicle with a high-accuracy position

3. 3D Map and ray-tracing method

4. Test and results

5. Summary

Typical Error Sources of GNSS

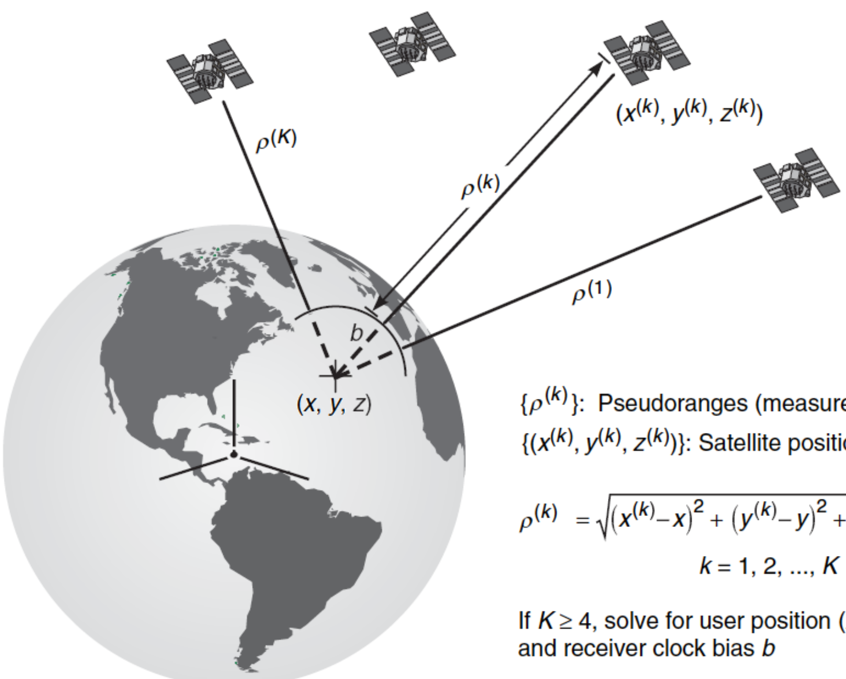
Source	Potential error size	Error mitigation using DGNSS
Satellite clock model	2 m (rms)	0.0 m
Satellite ephemeris prediction	2 m (rms) along the LOS	0.1 m (rms)
Ionospheric delay	2-10 m (zenith) Obliquity factor 3 at 5°	0.2 m (rms)
Tropospheric delay	2.3-2.5m (zenith) Obliquity factor 10 at 5°	0.2 m (rms) + altitude effect
Multipath (open sky)	Code : 0.5-1 m Carrier : 0.5-1 cm	→
Receiver Noise	Code : 0.25-0.5 m (rms) Carrier : 1-2 mm (rms)	→

Multipath error is the most difficult source to mitigate….

Positioning Performance of GNSS

Positioning Performance = <u>Measurements Accuracy</u> × <u>DOP</u>

6 error sources in the previous slide



$\{\rho^{(k)}\}$: Pseudoranges (measurements)

$\{(x^{(k)}, y^{(k)}, z^{(k)})\}$: Satellite positions (known)

$$\rho^{(k)} = \sqrt{(x^{(k)}-x)^2 + (y^{(k)}-y)^2 + (z^{(k)}-z)^2} - b$$

$$k = 1, 2, \ldots, K$$

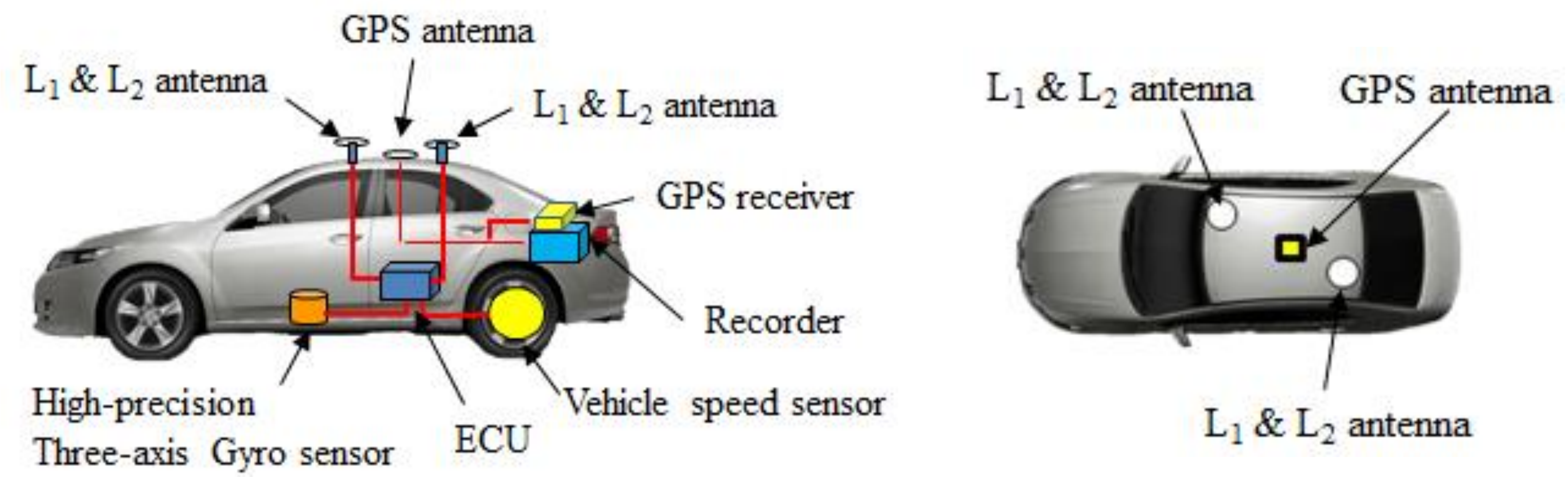
If $K \geq 4$, solve for user position (x, y, z), and receiver clock bias b

Bad news in GNSS

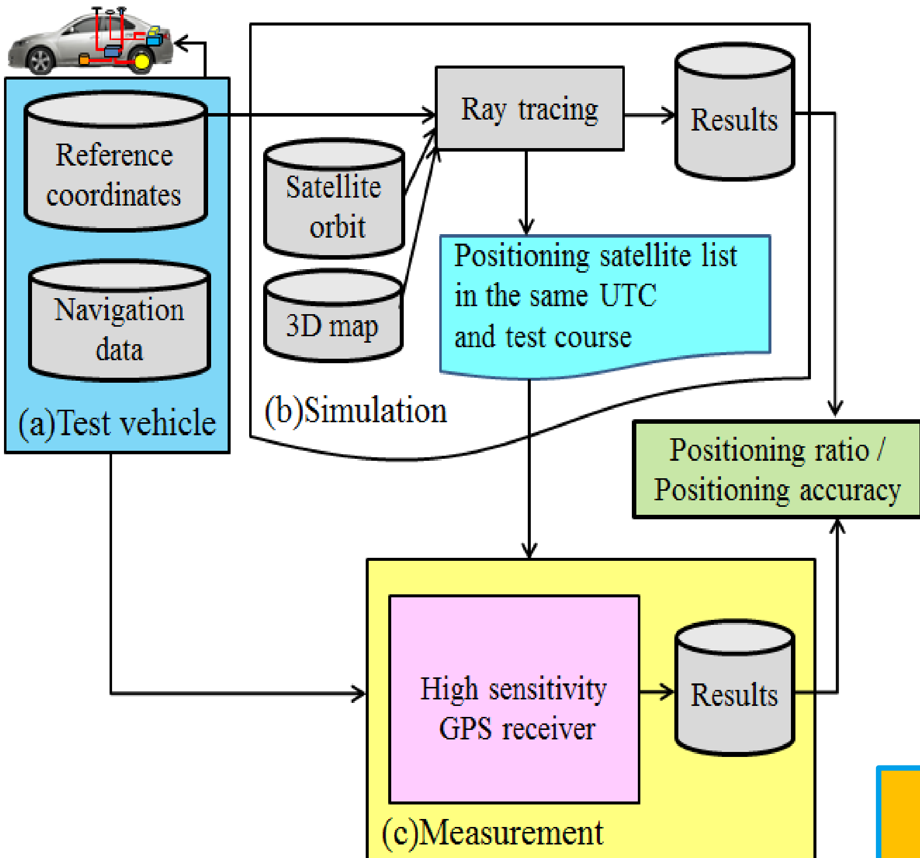
In the dense urban areas, multipath errors and DOP Increases simultaneously !

Test Vehicle equipped with POSLV

- POSLV provides a reliable and repeatable positioning solutions for land-based vehicle applications.
- Without reliable accurate positions (mostly 10cm accuracy), it is impossible to evaluate the errors of GNSS. Simulation also requires accurate position which means target position.



Block Diagram of this Study



Conventional positioning

<u>Test vehicle</u> : produces the reference positions

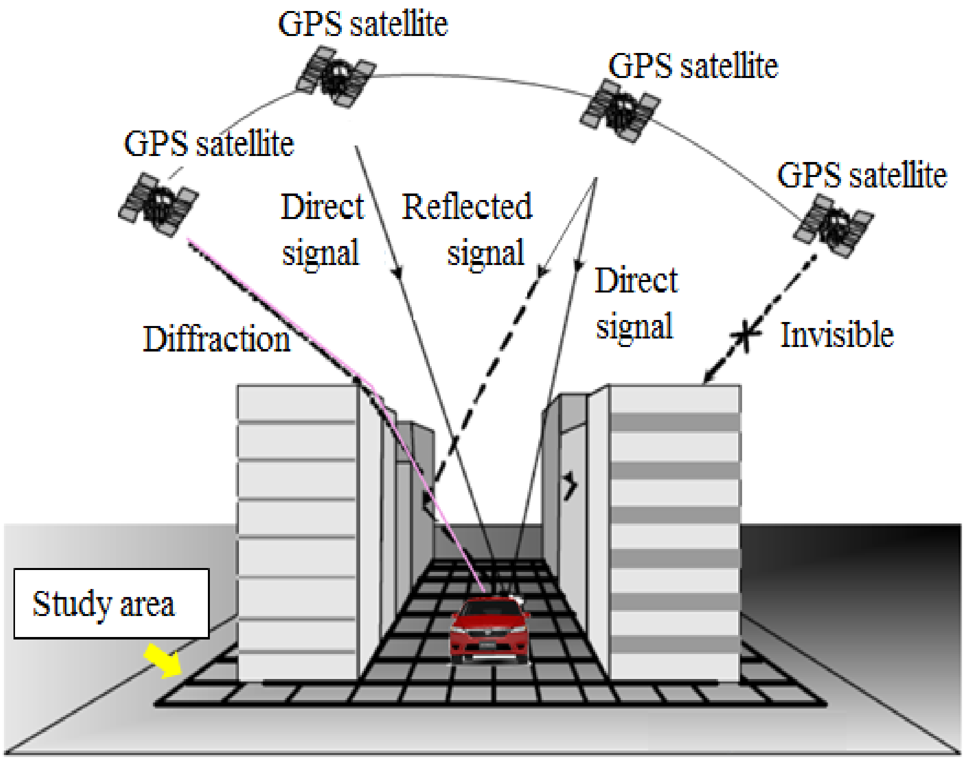
<u>Simulation</u> : Simulates positions using 3D map, satellite orbit and ray tracing

<u>Measurement</u> : Real performance of commercial receivers

Finally, <u>we compared the position errors between simulation and measurement</u>

Comparison! How does Simulation work ?

Simulation Method

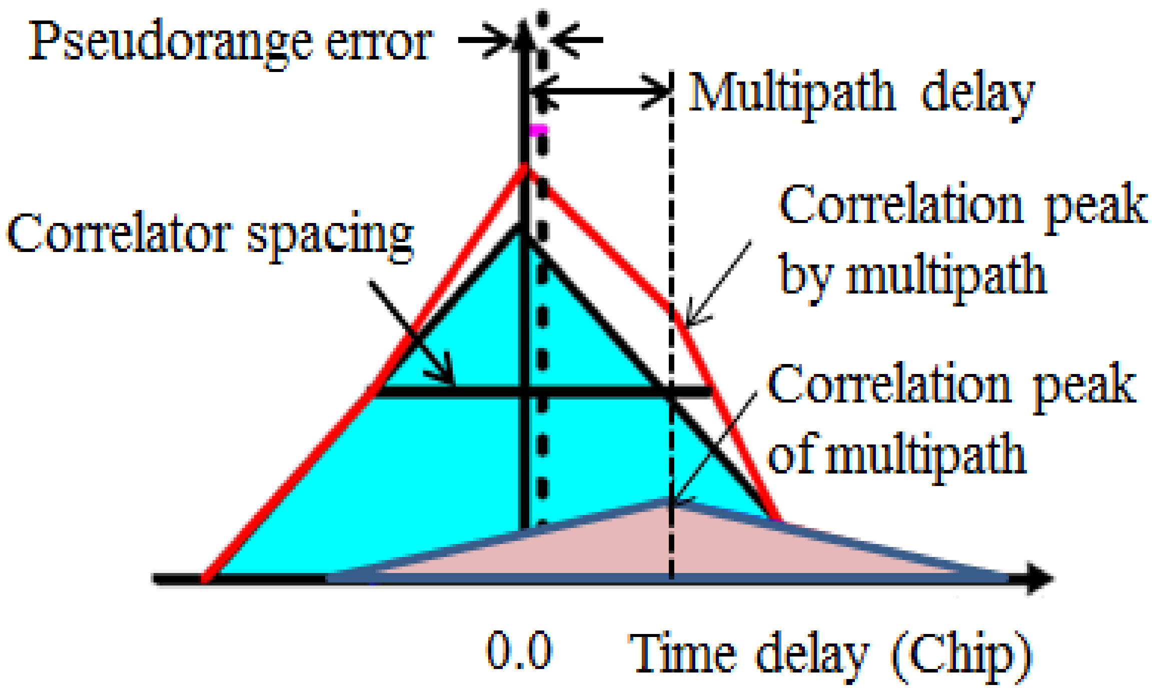


- **3D map :** **produced by laser. Overall accuracy is about 1 m**
- **Satellite orbit :** **Ephemeris**
- **Ray tracing :** **typical propagation model including diffraction and reflection**

http://www.kke.co.jp/en/

How do we simulate multipath errors ?

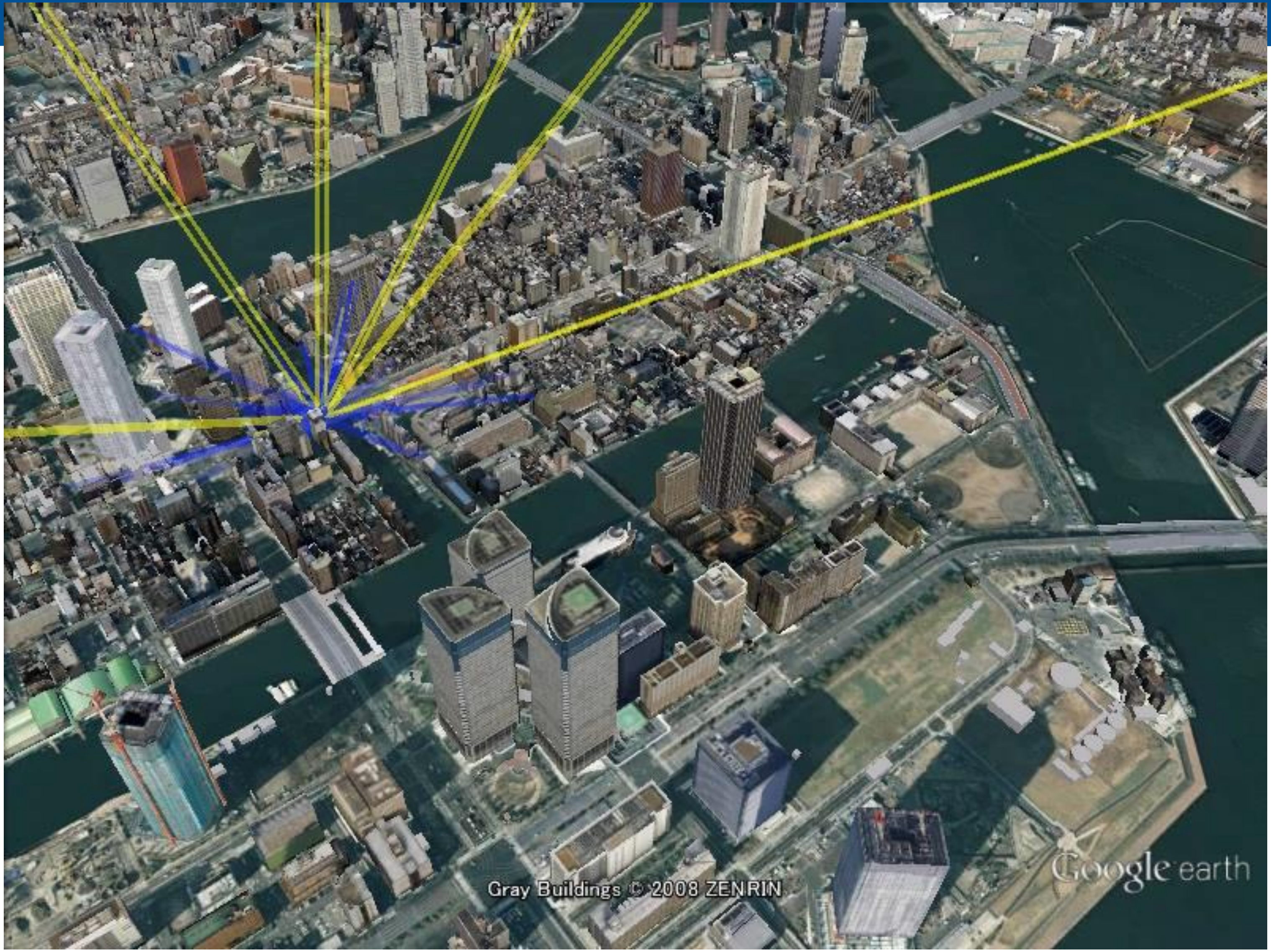
- **All we need is simulated "amplitude", "delay" (phase) of all rays including direct and multipath wave (reflection and diffraction)**



With LOS signal, the way to estimate multipath errors is shown in the above figure.

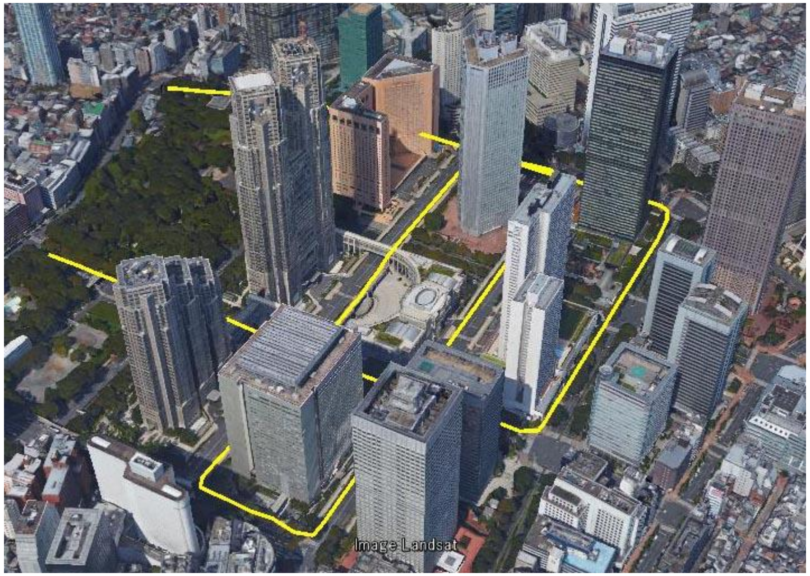
In the case of NLOS signal, we just calculate the errors between true range and simulated range.

Image of the Ray Tracing Simulation



http://www.kke.co.jp/en/

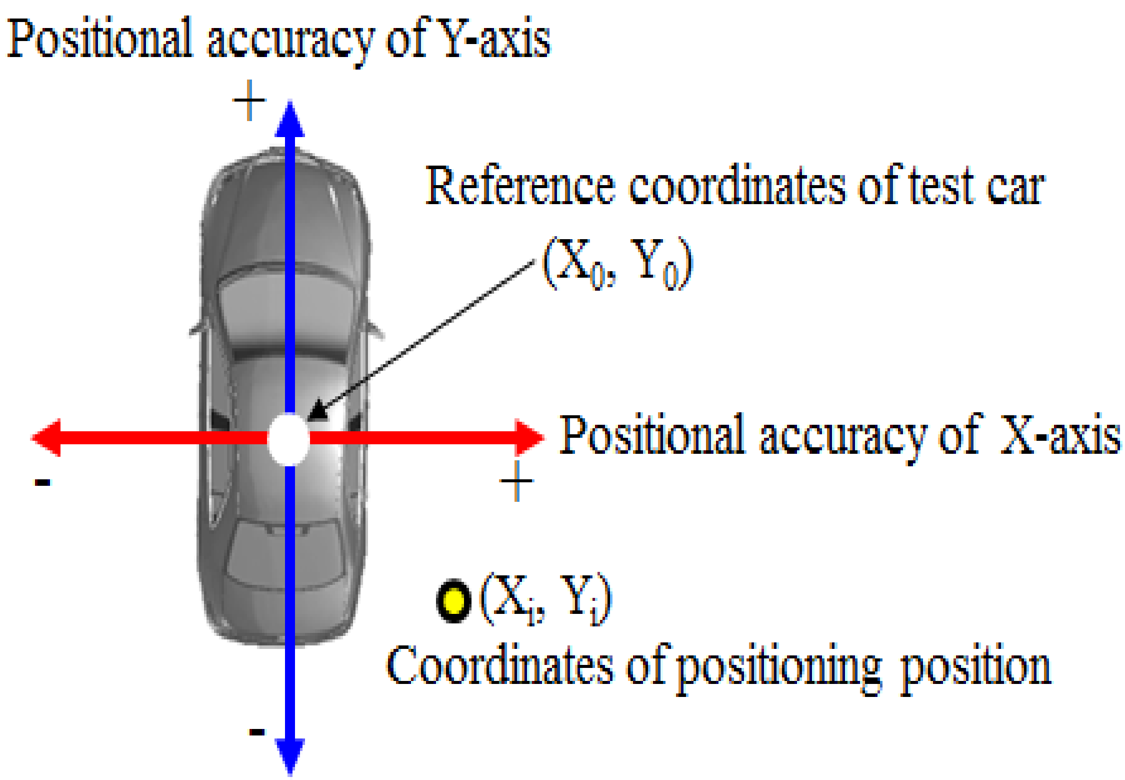
Test Configuration

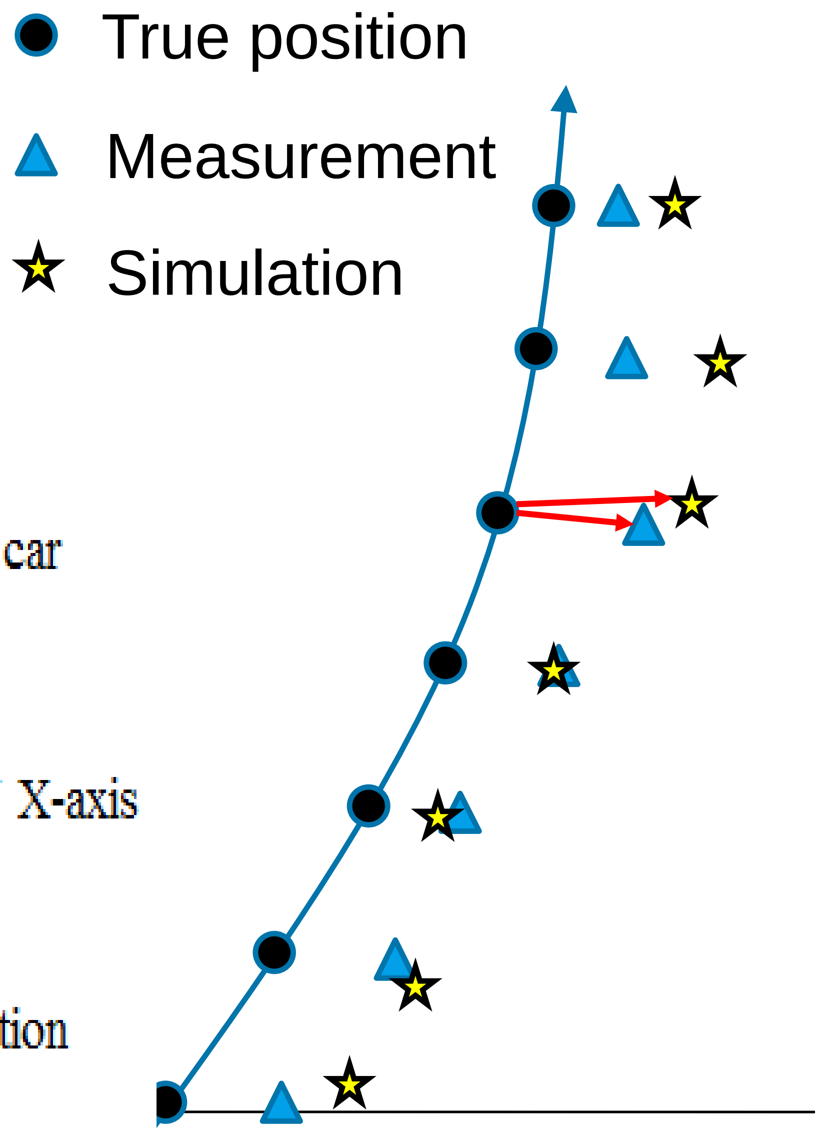


Round number		UTC
No.1	Start time	2:55:34
	Finish time	3:05:54
No.2	Start time	3:06:41
	Finish time	3:16:20
No.3	Start time	5:16:28
	Finish time	5:26:40
No.4	Start time	6:18:48
	Finish time	6:29:56
No.5	Start time	6:31:29
	Finish time	6:42:13
No.6	Start time	7:10:01
	Finish time	7:17:42

- **The data was obtained using “test vehicle” in the dense urban areas (many high-rise building). -> worst case for GNSS**
- **Repeated 3 km and 10-17 minutes course**
- **Total : 4 hours 22 minutes**
- **Constant speed as much as possible**
- **Commercial GPS receiver : u-blox 6T (raw data can be obtained)**

Evaluation of the Position Accuracy

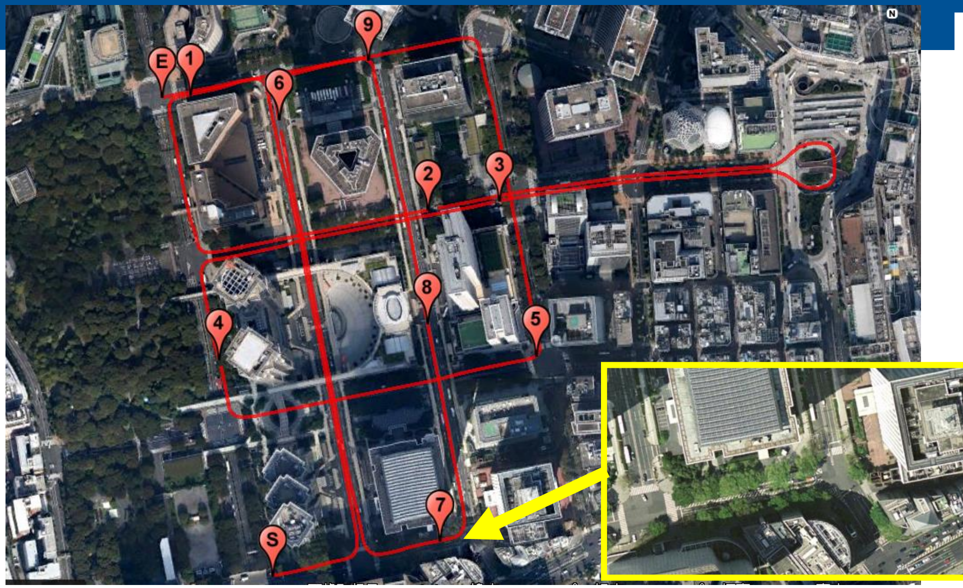


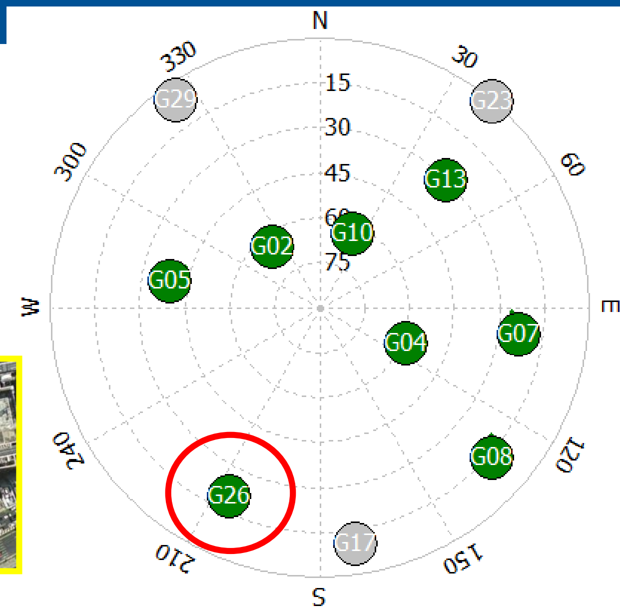


Test and Results

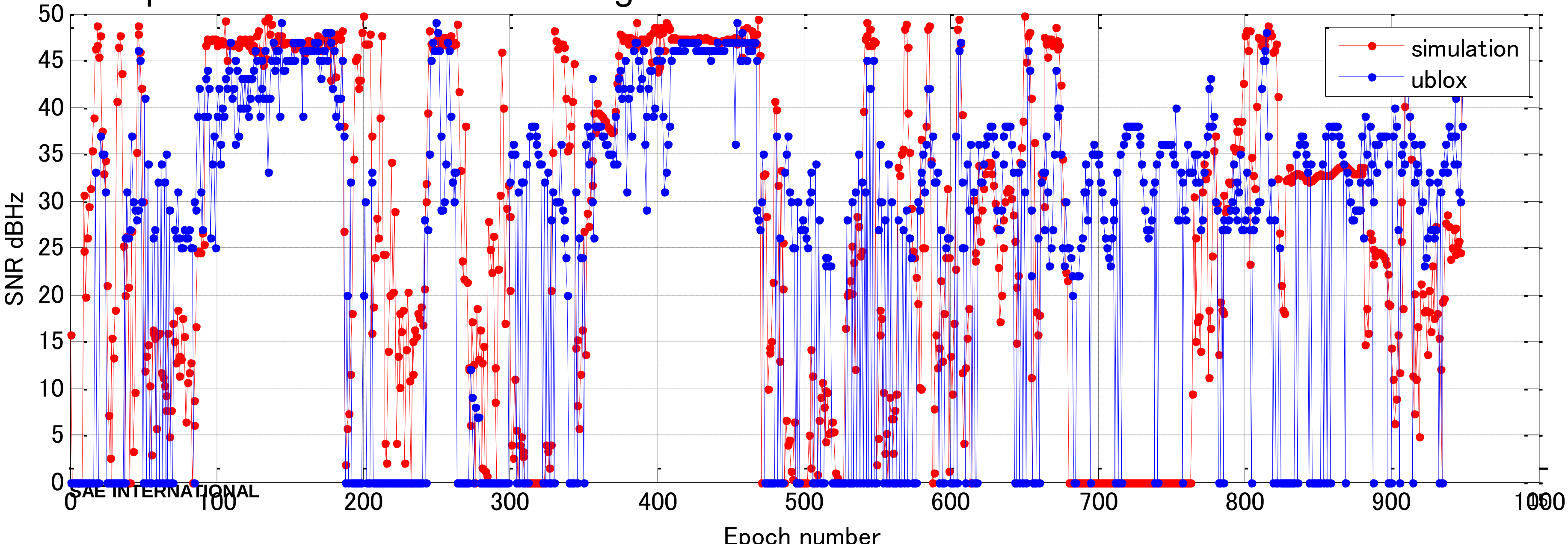
- C/N_0 comparison
- Position accuracy comparison (1)
- Position accuracy comparison (2)

C/N_0 Comparison GPS PRN26 (low elevation)

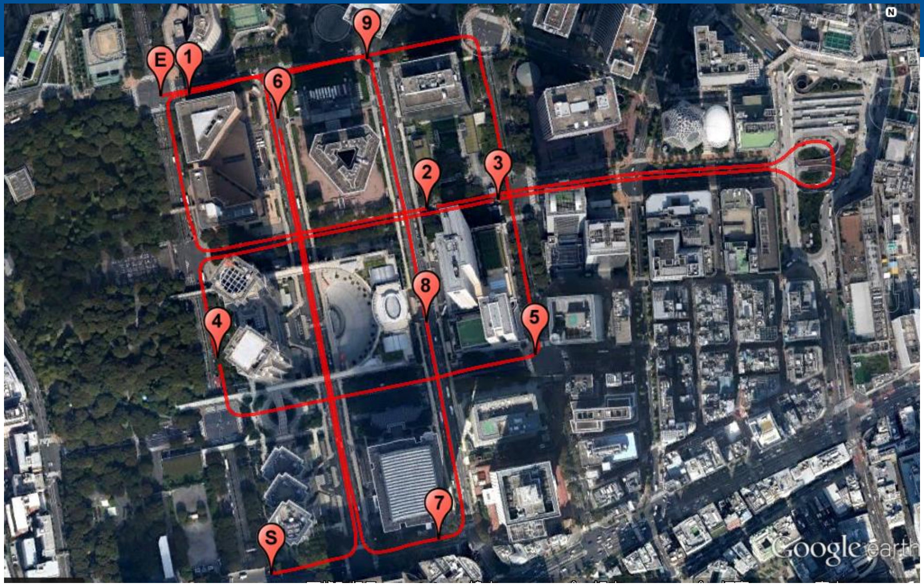


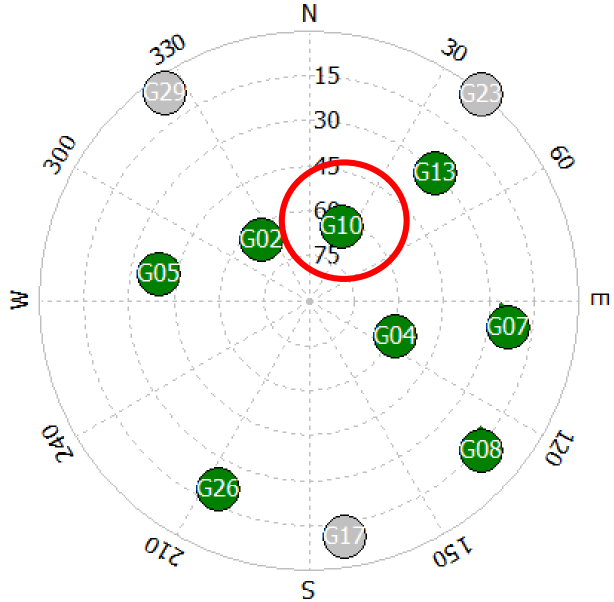


Epoch number is “Number in figure * 100”

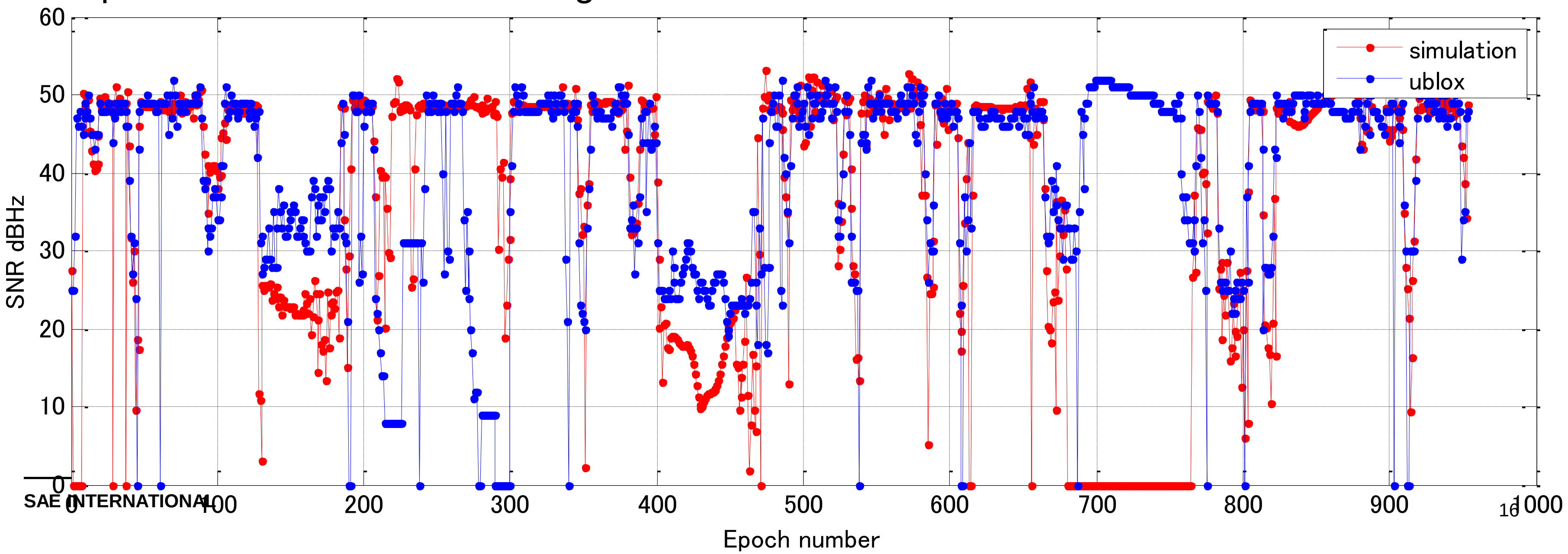


C/N_0 Comparison GPS PRN10 (high elevation)





Epoch number is "Number in figure * 100"

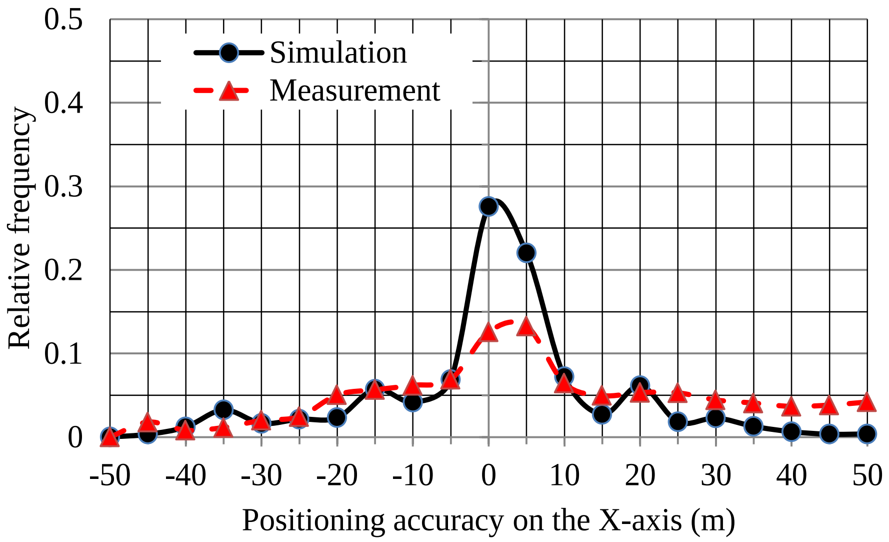


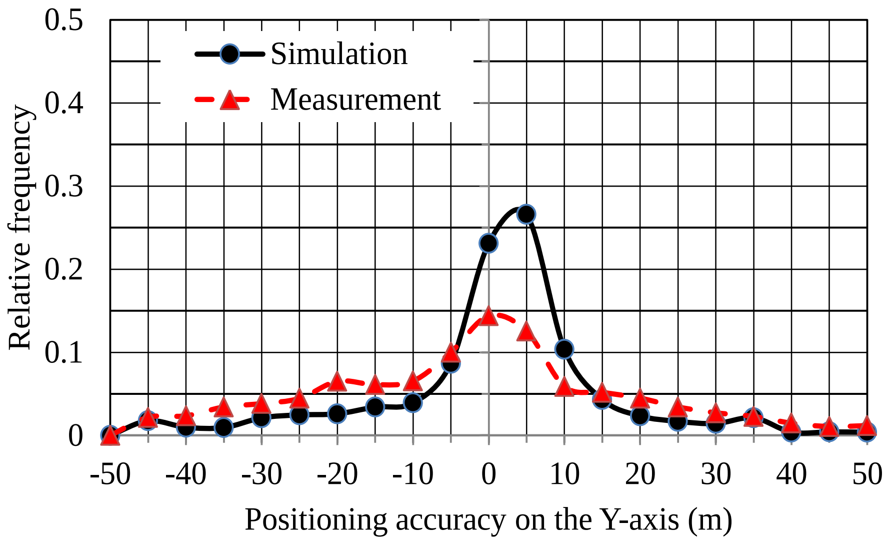
Position Accuracy Comparison 1 using all satellites (all data)

	Conditions of reception	Availability	Position Accuracy X (m)	Position Accuracy Y (m)
Simulation	All received satellites	**99.3 %**	**24.6**	**22.8**
Measured	C/N_0 > 20dBHz	**97.4 %**	**38.5**	**34.8**
	C/N_0 > 25dBHz	**96.6 %**	**38.5**	**34.7**
	C/N_0 > 30dBHz	**92.0 %**	**37.6**	**31.1**
	C/N_0 > 35dBHz	**76.6 %**	**28.3**	**24.4**

Standard deviation

Relative Frequency Distribution using all received satellites (all data)





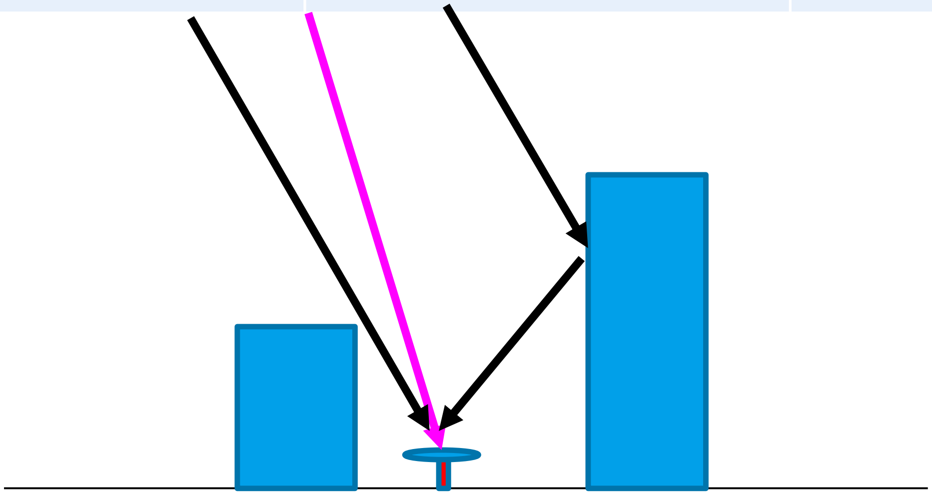
Simulation and measurement do not match well.

It is quite difficult to create a simulation model for diffracted waves in urban areas

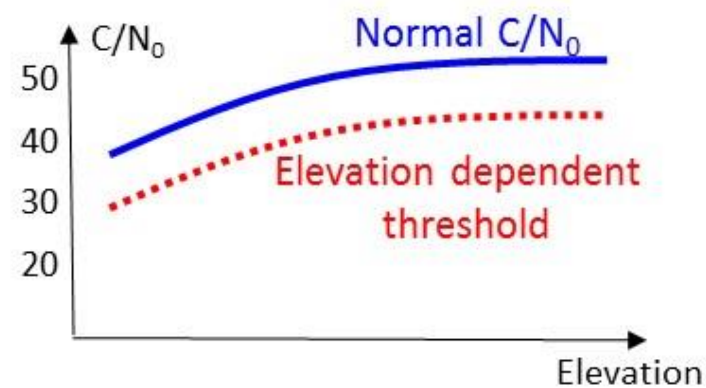
Position Accuracy Comparison 2 using selected satellites (all data)

	Conditions of reception	Availability	Position Accuracy X (m)	Y (m)
Simulation	Direct, Direct + Reflect	**68.5 %**	**14.8**	**11.7**
Measured	Strict C/N_0 selection	**61.8 %**	**15.3**	**14.1**

Standard deviation

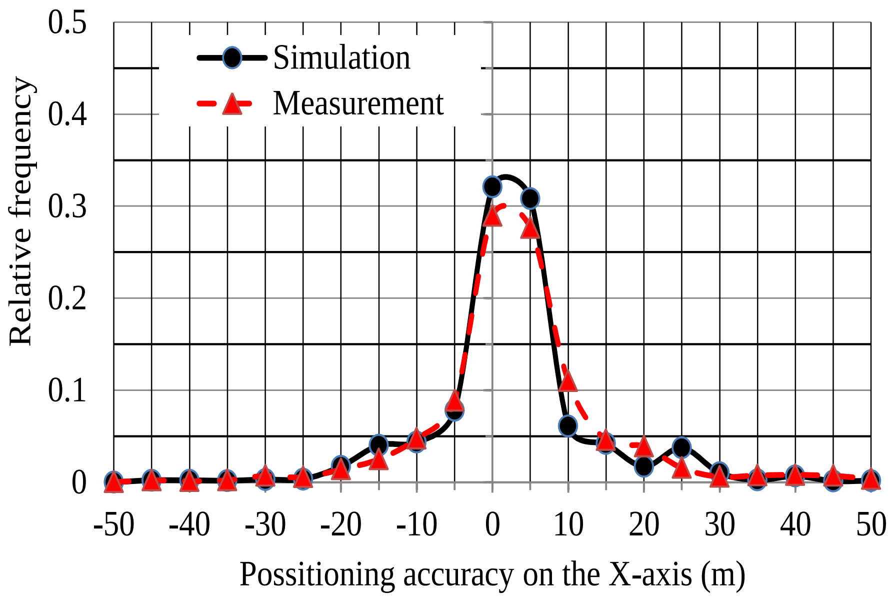


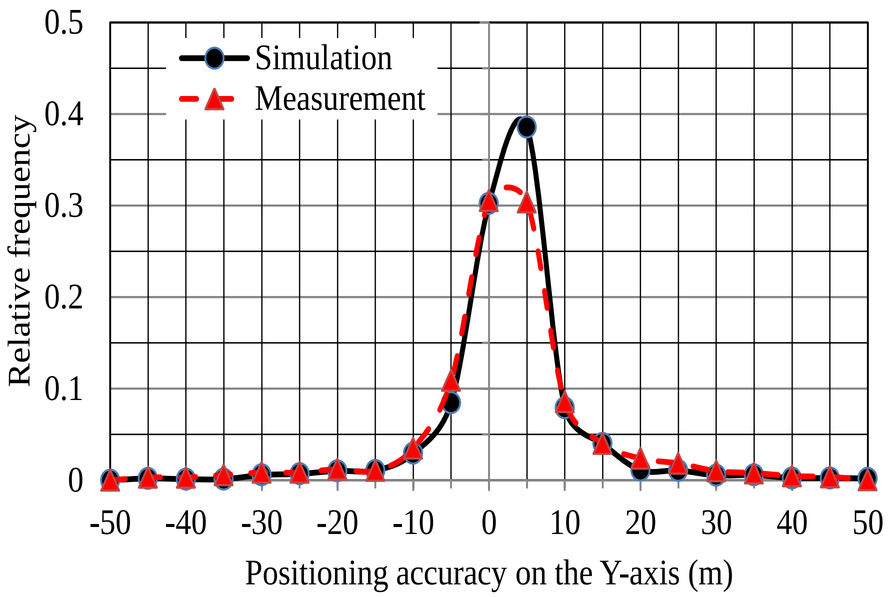
Direct, Direct + Reflect



Strict C/N_0 selection

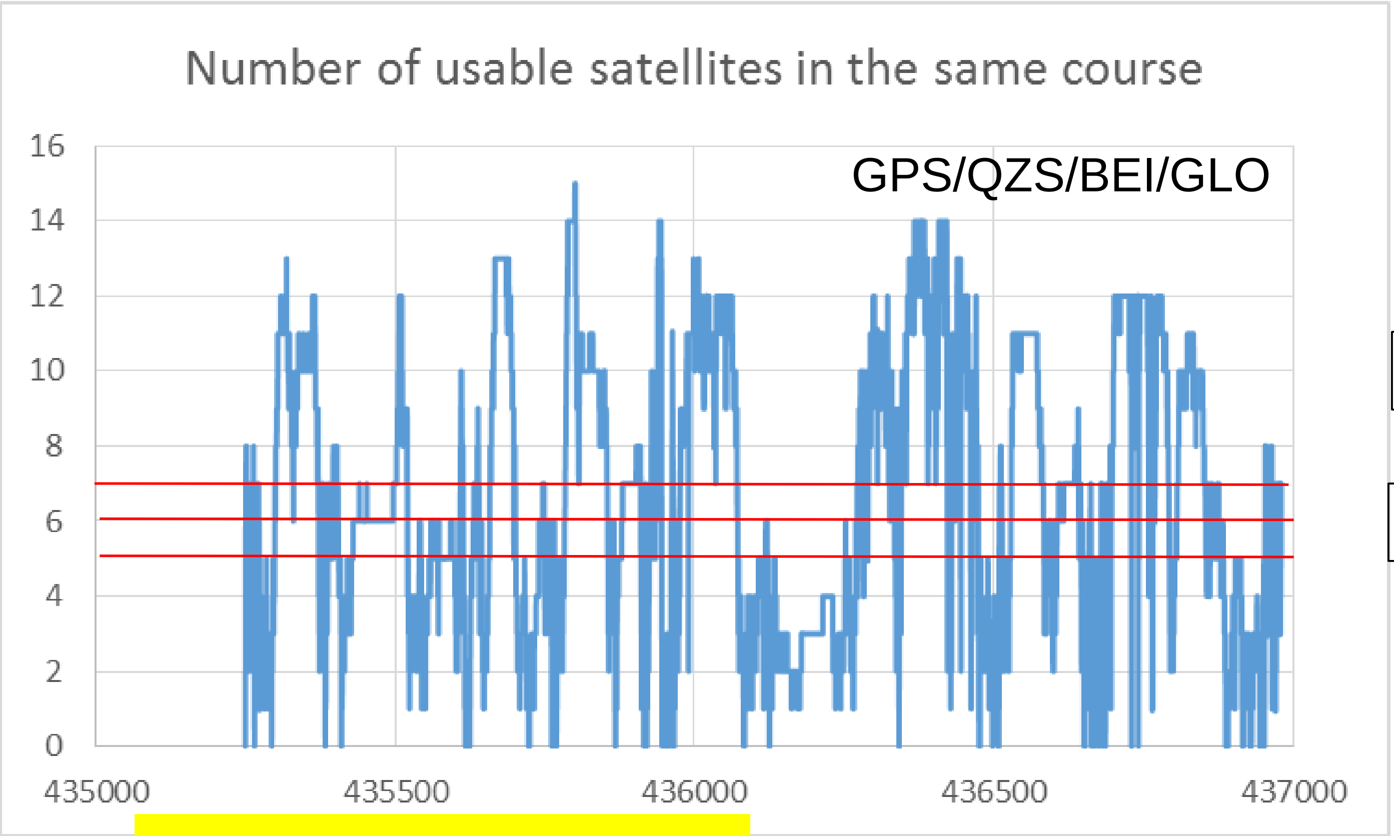
Relative Frequency Distribution using selected satellites (all data)





Simulation and measurement match well.

Availability Prediction of RTK-GNSS
(GPS/QZS/BEI/GLO)



What do we need for this prediction ?

Only usable satellites !

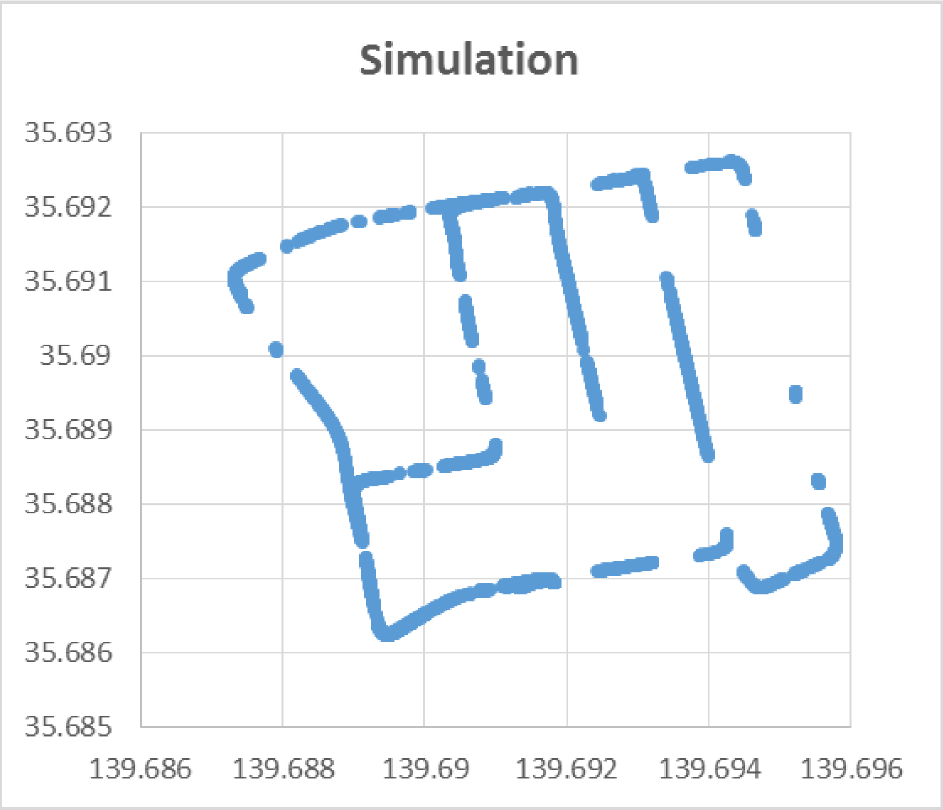
Possible for simulation

Simulation provides the good estimation of usable satellites

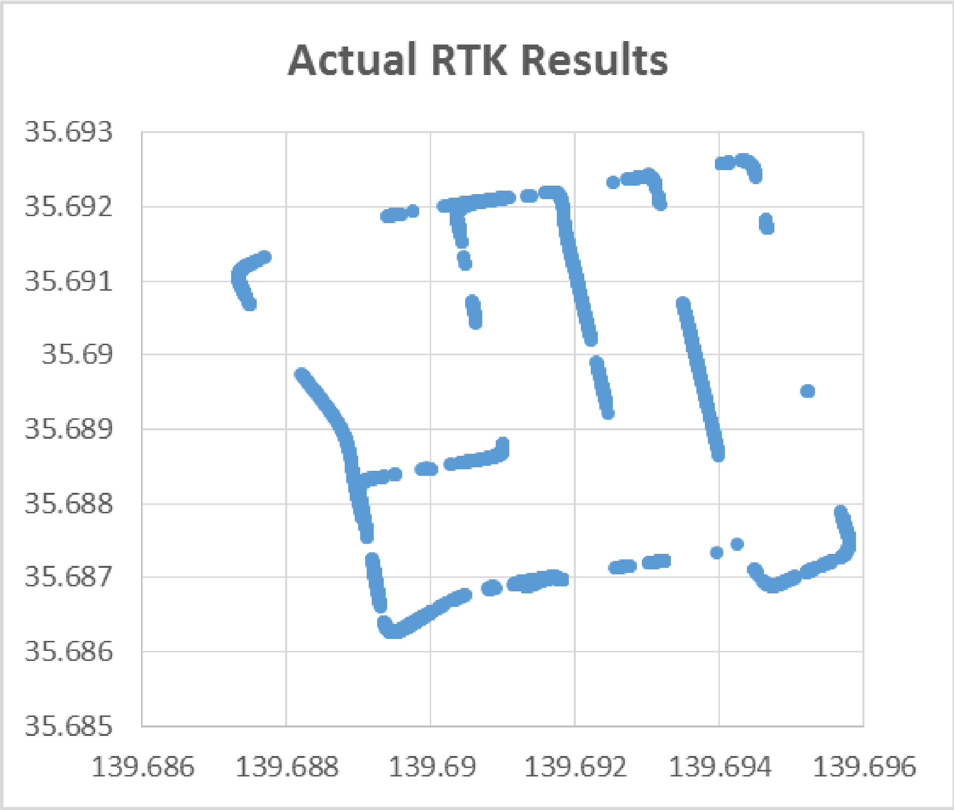
GPS>=5
GPS/BEI or GPS/GLO>=6
GPS/BEI/GLO>=7

The percentage satisfies the required number of satellites for RTK was **73.2%.**
The success probability of RTK is **about 80%** based on a large amount of data. **58.6%**
In reality, the percentage of RTK was **59.0%**

Comparison using Horizontal Positions



Prediction of RTK performance using usable satellite number



Actual RTK Results

It is possible to predict the rough availability of RTK in terms of location and time !

Summary

- Positional accuracy in an urban area was estimated by means of simulation. The validity of the simulation was done comparing with actual measurement.
- Temporal C/N_0 matches except for the effect of trees.
- Error distribution does not match well using all received satellites. It matches using received signals with direct wave.
- It is still difficult to simulate diffracted wave.

- Development of the method proposed here will probably make it possible to estimate availability and accuracy in a variety of regions using simulation alone.

Thank you for your attention

Any questions and comments

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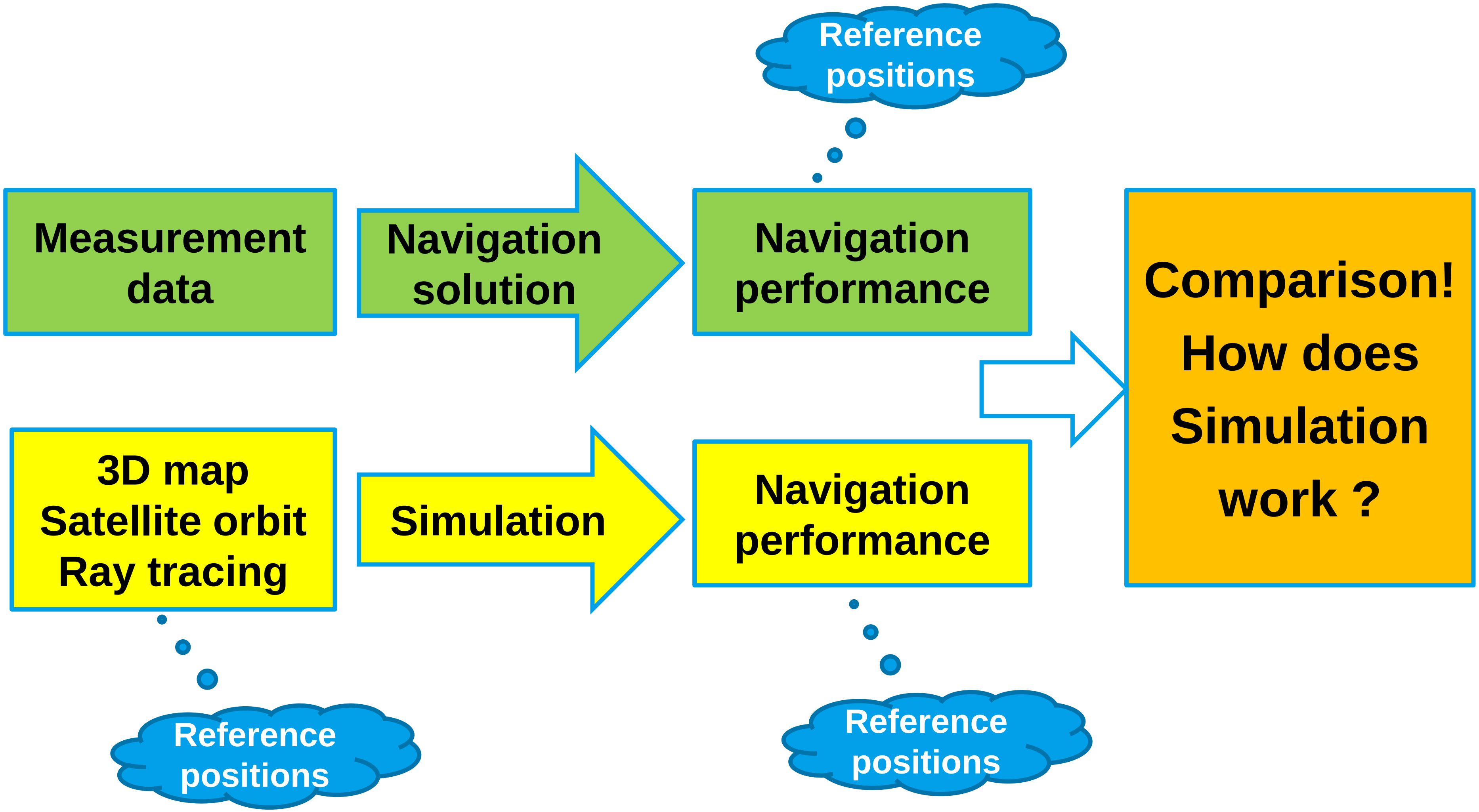
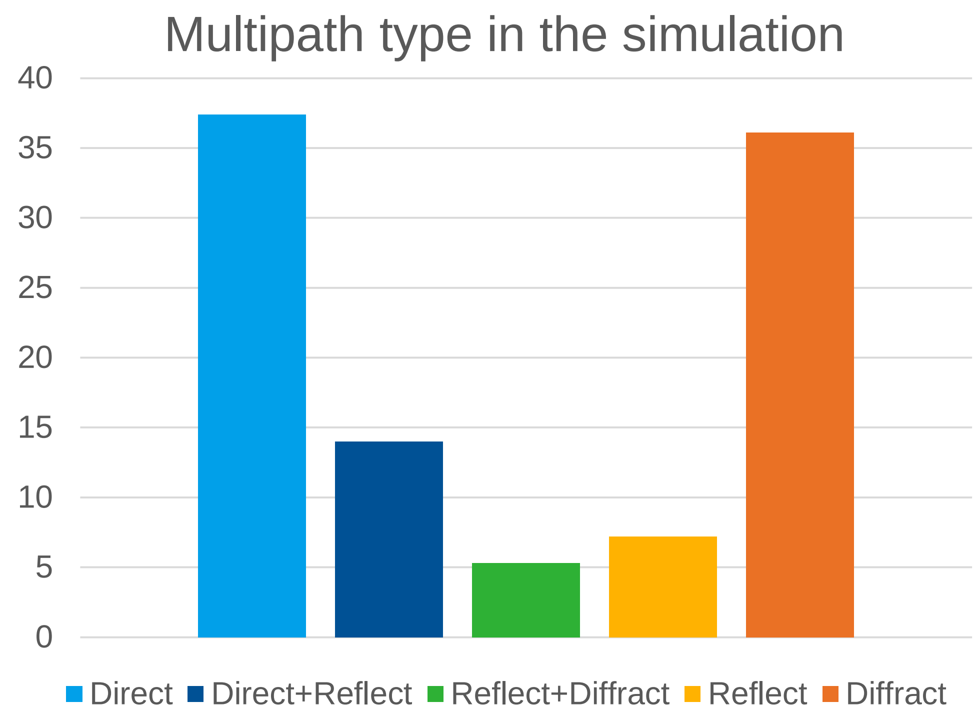
Other way to explain this Study



Frequency of Multipath Type

	Frequency	Possibility
Direct Only	2554	37.4%
Direct + Reflect	954	14.0%
Reflect + Diffract	359	5.3%
Reflect Only	495	7.2%
Diffract Only	2467	36.1%

Required received power = -160dBm



About half of received signals around high-rise buildings do not have Direct wave !