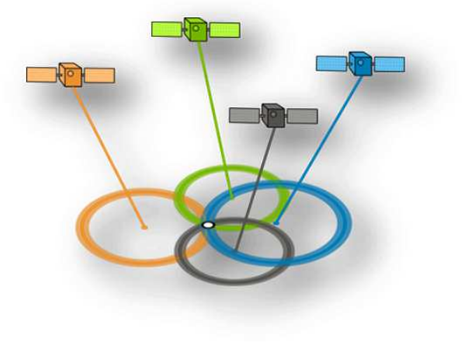
ICG Experts Meeting on GNSS Services, 14-18 December 2015, Vienna, Austria



Analysis and Simulation of GNSS for Peru

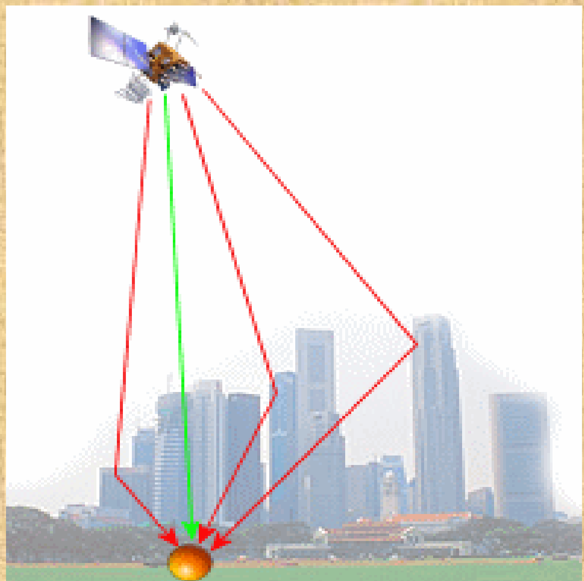
Dr. Fredy M. Villanueva
Space Agency of Peru
marcell385@yahoo.com

Capt. Winston R. Lastra
Peruvian Air Force
wlastra@hotmail.com

Contents

1. Introduction
2. Research Objective
3. Theoretical background
4. Modeling and simulation
5. Results
6. Conclusions

1. INTRODUCTION



Introduction

- Peru is a small country located in western South America with the main economic activities:
  - Mining industry (mainly – contributing to GDP)
  - Gas and Oil
  - Forestry
  - Agriculture
  - Fishery
  - Others

Introduction

- The visibility of satellites with different mask angles represent one of the method of characterization of the robustness of the constellation.

- Many surveying environments, like in urban canyons, deep open-pit mines and valleys, limit the number of visible satellites, deteriorating the survey accuracy and therefore a single satellite positioning system hardly satisfies the requirements.

The multipath signal is a delayed and attenuated copy of the direct signal (it can be several multipath signals)

Introduction

- Currently, in South America, two satellite navigation systems are available to civilian users, GLONASS and GPS. Simultaneously tracking both GPS and GLONASS satellites increases the number of satellites available for receivers to track by posing both satellite constellations.

- However the BeiDou (DBS) is a navigation system in development by China, that will be complete deployed by 2020. which represent an additional oportunity to satisfy the user requirement in terms of reduction of times and get more precision in measurements.

- In Peru there are numerous companies that provide services Surveying, mapping, mining, among others, for which measurement equipment used looking for the best accuracy for the realization of projects.

2. RESEARCH OBJECTIVE

Research Objective

- The main objective of this research is the analysis of the visibility of the satellites and estimate the DOP values obtained by simulation of the GPS, BDS and the GPS+BDS (combined) constellation for Peru.

Research content:

① Analyze the satellites visibility of GPS;

② Analyze the DOP of GPS;

③ Analyze the satellites visibility of BDS+GPS (Combined);

④ Analyze the DOP of BDS+GPS (Combined);

NOTE: In all the cases the analysis were in Peru

3. THEORETICAL BACKGROUND

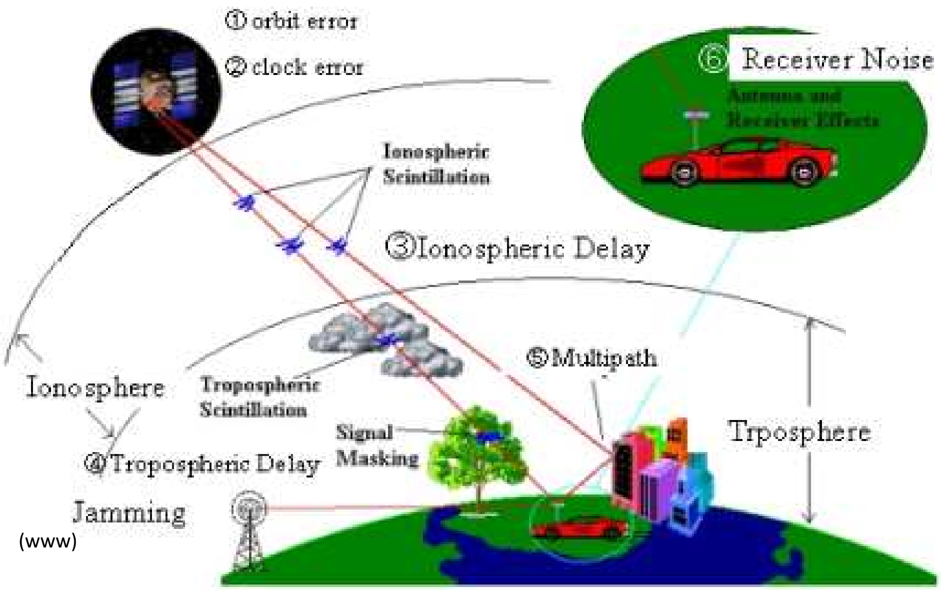
Research Consideration

Operation of a GNSS system

- The main sources causing positioning errors are:
  - Ionospheric delays
  - Errors Watch of Satellite and Receiver
  - Multipath effect
  - ***Dilution of Precision***

Not considered in this analysis

Error source	Potential error, m	Typical error, m
Ionosphere	5.0	0.4
Troposphere	0.5	0.2
Ephemeris data	2.5	0
Satellite clock drift	1.5	0
Multipath	0.6	0.6
Measurement noise	0.3	0.3
Total	~ 15	~ 10



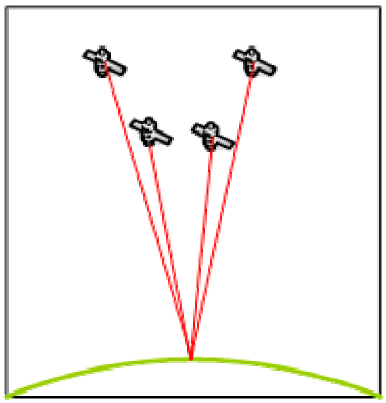
(www)

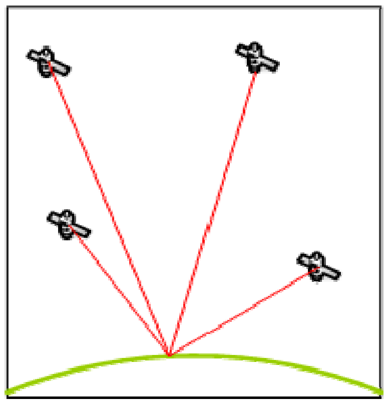
Dilution of Precision

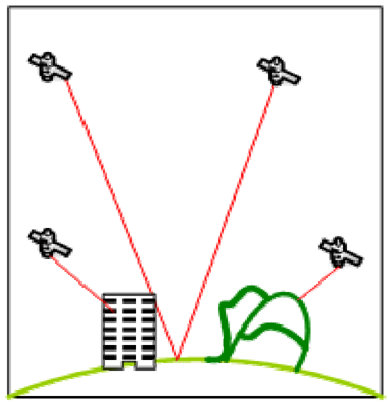
- Dilution of Precision (DOP) is a dimensionless value that describes the 'solidity' of the observable figure distanced metrically, consisting of the receptor and vectors that determines the receiver with the satellites in view.

- The satellite geometry plays a very important role in the total positioning accuracy. The better the satellite geometry strength, better is the positioning accuracy.

- Good satellite geometry is obtained when the satellites are properly distributed in the sky. The satellite geometry effect can be measured by a single dimensionless number.


Poor GDOP


Good GDOP


Good GDOP –
Bad Visibility

Dilution of Precision

Types of DOP:

- GDOP - Provides accuracy degradation in 3D position and time
- TDOP - Provides accuracy degradation in time
- PDOP - Provides accuracy degradation in 3D position
- VDOP - Provides accuracy degradation in vertical direction
- HDOP - Provides accuracy degradation in the horizontal direction

- When visible navigation satellites are close together in the sky, the geometry is said to be weak and the DOP value is high; when far apart, the geometry is strong and the DOP value is low.

- Thus a low DOP value represents a better positional precision due to the wider angular separation between the satellites used to calculate a unit's position.

x, y, z Position of the receiver

x_i, y_i , y_i Position of the satellite

$$R_i = \sqrt{(x_i - x)^2 + (y_i - y)^2 + (z_i - z)^2}$$

Geometric Dilution of Precision:

$$\boldsymbol{GDOP = \sqrt{\sigma_x{}^2 + \sigma_y{}^2 + \sigma_z{}^2 + \sigma_t{}^2}}$$

Time Dilution of Precision:

$$\boldsymbol{TDOP = \sqrt{\sigma_t{}^2}}$$

Position Dilution of Precision:

$$\boldsymbol{PDOP = \sqrt{\sigma_x{}^2 + \sigma_y{}^2 + \sigma_z{}^2}}$$

Horizontal Dilution of Precision:

$$\boldsymbol{HDOP = \sqrt{\sigma_x{}^2 + \sigma_y{}^2}}$$

Vertical Dilution of Precision:

$$\boldsymbol{VDOP = \sqrt{\sigma_z{}^2}}$$

Covariance Matrix

$$cov(x) = (A^T . A)^{-1} = \begin{bmatrix} \sigma_x{}^2 & \sigma_{xy} & \sigma_{xz} & \sigma_{xt} \\ \sigma_{yx} & \sigma_y{}^2 & \sigma_{yz} & \sigma_{yt} \\ \sigma_{zx} & \sigma_{zy} & \sigma_z{}^2 & \sigma_{zt} \\ \sigma_{xt} & \sigma_{yt} & \sigma_{zt} & \sigma_t{}^2 \end{bmatrix}$$

DOP value	Rating
1	Ideal
1-2	Excellent
2-5	Good
5-10	Moderate
10-20	Fair
> 20	Poor

Note: $PDOP^2 = HDOP^2 + VDOP^2$
$GDOP^2 = PDOP^2 + TDOP^2$

4. MODELING AND SIMULATION

Modeling and Simulation

4.1 Analysis and Study Tools

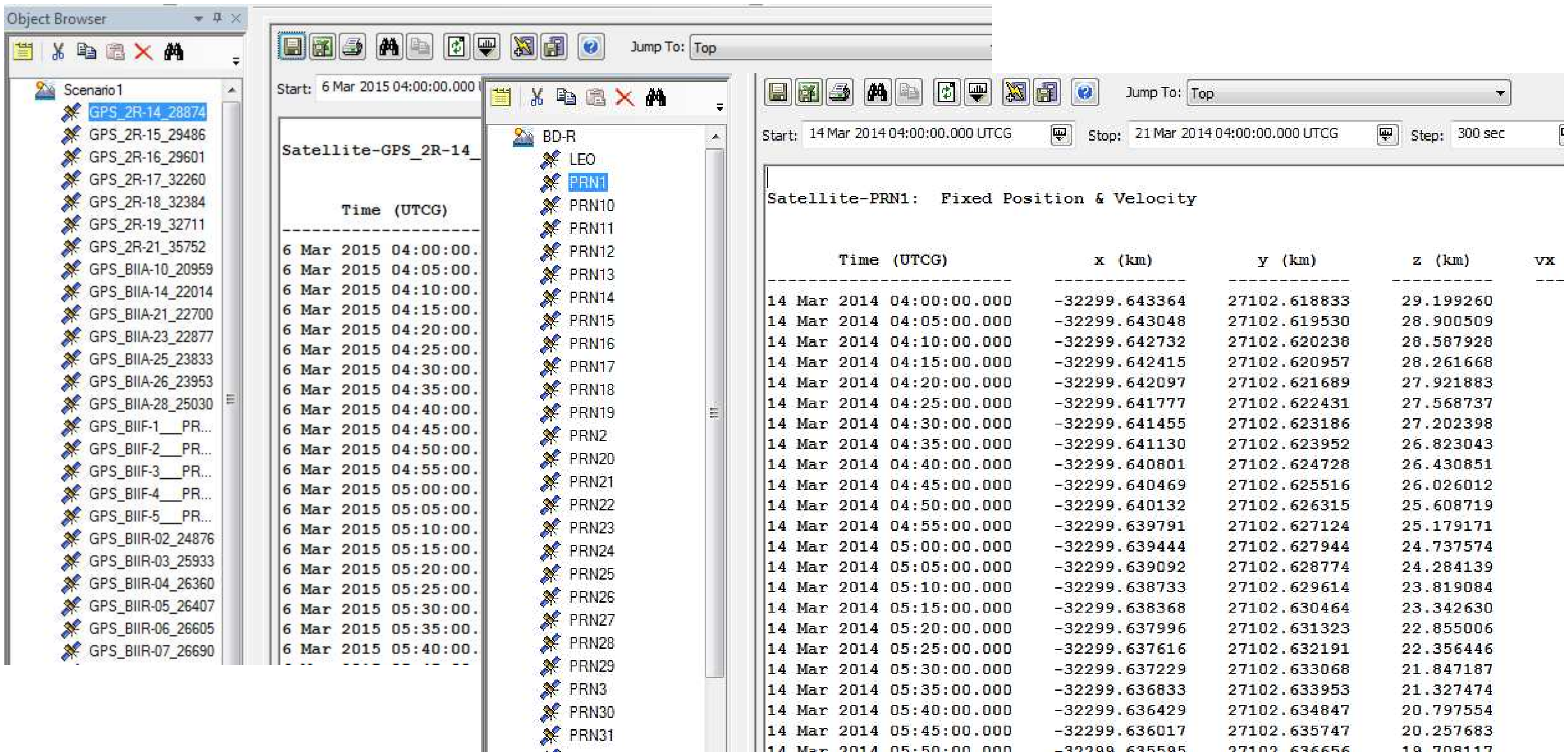
- STK Object Model (AGI) and
- Matlab (Mathworks).

System	:	GPS (31) and BDS (35)
Time and Date	:	23-12-2014 0:24h (temporal variation)
Interval Time	:	5 min x 288 = 1440 min (24hours)
Cutoff elevation	:	5°, 10°, 15° and 20°
Receiver type	:	Trimble R7 in Peru
Baseline model	:	Geometry Free
Locations	:	Lima (Peru) 12°29’07.81826’’ S, 76°47’49.02099’’ W
Outputs	:	Number of Satellites, GDOP, PDOP, TDOP, HDOP and VDOP

Modeling and Simulation: PRN coding

4.2. Insert the PRN CODE for each satellite Constellation

- Allocation of the PRN code for each satellite of the constellation.
- Ephemeris data.

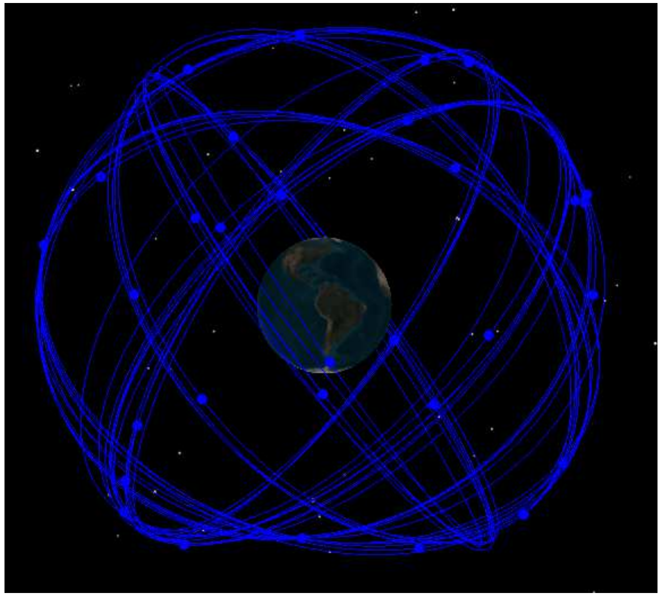


Modeling and Simulation: GPS

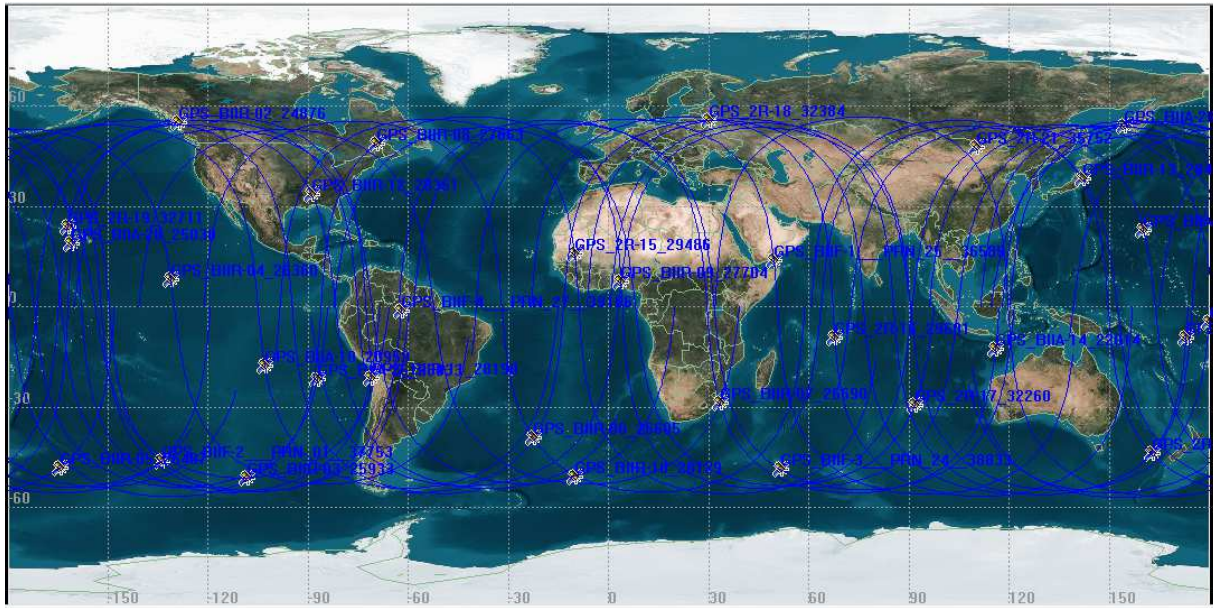
4.3 Modeling the GPS Constellation

- GPS constellation
  - 31 satellites not evenly distributed within the planes
  - 6 orbital planes

- Altitude: 20200 km
- Period: 11h58 min
- Inclination: 55 deg
- Eccentricity: 0.009



GPS constellation



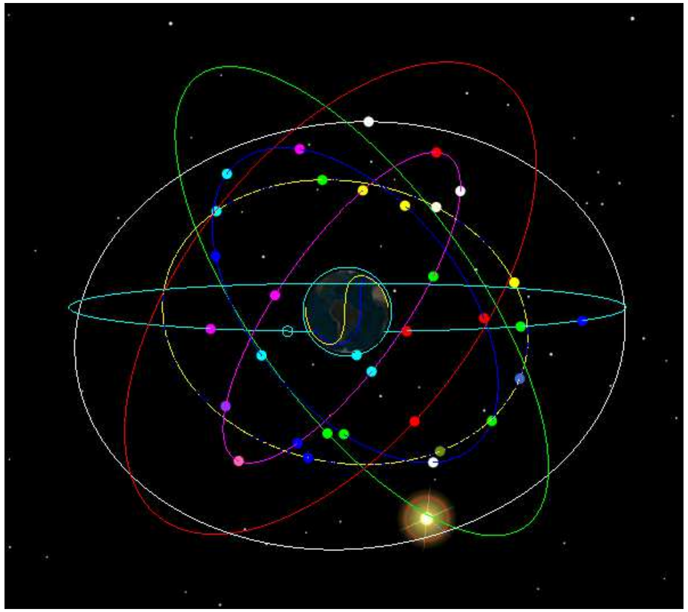
GPS ground track of 31 satellites

Modeling and Simulation: BDS

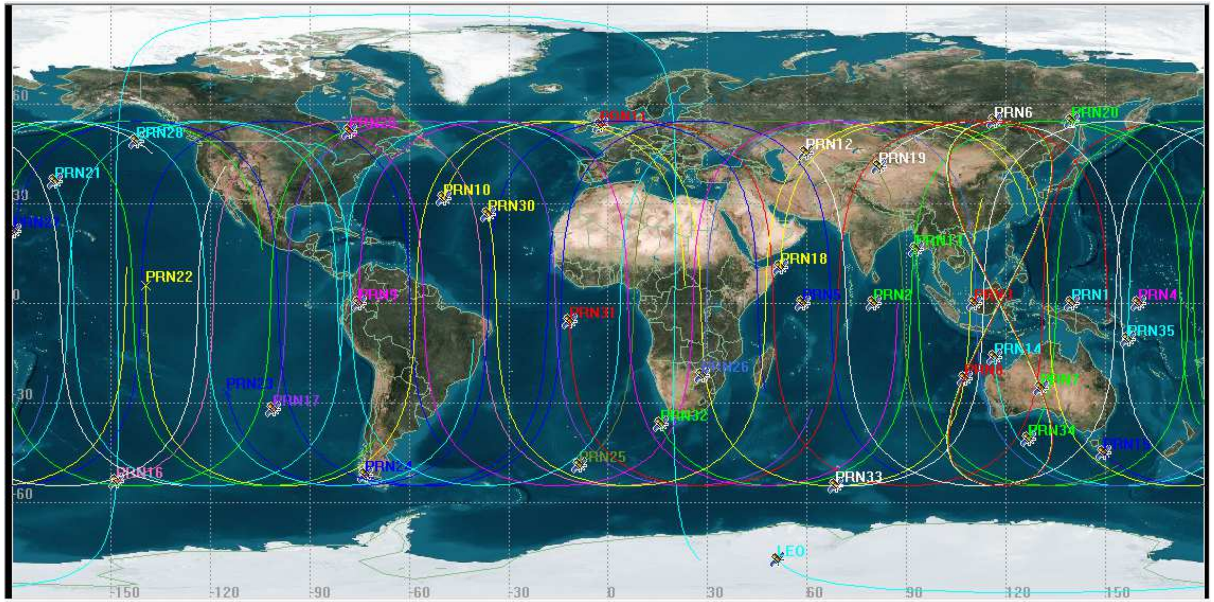
4.4 Modeling the BDS Constellation

- BDS Constellation
- 35 satellites, which include
  - 5 geostationary orbit (GEO) satellites and
  - 30 medium Earth orbit (MEO) satellites,

- Altitude: 21527 km
- Period: 12h53min
- Inclination: 55 deg
- Eccentricity: 0.0004



BDS Constellation

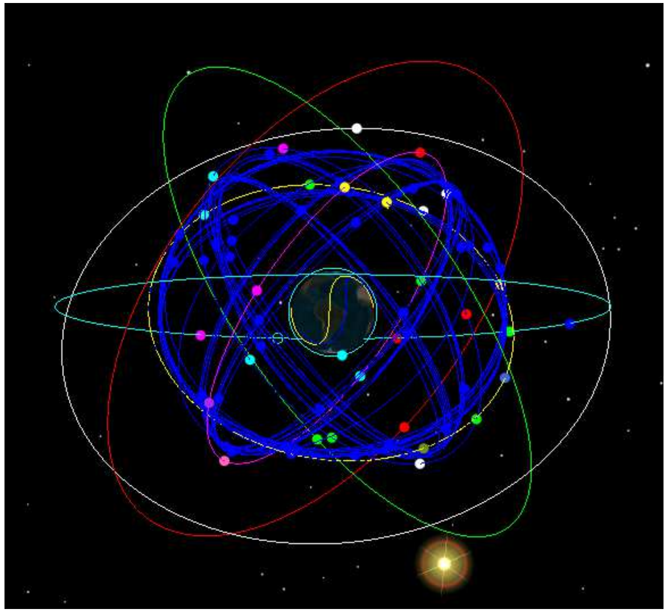


BDS ground track of 35 satellites

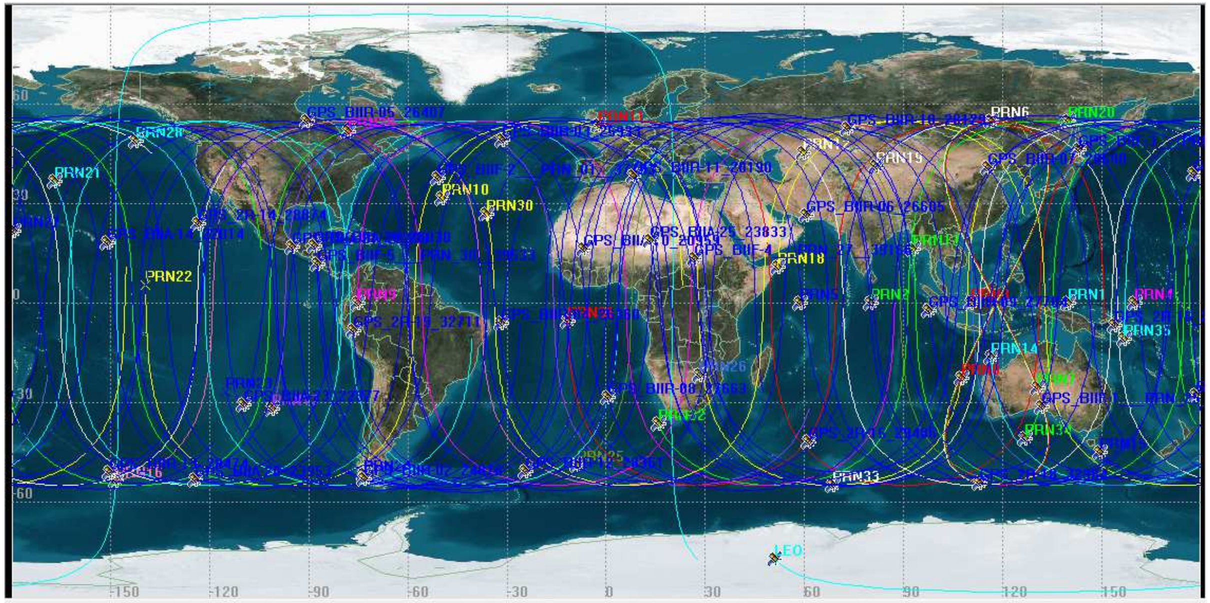
Modeling and Simulation: BDS+GPS

4.4.3 Modeling the combined BDS+GPS Constellation

- BDS+GPS Constellation
- 66 satellites, which includes
  - –35 BDS satellites and
  - –31 GPS satellites,



BDS+GPS Constellation



BDS+GPS ground track of 66 satellites

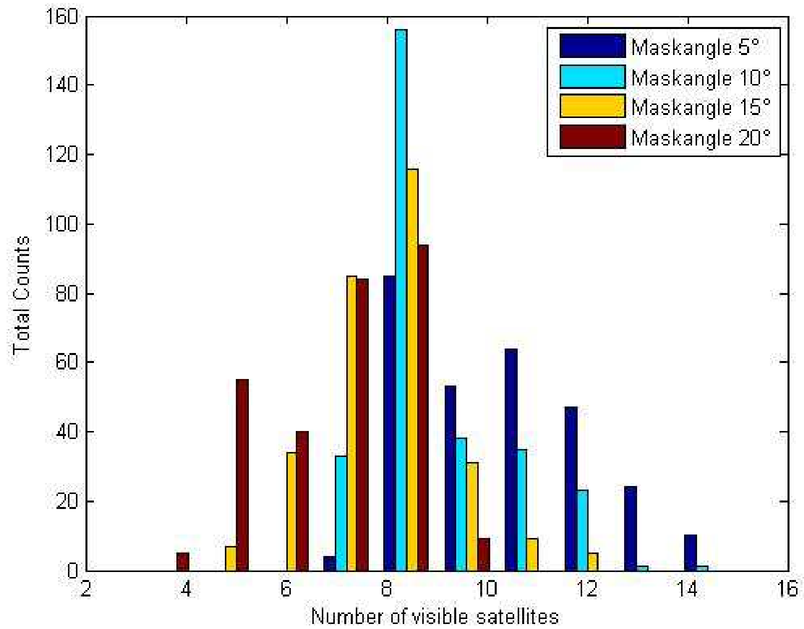
5. RESULTS

Visibility Results

5.1. Satellite visibility for GPS constellation

M.A.	5°		10°		15°		20°	
N.of S.	SAT	%	SAT	%	SAT	%	SAT	%
3	0	0.00	0	0.00	0	0.00	1	0.35
4	0	0.00	0	0.00	0	0.00	4	1.39
5	0	0.00	0	0.00	7	2.44	55	19.16
6	0	0.00	0	0.00	34	11.85	40	13.94
7	4	1.39	33	11.50	85	29.62	84	29.27
8	29	10.10	69	24.04	51	17.77	38	13.24
9	56	19.51	87	30.31	65	22.65	56	19.51
10	53	18.47	38	13.24	31	10.80	9	3.14
11	64	22.30	35	12.20	9	3.14	0	0.00
12	47	16.38	23	8.01	5	1.74	0	0.00
13	24	8.36	1	0.35	0	0.00	0	0.00
14	8	2.79	1	0.35	0	0.00	0	0.00
15	2	0.70	0	0.00	0	0.00	0	0.00

Satellite visibility percentage in Peru for GPS



Number of satellites visibility in Peru for GPS

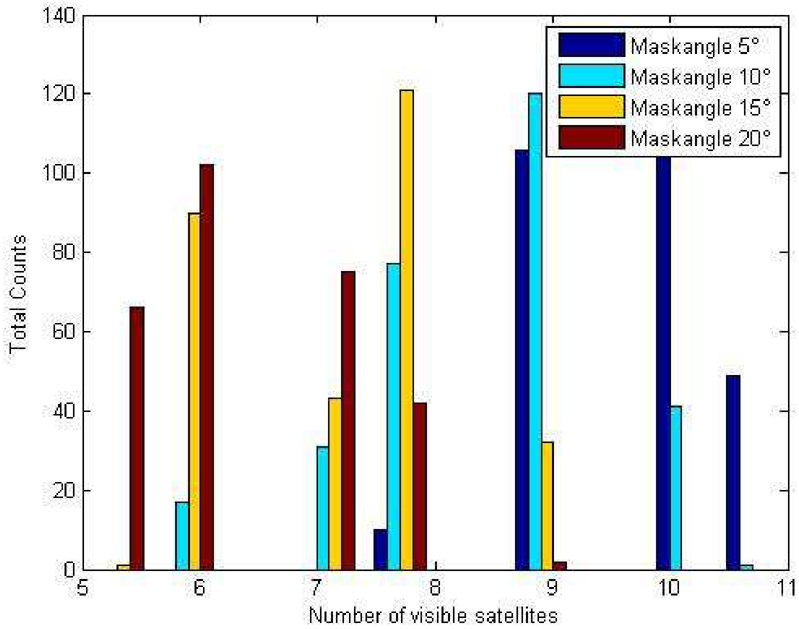
The number of Satellites in view for GPS constellation with 5°,10°,15° and 20° mask angle

Visibility Results

5.1. Satellite visibility for BDS constellation

M.A.	5°		10°		15°		20°	
N. of S.	SAT	%	SAT	%	SAT	%	SAT	%
5	0	0.00	0	0.00	1	0.35	66	23.00
6	0	0.00	17	5.92	90	31.36	102	35.54
7	0	0.00	31	10.80	43	14.98	75	26.13
8	10	3.48	77	26.83	121	42.16	42	14.63
9	106	36.93	120	41.81	32	11.15	2	0.70
10	122	42.51	41	14.29	0	0.00	0	0.00
15	49	17.07	1	0.35	0	0.00	0	0.00

Satellite visibility percentage in Peru for BDS



Number of satellites visibility in Peru for BDS

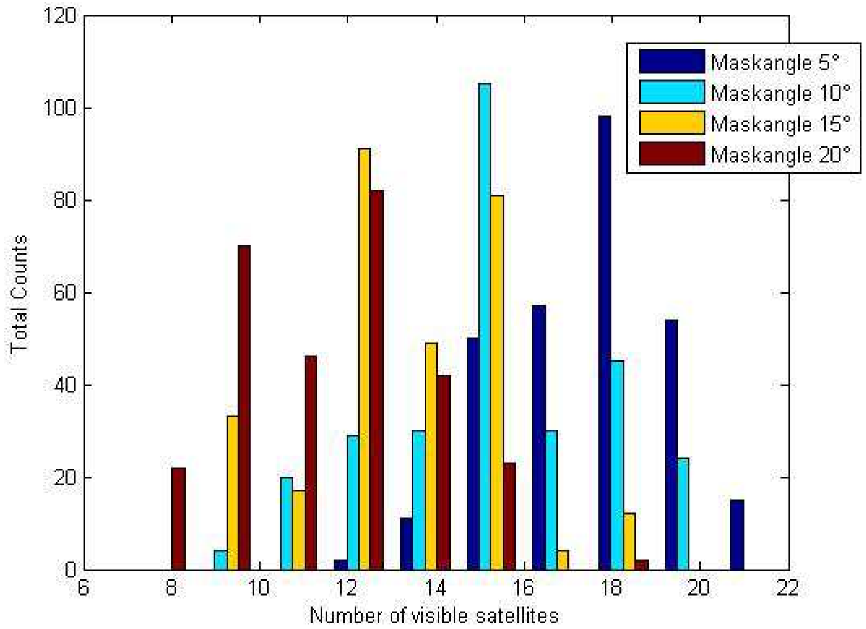
The number of Satellites in view for BDS constellation with 5°,10°,15° and 20° mask angle

Visibility Results

5.1. Satellite visibility for combined BDS+GPS constellation

M.A.	5°		10°		15°		20°	
N.of S.	SAT	%	SAT	%	SAT	%	SAT	%
7	0	0.00	0	0.00	0	0.00	6	2.09
8	0	0.00	0	0.00	0	0.00	16	5.57
9	0	0.00	4	1.39	25	8.71	28	9.76
10	0	0.00	0	0.00	8	2.79	42	14.63
11	0	0.00	20	6.97	17	5.92	46	16.03
12	0	0.00	10	3.48	53	18.47	62	21.60
13	2	0.70	19	6.62	38	13.24	20	6.97
14	11	3.83	30	10.45	49	17.07	42	14.63
15	32	11.15	52	18.12	36	12.54	12	4.18
16	18	6.27	53	18.47	45	15.68	11	3.83
17	57	19.86	30	10.45	4	1.39	0	0.00
18	54	18.82	45	15.68	12	4.18	2	0.70
19	44	15.33	0	0.00	0	0.00	0	0.00
20	54	18.82	24	8.36	0	0.00	0	0.00

Satellite visibility percentage in Peru for combined GPS+BDS



Number of satellites visibility in Peru for combined GPS+BDS

The number of Satellites in view for GPS+BDS constellation with 5°,10°,15° and 20° mask angle

Visibility Results

5.1.1 Satellite visibility Analysis

- The satellite's visible number of combined GPS+BDS is more than GPS most of the time.
- The visibility of combined GPS+BDS is better than GPS.
- The percentage of time with no less than 6 satellites of combined GPS+BDS is 100%, and that of GPS is 83.33% under 15° mask angle.

GNSS	MA	min	max	mean	success rate
GPS	5	7	15	11	100%
	10	7	14	11	100%
	15	5	12	9	100%
	20	3	10	7	100%
BDS	5	8	15	12	100%
	10	6	15	11	100%
	15	5	9	7	100%
	20	5	9	7	100%
GPS+BDS	5	13	20	17	100%
	10	9	20	15	100%
	15	9	18	14	100%
	20	7	18	13	100%

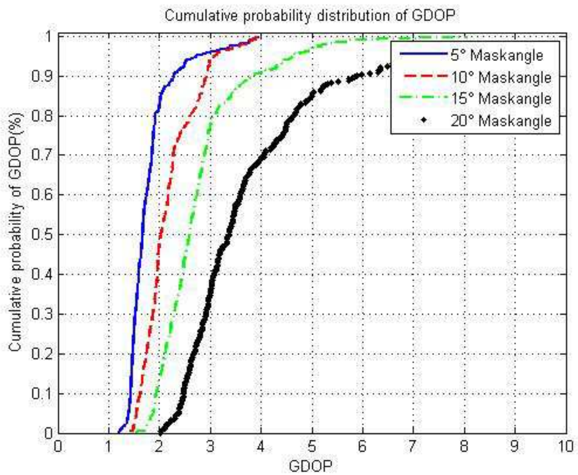
DOP Results

5.2.2. DOP values for GPS constellation

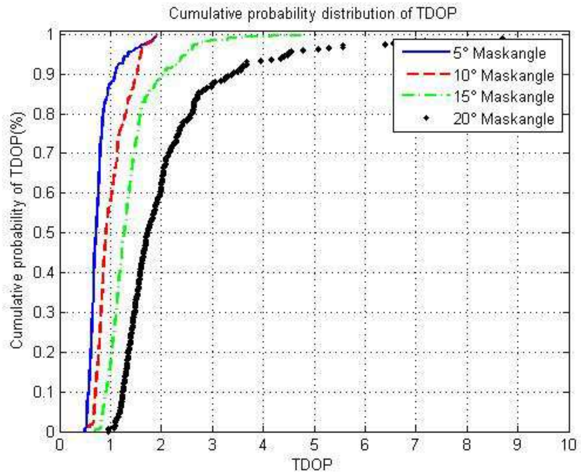
GNSS	MA	GDOP	PDOP	HDOP	VDOP	TDOP
GPS	5°	1.79	1.61	0.76	1.26	0.79
	10°	2.18	1.92	0.88	1.5	1.02
	15°	2.77	2.39	1.05	1.85	1.4
	20°	3.94	3.3	1.27	2.48	2.14

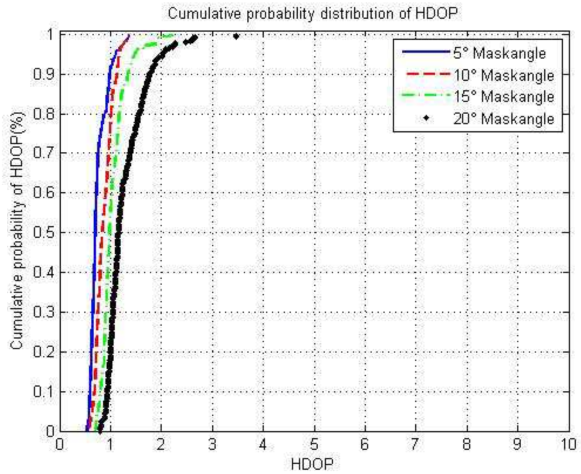
DOP Results

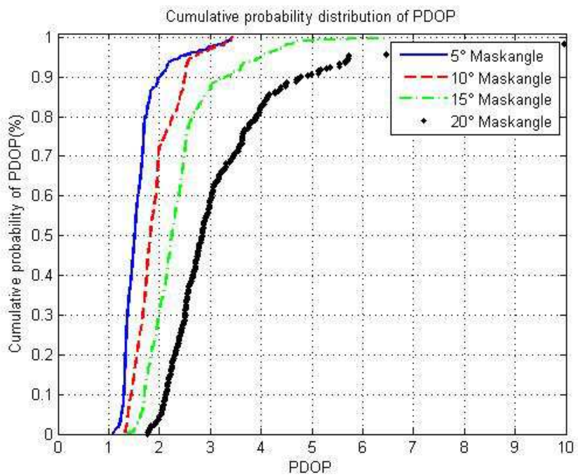
5.2. DOP values Analysis



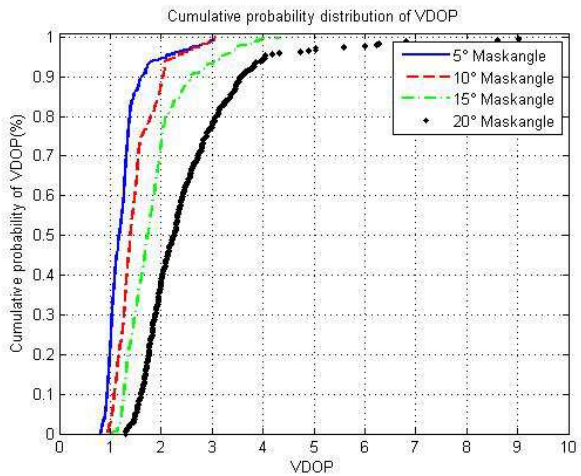
GPS







Cumulative probability distribution of GDOP, PDOP, HDOP, VDOP and TDOP under different mask angles.



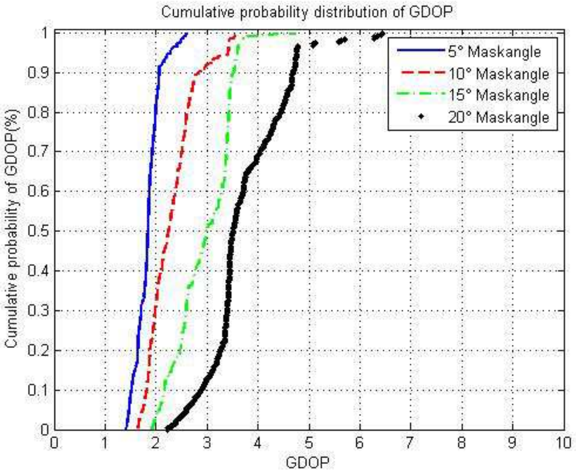
DOP Results

5.2.2. DOP values for BDS constellation

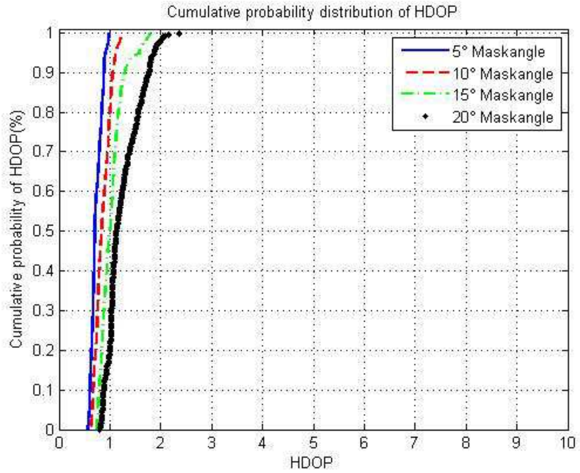
GNSS	MA	GDOP	PDOP	HDOP	VDOP	TDOP
BDS	5°	1.84	1.66	0.74	1.32	0.79
	10°	2.31	2.04	0.86	1.61	1.07
	15°	2.95	2.56	1.03	2.01	1.47
	20°	3.73	3.18	1.25	2.49	1.94

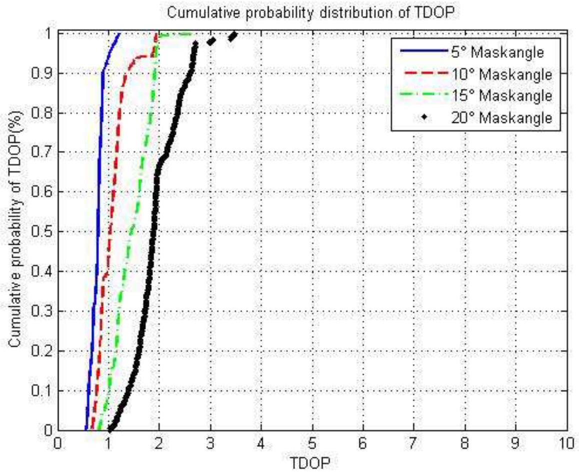
DOP Results

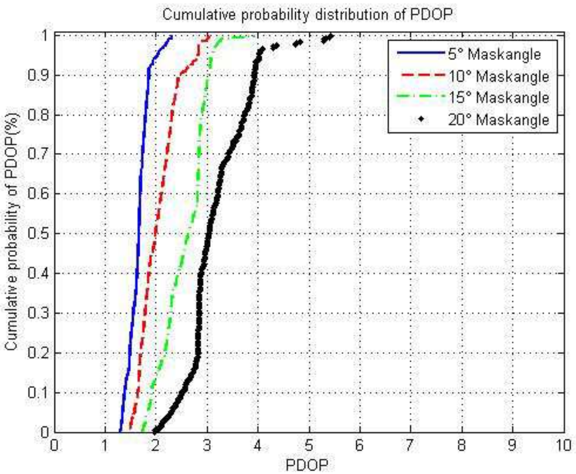
5.2. DOP values Analysis

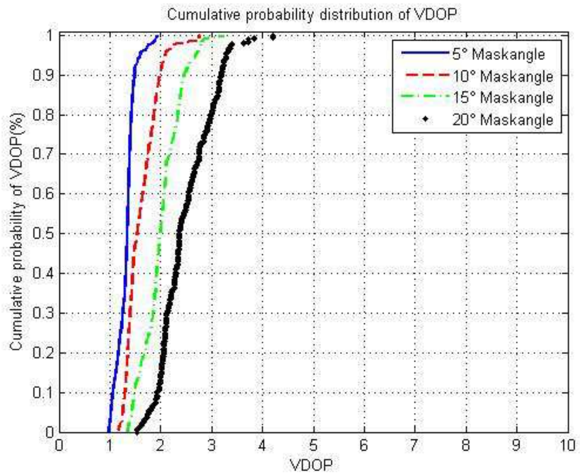


BDS









Cumulative probability distribution of GDOP, PDOP, HDOP, VDOP and TDOP under different mask angles.

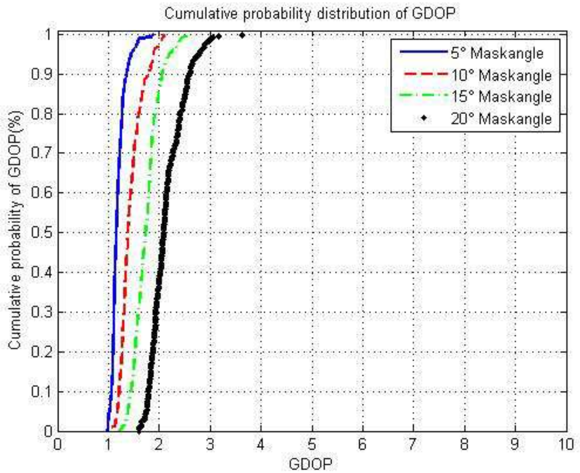
DOP Results

5.2.2. DOP values for combined BDS+GPS constellation

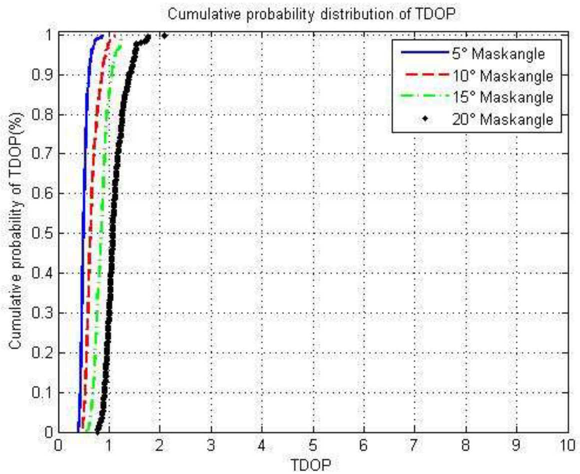
GNSS	MA	GDOP	PDOP	HDOP	VDOP	TDOP
GPS+BDS	5°	1.19	1.07	0.5	0.85	0.51
	10°	1.44	1.28	0.57	1.01	0.67
	15°	1.75	1.52	0.66	1.2	0.86
	20°	2.15	1.83	0.76	1.45	1.12

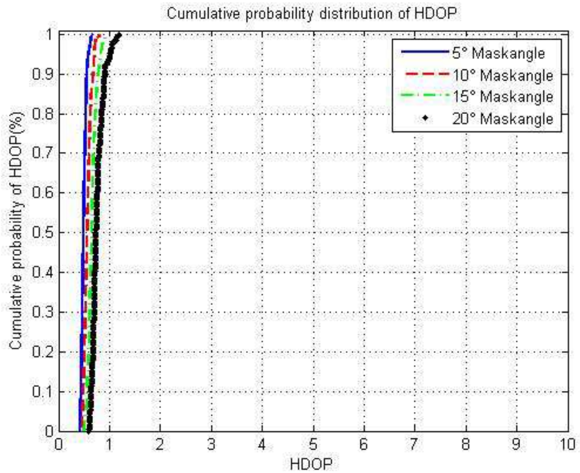
DOP Results

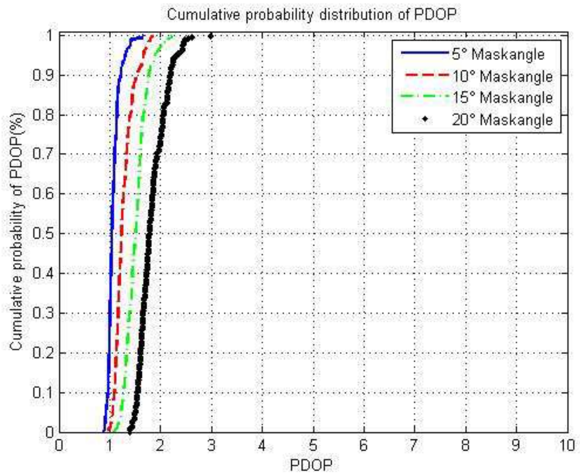
5.2.1. DOP values Analysis



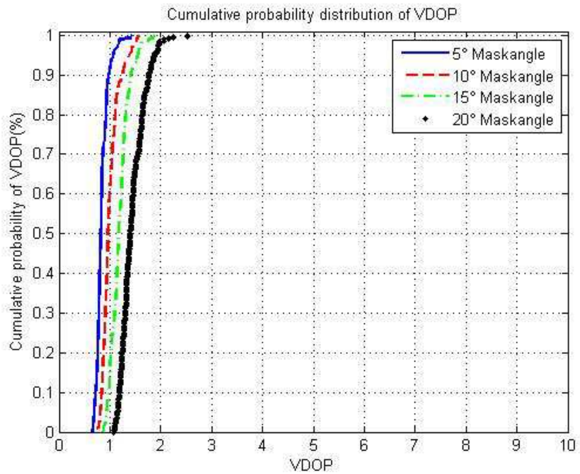
GPS+BDS







Cumulative probability distribution of GDOP, PDOP, HDOP, VDOP and TDOP under different mask angles.



DOP Results

5.2.3. DOP values Analysis

- From the tables we can see that 100% of the DOP values obtained using the combined GPS+BDS systems, are less than the DOP values obtained with the GPS system.

6. CONCLUSIONS

Conclusions

The presented results shown that the combined BDS+GPS constellation provides:

- **Higher availability:** up to 15 satellites were visible compared to 10 in some cases of GPS only;

- **Better geometry:** the PDOP for the combined GPS+BDS constellation was lower than the PDOP for each individual constellation;

- **Better precision:** the precisions of GPS are slightly better than that of BDS in both horizontal and vertical direction, but the combined GPS+BDS constellation got the best performance in all direction.

- The combined GPS+BDS constellation opens an additional possibility to improve the service in the territory of Peru,

Thank you