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Prepare Ships H2020 Project

ION INSTITUTE OF NAVIGATION

RI. SE

Session: C1b: Collaborative and Networked Navigation

SATELLITE SELECTION IN THE CONTEXT OF NETWORK RTK FOR LIMITED BANDWIDTH APPLICATIONS

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CONTENTS

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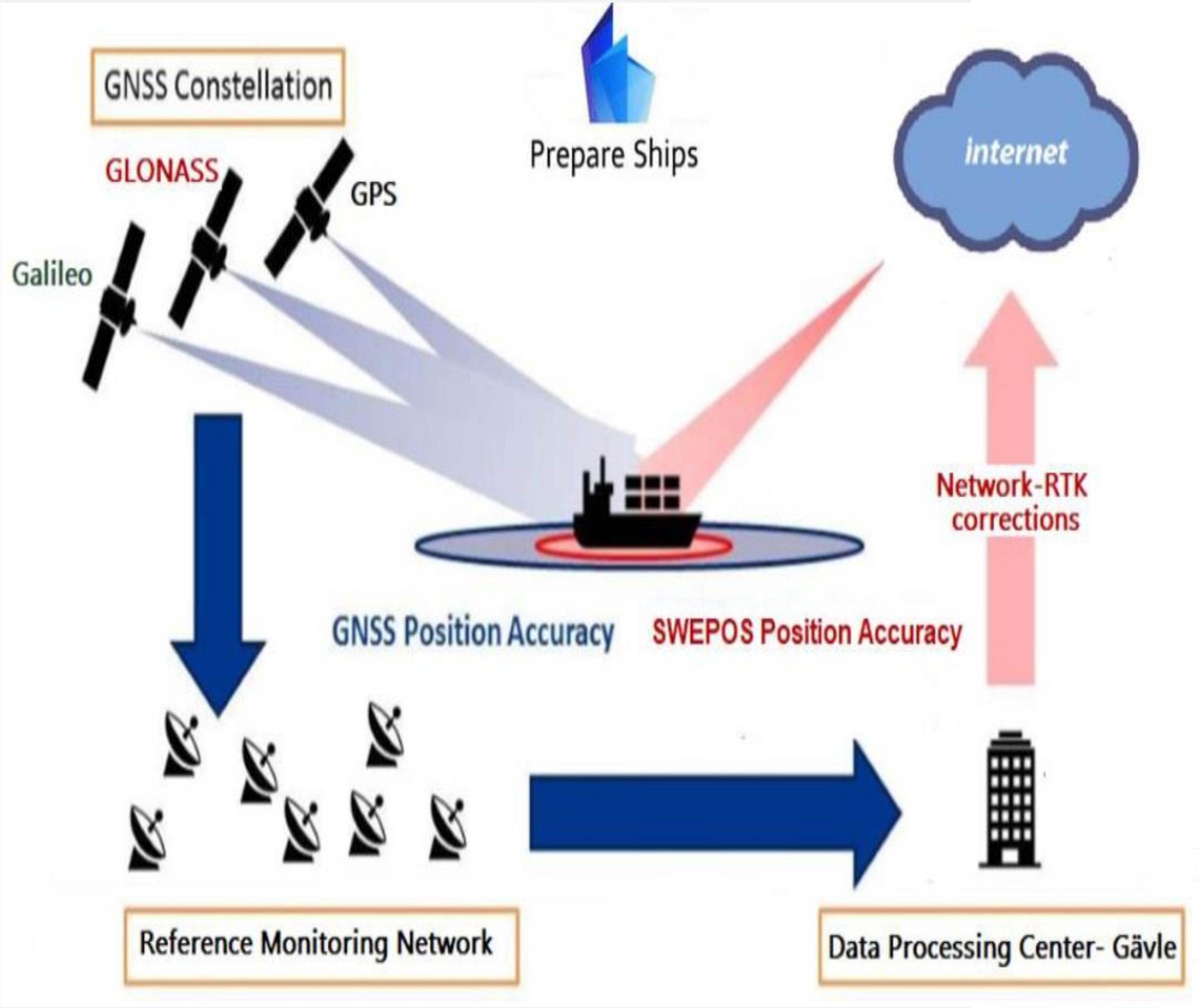
NETWORK RTK

- Accurate and seamless kinematic position
- The average baseline length 30 km and 70 km between two permanent reference stations



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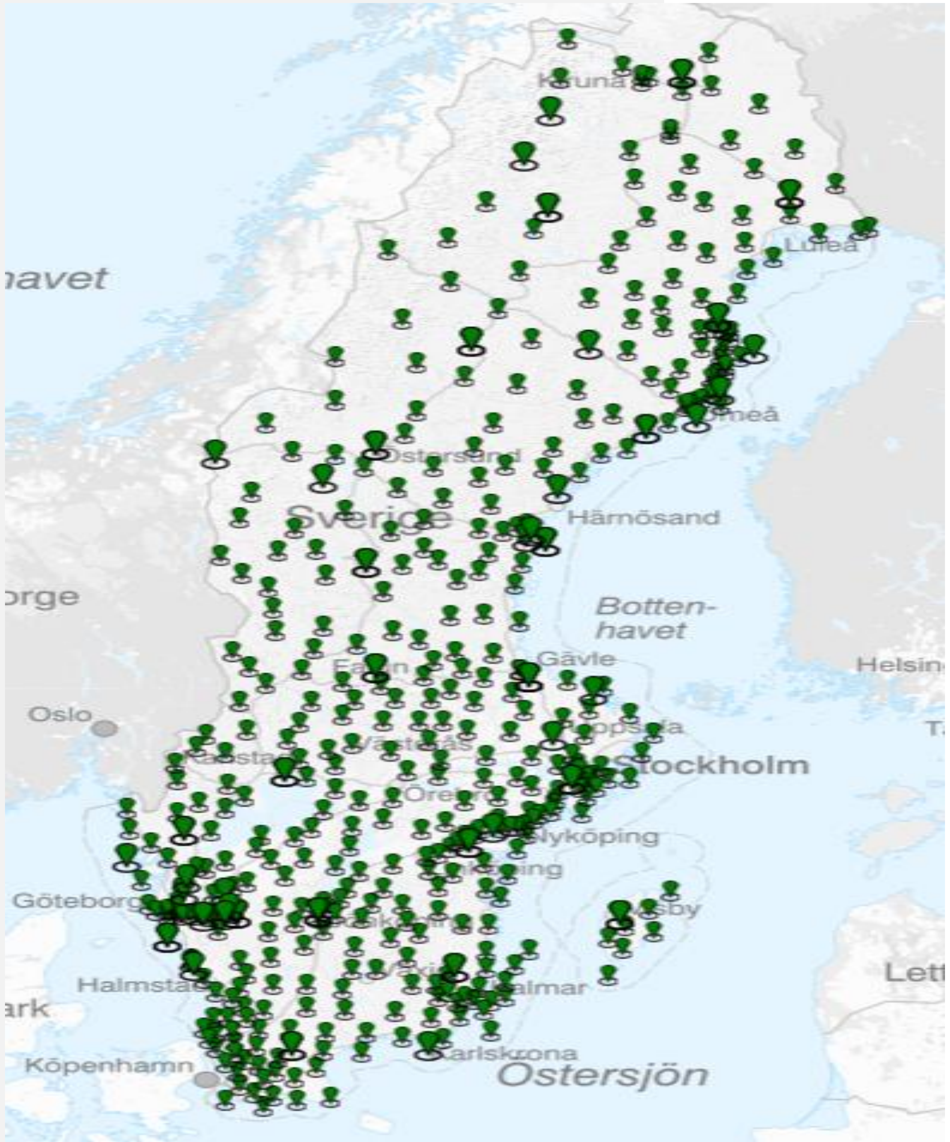
SWEPOS NETWORK

- The national CORS network of Sweden
- Consists of a physical infrastructure, transmission infrastructure and computing infrastructure
- The present SWEPOS Network-RTK Service is based on the VRS concept
- The present SWEPOS infrastructure consists of approximately 450 permanent GNSS reference stations



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SWEPOS NETWORK

- SWEPOS has two types of reference stations: Class A stations and Class B stations
- Class A stations (21 stations) have the best long-term coordinate stability
- The Class A stations are also used to monitor the coordinate stability of the Class B stations.
- The Class B stations are densifying the network of Class A stations in the expansion of the SWEPOS network

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SATELLITE-SELECTION

Methodology

The matrices Q and S are defined as,

$$\mathbf{Q} = (\mathbf{G}^{\mathbf{T}} \cdot \mathbf{W} \cdot \mathbf{G})^{-\mathbf{1}} \text{ and } \mathbf{S} = \mathbf{Q} \cdot \mathbf{G}^{\mathbf{T}} \cdot \mathbf{W} \qquad (1)$$

Where each row of **G**, known as $\mathbf{G_i}$ for the ith satellite with azimuth θ_i and elevation $\emptyset_i$ is defined as,

$$\mathbf{G_i} = [-\cos(\emptyset_i)\cos(\theta_i) \quad -\cos(\emptyset_i)\sin(\theta_i) \quad -sin(\emptyset_i) \quad 1\ ] \qquad (2)$$

For an elevation angle $\emptyset$, we compute troposphere and multipath errors as,

$$\sigma_{Trop}^2 = \frac{0.12012}{\sqrt{0.002001 + sin^2(\emptyset)}}$$

$$\sigma_{MP}^2 = 0.5 + 1.64e^{-\left(\frac{\emptyset}{14.5^\circ}\right)}$$

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SATELLITE-WEIGHTING TYPES

$$W = \begin{bmatrix} \frac{1}{\sigma^2_{1,UERE}} & 0 & \cdots & 0 \\ 0 & \frac{1}{\sigma^2_{2,UERE}} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & \frac{1}{\sigma^2_{i,UERE}} \end{bmatrix}$$

$$W = \begin{bmatrix} sin^2(\emptyset_1) * 10^{0.1SNR_1} & 0 & \dots & 0 \\ 0 & sin^2(\emptyset_2) * 10^{0.1SNR_2} & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & sin^2(\emptyset_i) * 10^{0.1SNR_i} \end{bmatrix}$$

$$W = \begin{bmatrix} sin^2(\emptyset_1) & 0 & \dots & 0 \\ 0 & sin^2(\emptyset_2) & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & sin^2(\emptyset_i) \end{bmatrix}$$

$$W = \begin{bmatrix} 10^{0.1SNR_1} & 0 & \dots & 0 \\ 0 & 10^{0.1SNR_2} & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & 10^{0.1SNR_i} \end{bmatrix}$$

Where elevation angle ($\emptyset_i$), variances of UERE values and Signal to noise ratio derived from the C/A data (SNR_i) are computed for the ith satellite

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SATELLITE-SELECTION- OPTIMIZATION TECHNIQUES

Methodology

We define the measures for initial selection for vertical, two- and three-dimensional optimization as,

$$S_{meas,i}(vertical) = \frac{S_{3,i}^2}{P_{i,i}} \qquad (3)$$

$$S_{meas,i}(2D) = \frac{S_{1,i}^2 + S_{2,i}^2}{P_{i,i}} \qquad (4)$$

$$S_{meas,i}(3D) = \frac{S_{1,i}^2 + S_{2,i}^2 + S_{3,i}^2}{P_{i,i}} \qquad (5)$$

Where $\mathbf{P} = \mathbf{W} - \mathbf{W} \cdot \mathbf{G} \cdot \mathbf{S}$ (6)

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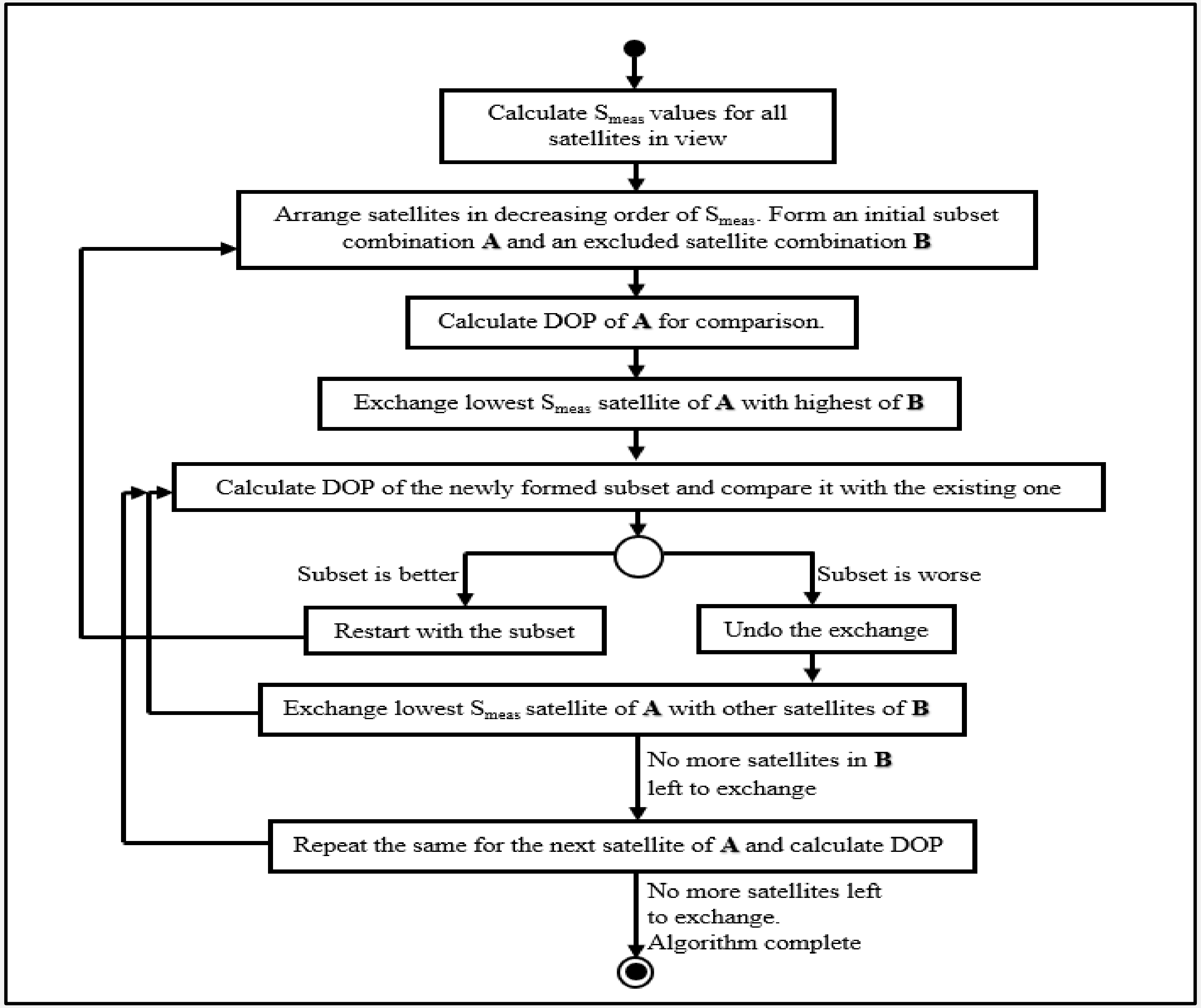
WORK FLOW



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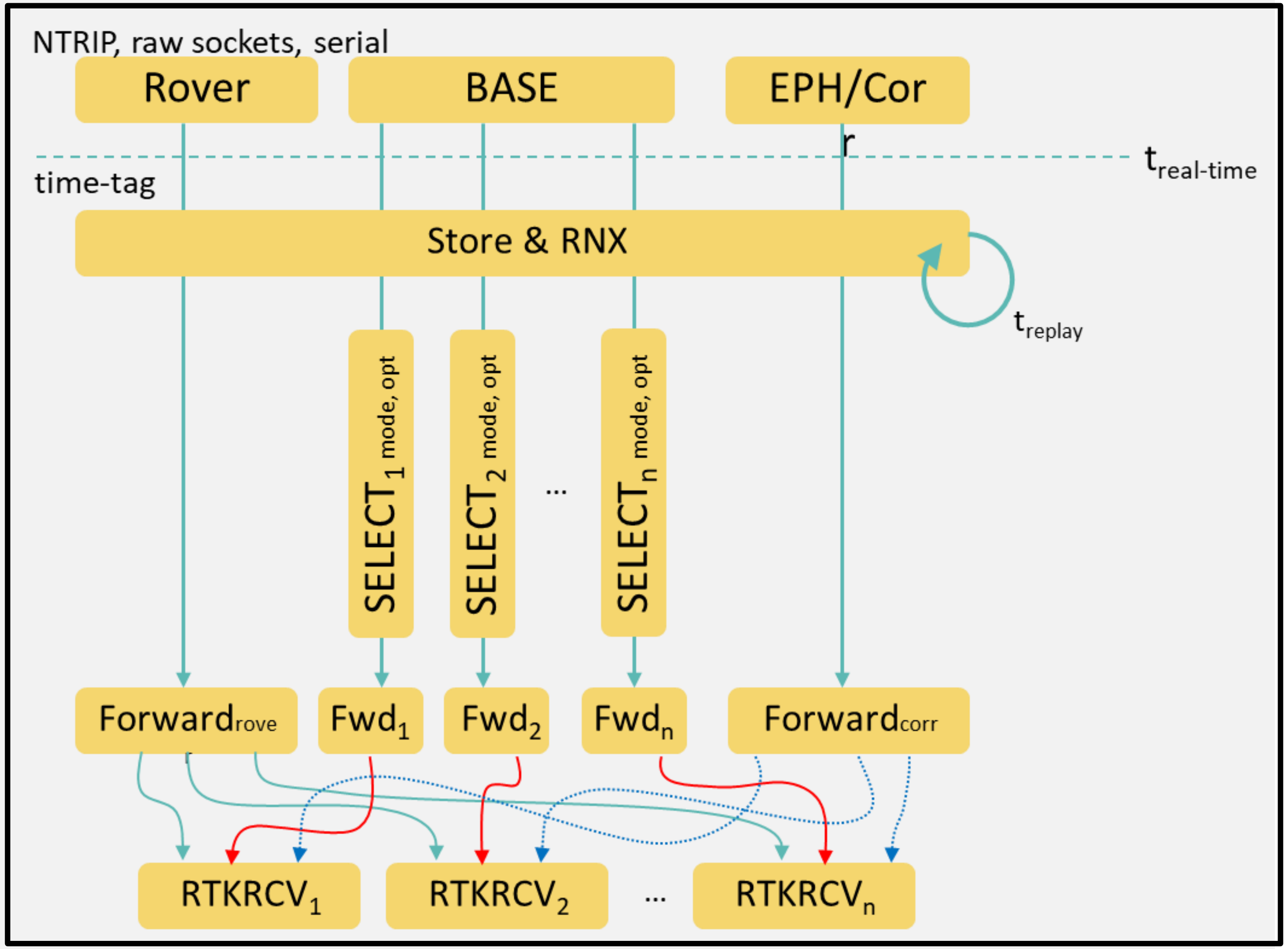
EXPERIMENTAL TEST SETUP

- Store and timely forward/replay multiple RTCM3 MSM based streams
- Replay functionality to test and implement inline algorithms, timing
- SWEPOS VRS with known "ground truth"
  - 5 and 12 km baseline static
  - dynamic



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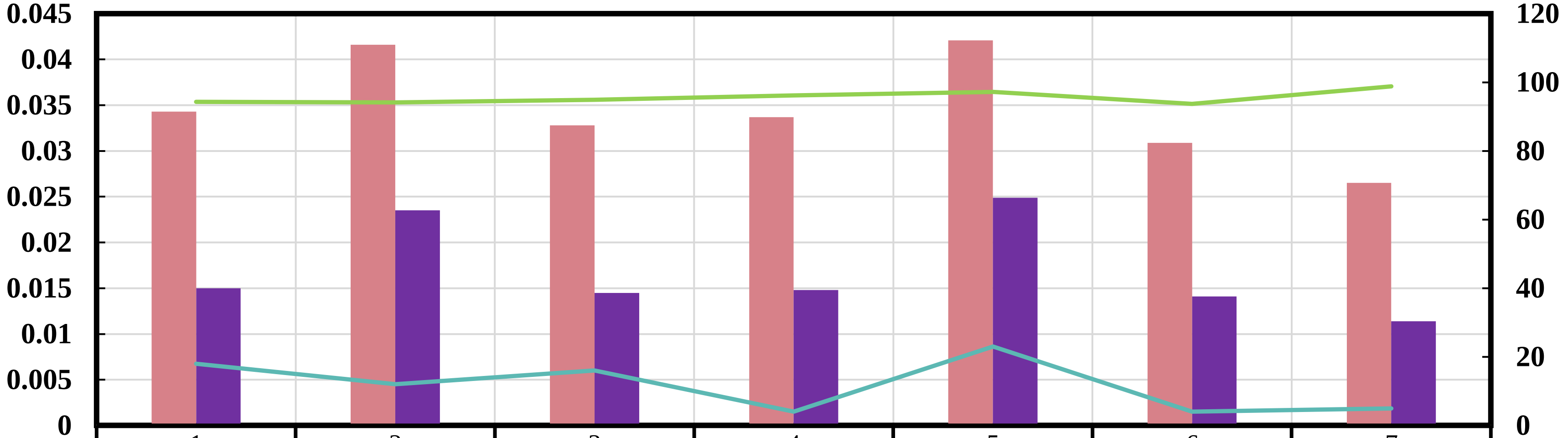
RESULTS

Satellite selection Algorithm	
Number	Name
1	Unweighted geometry optimization for H
2	Unweighted geometry optimization for 2D
3	Unweighted geometry optimization for 3D
4	UERE weighted geometry optimization for H
5	UERE weighted geometry optimization for 2D
6	UERE weighted geometry optimization for 3D
7	Baseline with no selection algorithm

Statistics for position errors for GPS and GAL (4 satellites each) Optimization algorithms tested on 31st Aug2021

(Baseline distance of 12km between Rover and Base)



	1	2	3	4	5	6	7
Mean error(m)	0.0343	0.0416	0.0328	0.0337	0.0421	0.0309	0.0265
Error deviations(m)	0.015	0.0235	0.0145	0.0148	0.0249	0.0141	0.0114
TTFF(s)	18	12	16	4	23	4	5
Percentage of posfix	94.309	94.121	94.948	96.179	97.212	93.736	98.792

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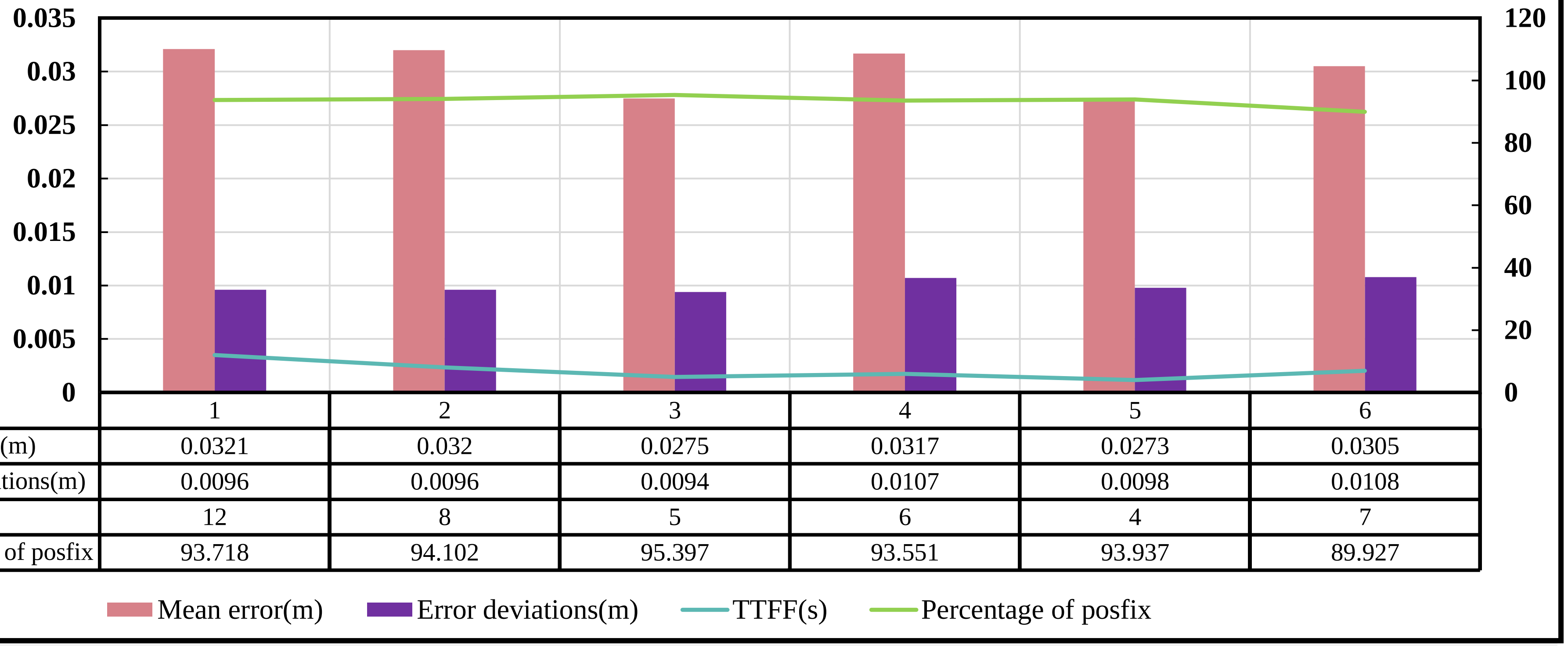
RESULTS

Satellite selection Algorithm	
Number	Name
1	Unweighted geometry optimization for H
2	UERE weighted geometry optimization for H
3	Elevation weighted geometry optimization for H
4	SNR weighted geometry optimization for H
5	SNR and elevation weighted geometry optimization for H
6	Baseline with no selection algorithm

Statistics for position errors - GPS and GAL (5 satellites each)
Height optimization algorithms tested on 3rd Sept 2021
(Baseline distance of 12km between Rover and Base)



	1	2	3	4	5	6
Mean error(m)	0.0321	0.032	0.0275	0.0317	0.0273	0.0305
Error deviations(m)	0.0096	0.0096	0.0094	0.0107	0.0098	0.0108
TTFF(s)	12	8	5	6	4	7
Percentage of posfix	93.718	94.102	95.397	93.551	93.937	89.927

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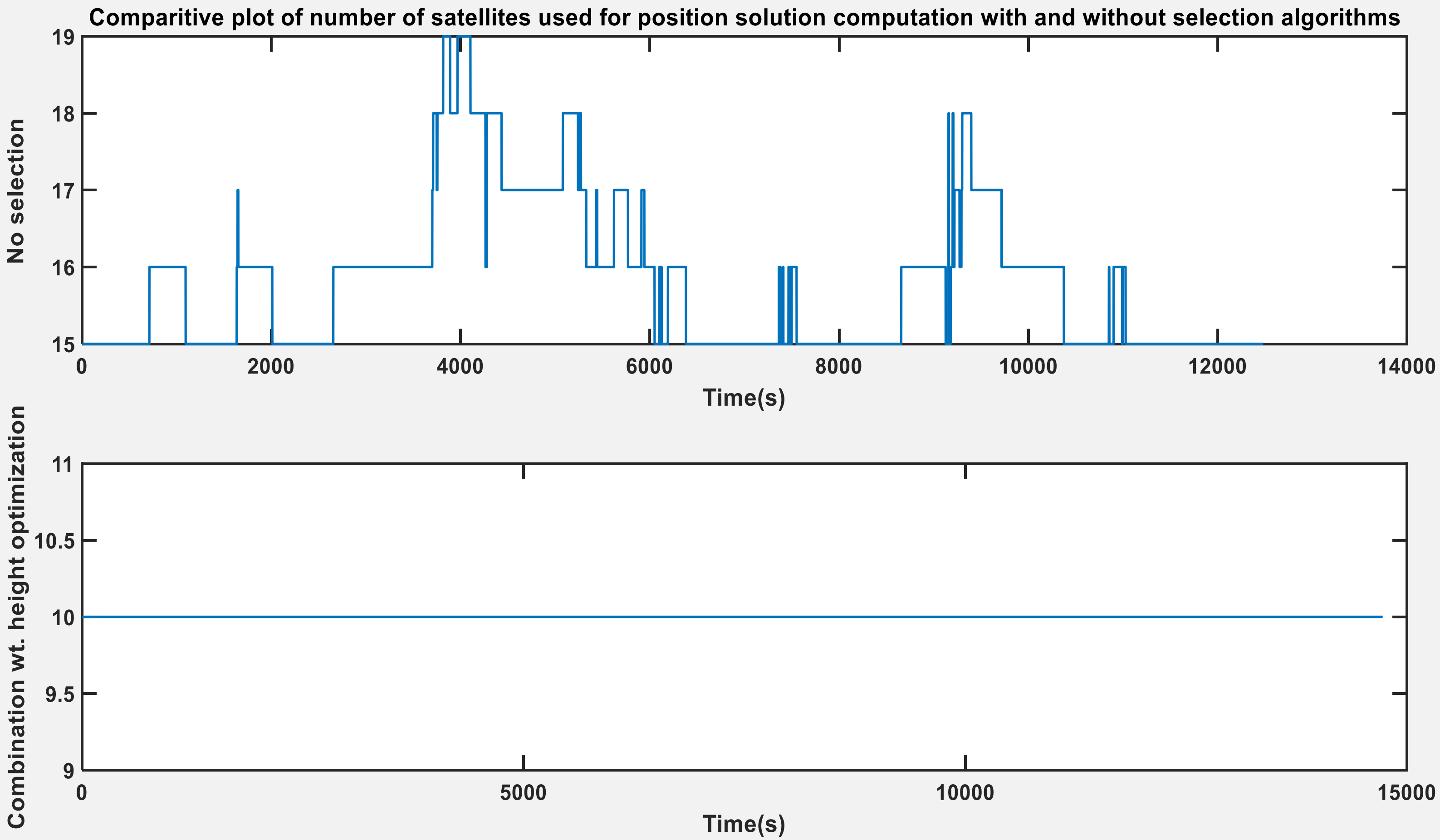
RESULTS



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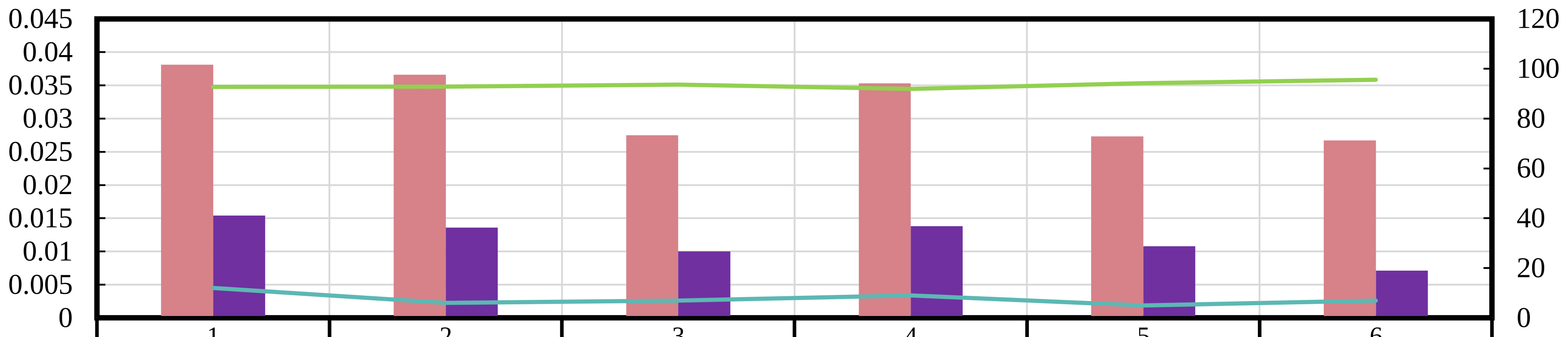
RESULTS

Satellite selection Algorithm	
Number	Name
1	Unweighted geometry optimization for 2D
2	UERE weighted geometry optimization for 2D
3	Elevation weighted geometry optimization for 2D
4	SNR weighted geometry optimization for 2D
5	SNR and elevation weighted geometry optimization for 2D
6	Baseline with no selection algorithm

Statistics for position errors for GPS and GAL (5 satellites each)
Two dimensional optimisation algorithms tested on 3rd Sept 2021
(Baseline distance of 12km between Rover and Base)



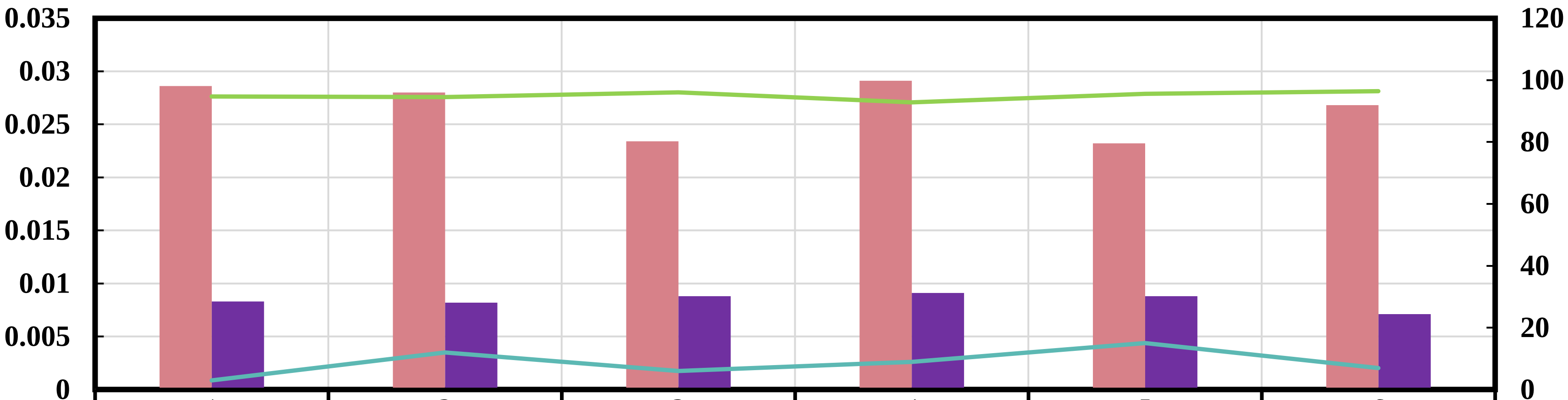
	1	2	3	4	5	6
Mean error(m)	0.0381	0.0366	0.0275	0.0353	0.0273	0.0267
Error deviations(m)	0.0154	0.0136	0.01	0.0138	0.0108	0.0071
TTFF(s)	12	6	7	9	5	7
Percentage of posfix	92.74	92.859	93.669	91.933	94.246	95.59

Mean error(m)   Error deviations(m)   TTFF(s)   Percentage of posfix

RESULTS

Satellite selection Algorithm	
Number	Name
1	Unweighted geometry optimization for 3D
2	UERE weighted geometry optimization for 3D
3	Elevation weighted geometry optimization for 3D
4	SNR weighted geometry optimization for 3D
5	SNR and elevation weighted geometry optimization for 3D
6	Baseline with no selection algorithm

Statistics for position errors for GPS and GAL (5 satellites each)
Three dimensional optimization algorithms tested on 3rd Sept 2021
(Baseline distance of 12km between Rover and Base)



	1	2	3	4	5	6
Mean error(m)	0.0286	0.028	0.0234	0.0291	0.0232	0.0268
Error deviations(m)	0.0083	0.0082	0.0088	0.0091	0.0088	0.0071
TTFF(s)	3	12	6	9	15	7
Percentage of posfix	94.713	94.56	96.029	92.807	95.545	96.462

Mean error(m) Error deviations(m) TTFF(s) Percentage of posfix

Satellite selection Algorithm	
Number	Name
1	Unweighted geometry optimization for H
2	Unweighted geometry optimization for 2D
3	Unweighted geometry optimization for 3D
4	UERE weighted geometry optimization fo H
5	UERE weighted geometry optimization for 2D
6	UERE weighted geometry optimization for 3D
7	Elevation weighted geometry optimization for H
8	Elevation weighted geometry optimization for 2D
9	Elevation weighted geometry optimization for 3D
10	SNR weighted geometry optimization for H
11	SNR weighted geometry optimization for 2D
12	SNR weighted geometry optimization for 3D
13	SNR and elevation weighted geometry optimization for H
14	SNR and elevation weighted geometry optimization for 2D
15	SNR and elevation weighted geometry optimization for 3D
16	Baseline with no selection algorithm

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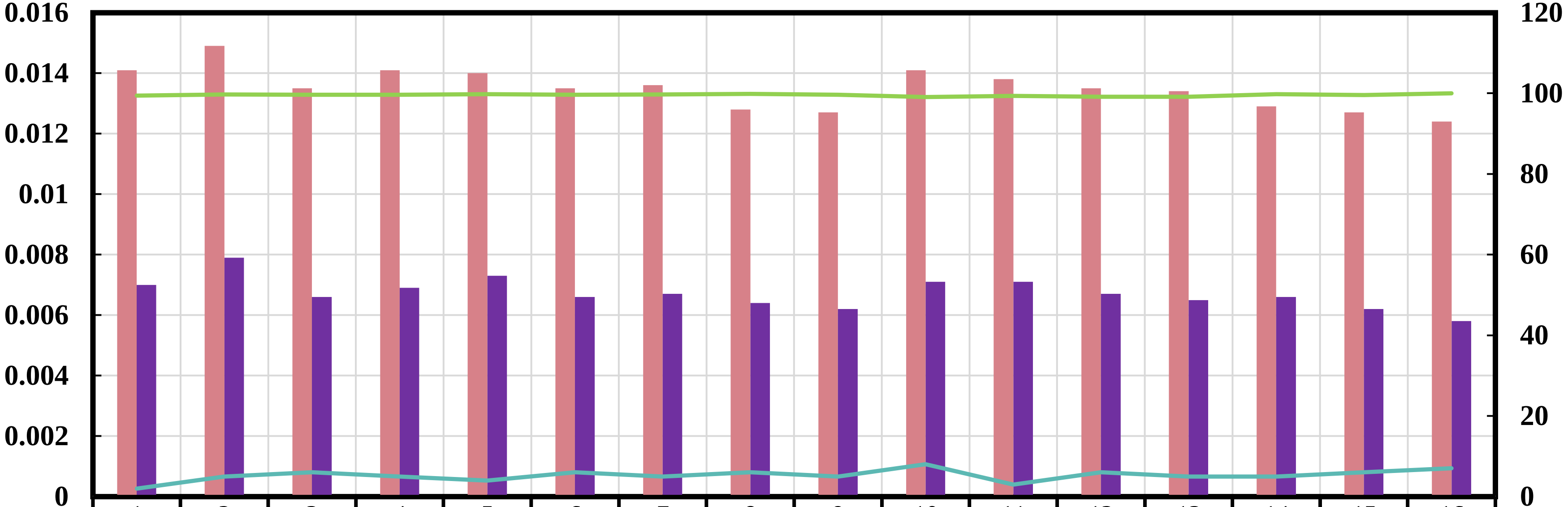
RESULTS

Statistics for position errors for GPS and GAL (5 satellites each) Optimization algorithms tested on 10th Sept 2021 (Baseline distance of 8.8km between Rover and Base)



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Mean error(m)	0.0141	0.0149	0.0135	0.0141	0.014	0.0135	0.0136	0.0128	0.0127	0.0141	0.0138	0.0135	0.0134	0.0129	0.0127	0.0124
Error deviations(m)	0.007	0.0079	0.0066	0.0069	0.0073	0.0066	0.0067	0.0064	0.0062	0.0071	0.0071	0.0067	0.0065	0.0066	0.0062	0.0058
TTFF(s)	2	5	6	5	4	6	5	6	5	8	3	6	5	5	6	7
Percentage of posfix	99.458	99.741	99.646	99.674	99.768	99.671	99.713	99.864	99.612	99.054	99.36	99.163	99.159	99.758	99.553	99.975

Mean error(m) Error deviations(m) TTFF(s) Percentage of posfix

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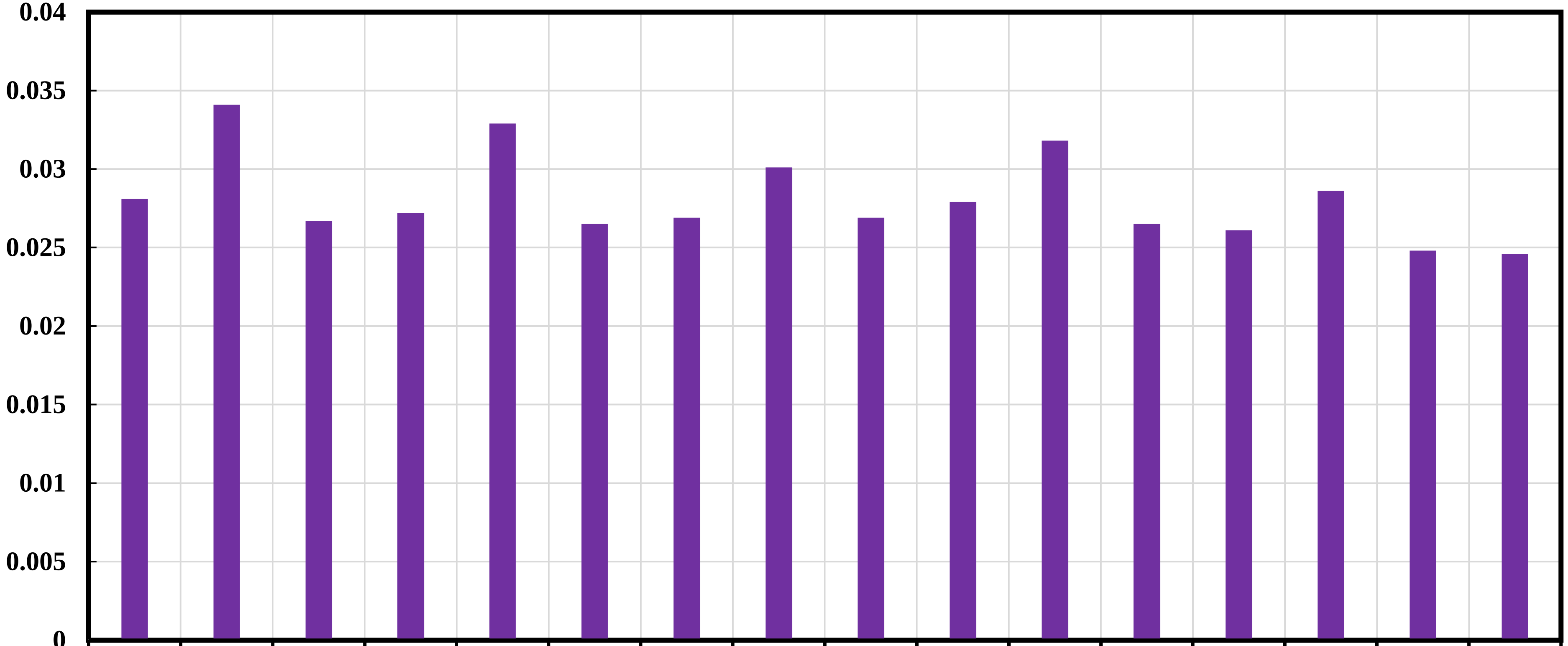
Satellite selection Algorithm	
Number	Name
1	Unweighted geometry optimization for H
2	Unweighted geometry optimization for 2D
3	Unweighted geometry optimization for 3D
4	UERE weighted geometry optimization fo H
5	UERE weighted geometry optimization for 2D
6	UERE weighted geometry optimization for 3D
7	Elevation weighted geometry optimization for H
8	Elevation weighted geometry optimization for 2D
9	Elevation weighted geometry optimization for 3D
10	SNR weighted geometry optimization for H
11	SNR weighted geometry optimization for 2D
12	SNR weighted geometry optimization for 3D
13	SNR and elevation weighted geometry optimization for H
14	SNR and elevation weighted geometry optimization for 2D
15	SNR and elevation weighted geometry optimization for 3D
16	Baseline with no selection algorithm

RESULTS

Stats for RMS errors in three dimension for GPS and GAL (5 satellites each)
Optimization algorithms tested on 10th Sept 2021
(Baseline distance of 17.8 km between Rover and Base)



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
3D error(m)	0.0281	0.0341	0.0267	0.0272	0.0329	0.0265	0.0269	0.0301	0.0269	0.0279	0.0318	0.0265	0.0261	0.0286	0.0248	0.0246

3D error(m)

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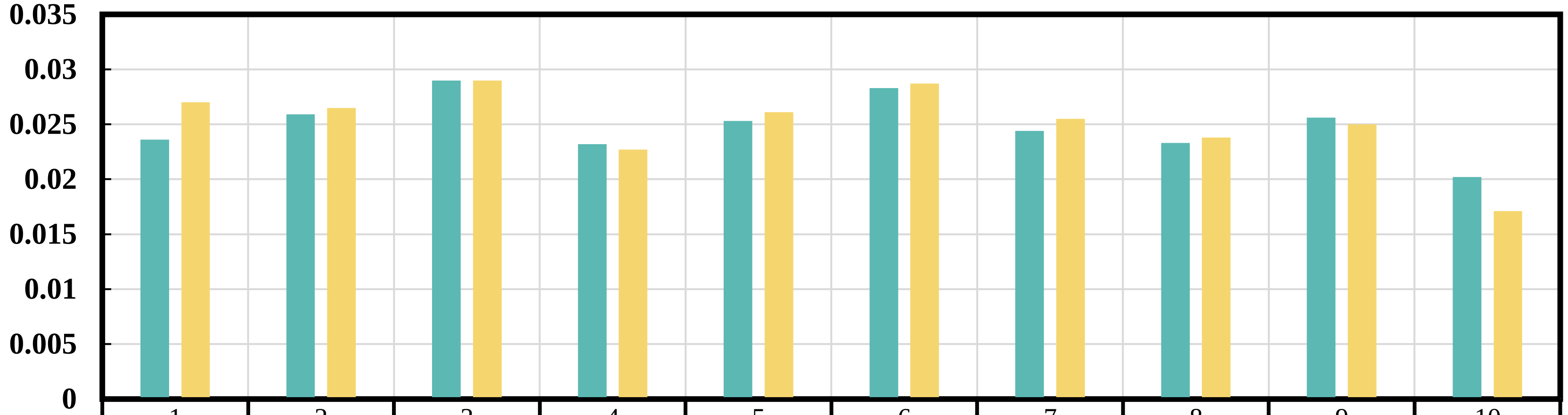
RESULTS

1	Unweighted geometry optimization for H
2	Unweighted geometry optimization for 2D
3	Unweighted geometry optimization for 3D
4	SNR weighted geometry optimization for H
5	SNR weighted geometry optimization for 2D
6	SNR weighted geometry optimization for 3D
7	SNR and elevation weighted geometry optimization for H
8	SNR and elevation weighted geometry optimization for 2D
9	SNR and elevation weighted geometry optimization for 3D
10	Baseline with no selection algorithm

Statistics for absolute errors in height for GPS and GAL (5 satellites each)
Optimization algorithms tested on 10th Sept 2021
(Baseline distance of 17.8 km between Rover and Base)



	1	2	3	4	5	6	7	8	9	10
Mean RMS error(m)	0.0236	0.0259	0.029	0.0232	0.0253	0.0283	0.0244	0.0233	0.0256	0.0202
Deviation of RMS error(m)	0.027	0.0265	0.029	0.0227	0.0261	0.0287	0.0255	0.0238	0.025	0.0171

Mean RMS error(m)   Deviation of RMS error(m)

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CONCLUSIONS

- It is needed to implement algorithms for retaining the satellite with the highest elevation. This empirically improves integer ambiguity resolution for position fixing

- A reduced number of carefully chosen observations from specific satellites is sufficient for precise positioning

- Fixing a minimum number of satellites for each constellation enables a fair weightage to the different constellations used.

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SIGNIFICANCE OF WORK.

- Development and testing of satellite selection algorithms were primarily supporting the development of Lantmäteriet Adjustment Solution (LAS*) in the context of the Prepare Ships project but was also important for understanding the consequences of bandwidth limitations for VHF dissemination from a user perspective.
- This research is among the first of its kind in the application of Network RTK in maritime and similar environment and resulted in adapted algorithms.
- However, the research and the achieved results extend beyond maritime applications and can be used for any general application for satellite selection with a Network RTK perspective

***Distribution of the Adapted-NRTK Correction Data via VDES for the Shipping Navigation Safety (**https://www.ion.org/gnss/abstracts.cfm?paperID=10039**)**

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ACKNOWLEDGMENTS

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We acknowledge that ‘rtcm3torinex’ by Dirk Stöcker (Alberding, BKG) was modified to capture NTRIP/RAW RTCM3, time-tag messages, store and forward, replay.

We also acknowledge the RTKLib project initiated by Tomoji Takasu and contributed to by others, notably Tim Everett of rtkexploer.com as a tool for testing the algorithms.

PREPARE SHIPS

PREParE SHIPS aims to develop a robust and accurate navigation solution for coastal and open-sea navigation based on the features of Galileo signals in combination with other in-ship sensors.

PREParE SHIPS will define and validate an innovative navigation decision support concept based on four key elements; resilient EGNSS positioning; real-time dynamic predictor; geo-fencing; and ship2ship/ ship2shore communication.

Call: Applications in satellite navigation – Galileo

- *Topic: H2020GSA-2018: EGNSS Transport applications*
- *Budget: ~3.5 M€*
- *EU Grant: ~3.0 M€*
- *Project start: 2019-12-01*
- *Project End: 2021-12-31*

THANKS!

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