High Accuracy Measurement of Geostationary Satellite Location Uncertainty using TWSTFT via NMI's Time and Frequency Laboratories

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I. INTRODUCTION

A dense distribution of space debris is present in geostationary orbit (GEO). To avoid collision with debris, maneuvers to change the satellite's position are necessary [1]. The uncertainty of the satellite's location defines the region that must avoid the passage of debris. The larger this uncertainty region, the greater the number of maneuvers.

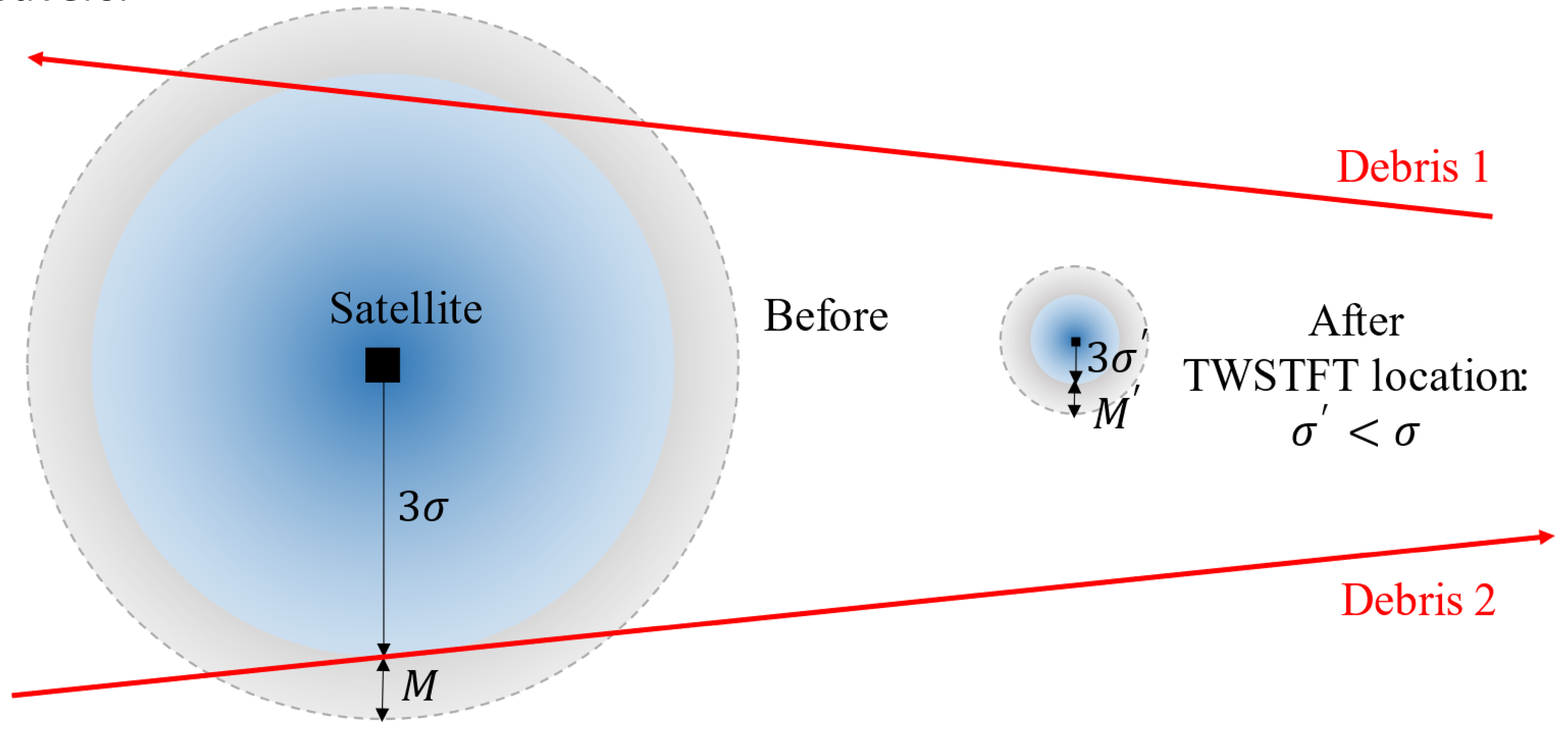

Fig. 1. Maneuver region defined by location uncertainty [4]

A reduced uncertainty region from a few kilometers to a few meters means decreasing the number of maneuvers, reducing fuel consumption, and increasing the satellite's lifetime and safety.

The characteristics of TWSTFT, such as high accuracy of time measurement [2] and multichannel SDR modems, allow that this technique be used to measure the GEO satellite's location with high accuracy.

II. MATHEMATICAL MODEL

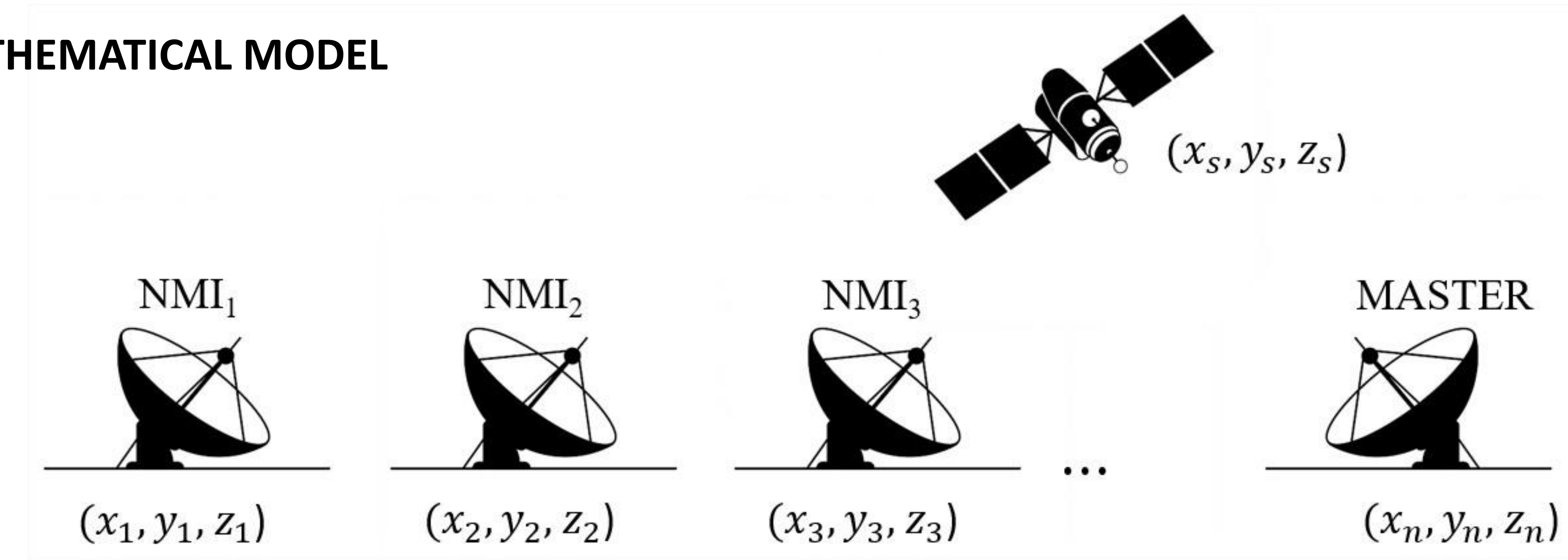

Fig. 2. NMI stations linked by TWSTFT for GEO satellite location uncertainty calculation.

$$\sigma = \sigma_r P \rightarrow \begin{cases} \sigma_r = \sqrt{\sigma^2_{IONO} + \sigma^2_{TROPO} + \sigma^2_{EQTO} + \sigma^2_{SAGNAC}} \\ P = \sqrt{\sigma^2_X + \sigma^2_Y + \sigma^2_Z} \end{cases}$$

σ_r → ranging uncertainty
- uses typical error sources of TWSTFT links (carrier-phase) [4]

σ ↓ GEO satellite location uncertainty

P ↓ position dilution of precision (PDOP):
- geometrical factor
- reduced as the area among stations increases

$$\Delta\boldsymbol{\rho} = \boldsymbol{A}\,\Delta\boldsymbol{x} \rightarrow \begin{aligned} A_{i,1} &= (x_i - x_S)/r_i + (x_n - x_S)/r_n \\ A_{i,2} &= (y_i - y_S)/r_i + (y_n - y_S)/r_n \\ A_{i,3} &= (z_i - z_S)/r_i + (z_n - z_S)/r_n \\ r_i &= \sqrt{(x_i - x_S)^2 + (y_i - y_S)^2 + (z_i - z_S)^2} \end{aligned}$$

NMI coordinates are known accurately and the GEO satellite coordinates is the well-known station keeping coordinates. → $\boldsymbol{A}$ is fully known.

Minimizing the residual vector $\boldsymbol{A}\,\Delta\boldsymbol{x}$ - $\Delta\boldsymbol{\rho}$

$$\Delta\boldsymbol{x} = (\boldsymbol{A}^T\boldsymbol{A})^{-1}\boldsymbol{A}^T\Delta\boldsymbol{\rho} \;\rightarrow\; cov(\Delta\boldsymbol{x}) = (\boldsymbol{A}^T\boldsymbol{A})^{-1} = \begin{pmatrix} \sigma^2_X & \sigma^2_{Xy} & \sigma^2_{Xz} \\ \sigma^2_{Yx} & \sigma^2_Y & \sigma^2_{Yz} \\ \sigma^2_{Zx} & \sigma^2_{Zy} & \sigma^2_Z \end{pmatrix} \rightarrow P$$

III. RESULTS

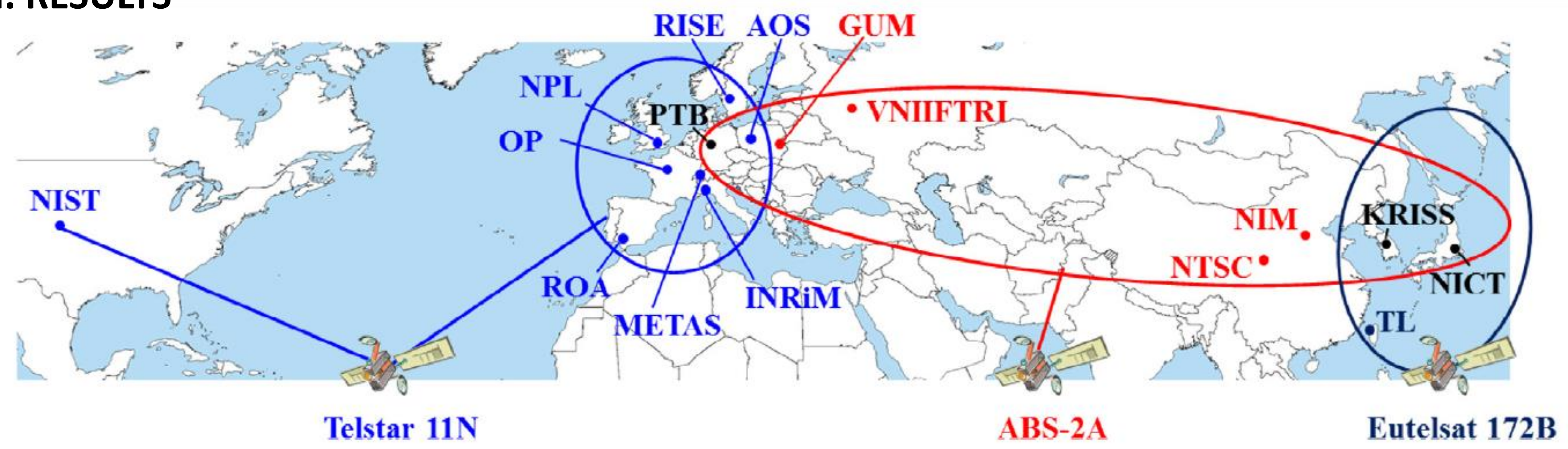

Fig. 3. Participating TWSTFT stations in the SDR pilot study of [3]

Table 1. Results considering NMI labs in Fig.3 and additional NMI labs.

SATELLITE	MASTER	(#) NMI	AREA [m²]	P	σ [m]
Telstar-11N	PTB	(9)	1.139e+07	35.5	10.9
ABS-2A	PTB	(8)	1.169e+07	74.5	22.9
Telstar-11N	PTB	(9) +Egypt (NIS)+Colombia (INM)	3.057e+07	14.2	4.4
ABS-2A	PTB	(8) +Singapore(SG)+Saudi Arabia (SASO)	3.505e+07	11.0	3.4

IV. CONCLUSION

The proposed TWSTFT network using NMI labs could be addressed by the BIPM CCTF-WGTWSTFT to develop proposals for the satellite operators. The GEO satellite location system would be a joint development with dual purpose: increase the satellite revenue (lifetime) and safety; and implement an intercomparison network between NMI for atomic and optical clocks and for contribution to UTC.

REFERENCES

[1] Kota Sato, et al. "The collision avoidance strategy for geostationary satellites considering orbit maintenance," Journal of Space Safety Engineering, vol. 8, Issue 4, 2021.

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[4] M. V. Lima and L. V. Tarelho, "Characterization of PDOP for Locating a Geostationary Satellite using TWSTFT Links", IEEE Latincom, 2022.