Departamento de Señales, Sistemas y Radiocomunicaciones

[EN-004] Joint target tracking and systematic error correction for Wide Area Multilateration

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1. Introduction

- In order to enable greater optimization in the use of airspace [1] [2], stricter aircraft positioning requirements can be expected in the near future.
- The trend in Air Traffic Management (ATM) is to rely on ADS-B as the main source of aircraft positioning.
- Wide Area Multilateration (WAM) can be used as a redundant system for ADS-B integrity monitoring.

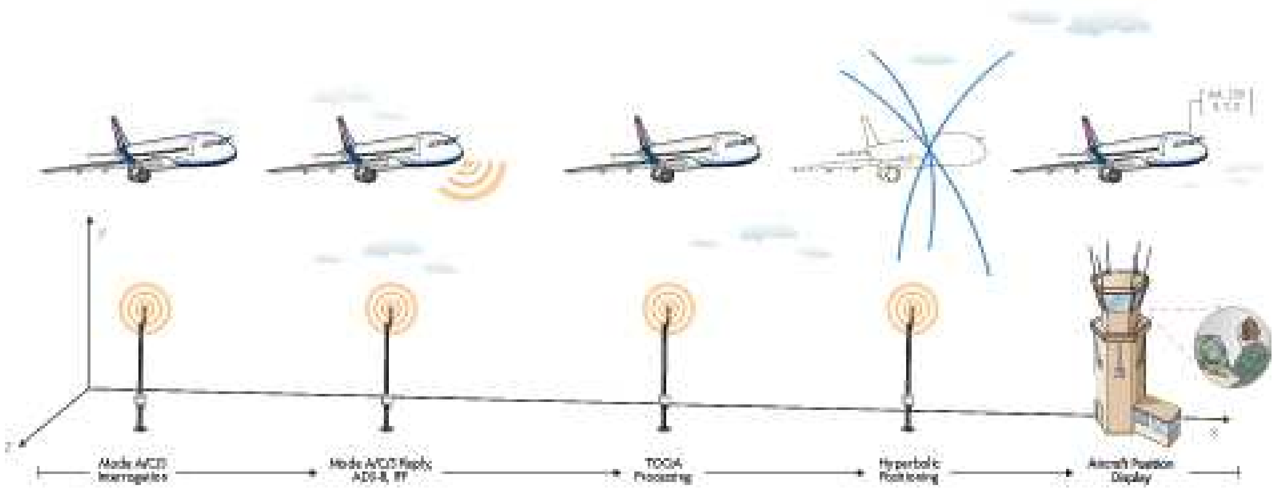
[1] "Introduction to the Mission Trajectory" EUROCONTROL, ed. 1.0, May 2010.
[2] "EUROCONTROL Specification for the application of the Flexible Use of Airspace (FUA)", EUROCONTROL, ed. 1.1, October 2009.

1. Introduction

(Principle of WAM)

- WAM systems are based on the reception of ADS-B transmissions (or Mode A/C/S replies) by the aircraft.

- The emitter (aircraft) position is determined from the Time Difference Of Arrival of the signal obtained in the ground stations.



2. Characterization of errors in WAM

$$TDOA_{i,1}^{j} = TOA_{i}^{j} - TOA_{1}^{j} = \frac{1}{c}\left(\rho_{ij} - \rho_{1j}\right)$$

$$\rho_{ij} = R_{ij} + \cancel{cT_{e}} + \Delta P_{ij} + c\Delta T_{i} + \cancel{n_{i}}$$

(TDOA) (SNR)

Pseudorange

Where:

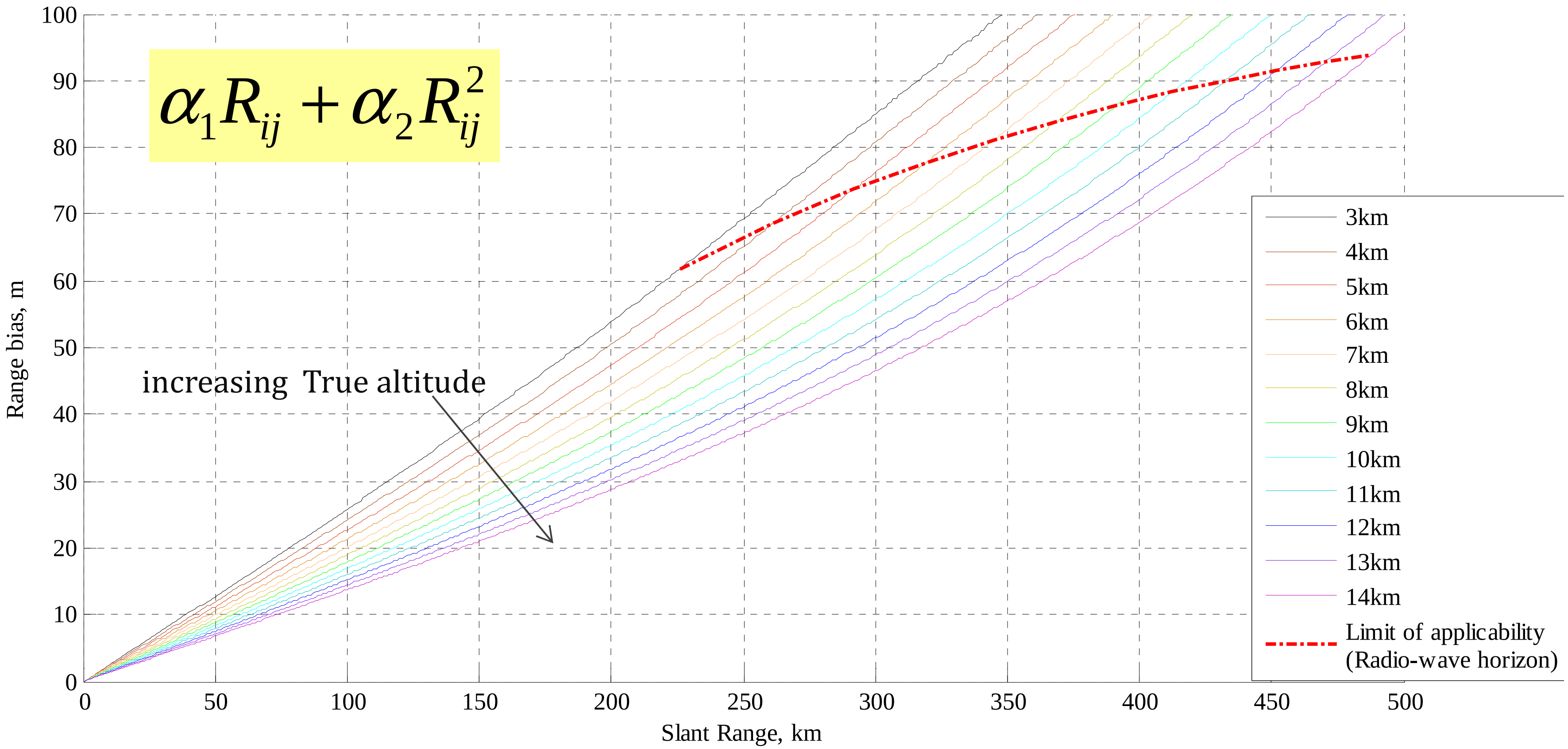
	i	stands for the base station number
	j	stands for the aircraft number
	~~cT_e~~:	~~uncertainty in the signal emission time~~
	ΔP_{ij} :	propagation error
	$c\Delta T_i$:	synchronization error
	~~n_i~~:	~~receiver noise (AWGN)~~

Goal: to solve the TDOA equation system

2. Characterization of errors in WAM

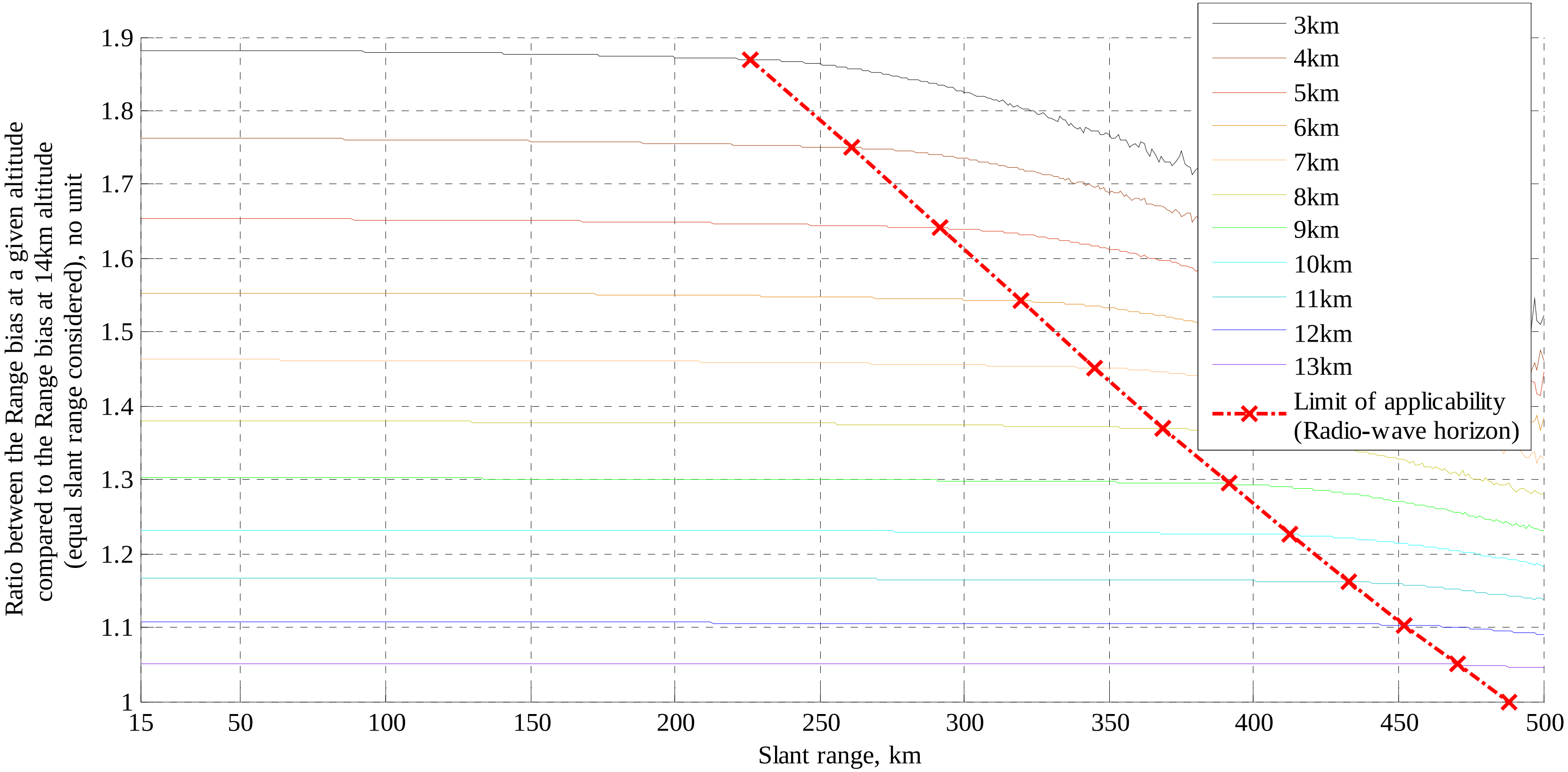
(Propagation error: Slant Range dependency)

Range bias caused by the troposphere propagation (ICAO Standard Atmosphere)



2. Characterization of errors in WAM
(Propagation error: True Altitude dependency)

Ratio between range bias for an aircraft flying at a given altitude compared to at 14km AMSL but equal slant-range



2. Characterization of errors in WAM

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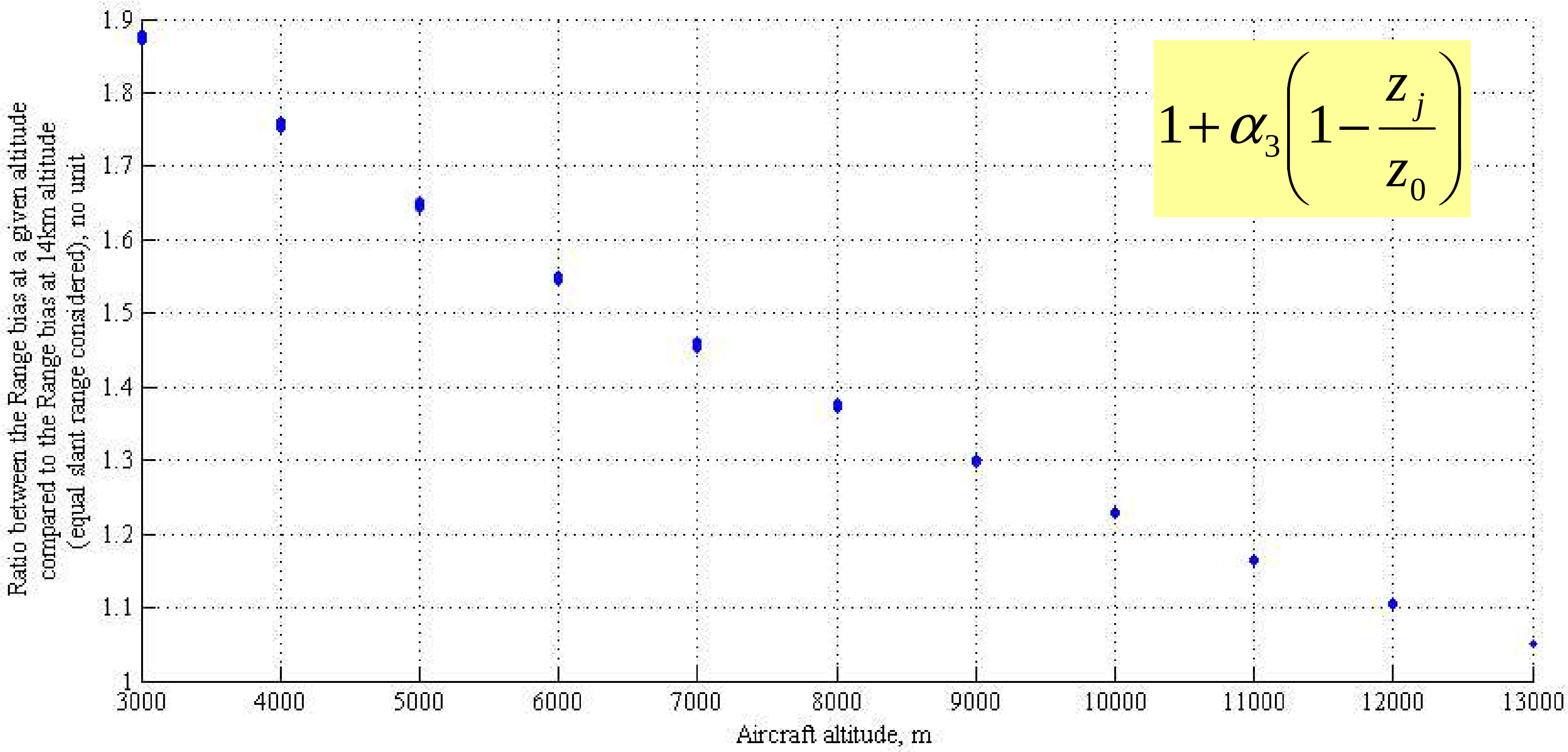


$$1+\alpha_3\left(1-\frac{z_j}{z_0}\right)$$

2. Characterization of errors in WAM

- The propagation error expression now becomes:

$$\Delta P_{ij}\left(R_{ij}, z_j\right) \approx \left(\alpha_1 R_{ij} + \alpha_2 R_{ij}^2\right)\left[1 + \alpha_3\left(1 - \frac{z_j}{z_0}\right)\right]$$

where $R_{ij} = \sqrt{\left(x_j - x_i\right)^2 + \left(y_j - y_i\right)^2 + \left(z_j - z_i\right)^2}$

- Hence, the **pseudorange** can be modeled as follows:

$$\rho_{ij} = R_{ij} + \left(\alpha_1 R_{ij} + \alpha_2 R_{ij}^2\right)\left[1 + \alpha_3\left(1 - \frac{z_j}{z_0}\right)\right] + c\Delta T_i + \cancel{cT_e} + \cancel{n_i}$$

(TDOA) (SNR)

3. Problem statement

- The aim is to **dynamically** estimate the effect of systematic errors, in order to mitigate them when calculating the target positions.

- Hence, for each instant, the following values have to be computed:
  - **State vector** of all aircrafts (position, velocity, acceleration)
  - **Covariance matrix** associated to the aircraft state vectors
  - **State vector** of the systematic errors ($\alpha_{1,}$ $\alpha_{2,}$ $\alpha_{3,}$ $c\Delta T_i$)
  - **Covariance matrix** associated to the systematic errors

4. Proposed solution (Concept)

- Use of **opportunity traffic** to obtain a set of new independent equations [4], thus avoiding an indeterminate equation system.

- **Joint** tracking and systematic error estimation [7]:

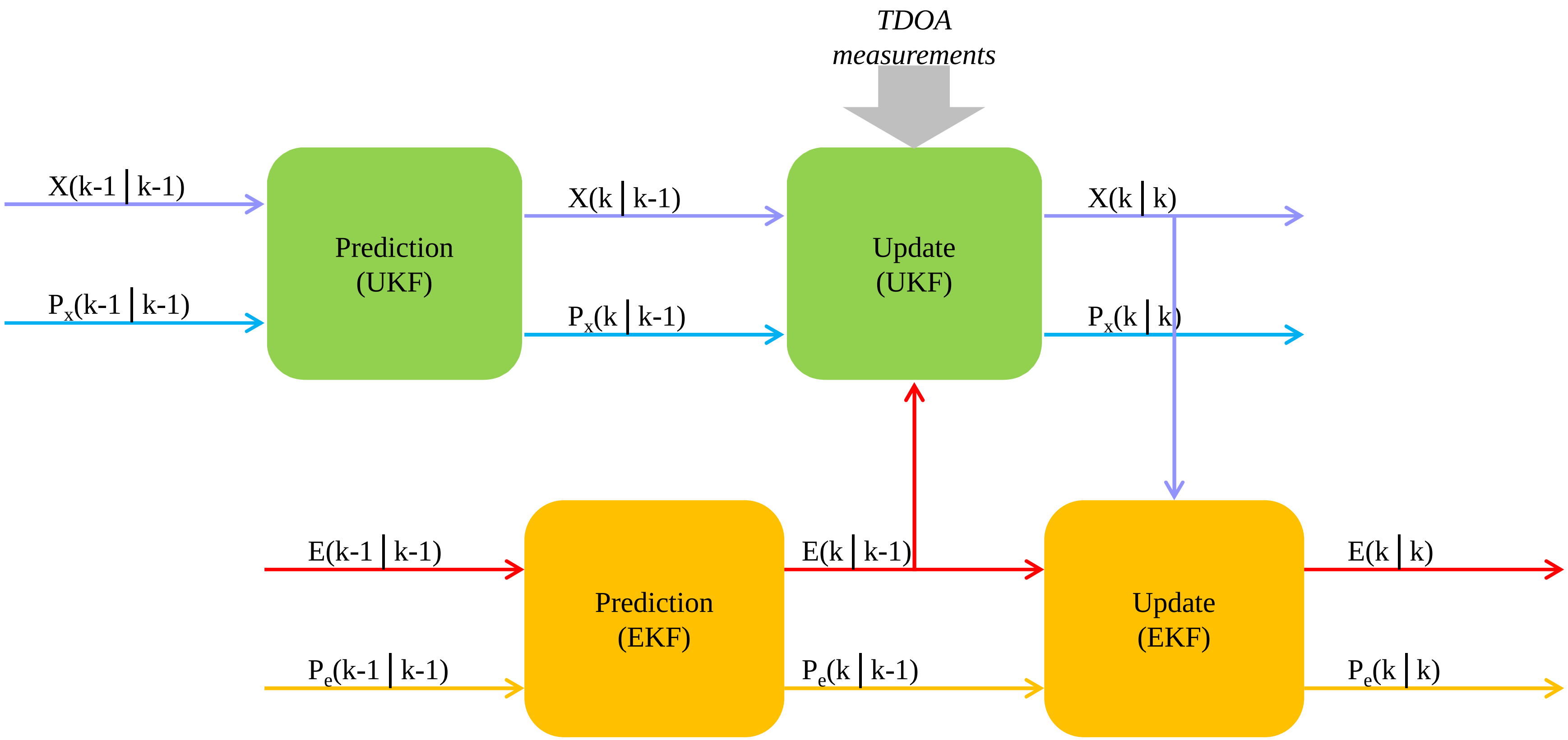
  - **Decoupling** the systematic error estimation from the target position estimation in the **prediction** phase

  - **Combination** of tracking and systematic error information in the **update** phase

[4] "Correction of systematic errors in Wide Area Multilateration", J.Abbud, G. De Miguel, J.A.Besada, Proceedings of the ESAV2011.

[7] "Multitarget-Multisensor tracking: Applications and Advances,Volume II", Y. Bar-Shalom, (Ed.), Artech House Inc., 1992.

4. Proposed solution (Design)



X: Target state vector
P_x: Covariance matrix associated to X
E: Systematic error vector
P_e: Covariance matrix associated to E

5. Experiment

Procedure:

- Monte Carlo experiments involving a hypothetical WAM scenario with 8 aircrafts and 6 base stations.

Assumptions:

- All aircrafts have constant groundspeed along a specified bearing and a specified height AMSL.
- Range bias due to propagation effects has been modeled following the path integration method presented in [9].
- Clock synchronization errors and receiver noise have been modeled via zero-mean Gaussian distributions.

[9] "Radar System Analysis and Modeling", D. K. Barton, Artech House Inc., 2005.

5. Experiment

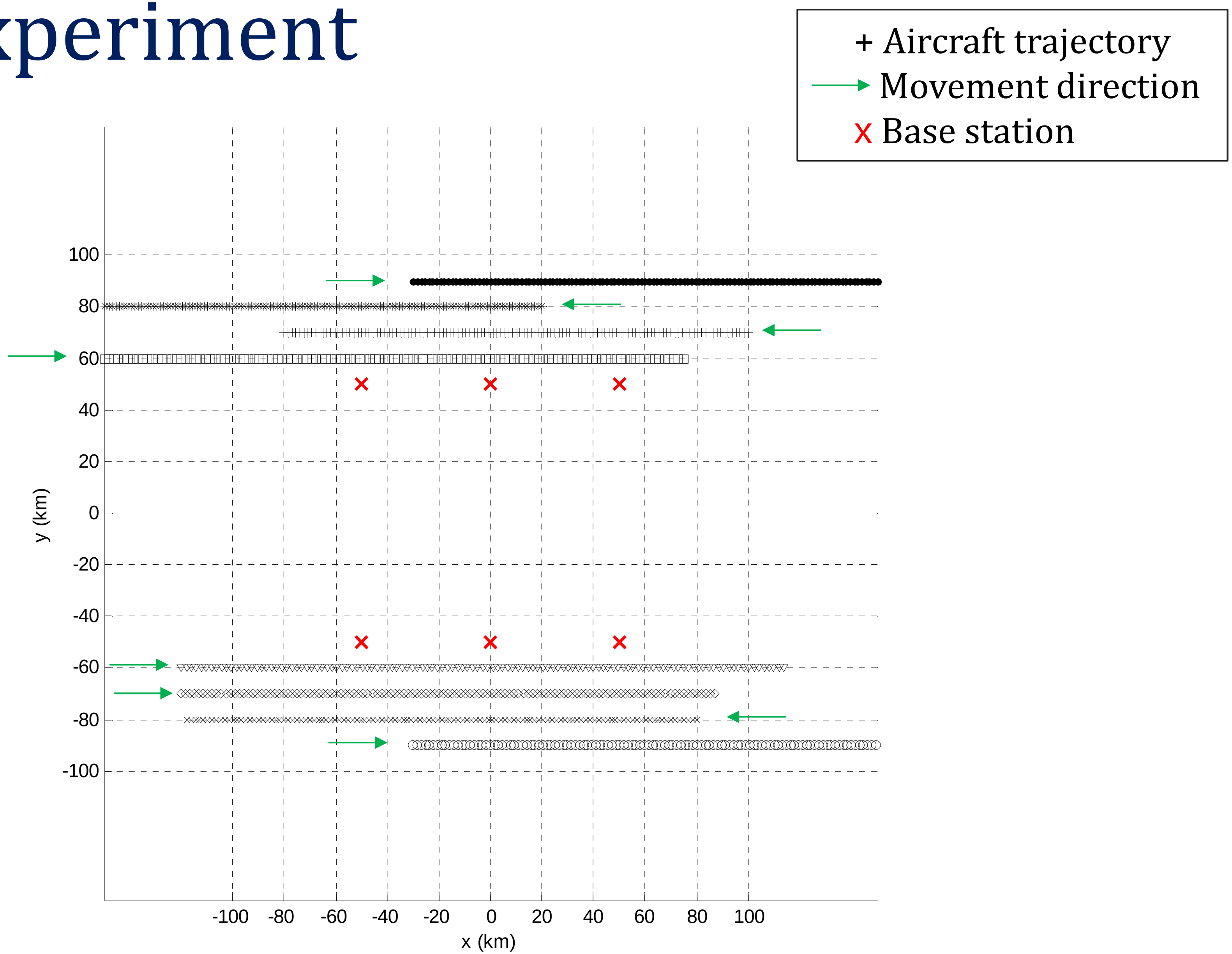
Settings:

- Each aircraft transmits every 4 seconds
- 1000 runs of 15-minute scenarios
- Aircraft maneuvering model (Singer acceleration model)

Assessment:

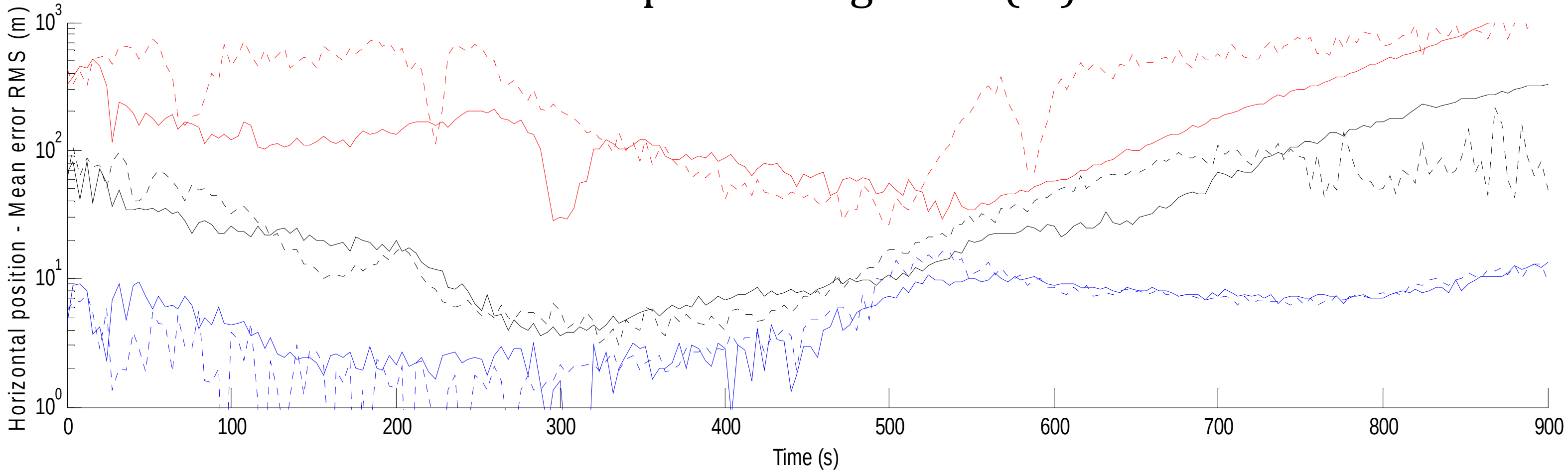
- Calculation of the mean and standard deviation of the positioning error (Horizontal and Vertical).
- Performance comparison of the proposed method versus hyperbolic location, in terms of mean and standard deviation (best, median, worst).

5. Experiment

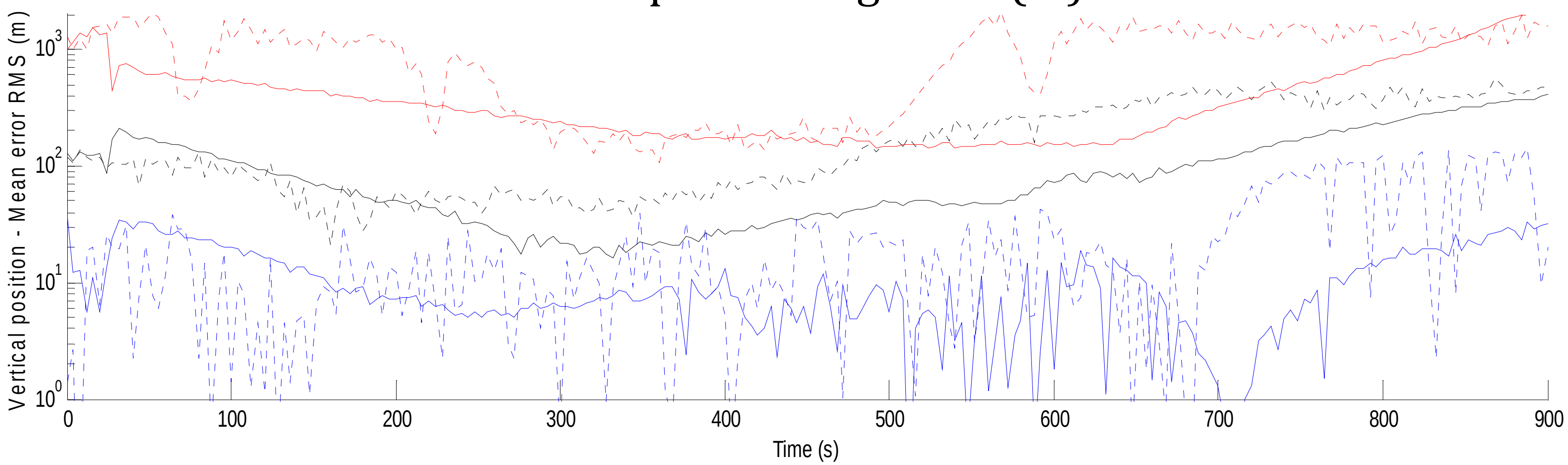


5. Experiment

Mean of the positioning error (m) - Horizontal

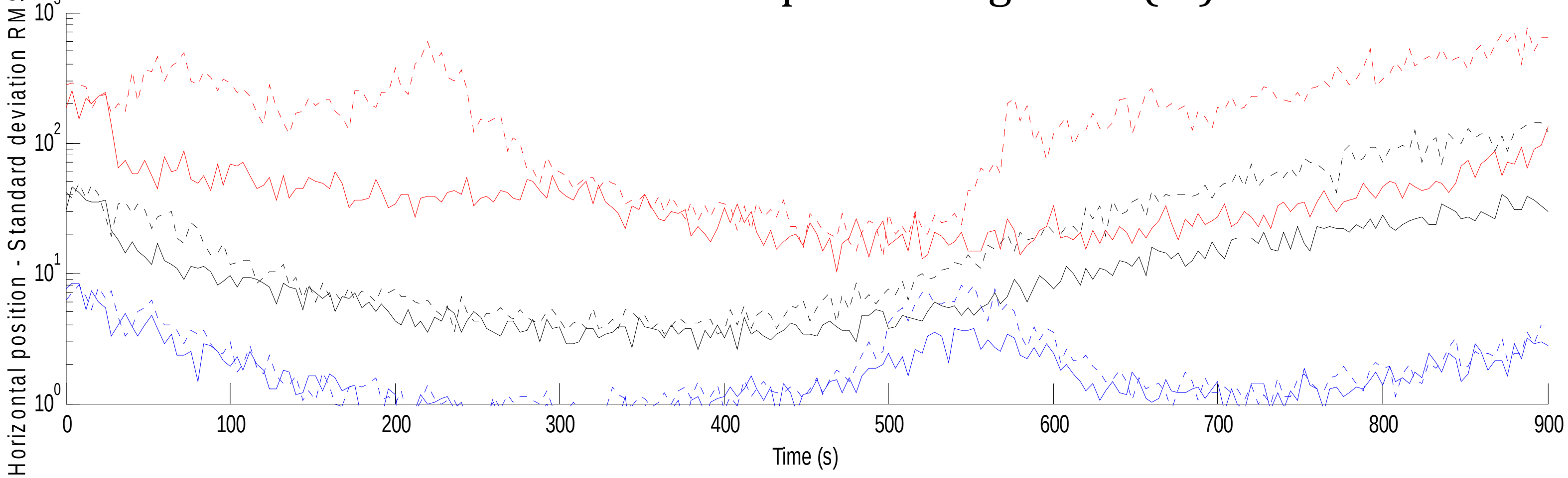


Mean of the positioning error (m) - Vertical

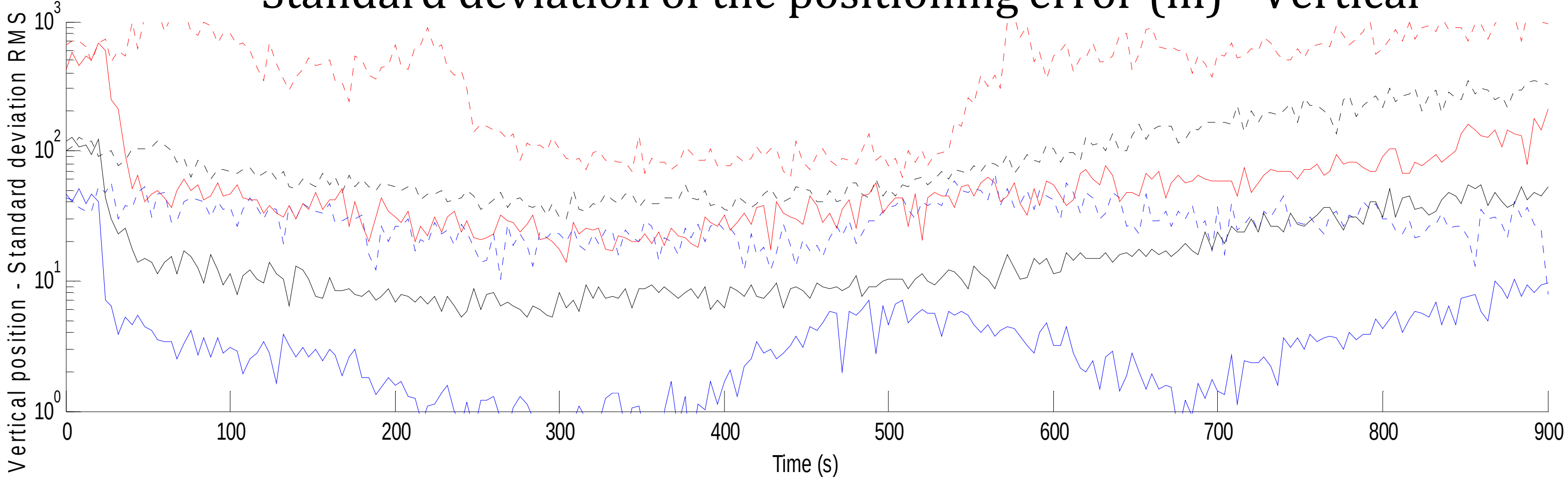


5. Experiment

Standard deviation of the positioning error (m) - Horizontal



Standard deviation of the positioning error (m) - Vertical



6. Conclusions

- The method presented in this paper tracks the systematic errors in order to mitigate their effect.
- The necessary amount of equations is obtained via opportunity traffic.
- Significant gains in accuracy and precision are obtained in target tracking with WAM, especially in scenarios with poor GDOP.

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Thank you for your attention.

ご清聴ありがとうございました