Precise GPS-Free Aircraft Localization Framework via Inertial Navigation System and Range-Based Localization Techniques

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Outline

- **Introduction**
- **Research Objectives**
- **Inertial navigation system**
- **Multilateration**
- ***Proposed MLAT/INS Integration***
- **Conclusion**

Introduction

According to the International Air Transport Association (IATA) passenger growth forecast, the passenger numbers are expected to reach 7.3 billion by 2034.
That represents a 4.1% average annual growth in demand for air connectivity.

such increase in air traffic density is to decrease the minimum separation between aircraft which necessitates precise aircraft localization techniques.

Navigation

Surveillance

Navigation

- A service providing guidance information or position data for the efficient and safe operation of aircraft supported by one or more radio navigation aids.

- **<u>Navigation systems</u>**
  - ❑GNSS/ ABAS/SBAS/GBAS
  - ❑Inertial Navigation System
  - ❑ILS
  - ❑VOR
  - ❑DME
  - ❑MLS

Surveillance

- Ability to accurately determine, track and update the position of aircraft

Separation standard

How efficiently air space can be utilized

An indication of any unexpected aircraft movements safely accommodating a higher density of aircraft through reduced separation

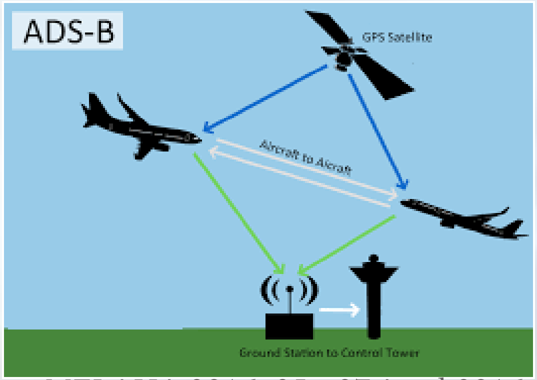
Surveillance systems

- PSR — Independent Non cooperative

- SSR
- MLAT

— Independent cooperative

- ADS-B/ ADS-C — dependent cooperative



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Research Objectives

- Surveillance
- Use the current available avionics systems.
- GPS-free
- Precise localization accuracy than using MLAT or INS alone.

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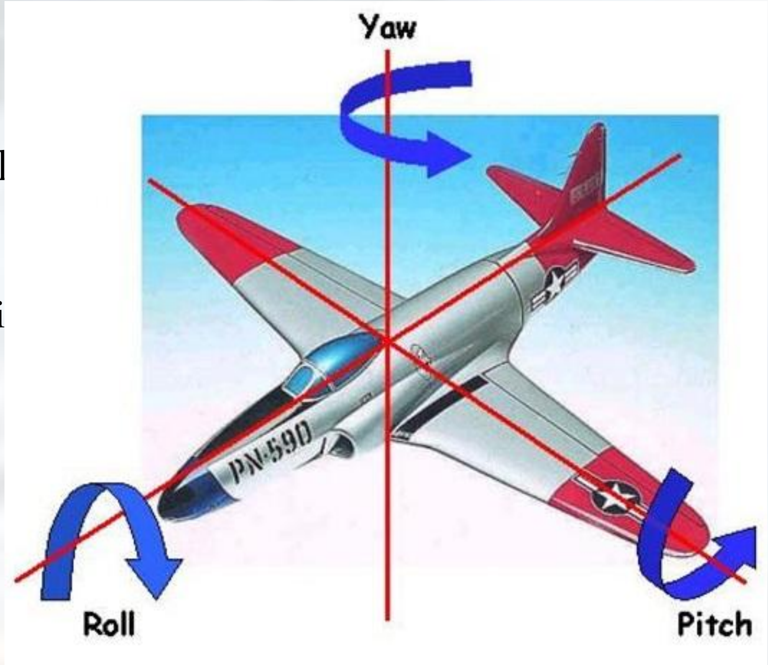
Inertial Navigation System

- An **inertial navigation system** is a navigation aid that uses motion sensors to continuously track the **position**, **orientation**, and **velocity** of aircraft without the need for external references
- Initial position and velocity must be provided before computing its own position and velocity by integrating information from sensors.

- Roll: orientation around longitudinal
- Pitch: orientation around wing axis
- Yaw : orientation around vertical Axi



Inertial Navigation System

- **INS Sensors**
  - ❑Accelerometers measure linear acceleration
  - ❑Gyroscopes measure angular velocity
  - ❑Magnetometer
- **Sensor error models**
  - ❑Fixed Bias
  - ❑Scale Factor Errors
  - ❑Random noises
- **Kalman Filter (EKF)**

Advantages and disadvantages of INS

- **<u>Advantages</u>**
  - ❑completely self contained
  - ❑all weather global operation
  - ❑High Update rate

- **<u>Disadvantages</u>**
  - ❑Position/velocity information degrade with time (1-2NM/hour). GPS, other navigation techniques
  - ❑Initial alignment is necessary (Calibration).

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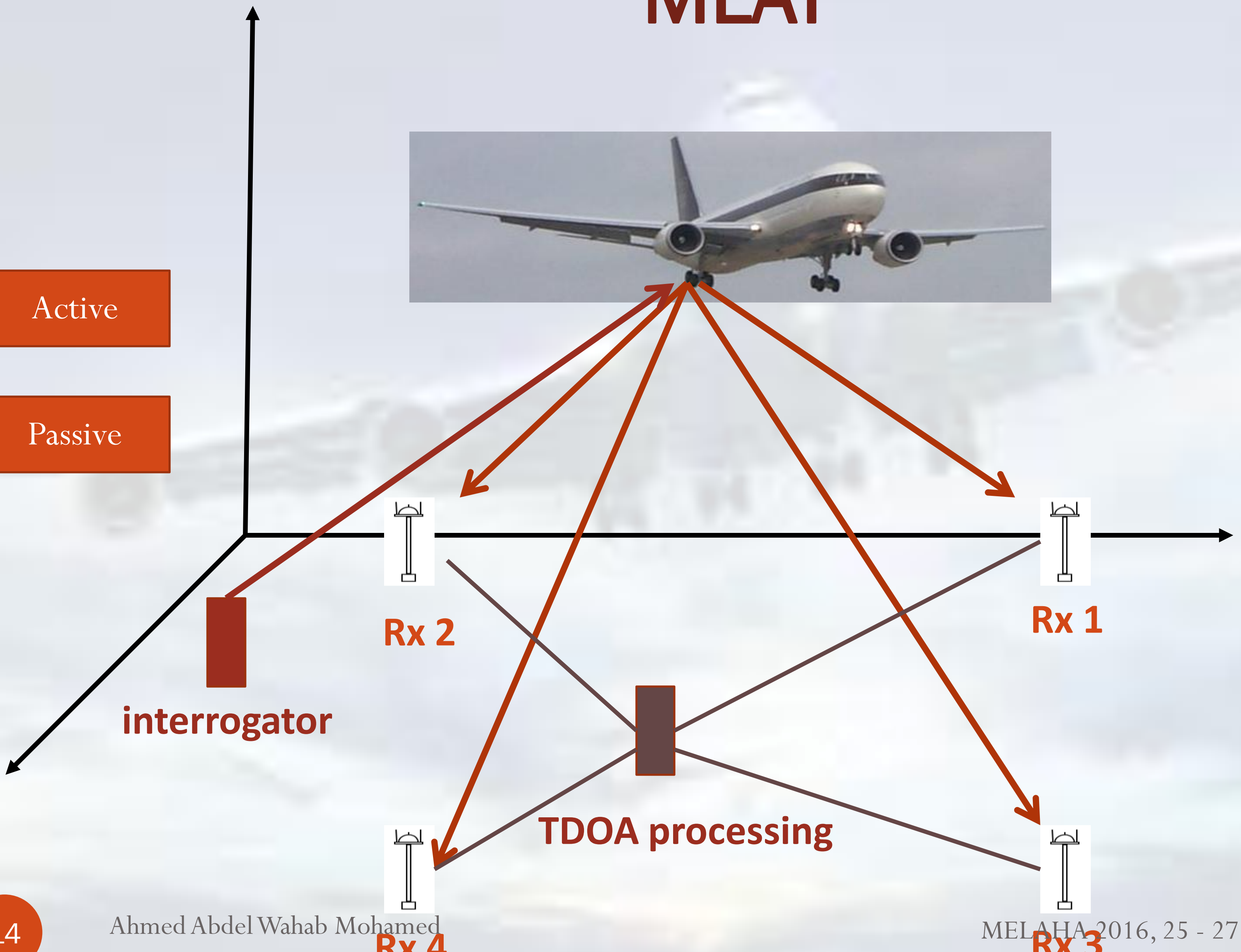
MLAT

Active

Passive

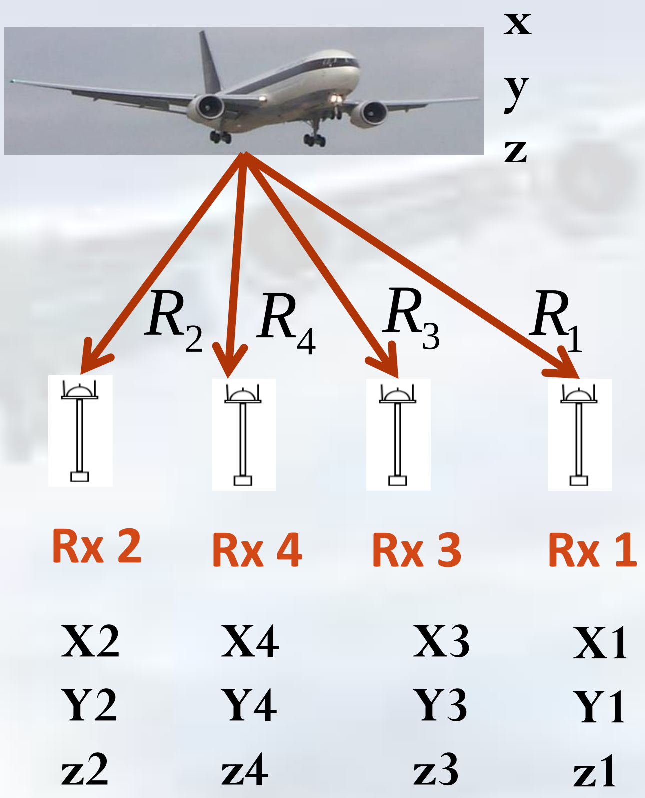


MLAT

$$R_i = \sqrt{(X_i - x)^2 + (Y_i - y)^2 + (Z_i - z)^2}, i = 1,2,.....,M$$

$$R_{i,1} = R_i - R_1 =$$
$$\sqrt{(X_i - x)^2 + (Y_i - y)^2 + (Z_i - z)^2} - \sqrt{(X_1 - x)^2 + (Y_1 - y)^2 + (Z_1 - z)^2}$$

- When number of receivers is greater than 4 --- over determined system of equations then least squares method is used.
- There are many ways to solve the minimum problem, including iterative algorithm such as Taylor method and non-iterative algorithm such as Chan, Si method.
- Taylor series expansion is the most accepted strategy to solve these hyperbolic equations, for estimating the target position.
- need a good initial guess and intensive computation



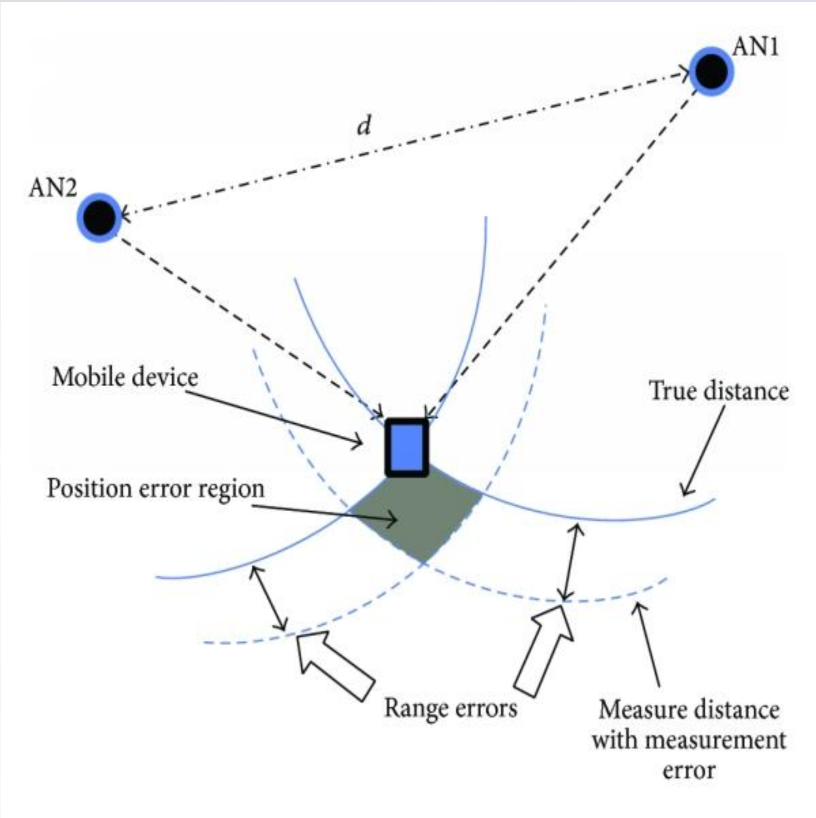
Advantages of MLAT

- low cost extension of the surveillance coverage for low altitudes (below existing radar coverage) and areas where no radar coverage currently exists.
- enabling airports to obtain surface and local surveillance.
- Unlike TOA methods, the hyperbolic position location method is able to reduce or eliminate common errors experienced at all receivers due to the channel.
- cost savings achieved from the implementation of an WAM rather than the life cycle expenses associated with installing, maintaining, and extending existing radar-based surveillance systems.

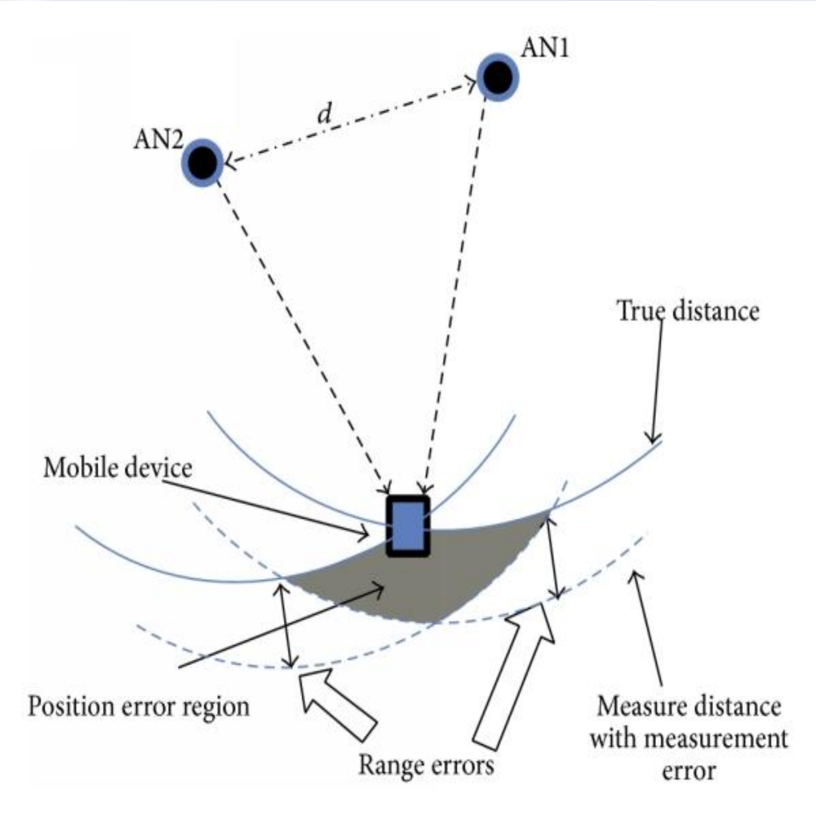
Disadvantages of MLAT

- **D**ilution **O**f **P**recision (DOP)

DOP

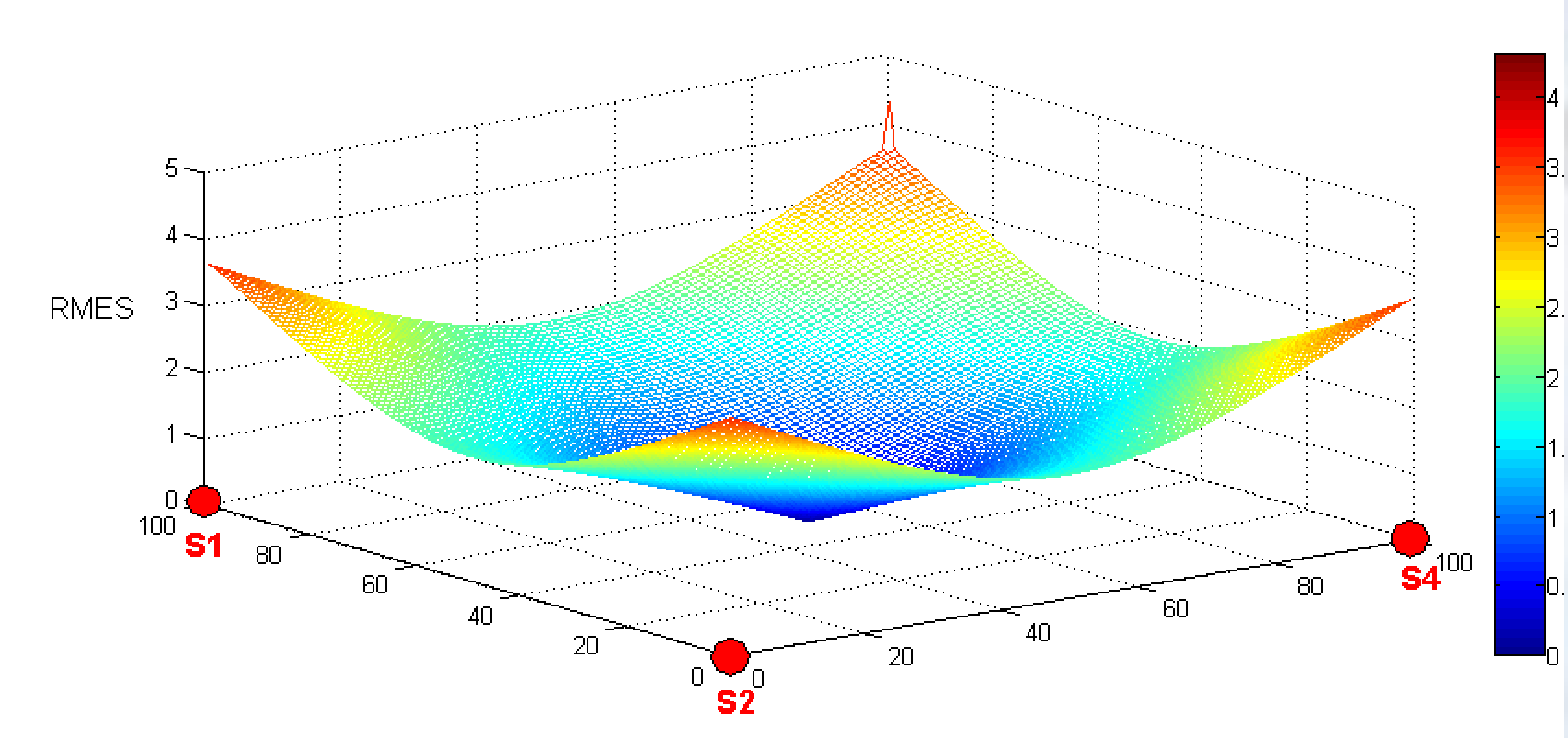


Good DOP



Poor DOP

DOP



- Average RMSE of different locations assume using 4 sensors

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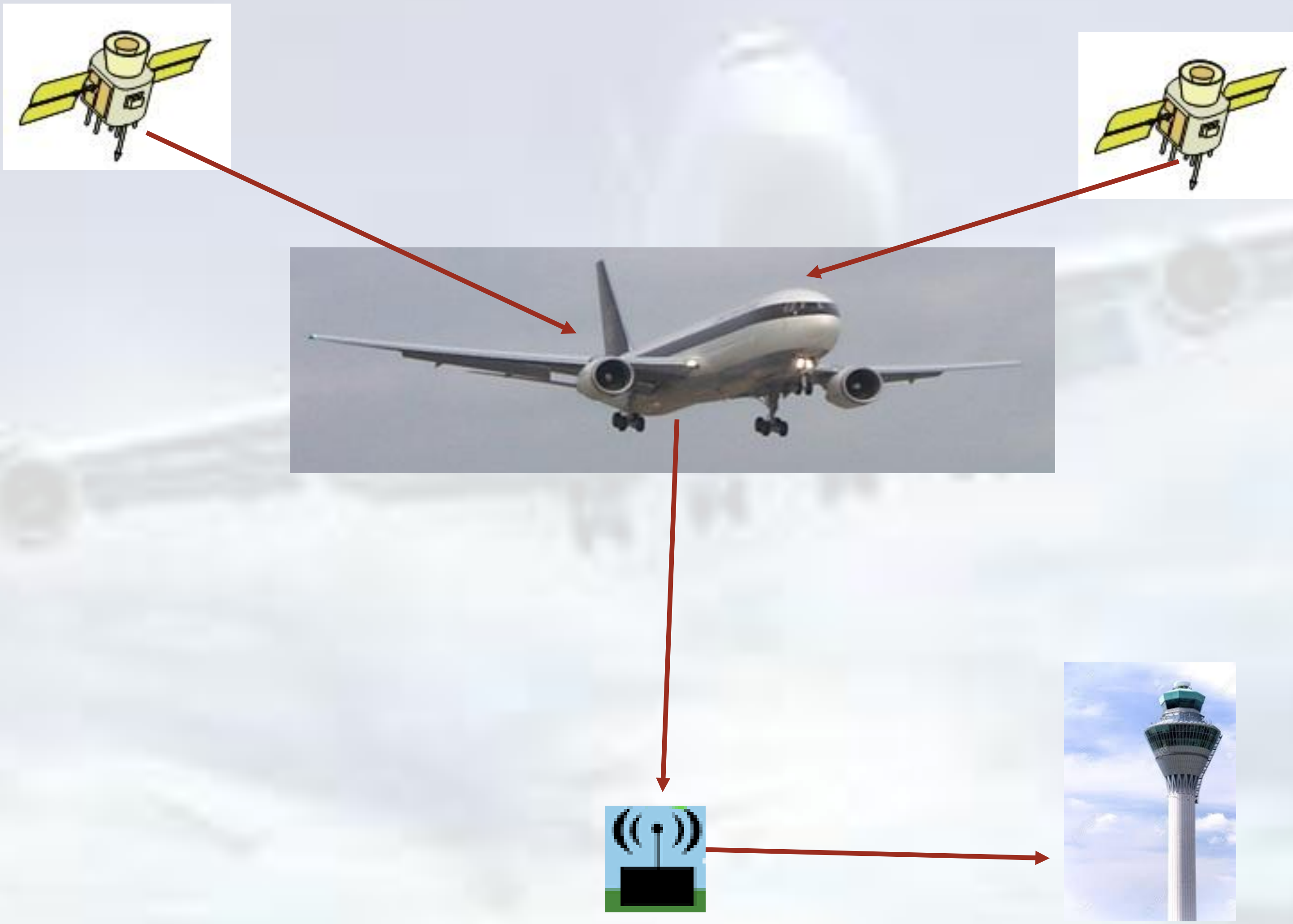
ADS-B



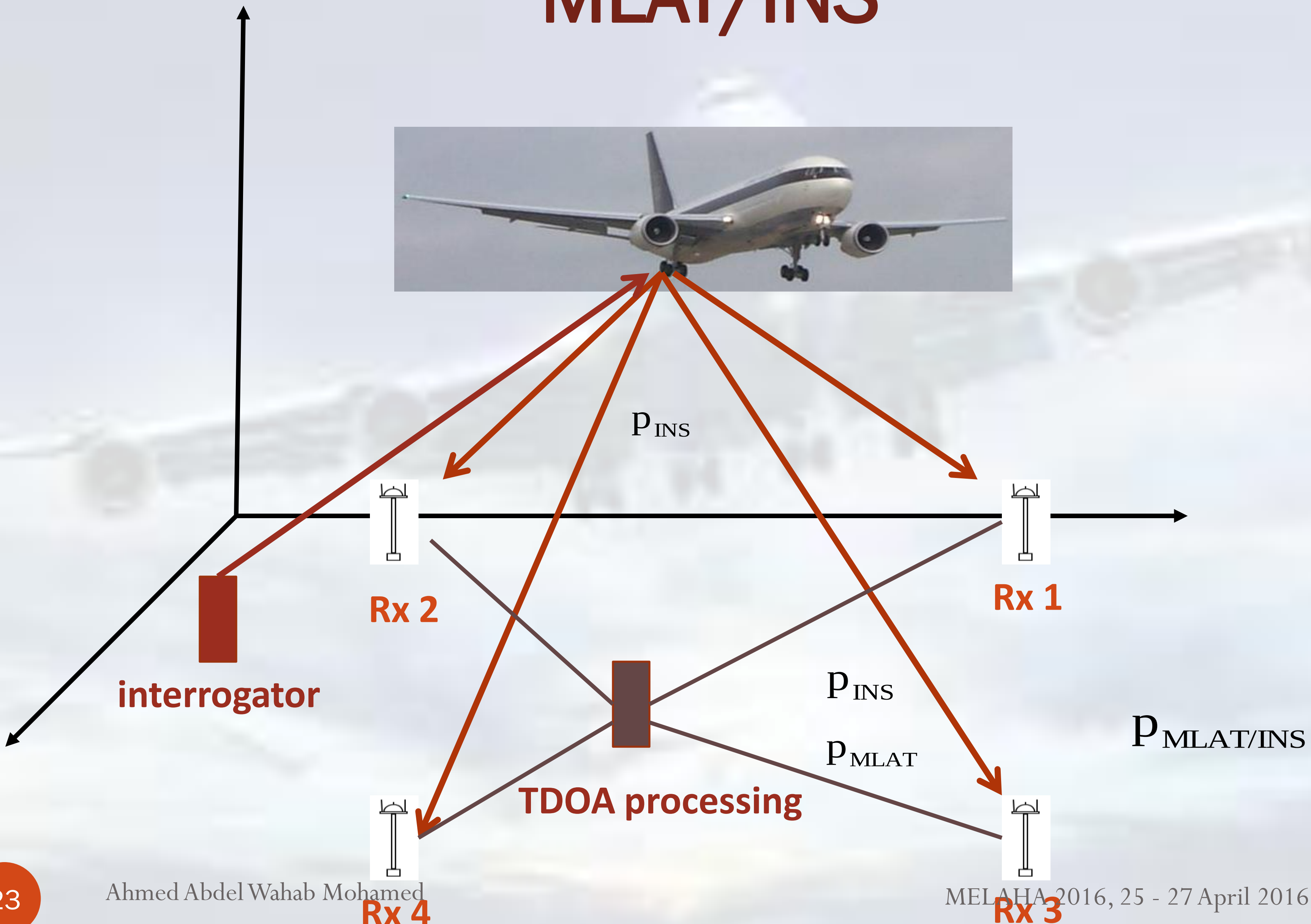
Use of WAM to verify ADS-B performance

- **WAM may be used to monitor the performance of ADS-B systems. There are a number of roles that multilateration could play.**

  - ***Anti-spoofing.*** ADS-B is vulnerable to spoofing. WAM systems can be used to identify genuine aircraft and the source of spoof transmissions.

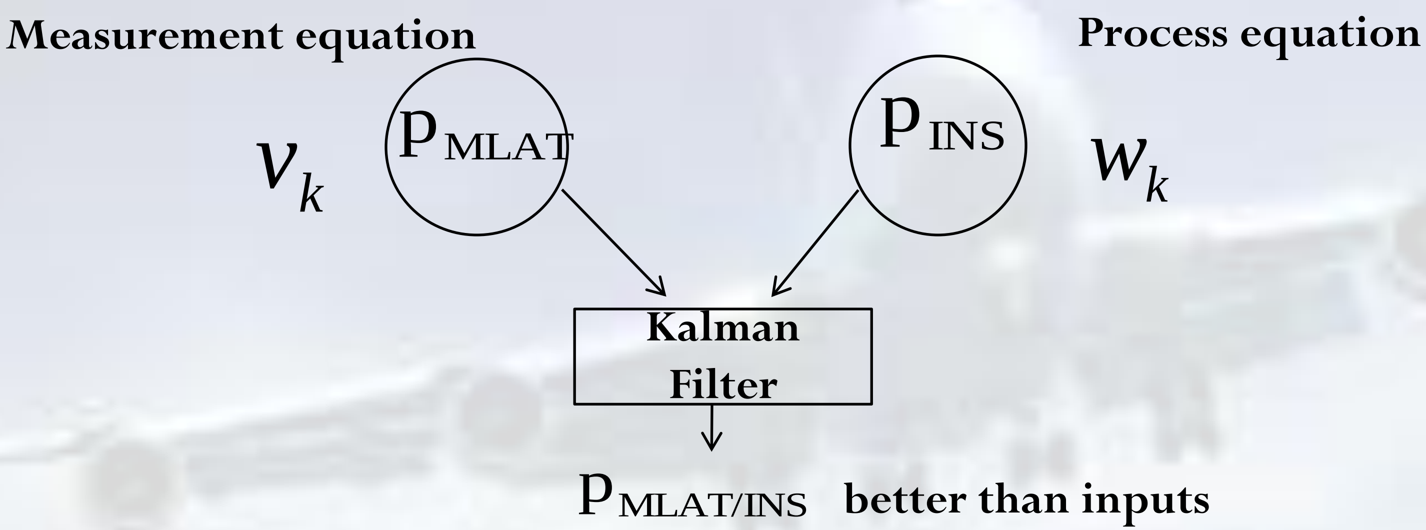
  - **Verification of Navigation Accuracy**. The ADS-B data can be checked against the multilateration data to verify the track keeping performance of the avionics.

MLAT/INS



p INS
Rx 2
Rx 1
interrogator
TDOA processing
p INS
p MLAT
p MLAT/INS
Rx 4
Rx 3

MLAT/INS



Kalman Filter: produce a statistically optimal estimate for linear measurement and process state.

MLAT/INS

Initialization

Initial Value of Position $p_{MLAT/INS}$

Initial Value of state Variance P

Measurement

$$Z = p_{MLAT}$$

Prediction (Time Update)

(1) Project the state ahead

$$\underline{\hat{p}}^{-}_{INS,k} = A\underline{\hat{p}}^{-}_{MLAT/INS,k-1} + Bu_k$$

(2) Project the error covariance ahead

$$P_k^{-} = AP_{k-1}A^T + Q$$

Correction (Measurement Update)

(1) Compute the Kalman Gain

$$K_k = P_k^{-}H^T(HP_k^{-}H^T + R)^{-1}$$

(2) Update estimate with measurement z_k

$$\underline{\hat{p}}_{MLAT/INS,k} = \underline{\hat{p}}^{-}_{INS,k} + K_k(z_k - H\underline{\hat{p}}^{-}_{INS,k})$$

(3) Update Error Covariance

$$P_k = (I - K_kH)P_k^{-}$$

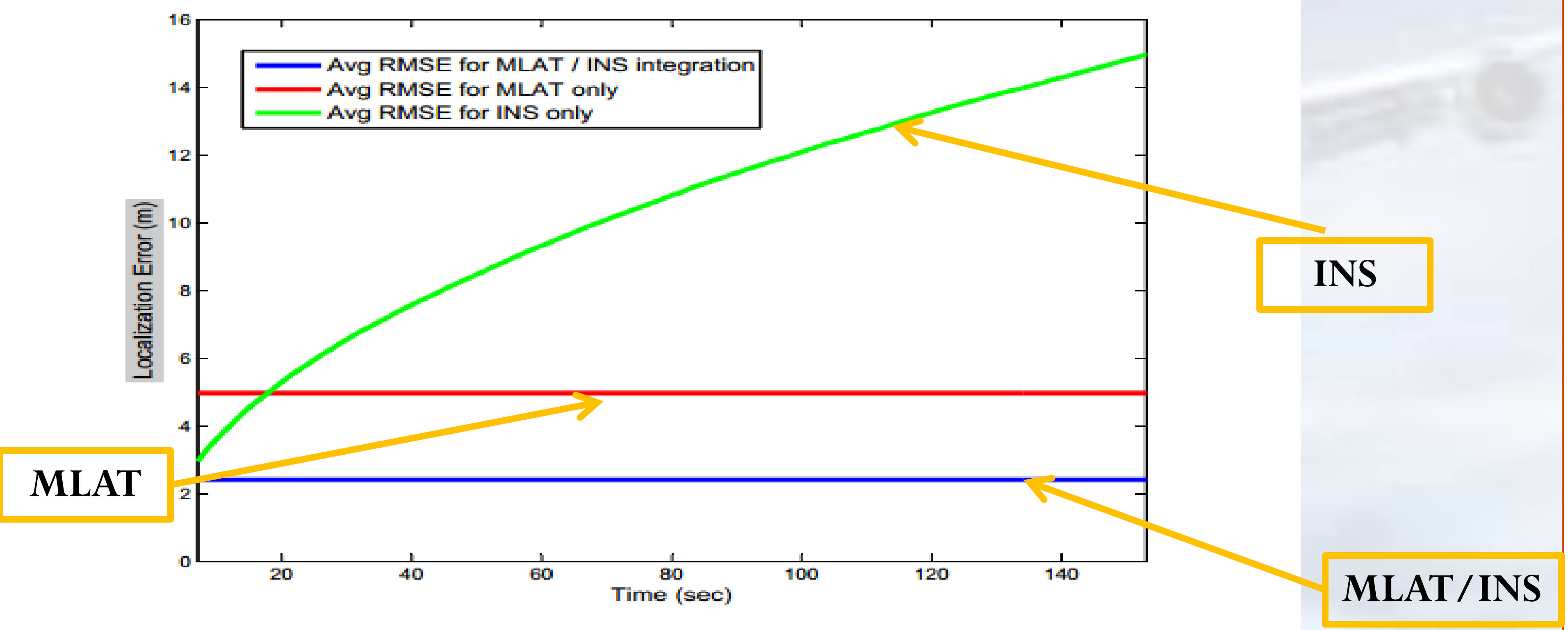
Simulation Environment

p_{MLAT} $v_k \sim (0, R)$ $\sigma = 5$

- **Metrics :** The root-mean-square error (***RMSE***) is used as our metric to evaluate the performance of our proposed framework

$$RMSE = \sqrt{\sum_{i=1}^{n} \frac{(x_{actual,i} - x_{est,i})^2 + (y_{actual,i} - y_{est,i})^2 + (z_{actual,i} - z_{est,i})^2}{n}}$$

Accuracy Comparison



- **Avg RMSE of MLAT/INS is only 2. 5 meters, which is approximately 50% of the RMSE of MLAT.**

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Conclusion

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- GPS-free
- Integrate MLAT & INS
- Use the current available avionics systems.
- Precise localization accuracy than using MLAT or INS alone.
- Our simulation results shows that the accuracy of our MLAT/INS framework
  - ❑ does not only significantly outperforms the localization accuracy of MLAT techniques but also
  - ❑ without using any additional ground infrastructure or avionics systems.

Future work

- Use real data from sensors
- Different trajectories
- Different scenarios


TIME FOR QUESTIONS
XII
I
II
III
IV
V
VII
VIII
IX
X
XI