Fusion of Inertial Sensors and OFDM Signals of Opportunity for Unassisted Navigation

Jason Crosby, Capt, USAF

Air Force Institute of Technology
Wright-Patterson AFB, Ohio

Overall Classification:
UNCLASSIFIED

Overview

- Motivation
- Goals
- Assumptions
- INS Model
- TDOA Model
- OFDM Signal Structure
- Receiver Model
  - Boundary Correlator
  - TDOA Calculations
- Simulation Results
- Conclusions
- Future Research

Motivation

- Current Reliability on GPS
  - Susceptible to Jamming
  - Unavailable Indoors
  - Poor Performance in Urban Areas and Canyons

Advantages/Disadvantages

ADVANTAGES

- Many possible signals
  - Great signal diversity (direction and frequency)
  - Number of signals is generally higher in urban areas
- Can be high power - potential to penetrate into buildings
- No infrastructure required - they already exist by definition!
- Advances in radio technology
  - Software-defined radios

DISADVANTAGES

- Signals are usually not optimized for navigation
  - Example: Timing not considered
- Availability varies according to location
- Usually need to know transmitter locations (or at least direction)
- Antenna/hardware challenges
- Multipath: Will be an issue with almost any indoor RF-based navigation system

Goals

Completed

1. **Combine previous approach with INS to remove reference receiver**

2. **Simulate system measurements and updates for proof of concept in 2D**

Future Research

3. **Analyze effects and propose mitigation techniques for transmitter clock drift**

4. **Use 6DOF model and actual INS measurements and analyze performance**

Assumptions

- Signal of Opportunity
  - Established Infrastructure
  - Operate within frequency range of receivers
  - Possess known modulation/signal structure (OFDM)
- Transmitter locations are known
- No Multipath
- Neglecting clock errors
- Can Initialize INS (at least initially)
  - Initial position known
  - Initial Transmitter locations relative to INS known

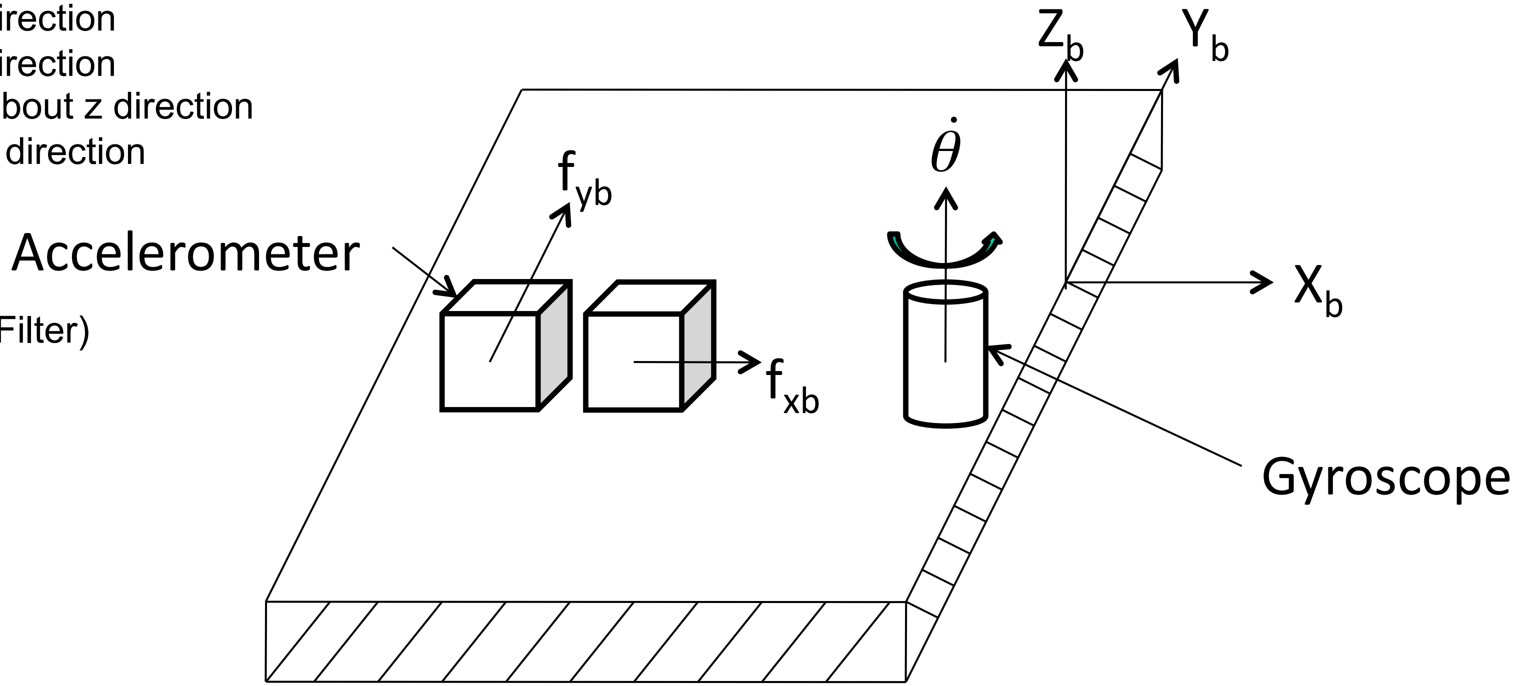
INS Model (2D)

VARIABLES

F_{xb} = acceleration from x accelerometer
F_{yb} = acceleration from y accelerometer
V_{xi} = velocity in x direction
V_{yi} = velocity in y direction
X_i = position in x direction
Y_i = position in y direction
$\dot{\theta}$ = Angular rate about z direction
θ = Angle about z direction

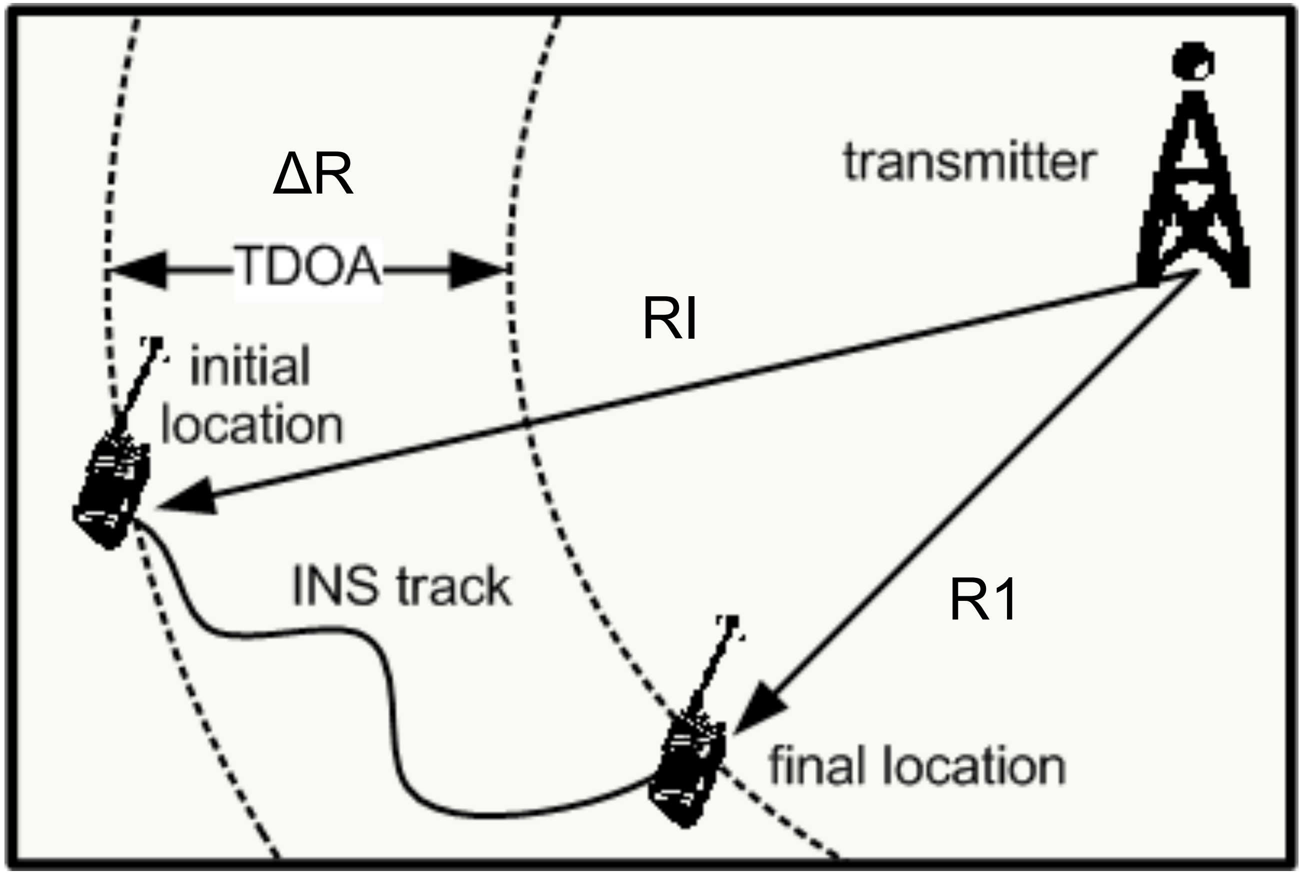
STATES (Kalman Filter)

X_i
Y_i
V_{xi}
V_{yi}
θ



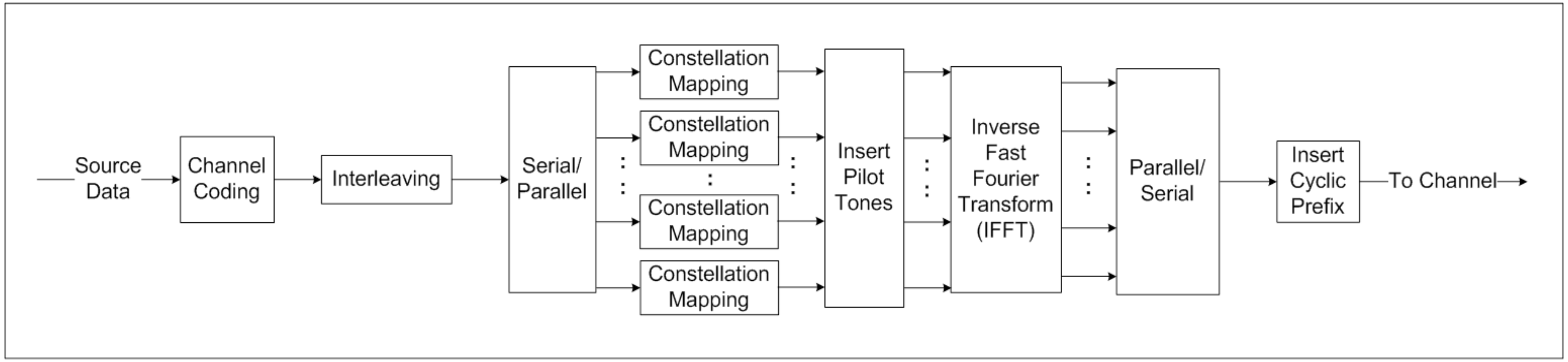
Removing the need for a Reference

- Use of a SoOp requires a reference to compute a TDOA
- The INS gives us a series of relative positions over time
- The different positions occur at different times, so how do we compute a TDOA? (next slide…)



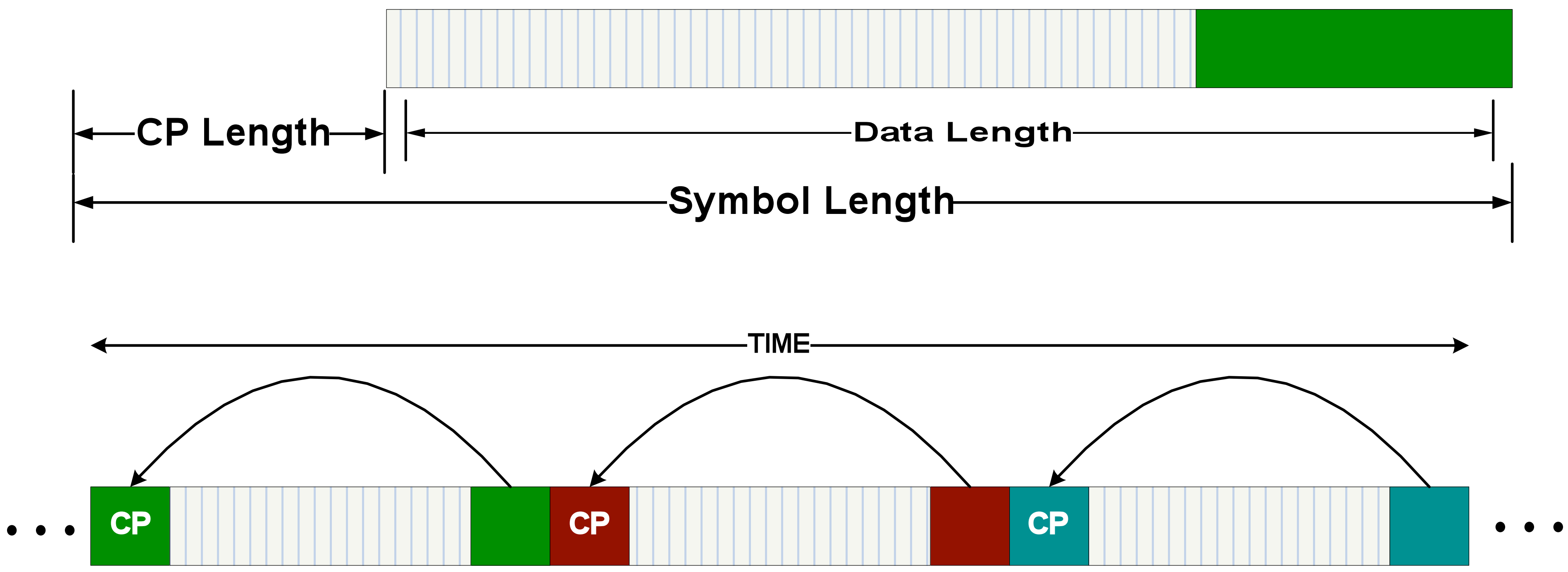
OFDM
Transmitter

OFDM Transmitter



OFDM Signal Structure

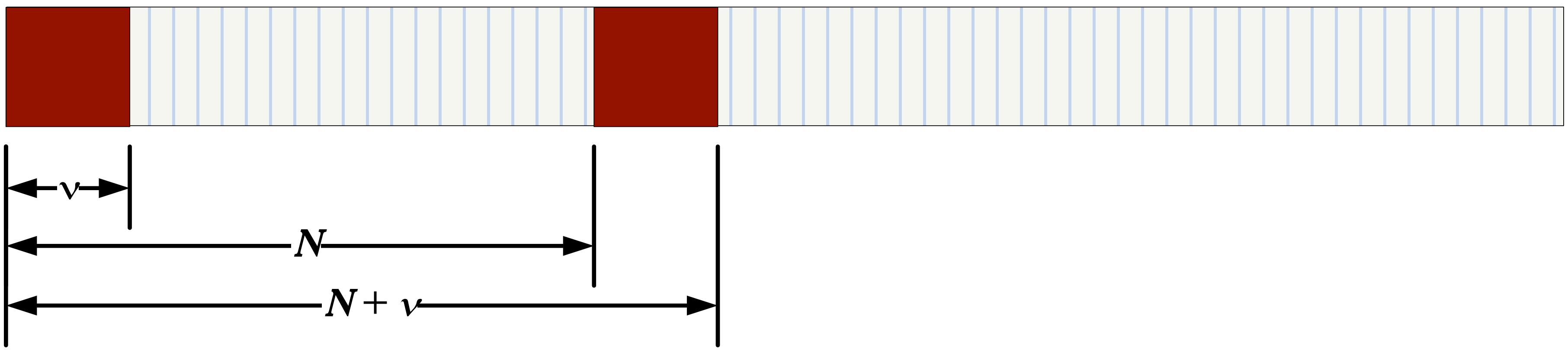
(Time Domain Representation)



Boundary Correlator

Algorithm

$$R_{rx}(m) = \sum_{k=m+1}^{m+\nu} y_{rx}(k) \cdot y_{rx}^{*}(k+N)$$



TDOA Calculation

Algorithm

$$TDOA = (\delta_{sample} - \delta_{initial}) \cdot T_{samp}$$

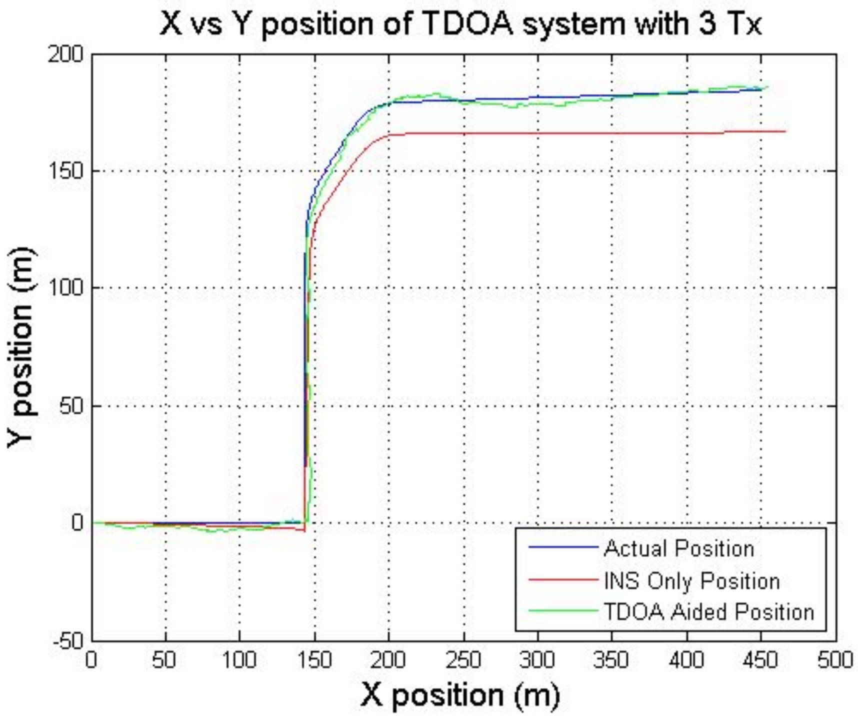
Where

$$\delta_{Sample} = \arg \max_{1 \le m \le (N+v)} \mathrm{Re}\{ave(R_{rx}(m))\}$$

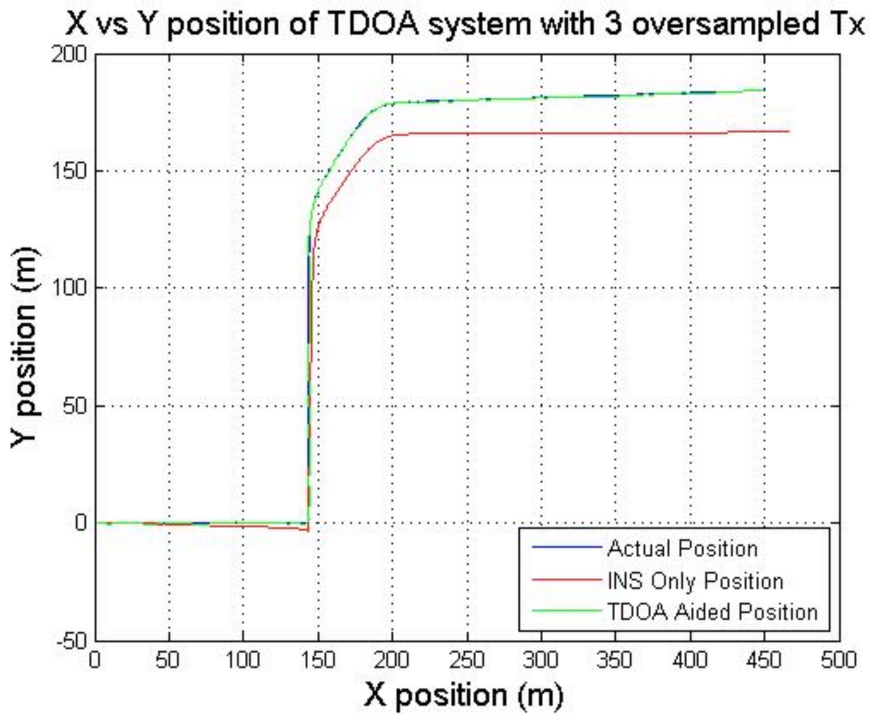
Note that $\delta_{initial}$ was 0 for all simulations

Simulation Results

Trajectory plot of TDOA aided INS with three transmitters

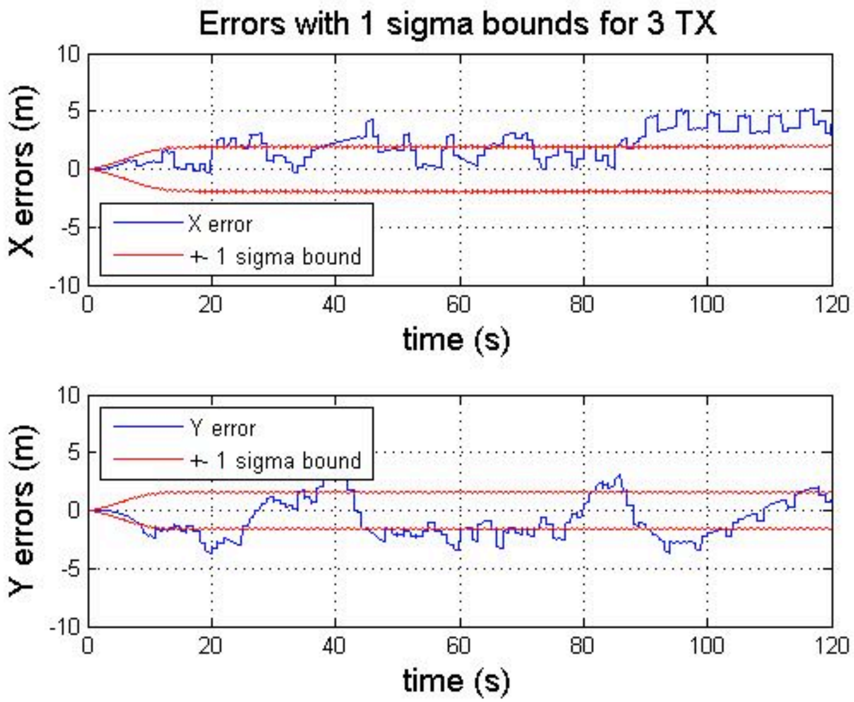


Trajectory plot of TDOA aided INS with three oversampled transmitters

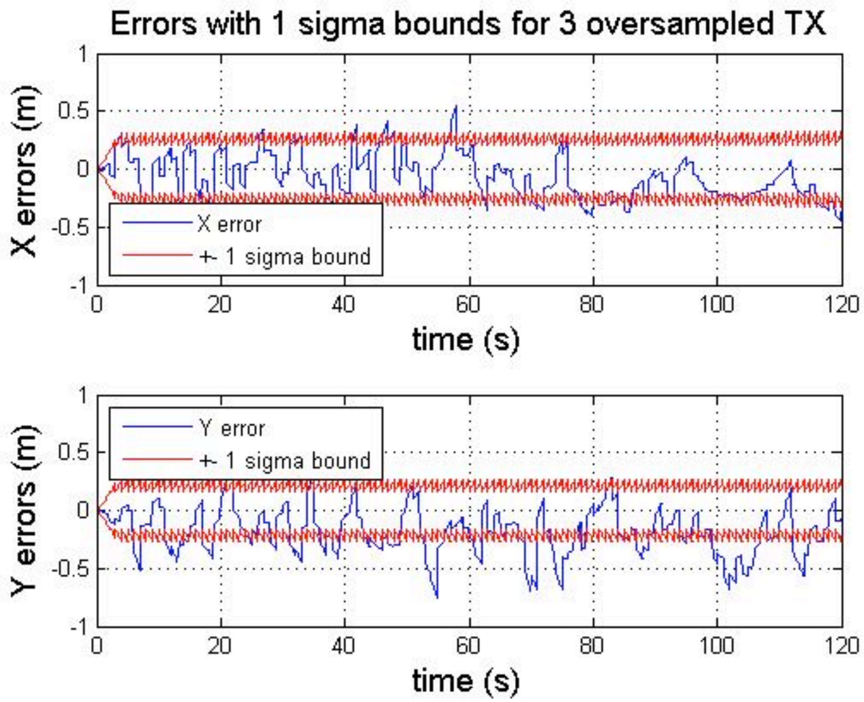


Simulation Results

Position errors for three transmitters

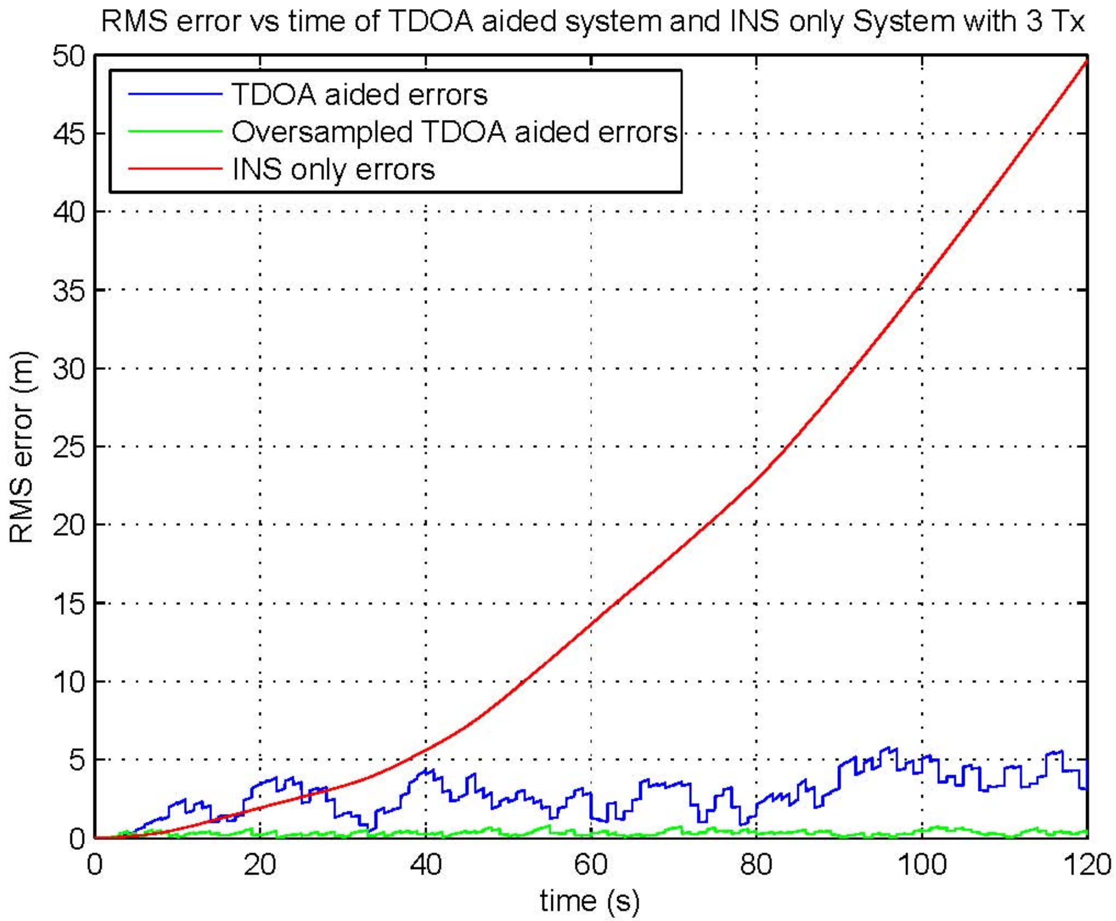


Position errors for three oversampled transmitters



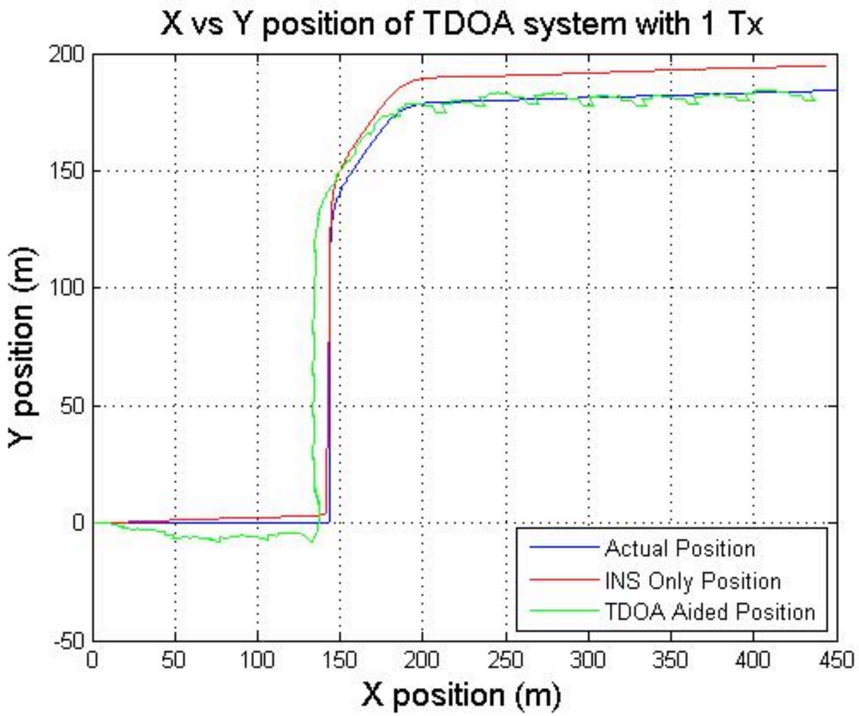
Simulation Results

RMS position error over time for three transmitters

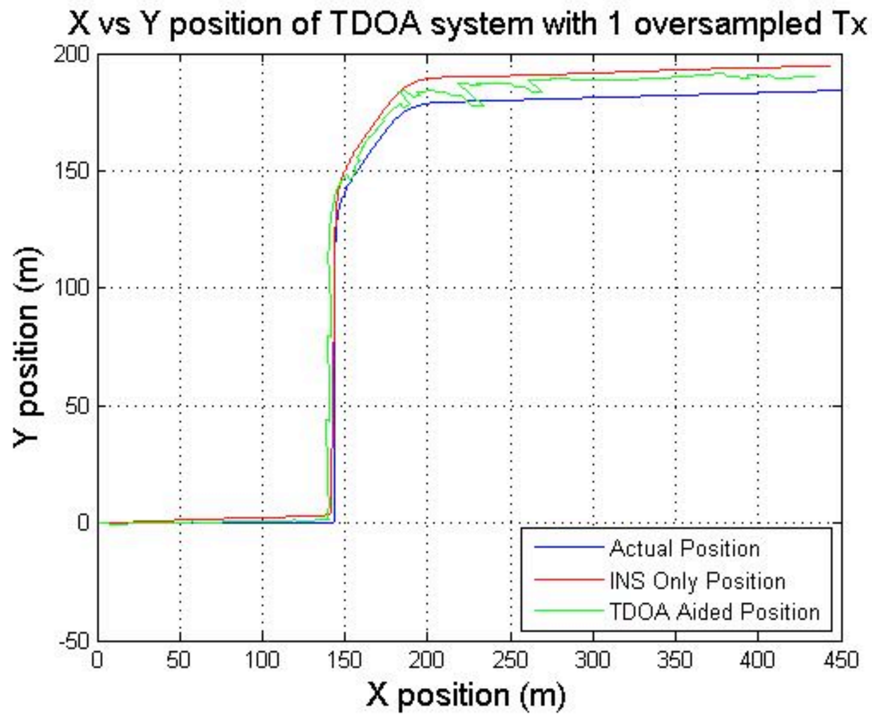


Simulation Results

Trajectory plot of TDOA aided INS with one transmitter

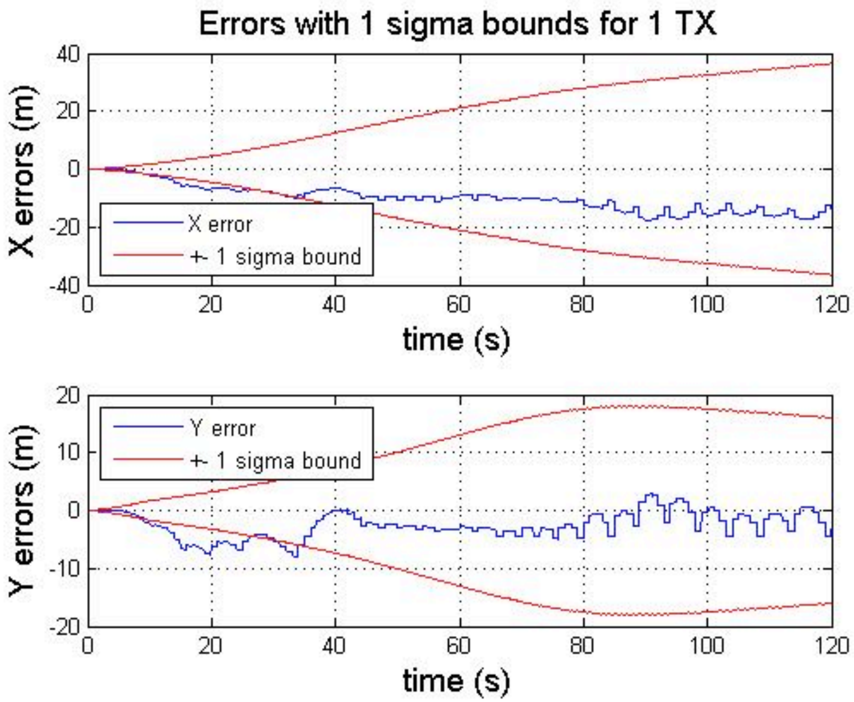


Trajectory plot of TDOA aided INS with one oversampled transmitter

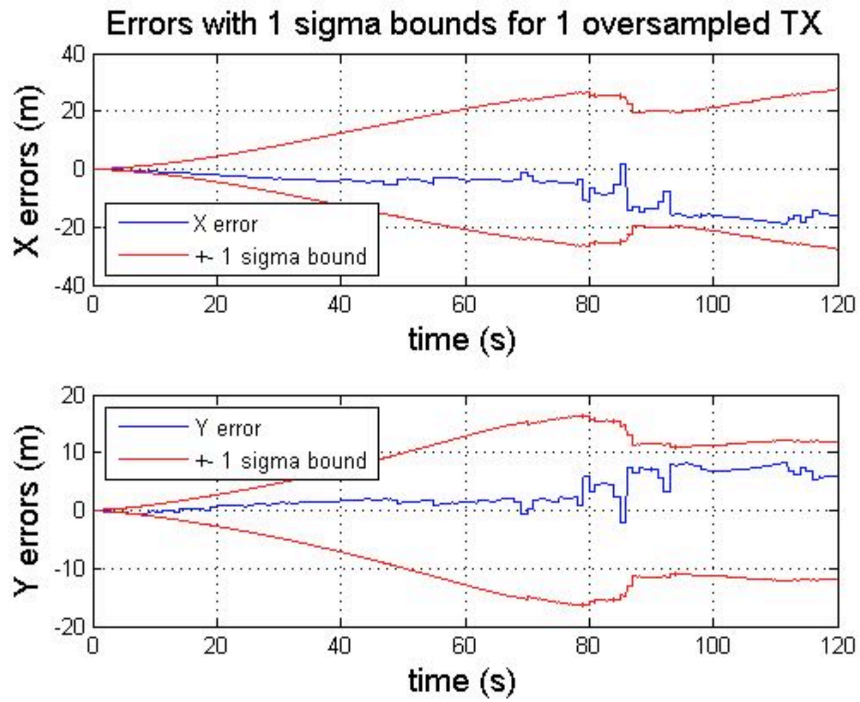


Simulation Results

Position errors for one transmitter

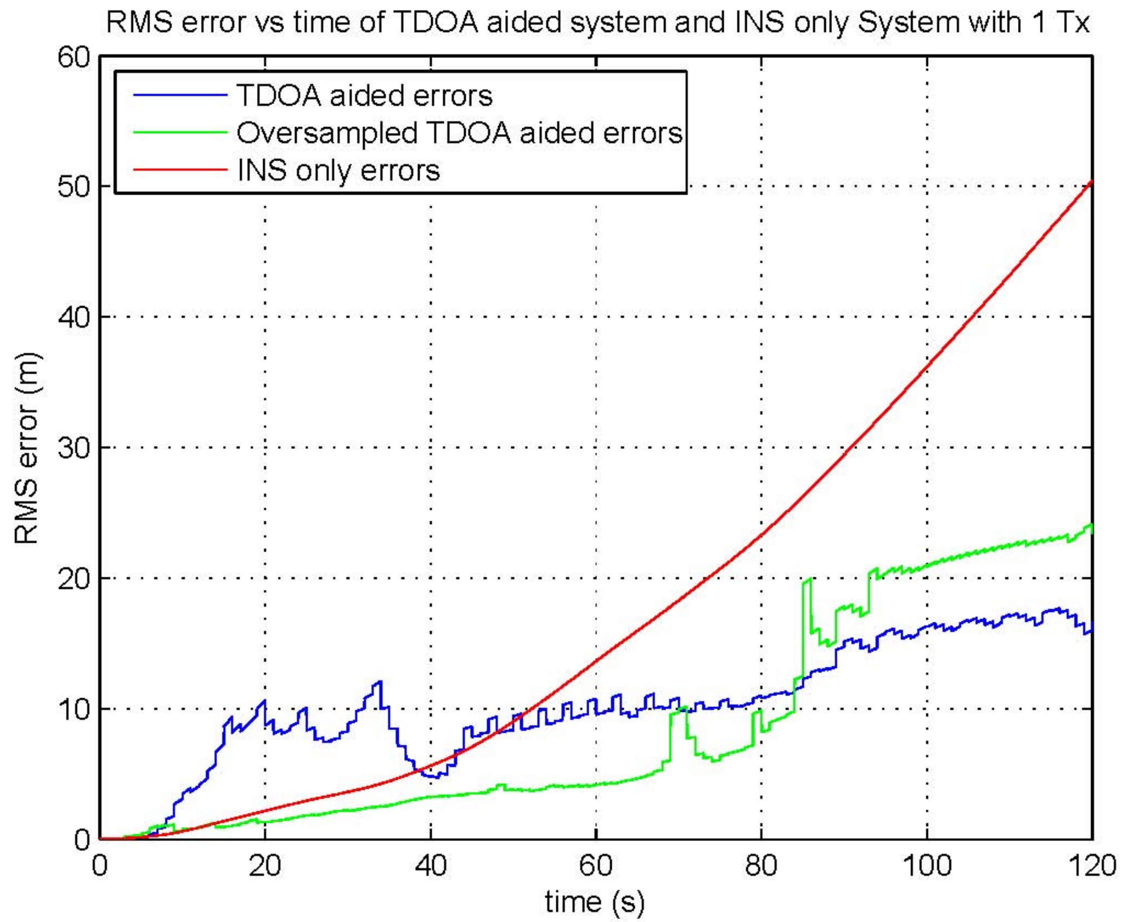


Position errors for one oversampled transmitter



Simulation Results

RMS position error over time for one transmitter



Conclusion

- OFDM signals can be used to aid an INS without the need for a reference receiver.
- Increasing the number of transmitters can increase position accuracy.
- Oversampling the OFDM signal can increase position accuracy.

Future Research

- Add and Analyze effects of transmitter and receiver clock errors
- Move to 3D 6DOF model with actual INS measurements

QUESTIONS?