TDOA Positioning Algorithms: Evaluation and Implementation

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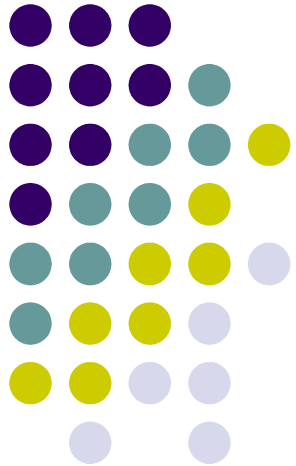
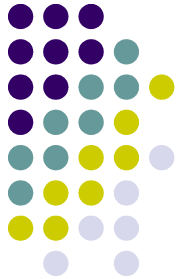


First Responder Location System



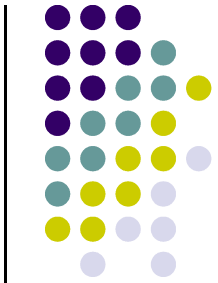
Target Scenario

- First Responders arrive on scene
- Desire to know position information
- Need deployable infrastructure

System Architecture

- Reference nodes (RN) deployed around site
- Individual to be tracked wears transmitter (TX)
- Reference nodes collaborate to **estimate position**

System Architecture

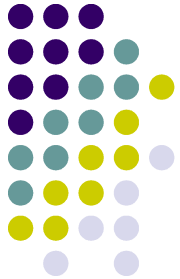


- RNs automatically determine distances between each other by exchange of TX-like signals.
- RNs calculate relative time of arrival (TOA) of TX signal.
- RNs collaborate (out of band), determine T**D**OAs
- Given TDOA data and RN positions, TX position can be estimated

TDOAs

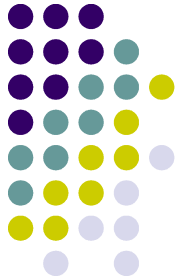
- Why TDOAs versus TOAs?
  - Synchronization with transmitter not needed.
  - Only inter-RN synchronization needed.
  - Advantages for TX
    - Simple
    - Independent
    - Low Power

TDOA Position Estimation



- **Involves highly nonlinear, coupled equations**
  - *The TDOA problem involves solving a highly nonlinear system of coupled equations given imperfect information (due to random statistic error induced by noise in a RF system).*
- **Estimation is difficult, and exact solution is generally intractable**
  - *Nonlinear estimation problems are notoriously difficult, and exact solution is generally intractable.*
- **Approximate methods show good performance with low noise.**
  - *Various approximate solution methods have been proposed that yield good solutions for sufficiently noiseless data.*

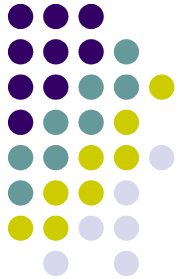
TDOA Position Estimation



We needed to develop a simulation test platform to evaluate the performance of each algorithm and to create design formulae which could be used to design a complete system.

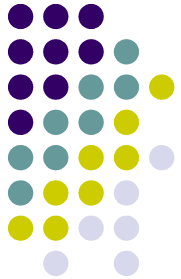
- Bucher Algorithm
  - + Exact solution
  - – Limited to four receivers
  - – Generates two roots; Correct root choice not well defined
- Bard
  - + Arbitrary number of receivers
  - + Computationally efficient
  - – Subject to symmetry problems
  - – Hyperbolic, “Spherical Intersection”
- Smith
  - + Arbitrary number of receivers
  - + “Spherical Interpolation” - Linear with respect to range estimate

Evaluation Environments

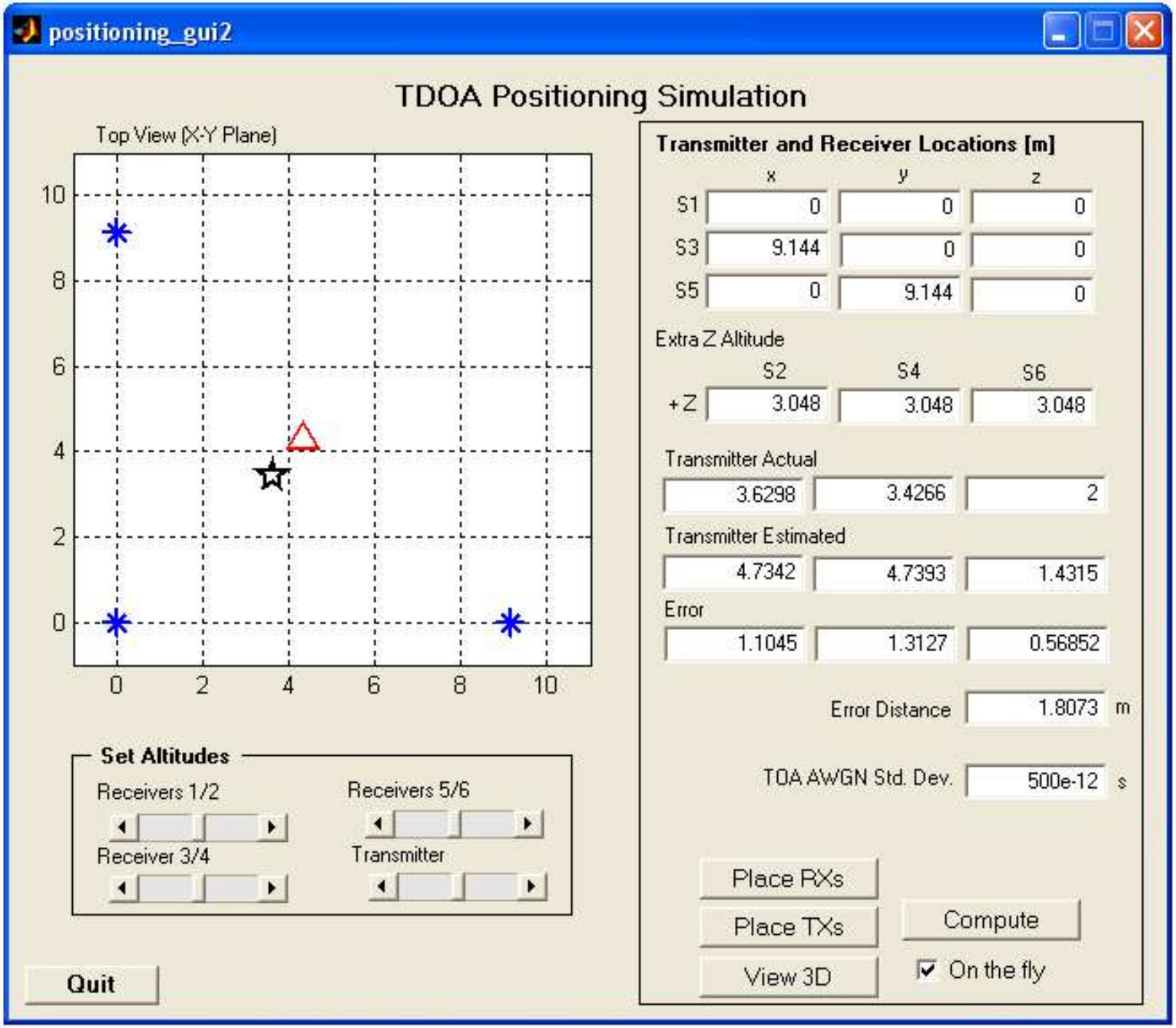


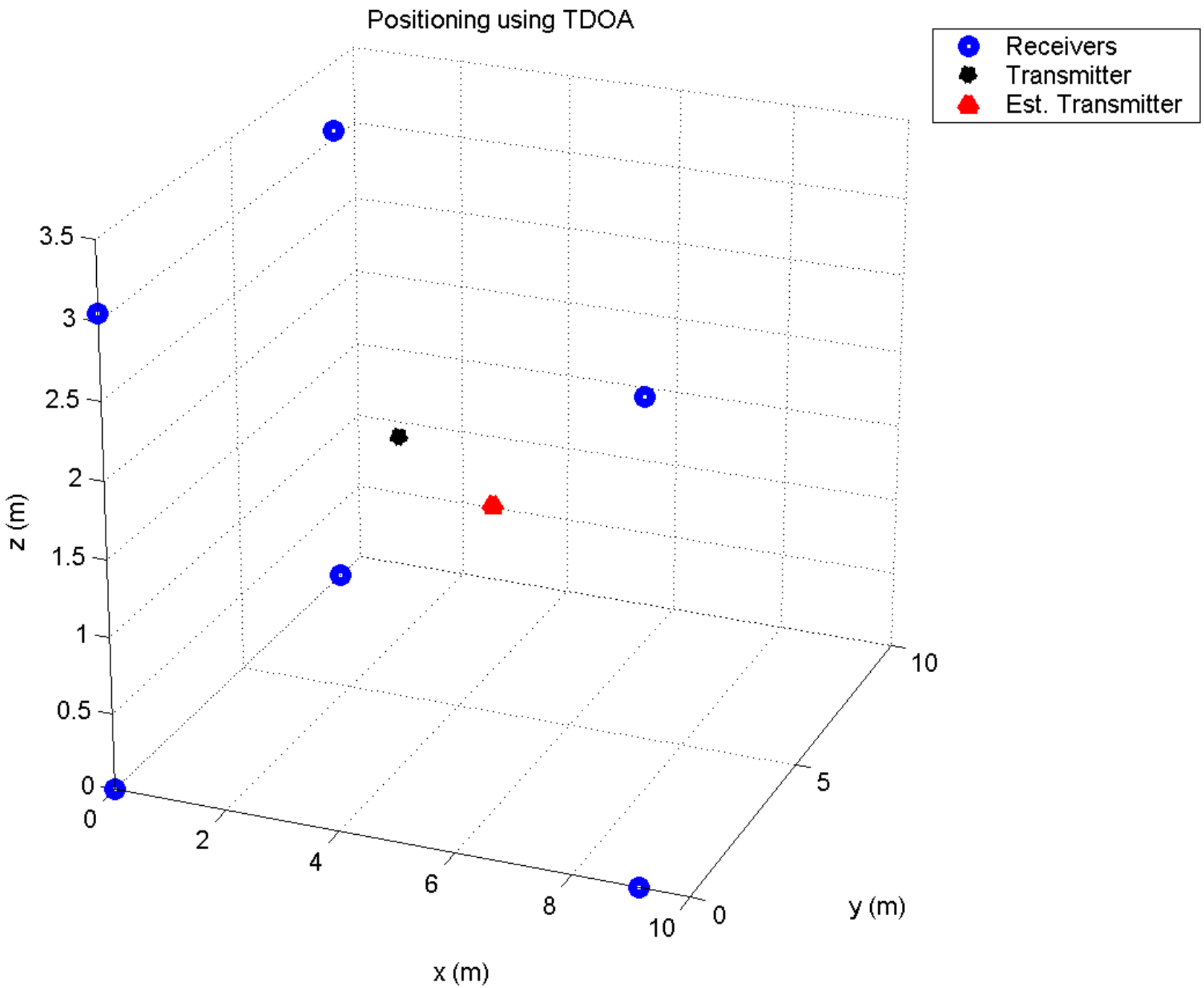
- Basic algorithm implementation
  - RN Positions, TDOAs >> Position Estimate
- Wrapper for simulation
  - Accepts RN configurations, test TX locations
- Degradation with noise
  - WGN added to TDOA data
- Manipulation for visualization

Simulation Interfaces

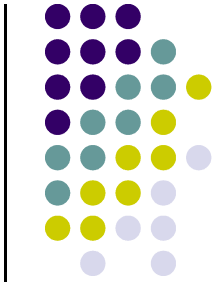


- One-shot GUI simulator
  - Easy, visual interface to algorithm
  - Ability to adjust simulation parameters
  - Quick feedback


positioning_gui2
TDOA Positioning Simulation
Top View (X-Y Plane)
10
8
6
4
2
0
0
2
4
6
8
10
Transmitter and Receiver Locations [m]
x
y
z
S1
0
0
0
S3
9.144
0
0
S5
0
9.144
0
Extra Z Altitude
S2
S4
S6
+Z
3.048
3.048
3.048
Transmitter Actual
3.6298
3.4266
2
Transmitter Estimated
4.7342
4.7393
1.4315
Error
1.1045
1.3127
0.56852
Error Distance
1.8073
m
TOA AWGN Std. Dev.
500e-12
s
Set Altitudes
Receivers 1/2
Receivers 5/6
Receiver 3/4
Transmitter
Place RXs
Place TXs
View 3D
Compute
On the fly
Quit

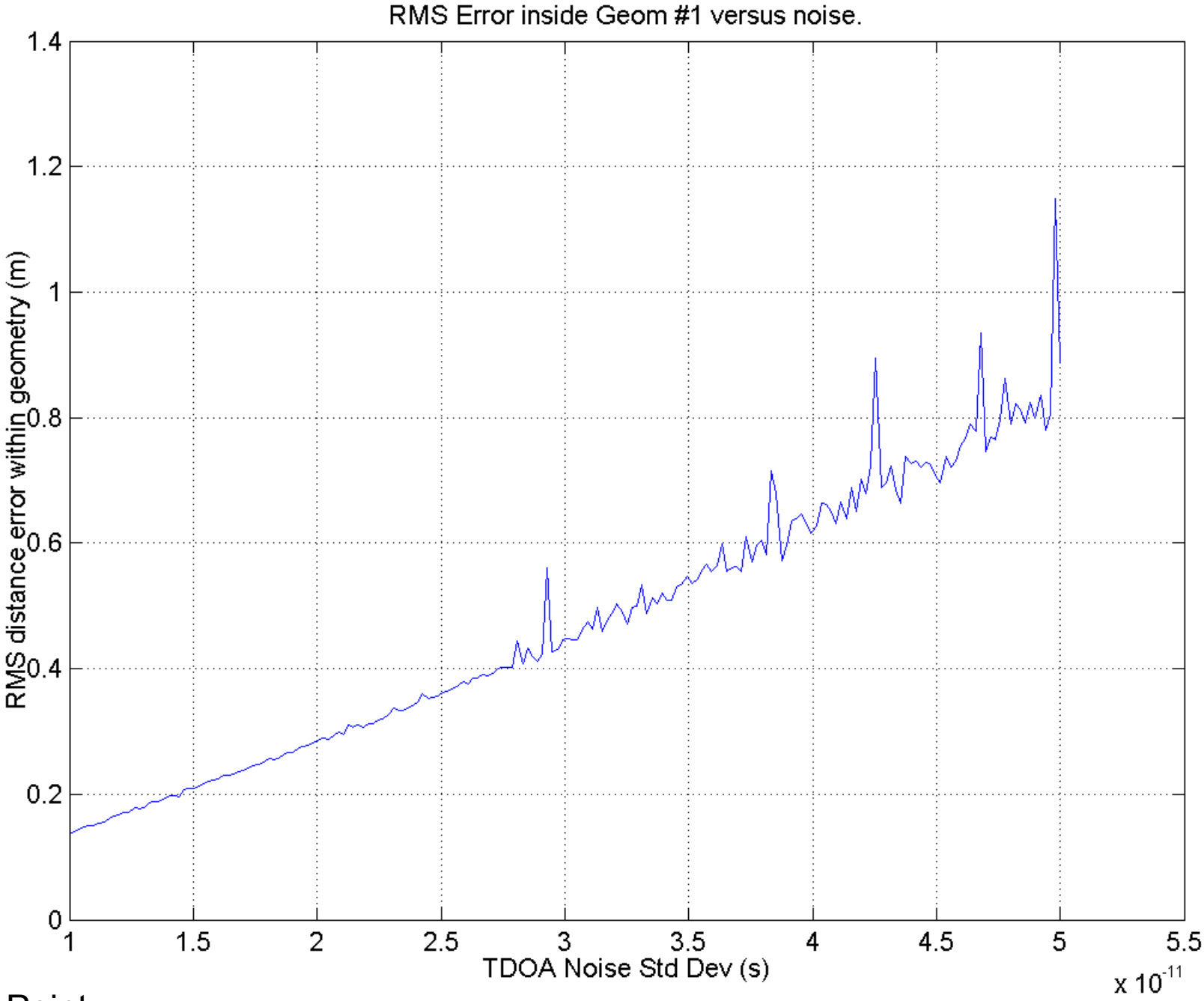

Positioning using TDOA
Receivers
Transmitter
Est. Transmitter
z (m)
3.5
3
2.5
2
1.5
1
0.5
0
x (m)
0
2
4
6
8
10
y (m)
0
5
10

Simulation Interfaces

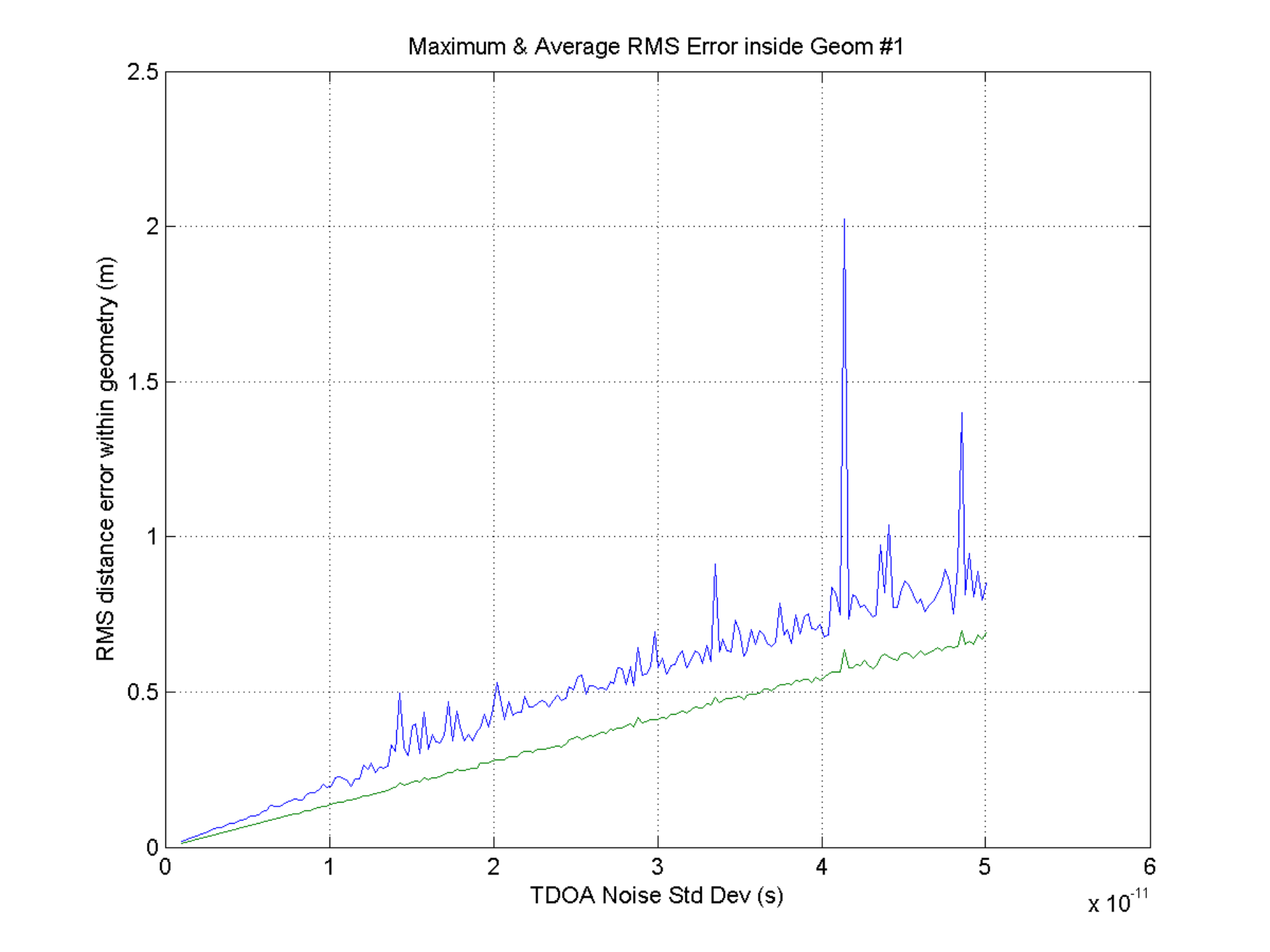


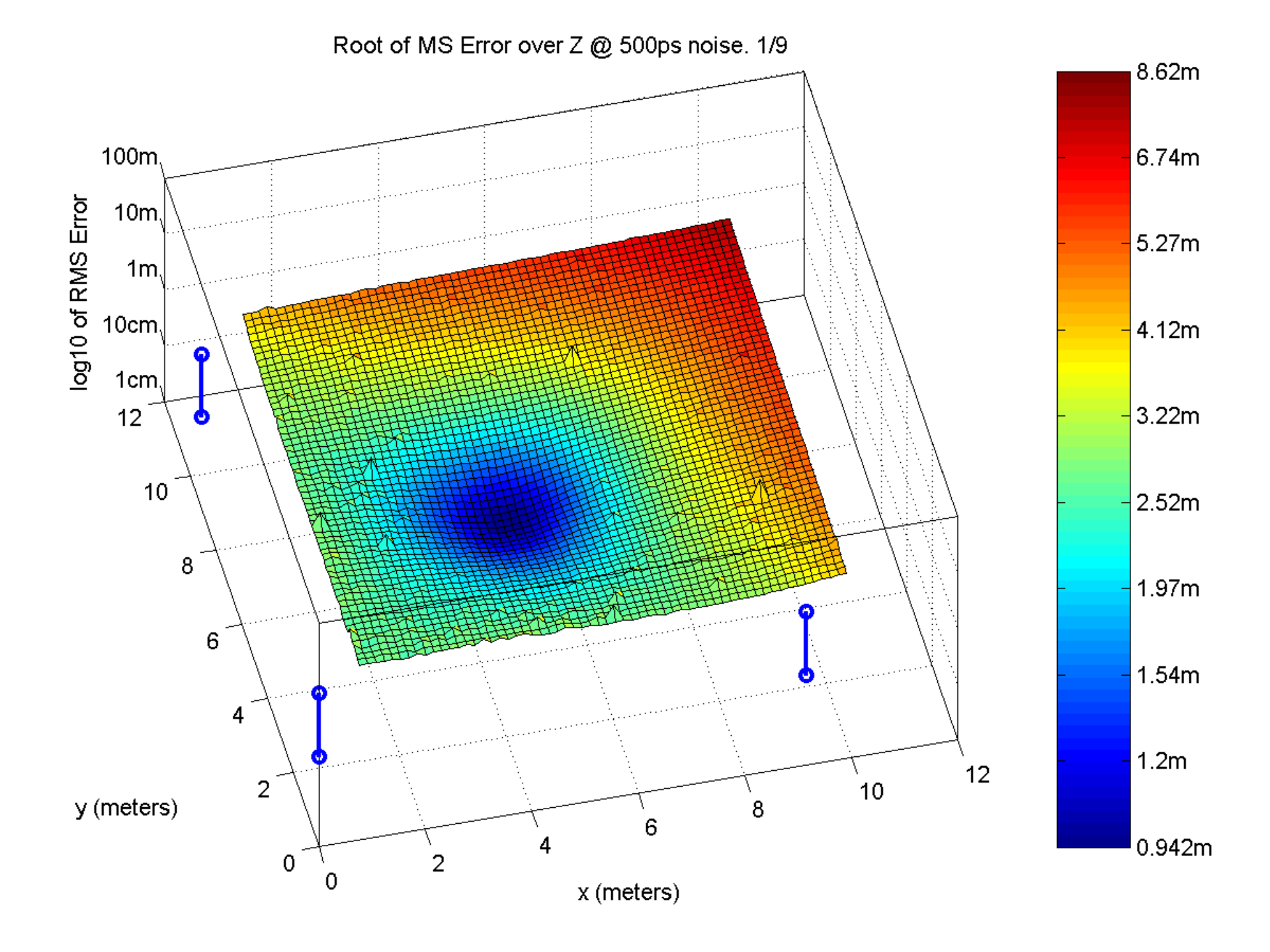
Monte Carlo simulation parameters

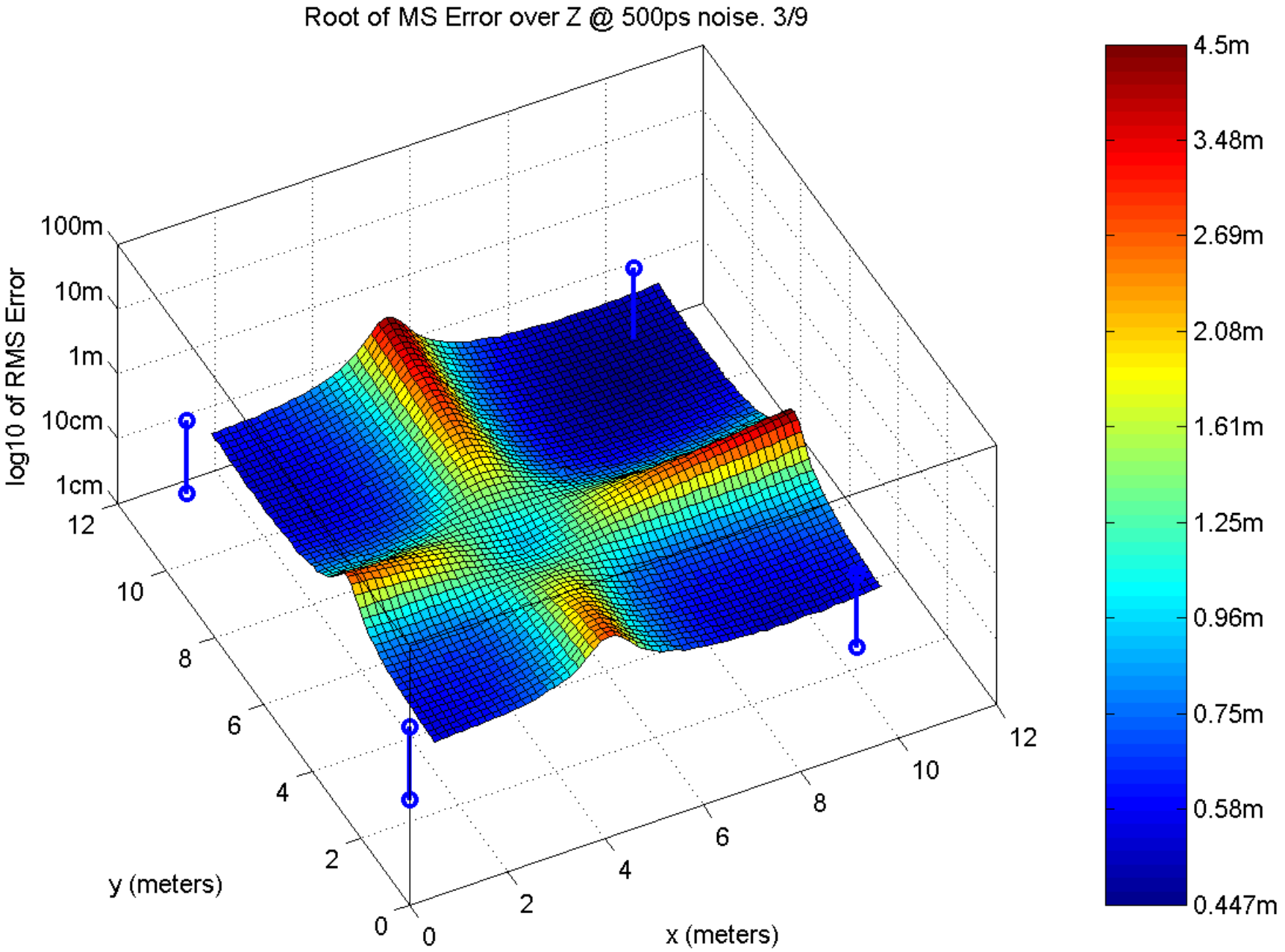
- AWGN noise standard deviation
- [X, Y, Z] ranges
- Number of tests to average over
- Sets of different receiver configurations
  - Static
  - Dynamic

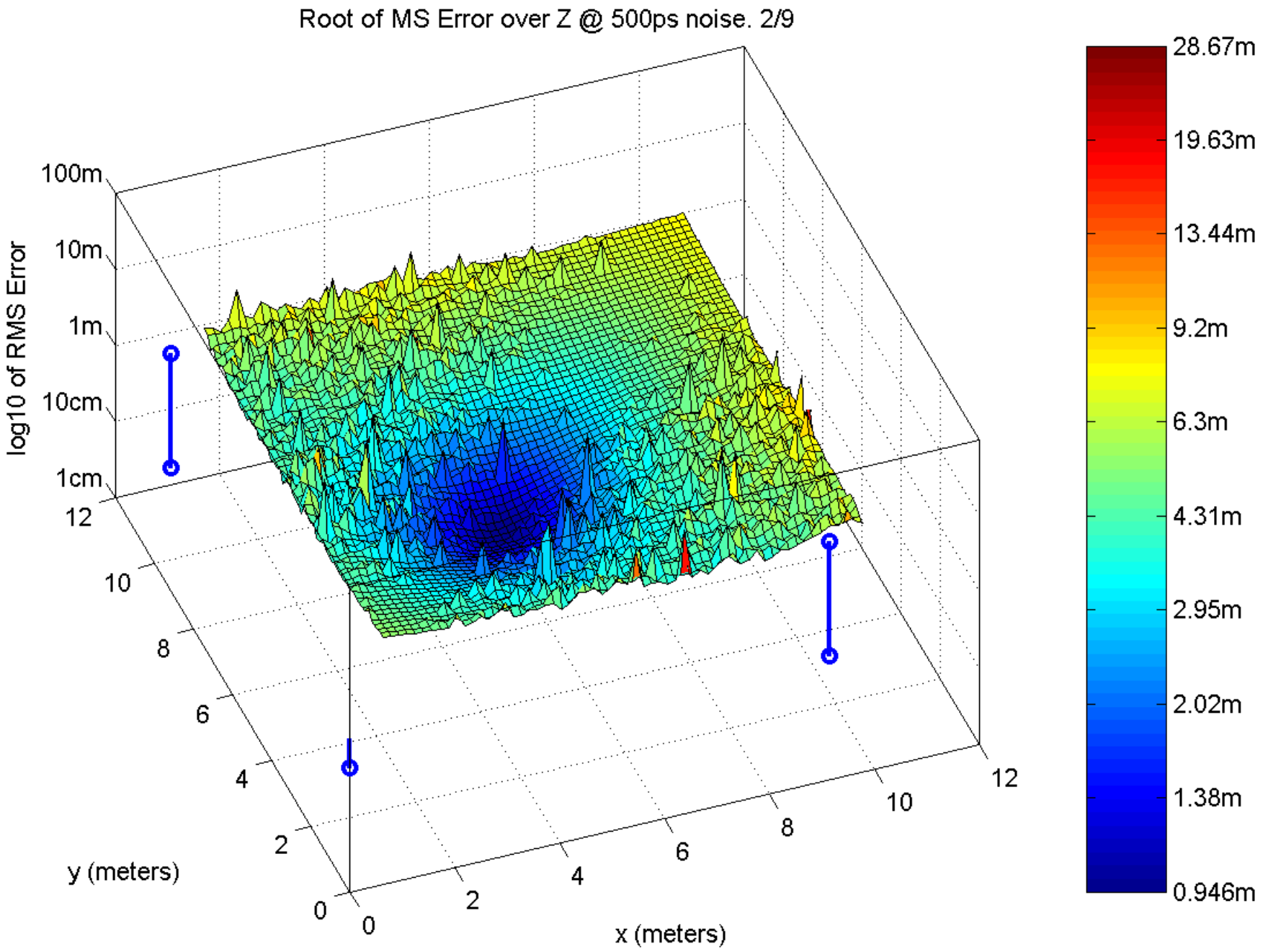


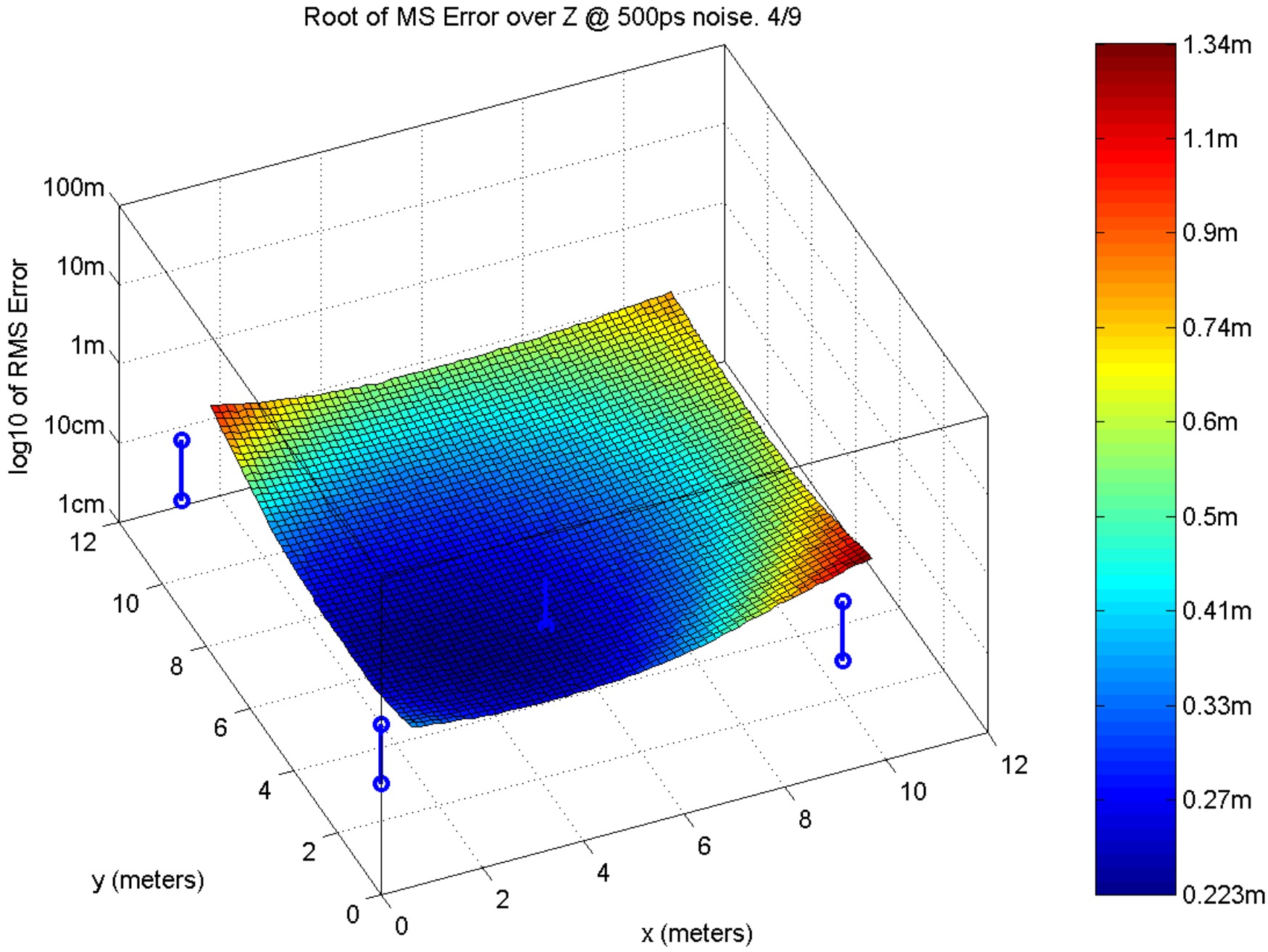
Single Point

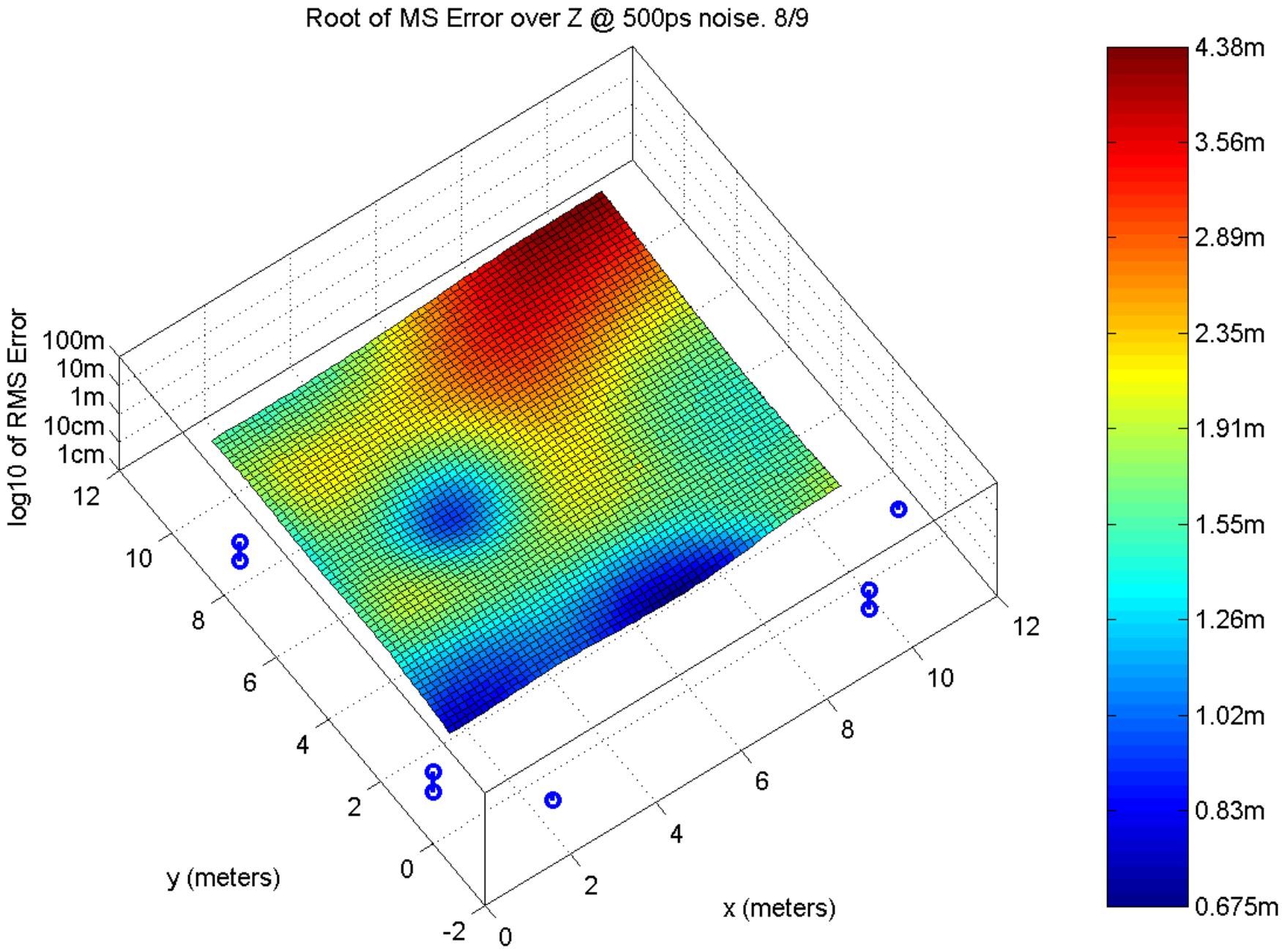

Maximum & Average RMS Error inside Geom #1
RMS distance error within geometry (m)
TDOA Noise Std Dev (s)
x 10^-11
0
0.5
1
1.5
2
2.5
0
1
2
3
4
5
6


Root of MS Error over Z @ 500ps noise. 1/9
log10 of RMS Error
100m
10m
1m
10cm
1cm
y (meters)
0
2
4
6
8
10
12
x (meters)
0
2
4
6
8
10
12
8.62m
6.74m
5.27m
4.12m
3.22m
2.52m
1.97m
1.54m
1.2m
0.942m

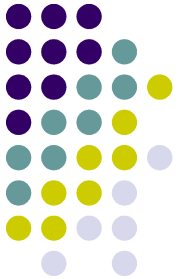

Root of MS Error over Z @ 500ps noise. 3/9
log10 of RMS Error
100m
10m
1m
10cm
1cm
y (meters)
x (meters)
0
2
4
6
8
10
12
4.5m
3.48m
2.69m
2.08m
1.61m
1.25m
0.96m
0.75m
0.58m
0.447m


Root of MS Error over Z @ 500ps noise. 2/9
log10 of RMS Error
100m
10m
1m
10cm
1cm
y (meters)
0
2
4
6
8
10
12
x (meters)
0
2
4
6
8
10
12
28.67m
19.63m
13.44m
9.2m
6.3m
4.31m
2.95m
2.02m
1.38m
0.946m


Root of MS Error over Z @ 500ps noise. 4/9
log10 of RMS Error
100m
10m
1m
10cm
1cm
y (meters)
0
2
4
6
8
10
12
x (meters)
0
2
4
6
8
10
12
1.34m
1.1m
0.9m
0.74m
0.6m
0.5m
0.41m
0.33m
0.27m
0.223m

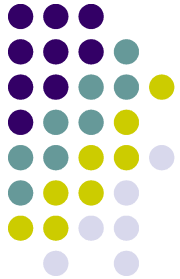

Root of MS Error over Z @ 500ps noise. 8/9
log10 of RMS Error
100m
10m
1m
10cm
1cm
y (meters)
x (meters)
4.38m
3.56m
2.89m
2.35m
1.91m
1.55m
1.26m
1.02m
0.83m
0.675m

Pictures to show



1. GUI in action, one at a time w/ noise.
2. Statistical performance graphs
   - Different RX Geometries
   - Noise sweeps over point, line, volume.
3. Geometric dilution of performance
   - Sensor Configurations
   - Performance Analyses + Surface Plots

Future Work



- Derivation of the CRB for location error
  - Mathematically optimize location algorithm further if CRB allows
  - Develop a strategy for RN placement
- Dynamic introduction of additional RNs
  - In environments with signal obstructions additional RNs could be dropped in place and automatically incorporate into RN network.
- Kalman Filtering
  - Improved track identification through physical constraints on target dynamics

Questions???