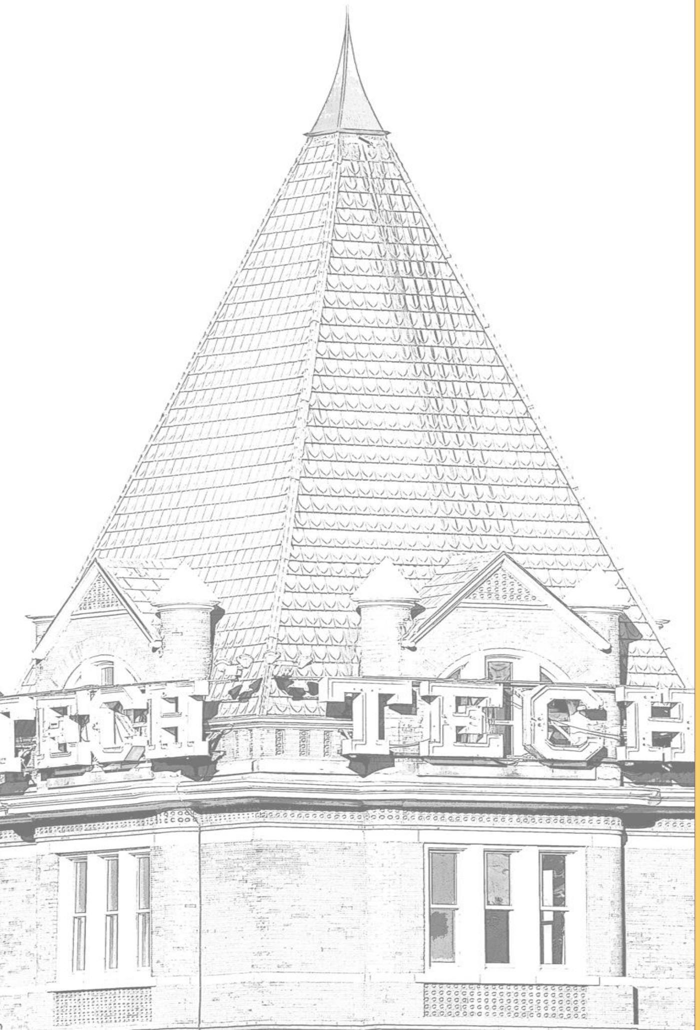


Time Difference of Arrival Localization Testbed: Development, Calibration, and Automation

GRCon 2017

Intelligent Digital Communications
Georgia Tech VIP Team

Overview

- Introduction
  - IDC Team
  - Stadium Testbed
- RFSN Control Center (RFSNCC)
  - Why?
  - How?
- Lab Setup and ToA Calibration
  - Why?
  - Experiment Setup
  - Results

Introduction

Hayden Flinner

IDC Team Purpose

- IDC is using software defined radio to enhance spectrum utilization
  - Radio frequency (RF) spectrum is a valuable, limited resource
  - Analyzing how devices interact over RF spectrum allows us to find ways to improve communication in an optimal manner

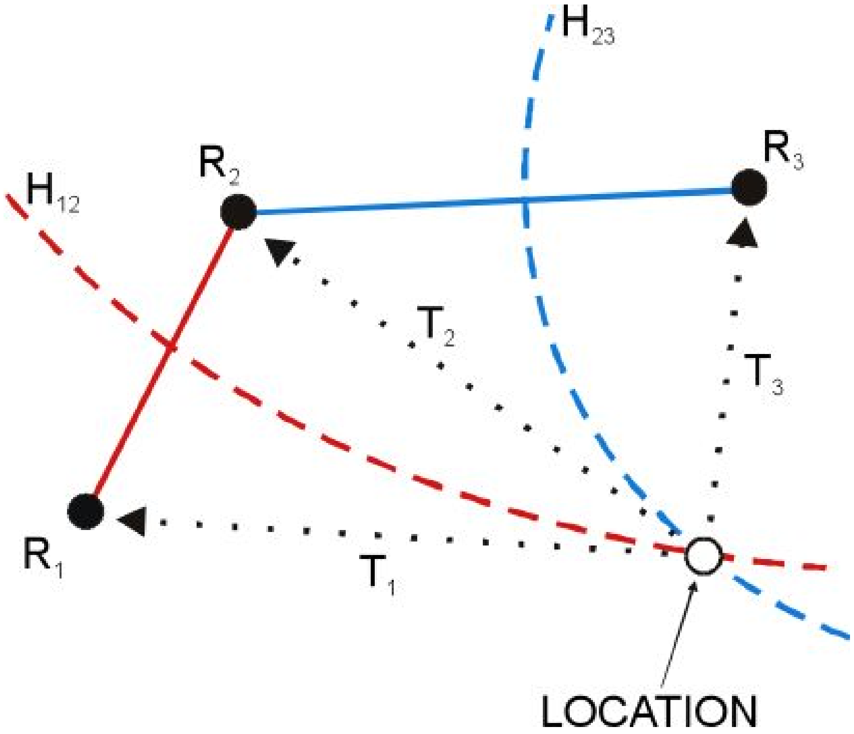
Localization

- Using SDR to develop localization algorithms for Extreme Emitter Density environments (10k-100k people/km2)

- Recorded terabytes of time synchronous RF IQ data, during football games, at the GT football stadium to assist in algorithm development

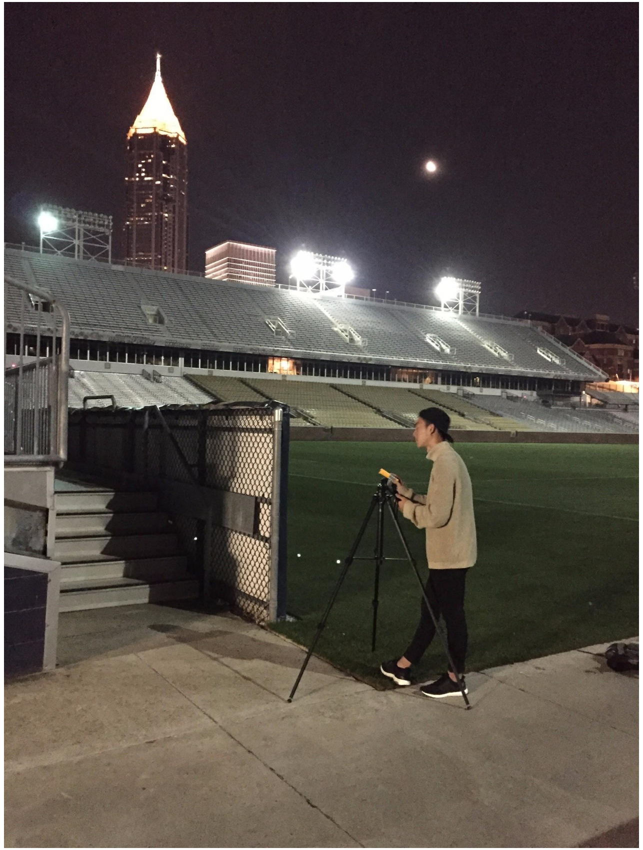
TDoA Localization

- Assuming time-synced nodes:
  1. Record ToAs
  2. Take differences
  3. Apply **Δd = cΔt**

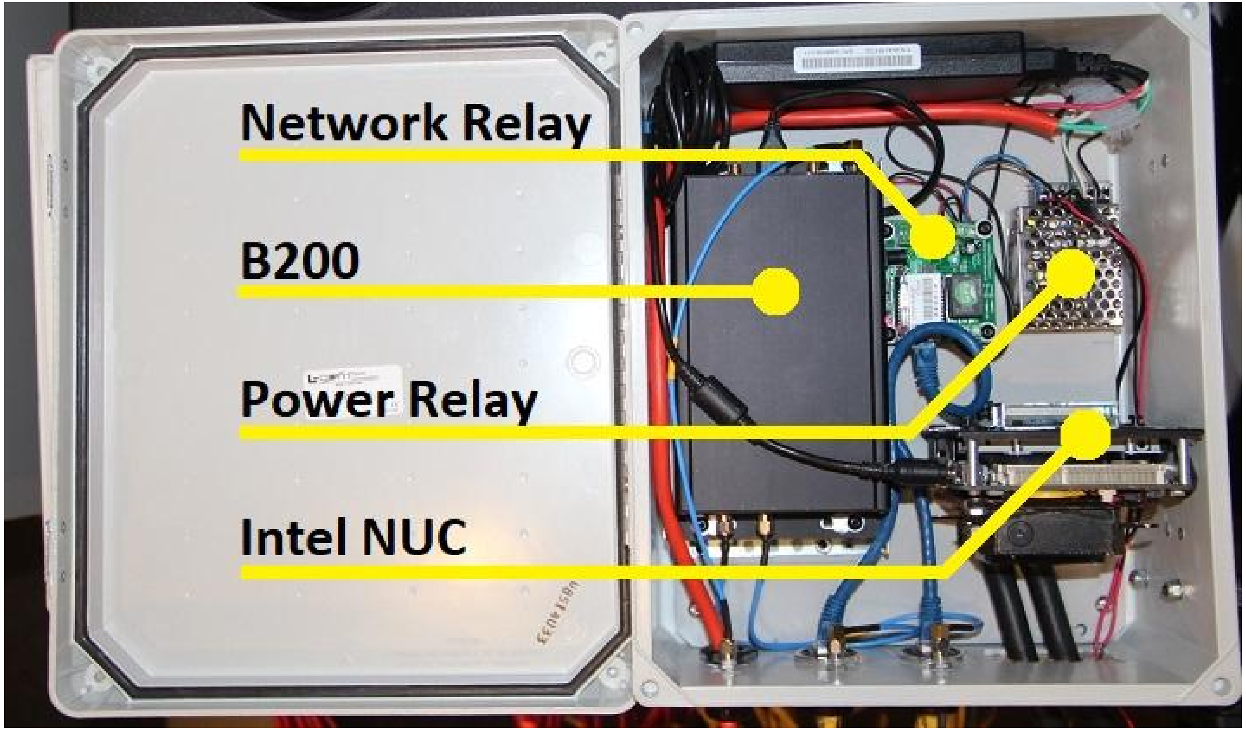


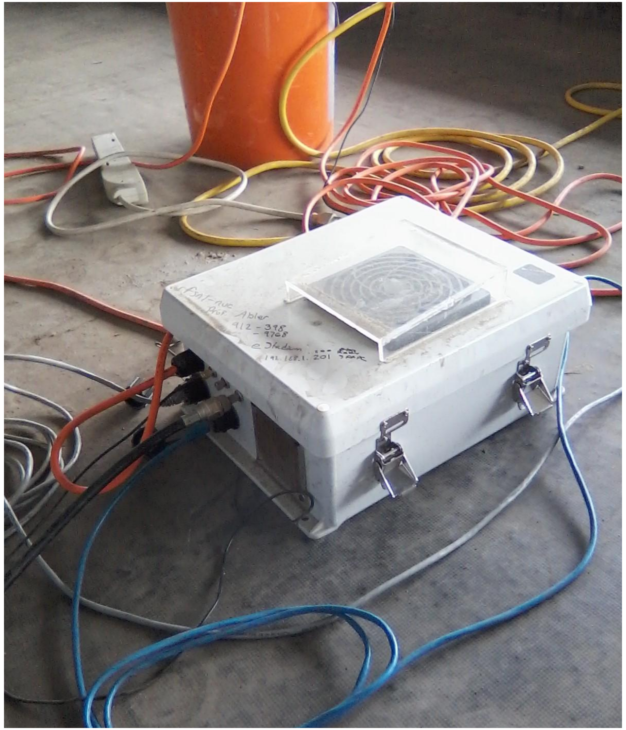
Stadium Testbed

Hayden Flinner

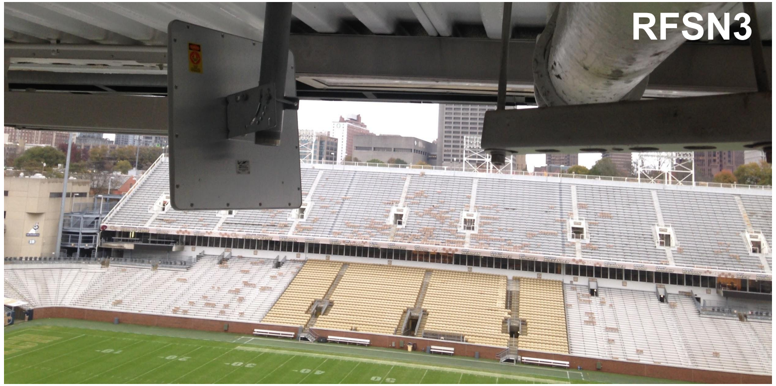


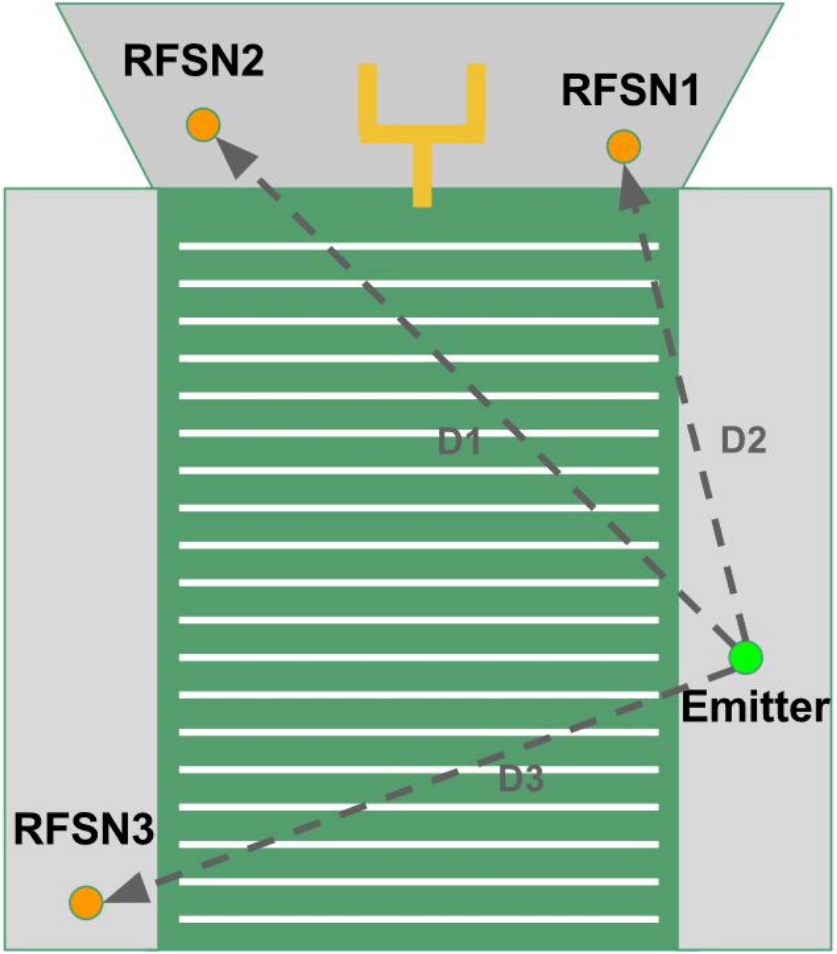
RF Sensor Node (RFSN)





Stadium Testbed





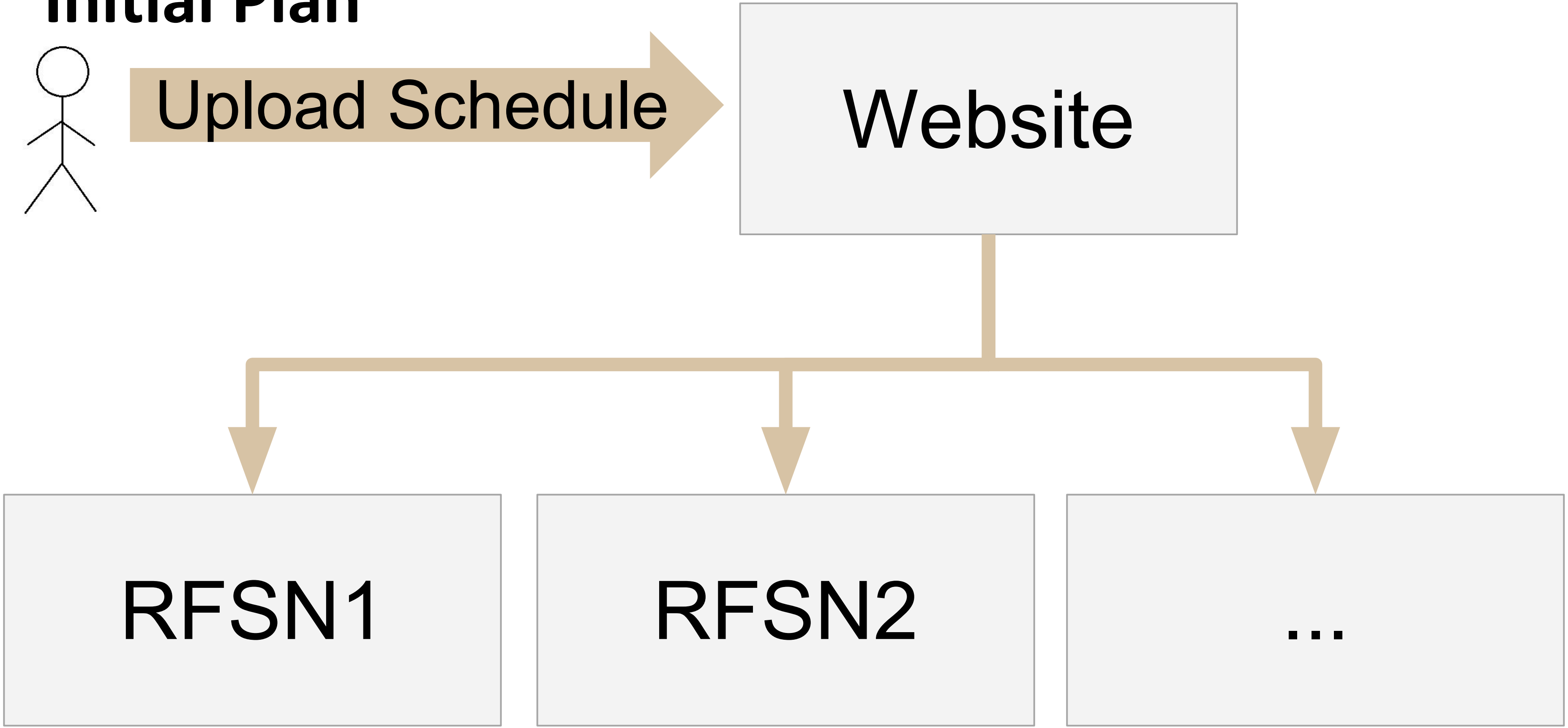
2 Mobile Nodes

RFSN Control Center (RFSNCC)

Why RFSNCC?

1. Currently 3 fixed nodes - Goal 10+
2. Logging into each machine and running long series of time-synced record commands is not scalable
    a. Excessive man-hours
    b. Error-prone
3. Maintaining RF IQ dataset and associated metadata is tedious

Initial Plan



Current Site

CSV Scheduling

CSV Formatting Reference

Choose File No file chosen

Submit

Schedule Recording Form

Session Name	Starting Path (/path/)	Log Name (test.log)	Start Early (sec)	Sample Rate (samples/sec)
Spring17Test	/spring17/test/	log.txt	60	25e6

☑ RFSN Node 1 ☑ RFSN Node 2 ☑ RFSN Node 3

Time Offset (min)

5

Date	Time	Length (sec)	Gain (db)	Frequency (hz)
04/21/2017	03:00 AM	5	55	2.4E+9
04/21/2017	03:05 AM	5	55	2.4E+9
04/21/2017	03:10 AM	5	55	2.4E+9
04/21/2017	03:15 AM	5	55	2.4E+9
04/21/2017	03:20 AM	5	55	2.4E+9

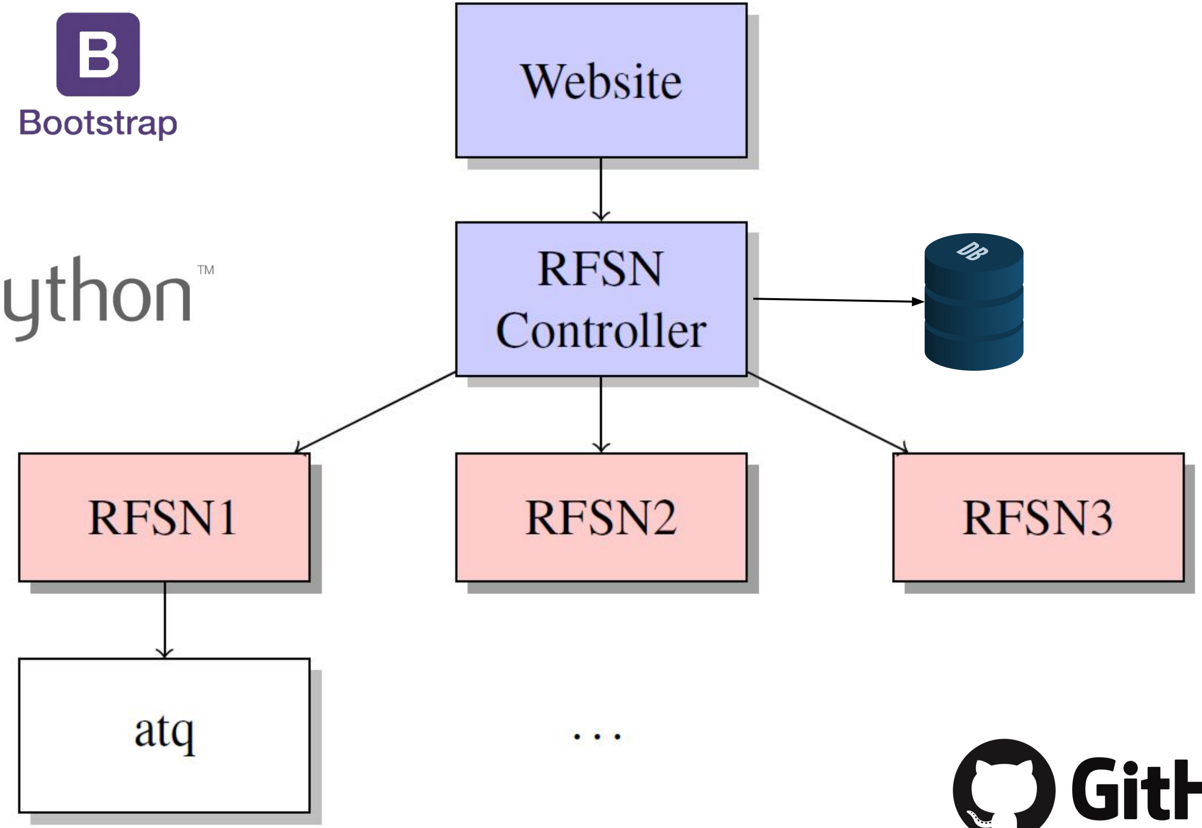
Add Submit Form

Current Site

RFSNS

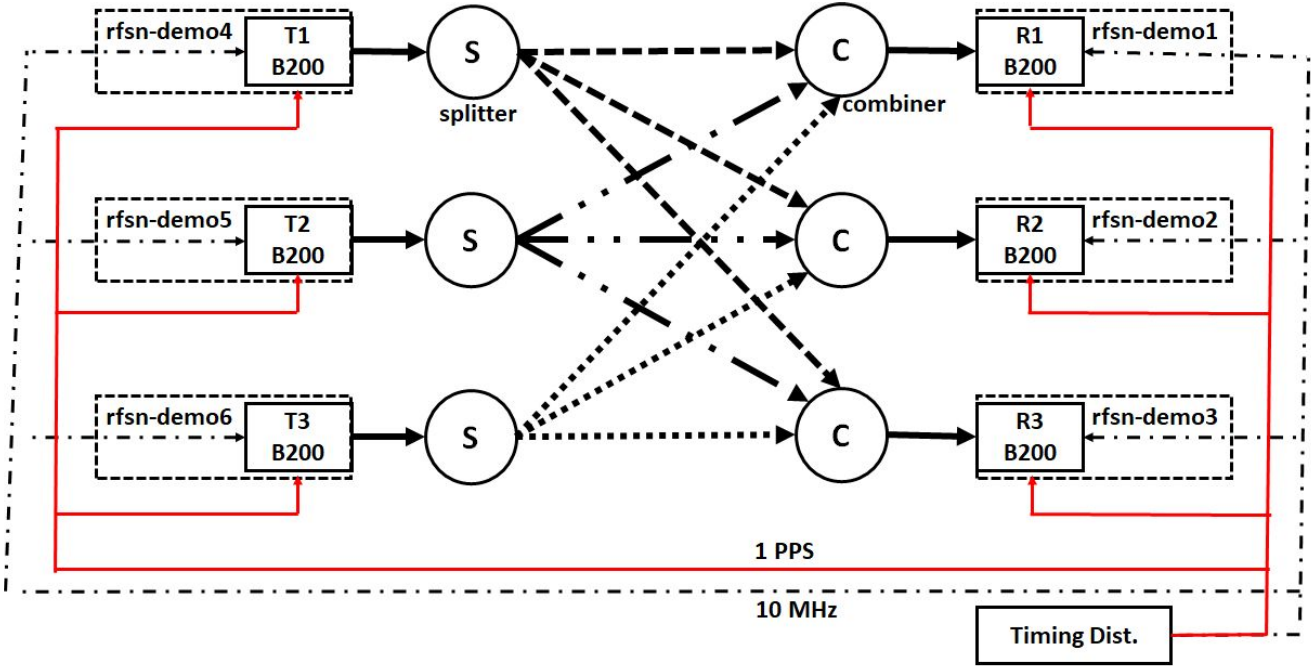
RFSN	Power	Status
RFSN Node 1	RFSN Node 1: ON/OFF	Click to see Status
RFSN Node 2	RFSN Node 2: ON/OFF	Click to see Status
RFSN Node 3	RFSN Node 3: ON/OFF	Click to see Status

Architecture



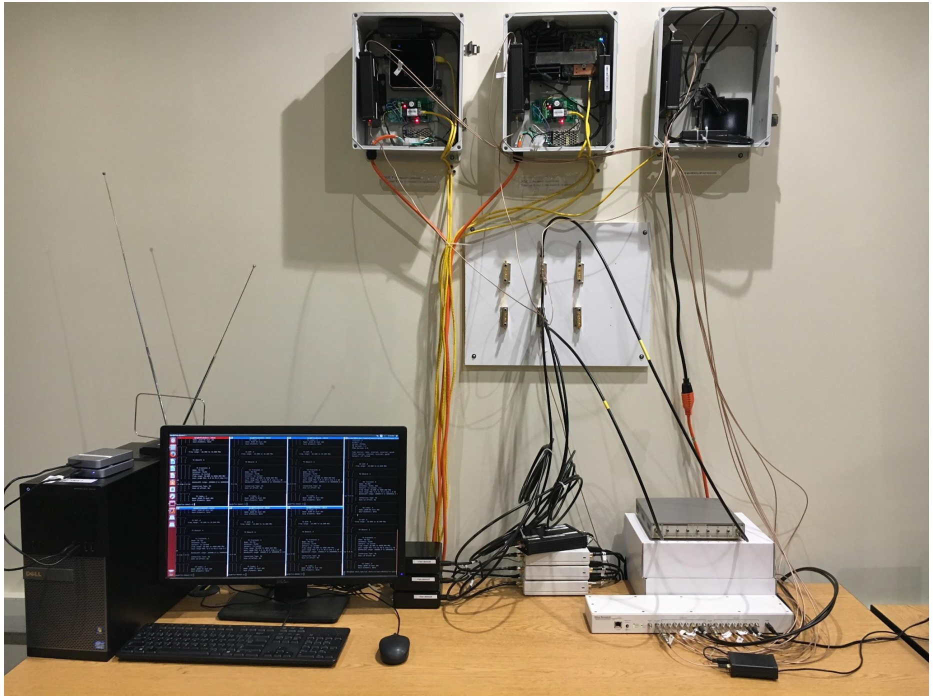
Lab Setup and ToA Calibration

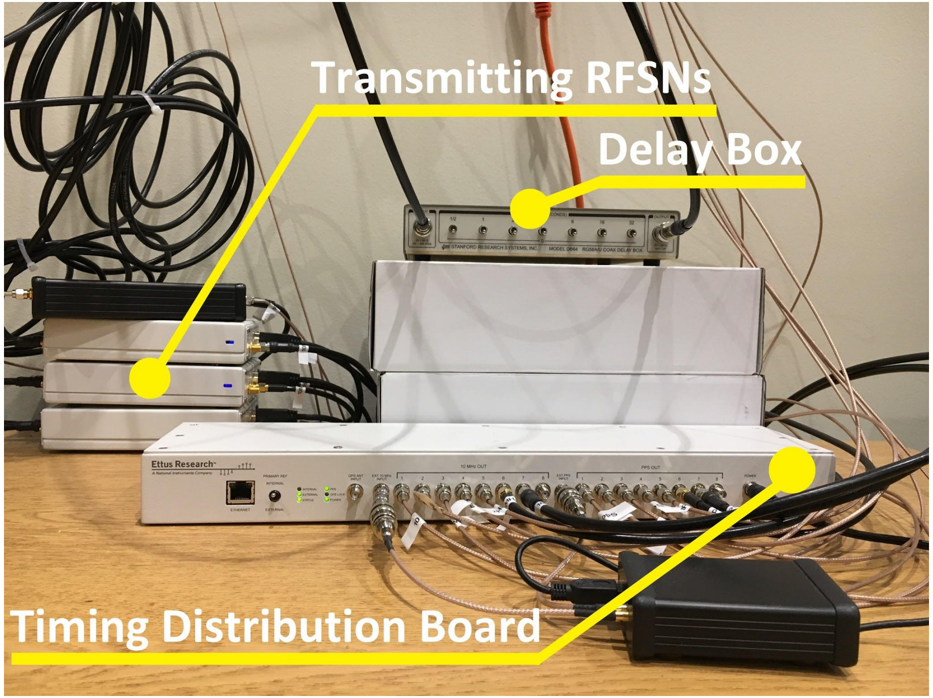
Why a Lab Testbed?



- Wired nodes provide controlled test environment.
- Easier to vary cable lengths to test emitter/receiver positions than to run around stadium

Lab Testbed




Transmitting RFSNs
Delay Box
Timing Distribution Board
Ettus Research

Why Calibration Experiment?

- Verify that ToAs being recorded are plausible
- Remove delay inherent to USRPs for more accurate location measurements

Cramer-Rao Lower Bound (CRLB)

- CRLB for the standard deviation of the TDoA is theoretic limit on how accurate results can be

$$\sigma^2(\widehat{t_2} - \widehat{t_1}) \geq \frac{1}{4\pi^2(SNR_{linear})\beta_{rms}{}^2} \quad (s^2)$$

$$SNR_{linear} = 10^{\frac{SNR_{dB}}{10}}$$

$$\beta_{rms} = \frac{\beta}{\sqrt{12}}$$

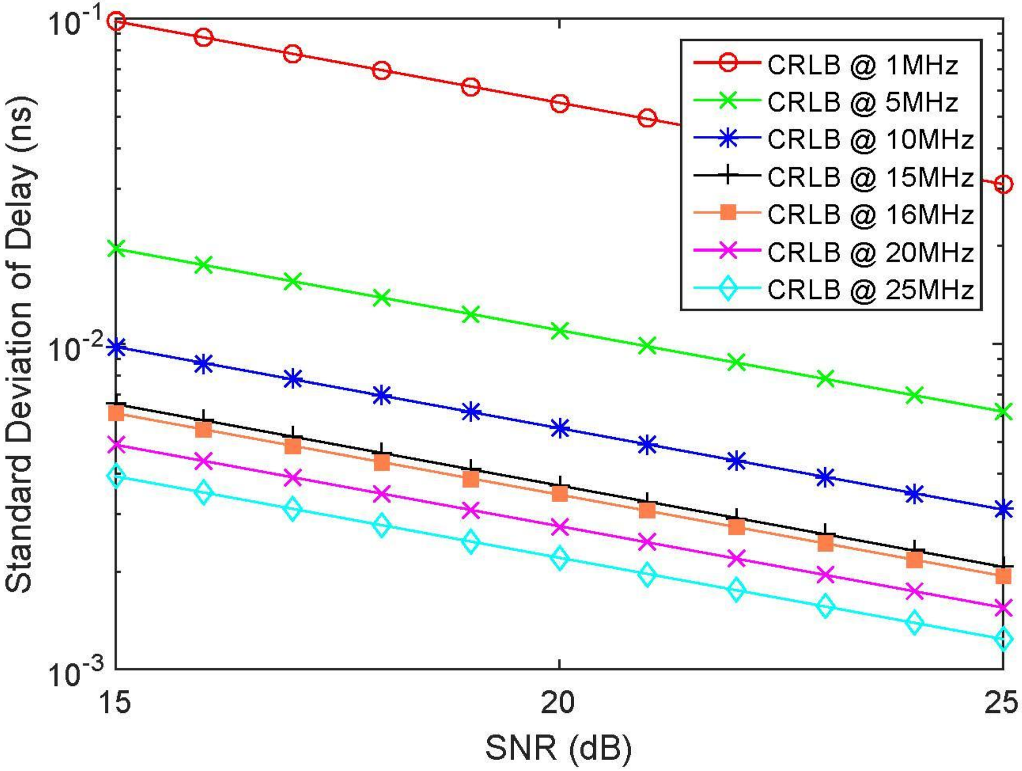
β *is the BW*

$\widehat{t_n}$ *is the uknown ToA at sensor i*

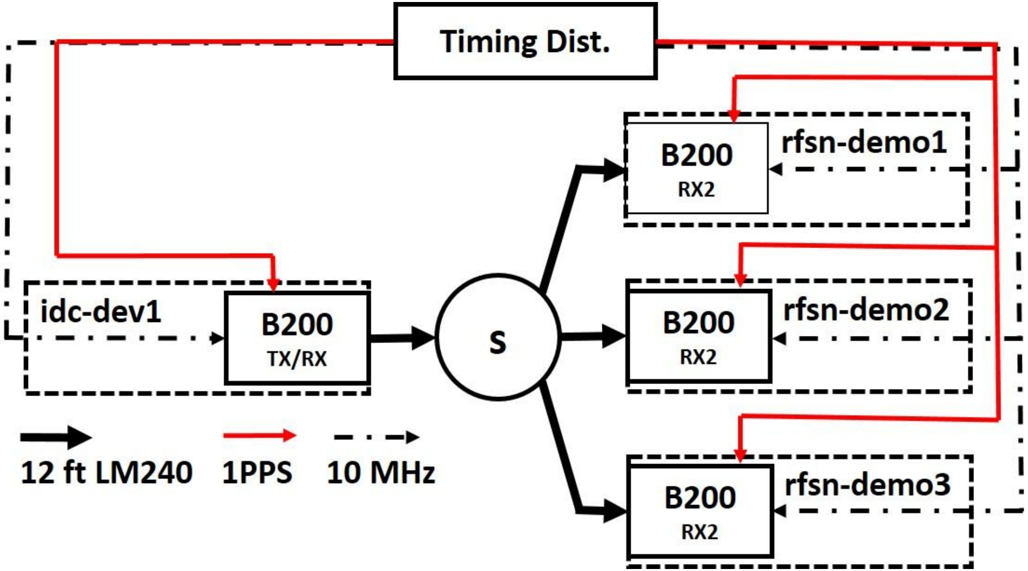
$$SNR_{dB} = 10log_{10}\left(\frac{\sum|X_i|^2}{\sigma_{noise}{}^2}\right)$$

Cramer-Rao Lower Bound (CRLB)

Relationship between CRLB and bandwidth



Q: Does our testbed give us sane results?

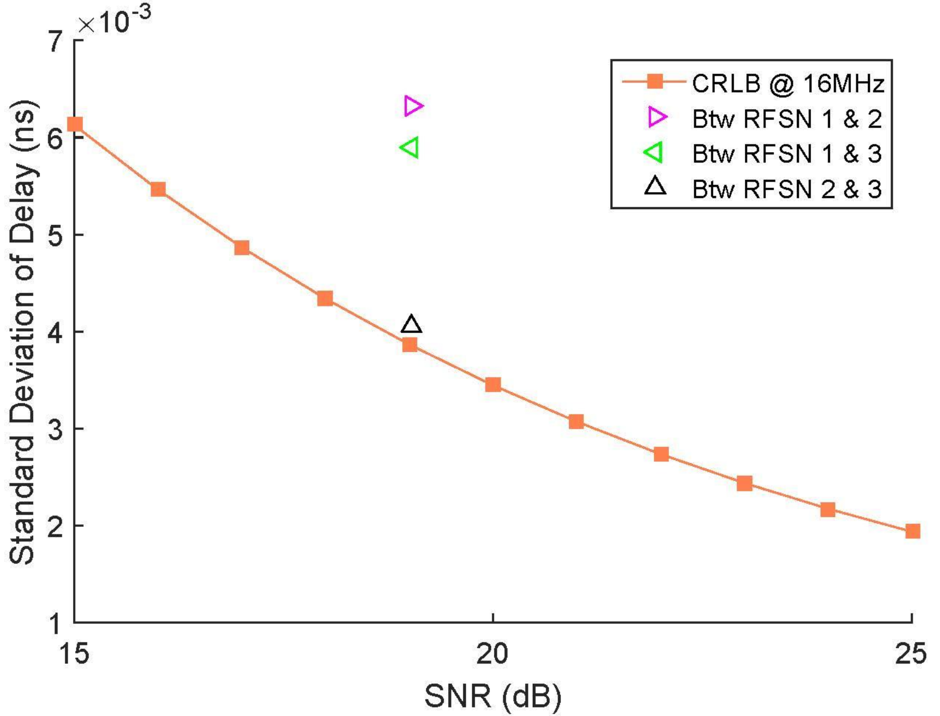


TDoA ->	Btw 1 & 2	Btw 1 & 3	Btw 2 & 3
Mean (ns)	18.228	26.440	8.213
Variance (ns^2)	4.004E-5	3.478E-5	1.644E-5
Std Dev (ns)	6.327E-3	5.898E-3	4.054E-3
MSE (ns^2)	7.241E-5	3.506E-5	5.508E-5
SNR (dB)	79.904	80.279	80.279

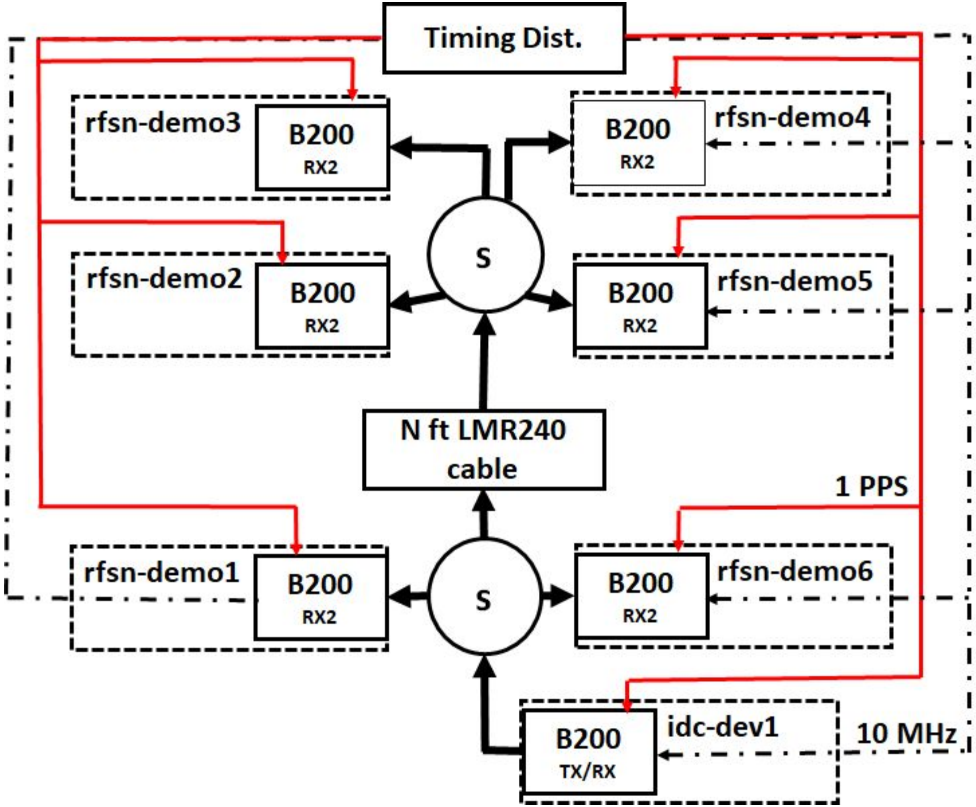
- TX sampling rate: 16 Msps
- RX sampling rate: 16 Msps with 32 MHz master clock.

A: Yes! Std. Devs. above CRLB!

SD of TDoA data plotted against its CRLB at 16 MHz sampling bandwidth



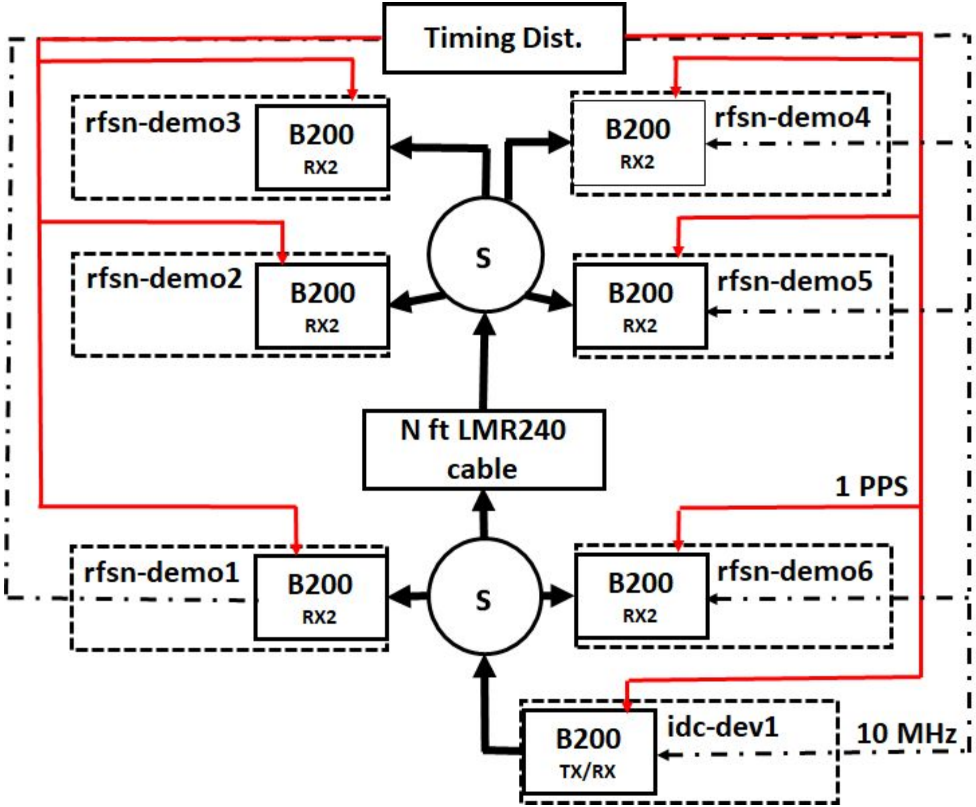
Calibration: Testbed Setup



- Nodes 2, 3, 4, and 5 were passed delayed signal sequence.
- Nodes 1 and 6 received non-delayed signal sequence.

TX: 25 Msps -- RX: 25 Msps, 50 MHz master clock.

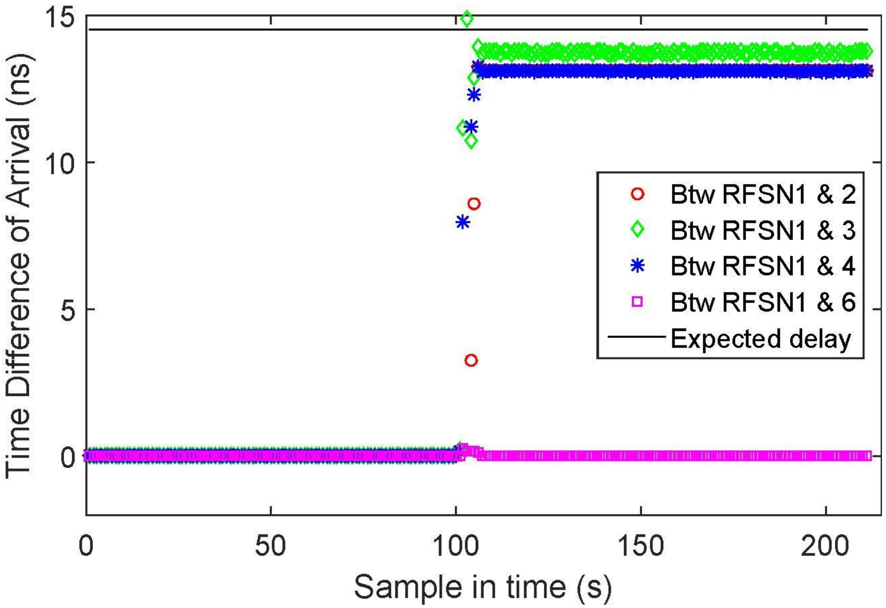
Calibration: Running Experiment



- LMR-240 cables of known lengths were attached 110 seconds into each recording session.
- For each node, average ToAs seen during first 100 seconds was subtracted from ToA vector during each recording session.
- Used magnitude interpolation around the cross-correlation peak value to compute ToA estimate.

TX: 25 Msps -- RX: 25 Msps, 50 MHz master clock.

Time Difference of Arrival over 12 ft LMR240 cable

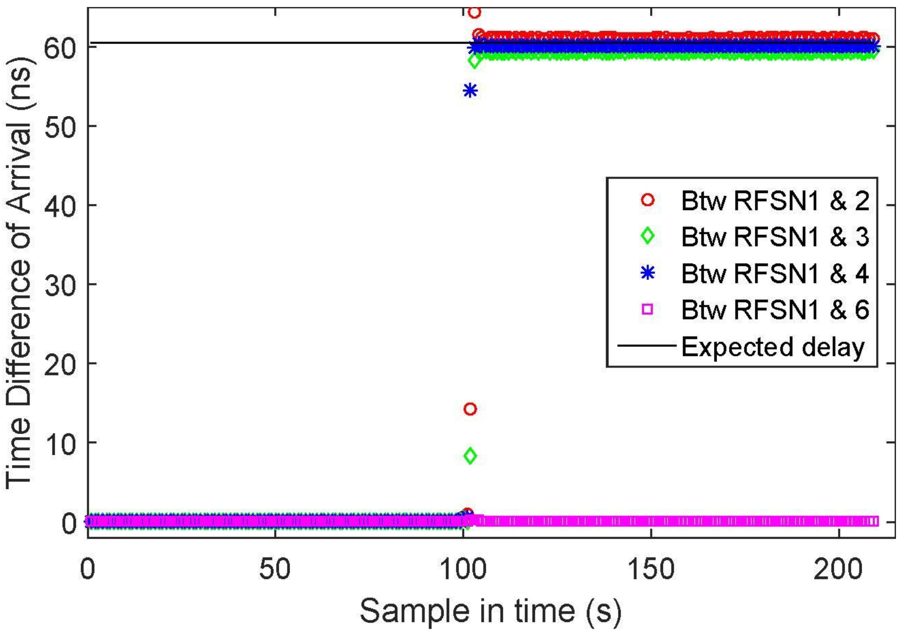


TDoA ->	Btw 1 & 2	Btw 1 & 3	Btw 1 & 4	Btw 1 & 6
Mean (ns)	**13.0750**	**13.7267**	**13.1034**	**0.0242**
Variance (ns^2)	**1.8990E-1**	**9.5577E-3**	**6.6974E-3**	**3.0686E-4**
Std Dev (ns)	**0.4358**	**0.0978**	**0.0818**	**0.0175**
MSE (ns^2)	**2.2976E-0**	**6.4481E-1**	**2.0323E-0**	**8.9917E-4**

Results are of average TDoA vector from four runs

- Expected delay through 12 ft LMR240 cable is: 12 ft / 0.8262 ft/ns = **14.5243 ns**

Time Difference of Arrival over 50 ft LMR240 cable

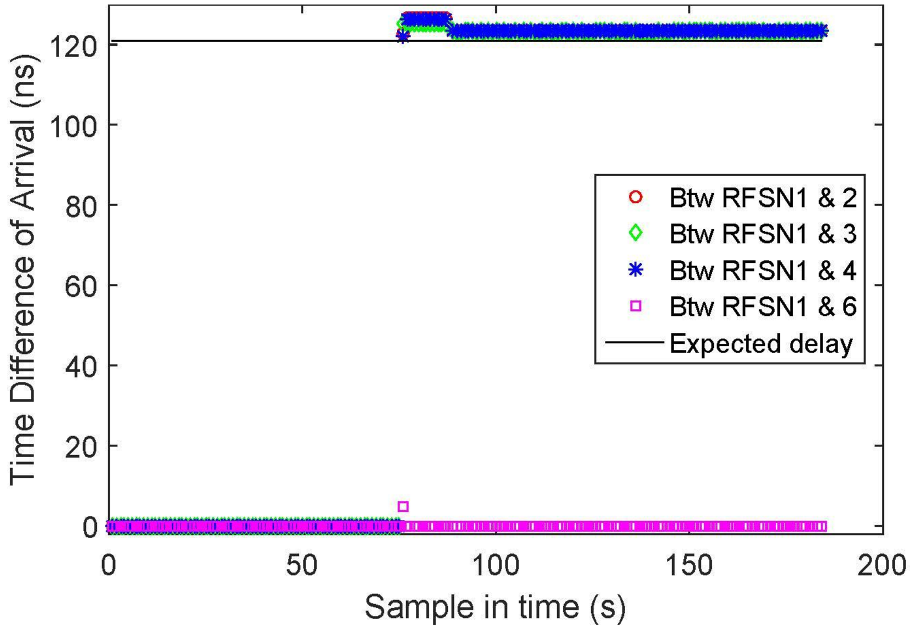


TDoA ->	Btw 1 & 2	Btw 1 & 3	Btw 1 & 4	Btw 1 & 6
Mean (ns)	61.0461	59.4250	60.1079	0.0035
Variance (ns^2)	1.9459E-4	6.0374E-4	3.7281E-5	4.1453E-6
Std Dev (ns)	0.0139	0.0246	0.0061	0.0020
MSE (ns^2)	3.0133E-1	1.1676E-0	1.5527E-1	1.6303E-5

Results are of average TDoA vector from four runs

- Expected delay through 12 ft LMR240 cable is: 50 ft / 0.8262 ft/ns = **60.5181 ns**

Time Difference of Arrival over 100 ft LMR240 cable

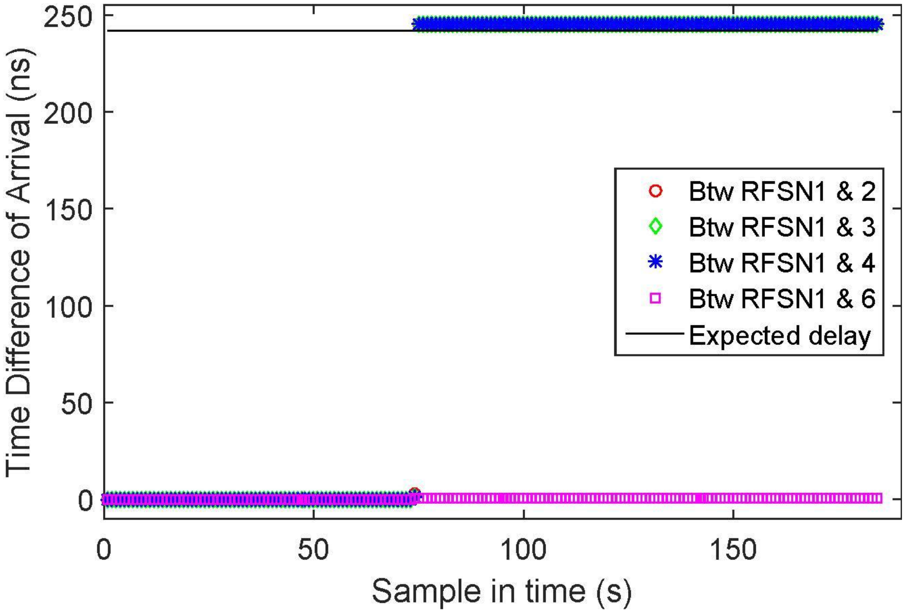


TDoA ->	Btw 1 & 2	Btw 1 & 3	Btw 1 & 4	Btw 1 & 6
Mean (ns)	**121.7498**	**123.1022**	**122.7003**	**0.4180**
Variance (ns^2)	**5.6723E-4**	**1.0220E-3**	**1.3408E-4**	**9.6546E-5**
Std Dev (ns)	**0.0238**	**0.0320**	**0.0116**	**0.0098**
MSE (ns^2)	**0.5706**	**4.4814**	**2.9312**	**0.1772**

Results are of average TDoA vector from four runs

- Expected delay through 100 ft LMR240 cable: 100 ft / 0.8262 ft/ns = **121.0361 ns**

Time Difference of Arrival over 200 ft LMR240 cable



TDoA ->	Btw 1 & 2	Btw 1 & 3	Btw 1 & 4	Btw 1 & 6
Mean (ns)	**244.9814**	**245.0107**	**245.1557**	**0.8586**
Variance (ns^2)	**1.7674E-4**	**2.5461E-4**	**1.2964E-5**	**9.3918E-6**
Std Dev (ns)	**0.0133**	**0.0160**	**0.0036**	**0.0031**
MSE (ns^2)	**8.9707**	**9.1476**	**10.0497**	**0.7439**

Results are of average TDoA vector from four runs

- Expected delay through 200 ft LMR240 cable: 200 ft / 0.8262 ft/ns = **242.0722 ns**

Wrapping Up

- Experiments show our timing variance on 4 different cable lengths (with 4 trials apiece) match expectations
- RFSNCC allows us to schedule and collect data easily
- Already collected relatively large (40TB) dataset from stadium

Contact

Github Repo - http://bit.ly/2vlgQBQ

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ToA Calculation

- Simple parabolic interpolation

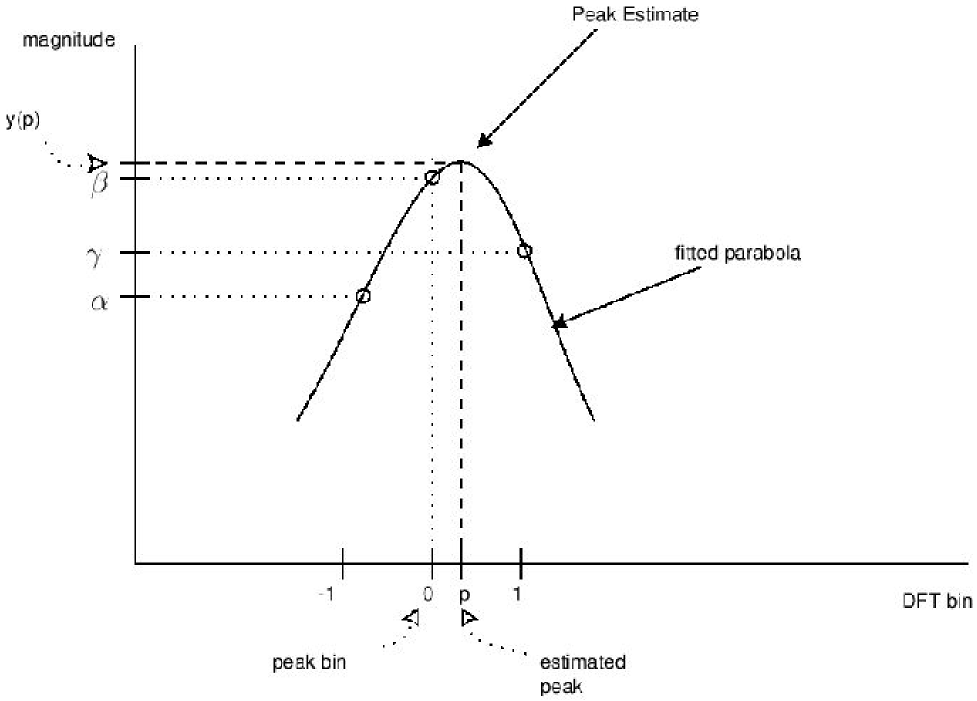

Figure 12.1: Illustration of parabolic peak interpolation using the three samples nearest the peak.

Source: DSPrelated.com