Antenna Characterization for Bluetooth-based Travel Time Data Collection

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Outline

- Acknowledgements
- Project objectives
- Test setup
- Single antenna testing
- Travel time data collection
- Discussion and Q & A

Acknowledgements

- ODOT Research and OTREC
  - Research Technical advisory committee
- ODOT ITS

Project Objectives

- Understand the affect of different antenna characteristics on the performance of Bluetooth-based data collection units.

Current Bluetooth Reader

Board: ALIX WIFI
(Mini-box/Ituner Networks Corp)

Cost: ~ $ 240 / unit

Single Antenna Testing Setup

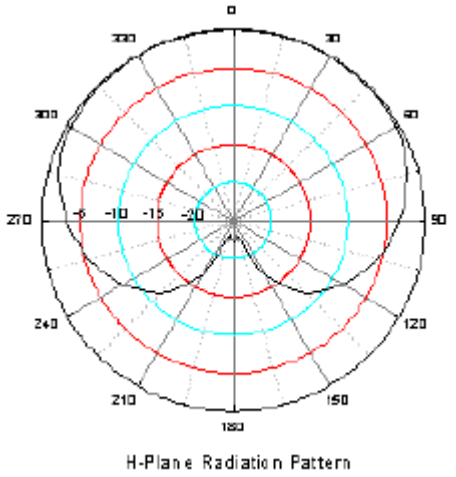
- Test location - Wallace Road in Salem, Oregon
  - Power source , mounting location (□10 ft.), adjacent loop detectors, digital modem.

Antenna Types Tested

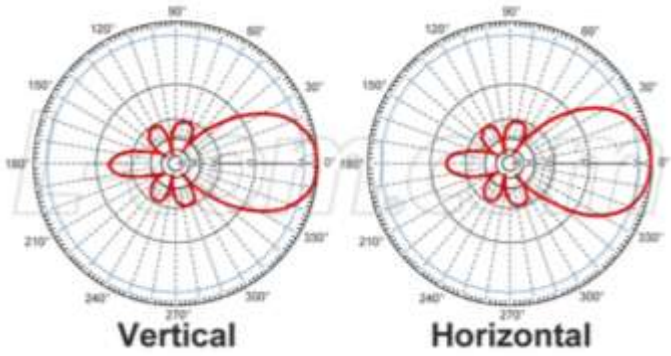
- Antenna types varied mainly on the following three characteristics
  - Gain
  - Polarization
  - Shape and size of the coverage patterns
- The ultimate objective was to determine whether or not the above factors had an impact on the performance of the Bluetooth readers
- Antennas were oriented to maximize road coverage

Review of Antenna Types Tested

Frequency: 2400-2483 MHz
Gain: 8.6 dBi
Polarization: Vertical

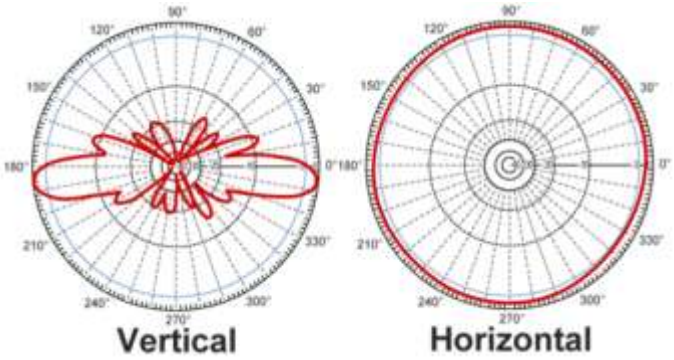


Frequency: 2400-2483 MHz
Gain: 12 dBi
Polarization: Vertical

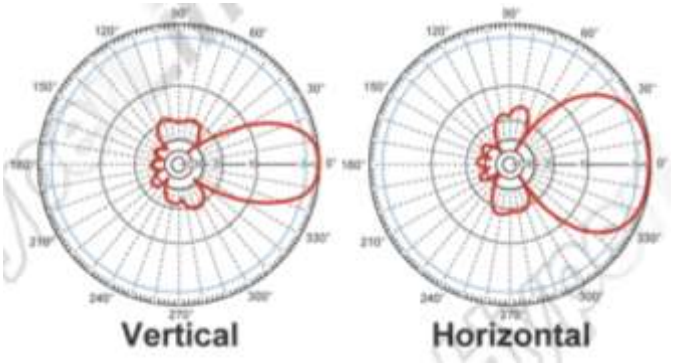


Review of Antenna Types Selected (cont.)

Frequency: 2400-2500 MHz
Gain: 9 dBi
Polarization: Vertical

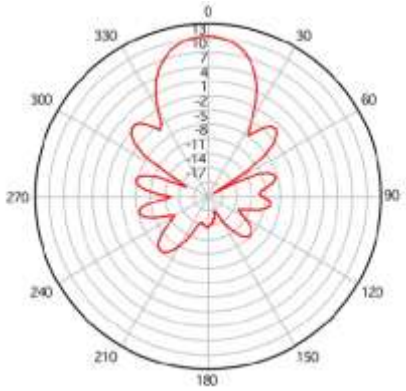


Frequency: 2400-2483 MHz
Gain: 11 dBi
Polarization: Both vertical and horizontal



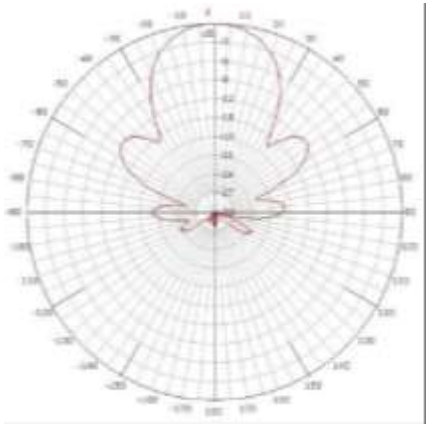
Review of Antenna Types Selected (cont.)

Frequency: 2400-2500 MHz
Gain: 7 dBi
Polarization: Right hand circular



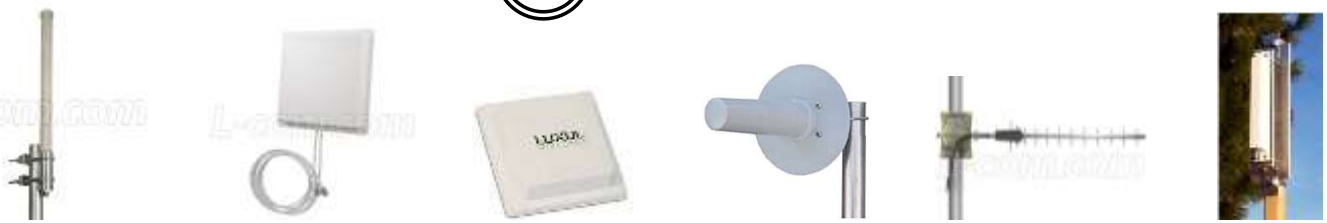
Horizontal

Frequency: 2400-2500 MHz
Gain: 12 dBi
Polarization: Right hand circular



Horizontal

Review of Antenna Types Selected (cont.)



	Antenna					
	1	**2**	**3**	**4**	**5**	**6**
Type	Omnidirectional	Dual Polarization	Directional Circular Polarization	Directional Circular Polarization	Directional Linear Polarization	Directional Wide Pattern
Frequency Range (MHz)	2400-2500	2400-2500	2400-2500	2400-2485	2400-2483	2400-2483
Polarization	Vertical	Both vertical and horizontal	Right Hand Circular	Right Hand Circular	Vertical	Vertical
Maximum Gain (dBi)	9	11	7	12	12	8.6

Review of Antenna Types Selected (cont.)

Antenna	Picture	Cost	Manufacturer
1		$72	L-com, Inc., Antenna model #: HG2409UDT-PRO, http://www.l-com.com
2		$35	L-com, Inc., Antenna model #: RE11DP, http://www.l-com.com
3		$55	Luxul Wireless, Antenna model #: RE11DP, http://www.luxulwireless.com
4		$64	Laird Technologies, Antenna model #: CP24-12, http://www.lairdtech.com
5		$45	L-com, Inc., Antenna model #: HG2412SY, http://www.l-com.com
6		$100	Superpass™, Antenna model #: SPDG13H22, http://www.superpass.com

Experimental Design, Data Collection and Analysis

- Antennas were tested in a random order
- Traffic count data was collected
  - In each lane adjacent to the Bluetooth (BT) reader, inductive loop detectors were present and collecting traffic count data
    - Counts for every 15 minute interval
- The BT reader unit with a specific antenna collected MAC address data for a period of between three and seven days
  - Time periods dictated by availability of ODOT personnel

Data Collection and Analysis

- The antenna performance measure computed was referred to as the *fraction read*
  - Total number of unique MAC addresses read divided by the total traffic volume over the same time period
    - Some vehicles traveled past the reader multiple times
    - Some vehicles may contain more than one active BT device
- It is assumed that the fraction of vehicles with active BT devices is constant
  - A large number of vehicles (minimum 39K) passed the reader
  - No changes in laws related to cell phone use in vehicles
  - 30% of the Mac addresses were the same across different antennas
  - See slide 18

Data Collection and Analysis

- The average number of reads per MAC address was also computed
  - Total number of MAC address records over the test period (including multiple reads of the same address) divided by the total number of unique MAC addresses read
  - This measure is indicative of the total volume of data collected
    - A higher fraction read measure combined with a relatively low reads per MAC address measure seems ideal

Single Antenna Testing Results






	Antenna					
	1	**2**	**3**	**4**	**5**	**6**
Type	Omnidirectional	Dual Polarization	Directional Circular Polarization	Directional Circular Polarization	Directional Linear Polarization	Directional Wide Pattern
Fraction Read	0.109	0.082	0.085	0.090	0.097	0.090
Average Reads Per MAC Address	6.8	3.4	4.0	7.1	8.3	8.2
Traffic Volume	85,936	39,374	58,438	54,645	89,280	48,189
Hours Tested	168.25	70.25	110.5	98.0	167.25	95.25

Best **Worst** **2nd Best**

Single Antenna Testing Results

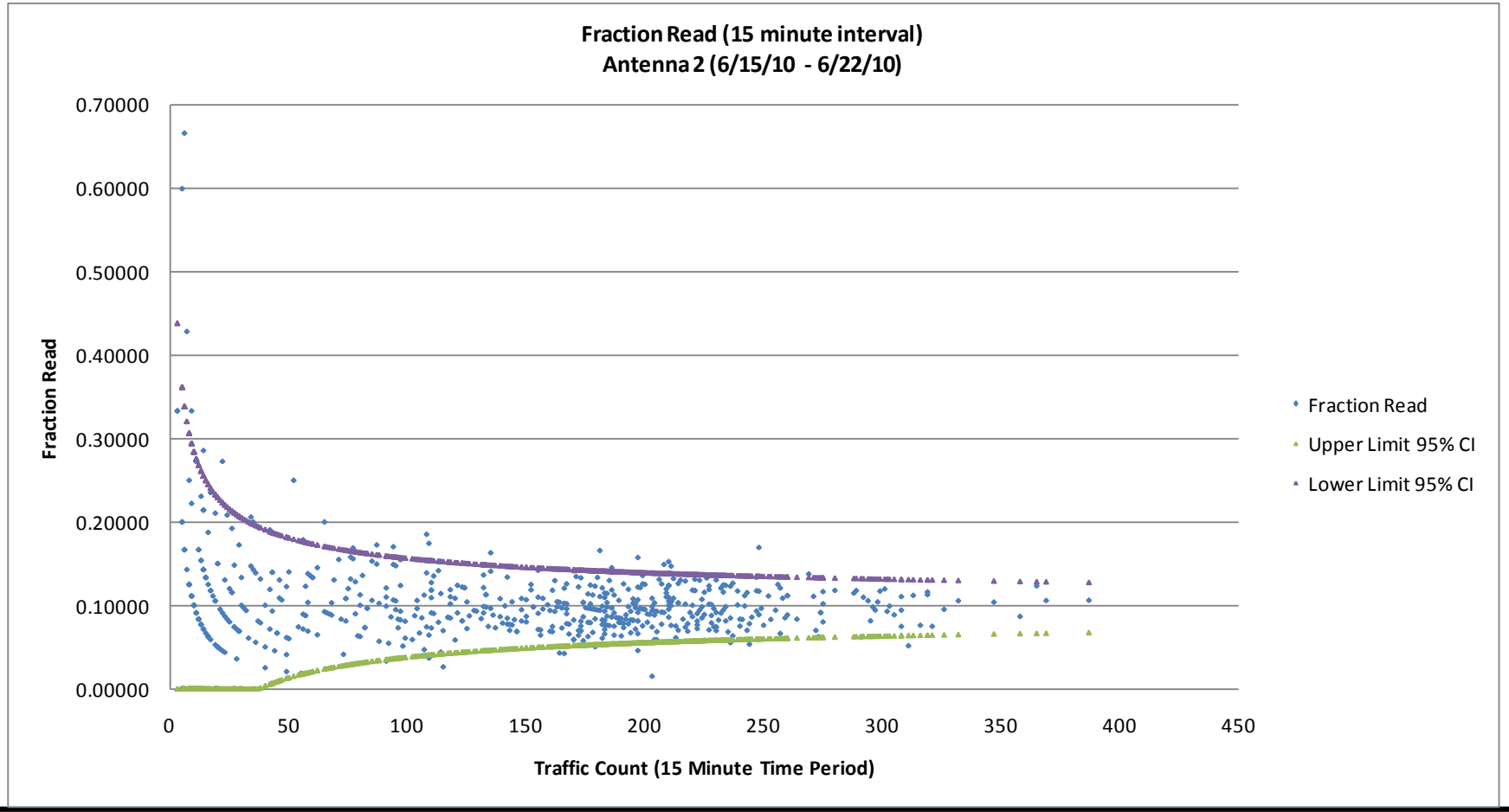
Pair-wise comparison of antenna with respect to fraction read performance

- **Marascuillo procedure applied – 95% "overall" confidence level.**
- **0 - no significant pair-wise difference,**
- **1 - significant pair-wise difference.**

Antenna #	1	5	4	6	3	2
1	0	1	1	1	1	1
5		0	1	1	1	1
4			0	0	0	1
6				0	0	1
3					0	0
2						0

Single Antenna Testing Results

95% CI for fraction read – Binomial distribution model.



Collection and Analysis of Travel Time Samples

- Tests to assess the impact of antenna characteristics on the collection of travel time samples were conducted.

Travel Time Data Collection Testing Setup

- Test Location

- Reader & antenna installation

Reader #1

Reader #2

Travel Time Data Collection Testing Setup

- Both locations
  - Power
  - Mounting structure (reader 2 was lower with respect to the road)
  - Connection to a cellular modem
- Reader 1 was adjacent to loop detectors
- Low volume of traffic onto roads between readers

Experimental Design, Data Collection and Analysis

- The order of tests was randomized
  - Same antenna used with both readers
- Collected MAC addresses for two separate periods of between 3 and 7 days
  - Is there a difference within the same antenna type?
- Probe vehicle runs were also conducted
  - Contained an active BT device with a known MAC address and a clock synchronized with the readers
  - The time that the probe vehicle passed each reader was recorded
  - A line drawn from the reader and perpendicular to the road was used as the location where the vehicle passed the reader

Collection and Analysis of Travel Time Samples (cont.)

- Performance measures computed for each antenna pair
  - Traffic volume (from the loop detectors)
  - The number of travel time samples computed from the collected data
  - The percentage of travel time samples obtained with respect to traffic volume
  - The average absolute percent difference in travel times (between reader #1 and reader #2) between the probe vehicle and the travel times computed for the probe vehicle from collected MAC address data

Collection and Analysis of Travel Time Samples (cont.)

- Computing travel time samples
  - A computer program written in Visual Basic for Applications (VBA) in Microsoft Excel was used
  - General procedure
    1. Identify all MAC addresses detected by each reader
    2. Eliminate those MAC addresses not detected by both readers
    3. For data from a single reader, organize the MAC address data into *groups*
    4. Compute travel time samples from the groups of MAC addresses for each reader
  - A *group* is a collection of data records with the same MAC address sorted sequentially by time, where the time between any adjacent records is no greater than a fixed threshold
    - Within group threshold = 30 second
    - Between groups threshold = 2 minutes

Collection and Analysis of Travel Time Samples (cont.)

- Results – Sampling Rate

	180 Degree		Omni		Dual		Circular		Yagi	
	8/17 - 8/20	7/27 - 7/30	7/30 - 8/3	8/27 - 8/31	8/8 - 8/10	8/24 - 8/27	8/31 - 9/3	9/7 - 9/10	8/24 - 8/27	9/10 - 9/15
Traffic Volume	40164	40955	49995	48177	24416	48610	53148	40047	39278	65371
# Travel Time (TT) Samples	3837	3916	3839	3693	1398	2781	4125	2847	3898	4987
TT Samples as % of Vol.	9.55%	9.56%	7.68%	7.67%	5.73%	5.72%	7.76%	7.11%	9.92%	7.63%
Weighted Avg. % Match	9.56%		7.67%		5.72%		7.48%		8.49%	

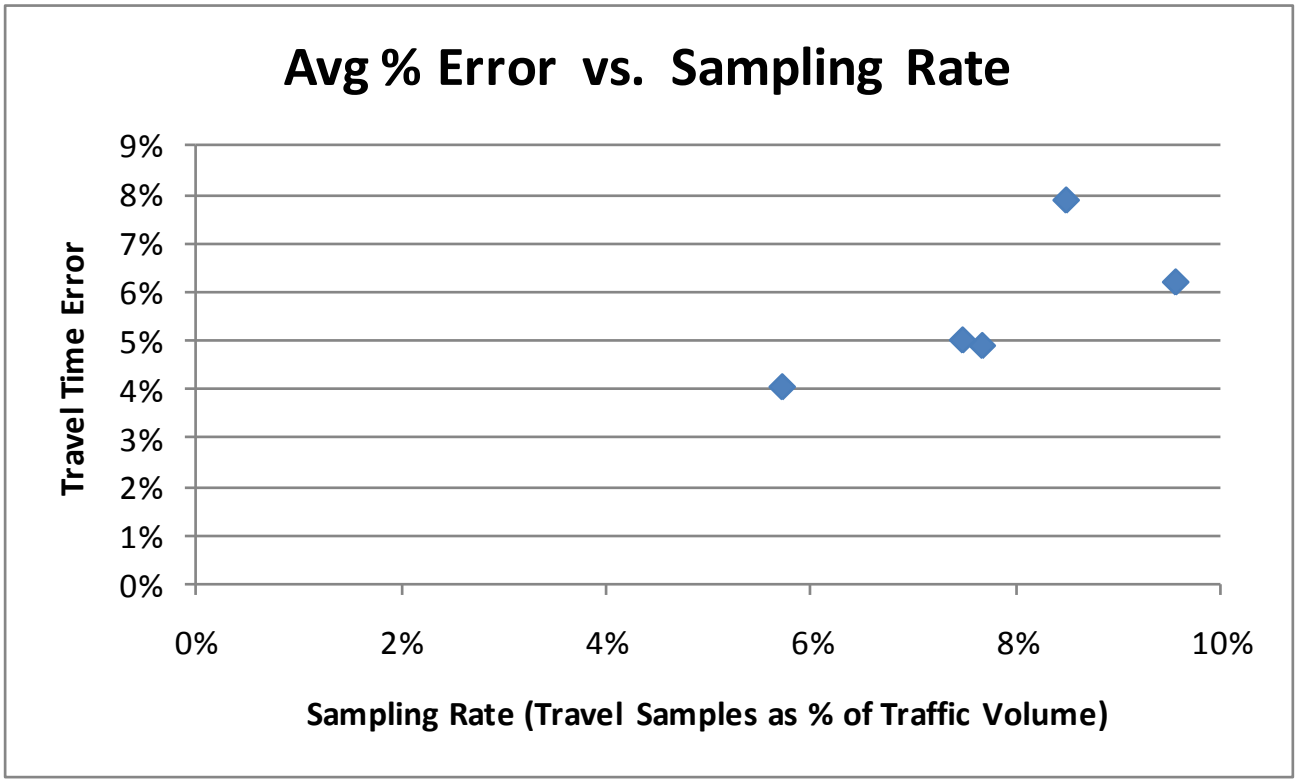
Collection and Analysis of Travel Time Samples (cont.)

- Results – Accuracy of Travel Time Samples

	180 Degree		Omni		Dual		Circular		Yagi	
	8/17 - 8/20	7/27 - 7/30	7/30 - 8/3	8/27 - 8/31	8/8 - 8/10	8/24 - 8/27	8/31 - 9/3	9/7 - 9/10	8/24 - 8/27	9/10 - 9/15
Calc. Method	**Avg-Avg**	**Avg-Avg**	**Avg-Avg**	**Avg-Avg**	**First-First**	**Avg-Avg**	**Avg-Avg**	**Last-Last**	**Avg-Avg**	**Avg-Avg**
Avg	6.38%	6.06%	3.26%	6.61%	4.02%	4.08%	4.38%	5.88%	8.05%	7.82%
Max	15.79%	16.42%	8.16%	13.28%	11.32%	7.94%	9.84%	15.29%	21.05%	16.45%
Min	0.00%	0.00%	0.00%	1.85%	0.00%	0.00%	0.00%	0.00%	1.27%	0.94%
Stddev	5.25%	5.55%	2.51%	3.69%	3.25%	2.96%	3.53%	5.15%	6.74%	5.24%

Collection and Analysis of Travel Time Samples (cont.)

- Results – Trade-off b/w sampling rate and accuracy of travel time samples



Conclusions

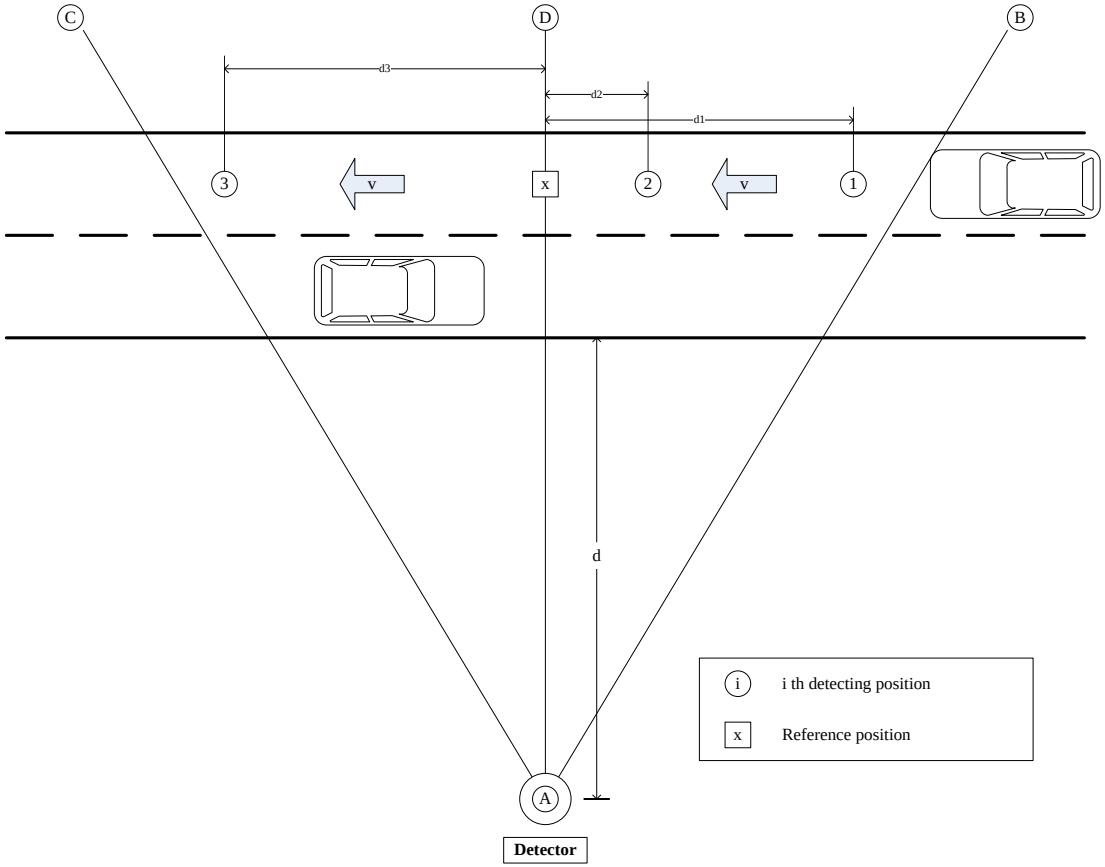
- There was no benefit realized by utilizing circularly or dual polarized antennas
- A good match between the BT reader and antenna makes a difference
  - Vertically polarized antennas with gains between 9 and 12 dBi had the best performance
  - Gain should translate into a greater coverage area with more reads but it seems to be affected by polarization.
- Collecting travel time samples
  - Narrower antenna coverage patterns translate into smaller groups
  - Accuracy of the travel time samples is more critical than sampling rate

Current Research

- Utilize Received Signal Strength Indicator (RSSI) to improve the accuracy of travel time samples computed from matched BT addresses.
- RSSI can be obtained during the inquiry procedure when MAC addresses are detected.
- RSSI is correlated to distance
  - Use RSSI measurements to select a single time-stamped MAC address from a group.
  - Use the selected MAC address to compute a travel time sample.

Current Research

- Testing – Does the MAC address record with the highest RSSI represent when the vehicle is close to the antenna?



Current Research

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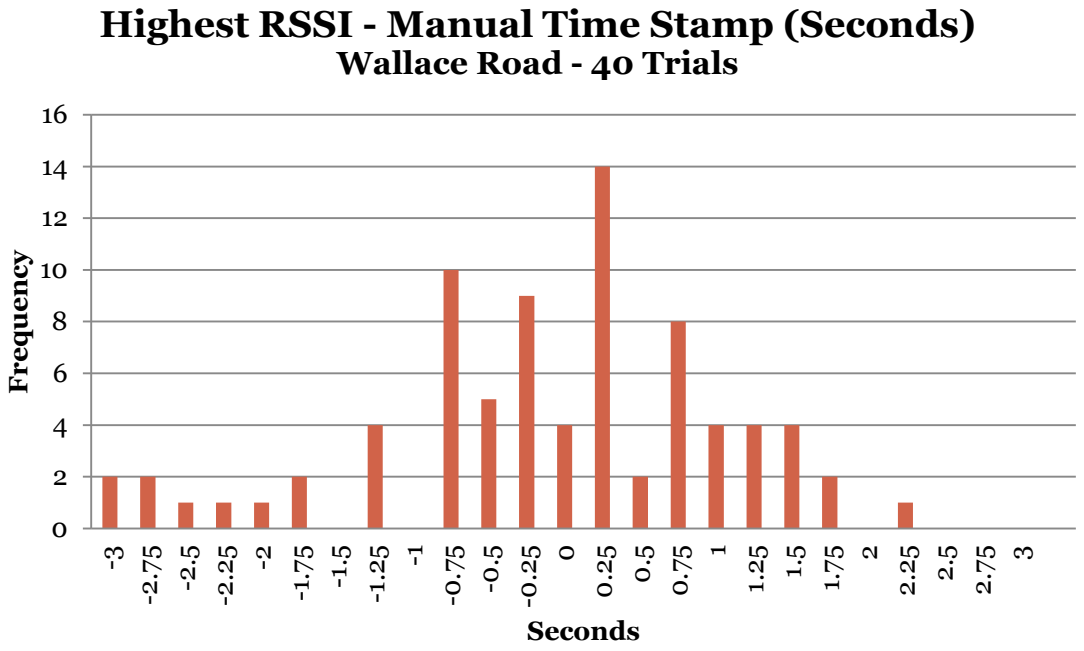

DISCUSSION
&
QUESTIONS