UW STAR LAB 11111010011
Smart Transportation Applications and Research

Field Experiments with Bluetooth Sensors

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Presentation Outline

- Concept
- Bluetooth Basics
- Preliminary Studies
- Field Experiments
- Discussion

Main Concept

- Bluetooth basics
  - Each device has unique 48-bit MAC address
  - A device can be found when its “visible” or in “discovery mode”
  - More popular than ever before due to recent cell phone use regulations (hands-free)

- Travel time estimation
  - Obtain MAC addresses at various locations and match identical ones

Bluetooth Applications

- Congestion reporting (which bridge?)
- Network analysis (shortest path)
- Bus stop waiting time
- Bicycle/ped travel time
- Pass travel times
- Before/after studies
- Rural travel time reporting?

Bluetooth Basics

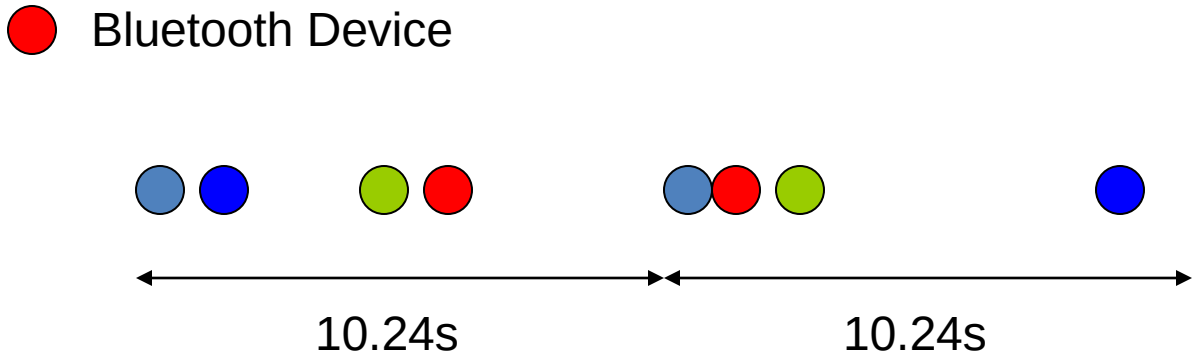
- 2.402 – 2.480 Ghz Radio Frequency
- Weak signal to prevent interference:
  - Cell phone: up to 3 W
  - Class I: 100 mW ~ 100 m
  - Class II: 2.5 mW ~ 10 m
  - Class III: 1 mW ~ 1 m
- Uses spread-spectrum frequency hopping
  - 79 randomly chosen frequencies
  - Changes frequency 1600 times a second

Bluetooth Discovery

- How to find a device
  - Full spectrum must be scanned, randomly jumping from frequency to frequency

- From Bluetooth specs:
  - “The inquiry substate may have to last for 10.24 seconds unless the inquirer collects enough responses and determines to abort the inquiry substate earlier.” - [Bluetooth SIG]

Bluetooth Discovery



$$\text{Chance of obtaining MAC address} = \frac{\text{Time Spent in Detection Zone}}{10.24\text{s}}$$

Detection Zone

- If a vehicle is moving at 60mph, the detection zone needs to be about 900ft (275m).
  - Requires a Bluetooth antenna booster
  - Several versions tested 5,7,9dBi…

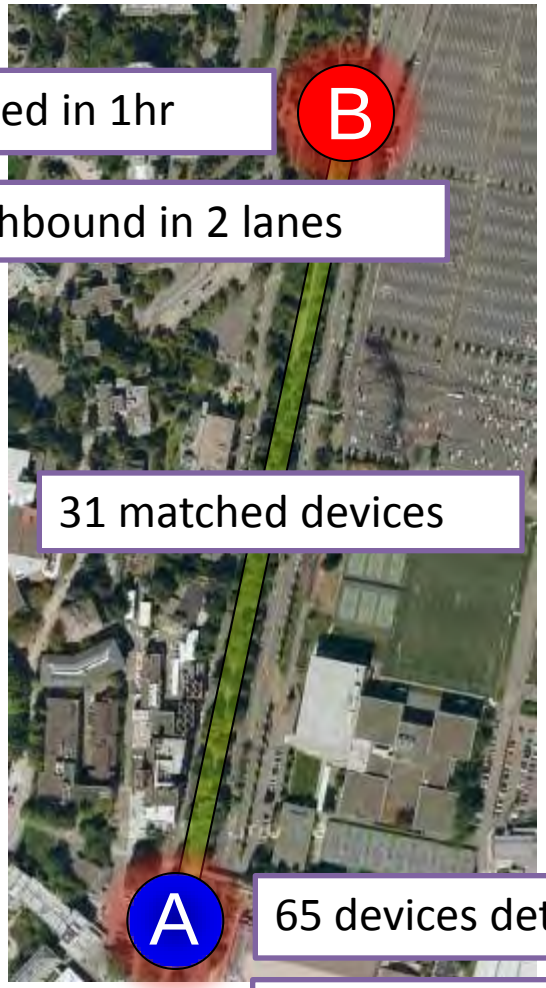
- Point to point travel times on both freeways and arterials can be collected, as a Bluetooth device will remain visible for at least 10 seconds.

Images courtesy of aircable.com

Preliminary Study

- Montlake Boulevard
  - 12:00pm – 1:00pm Mon, Nov 10th
  - Low volumes
  - ~35 mph vehicle speed
  - Burke-Gilman trail adjacent
  - Parking in-between detection zones
- Low Power Antenna (5 dBi)

Study Corridor



117 devices detected in 1hr

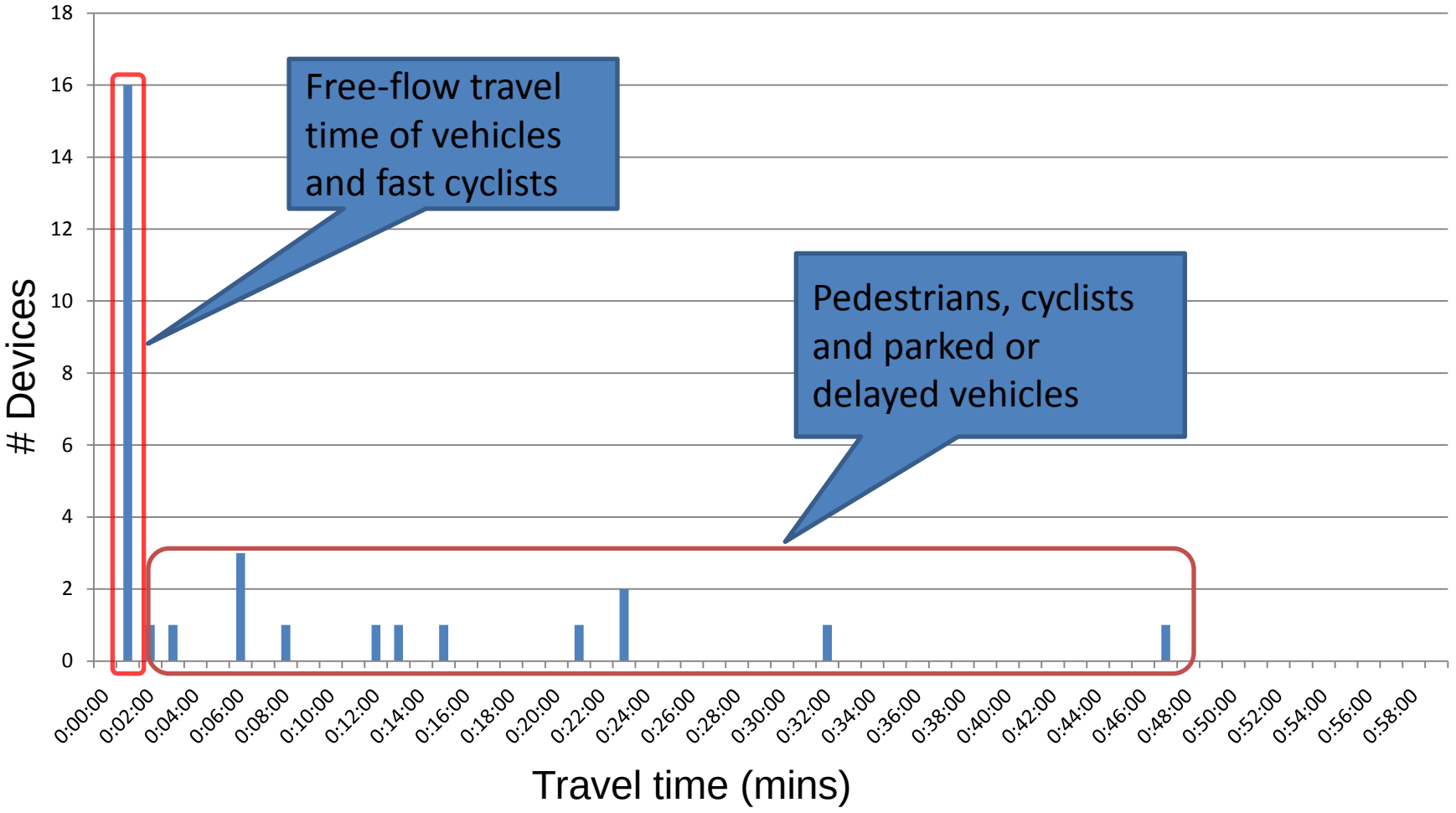
1351 vehicles Northbound in 2 lanes

31 matched devices

65 devices detected in 1hr

1427 vehicles Southbound in 2 lanes

60-min Distribution

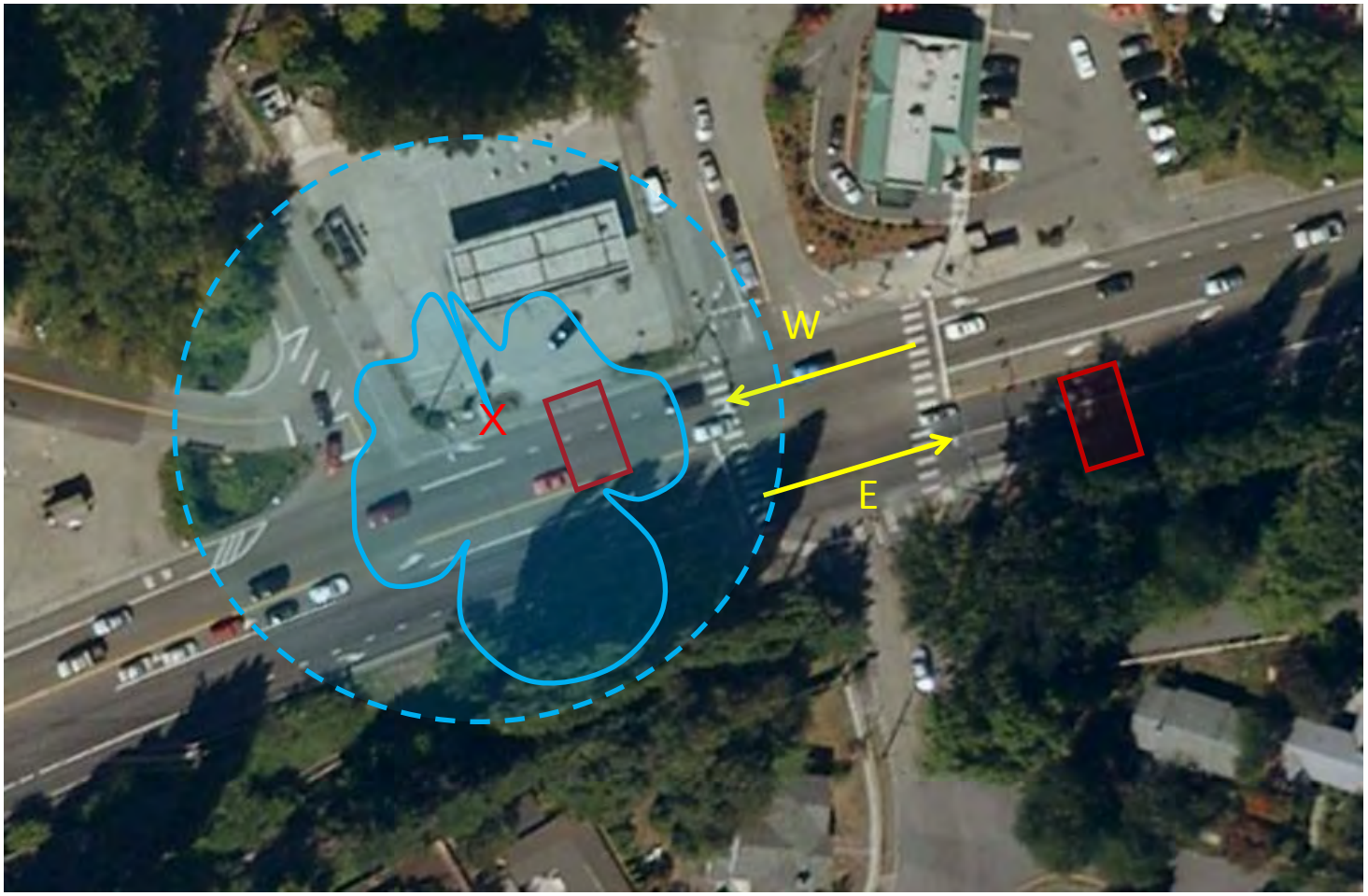


SR-522 Study Segment

- Available ALPR sensors in place
  - BT sensors may be mounted nearby
- Moderate traffic volumes
  - 20,000 – 40,000 AADT
- Speeds around 40 - 50 mph
  - Had success with higher speeds
- Vandalism
  - Avoid bus stops

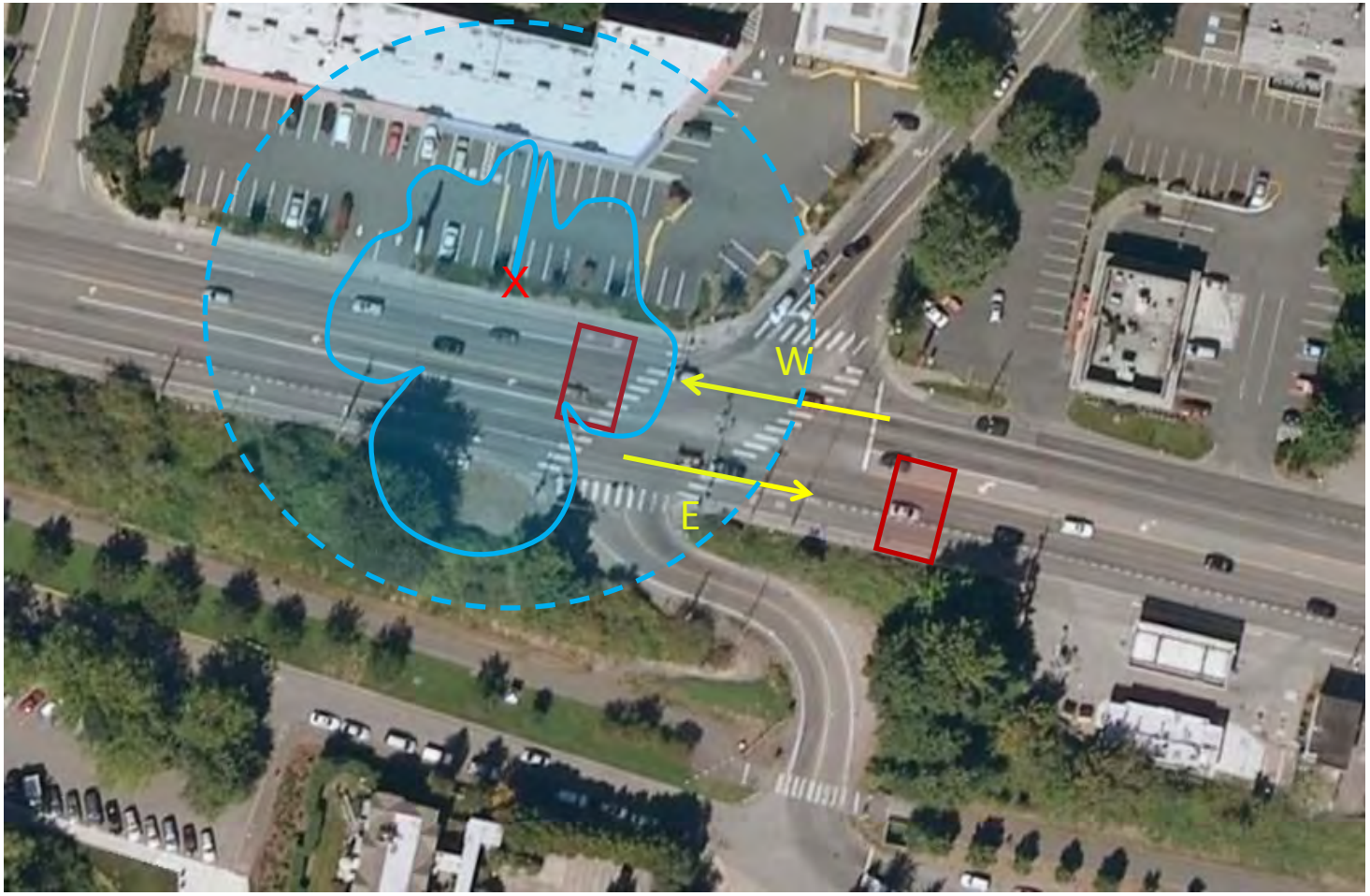
SR-522 Corridor Segment

NE 170th St Location



Dotted Blue – Omni-Directional Range; Solid Blue – Directional Range; Solid Red – ALPR Zone

61st Ave NE Location



Dotted Blue – Omni-Directional Range; Solid Blue – Directional Range; Solid Red – ALPR Zone

SR-522 Data Collected

- 24 hr continuous tests
  - October 8th and October 9th
  - 12 dBi Directional antenna (24 hours)
    - ~1,400 readings at each location per day per site
    - 792 matches (0.55 matches per minute)
  - 7dBi Omni-Directional antenna (24 hours)
    - About 2,000 readings per day per site
    - 1340 matches (.93 matches per minute)

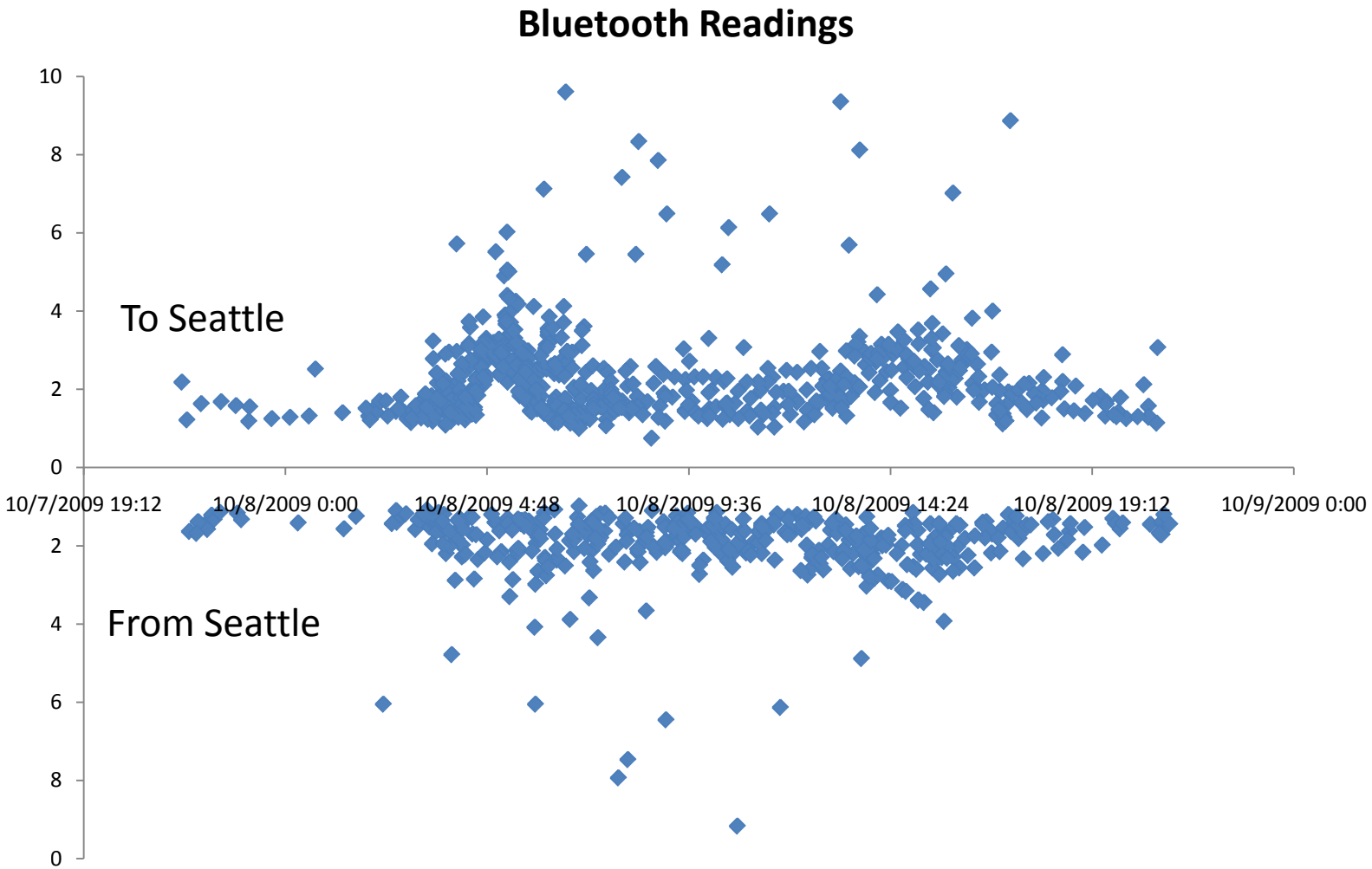
SR-522 Data Collected (Directional)

- During October 8th, at 61st AVE
  - ALPR reading: 9879 (WB) and 6598 (EB)
  - Bluetooth reading: 1595 for both directions
  - Detection rate: 10%
- During October 8th, at 170th ST
  - ALPR reading: 9434 (WB) and 7956 (EB)
  - Bluetooth reading: 1375 for both directions
  - Detection rate: 8%
- Matching rate: 57% (792 out of 1375)

SR-522 Data Collected (Omni)

- During October 9th, at 61st AVE
  - ALPR reading: 10228 (WB) and 6666 (EB)
  - Bluetooth reading: 1926 for both directions
  - Detection rate: 11%
- During October 9th, at 170th ST
  - ALPR reading: 9732 (WB) and 8162 (EB)
  - Bluetooth reading: 2124 for both directions
  - Detection rate: 12%
- Matching rate: 70% (1340 out of 1926)

SR-522 October 8th Data

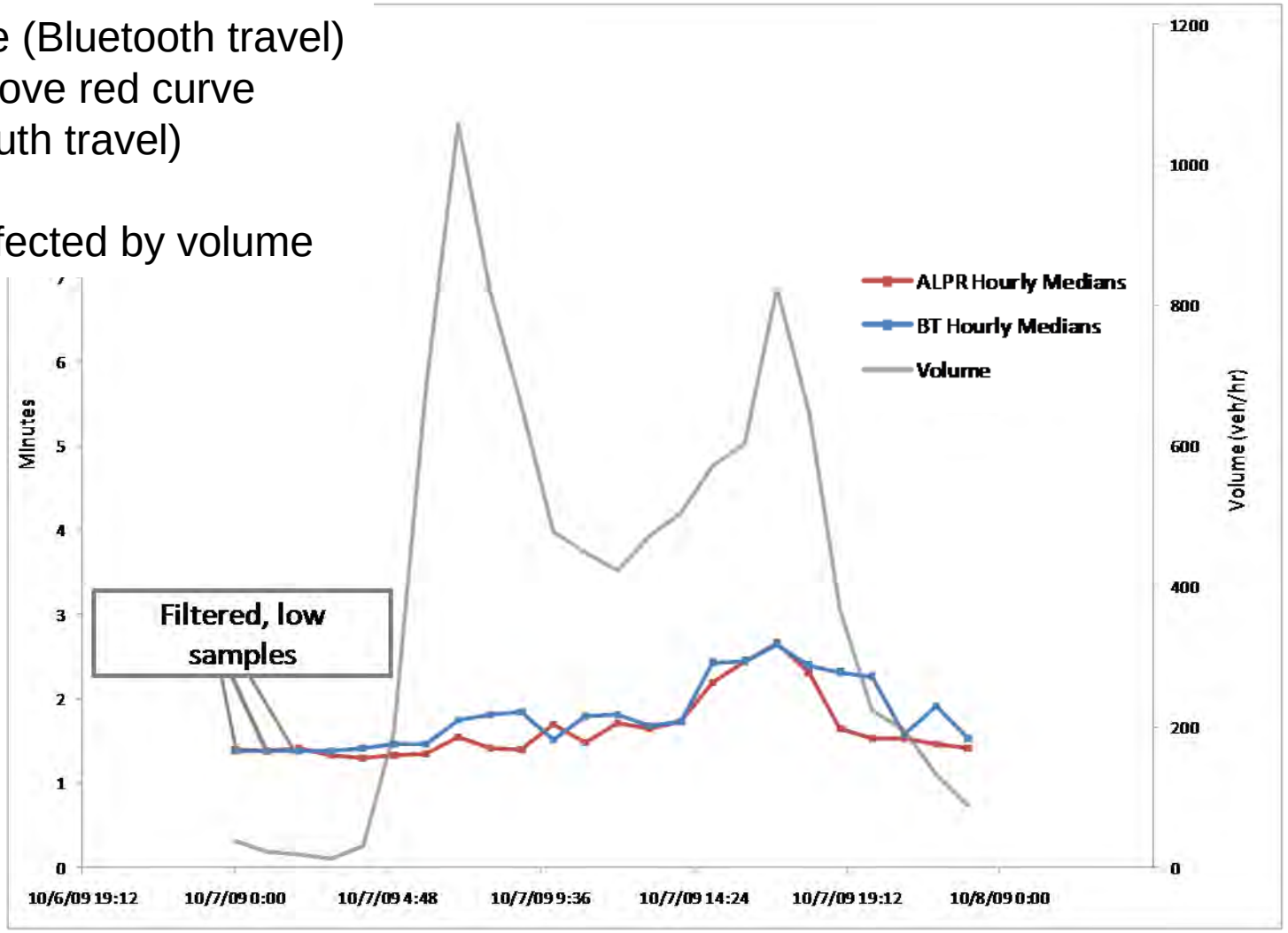


Collected Bluetooth travel times for a 24-hr period

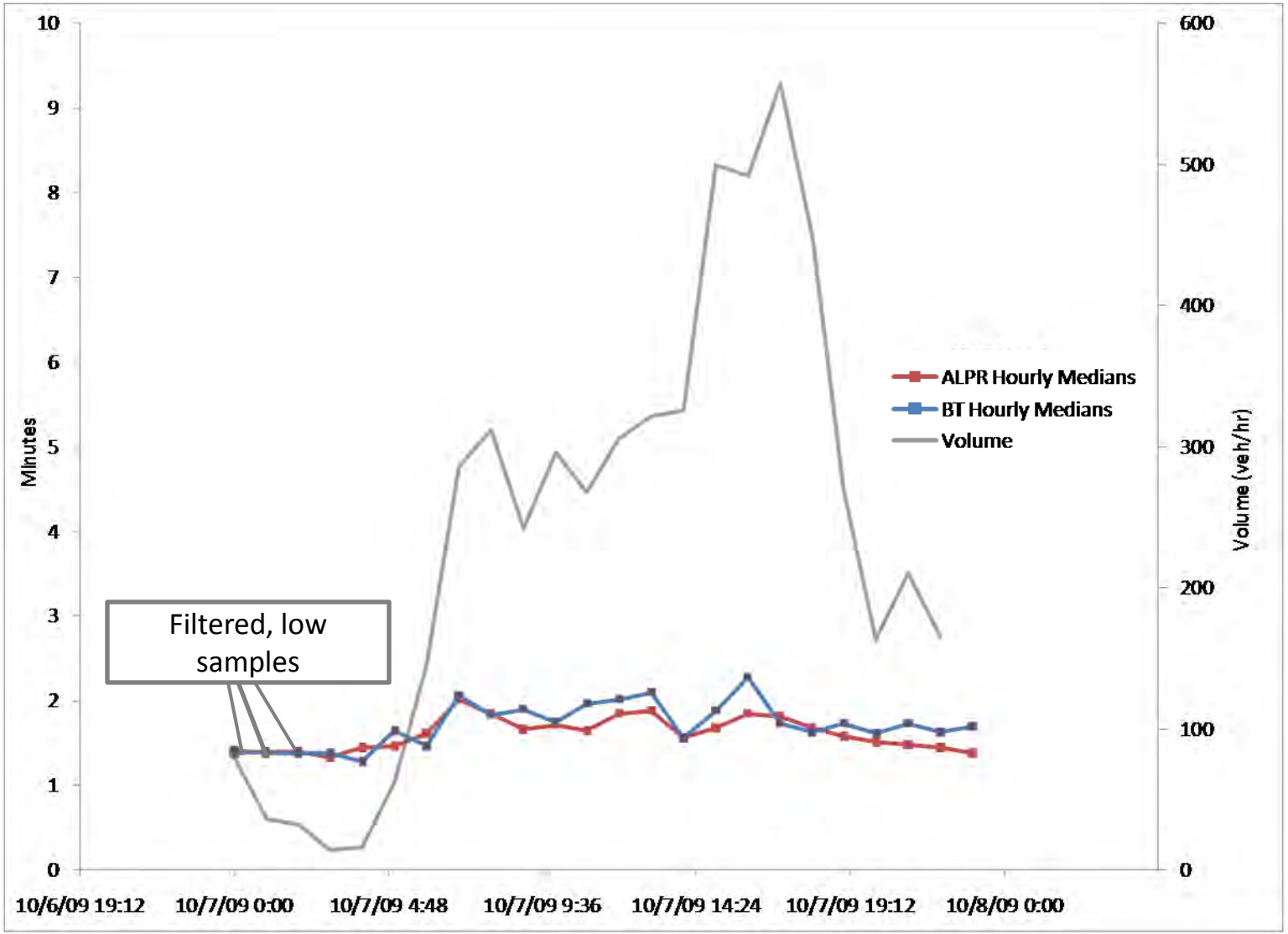
SR-522 Comparison with ALPR WB, Directional (Oct 8th)

Blue curve (Bluetooth travel) always above red curve (ground truth travel)

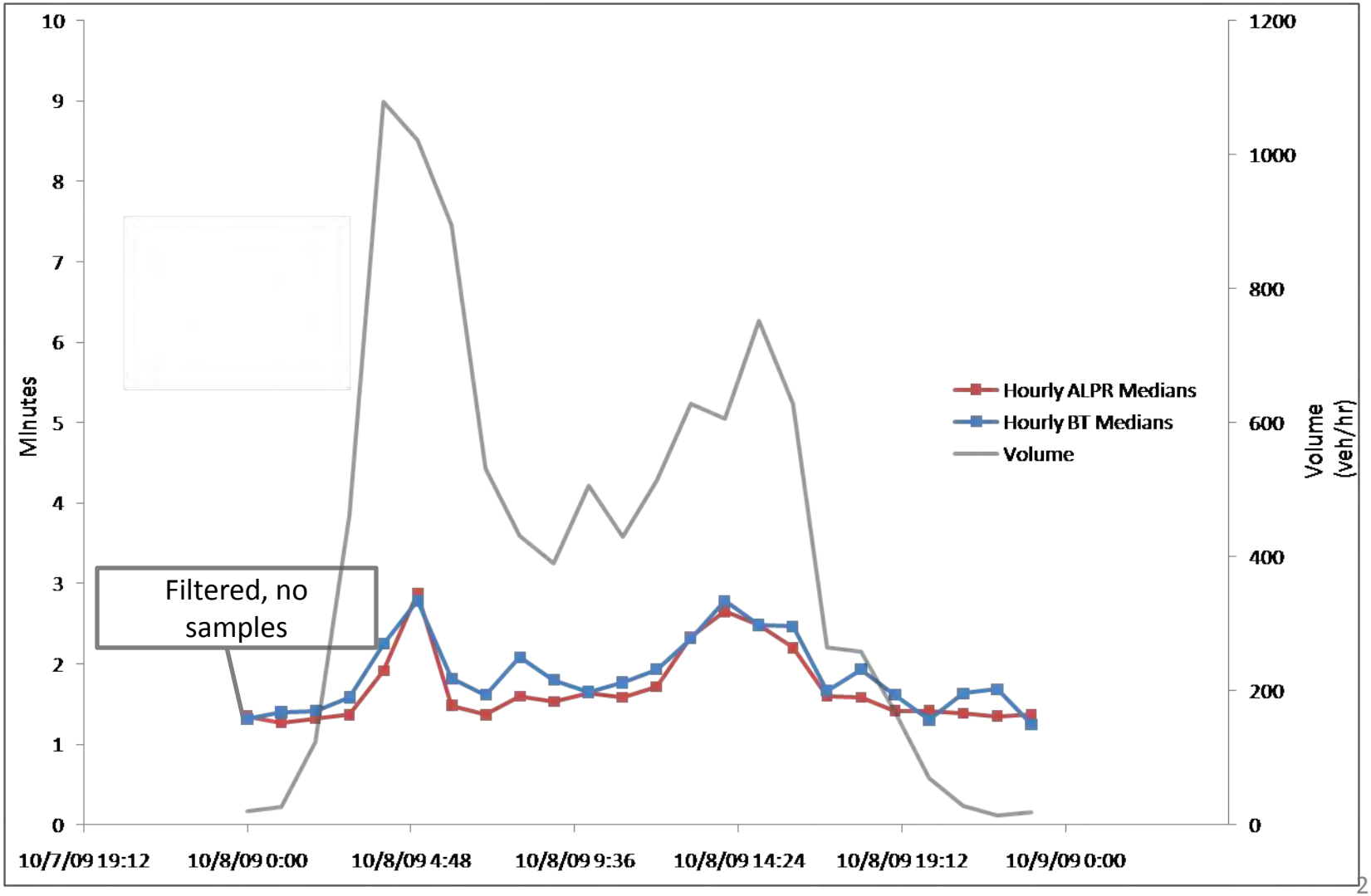
Data unaffected by volume



SR-522 Comparison with ALPR EB, Directional (Oct 8th)



SR-522 Comparison with ALPR WB, Omni-Directional (Oct 9th)



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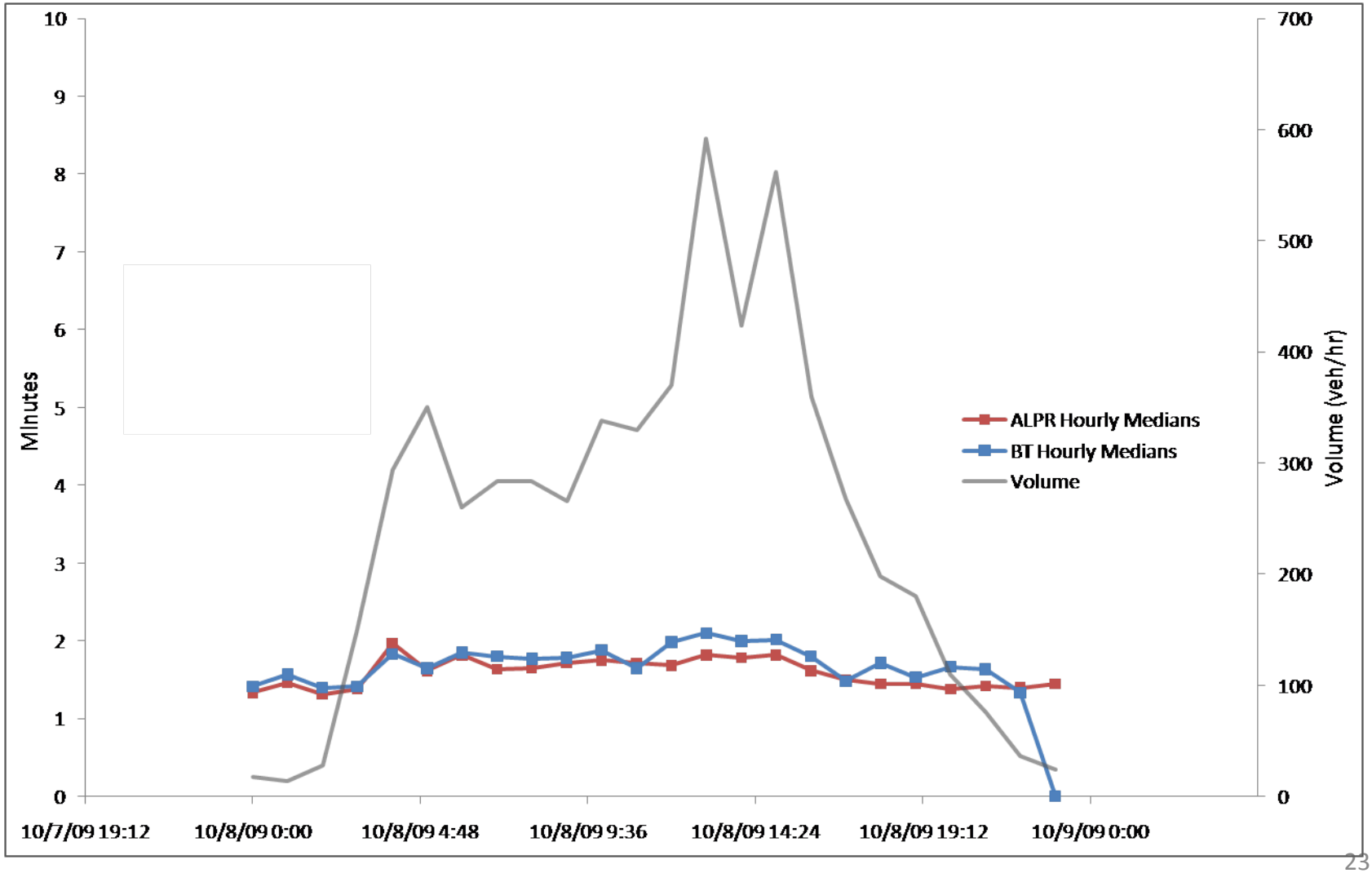


SR-520 Freeway Test

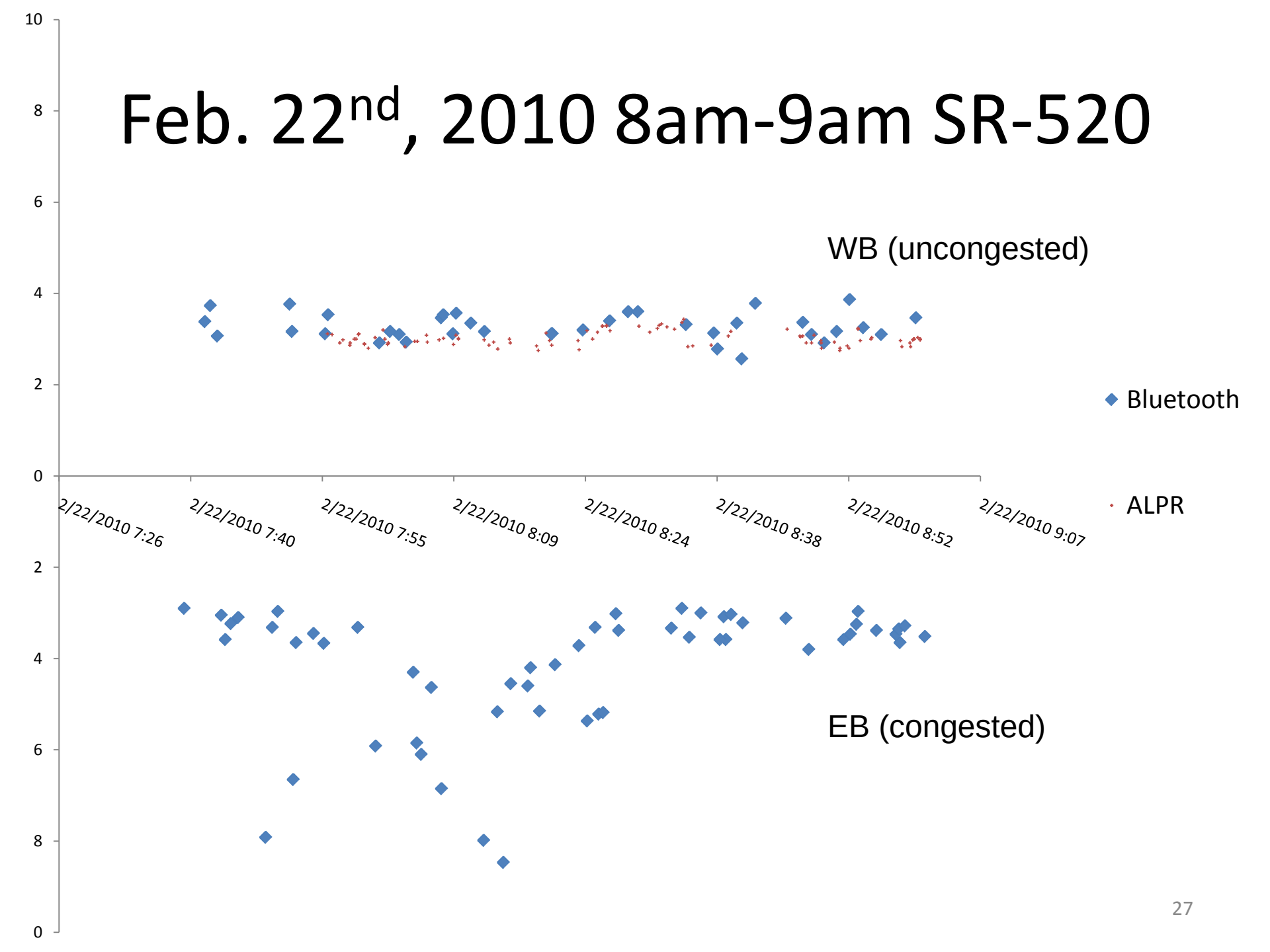
- Much higher speeds
- Longer corridor
- Band-mounted to the inside of overpass
- Mounted next to rear-firing ALPR
- 7 dBi omni-directional antenna

SR-520 Freeway Test Setup

SR-520 (Omni-Directional)

- During February 22nd, at 24th AVE and SR-520
  - 8am to 9am
  - ALPR reading: 1957 (EB)
  - Bluetooth reading: 432 for both directions
- During February 22nd, at 76th AVE and SR-520
  - 8am to 9am
  - ALPR reading: 1368 (EB)
  - Bluetooth reading: 190 for both directions
- Matching rate: 61% (116 out of 190)

Feb. 22nd, 2010 8am-9am SR-520



Yreka Test Site

- 7.6 miles on I-5
- Very high speeds
- Mount to signs
- 4 devices
- 2 x 7dBi
  - ~100m
- 2 x 9dBi
  - ~150m

Mounting on I-5

Anderson

Walter

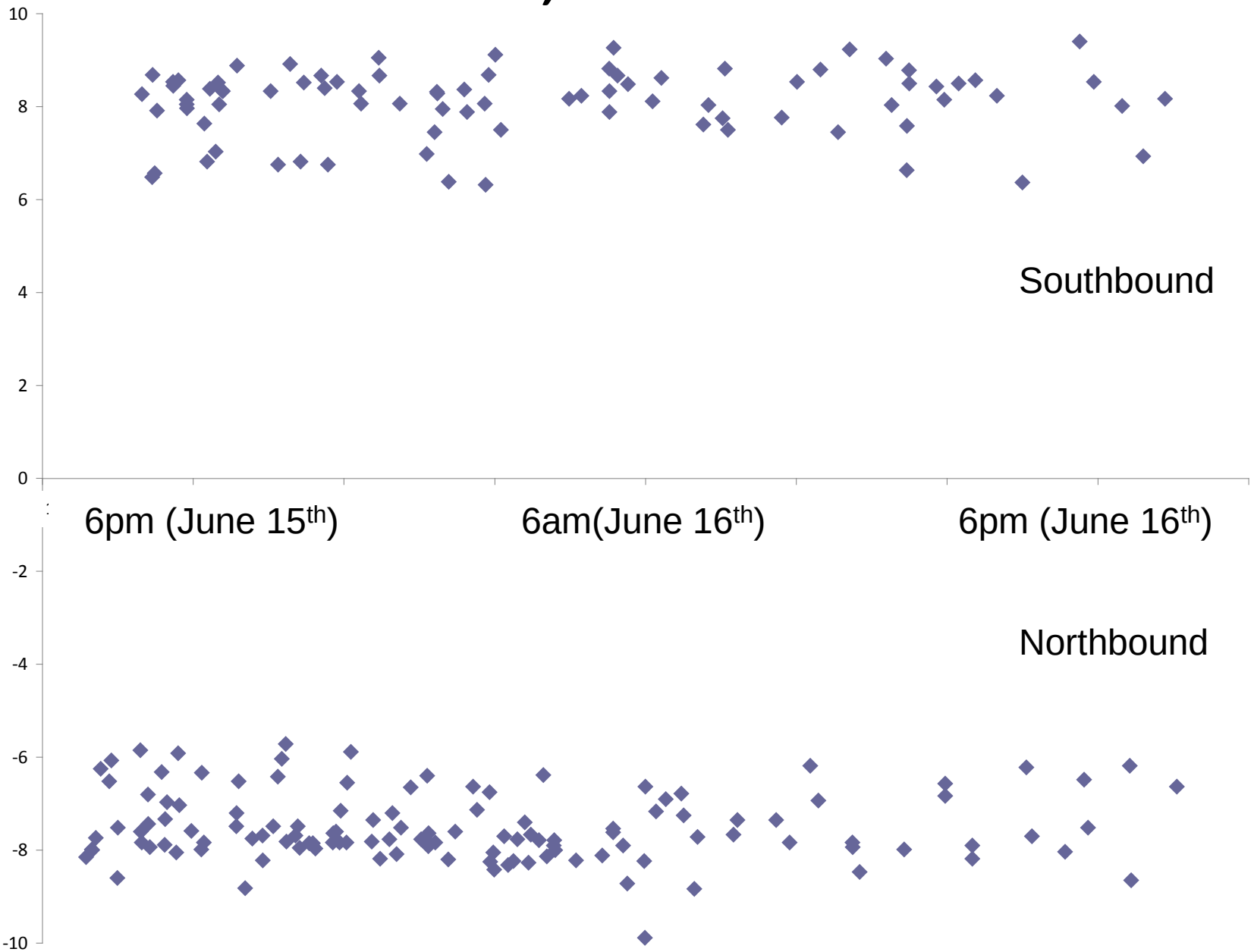
Yreka June 15th-16th

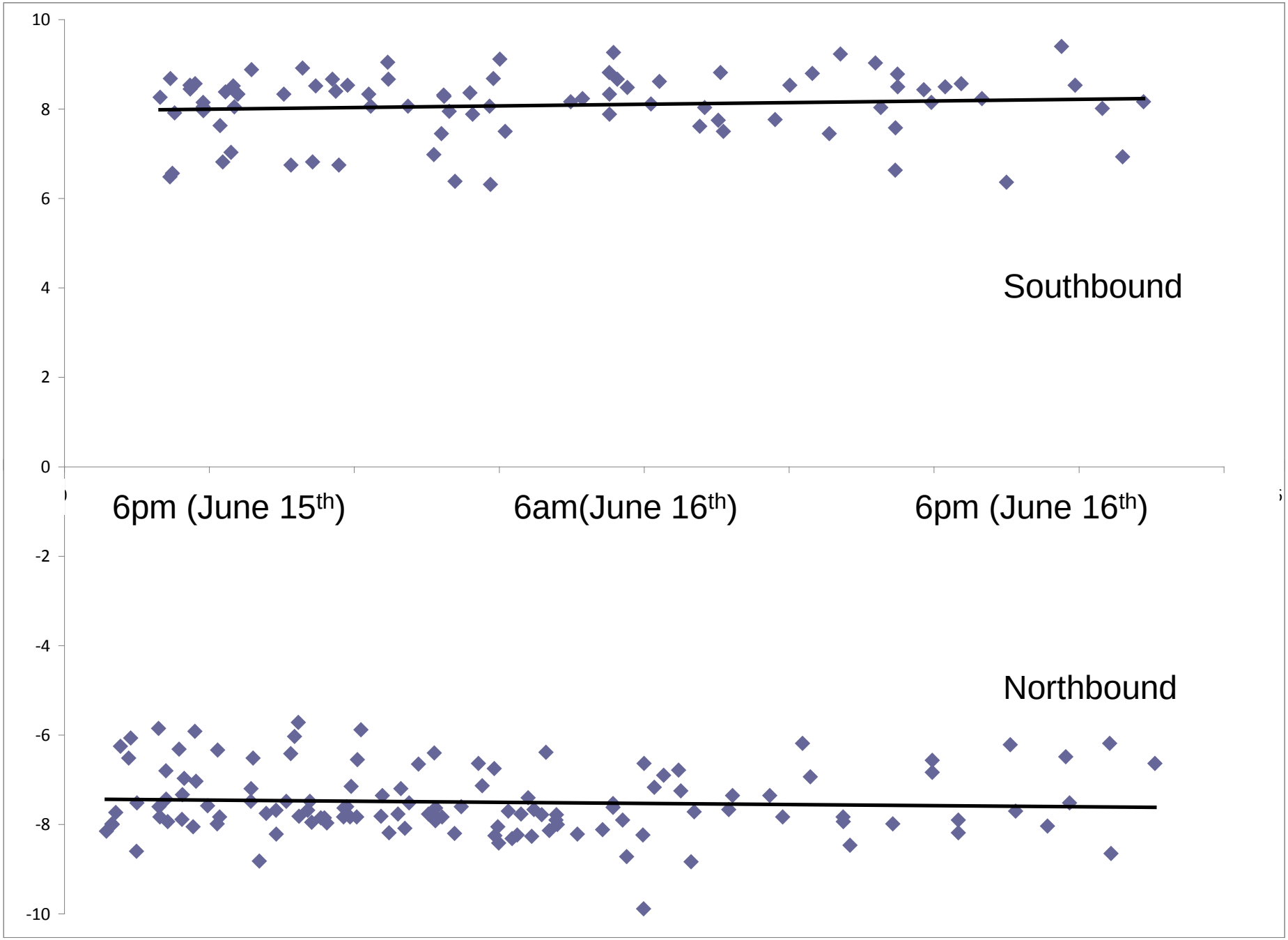
- 7 dBi with GSM closer to Southbound
  - 385 reads at Anderson, 336 at Walter
- 9 dBi w/out GSM closer to Northbound
  - 913 reads at Anderson, 336 at Walter
- ~20,000 AADT for corridor

Yreka Omni-Direction

- June 15-16th Anderson Grade
  - 6pm to 6pm (24hrs)
  - Bluetooth reading: 1118 for both directions
- June 15-16th Yreka Walter's Road
  - 6pm to 6pm (24hrs)
  - Bluetooth reading: 336 for both directions
- Matching rate: 68% (228 out of 336)

Jun. 15th, 2010 I-5 Yreka




10
8
6
4
2
0
-2
-4
-6
-8
-10
Southbound
Northbound
6pm (June 15th)
6am(June 16th)
6pm (June 16th)

Discussion

- Installation
- Challenges
- Antennae
- Noise
- Privacy
- Device Development

Installation Details

- Arterials
  - Have been band-mounting to poles
    - Left alone for a week, no vandalism
    - Avoid bus stops and other “tempting” locations
    - Careful of intersection delay
- Freeways
  - Band-mount to overpass railings
    - Warn DOTs and local Police
    - Mount on the inside for safety reasons

Some Observations

- The Bluetooth travel time data collection device produces reasonably accurate travel time measurements.
- High matching rate (60-70%) implies that majority of the Bluetooth devices have been captured by our devices.
- Error % rate varies with distance – longer corridors have a lower error rate.
- Bluetooth travel times are generally overestimates – there is bias towards slower vehicles.

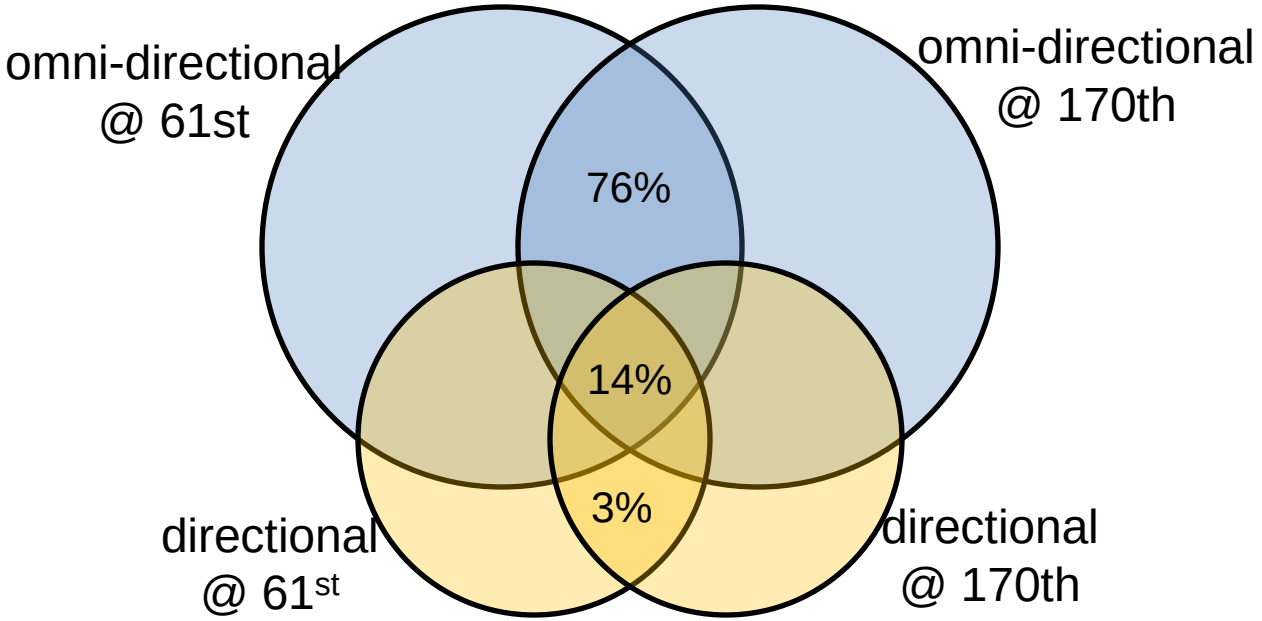
Potential Rural Challenges

- 5-10% of traffic is detected (at each location)
- 70% of that is matched (obtained travel time)
  - To get one reading every minute, you would need to have at least 120 vehicles per hour
  - Low volume roads may get lower frequency data
- Some bias towards buses
  - A lot of devices on one “vehicle”
- Are trucks more likely to have Bluetooth?
- What about rest areas?

Rural Data Frequency Scenario

- Volume? (500 veh/hr)
  - Assume 10% penetration (50 veh/hr)
- Diversion?
  - Assume 50% matching (25 veh/hr)
- Speed?
  - Assume 80% capture (20 veh/hr)
- Is a reading every 3 minutes good enough?
  - Will 10 vehicles in 30 mins be enough to determine the conditions?

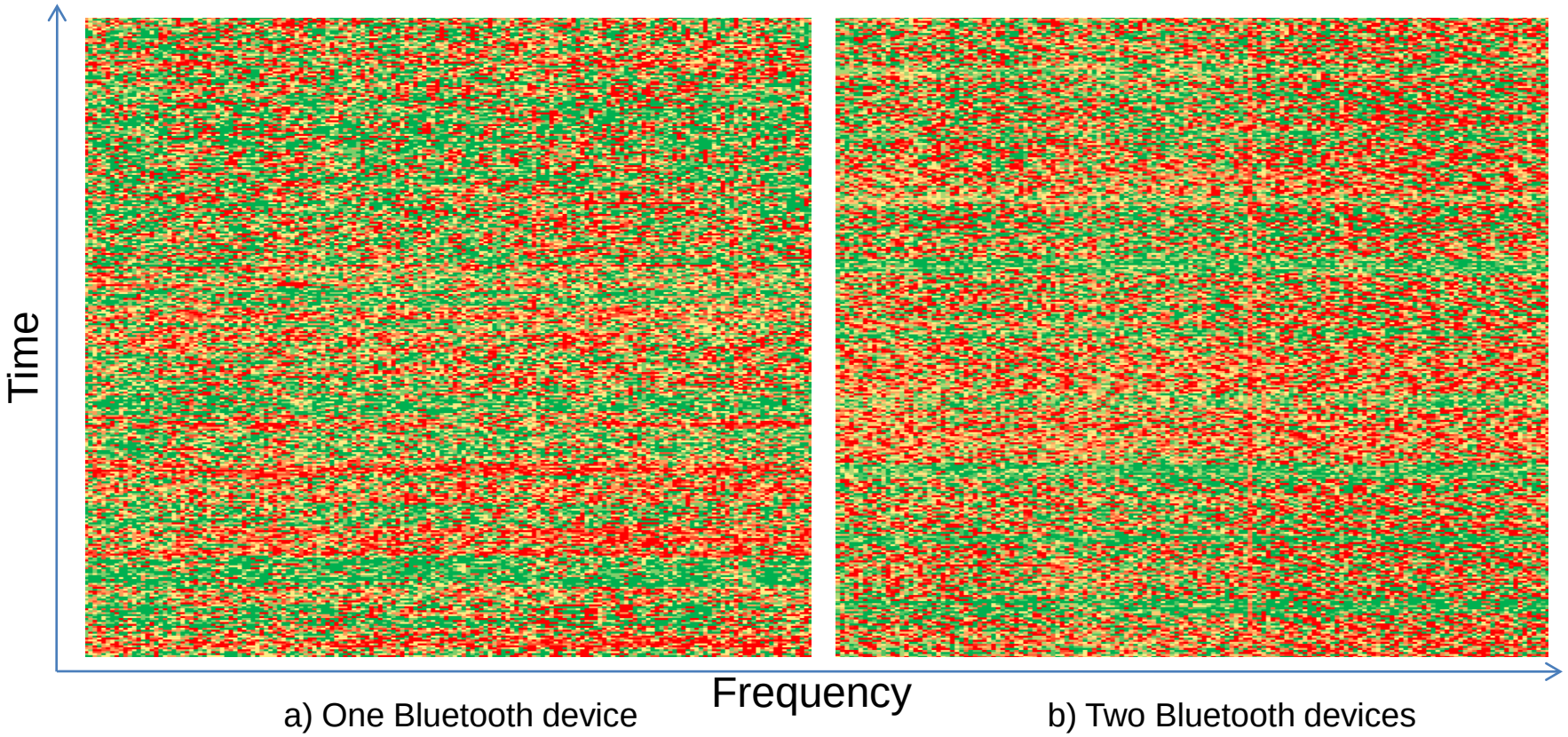
Antenna Selection (SR-522)



Data overlap when using both Omni-directional and Directional antennae. Using both at the same time results in 3% more matches

Noise

- WiFi network in area can cause interference
- Other Bluetooth readers also interfere



Red pixels represent collisions (interference). There is little difference between using two devices vs. one at the same location in terms of interference.

Privacy

- Important to maintain trust
- However, no central database
  - Cannot tie MAC to individual
- MAC address scrambling
- Deleting expired addresses

Device Evolution

BT v 2.0

Sparkfun 60 MHz
ROM-based
6 D cells – 5 days

07/2009 09/2009 10/2009 12/2009 3/2010 5/2010

BT v 1.0

Gumstix 600 MHz
Linux system
8 D cells – 40 hrs

BT v 2.1

LiFE Cell – Faster charging time

Weatherproof Omni Antenna

Device Evolution

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Weatherproof Omni Antenna

BT v 2.2

GSM - Online data retrieval
GPS – Automated synchronization
Solar Panel – Continuous operation

Device Evolution

BT v 2.0

Sparkfun 60 MHz
ROM-based
6 D cells – 5 days

BT v 2.3

Custom Board w/ ARM Processor
3 antennae – Bluetooth, GPS, GSM
3x 2000mAh LiPo Batteries

07/2009 — 09/2009 — 10/2009 — 12/2009 — 3/2010 — 5/2010

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Weatherproof Omni Antenna

BT v 2.2

GSM - Online data retrieval
GPS – Automated synchronization
Solar Panel – Continuous operation

BT v 2.3

Final Testing
- Weather
- Duration
- Signal

Privacy Filters
DRIVE Net

Device Evolution

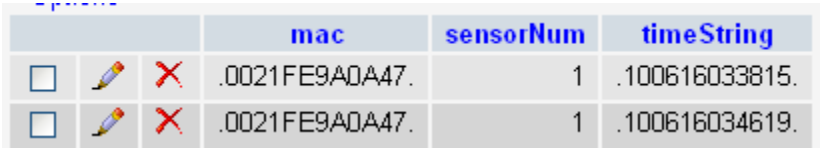
- Cost
  - Battery is the most expensive component
  - Increases with features – GSM, GPS, Solar
- Component hardening
  - Batteries have been the most fickle
    - Three different types tested
  - Enclosures
    - Steel (durability) vs. Plastic (internal antennae) lid

GPS Functionality

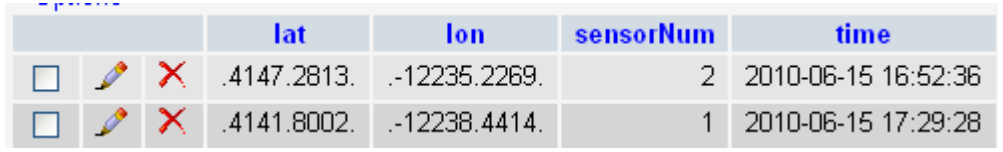
- Synchronization
  - Identical timestamps
- Location
  - Organizing data in space
  - Sensor networks
- Separate Antenna
  - Requires a plastic lid, or a sealed port outside

Real-Time Data Processing

- GSM to communicate via HTTP
  - About 1 cent per update w/ AT&T
- Push to MySQL server
- Updates every minute, only if data present
  - Save power and money



			mac	sensorNum	timeString
☐	✎	✕	.0021FE9A0A47.	1	.100616033815.
☐	✎	✕	.0021FE9A0A47.	1	.100616034619.



			lat	lon	sensorNum	time
☐	✎	✕	.4147.2813.	.-12235.2269.	2	2010-06-15 16:52:36
☐	✎	✕	.4141.8002.	.-12238.4414.	1	2010-06-15 17:29:28

UW Drive NET

DRIVE Net | *Digital Roadway Interactive Visualization and Evaluation Network*

Arterial Real-Time Map

- Google Map Traffic
- Arterial Real-time map
- Show Intersection

Traffic Congestion Legend

- Very Light
- Light
- Moderate
- Heavy
- Severe
- No Data

Arterial Data Analysis

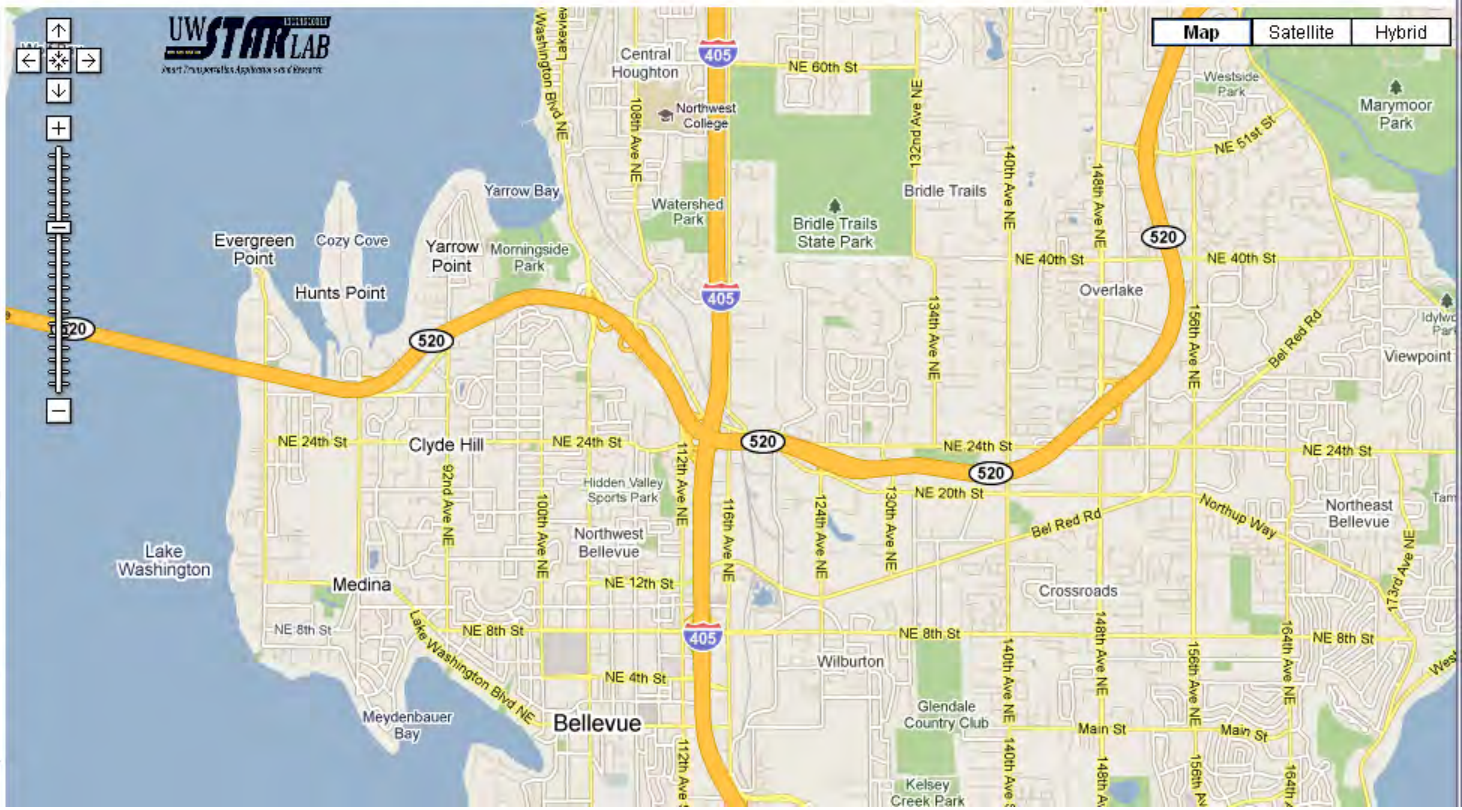
Arterial Historical Query

Dynamic Shortest Path

Freeway DataMart

Freight Performance Measures

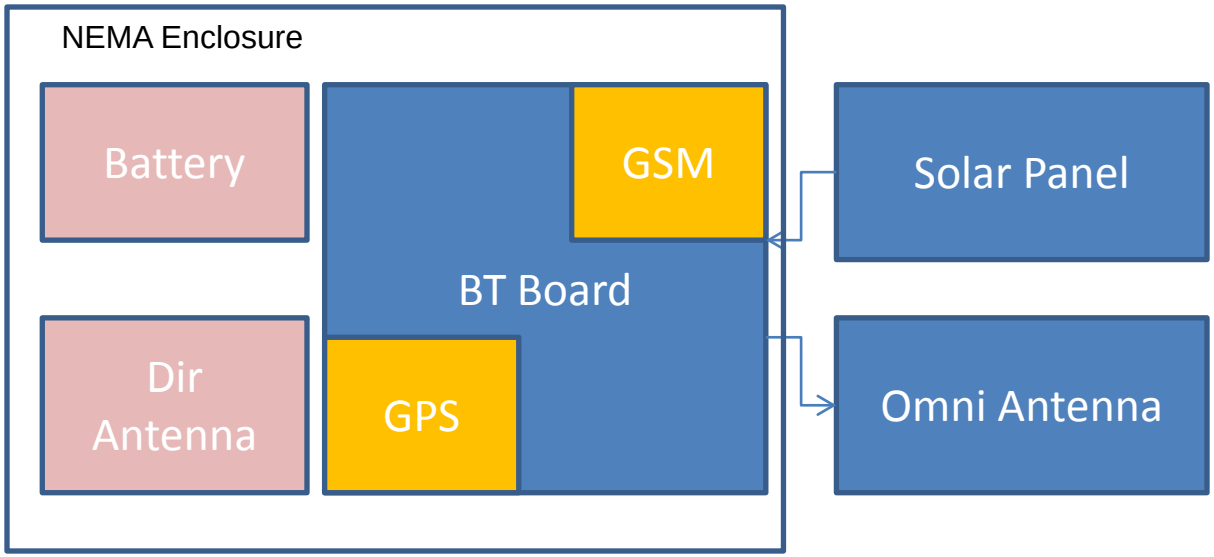
Incident Induced Delay



			id	pt1X	pt1Y	pt2X	pt2Y	tt	tod
☐	✎	✕	AAA1	47.391097	-122.182572	47.391754	-122.182355	11.02	2010-06-11 17:28:22
☐	✎	✕	AAA2	47.391235	-122.182435	47.391532	-122.182986	11.02	2010-06-11 11:28:22
☐	✎	✕	1078	47.39113	-122.182574	47.391203	-122.182639	-14.7666666666667	2010-06-14 16:36:47
☐	✎	✕	8650	47.39113	-122.182574	47.391203	-122.182639	966.716666666667	2010-06-12 17:20:03

Solar Panel Functionality

- Continuous operation
- Trickle charge
- Not very sunny in Seattle
  - Three days w/out solar power



Current Device Incarnation

- Pacific Wireless (Laird) DCE-ANT Box
- 12 dBi Directional antenna in lid (optional)
- 7 and 9 dBi Omni-directional Weatherproof Antenna
- 5-day Li-Po battery

Questions/Comments

- Use scenarios?
- Test edge cases?
- Practical suggestions?