Error Assessment for Emerging Traffic Data Collection Devices

Ted Bailey, WSDOT
Ron Vessey, WSDOT
Bahar Namaki, Aalborg Univ.
Jonathan Corey, UW
Yegor Malinovskiy, UW
Yinhai Wang, UW
Presentation Outline

• Quick MAC* Sensing Overview
• Bluetooth Accuracy Background
• Technology Overview
• Study Overview
• Analysis Platform
• Results
• Discussion

*Media Access Control Number
Re-Identification Methods

Pattern Approaches
- Video
- Magnetometer

Population Surveys
- Trip Diaries
- Check-in logs

Communication Approaches
- RFID
- Device Sensing
- Carrier Data

Inexpensive
Prevalent
Scalable
Non-proprietary
Device Sensing

- **Short Range Protocols**
  - Primarily Bluetooth
- **Communication Type**
  - Unique ID
    - Promiscuous broadcast
  - Device Type*
    - “I am a valve cap”
  - State Info*
    - Air pressure
    - Temperature
Device Sensing

• Bluetooth basics
  – Each device has unique 48-bit MAC address
  – A device can be found when it’s “visible” or in “discoverable mode”

• WiFi basics
  – Each device has unique 48-bit MAC address
  – A device can be found when its searching for hotspots
  – Have found WiFi to be 2x more prevalent than Bluetooth on UW campus
Device Sensing

**Classic Bluetooth**

- Chance of obtaining MAC address = Time Spent in Detection Zone
  - 10.24 sec
- Promiscuous Broadcast: MAC
- Class I: 100m range
- Class II: 10m range
- Class III: 1m range

**Bluetooth LE**

- Chance of obtaining MAC address = Time Spent in Detection Zone
  - 3 ms
- Promiscuous Broadcast: MAC
- Device Type
- Device State
- Up to 150m range (open field)
- Dedicated ad channel
- $0.25 per chip
Presentation Outline

• Quick MAC Sensing Overview
• Bluetooth Accuracy Background
• Technology Overview
• Study Overview
• Analysis Platform
• Results
• Discussion
Opportunistic Sensing Issues

Opportunistic Sensing

Data Sparseness

Population Uncertainty
- Volume Error
- Population Bias

Temporal Uncertainty
- Travel Time Error
- Dwell Time Error

Spatial Uncertainty
- Trajectory Error
Data Analysis Schema

MAC Database → Device → Trips → Dwell Time Analysis

Travel Time Analysis

Filtering

Dwell Time Analysis

Filtering

Filtering

Excel File → DRIVE NET → Users
Presentation Outline

• Quick MAC Sensing Overview
• Bluetooth Accuracy Background
• Technology Overview
• Study Overview
• Analysis Platform
• Results
• Discussion
Commercial Technologies

Bluetoad BT
- GPS Antenna
- Patent Pending BlueTOAD PCB
- GSM Blade Antenna
- GSM Cellular Modem Bluetooth Radio
- Solar Charge Controller
- 7-Day Backup Battery
- Environmental Bluetooth Antenna

Blip BT
- 3G Modem Directional Antennas
- GPS Antenna
- Backup Battery
- Blipnode L2i with Internal Antenna
- Polycarbonate box
- Mounting Brackets

Blip WiFi
- WiFi Directional Antennas
- 3G Modem
- Polycarbonate box
- WiFi Connection to BlipTrack™ unit

Sensys Magnetometer
UW Bluetooth Technology

**BT v 1.0**
- Gumstix 600 MHz
- ROM-based
- 6 D cells – 5 days

**BT v 2.0**
- Sparkfun 60 MHz
- 6 D cells – 40 hrs

**BT v 2.2**
- GSM - Online data retrieval
- GPS – Automated synchronization
- Solar Panel – Continuous operation

**BT v 2.3**
- Custom Board
- Bluetooth, GPS, GSM
- 2x 15.6Ah Batteries

**BT v 2.3**
- GSM - Online data retrieval
- GPS – Automated synchronization
- Solar Panel – Continuous operation

**BT v 2.3**
- GSM - Online data retrieval
- GPS – Automated synchronization
- Solar Panel – Continuous operation

**BT v 3.0**
- Bluetooth 4.0
- WiFi onboard
- Low-Power
- ARM Processor
- 2x15.6Ah LiPo Batteries
- Waterproof
- Enclosure

**Mobile Monitor App**

Timeline:
- 07/2009
- 09/2009
- 12/2009
- 3/2010
- 2/2011
- 12/2012
Overarching System Design

**DRIVENet**
Digital Roadway Interactive Visualization and Evaluation Network

**Analysis Framework**

*Device/vehicle* via *GSM/SD Card/web*

*via GSM/SD Card/web*

*via GSM/SD Card/web*

**DRIVENet**

**Users**
Presentation Outline

• Quick MAC Sensing Overview
• Bluetooth Accuracy Background
• Technology Overview
• Study Overview
• Analysis Platform
• Results
• Discussion
Motivation

• Previous work
  – Focus on sensor development
  – ALPR-based evaluation
  – Antennae/configuration testing

• This presentation
  – Side by side sensor comparison
    • Bluetooth vs. ALPR
    • Bluetooth vs. Bluetooth
    • Bluetooth vs. Other
  – Sensor evaluation platform
Sensor Comparison Study

• Concurrent comparison of multiple sensing technologies and vendors:
  – Bluetoad Bluetooth
  – Sensys Magnetometers
  – UW Bluetooth
  – Blip Systems Bluetooth + WiFi
  – INRIX Probe data

• Compared against PIPS license plate readers
  – Loop and video counts as well
Evaluation Methodology

• Identify links to evaluate
• Determine appropriate resolution
• Obtain sufficient data sample
• Determine interval accuracy
Objectives

• Evaluate multiple travel time, volume and speed data collection technologies side by side;
• Determine the relative accuracy and performance of the evaluated technologies;
• Evaluate data confidence as it pertains WSDOTs ability to use the sensor data to predict reliable travel times;
• Define appropriate technologies for common data collection scenarios and needs.
Benefits

• A side by side comparison of the selected emerging traffic data collection technologies.
• Error and performance assessment for each data collection technology tested.
• Guidelines for appropriate uses of tested data collection technology types.
Metrics

- Aggregated interval vehicle volumes
  - Match rate where appropriate
- Average interval speeds
- Average node to node interval travel time
Study Specifics – SR522

INRIX Data Available for Corridor

- Inductance loops
- License plate readers
- Magnetometers
- Video detection units
- Bluetooth sensors: UW, Blip, Bluetoad
Study Specifics – I90

Maps courtesy of Google Maps
Bluetooth sensors: UW, Bluetooth

INRIX Data Available for Corridor
Location A (Milepost 32)

- Sensor Location:
  Milepost 32 Median
- Seattle (west) side of Snoqualmie Pass
Location B (Milepost 52)

- Sensor Location: Snoqualmie Pass Summit (EB side of I-90)
Location C (Milepost 70)

- Sensor Location: Easton
- East side of Snoqualmie Pass
Location D (Milepost 109)

- Sensor Location: Ellensburg
- East of Easton
Presentation Outline

• Quick MAC Sensing Overview
• Bluetooth Accuracy Background
• Technology Overview
• Study Overview
• Analysis Platform
• Results
• Discussion
User Benefit and Error

Figure 1. Benefit-Accuracy Relationship for Los Angeles

From Travel Time Data Collection for Measurement of Advanced Traveler Information Systems Accuracy, 2003
Obtaining Travel Time Error

• Mean Absolute Deviation

\[ MAD = \frac{1}{n} \sum |\hat{y}_t - y_t| \]

• Mean Absolute Percent Error

\[ MAPE = \frac{1}{n} \sum \left| \frac{\hat{y}_t - y_t}{y_t} \right| \]

• Mean Percent Error

\[ MPE = \frac{1}{n} \sum \frac{\hat{y}_t - y_t}{y_t} \]

• Root Mean Squared Error

\[ RMSE = \sqrt{\frac{1}{n} \sum (\hat{y}_t - y_t)^2} \]
Sample Size Selection

As suggested by BTS:

\[
\sqrt{\frac{(n-1)}{\chi^2(n-1)_{\alpha/2}}} \cdot S_E < \sigma_E < \sqrt{\frac{(n-1)}{\chi^2(n-1)_{1-\alpha/2}}} \cdot S_E
\]

Travel Time Data Collection for Measurement of Advanced Traveler Information Systems Accuracy, 2003
Aggregation Selection

• License Plate Readers
  – 5 minute unfiltered
• Bluetooth Loggers
  – 5-min filtered
  – 15 minute unfiltered
• Sensys pucks
  – 1,5,15 minute filtered, aggregated bins
• 5-minute is highest possible common resolution
Data Visualization in DriveNet
Presentation Outline

• Quick MAC Sensing Overview
• Bluetooth Accuracy Background
• Technology Overview
• Study Overview
• Analysis Platform
• Results
• Discussion
SR-522: SR104 to NE 153rd Eastbound

February 11th to 15th, 2013

<table>
<thead>
<tr>
<th></th>
<th>Min.</th>
<th>Q1</th>
<th>Median</th>
<th>Mean</th>
<th>Q3</th>
<th>Max.</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALPR Travel Time (secs):</td>
<td>0.0</td>
<td>99.0</td>
<td>107.0</td>
<td>126.1</td>
<td>129.0</td>
<td>490.0</td>
</tr>
<tr>
<td>BlueToad Travel Time (secs):</td>
<td>0.0</td>
<td>106.6</td>
<td>110.4</td>
<td>129.0</td>
<td>130.1</td>
<td>476.4</td>
</tr>
<tr>
<td>Inrix Travel Time (secs):</td>
<td>0.0</td>
<td>134.9</td>
<td>140.3</td>
<td>149.9</td>
<td>148.8</td>
<td>774.6</td>
</tr>
</tbody>
</table>
SR-522: SR104 to NE 153rd Eastbound

• February 11th to 15th, 2013
SR-522: SR104 to NE 153rd Eastbound

• February 11th to 15th, 2013

ALPR Standard Deviation: 70.13707 seconds

BlueToad Standard Deviation: 59.21642 seconds

Inrix Standard Deviation: 47.98466 seconds

Inrix Error: 20.96 seconds
Inrix MAD: 36.54 seconds
Inrix MPE: 24.4 percent
Inrix MAPE: 29.2 percent
Inrix RMSE: 50.80 seconds

BlueToad Error: 0.626 seconds
BlueToad MAD: 20.03 seconds
BlueToad MPE: 4.4 percent
BlueToad MAPE: 13.6 percent
BlueToad RMSE: 40.05 seconds
I-90 Exit 70 to Exit 109 Eastbound

- February 11th to 15th, 2013
I-90 Exit 70 to Exit 109 Eastbound

- February 11th to 15th, 2013
I-90 Exit 70 to Exit 109 Eastbound

- February 11\textsuperscript{th} to 15\textsuperscript{th}, 2013

- BlueToad Standard Deviation: 410.9526 seconds
- Inrix Standard Deviation: 343.6212 seconds
I-90 Exit 70 to Exit 109 Eastbound

- February 13th, 2013, 12:00am to 11:59pm
I-90 Exit 70 to Exit 109 Eastbound

- February 13th, 2013, 12:00am to 11:59pm

Histogram of BlueToad

- BlueToad Standard Deviation: 184.1271 seconds

Histogram of Inrix

- Inrix Standard Deviation: 42.33412 seconds
I-90 Exit 70 to Exit 109 Eastbound

- February 16\textsuperscript{th}, 2013 (Sat)
- 11am to 3pm

- February 13\textsuperscript{th}, 2013 (Wed)
- 11am to 3pm
Presentation Outline

• Quick MAC Sensing Overview
• Bluetooth Accuracy Background
• Technology Overview
• Study Overview
• Analysis Platform
• Results
• Discussion
Results/System Demonstration
Lessons Learned So Far

• Smoothing algorithms play a big role
  – Bluetoad smoothes heavily
  – Inrix is very conservative

• Configuration effects
  – Multiple sensors on one pole have high interference
  – Some disparity due to offset

• Bluetooth provides finer grained detail, particularly on rural corridors (e.g. I-90)

• WiFi vs. Bluetooth
Data Platform Extensions

• Continual monitoring of sensor performance
  – XML feed setup
• Additional sensor evaluations
  – Radar, RFID, etc...
• Filtering and smoothing algorithm development
  – Ideal test bed for investigation of travel time error
Questions?