Travel Time Related Research Using Bluetooth Technology
Bluetooth Technology

- A standard for short range, low power, low cost wireless communication that uses radio technology
- Widespread in numerous types of devices
- Signal sending range: 3 feet (1m) ~ 330 feet (100m) [1]
- Class 3, Class 2 and Class 1 radios provide a range of 3 feet, at least 33 feet, and minimum 330 feet

<table>
<thead>
<tr>
<th>Class</th>
<th>Zone radius (m)</th>
<th>Radio frequency power output (max)</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class-1</td>
<td>100</td>
<td>20 dBm</td>
<td>Primarily for industrial use</td>
</tr>
<tr>
<td>Class-2</td>
<td>10</td>
<td>4 dBm</td>
<td>Most commonly found in mobile phones, car navigation etc.</td>
</tr>
<tr>
<td>Class-3</td>
<td>1</td>
<td>0 dBm</td>
<td>For very short range devices such as keyboard, mouse, etc.</td>
</tr>
</tbody>
</table>

Bluetooth Technology

- Discover devices via two steps: inquiry and paging
- Minimum time required for discovery of all Bluetooth devices within range is 10.24 seconds\(^2\)
- Discover devices with discovery mode - using the MAC-48 identifier format (a unique identification)

Obtain Travel Time By Bluetooth

- Scan the MAC IDs of the discoverable Bluetooth devices within its communication zone.
- Obtain travel time of the device from one detective location to another by matching the MAC-IDs from the two respective time-synchronized Bluetooth detectors.
Advantages of Using Bluetooth

- **Accuracy**
- Feasibility of reporting travel times[^3]
- Effective in measuring travel times[^4]
- Compared to floating car methods and radio-frequency identification (RFID)[^5,^6]
- Relatively low cost[^7]
- Flexibility of installation
- Low cost for and data collection

[^4]: M. Martchouk and F. Mannering, "Analysis of Travel Time Reliability on Indiana Interstates," Purdue University 2009.
Problems of Data Collection

- Limited Sample Size
- Over-counting
- Unknown travel mode
- Missed observation
- No spatial indication
- No direction indication
- No information outside the zone
Application- Antenna Influence

- **Because:**
  - 10.24 second inquiry time may exceed the time for the vehicle to traverse the detection range
  - Intensive interference of signals may affect the detection

- **Antenna setting attributes:**
  - The lengths of the study segments;
  - The horizontal and vertical placement of readers;
  - The type and number of readers;
  - And the start time, end time, and duration of the study period

- **Methodology**
  - Probe vehicles equipped with GPS devices provide the ground truth travel time data.
  - High resolution cameras were used to obtain traffic volume counts
  - Travel Times and Travel Time Accuracy Comparison
Application- Data Filtering

- **Outlier**:
  - Excessively fast speeds
  - Excessively slow speeds
  - Other travel modes

- **Filter technology**
  - Moving Median Filter
  - Median Absolute Deviation (MAD)
  - Box-and-Whisker filter
  - Traffic flow models
  - Multiple-matched filter
Application - Data Filtering

- Data accuracy evaluation
- Distribution of temporal error
- **Accuracy and reliability for travel time estimation**
- Absolute error
- Percentage of actually travel time
- Accuracy of average travel time estimation
Application - Fusing Data

- Limited amount of detected vehicles by Bluetooth
- Good spatial coverage on entire segment
- Data fusion technology
- Simple Convex Combination and Bar-Shalom/Campo Combination
- Measurement Fusion Kalman Filter and Single-constraint-at-a-Time Kalman Filter
- Ordered Weighted Average
- Fuzzy Integral
- Artificial Neural Network

- Cross-Validation

(a) A competitive data fusion architecture ("architecture 1"); (b) cooperative and competitive data fusion architecture ("architecture 2")
Application - Arterial Travel Time Estimation

- **Signal interruption**
  - an unmatched vehicle does not yield a travel time, and may indicate a turning movement

- **Method 1:**
  - Design a matching matrix based on the observation matrix to maximum a posteriori matrix
  - Statistical model is estimated from the data
  - signal settings can be inferred from the matched vehicle results

- **Method 2:**
  - Integrating classical procedure with cumulative plots and probe vehicle data
  - Refine upstream travel time by probe vehicles
  - Historical Database providing effective scaling factor to define downstream travel time
  - Real time data from detectors and cumulative plots
Application - Work Zone

- **Interpretation of travel time data**
- Visually inspect observation data
- Capacity
- Delay and queue duration
- Dynamic Message Signs Influence

- **Route Choice**
- Field data supplementing conventional methods
- Comparing detected data in different conditions
Applications - OD Estimation

Figure 9 Methodological design of the computational experiment by simulation.
Applications - Route Choice

- **Interpretation of detected data**
  - A field sampling technique

- **Route Choice**
  - Estimate the distribution of traffic on alternate routes
  - Interquartile range as a travel time reliability indicator
Empirical Study
- Bluetooth data are supplemented with speed and volume data obtained from other detectors
- Find correlation between travel time and variables, e.g. speed, adjacent vehicle travel time, volume

Travel Time Duration Model
- Hazard model for duration
- Estimating parameters of individual vehicle travel time by Log-Logistic model
- Unrelated Regression Model for average travel time
- Compare observed travel time data and predicted travel time
Thank you!

Q & A

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Application- Data Acquisition

- **Filtering Techniques** [8-11]


- **Antenna Influence** [12-15]


- **Fusing Data,**
  i.e., with loop detectors data [16-18]


Application-Estimate travel time

- **Arterials** [19-23]
  

- **Other modes** [24-27]
  
Application

- **Work zone** [28,29]
  
  

- **Origin–Destination estimation** [30-32]
  
  
  

- **Route choice analysis** [35,36]
  
  

- **Freeway travel time variability** [37]
  