How Long to Wait?
Predicting Bus Arrival Time with Mobile Phone based Participatory Sensing

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Predicting bus arrival time

How long to wait?
- Alternative transit choices
- Better travel plans
Predicting bus arrival time
Predicting bus arrival time
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### Predicting bus arrival time

**Time table:** limited information, not timely updated

<table>
<thead>
<tr>
<th>199</th>
<th>TRUNK (AIRCON)</th>
<th>Weekdays</th>
<th>Saturdays</th>
<th>Sundays &amp; Public Holidays</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1st Bus</td>
<td>Last Bus</td>
<td>1st Bus</td>
</tr>
<tr>
<td></td>
<td>DIRECTION 1 BOON LAY INT</td>
<td>06:00</td>
<td>00:00</td>
<td>06:00</td>
</tr>
<tr>
<td></td>
<td>LOOPING NIE LIB</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Service Frequency**

<table>
<thead>
<tr>
<th>Period (hours)</th>
<th>0630-0830</th>
<th>0831-1659</th>
<th>1700-1900</th>
<th>After 1900</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency Range (mins)</td>
<td>DIRECTION 1</td>
<td>8-11</td>
<td>8-12</td>
<td>8-13</td>
</tr>
<tr>
<td></td>
<td>LOOPING</td>
<td>0-0</td>
<td>0-0</td>
<td>0-0</td>
</tr>
</tbody>
</table>
Predicting bus arrival time

Complex information system
- Substantial cost
- Collaborative bus operators
- Local availability
Design goal

- Crowdsourcing approach
- Independent of transit operators
Design goal

✓ No GPS or vehicle devices
Design goal

- No GPS or vehicle devices
- Energy efficiency
Design goal

- No GPS or vehicle devices
- Energy efficiency
- Fully automatic
GPS : 2D positions
In cellular space
In cellular space

Cell tower set sequence: Top-3 strongest cell tower IDs
Framework
Sharing user

Celltower Seq. Audio Signal

Bus Detection
Bus detection: the beeps

- Transit IC card readers on buses
Bus detection: the beeps

- Transit IC card readers on buses: 1K+3K Hz beeps
Bus detection: the beeps
- Pre-survey: Cell tower sequence database
- Online processing:
  - Cell tower sequence matching
  - Bus classification
  - Arrival time prediction
Bus route classification

- Extended Smith-Waterman algorithm
- Matching algorithm:
  - Scoring function: If matches $i^{th}$ cell tower, $+0.5^{i-1}$
  - Penalty function: -0.5
• $T = T_2 - t_2 + T_3 + t_{bs}$

Arrival time
Bus v.s. Train
Trains are more stable than buses: Accelerometer
• Concatenate short sequences
Sequence concatenation

• Beep intervals along with time
Experimental evaluation

• Phones

  ✓ Accelerometer
  ✓ Microphone
  ✓ 1GB RAM
  ✓ 1.2GHz Cortex-A9 Processor

  Samsung i9100

  ✓ Accelerometer
  ✓ Microphone
  ✓ 768MB RAM
  ✓ 1GHz Scorpion Processor

  HTC Desire S

• Buses

  SBS Transit Bus

  Campus Shuttle Bus
**Bus detection**

- Two or more IC card readers on different gates
- Entrance gate of the bus is about 1.4 meters wide.
- Mobile phone is normally less than 1 meter away from the IC card reader when the user enters a bus
Campus shuttle bus routes

<table>
<thead>
<tr>
<th>Route</th>
<th>Length</th>
<th>Avg. vel.</th>
<th>Stop</th>
<th>Seq. Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>4.0km</td>
<td>22.1km/h</td>
<td>11</td>
<td>14-15</td>
</tr>
<tr>
<td>B</td>
<td>3.8km</td>
<td>21.2km/h</td>
<td>9</td>
<td>9-10</td>
</tr>
<tr>
<td>C</td>
<td>5.5km</td>
<td>20.6km/h</td>
<td>13</td>
<td>16-17</td>
</tr>
<tr>
<td>D</td>
<td>5.8km</td>
<td>18.3km/h</td>
<td>9</td>
<td>20-22</td>
</tr>
</tbody>
</table>
Bus classification

✓ 20 runs for each shuttle bus
✓ Low misclassification rate even for routes with high overlap ratio
Bus arrival time prediction

✓ Error = |predicted arrival time − actual arrival time|
Public bus routes

- **Bus routes**
  - SBS 179: 23 stops, 8.6km, 27~33 cell towers
  - SBS 241: 17 stops, 5.2km, 20~23 cell towers
- **Land Transport Authority (LTA) prediction**
  - On-bus localization devices: GPS
  - SMS-based arrival time query: sending bus stop codes
Comparison with LTA results

![Diagram](image-url)

- **CDF**: Cumulative Distribution Function
- **Error of arrival time prediction**: Time difference between predicted and actual arrival times
- **our system prediction**: Line showing prediction results for the system being compared
- **LTA prediction**: Dashed line showing prediction results for LTA
Future work

• Preprocessing phase with crowdsourcing
  • Querying user => Sharing user

• Alternative reference points: Roadside WiFi

• Trip planning
  • From “how long to wait” to “where to go”
Thanks

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Cell tower signal

Phones connect to the top-3 strongest cell towers for most of the time
Bus v.s. Train
Bus route classification
Distance: the # of bus stops between the waiting user and the bus
The prediction error rises with longer distance