The Multi-Modal Intelligent Traffic Signal System (MMITSS)

Larry Head
Systems and Industrial Engineering
University of Arizona

September 11, 2014
Connected Vehicles ......

5.9 GHz vehicle-to-vehicle (v2v) and vehicle-to-infrastructure (v2i) communications
SAFETY
MOBILITY

Dynamic Mobility Applications (DMA)

- Queue Warning
- Speed Harmonization
- Cooperative-Adaptive Cruise Control
- Eco-Driving
- Performance Measures
- Multi-Modal Intelligent Traffic Signal Control (MMITSS)
  
  — [UA, PATH, Econolite, Savari]


September 11, 2014
Multi-Modal Intelligent Traffic Signal System (MMITSS)

The objectives of this project are:

1. To develop a comprehensive traffic signal system that services multiple modes of transportation including
   - Passenger vehicles,
   - Transit
   - Emergency vehicles
   - Freight fleets (e.g. Trucks)
   - Pedestrians

2. To field testing/demonstrate the developed Multi-Modal Intelligent Traffic Signal System.

*The Multi-Modal Intelligent Traffic Signal System (MMITSS) Project is sponsored by the states and US DOT through the Pooled Fund Program*
MMITSS Team

• Technical
  ─ University of Arizona (Prime)
  ─ University of California Berkeley (PATH)
  ─ Savari
  ─ Econolite

• Sponsors
  ─ Pooled Fund Project
    • FHWA
    • Virginia DOT/UVA
    • Maricopa County DOT
    • Caltrans
    • Minnesota DOT
    • Florida DOT
    • Michigan DOT
    • ......
MMITSS Basic Concepts

Priority Hierarchy
- Rail Crossings
- Emergency Vehicles
- Freight
- Transit
  - BRT
  - Express
  - Local (Late)
- Coordination
- Pedestrians

A Traffic Control System

Section 1
- Priority for
  - Freight
MMITSS Basic Concepts

Priority Hierarchy
- Rail Crossings
- Emergency Vehicles
- Transit
  - BRT
  - Express
  - Local (Late)
- Pedestrians
- Coordination
- Freight

A Traffic Control System

Section 2
- Priority for
  - Transit
  - Pedestrians
Real-Time Performance Measures – by mode, by movement

- Volume (mean, variance)
- Delay (mean, variance)
- Travel Time (mean, variance)
- Throughput (mean, variance)
- Stops (mean, variance)
MMITSS Architecture
DSRC WAVE Channels

<table>
<thead>
<tr>
<th>HALL</th>
<th>Service Channel</th>
<th>Service Channel</th>
<th>Control Channel</th>
<th>Service Channel</th>
<th>Service Channel</th>
<th>HPLR</th>
</tr>
</thead>
<tbody>
<tr>
<td>172</td>
<td>174</td>
<td>176</td>
<td>178</td>
<td>180</td>
<td>182</td>
<td>184</td>
</tr>
</tbody>
</table>

Frequency (GHz):
- 5.850
- 5.855
- 5.865
- 5.875
- 5.885
- 5.895
- 5.905
- 5.915
- 5.925

- High Availability, Low Latency
- BSM 10 Hz
- MAP 1 Hz
- SPaT 10 Hz
- WSA – WAVE Service Announcement
- Service on Channel (PSID+PSC)
- Selected MMITSS Priority Channel
- SRM
- SSM
- Public Service Emergency
- High Power Long Range (Public Service)

Core MMITSS Features

• Intelligent Traffic Control based on Awareness of Equipped Vehicles
  – Signal actuation, gap out, extension, dilemma zone protection
  – Pedestrians, Disabled Pedestrians
  – Signal coordination, congestion control

• Traffic State, Flow, and Performance Observation

• Priority Control for EV, Transit, Trucks, and other Special Vehicles

• Smartphone application for Pedestrians
Intelligent Traffic Control

• Responsible for allocation of available green, given priority control constraints (coordination, priority requests)

• Responsible for providing Dilemma Zone protection

Bi-Level COP (Dynamic Program)
Allocation of available green time based on predicted arrival table

Yiheng Feng, PhD student
Estimation of Arrivals – 50% Market

Vehicle Position Estimation Phase 2 (50% Penetration Rate)

- Unequipped Vehicle Location
- Estimated Vehicle Location
- Connected Vehicle Location
Estimation of Arrivals – 25% Market

Vehicle Position Estimation Phase 2 (25% Penetration Rate)

- □ Unequipped Vehicle Location
- ○ Estimated Vehicle Location
- ■ Connected Vehicle Location

Lane Number

Distance to Stop Bar (m)

September 11, 2014
Simulation Results (October 2014)

100% Penetration Rate

Traffic Demand: 500 EB/WB; 375 NB/SB

100% Penetration Rate

Traffic Demand: 667 EB/WB; 500 NB/SB

75% Penetration Rate

Traffic Demand: 500 EB/WB; 375 NB/SB

75% Penetration Rate

Traffic Demand: 607 EB/WB; 500 NB/SB
Simulation Results (October 2014)

50% Penetration Rate

Traffic Demand: 590 EB/WB; 375 NB/SB

50% Penetration Rate

Traffic Demand: 667 EB/WB; 500 NB/SB

25% Penetration Rate

Traffic Demand: 500 EB/WB; 375 NB/SB

25% Penetration Rate

Traffic Demand: 667 EB/WB; 500 NB/SB
Priority Request Server
Priority Control (SCP) Architecture

Priority Request Generator
Fleet Management Center

Fleet Vehicle

Priority Request Server
Traffic Management Center

NTCIP 1211

Controller (CO)
NTCIP 1202 & 1211

OBE
SAE J2735
RSE

Note: NTCIP 1211 assumes that there are many possible architectures. The one shown above highlights the roles of both J2735 and NTCIP
NTCIP 1211 — NCHRP 3-66 Framework

• Multi-priority request framework definition

• Priority Request Generator
  - On-vehicle system that is responsible for knowing the vehicle position, velocity, route, and relation to intersection (via GID or other)
  - Vehicle must compute the desired service time from position, velocity (desired and actual), and relation to intersection
  - Vehicle must request desired phase (information is in GID or other) based on desired route
  - Vehicle must cancel, or signal, when priority is no longer needed – either when served or when cancelled
  - Vehicle must update request when arrival time changes

• Priority Request Server
  - Responsible for gathering requests and updates from vehicles [Priority Request Generators], solving the priority timing problem, and making a schedule available to the Priority Timing Controller
  - Responsible for limiting number of active requests to maxRequests
  - Responsible for managing different classes of service (Fire, Ambulance, Police, etc.) and implementing priority policy
Numerical Result

- Priority eligible requests come from Transits and Trucks
- Transits headway is 10 minutes, requesting phase 2, 6
- Trucks are 6% of vehicles, requesting phase 4, 8
Preliminary Numerical Results

• **Active Request Table (ART)**

<table>
<thead>
<tr>
<th></th>
<th>Request</th>
<th>Range (seconds)</th>
<th>Requested Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Transit#1</td>
<td>[10,15]</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>Transit#2</td>
<td>[42, 47]</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>Truck</td>
<td>[50, 60]</td>
<td>4</td>
</tr>
</tbody>
</table>
Serving Priority Requests – Phase Time Diagram

- Request for Phase 2 at Time 50
- Request for Phase 8 at Time 60
- Request for Phase 3 at Time 120
- Request for Phase 2 at Time 170

September 11, 2014

Qing He, PhD
Serving Priority Requests – Phase Time Diagram

- Request for Phase 2 at Time 50
- Request for Phase 8 at Time 60
- Request for Phase 7 at Time 120
- Request for Phase 2 at Time 170
Priority Policy Objective Function

\[
\min_{g,\theta} \quad \alpha \left( \sum_m w^m D_m \right) + \beta \left( \sum_{p,k} d^c_{p,k} \right) - \gamma \left( \sum_{p,k} a_{p,k} \right)
\]

- **Multi-Modal Delay**
- **Coordination Delay**
- **Actuation Flexibility**

• \( w^m \) is the weight assigned to mode \( m \)
• \( D_m \) is the delay of mode \( m \) vehicles
• \( \alpha, \beta, \gamma \) are the weights assigned to priority vehicles, coordination, and actuation flexibility
• \( d^c \) is coordination delay for phase \( p \) in cycle \( k \)
• \( a_{p,k} \) is the actuation time assigned to phase \( p \) in cycle

Mehdi Zamanipour, 2013
N-Level Priority Policy

- Priority Hierarchy
  - Rail Crossings
  - Emergency Vehicles
  - Freight
  - Transit
    - BRT
    - Express
    - Local (Late)
  - Pedestrians
  - Coordination

- $w^m$ is the weight assigned to mode $m$
- $\alpha$, $\beta$, $\gamma$ are the weights assigned to priority vehicles, coordination, and actuation flexibility
- $a_{pk}$ is the actuation time assigned to phase $p$ in cycle
Preliminary Numerical Results: Impact of Weight Selection on Policy

• Comparing average truck and transit delay with and without considering priority
Performance Observer

• Performance Observation
  – Derived from BSM Data (Trajectories)
  – Process Trajectories to compute observed
    • Delay (Average, Variability)
    • Travel Time (Average, Variability)
    • Traffic States (Queue Length)
  – Performance Measures Used for
    • Monitoring and Assessment
    • DSRC Performance
    • Section Level Control (Coordination Updates)

Shayan Khoshmagham, 2013
Approach

1. Defining appropriate performance measures and metrics
   - Traditional: Overall Vehicle Delay, Number of Stops, Throughput, Maximum Queue Length, Total Travel Time
   - More recent: Time to Service, Queue Service Time
   - Connected Vehicle System: DSRC Range, Packet Drop

2. Understanding how improvements to one mode may impact another mode

3. Understanding how connected vehicles information, can help to estimate performance measures
Visualization Method

Radar (Spider Web) Diagram:

- Demonstrating multivariate data in the form of a two-dimensional chart.
- Multiple transportation modes, various performance measures, and different scenarios/designs

![Radar Diagram for Passenger Vehicles](image)
Intersection-Level Dashboard
Section-Level Dashboard By Mode
Pedestrian Smartphone App

MMITSS Pedestrian Smartphone app

Allows Pedestrian to receive auditory and haptic feedback
- Align with Crosswalk
- Send Call for Service
- Be given WALK
- PedCLEAR Countdown

Savari SmartCross Application Architecture
Section Level Control and Priority

• Section Level Control
  – Coordination Plan – Cycle Length, Offset
    • Offset adjustment (based on arrivals during coordinated phase red)
  – Priority Coordination
    • Determine if a request granted at upstream intersection will be delayed at downstream
      – If no, local priority control allowed
      – If yes, no local priority control allowed
    • Forward Priority Requests to Downstream Signal(s)
      – Longer Time Horizon of accommodation
Should Coordination be considered a type of Priority?

• What is the goal of coordination?
  – To have the desired phase green at a specific point in time during the cycle to provide progression to a platoon of vehicles
    • Accomplished through a fixed cycle length and an offset
    • Accomplished by identifying platoons of vehicles and providing “progression window”

• What is the goal of priority?
  – To have the desired phase green at a specific point in time during the cycle to provide service to a class of vehicles (transit, EV, freight, pedestrian)
MMITSS Status

- April 2015 – Demonstrations in Arizona and California
- USDOT Impact Assessment Contractor
  - Assess Effectiveness of MMITSS
  - Field Data Collection and Simulation
Arizona Connected Vehicle Test Network
Larry Head
Systems and Industrial Engineering
University of Arizona
larry@sie.arizona.edu
(520) 621-2264

Thank you.

The future is exciting – not BORING!!

Questions?