TRAFFIC CONTROL AND ROUTING IN A CONNECTED VEHICLE ENVIRONMENT

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A network of roads with given demand
- Limited measurements
- Traffic models
- Estimation
- Controls
  - Boundary control
  - Routing (indirect)
  - Nodal control (traffic lights scheduling)
A network of roads with given demand

- Abundant measurements
- Traffic models
- Estimation
- Controls
  - Boundary control
  - Routing (direct) +
  - Nodal control (traffic lights scheduling)
CONSIDER INTERACTIONS BETWEEN TRAFFIC LIGHT CONTROL AND ROUTING IN THREE TIME SCALES

- Long term: static user equilibrium (UE)
  - Minimize network delay while maintaining static UE traffic assignment (MPEC)
  - e.g., Smith, 1979; 1981; Yang and Yagar, 1995; Ghatee and Hashemi, 2007

- Intermediate term: dynamic user equilibrium (DUE)
  Minimize network delay while maintaining DUE (Dynamic MPEC)

- Short-term: adaptive routing and control without equilibrium
  e.g., Local minimization of cycle and phases with real-time hyperpath rerouting
TWO CASE STUDIES

- CASE I (short term): adaptive routing + distributed traffic light control (Chai et al 2017)
- CASE II (medium term): dynamic user equilibrium + system optimal traffic light control (Yu, Ma & Zhang 2017)
CASE 1: adaptive routing + distributed traffic light control
ADAPTIVE TRAFFIC SIGNAL CONTROL LOGIC

- Low-density control
  - A typical vehicle actuated control

- High-density control
  $$ G_{ij}^{h:g}(t) = \frac{q_{ij}^{h:g}(t)}{\sum_{h,j \in \Gamma(i), h \neq j} q_{ij}^{h:g}(t)} G_i^g(t) $$

- Phase selection control

  $$ (\varepsilon_{ij}^l, G_{ij}^{h:g}(t)) = \arg \max_{(\varepsilon_{ij}^l \in \varepsilon_{ij}, t_g \in [G_{min}, G_{max}])} \left\{ \frac{\text{The estimated number of vehicles passing in phase } \varepsilon_{ij}^l \text{ during time } t_g}{t_g} \right\} $$
DYNAMIC TRAFFIC ROUTING LOGIC

- Time-dependent stochastic routing

\[ \lambda_i^{h:s;g}(t) = \min_{j \in \Gamma(i)} \left\{ \sum_{k=1}^{K_{ij}^g(t)} \left( \tau_{ij}^{k;g} \left( t + \phi_{ij}^{l;g}(t) \right) + \lambda_j^{s;g} \left( t + \phi_{ij}^{l;g}(t) \right) + \phi_{ij}^{l;g}(t) \right) \cdot \rho_{ij}^{k;g} \left( t + \phi_{ij}^{l;g}(t) \right) \right\} \]

- \( \lambda_i^{h:s;g}(t) \): The minimum cost from node \( i \) to destination \( s \) at time \( t \) in day \( g \), the previous node is \( h \).

- \( \phi_{ij}^{l;g}(t) \): The delay from intersection \( i \) at time \( t \) in day \( g \); \( \varepsilon_{ij}^{l} \) is the \( l^{th} \) phase of intersection \( i \) whose down steam node is \( j \).

- \( \tau_{ij}^{k;g}(t) \): the \( k^{th} \) possible link travel time for link \((i, j)\) at time \( t \) in day \( g \).

- \( \rho_{ij}^{k;g}(t) \): the probability for link travel time \( \tau_{ij}^{k;g}(t) \) in day \( g \).

- \( K_{ij}^g(t) \): The total number of possible link travel times for link \((i, j)\) at time \( t \) in day \( g \).

- \( \Gamma(i) \): The set of all the adjacent codes of node \( i \).
A 10x3 grid network is used

Three different traffic demand levels considered

- Light traffic, no congestion
- Moderate traffic, mildly congested
- Heavy traffic, highly congested
NUMERICAL RESULTS: AVERAGE TRAVEL TIME
EFFECTS OF MARKET PENETRATION OF DTR TRAVELERS

Average travel time over the entire simulation horizon with 500 vehicles

Average travel time over the entire simulation horizon with 6000 vehicles
CASE II: dynamic user equilibrium + system optimal traffic light control
UE route choice behavior: routes with minimum perceived travel time are selected

Signal control plans affect travel times
- Flow capacity changes due to signal timing
- Queue spillbacks due to high demand and low capacity

Minimizing total travel costs

A mathematical program with equilibrium constraints (MPEC)
- Use PATH solver in GAMS
- Global optimum may not be found (due to nonlinearity and non-convexity)
MODELLING FRAMEWORK

\[ \min_{\{g_i^c(c)\}} \quad TTT \]

**Flow dynamics**

Double-queue link model

\[ q_{i,j}^e(t) \quad \tau_{i,j}^w \quad \tau_{i,j}^e \]

\[ \text{Inflow} \quad p_{i,j}(t) \quad \text{link} (i,j) \quad \text{Exit flow} \quad v_{i,j}(t) \]

\[ \min \{ g_i^m(c) \} \]

\[ \text{UE behavior} \]

Dynamic User Equilibrium Constraints

\[ 0 \leq p_{i,j}^{s'}(t) \perp (\tau_{(i,j)}(t) + \pi_{j}^{s'}(t + \tau_{(i,j)}(t)) - \pi_{i}^{s'}(t)) \geq 0 \]

\[ \text{approximation} \]

\[ 0 \leq p_{i,j}^{s'}(t) \perp (\tau_{(i,j)}(t) + \pi_{j}^{s'}(t + \tau_{(i,j)}^0) - \pi_{i}^{s'}(t)) \geq 0 \]

**Green time allocation**

Traffic Signal Control Constraints

\[ \text{link 1} \quad g_j^1 \quad g_j^2 \]

\[ \text{link 2} \]

\[ \overline{C}_{\text{link1}} = C_{\text{link1}} \frac{g_j^1}{g_j^1 + g_j^2} \quad \overline{C}_{\text{link2}} = C_{\text{link2}} \frac{g_j^2}{g_j^1 + g_j^2} \]

**Other constraints**

- Initial condition: empty network
- Terminal condition: traffic cleared
- Non-negativity conditions
- Traffic demand
NUMERICAL RESULTS

Origin-Destination (OD) Demand

1->7  100
3->7  50
13->7 100
15->7  50
2->20 100
3->20  50
5->20 100
15->20  50

## Numerical Results

### Scenarios

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>UE constr.</th>
<th>No UE constr.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed signal</td>
<td>I</td>
<td>II</td>
</tr>
<tr>
<td>Adaptive signal</td>
<td>III</td>
<td>IV</td>
</tr>
</tbody>
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### System Total Travel Time

- Fixed Signal Control:
  - UE Constraints: 30094 min
  - No UE Constraints: 18917 min
- Adaptive Signal Control:
  - UE Constraints: 20186 min
  - No UE Constraints: 18795 min
SOME REMARKS

- Traffic signal control cannot ignore traveler’s response (in the form of route choices and induced demand)
- Joint routing/control in different levels can improve overall network performance
- Joint routing and control presents many challenging control/optimization problems
  - Solution of non-convex large scale MPEC problems
  - Model realism vs complexity,
  - Parameter identification and simulation of large networked systems
  - Stability of adaptive routing/control
  - Testbeds for validation
SOME REMARKS

- With automatous vehicles, a variety of new control problems arises
  - Platooning and trajectory control
  - Fully or partially scheduled systems
  - Mixed traffic flow control
REFERENCES


- H Yu, R Ma, HM Zhang. Optimal traffic signal control under dynamic user equilibrium and link constraints in a general network. Transportation Research Part B: Methodological 110, 302-325, 2018


