TRAFFIC CONTROL AND ROUTING IN A CONNECTED VEHICLE ENVIRONMENT

MICHAEL ZHANG

CIVIL AND ENVIRONMENTAL ENGINEERING

UNIVERSITY OF CALIFORNIA DAVIS

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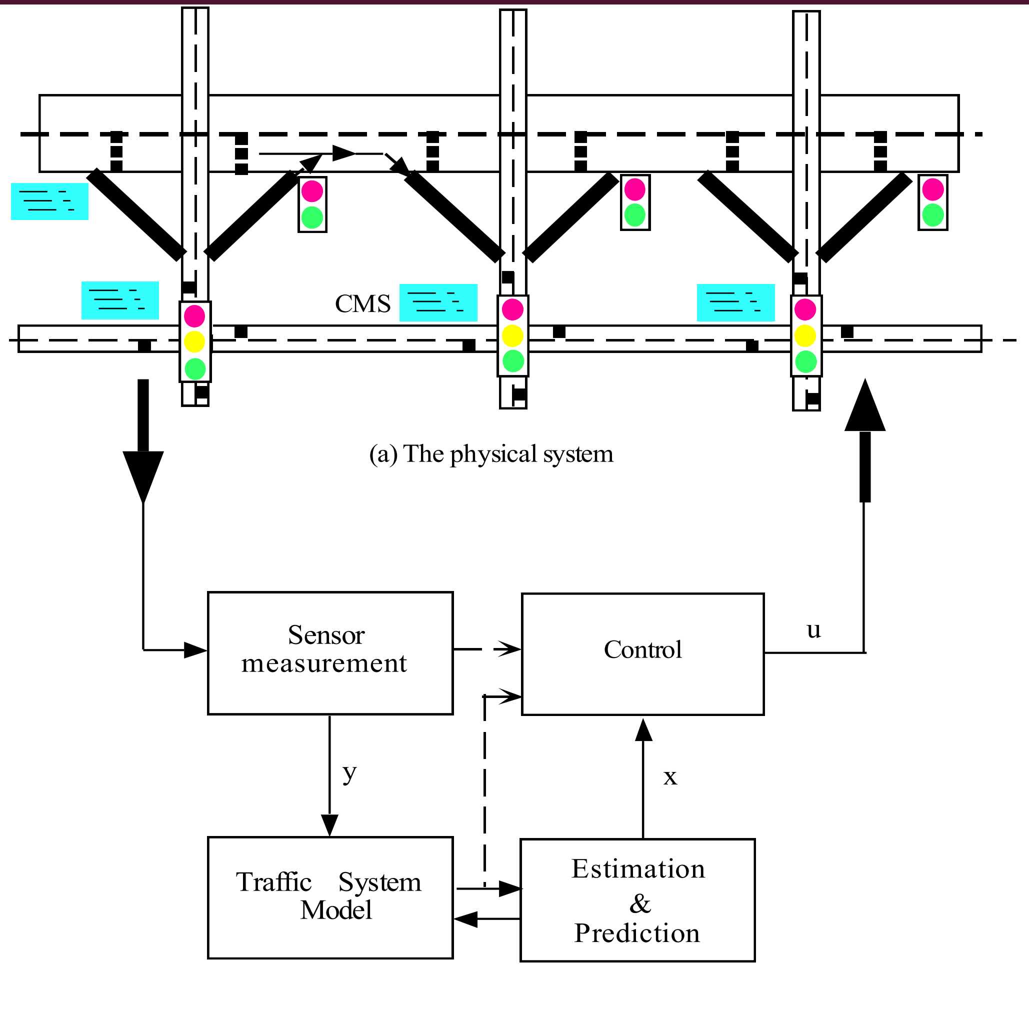
THE CONTROL PROBLEM IN THE TRADITIONAL SETTING

A network of roads with given demand

- Limited measurements
- Traffic models
- Estimation
- Controls
  - Boundary control
  - Routing (indirect)
  - Nodal control (traffic lights scheduling)



(b) The mathematical abstraction

THE CONTROL PROBLEM IN THE CONNECTED VEHICLE SETTING

A network of roads with given demand

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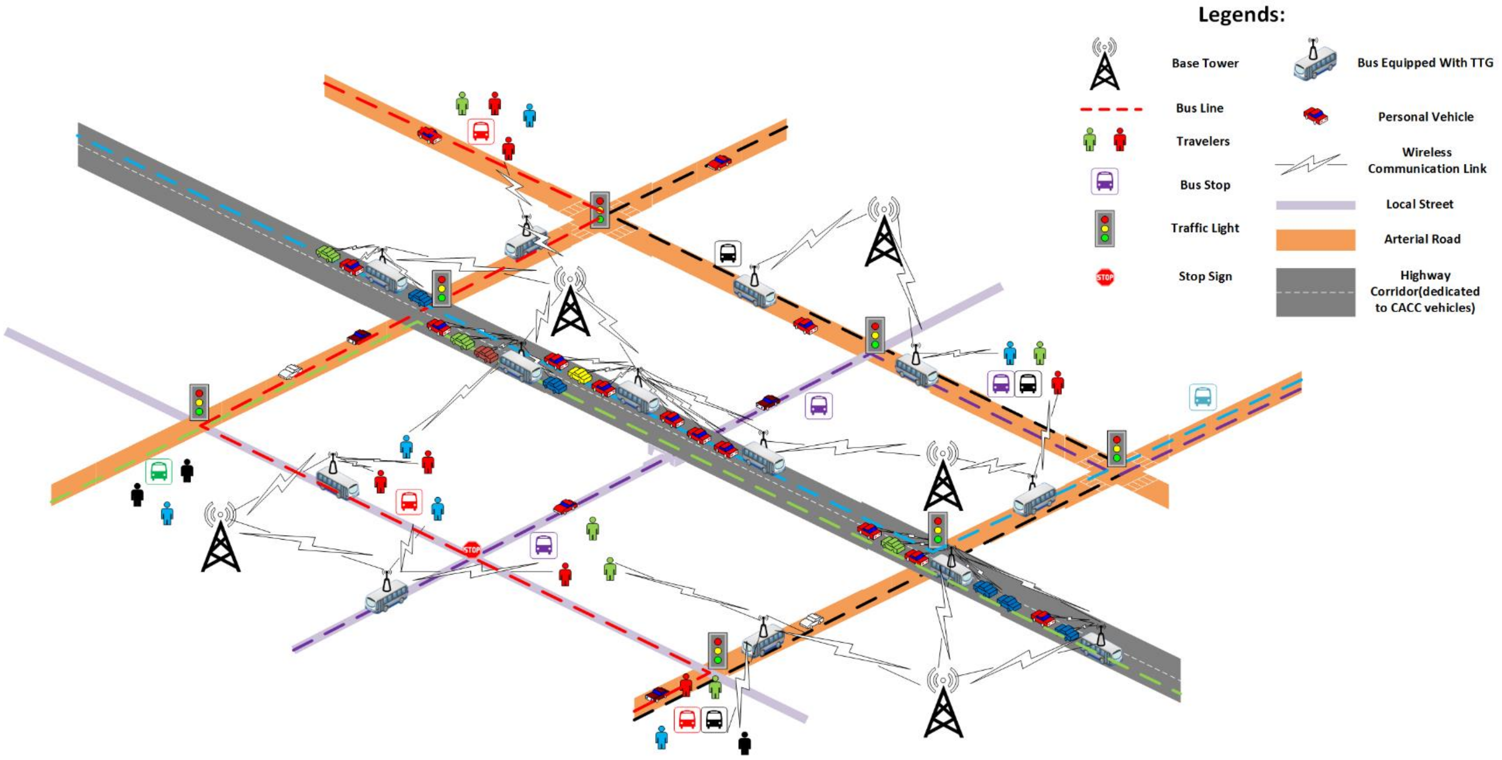
  - Boundary control
  - Routing (direct) +
  - Nodal control (traffic lights scheduling)

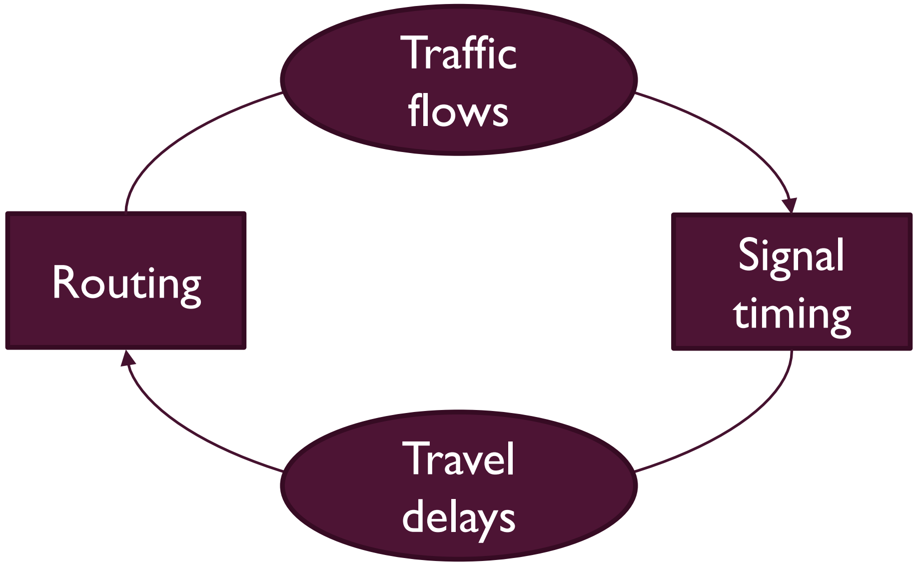


CONSIDER INTERACTIONS BETWEEN TRAFFIC LIGHT CONTROL AND ROUTING IN THREE TIME SCALES

- 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

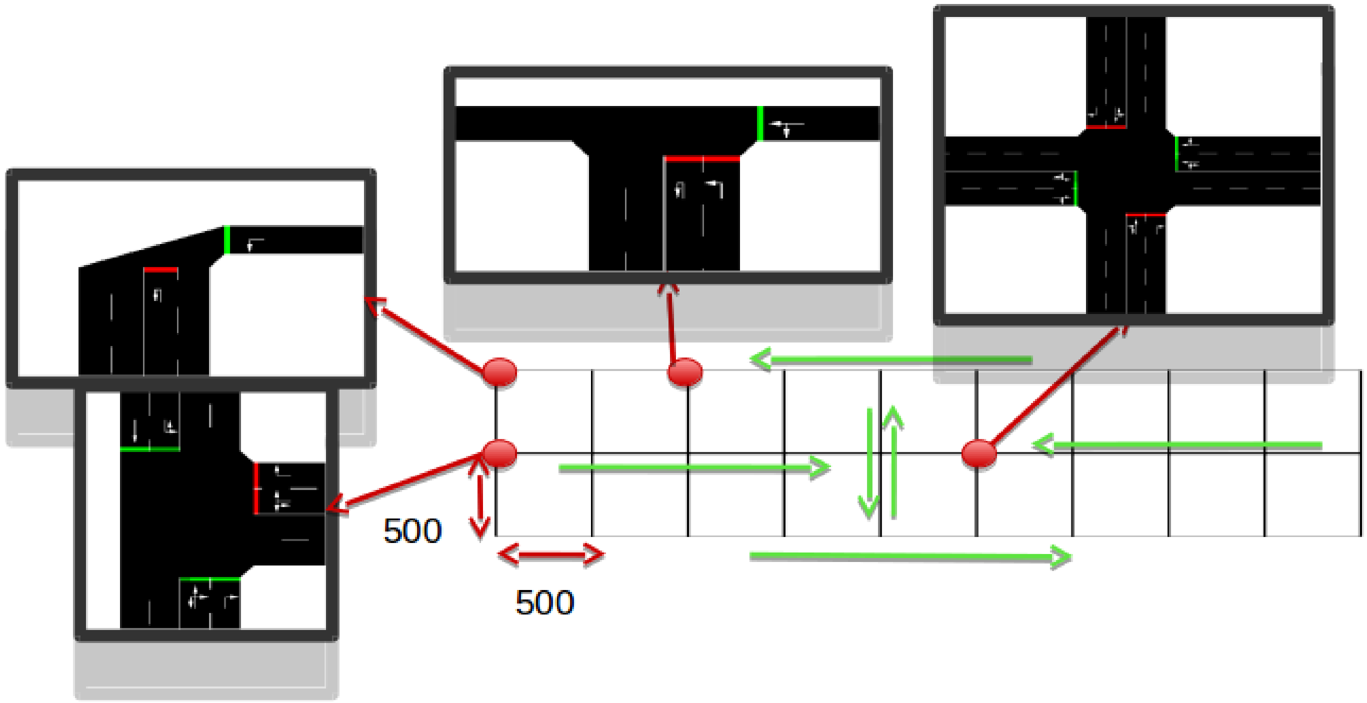
- Low-density control
  - A typical vehicle actuated control
- High-density control
  - $G_{ij}^{h;g}(t) = \frac{q_{ij}^{h;g}(t)}{\sum_{h,j\in\Gamma(i),h\neq j} q_{ij}^{h;g}(t)} G_i^g(t)$
- Phase selection control
  - $\left(\varepsilon_{ij}^l, G_{ij}^{h;g}(t)\right) = \arg \max_{(\varepsilon_{ij}^l \in \varepsilon_{ij}, t_g \in [G_{min}, G_{max}])} \left\{ \frac{\textit{The estimated number of vehicles passing in phase } \varepsilon_{ij}^l \textit{ during time } t_g}{t_g} \right\}$

DYNAMIC TRAFFIC ROUTING LOGIC

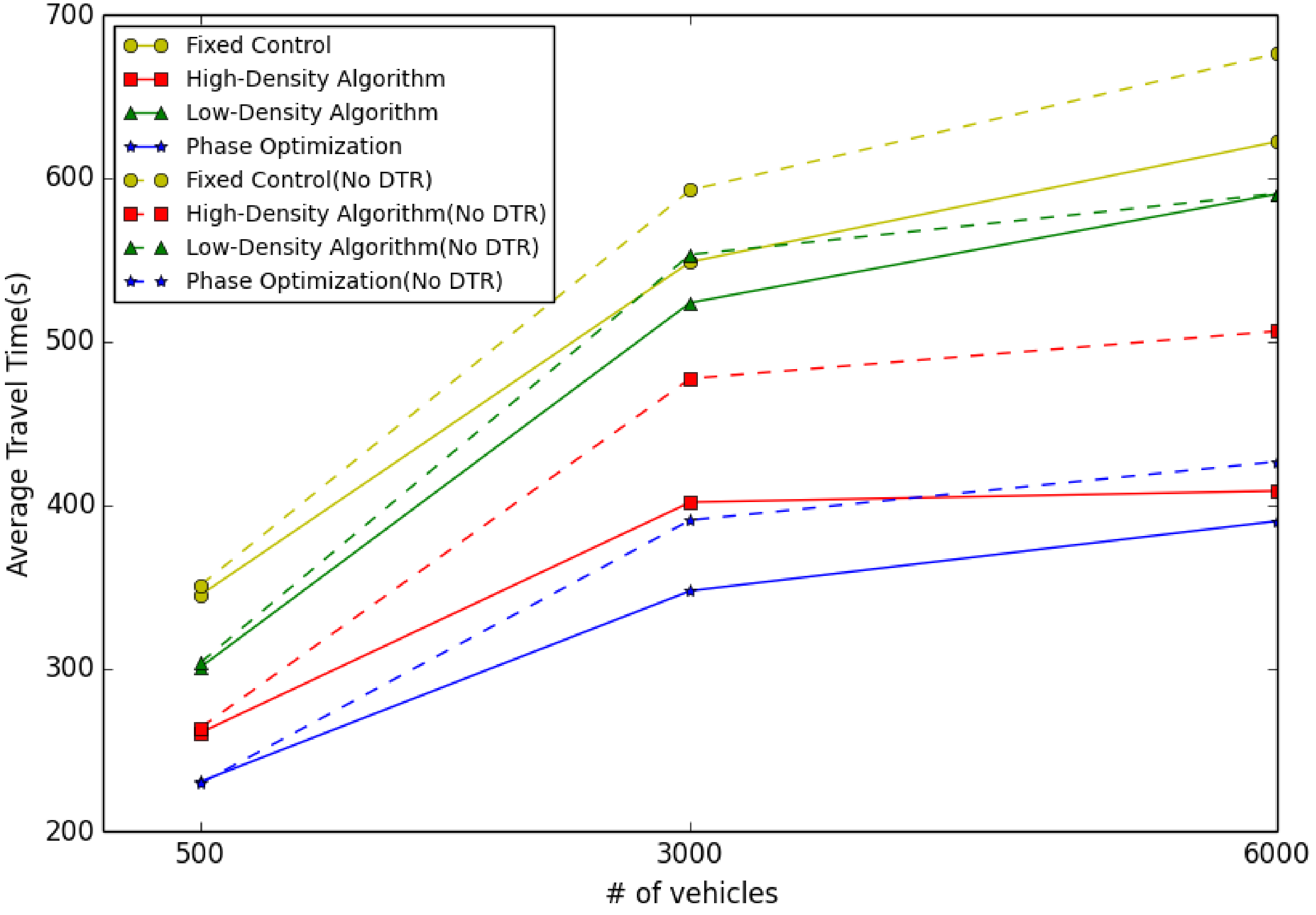
- Time-dependent stochastic routing
  - $\lambda_{\mathrm{i}}^{\mathrm{h;s;g}}(\mathrm{t}) = \min_{j\in\Gamma(i)}\left\{\sum_{k=1}^{\mathrm{K}_{\mathrm{ij}}^{g}(t)}\left[\tau_{ij}^{k;g}\left(t+\phi_{ij}^{\varepsilon_{ij}^{l};g}(t)\right)+\lambda_{j}^{i;s;g}\left(t+\phi_{ij}^{\varepsilon_{ij}^{l};g}(t)+\tau_{ij}^{k;g}\left(t+\phi_{ij}^{\varepsilon_{ij}^{l};g}(t)\right)\right)+\phi_{ij}^{\varepsilon_{ij}^{l};g}(t)\right]\bullet\rho_{ij}^{k;g}\left(t+\phi_{ij}^{\varepsilon_{ij}^{l};g}(t)\right)\right\}$
- $\lambda_{\mathrm{i}}^{\mathrm{h;s;g}}(\mathrm{t})$: The minimum cost from node i to destination s at time t in day g, the previous node is h.
- $\phi_{\mathrm{ij}}^{\varepsilon_{ij}^{l};\mathrm{g}}(\mathrm{t})$: The delay from intersection i at time t in day g; ε_{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.

TESTING WITH MICROSCOPIC TRAFFIC SIMULATION (VENTOS)

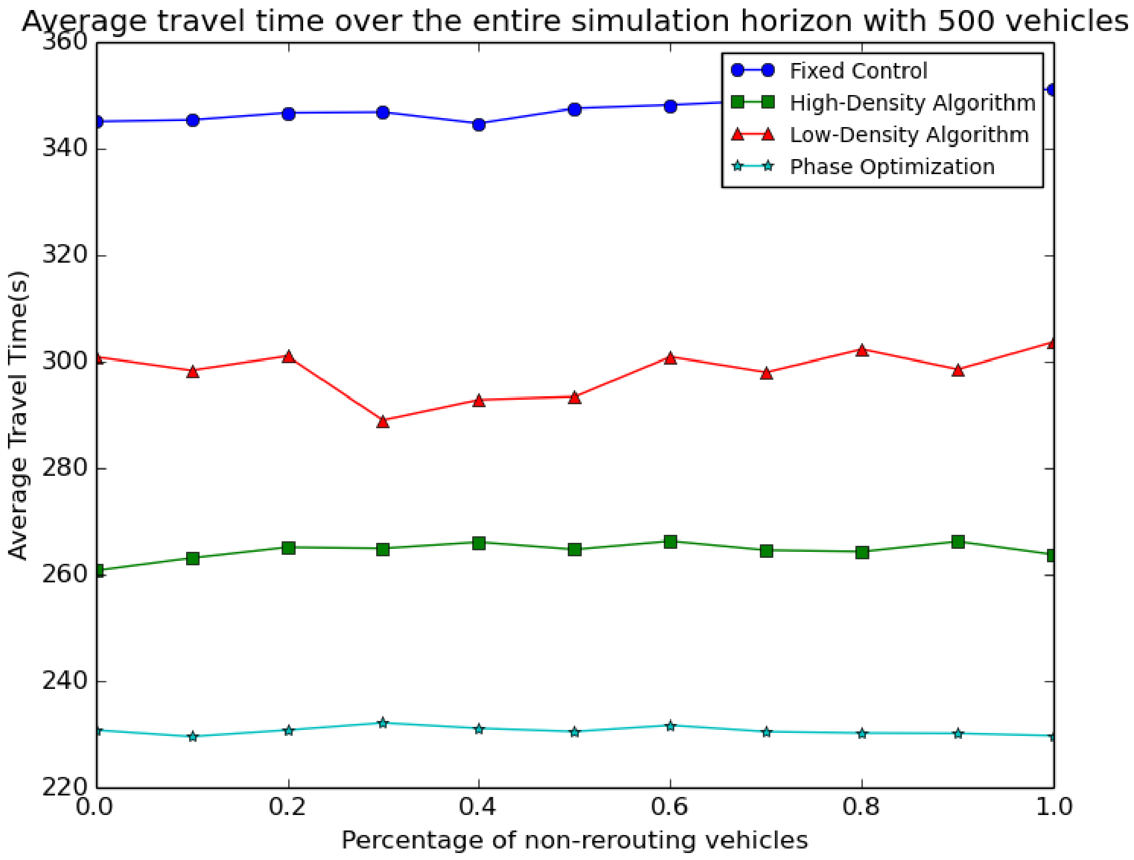
- A 10x3 grid network is used
- Three different traffic demand levels considered
  - Light traffic, no congestion
  - Moderate traffic, mildly congested
  - Heavy traffic, highly congested

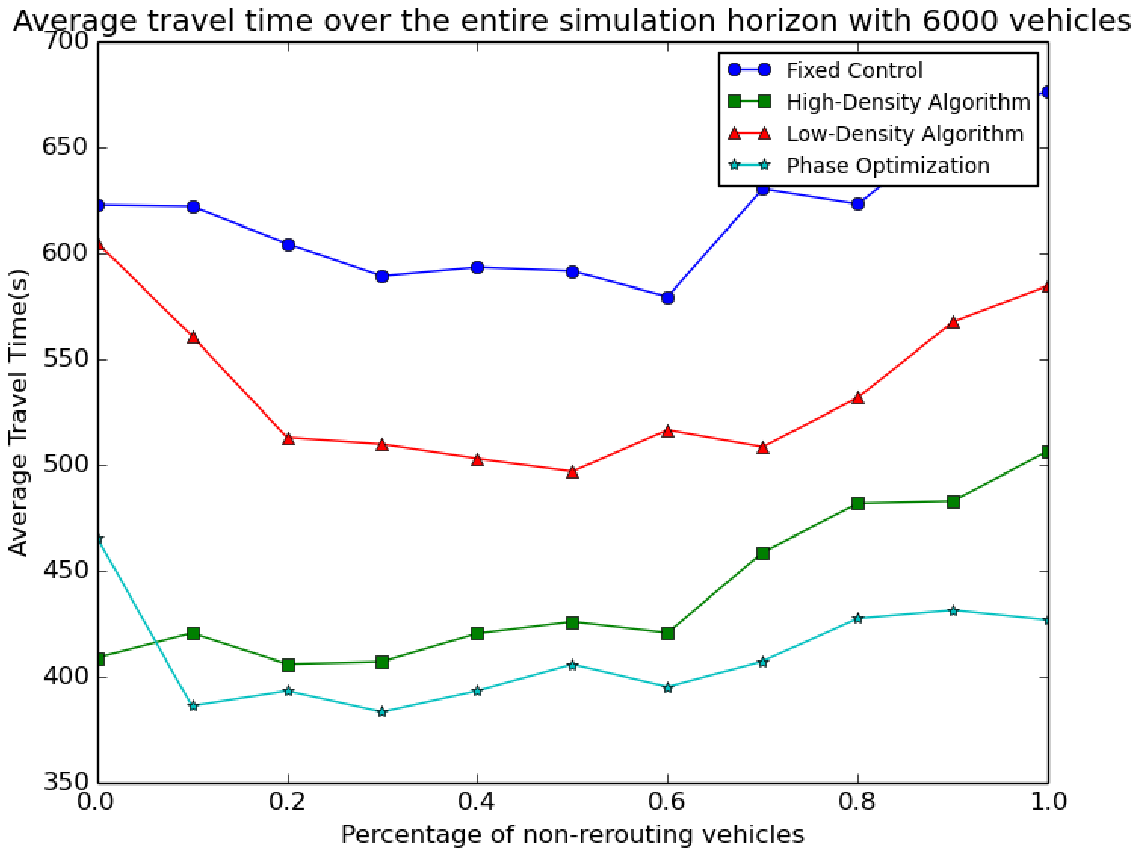


NUMERICAL RESULTS: AVERAGE TRAVEL TIME



EFFECTS OF MARKET PENETRATION OF DTR TRAVELERS





CASE II : dynamic user equilibrium + system optimal traffic light control

OPTIMAL TRAFFIC SIGNAL CONTROL CONSIDERING DYNAMIC USER EQUILIBRIUM ROUTE CHOICE

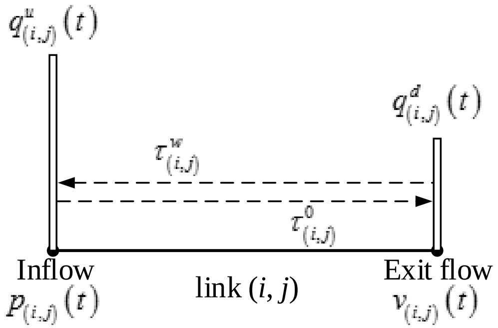
- UE route choice behavior: routes with minimum perceived travel time are selected
- Signal control plans affects travel times
  - Flow capacity changes due to signal timing
  - Queue spillbacks due to high demand and low capacity
- Minimizing total travel costs
- A mathematical program with equilibrium constraints (MPEC)
  - Use PATH solver in GAMS
  - Global optimum may not be found (due to nonlinearity and non-convexity)

MODELLING FRAMEWORK

$$\min_{\{g_i^m(c)\}} \quad TTT$$

Flow dynamics

Double-queue link model



UE behavior

Dynamic User Equilibrium Constraints

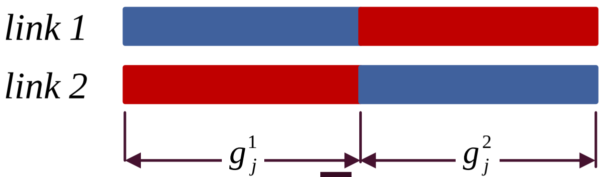
$$0 \le p^{s'}_{(i,j)}(t) \perp \left(\tau_{(i,j)}(t) + \pi^{s'}_j(t + \tau_{(i,j)}(t)) - \pi^{s'}_i(t)\right) \ge 0$$

approximation

$$0 \le p^{s'}_{(i,j)}(t) \perp \left(\tau_{(i,j)}(t) + \pi^{s'}_j(t + \tau^0_{(i,j)}) - \pi^{s'}_i\right) \ge 0$$

Green time allocation

Traffic Signal Control Constraints



$$\overline{C}_{link1} = C_{link1} \frac{g_j^1}{g_j^1 + g_j^2} \qquad \overline{C}_{link2} = C_{link2} \frac{g_j^2}{g_j^1 + g_j^2}$$

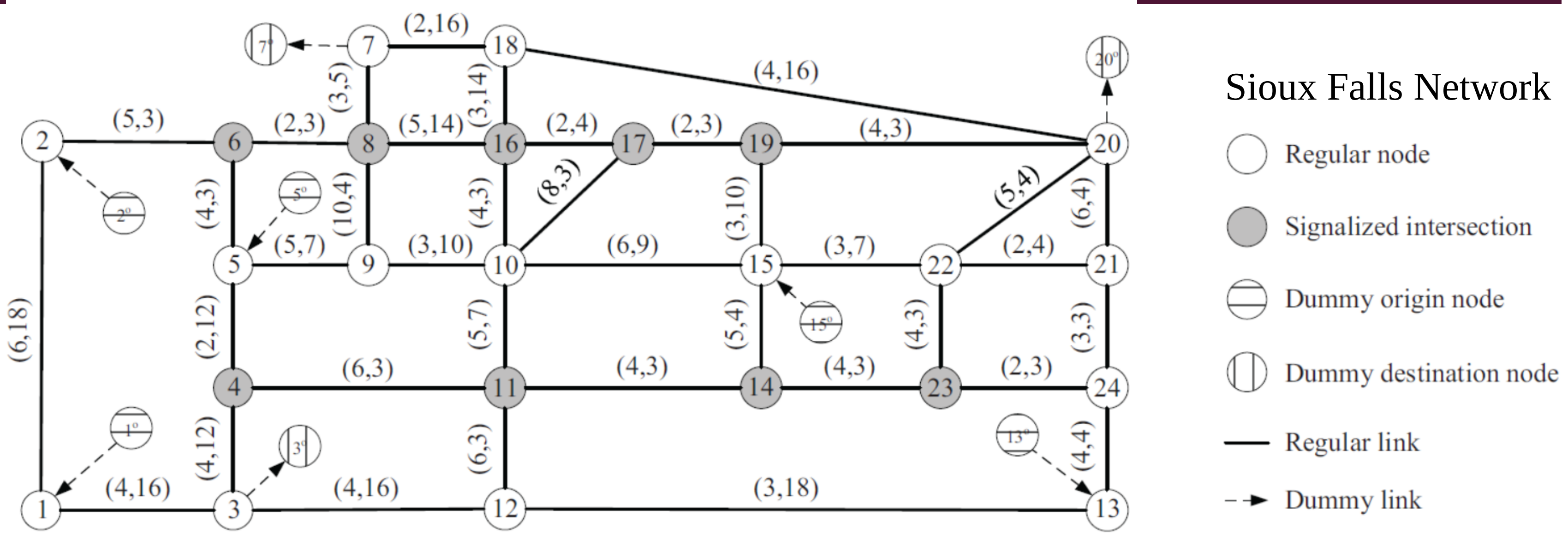
Other constraints

- 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

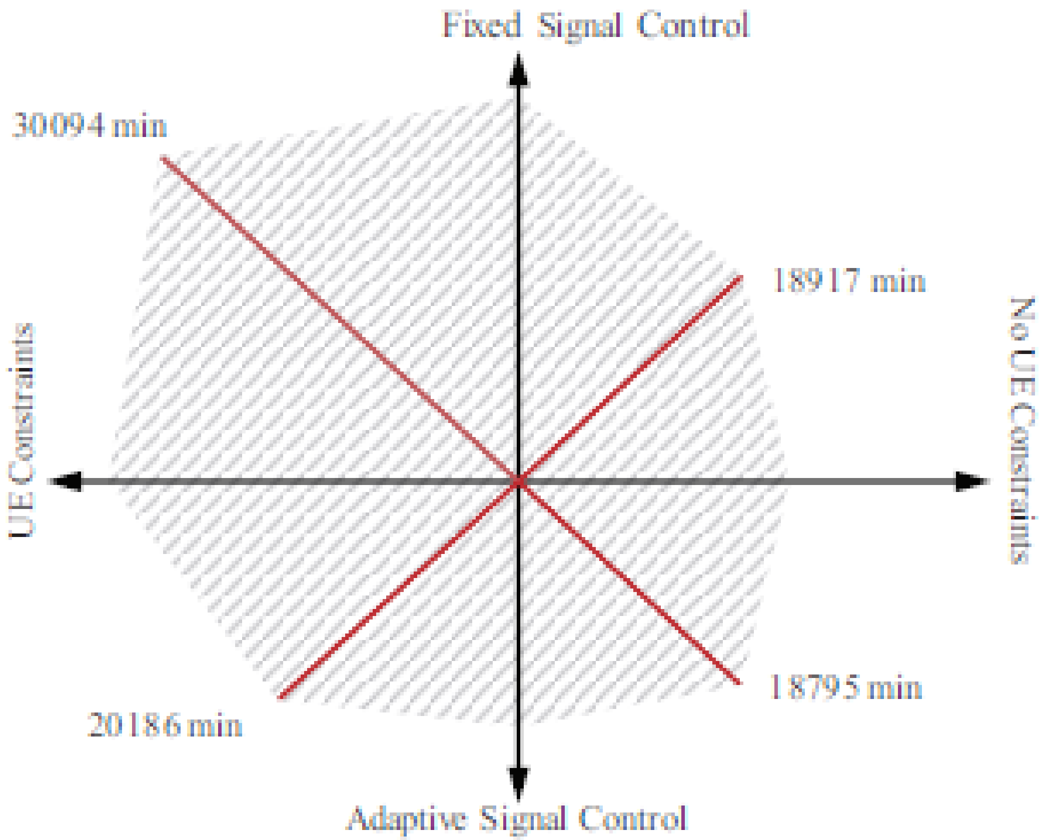


Layout and data of the Sioux Falls network, http://http://www.bgu.ac.il/bargera/tntp/

NUMERICAL RESULTS

System total travel time

Scenarios	UE constr.	No UE constr.
Fixed signal	I	II
Adaptive signal	III	IV

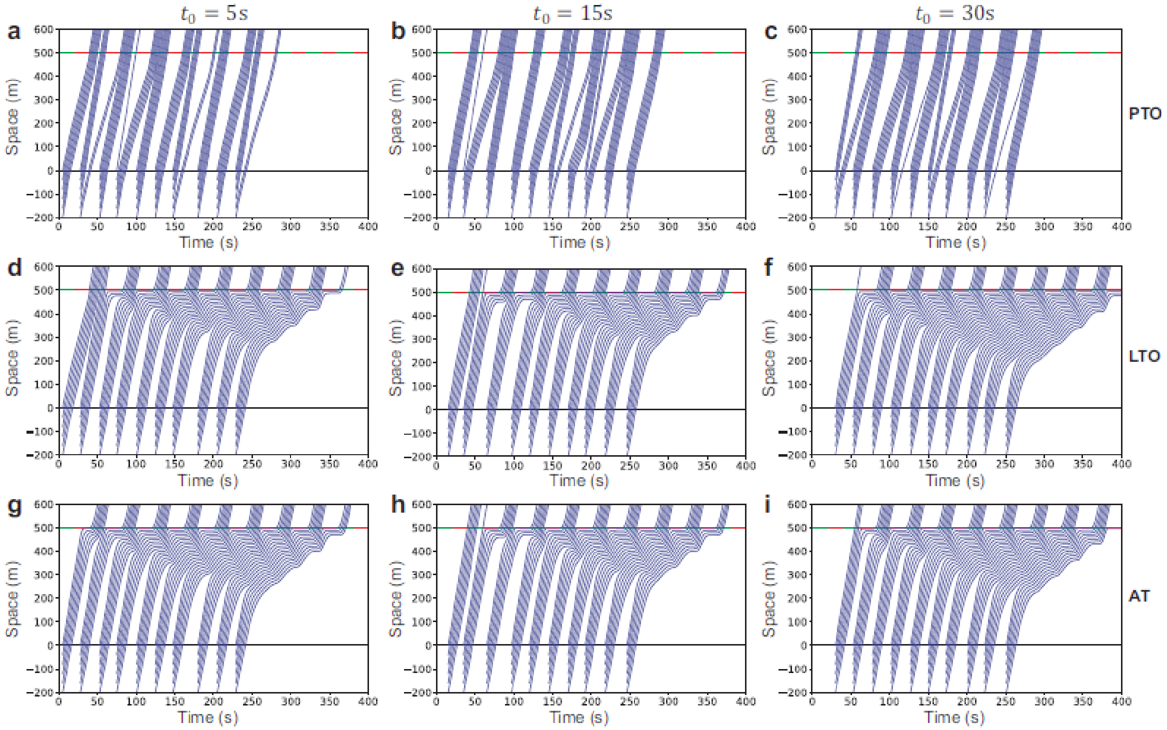


SOME REMARKS

- 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



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