Coordinated Look-Ahead Scheduling for Real-Time Traffic Signal Control

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Problem

- Traffic congestion is a *practical* problem resulting in substantial delays and extra fuel costs for drivers, and has negative impacts on environmental conditions

- For urban road networks, better traffic flow requires better traffic signal control, and *real-time, adaptive strategies* offer the biggest payoff

- Real-time decisions: traffic light cycles through a sequence of phases I, each phase i has a variable duration that can range between a minimum and a maximum
- Local observation: inflows of vehicles in the prediction horizon (H), the current phase index and duration of traffic light, and the current decision time

Challenge

Goal: Scalable network-wide optimization

- Intersection level: the number of joint signal control sequences and local observations is huge in the prediction horizon
- Network level: effective coordination for handling non-local impacts between tightly-coupled intersections in a complex network

Contributions

- Real-time traffic signal control based on coordinated look-ahead scheduling

- Each intersection is locally controlled by an agent using a schedule-driven intersection control strategy (SchIC) [3]. At each decision point, each agent constructs a schedule that optimizes movement of the observable traffic through its intersection, and uses this schedule to determine the best control action to take
- For strengthening its local view, each agent queries the scheduled outflows from its upstream neighbors to obtain an optimistic observation, which is capable of incorporating non-local impacts from indirect neighbors

⊛ Summary: *Multi-agent coordination = look-ahead scheduling + coordination mechanism(s)*

References

[1] G. J. Barlow. *Improving Memory for Optimization and Learning in Dynamic Environments*. PhD Thesis, 2011.
[2] S. Sen and K. L. Head. Controlled optimization of phases at an intersection. *Transport. Sci.*, 31, 1997.
[3] X.-F. Xie, S. F. Smith, L. Lu, G. J. Barlow. Schedule-driven intersection control. *Transport. Res. C*, 2012.

Acknowledgements

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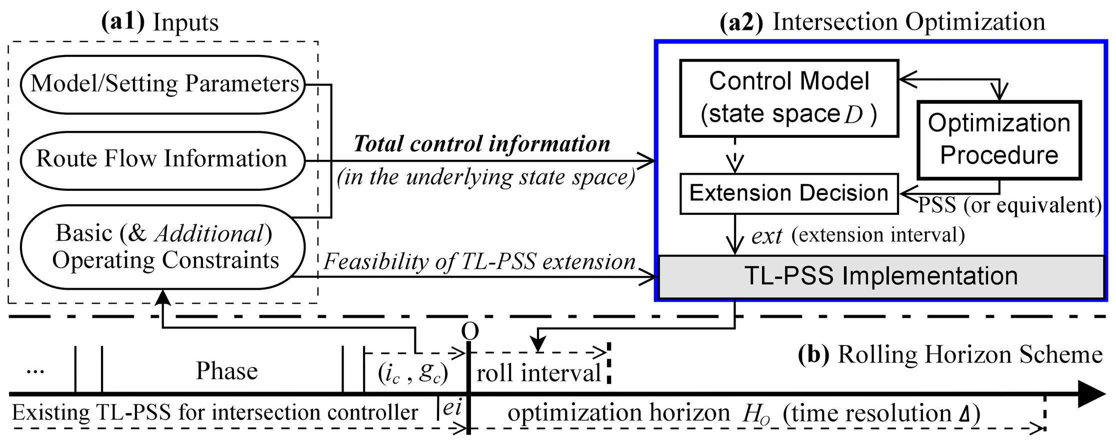
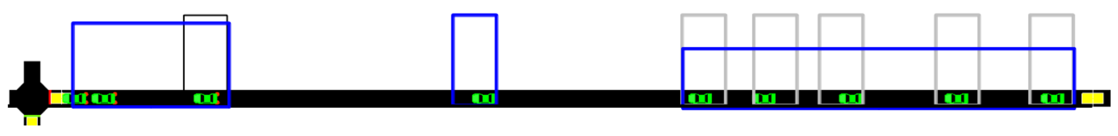
Intersection Control

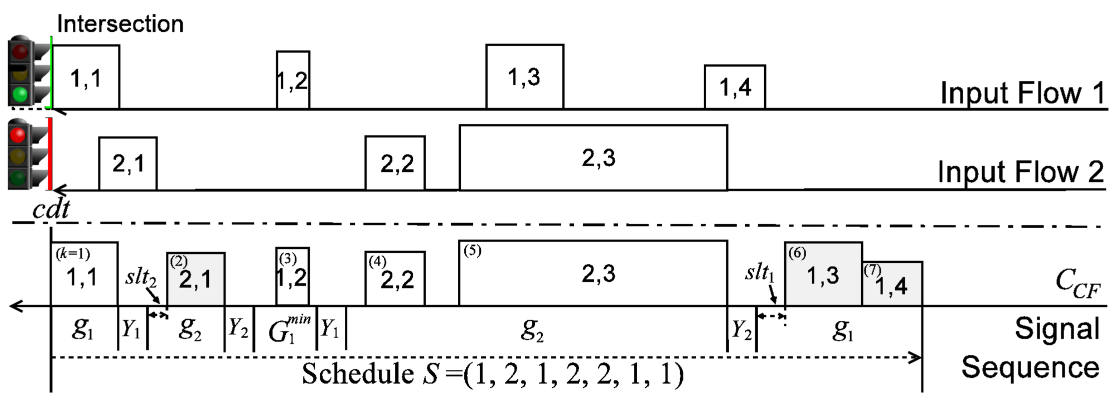
- *Look-ahead scheduling* in a rolling horizon



- Aggregate non-uniform flow into *jobs*



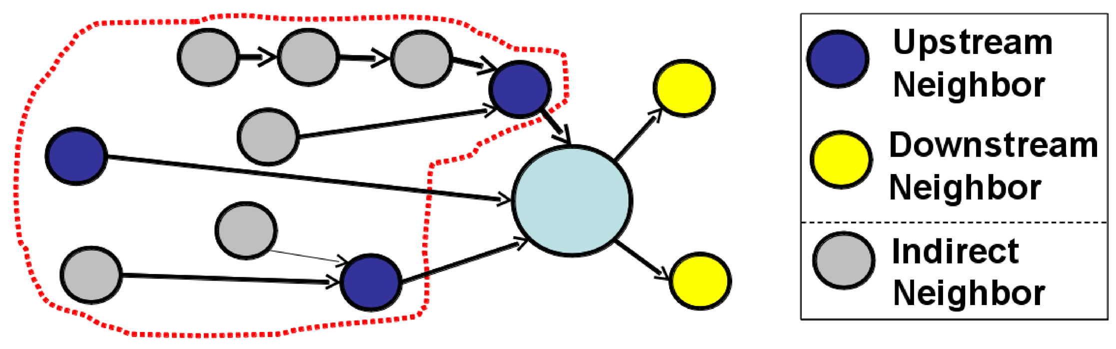
- Optimize in a *scheduling search space*



- Construct a schedule that optimizes movement of the currently approaching traffic in the local observation
- Worst-case complexity: $|I|^2 \cdot \prod_{i=1}^{|I|}(|C_{IF,i}|+1)$ state updates, where $|I|$ is the number of phases/inflows, and $|C_{IF,i}|$ is the number of jobs on inflow i
- Performs 2-4 orders of magnitude faster than COP [2]

Coodination in Network

- Consider non-local impacts in the network



Intuition: Predicted inflows (IFs) $\xrightarrow{schedule}$ Control flow (CF) $\Rightarrow$ Planned outflows (OFs) = Predicted non-local inflows for downstream neighbors

- Use an optimistic coordination protocol

- *Decentralized / Scalable*: each agent only communicates with its direct neighbors, but can incorporate non-local impacts from direct and indirect upstream neighbors
- *Optimistic*: each agent tries to follow its own schedule, minor schedule changes in neighbors can be absorbed

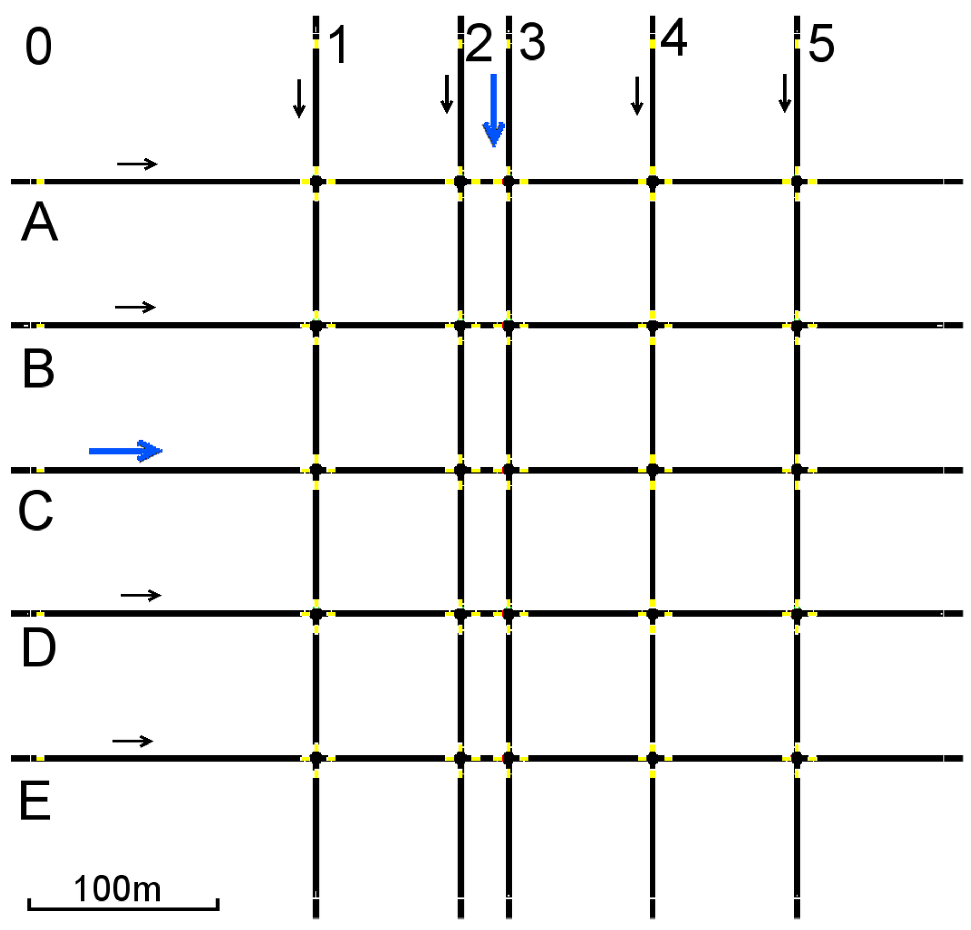
Algorithm 1 Obtain an optimistic non-local observation

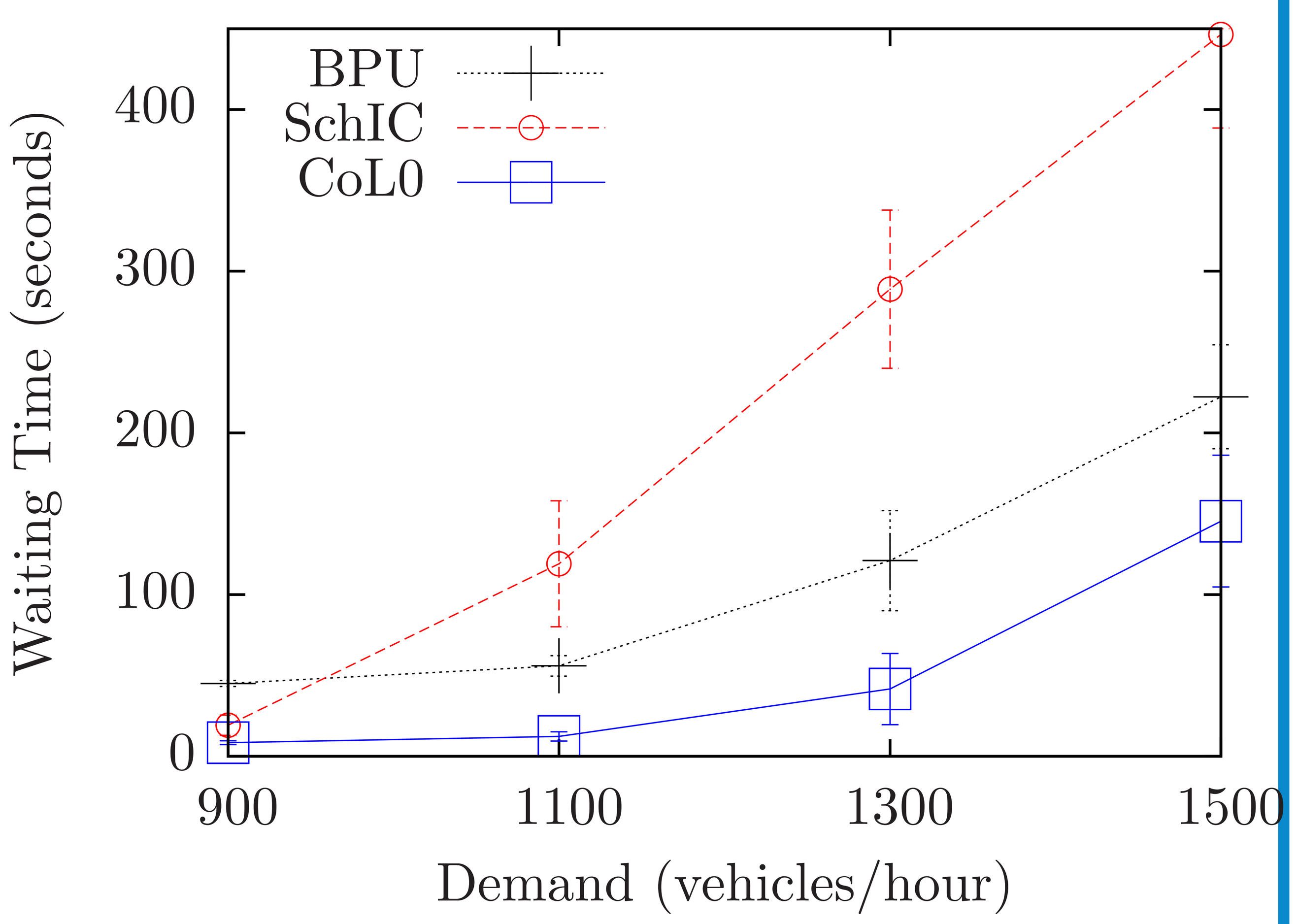
1: $m = GetEntryRoadByPhase(i)$ {For each phase i}
2: $UpAgent = GetUpstreamAgent(m)$
3: Request C_{OF} from $UpAgent$ using (cdt, m, H_{ext})
4: $Shift(C_{OF}$, the travel time on $m)$
5: Append C_{OF} into $C_{IF,i}$

Algorithm 2 Return C_{OF} for a message (cdt, n, H_{ext})

1: $(C_{OF}, S_{OF}) = (C^*_{CF}, S^*) \cap [cdt, cdt + H_{ext}]$
2: **for** $k = |C_{OF}|$ to 1 **do**
3: $|c_{OF,k}| = |c_{OF,k}| \cdot tp(s_{OF,k}, n)$ {turning proportion}
4: **end for**

Performance Evaluation





Simulation Settings

- Scenario: grid network with tightly-coupled intersections (with 2.5 or 7.5-second travel time on one edge)
- Dynamic demands on the bottleneck intersection C3

Control Strategies

- BPU: Balanced phase utilization [1] (offset calculation)
- SchIC: Schedule-driven intersection control [3]
- CoL0: SchIC + Optimistic non-local observation

- CoL0 produced lower waiting times than both other strategies. Comparison to SchIC demonstrates the added benefit of optimistic non-local observation. Furthermore, CoL0 outperforms BPU without requiring explicit offset calculation; coordination between neighbors is instead accomplished implicitly by looking ahead to upstream output flows.

Ongoing Work and Future Directions

- Pilot test: *Scalable urban traffic coordinator*

- Currently testing approach on a 9-intersection 2-way road network in the East Liberty area of Pittsburgh, PA, USA
- Real-world challenges: uncertainty, robustness to failures
- URL: `https://pilot.surtrac.net` (available soon)

- Advanced coordination mechanisms

- Pricing mechanisms to dampen any disruptive changes on schedules made by upstream agents (intersections)
- Negotiation mechanisms to reach for an equilibrium in an over-saturated traffic sub-network
- Dynamic learning of edge weights for critical flows