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ADVANCING ROAD SAFETY THROUGH TWINNING

PhD SEMINAR SESSIONS

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Learning Cooperative Multi-Agent Adaptive Control System of Signalized Intersections based on Growing Neural Gas for Mixed Traffic Flows

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Contents

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Introduction

- Traffic in urban cities is primarily controlled by traffic signal control systems
    - Fixed Traffic Signal Control (FTSC)
    - Traffic Actuated Signal Control (TASC)
    - **Adaptive Traffic Signal Control (ATSC)**
- Wrong choice of signal programs can have a negative impact on the traffic flow and cause significant delays in the transport network

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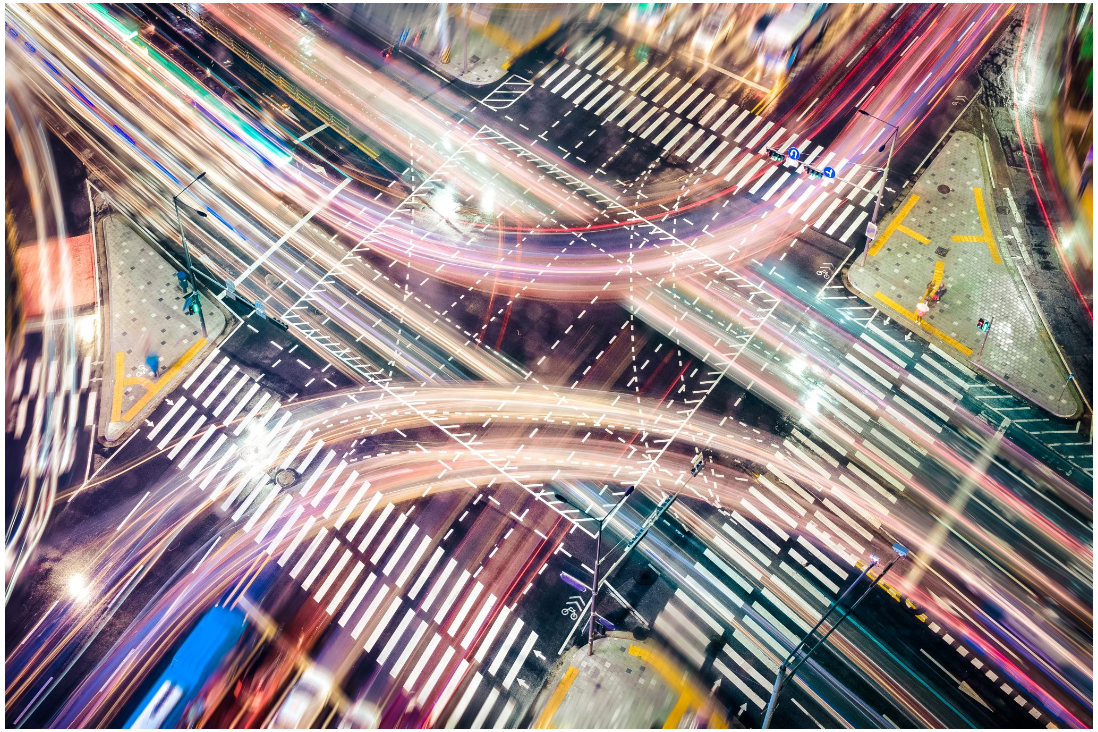
Adaptive Traffic signal control

- Signal program changes according to the current traffic state to satisfy desired operational objective
    - Smooth traffic flow
    - Maximization of throughput
    - Access equity
    - Queue management
- Real time traffic data is a requirement for ATSC
- Commercial systems: SCOOT, SCATS, UTOPIA, ImFlow...
- Modern research approaches based on **reinforcement learning**



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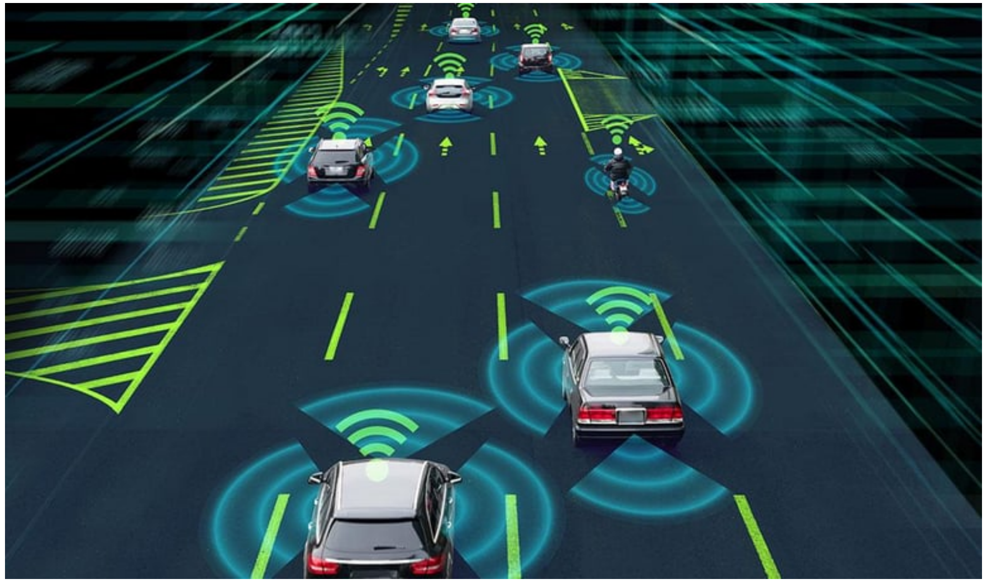
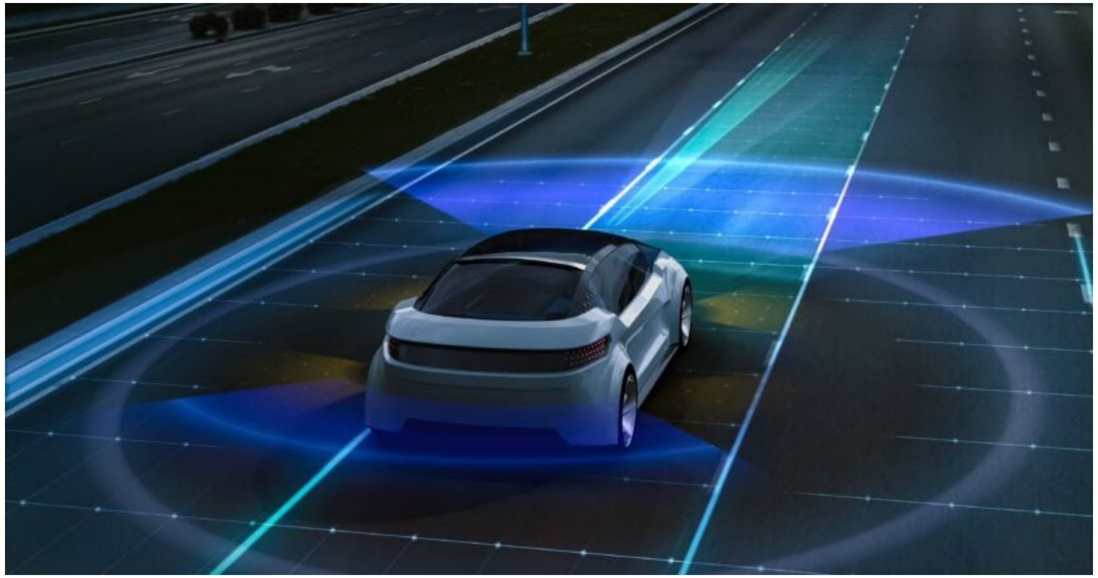
Mixed traffic flows

- Connected Vehicles (CV)



https://www.tataelxsi.com/news-and-events/how-connected-vehicles-can-make-indian-roads-safer

- Autonomous Vehicles (AV)



https://tempuslogix.com/available-autonomous-vehicles/

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Mixed traffic flows

- Connected and Autonomous Vehicles (CAV)
  - Combination of CV and AV
  - Send data
  - Receive data
  - React do the data

- Mixed traffic flows
  - Human driven vehicles (HDVs)
  - CAVs with variable penetetration rate

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Mixed traffic flows

- How can we exploit mixed traffic flows for traffic signal control?
- Do we need traffic signal control if all vehicles are CAV?

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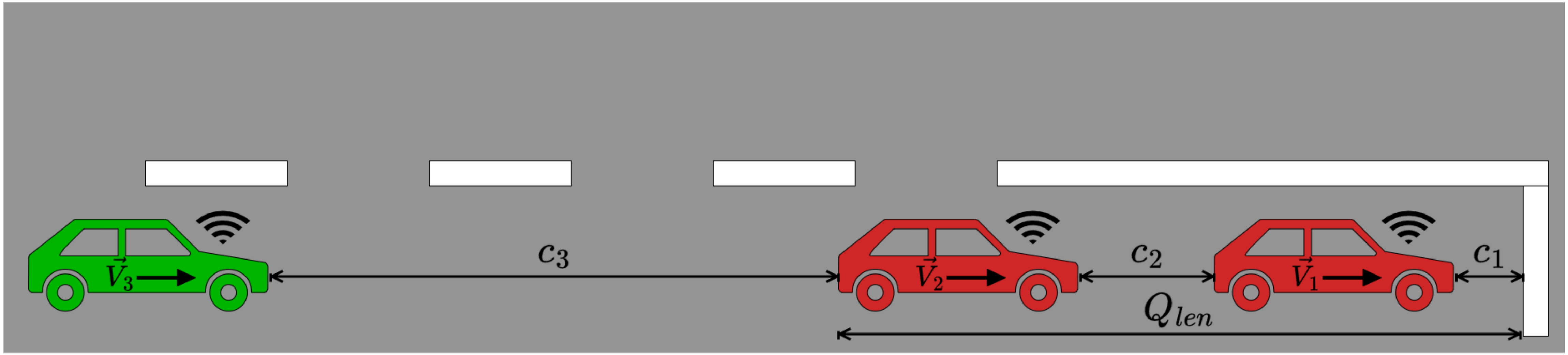
Mixed traffic flows

- Estimation of queue lengths



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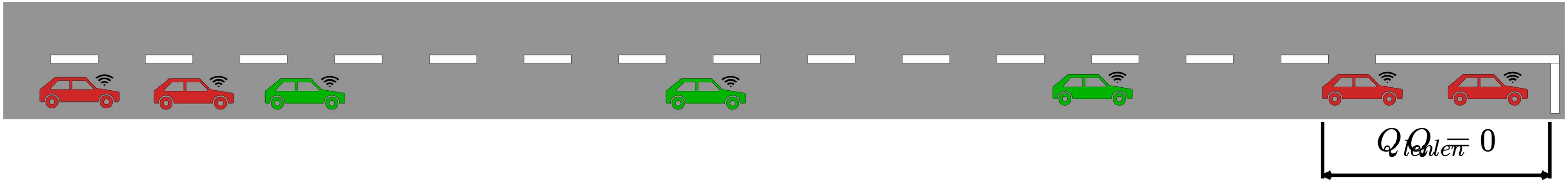
Mixed traffic flows

- Problems?



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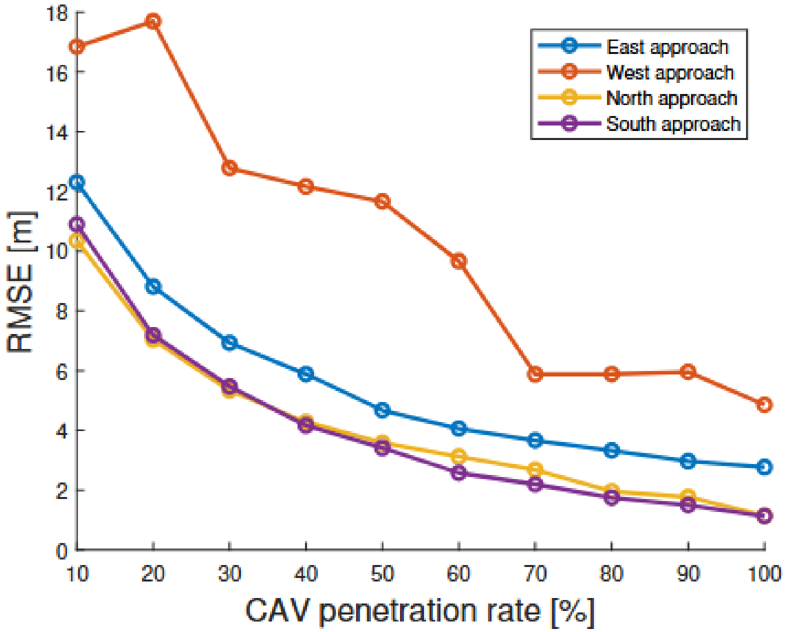
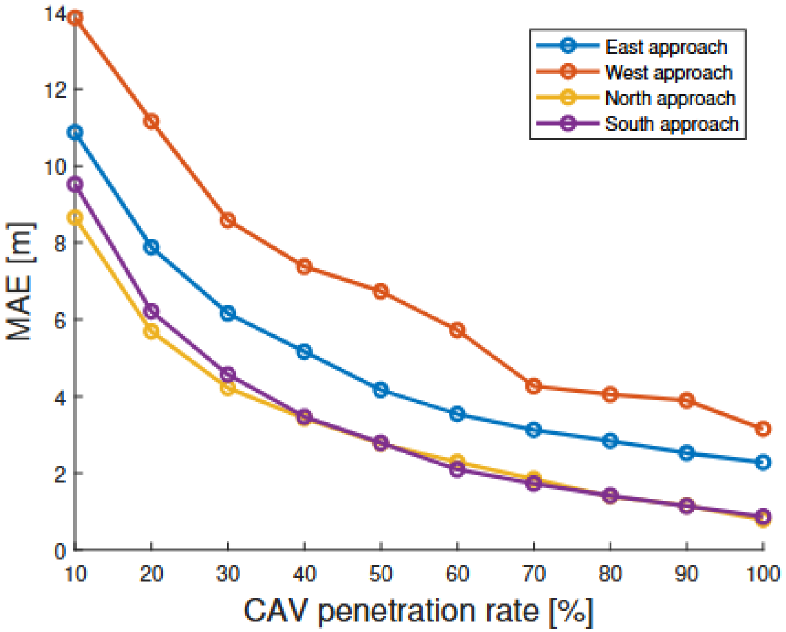
Mixed traffic flows



(a) RMSE



(b) MAE

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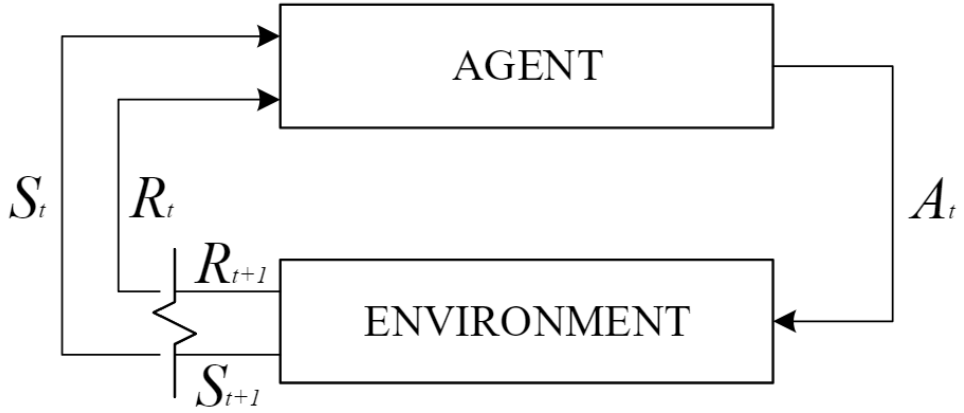
Reinforcement learning

- Subset of machine learning
- „Learning by doing“
- Attempt to construct an optimal control policy
- Formaly the controller is defined as a Markov Decision Process (MDP) using a tuple $<S, A, T, R, \gamma>$



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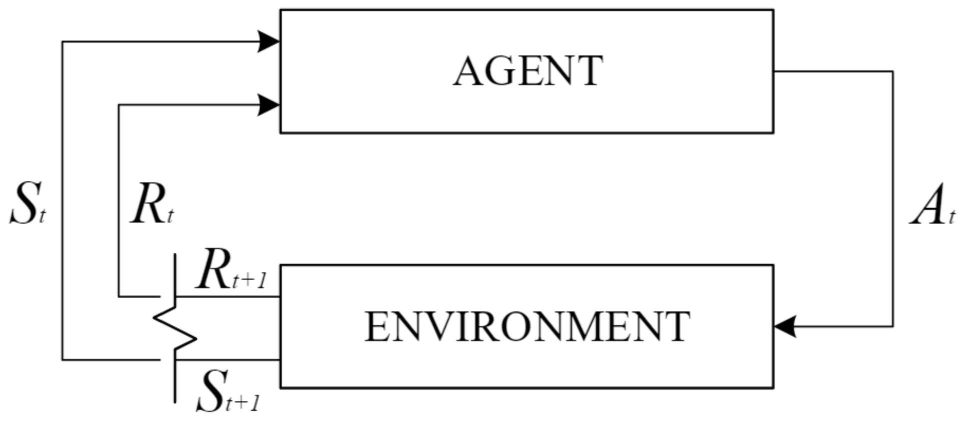
Reinforcement learning

- Formaly the controller is defined as a Markov Decision Process (MDP) using a tuple <S, A, T, R, γ>
  - State – S
  - Action – A
  - Transition – T
  - Reward – R
  - Discount Factor – γ



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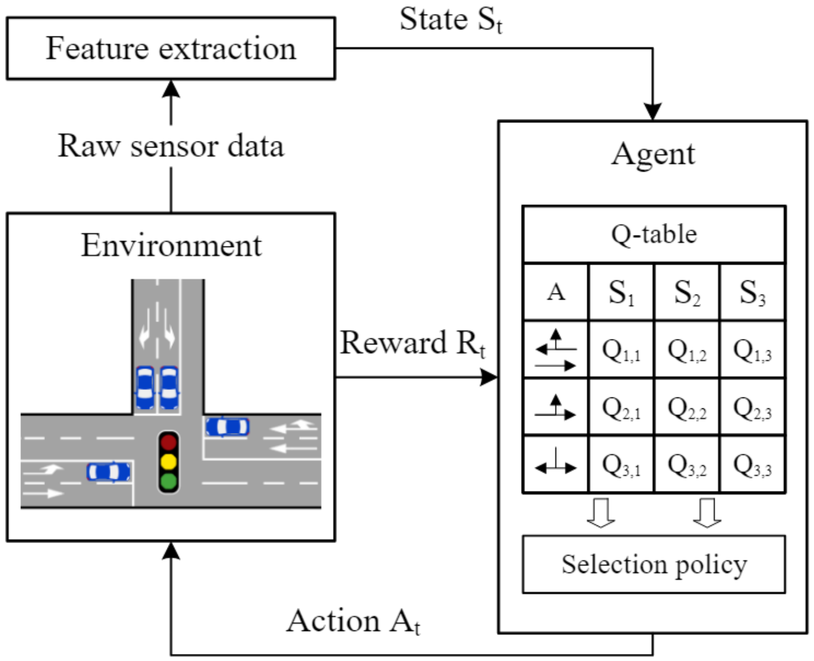
Reinforcement learning for ATSC

- State – S (Traffic situations)
- Action – A (Chages to signal program)
- Transition – T (Moving from one traffic situation to another)
- Reward – R (The operational objective in numerical form)



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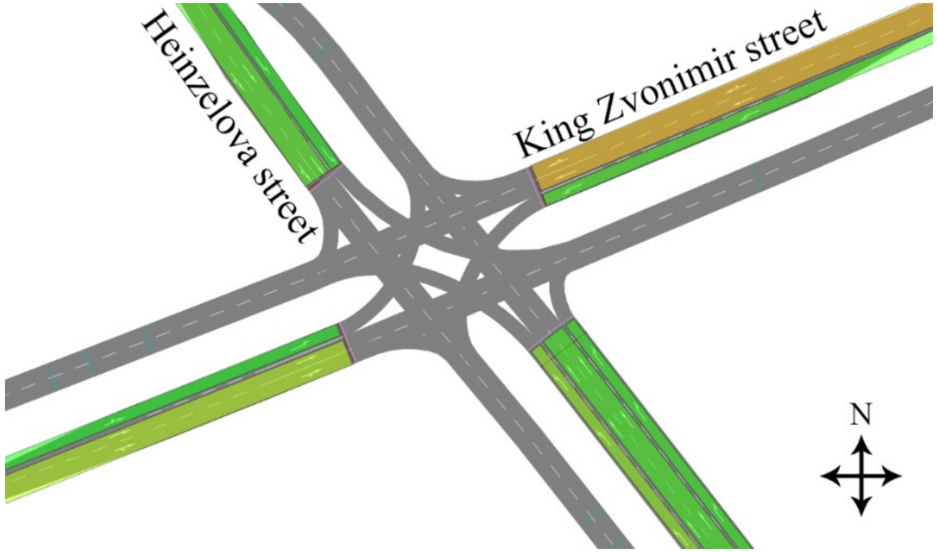
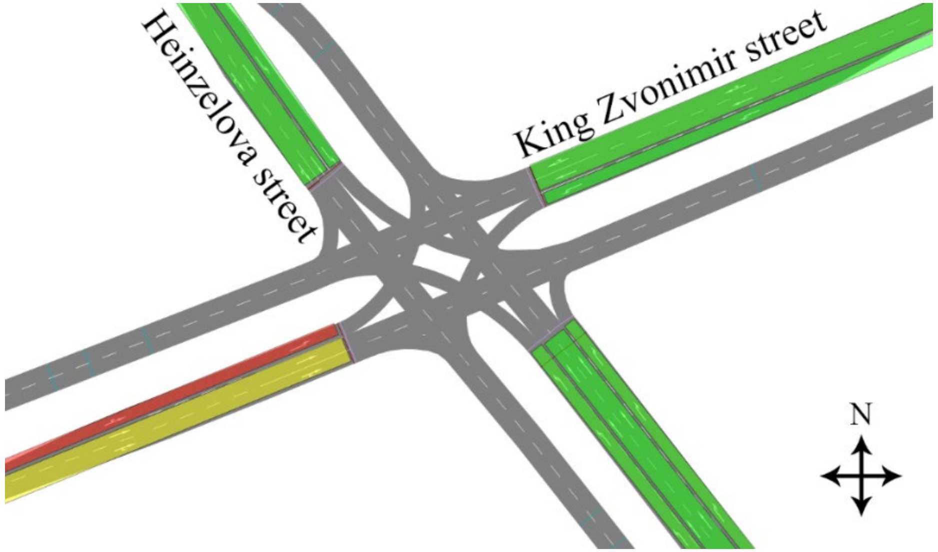
Reinforcement learning for ATSC





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Reinforcement learning for ATSC

- Actions
  - Change phase duration
  - Change cycle time
  - Change offset
  - Switch to next phase
  - Do nothing

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Reinforcement learning for ATSC

- Reward – tied to the operational objective!

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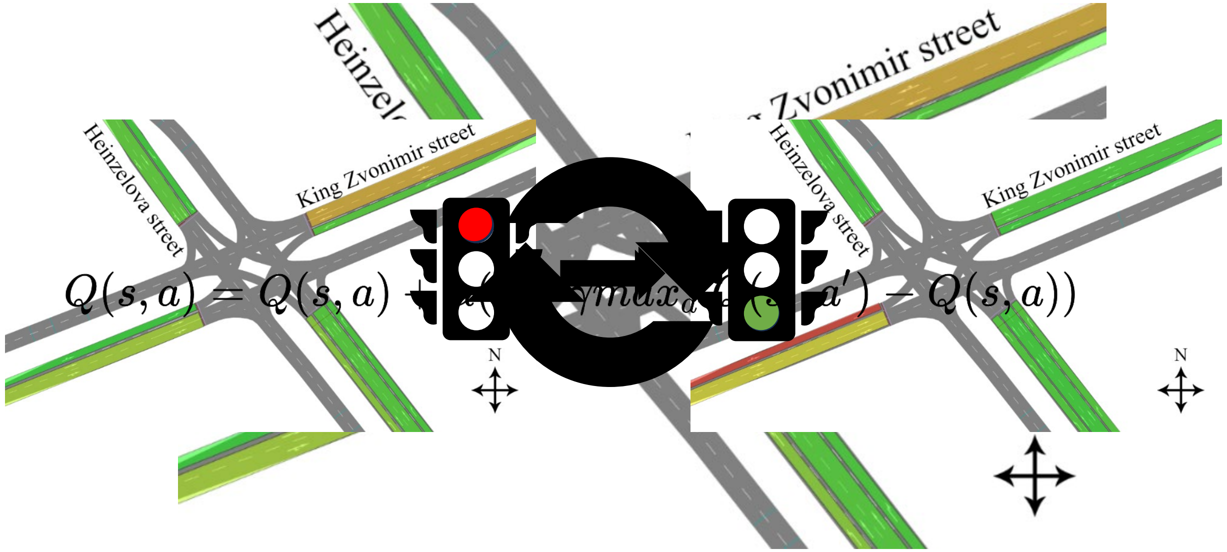
Reinforcement learning for ATSC

- Algorithm (Q-learning)
  - Observe the environment
  - Do something
  - Observe what happened
  - Update knowledge
  - Repeat!



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Reinforcement learning for ATSC

- Wait?! What about traffic safety?
- Can ATSC systems learn about safety?
- Can we measure safety?

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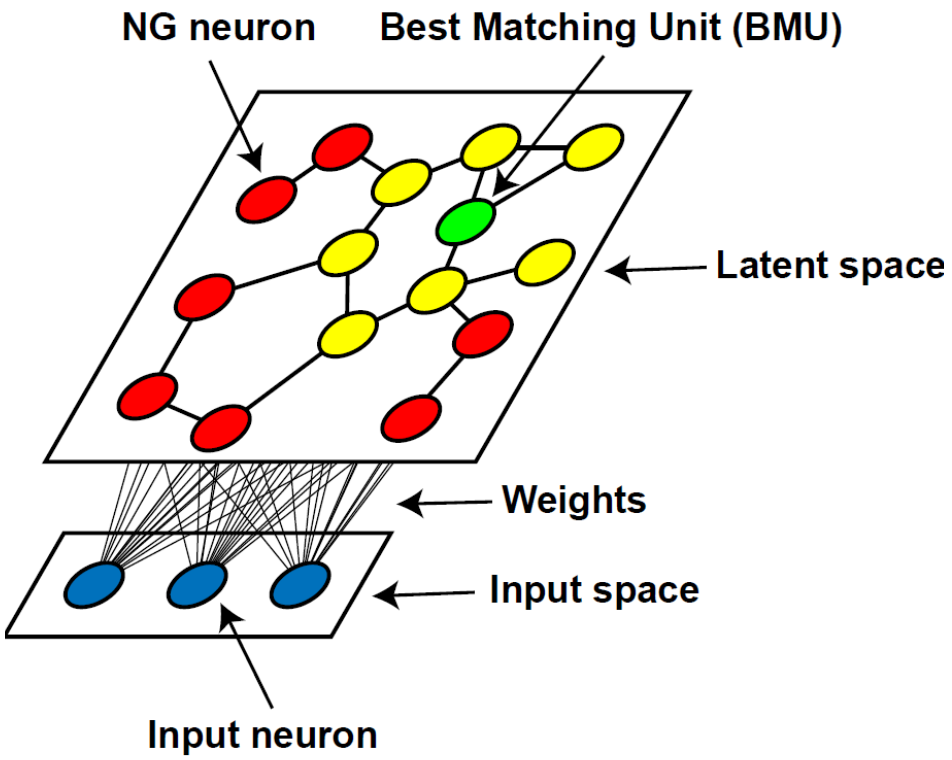
Growing Neural Gas

- A type of Neural Network (sort of)
  - Only one layer
  - Lateral connections between neurons
  - Dimensionality reduction
  - Topology preservation



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Growing Neural Gas

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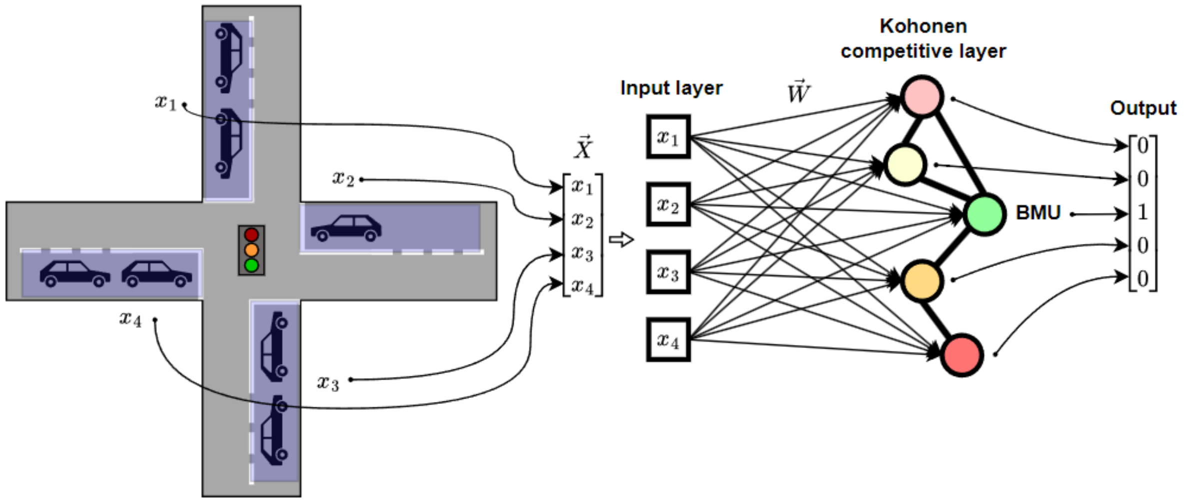
Growing Neural Gas for ATSC

- Combining GNG with Q-learning



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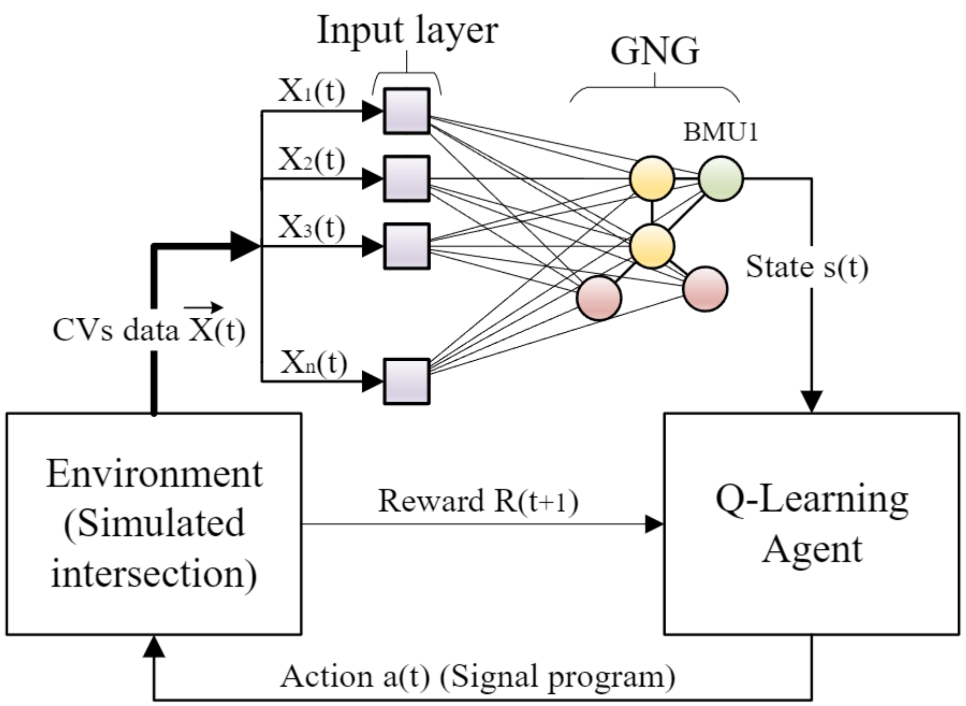
Growing Neural Gas for ATSC



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Multi-agent systems

- Multiple agents acting in the same environment!
- Why not just one?
- Any problems with multiple agents?

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Multi-agent systems for ATSC

- Configurations analyzed
  - Fully independent
    - Non-cooperative
    - Limited state knowledge
  - State sharing
    - Non-cooperative
    - Increased state knowledge
  - Centralized state with decentralized agents
    - Non-cooperative
    - Maximum state knowledge
  - Reward sharing
    - Addition to each of the configurations above
    - Cooperative behavior

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Multi-agent systems for ATSC

- Fully independent agents
  - Simple to implement
  - No communication between agents needed
  - Will continue working even if other agents malfunction
  - Can negatively affect neighboring agents
  - Can positively affect neighboring agents

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Multi-agent systems for ATSC

- State sharing
  - Agent is aware of what is happening on neighboring agents
  - Easier to prepare for upcoming traffic
  - Affect neighbors without knowing

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Multi-agent systems for ATSC

- Centralized state with distributed agents
  - Complete knowledge of the entire network
    - Is this good?
    - Is this bad?
    - It depends?
  - Still acting independently while affecting others

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Multi-agent systems for ATSC

- Reward sharing
  - The agents receives positive reward if its neighbors perform well
  - How do we balance between local reward and global reward?
    - Easy! We introduce a scaling parameter β

$$r = LT(k) - LT(k+1) + \beta\left(\frac{1}{n}\sum_{m=1}^{n} LT_m(k) - LT_m(k+1)\right)$$

    - $\beta = \{0.25, 0.5, 0.75, 1.00\}$
  - Is this the answer to all our problems?

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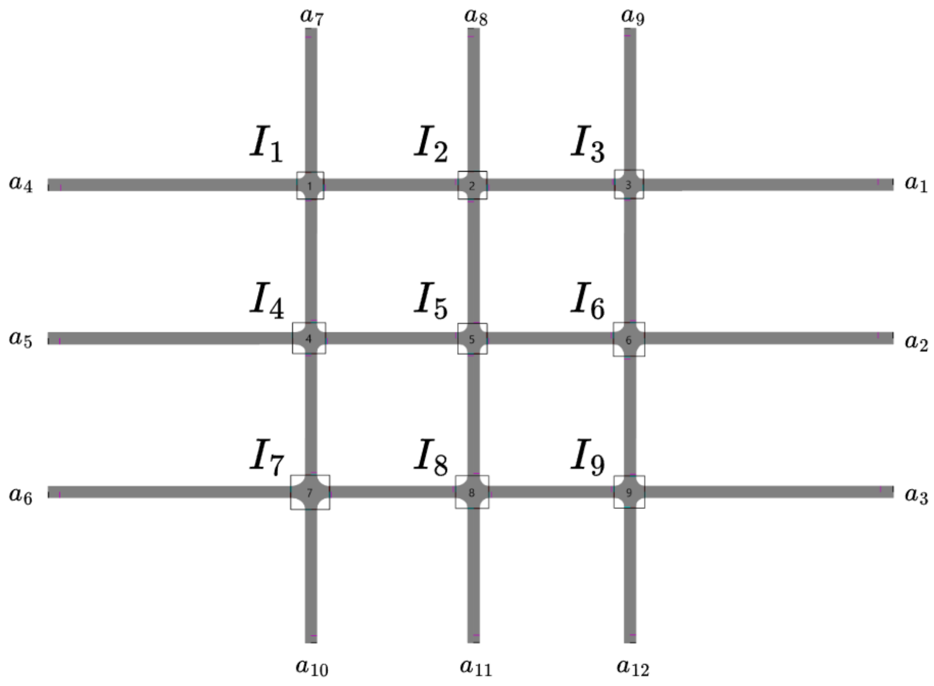
Multi-agent systems for ATSC

- VISSIM model



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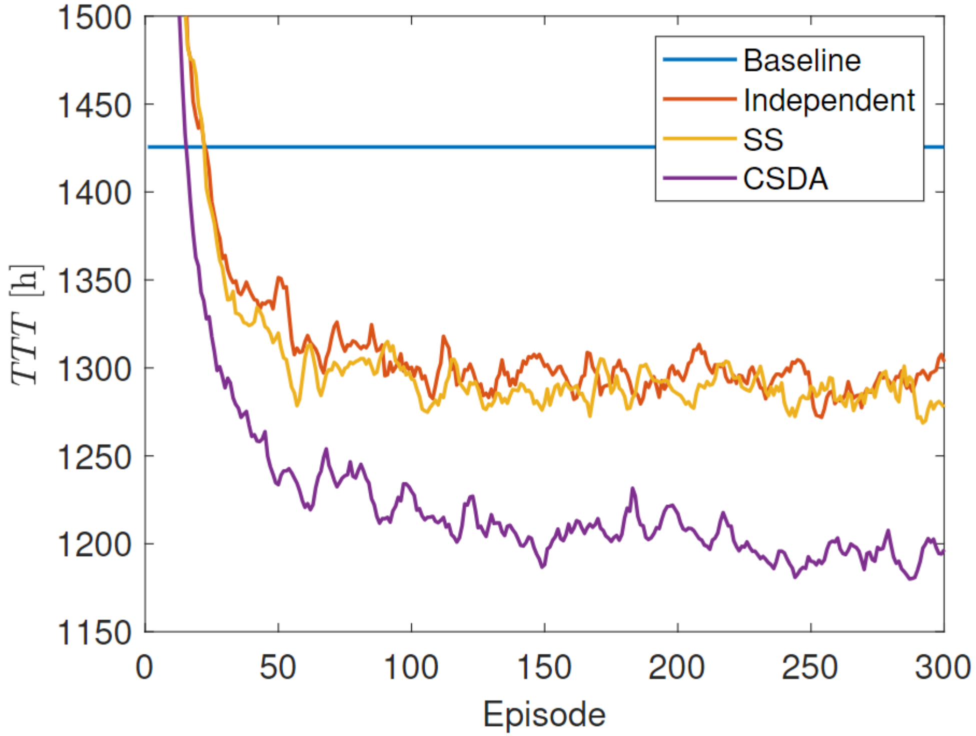
Multi-agent systems for ATSC

- Results



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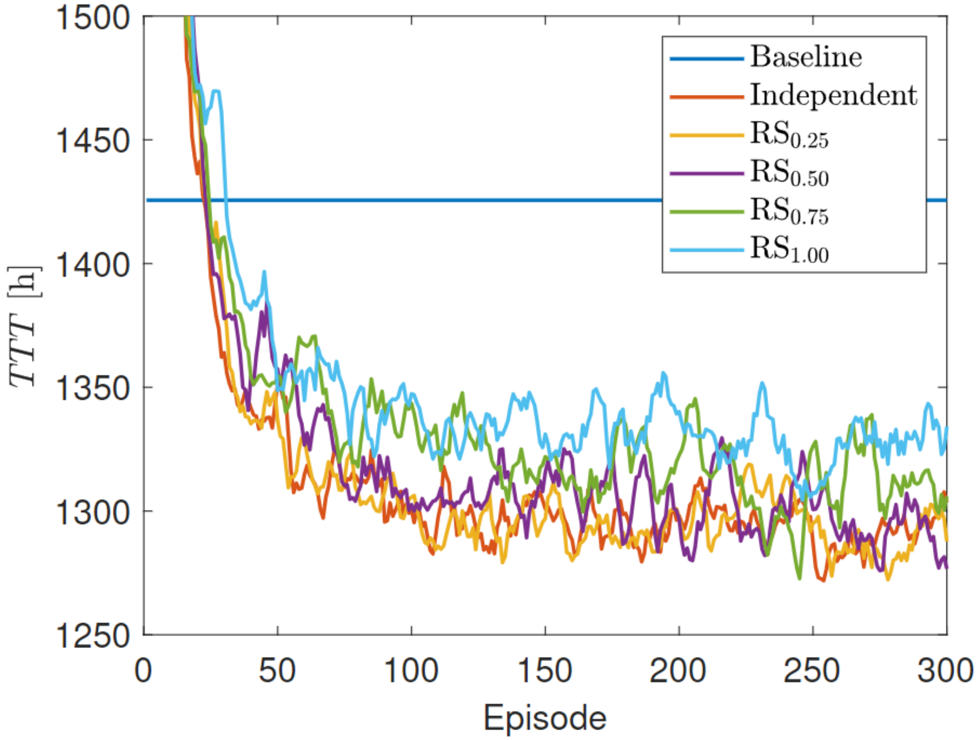
Multi-agent systems for ATSC

- Results



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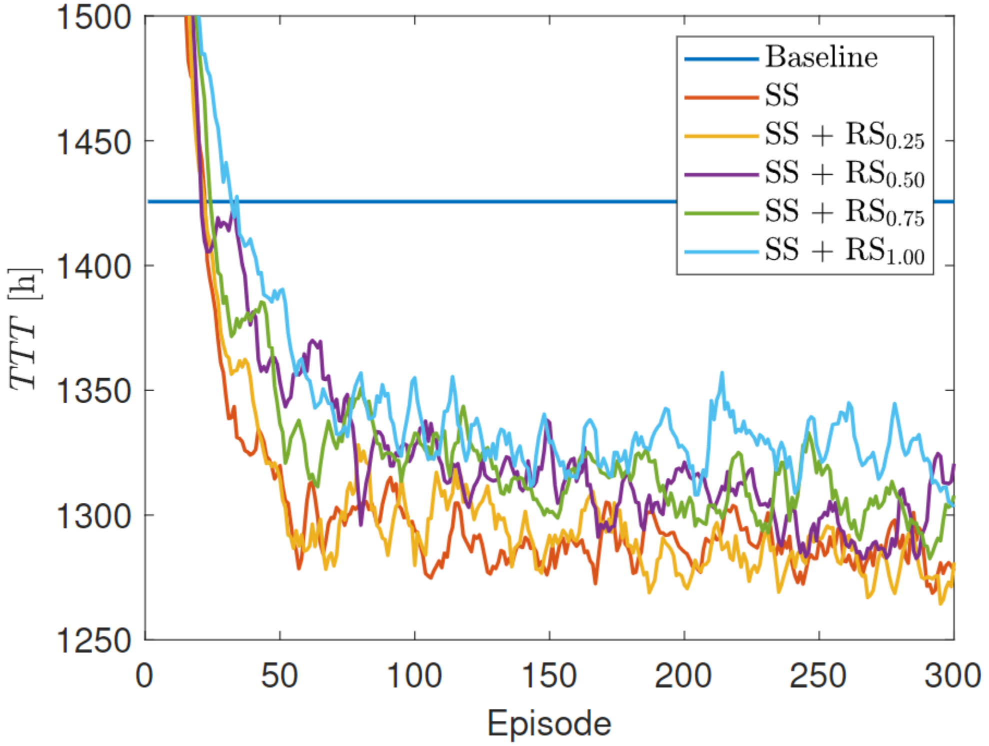
Multi-agent systems for ATSC

- Results



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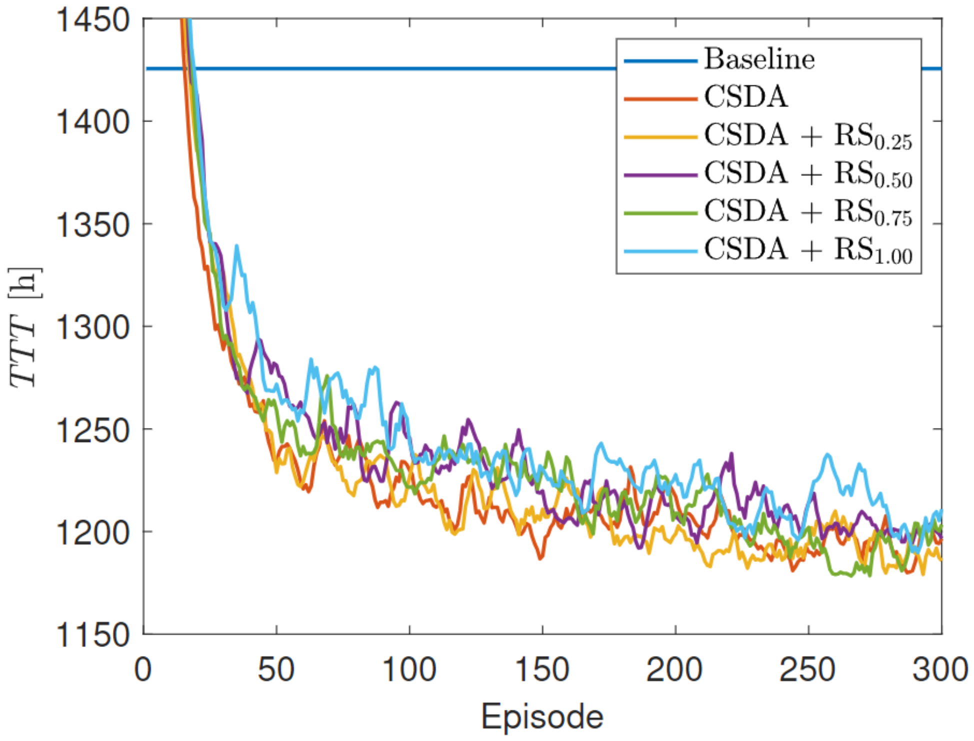
Multi-agent systems for ATSC

- Results



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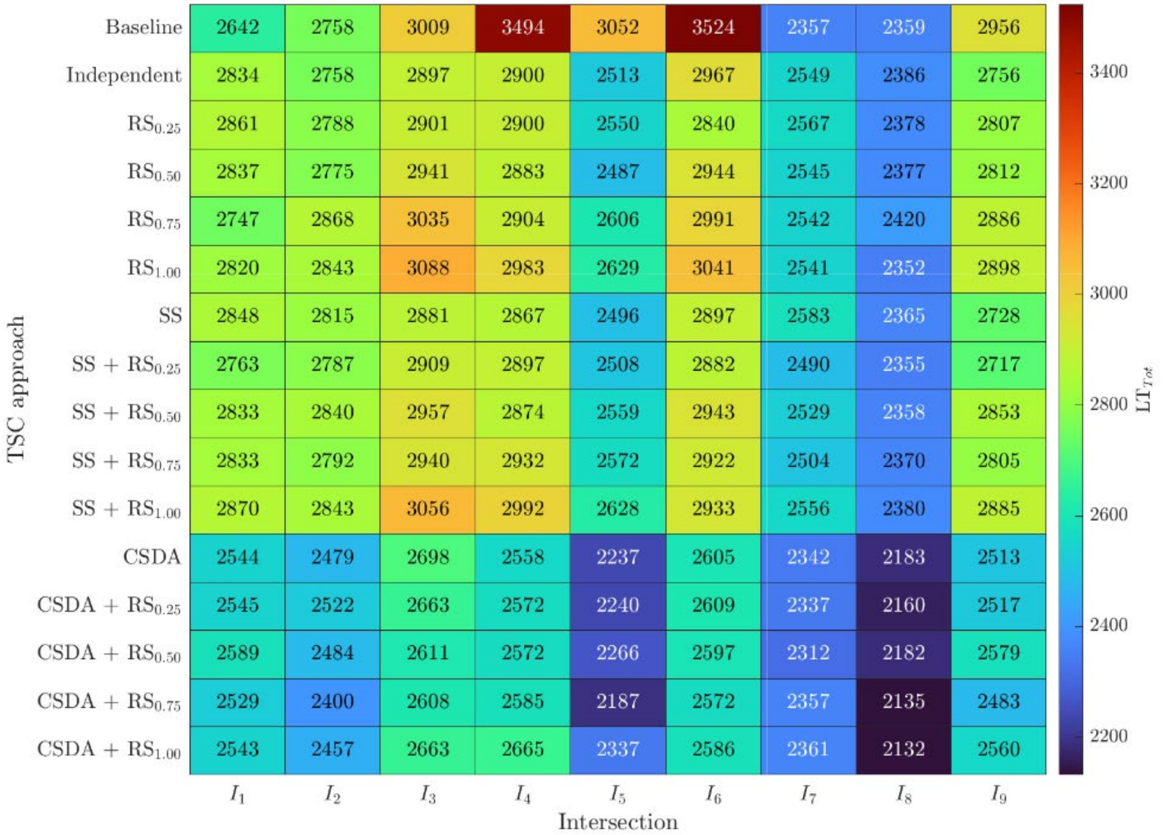
Multi-agent systems for ATSC

- Results



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Putting it all together

- CVs give data
- GNG builds state representation
- Q-learning learns optimal control policy

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Conclusion

- CV data important but mixed flows are ok
- Several families of algorithms analyzed
- CSDA performs the best with reward sharing

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Future work

- Heterogenous agents
- Realistic traffic networks
- Environmental impact analysis
- Traffic safety analysis

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Acknowledgements

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