Distributed Dynamic Routing Using Network of Intelligent Intersections

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The Project Synopsis

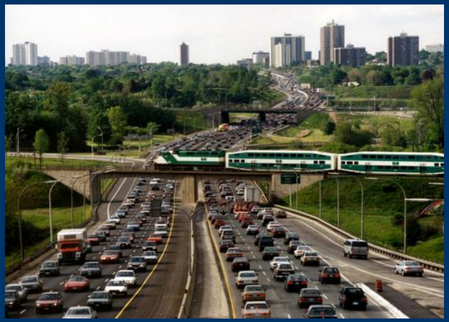
Distributed dynamic routing system development

- Provides single integrated and coherent picture of the network that is frequently and reliably updated
- Reduces congestion and maximizes capacity without worrying about drivers' compliance and inertia
- Scalable, no need for costly infrastructure, and computationally less expensive

Outline of Presentation

- Motivation & Background
- End-to-End Dynamic Routing in Connected & Automated Vehicle Environment (E2ECAV)
- Case Study
  - Downtown Toronto Network
- Summary and Future Work

Motivation



Congestion

Accidents

Pollution

- Annual cost to commuters in the Greater Toronto and Hamilton Area was $3.3 billion in 2006

- Estimated cost for 2031 will balloon to $7.8 billion (commuters) and $7.2 billion (economy)

[METROLINX]

Motivation

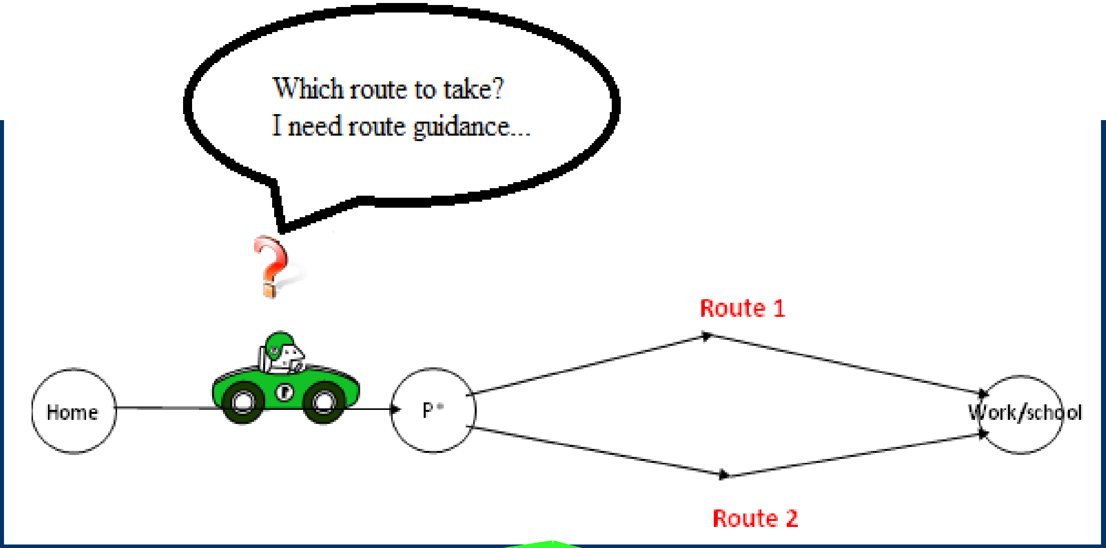
Problem

- **Congestion** (Inefficient use of roads)
  1. Local factors that are responsible for local perturbations
  2. Global factors impacting the entire network

Solution

- Distribute traffic optimally over the network using vehicle routing

Background



Static Route Guidance
- Historical information
- Geographical locations

Dynamic Route Guidance (DRGS)
- Real time Traffic Info

Control Structure: Distributed (V2I) + (I2I) | Centralized

Role: System Optimal (SO) ↔ User Optimal (UO)

Background – DRGS

User Optimal Solution (e.g. Waze)

- Stable and fair from the perspective of drivers
- Potential of reducing travel time in the case of low to medium congestion

Drawbacks

- High congestion, high penetration rate and adverse condition
  - Increase in travel time and increase in congestion

- Efficiency depends on the market penetration rate and the communication range of CAVs

Yange & Recker (2006); Lee & Park (2008); Katan et al (2012)

Background – DRGS

System Optimal Solution

- 30% reduction in travel time under high congestion and adverse conditions

Drawbacks

- Unstable and unfair from drivers' perspective
- Success depends on % compliance of the drivers

Zuurbier (2010); Wie et al (1995); Roughgarden & Tardos (2002); Boyce & Xiong (2004); Peeta & Mahmassani (1995); van den Bosch et al (2011)

Background – DRGS

Research Gaps

- Effects of individualistic and non-compliant behaviour of drivers

- V2V Solutions
  - No single integrated and coherent view of the network
  - Relies on MPR and range

Vehicle Routing Requirements

- Provide up to date and reliable real time traffic information
- Have single integrated and coherent view of the network
- Responsive to the changes in the network
- Maximize capacity & minimize travel time
- Scalable, and computationally less extensive

End-to-End Distributed Routing in Connected and Automated Vehicle Environment (E2ECAV) using Network of Intelligent Intersections

E2ECAV – Components

- **The agents**

  Agent Type 1: Connected and Automated Vehicles

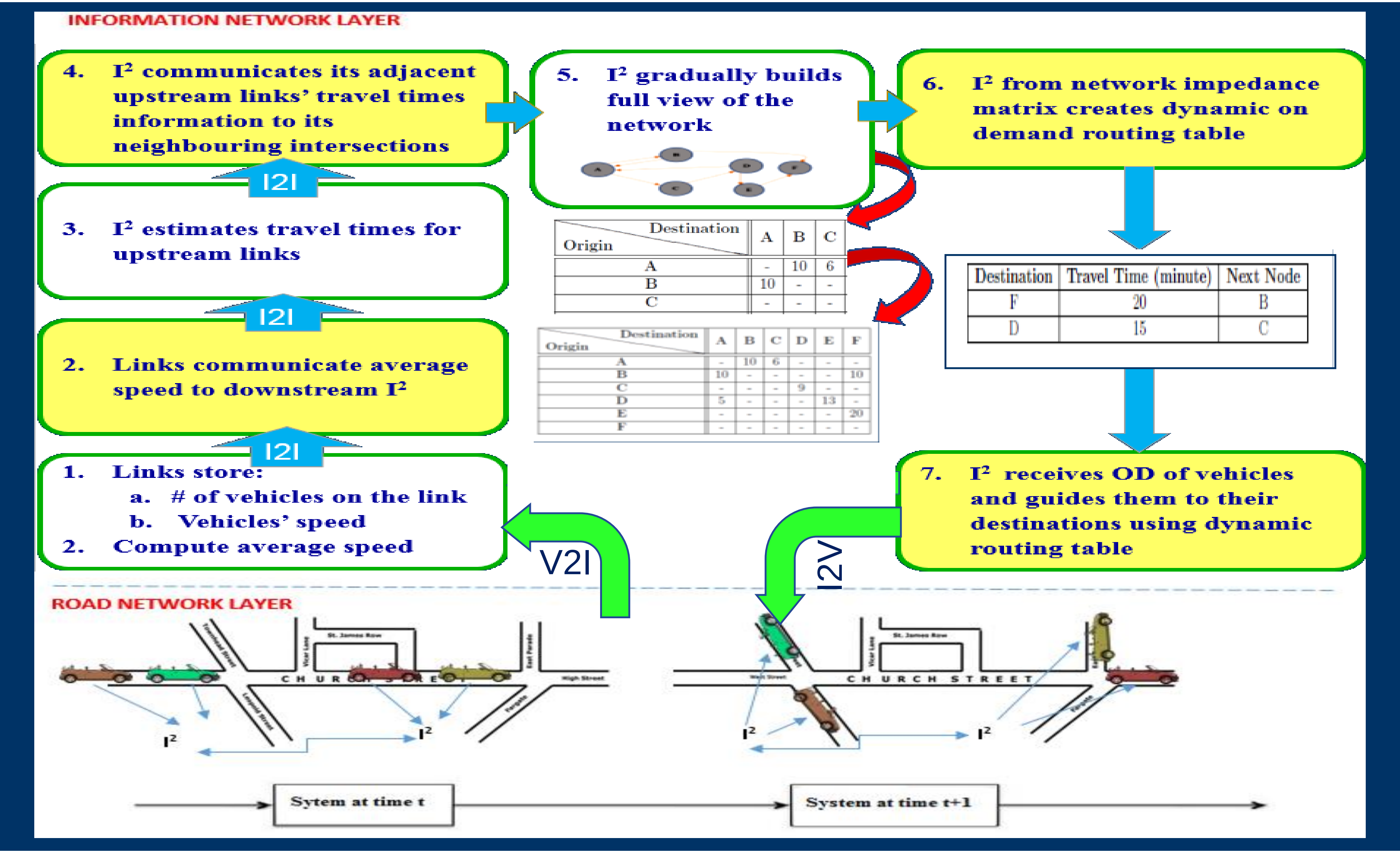
  Agent Type 2: Infrastructure

  - Links
  - Intersections

- **The agents' environment**
  - Road network
  - Communication network

- **Interaction Rules**
  - **Defined by the city**

E2ECAV


INFORMATION NETWORK LAYER
4. I² communicates its adjacent upstream links' travel times information to its neighbouring intersections
5. I² gradually builds full view of the network
6. I² from network impedance matrix creates dynamic on demand routing table
I2I
3. I² estimates travel times for upstream links
I2I
2. Links communicate average speed to downstream I²
I2I
1. Links store:
a. # of vehicles on the link
b. Vehicles' speed
2. Compute average speed
Destination Origin A B C
A - 10 6
B 10 - -
C - - -
Destination Travel Time (minute) Next Node
F 20 B
D 15 C
7. I² receives OD of vehicles and guides them to their destinations using dynamic routing table
V2I
I2V
ROAD NETWORK LAYER
CHURCH STREET
St. James Row
I²
Sytem at time t
System at time t+1

E2ECAV – Information Network Layer

1. Links store:
   a. # of vehicles on the link
   b. Vehicles' speed
2. Compute average speed

I2I

2. Links communicate average speed to downstream I^2

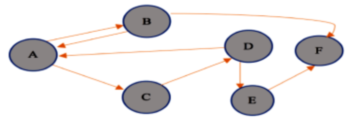
I2I

3. I^2 estimates travel times for upstream links

I2I

4. I^2 communicates its adjacent upstream links' travel times information to its neighbouring intersections

5. I^2 gradually builds full view of the network



Origin \ Destination	A	B	C
A	-	10	6
B	10	-	-
C	-	-	-

Origin \ Destination	A	B	C	D	E	F
A	-	10	6	-	-	-
B	10	-	-	-	-	10
C	-	-	-	9	-	-
D	5	-	-	-	13	-
E	-	-	-	-	-	20
F	-	-	-	-	-	-

6. I^2 from network impedance matrix creates dynamic on demand routing table

Destination	Travel Time (minute)	Next Node
F	20	B
D	15	C

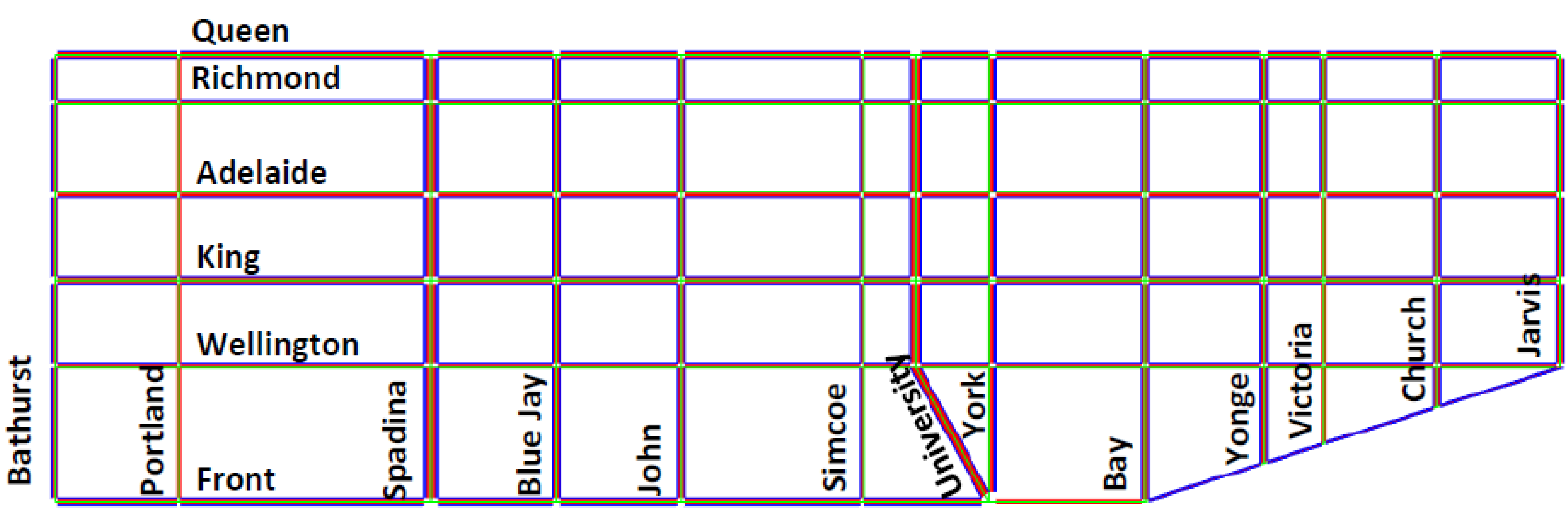
7. I^2 receives OD of vehicles and guides them to their destinations using dynamic routing table

V2I

I2V

Road Network Layer

Case Study – Toronto Network



Case Study –Toronto Network

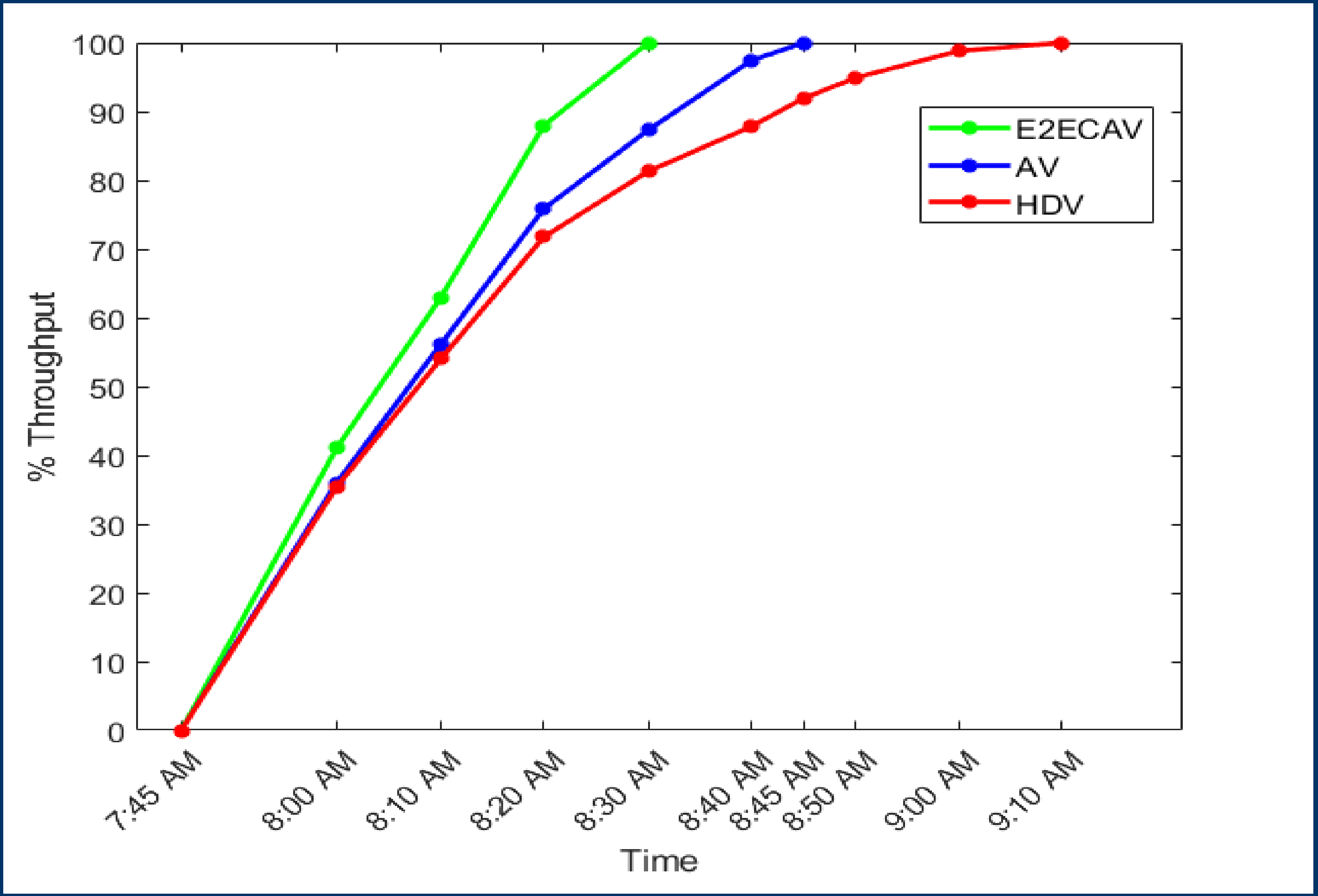
Specifications

- Study period: 7:45am-8:00am
- Dynamic 5 min OD Matrices (Transportation Tomorrow Survey, 2011)
- 76 intersections, 223 links
- Three types of vehicles: HDV , AV, CAV
- Movement: Intelligent Driver Model (IDM)
  - Same a_{max} & b_{max} for all three vehicle types
  - $T_{r,AV\ or\ CAV} = 2T_{r,HDV}$ and $s0_{AV\ or\ CAV} = 2s0_{HDV}$
- HDV & AV routed based on pre-trip dynamic shortest path
- CAV routed based on E2ECAV

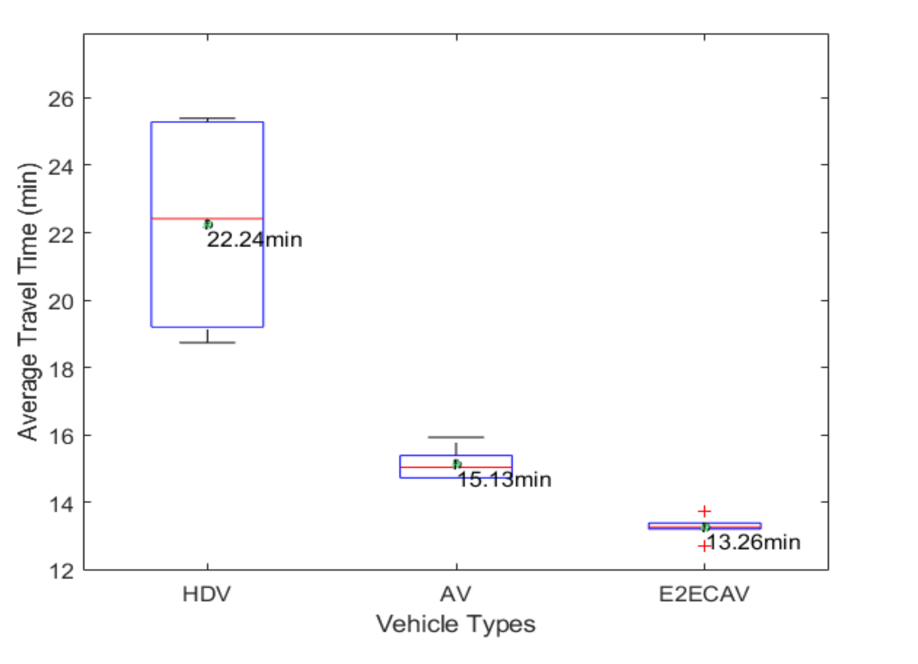
Case Study – Goal

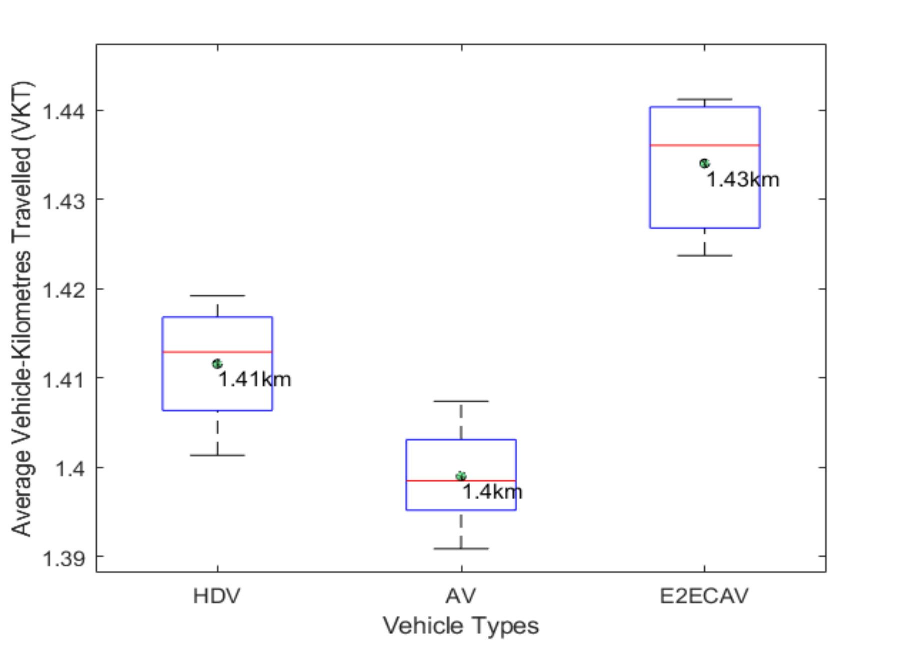
- Evaluating the performance of 100%E2ECAV and its impact on throughput/travel time in comparison to 100%HDV & 100%AV

Case Study – % Throughput Analysis



Case Study – Travel Time (min) & VKT Analysis





- E2ECAV resulted in 40% decrease in travel time in comparison to HDV
- AV resulted in 31% decrease in travel time in comparison to HDV

Summary

- Dynamic distributed E2E routing based on the network of connected intelligent intersections and level 5 CAVs
    - Reliable and up-to-date traffic information along with single integrated and coherent view of the network
    - Responsive to the real time changes in the system
    - With drivers no longer the decision makers full cooperation and coordination can be expected
    - Distributes traffic in the network in such a way that maximizes capacity and minimizes travel time

Future Work

- Different queuing strategies and different classes of vehicles with different priority levels (e.g. emergency vehicles, street cars, etc.)

- Investigate the behavioral response of the drivers in CAV environment
    - Virtual Reality based experiments

- Comparison of E2ECAV with cooperative CAV using only V2V communication

- Shared and on-demand services

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