Smart Traffic Lights that Learn !

Multi-**A**gent **R**einforcement **L**earning **I**ntegrated **N**etwork of Adaptive Traffic Signal Controllers

M A R L I N

UNIVERSITY OF TORONTO

Samah El-Tantawy, Ph.D. — Post Doctoral Fellow, Dept of Civil Engineering

Baher Abdulhai, Ph.D., P.Eng. — Director, ITS Centre and Testbed, Dept of Civil Engineering

Hossam Abdelgawad, Ph.D., P.Eng. — Manager of ITS Centre and Testbed

ITS • STI CANADA

ACGM 2013- Intelligent Transport for Smart Cities

Outline

1. **In a Nutshell**
2. **Theory in Brief**
   - Reinforcement Learning and Game Theory
3. **Applications**
   - City of Toronto Testbed
4. **Hardware in the Loop Testing**
   - Approach
   - Integration with PEEK ATC-1000

- Next Steps
- Q&A

In a Nutshell

- **Grand objective**
  - Intersections "talk to each other",
  - Each is affected by what is happening upstream
  - Each affects what is happening downstream –
  - Whole network control in one shot from a grand brain is the dream
- **Issue**
  - Intractable theoretically,
  - Too complex practically,
  - Requires massive and very expensive communication
- **Solution**
  - Decentralized,
  - Self learning: **agents learn to control** their local intersection, and
  - Game theory based: **agents learn to collaborate**

What is MARLIN?

- Artificial-intelligence-based control software
- Enables traffic lights to self-learn and self-collaborate with neighbouring traffic lights
- Cuts down motorists' delay, fuel consumption and the negative environmental effects of congestion
- Easier to operate (self learning)
- Less expensive communication if even necessary (less costly)

Evolution of “Adaptive” Signal Control

MARLIN-ATSC: Level 4

Level 0

- Fixed-Time and Actuated Control
- **TRANSYT**
- 1969, UK

Level 1

- Centralized Control, Off-line Optimization
- **SCATS**
- 1979, Australia
- >50 installations worldwide

Level 2

- Centralized Control, On-line Optimization
- **SCOOT**
- 1981, UK
- >170 installations worldwide

Level 3

- Distributed Control, Model-Based
- **OPAC, RHODES**
- 1992, USA
- 5 installations in USA

Level 4

- Distributed Self-Learning Control
- **MARLIN-ATSC**
- 2011, Canada

Issues with Leading ATSC Technologies?

Centralized

- Expensive
- Not scalable
- Not robust

Model-Based

- Relying on an accurate traffic modelling framework
- the accuracy of which is questionable

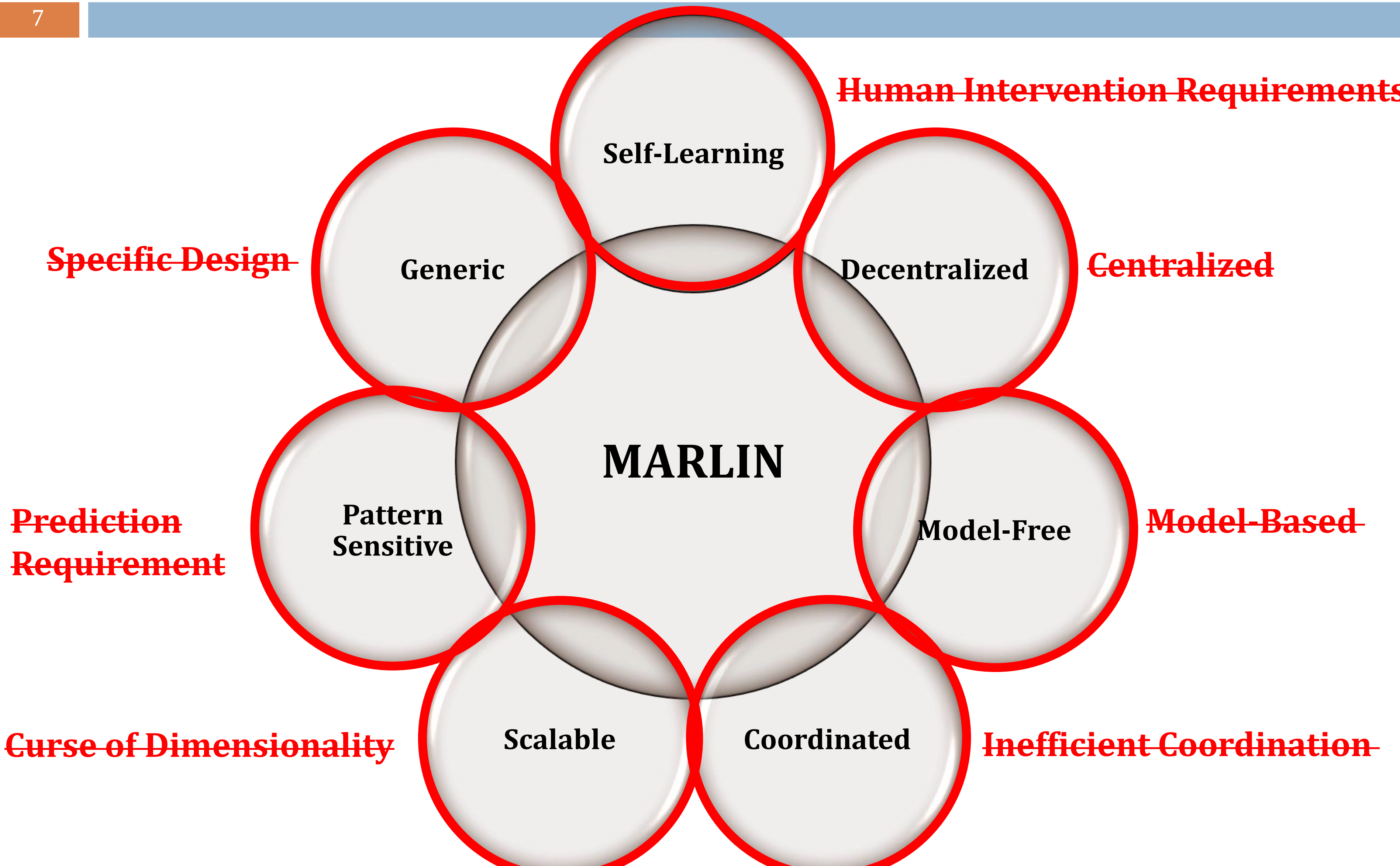
Curse of Dimensionality

- Increasing the complexity of the system exponentially with the increase in the number of intersections/controllers

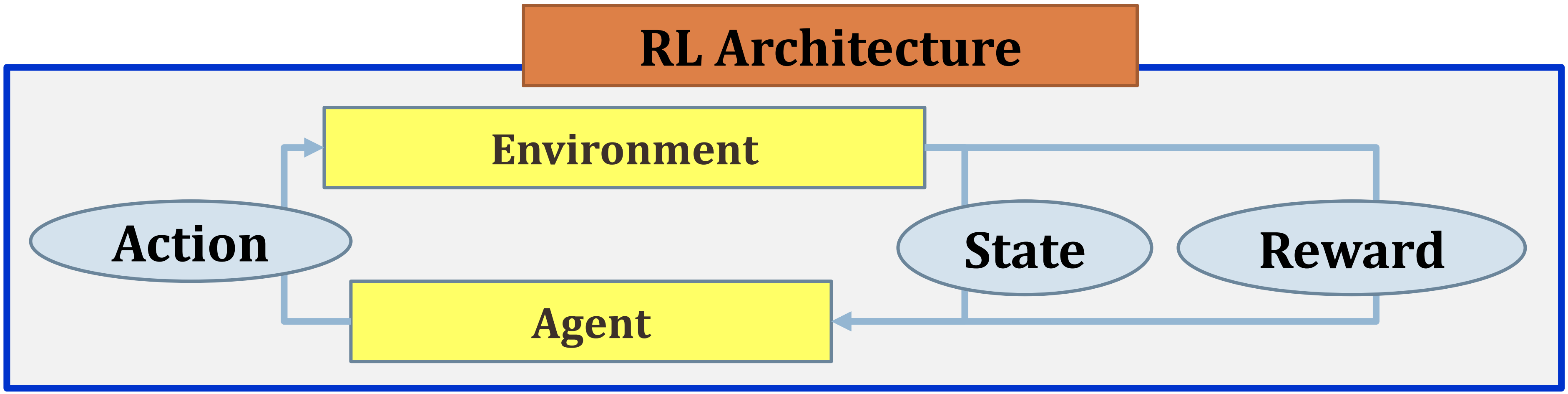
Human Intervention Requirements

- Requiring highly skilled labour to operate due to their complexity.

Why is MARLIN Different?



Learning the Control Law: Reinforcement Learning Architecture



Goal: Optimal Control law = mapping between states and actions

$$Q^{k+1}(s^k, a^k) = Q^k(s^k, a^k) + \alpha[r^{k+1} + \gamma \max_a Q^k(s^{k+1}, a) - Q^k(s^k, a^k)]$$

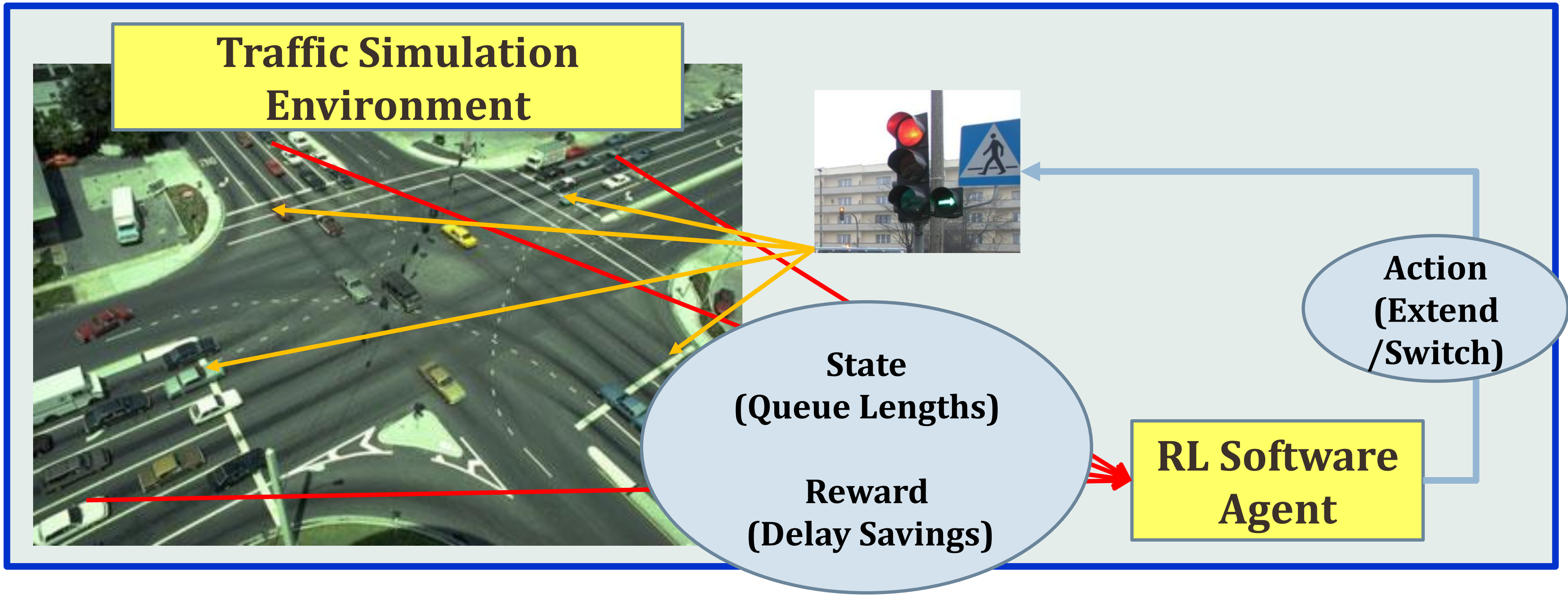
$$a^{k+1} = \arg\max_a Q^k(s^{k+1}, a)$$

Balancing exploration and exploitation

Q Table

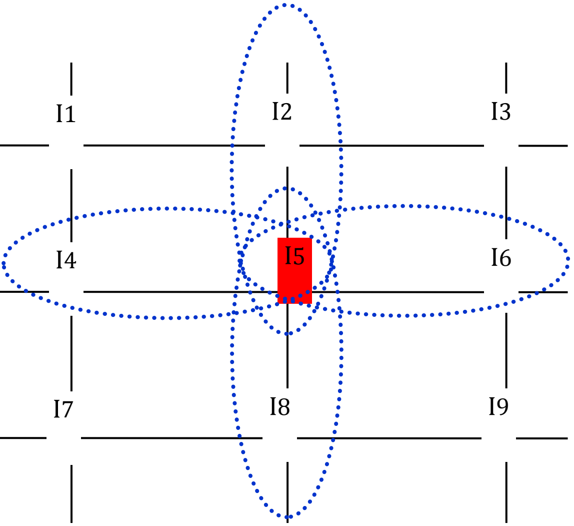
Q	a_1	a_2
s_1	-10	-5
s_2	-3	-15

RL-based ATSC Architecture

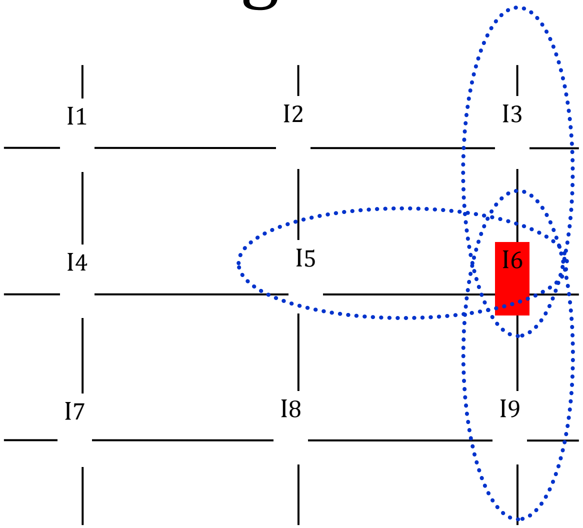


MARLIN- ATSC: Coordination Principle

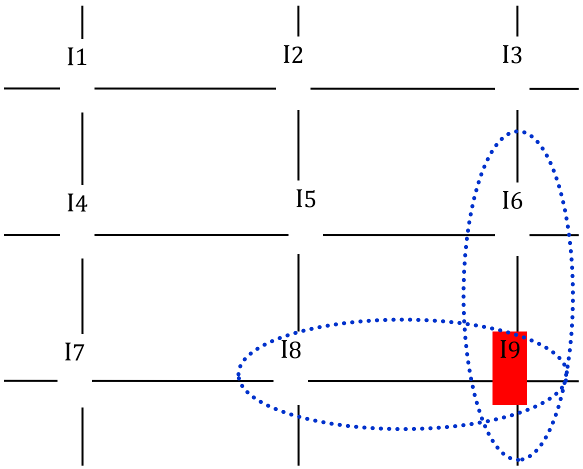
- Each agent plays a game with each adjacent intersection in its neighborhood



Example for Intermediate Intersection
(4 Games)



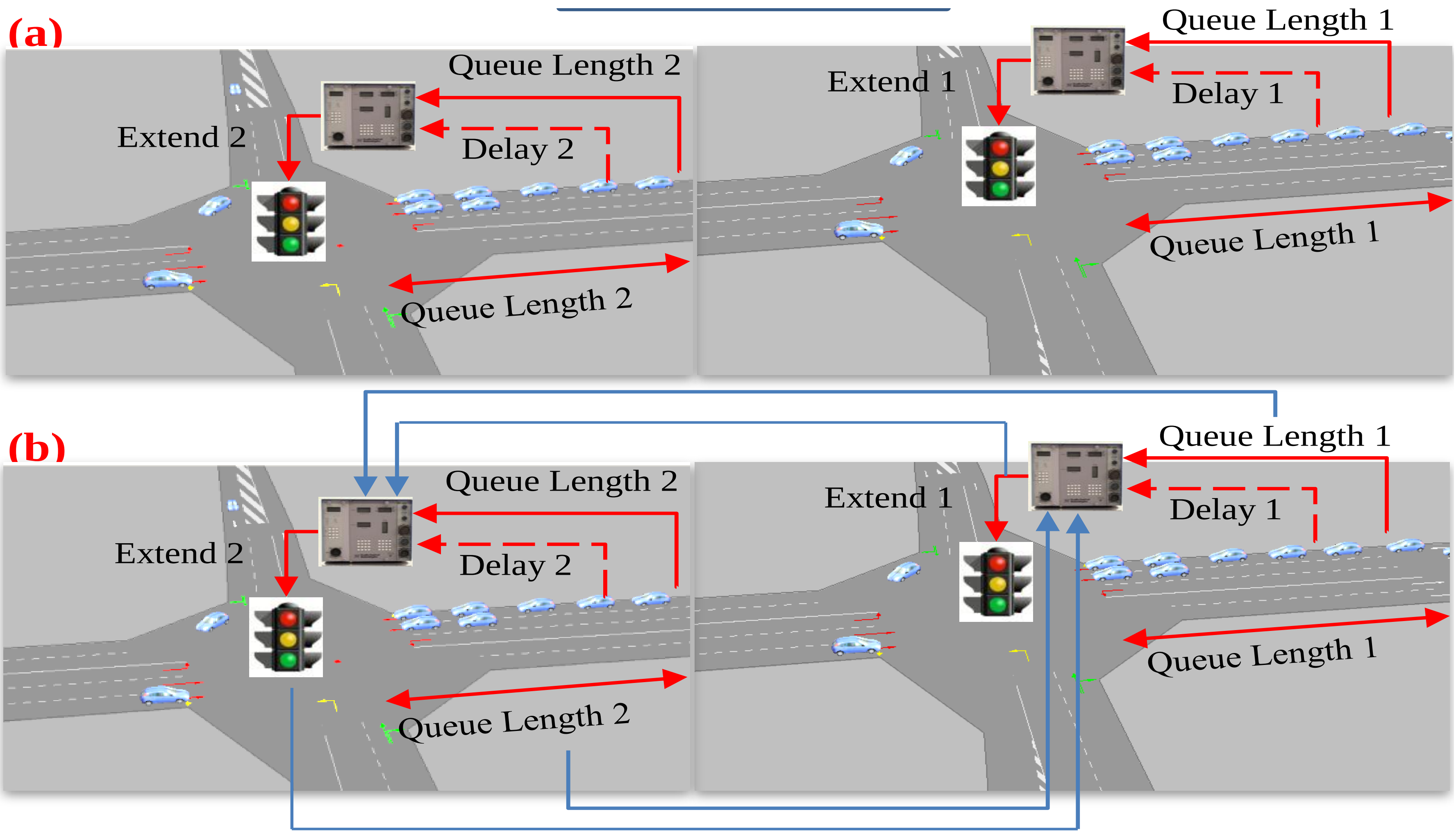
Example for Edge Intersection
(3 Games)



Example for Corner Intersection
(2 Games)

MARLIN-ATSC Available Modes

- MARLIN-ATSC: (a) Independent Mode, (b) Integrated Mode



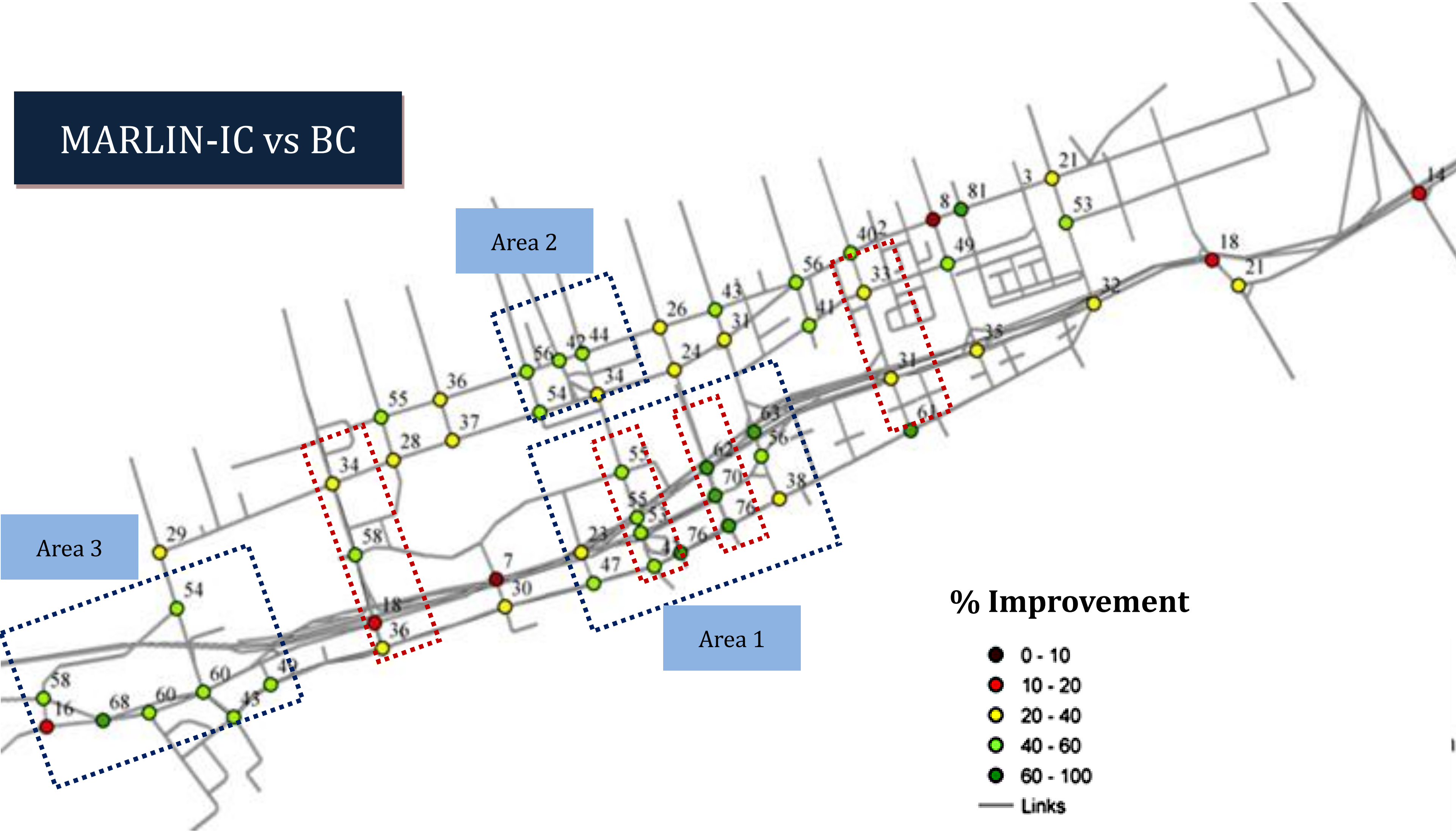
Large-Scale Application
Network-Wide MOE in the Normal Scenario

System / MOE	BC	% Improvments MARL-TI Vs. BC	% Improvments MARLIN-IC Vs. BC	% Improvments MARLIN-IC Vs. MARL-TI
Average Intersection Delay (sec/veh)	35.27	27%	38%	14%
Throughput (veh)	23084	3%	6%	3%
Avg Queue Length (veh)	8.66	24%	32%	11%
Std. Avg. Queue Length (veh)	2.12	23%	31%	10%

Large-Scale Application

% Improvement in Average Delay

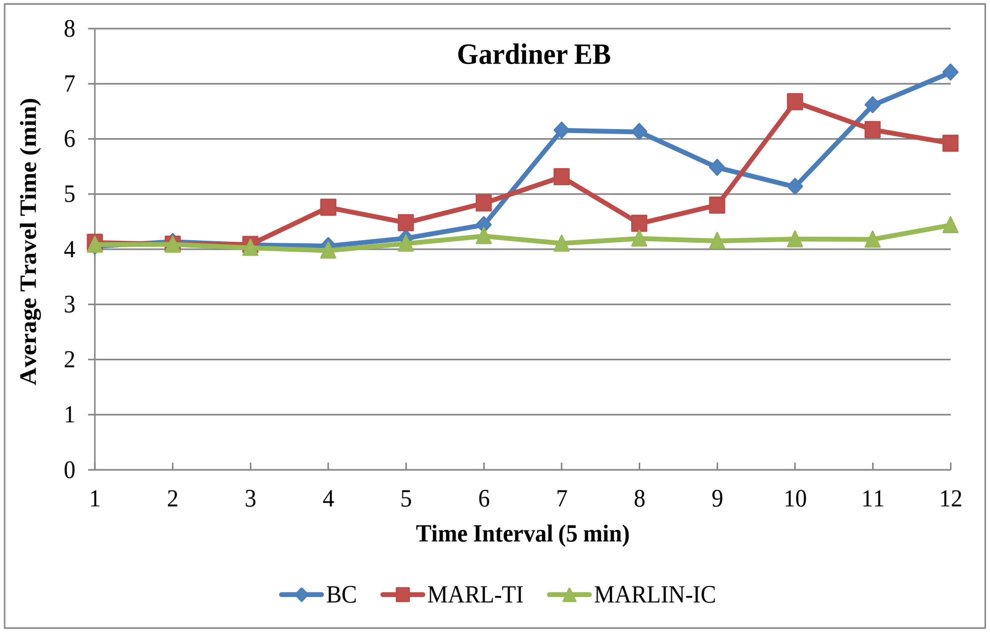
MARLIN-IC vs BC

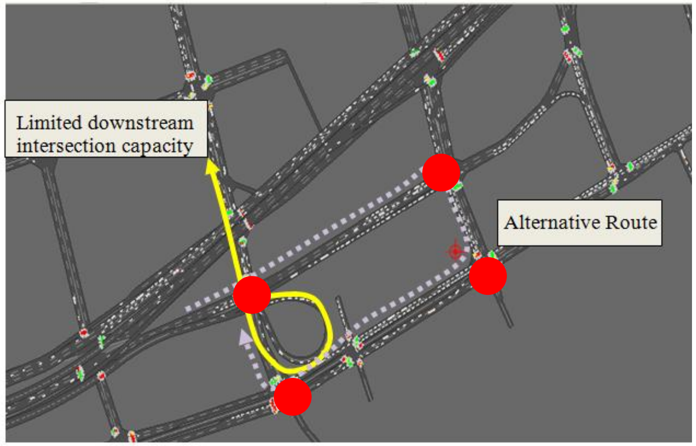


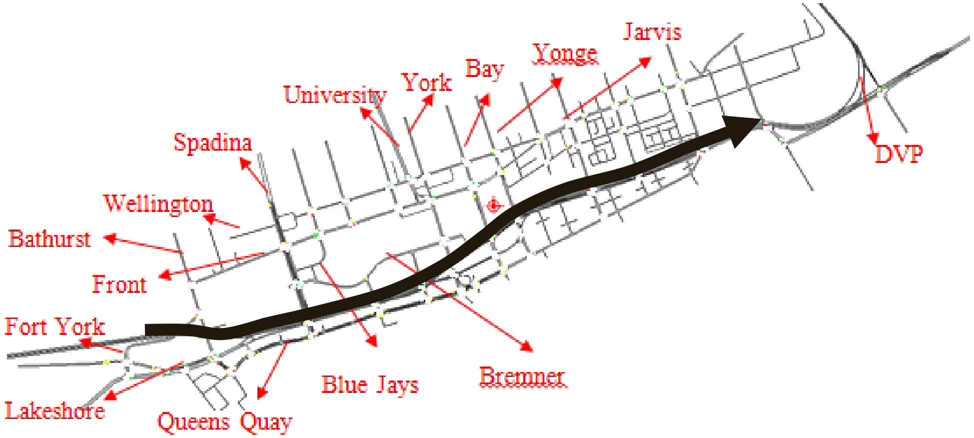
Large-Scale Application

Average Route Travel Time for Selected Routes

Freeway



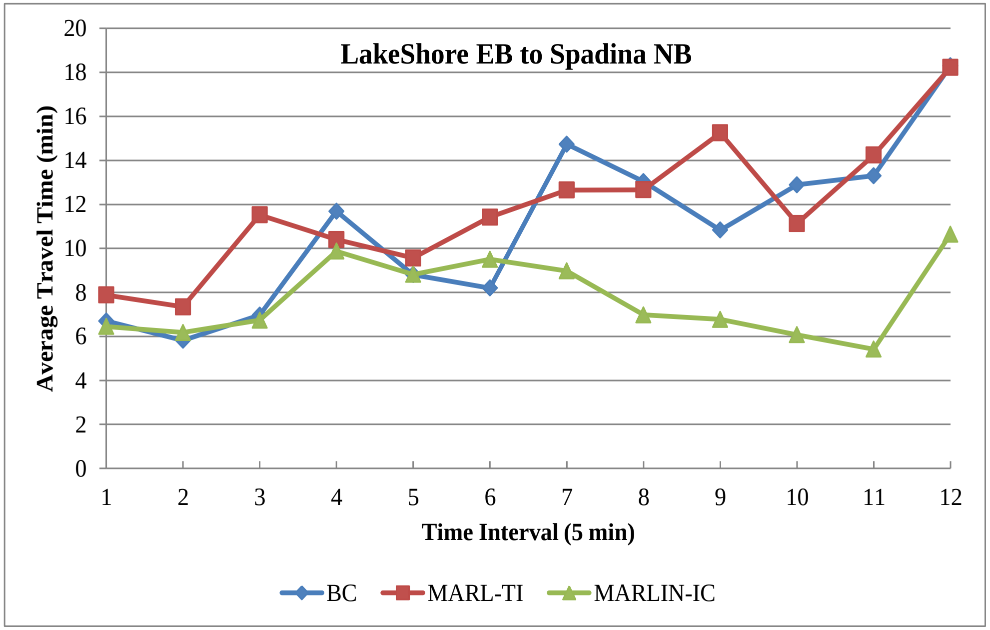


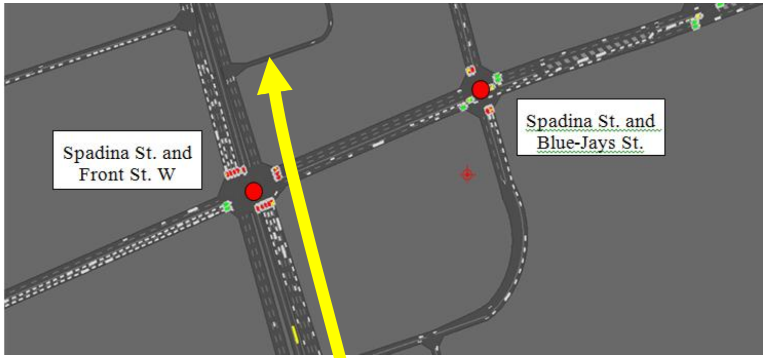


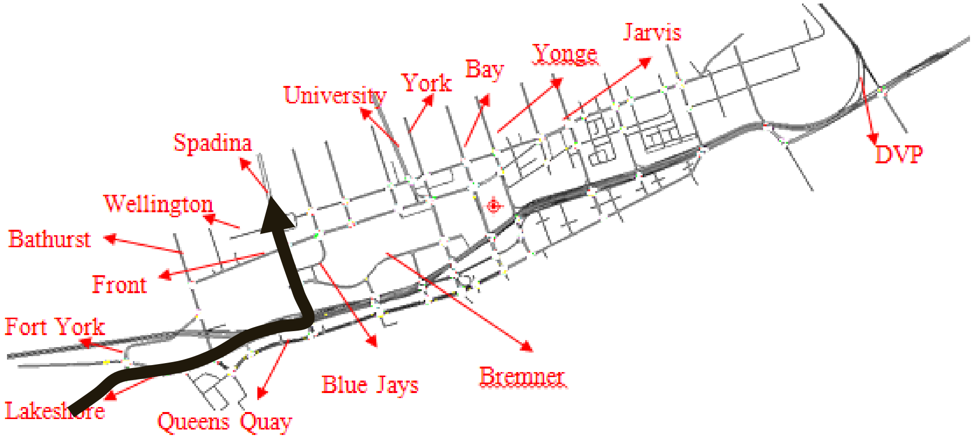
Large-Scale Application

Average Route Travel Time for Selected Routes

Major Arterial







MARLIN-HILS Architecture

Controller Interface Device(CID)
RS485 to USB

RS485 -
SDLC protocol

Traffic Signal Controller

USB -
SDLC protocol

Ethernet -
NTCIP protocol

Paramics
Modeller

Industrial Computer

HILS Setup: Demo

Conclusion

- MARLIN state of the art gen4+
- Thoroughly developed and tested
- Patent Pending Status
- On going:
  - HILS & PEEK ATC-1000 Integration
  - Potential Field Operation Test
  - Productization
- From TSP to People Priority (PSP)

Samah El-Tantawy samah.el.tantawy@utoronto.ca
Baher Abdulhai baher.abdulhai@utoronto.ca
Hossam Abdelgawad h.abdel.gawad@utoronto.ca

Smart Traffic Lights that Learn !

Multi-**A**gent **R**einforcement **L**earning **I**ntegrated **N**etwork of Adaptive Traffic Signal Controllers

MARLIN

UNIVERSITY OF TORONTO

Samah ElTantawy, Ph.D. — Post Doctoral Fellow, Dept of Civil Engineering

Baher Abdulhai, Ph.D., P.Eng. — Director, ITS Centre and Testbed, Dept of Civil Engineering

Hossam Abdelgawad, Ph.D., P.Eng. — Manager of ITS Centre and Testbed

ITS • STI CANADA

ACGM 2013- Intelligent Transport for Smart Cities