Designing Real-Time, Reliable and Efficient Cyber-Physical Systems for Future Smart City

- Cyber-Physical Systems: Integration of computational algorithms and physical processes

- Deployed in various areas, e.g., automobile, healthcare, manufacturing, transportation, energy and etc.

- **Our Focus**
  1. Wireless Networked Sensing and Control
  2. Intelligent Transportation Systems
  3. Electric-Vehicle-Integrated Smart Grid
Deployed in Many Mission-Critical CPS Applications

- Wireless Sensor Networks: communication infrastructure of WNSC
- In-Network Processing: reduce data traffic flow in WNSC

Challenges

- a) Stringent QoS Requirement;
- b) Resource-constraint;
- c) Dynamic environment.

To cope with these challenges, we investigate

- Joint optimization between In-Network Processing and QoS
  - Real-time packet packing scheduling
  - Optimal network-coding-based routing

Figure source: environment.ucla.edu
Packet Packing and Network Coding

Packet Packing Scheduling: \textit{tPack}

Network-Coding-Based Routing: \textit{ONCR}

NetEye Sensor Testbed@Wayne State University
ONCR: Optimal Network-Coding-Based Routing Protocol

- **Reliability**
  - ONCR, CTP, MORE, CodeOR

- **Delivery Cost**
  - ONCR, CTP, MORE, CodeOR

- **Goodput**
  - ONCR, CTP, MORE, CodeOR

- **Routing Diversity**
  - ONCR, MORE, CodeOR
Intelligent Transportation Systems

A Smarter and Safer Transportation Network

- **Dedicated Short Range Communication (DSRC):** communication infrastructure specified by U.S. DoT

- Challenges:
  
  - Dynamic Channel Under High Mobility
  - Severe Broadcast Storm

To cope with these challenges, we explore

- the correlation between transmission power and data rate during broadcast

- vehicle’s data preference when collecting safety-data

Figure source: www.gm.com
Adaptively controls transmission power and data rate of DSRC
VSmart: DSRC-Enabled Smart Vehicle Testbed

Laptops or tablets as in-vehicle CPU

iRobot Create as vehicles

USRP B210 boards as DSRC radios

Radio control, robot control, measurements ...

Sensor data

Movement commands

Radio setting adjustments

DSRC messages

Qiao Xiang (McGill)
Senseable City Lab, MIT
05/07/2015
OnCAR in VSmart: Adaptive Cruise Control

Leader sends movement command via DSRC

Follows repeats the movement

Baseline DSRC: 4/10 commands received

OnCAR DSRC: 10/10 commands received

Upon receiving DSRC message, repeat the movement.
Vehicles have preferences when collecting safety data:

- **Spatial preference**: closer over farther;
- **Temporal preference**: newer over older;
- **Type preference**: emergency over routine.

Quantify these preferences on a per-packet level

Packet Value = Spatial Value \times Temporal Value \times Type Value.
Intelligent Transportation Systems

Data Preference: A New Perspective of Safety Data Dissemination

PVCast: a Packet-Value-Based Dissemination Protocol

Throughput

Coverage

Delay

Emergency Throughput

Throughput

Coverage

Delay

Emergency Throughput

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Senseable City Lab, MIT
05/07/2015
Intersection of Smart Energy and Transportation Systems

- Challenges
  
a) Unpredictable supply and demand;
  b) Limited information exchange;
  c) Lack of market mechanism.

To cope with these challenges, we develop

- demand-response-based optimal operation strategy for commercial EV charging stations
- online auction framework for EV park-and-charge

Figure source: www.gm.com
Charging stations are not good Samaritans. They pursue profit.

**GreenBroker:** an online distributed operation strategy achieving an $[O(V), O(1/V)]$ tradeoff between customer charging delay and charging station revenue.
Green Revenue: Demand-Response-Based Charging Station

1000 EVs: Delay

Time Average of Queue Backlog (kWh)

CF–BE
GreenBroker
Delay–Aware GreenBroker

1000 EVs: Revenue

Time Average of Total Revenue ($)

GreenBroker
Delay–Aware GreenBroker

2000 EVs: Delay

Time Average of Queue Backlog (kWh)

CF–BE
GreenBroker
Delay–Aware GreenBroker

2000 EVs: Revenue

Time Average of Total Revenue ($)

GreenBroker
Delay–Aware GreenBroker
Electricity Allocation in Park-and-Charge

Inefficient allocation

Efficient allocation
Existing pricing scheme could jeopardize the allocation efficiency and the social welfare

**Auc2Charge**: An online, truthful, individual rational and efficient mechanism with social-welfare guarantee
### Auc2Charge: Online Auction for EV Park-and-Charge

**Social Welfare Ratio: T=12**

- **Average of User Satisfaction Ratio**
  - T=12
  - T=18
  - T=24

- **Average of Unit Payment**
  - T=12
  - T=18
  - T=24

**Social Welfare Ratio: 100 EVs**

- **Ratio of Offline/Online Social Welfare**
  - Auc2Charge
  - OffOptimal

**User Satisfaction Ratio**

**Unit Charging Payment**

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Qiao Xiang (McGill)  
Senseable City Lab, MIT  
05/07/2015
What is the Future of CPS?

Smart City: A System of Many Inter-Connected CPS

Figure source: holyroodconnect.com
Research Opportunities

Exploring larger physical space in CPS design

Joint Scheduling of Generation and Deferrable Load in Microgrid

Exploring interaction between different CPS

Connecting Intelligent Transportation System and Smart Grid through EV

Figure sources: www.civicsolar.com, www.gm.com
Research Opportunities

Efficient Market Mechanism

- Single Microgrid
- Multiple Microgrids

Mechanism design for microgrid-based electricity market

Data Security and Privacy

- Develop unified differential privacy solution for CPS data management

Figure sources:  www.finextra.com,  ourenergypolicy.org
I am devoted to utilizing information technology to improve people’s daily life.