Networked Control Challenges and Applications in the Internet of Things

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KTH and ACCESS Center

KTH represents one third of Sweden's technical research and engineering education capacity at university level
KTH Center ACCESS is one of Europe’s largest university research centers in networked systems with applications to IoT & CPS
- 35 faculty, 20 postdocs, 100 PhD students
- 10 year funding by Swedish Research Council
- Graduate School, Mobility Program
- Extensive industrial and international collaborations
- Government Strategic Agenda in ICT, EIT
Motivation: The Great Societal Challenges

Environmental Demands and Innovation Opportunities

Technology Trends

- Internet
- WWW
- Ubiquitous computing

- Remote sensing
- Monitoring environments
- Wireless sensor networks

- Closing the loop
- Critical infrastructures
- Humans in the loop

Characteristics of Future Smart Infrastructures

Unprecedented scale

Mission-critical

Trusted

Smart Grid | Transport | eHealth
---|---|---

Common Smart Infrastructure
An IoT Agenda

- Intelligent Transportation
- Smart City
- Cyber-Security
Goods Transportation: Societal Perspective

- Goods transportation accounts for **30 % of CO₂ emissions**
  15 % of greenhouse gas emissions of the global fossil fuel combustion
- Goods transport is projected to **increase by 50%** from 2000 to 2020

[International Transport Forum, 2010; European Commission, 2006]

Goods Transportation: Fleet Owners Perspective

Life cycle cost for a heavy duty vehicle in Europe

- Fuel: 70.3%
- Insurance: 6%
- Interest & Depreciation: 14.8%
- Time: 7.2%
- Maintenance & Service: 7.3%
- Oil: 1.5%
- Salary: 30.9%

Total fuel cost 80 k€/year/HDV

[Schittler, 2003]
Automated Platooning as a Solution

- May triple highway throughput
- May reduce fatalities by 10%
- May reduce emissions by 20%

[Varaiya et al., PATH project, 2010; Robinson et al., 2010]

Collaborative Driving for Fuel Reduction

- Drive closer together to reduce air drag and prepare vehicles based on road and traffic information
- Not possible by manual driving, but enabled by new communication and sensor technologies
- Safety guaranteed by advanced networked control

[Allam et al., 2010]
Real-time Services for Transportation

- Vehicle-to-vehicle and vehicle-to-infrastructure communications enable **new set of transport applications**
- Sensor data collection, information fusion, decision-making
- Design and management tools to handle operation complexity

Traffic Prediction from Large Mobile Sensor Network

Real-time GPS data from 1,500 Stockholm taxi cars

Koutsopoulos et al., 2010, KTH ITS laboratory
Collaborative Road Grade Estimation

Real-Time Optimal Fleet Management

How to plan transportations over dynamic traffic networks?
- Time- and fuel-optimal route decisions
- Platooning and other collaborative actions
- Pricing mechanisms based on societal and industrial demands

Liang et al., 2012
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Smart City

Stockholm Challenge

Graph showing:
- Regional GNP
- Population
- CO₂ equivalent

Year: 2000 to 2009
Integrate Renewable Energy into the Smart City

Stockholm Royal Seaport

2010
- Oil depot
- Container terminal
- Ports
- Gas plant

2030
- 10,000 new homes
- 30,000 new work spaces
- 600,000 m² commercial space
- Modern port and cruise terminal
- 236 hectares sustainable urban district
- Walking distance to city centre

From a brown field area to a sustainable city district
Stockholm Royal Seaport

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Goals
- CO₂ emissions <1.5 tons per person by 2020 (today 4.5)
- Fossil fuel-free by 2030

Smart Grid in the Stockholm Royal Seaport

1. Smart homes/Buildings and Demand Response
2. Distributed Energy Systems
3. Integration and Use of electric vehicles
4. Energy Storage for customers and the grid
5. Smart electrified harbour
6. Smart Primary Substations
7. Smart Grid Lab (part of an innovation Center)
Smart Grid Communications over 4G LTE

Enable the future Smart Power Grid to be controlled over mobile cellular networks?

Experiments
- 2 Stockholm LTE services
- Off-the-shelf modems
- ICMP response times

Results
- Meet some requirements
- Comparison to 3GPP
- Further studies needed

Weimer et al., 2012
Smart Home Appliances Scheduling

Optimal power profile scheduling for smart appliances
Decision: when to run? How much power to assign?

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Cyber-Security
From Resilience and Security to Societal Cost

Northeast U.S. Blackout of August 14th, 2003: 55 million people affected

http://www.vikingproject.eu

Cyber-Security of Networked Control Systems

- Networked control systems are to a growing extent based on open communication and software technology
- Leads to increased vulnerability to cyber-threats with many potential points of attacks
  - How to model attacks?
  - How to measure vulnerability?
  - How to compute consequences?
  - How to design secure control systems

- Traditional computer and information security do not provide answers these questions
- Need for theory and tools for secure control systems

Sandberg et al, 2010; Teixeira et al, 2012
Tunnel disaster relief scenario
IoT technology to support rescue operation at tunnel accident

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Intelligent Transportation  Smart City  Cyber-Security
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<th>Summary: Internet of Things Research Challenges</th>
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<td><strong>Societal Scale</strong></td>
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<td>• Global and dense instrumentation of physical phenomena</td>
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<td>• Interacting with a computational environment: closing the loop</td>
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<td>• Security, privacy, usability</td>
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<td><strong>Distributed Services</strong></td>
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<td>• Self-configuring, self-optimization</td>
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<td>• Reliable performance despite uncertain components, resilient aggregation</td>
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<td><strong>Programming the Ensemble</strong></td>
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<td>• Local rules with guaranteed global behavior</td>
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<td>• Distributed and networked control</td>
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<td><strong>Network Architectures</strong></td>
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<tr>
<td>• Heterogeneous systems: local sensor/actuator networks and wide-area networks</td>
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<td>• Self-organizing multi-hop, resilient, energy-efficient routing</td>
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<td>• Limited storage, noisy channels</td>
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<td><strong>Real-Time Operating Systems</strong></td>
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<td>• Extensive resource-constrained concurrency</td>
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<td>• Modularity and data-driven physics-based modeling</td>
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<tr>
<td><strong>1000 Radios per Person</strong></td>
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<tr>
<td>• Low-power processors, radio communication, encryption</td>
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<td>• Coordinated resource management, spectrum efficiency</td>
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Sastry & J, 2010

[http://www.ee.kth.se/~kalle](http://www.ee.kth.se/~kalle)