Networked Control Challenges and Applications in the Internet of Things

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Workshop on Internet of Things, Nanyang Technological University
Singapore, Oct 18-19 2012

KTH and ACCESS Center

ROYAL INSTITUTE OF TECHNOLOGY

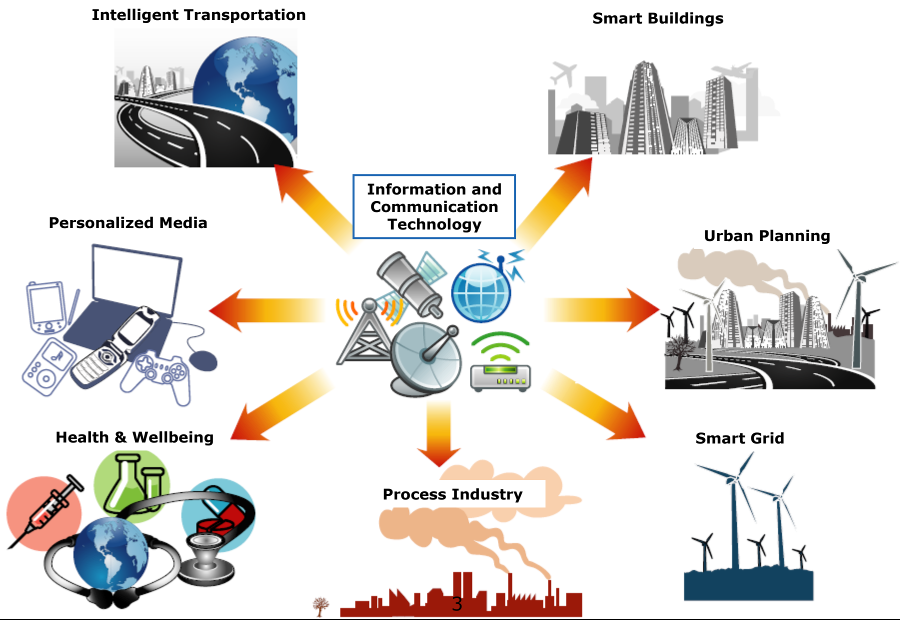
KTH represents one third of Sweden's technical research and engineering education capacity at university level

KTH Center **ACCESS** is one of Europe's largest university research centers in networked systems with applications to IoT & CPS

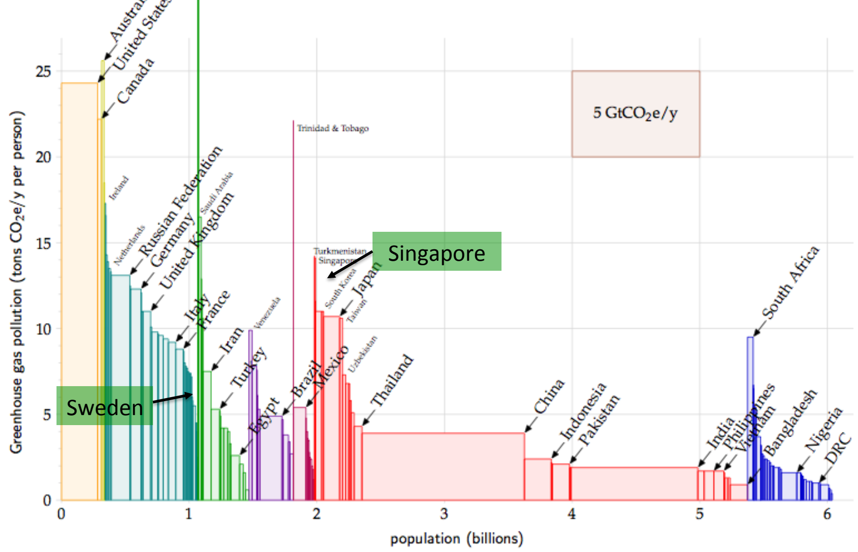
- 35 faculty, 20 postdocs, 100 PhD students
- 10 year funding by Swedish Research Council
- Graduate School, Mobility Program
- Extensive industrial and international collaborations
- Government Strategic Agenda in ICT, EIT

ACCESS

Motivation: The Great Societal Challenges



Environmental Demands and Innovation Opportunities

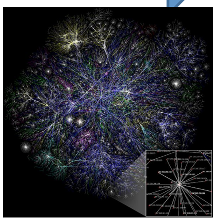


D. J.C. MacKay, Sustainable Energy–without the hot air, UIT Cambridge, 2008

Technology Trends

- Internet
- WWW
- Ubiquitous computing

Info Web



The Internet

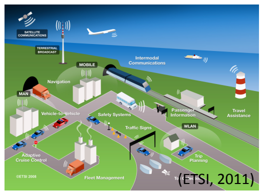
- Remote sensing
- Monitoring environments
- Wireless sensor networks

Sensor Web

Monitoring natural phenomena

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

Action Web



Smart infrastructures

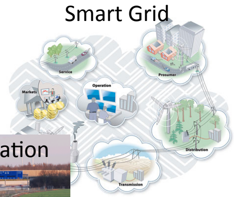
Characterstics of Future Smart Infrastructures

Unprecedented scale

Mission-critical

Trusted

Smart Grid



eHealth

Smart Grid	Transport	eHealth	---
Common Smart Infrastructure			

An IoT Agenda

Intelligent Transportation

Smart City

Cyber-Security

An IoT Agenda

Intelligent Transportation

Goods Transportation: Societal Perspective

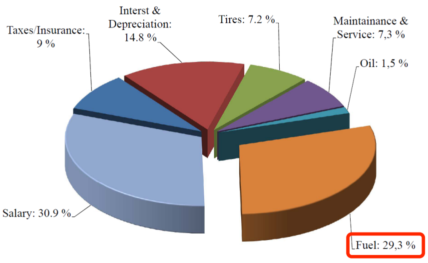
- Goods transportation accounts for
  30 % of CO_2 emissions
  15 % of greenhouse gas emissions
  of the global fossil fuel combustion

- 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



Total fuel cost 80 k€/year/HDV

[Schittler, 2003]

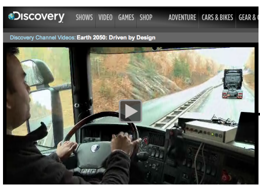
Automated Platooning as a Solution

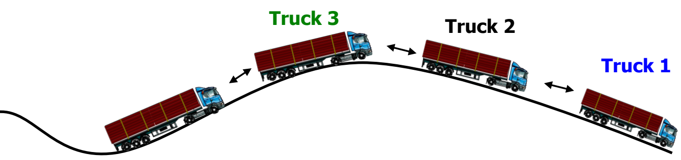
- May tripple highway throughput
- May reduce fatalities by 10%
- May reduce emissions by 20%

[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**

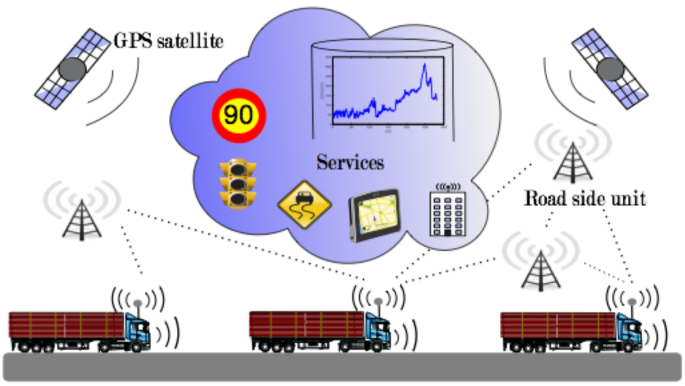




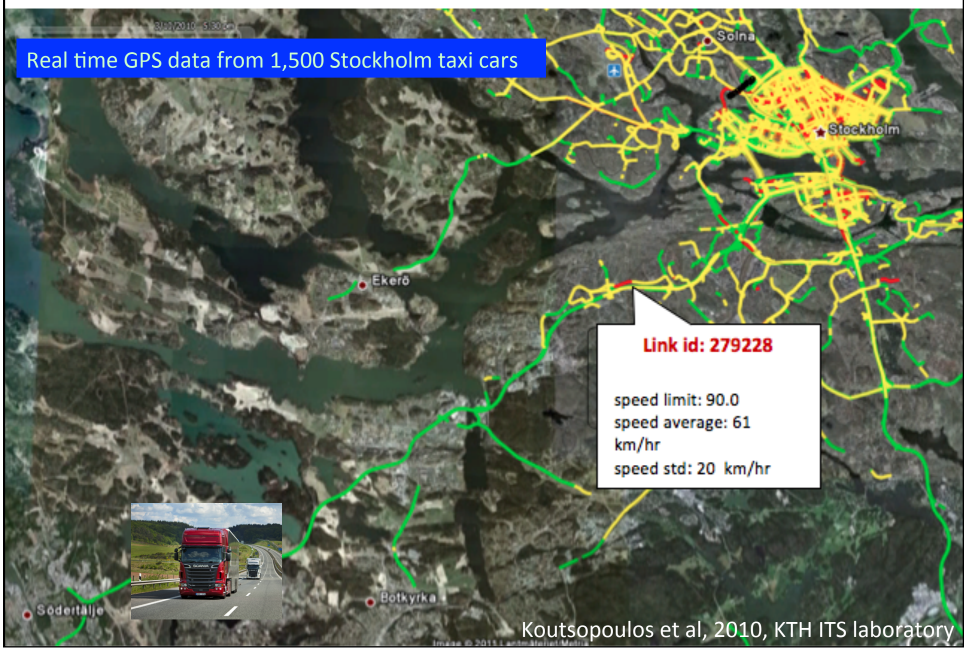
Allam et al., *2010*

Real-time Services for Transportation

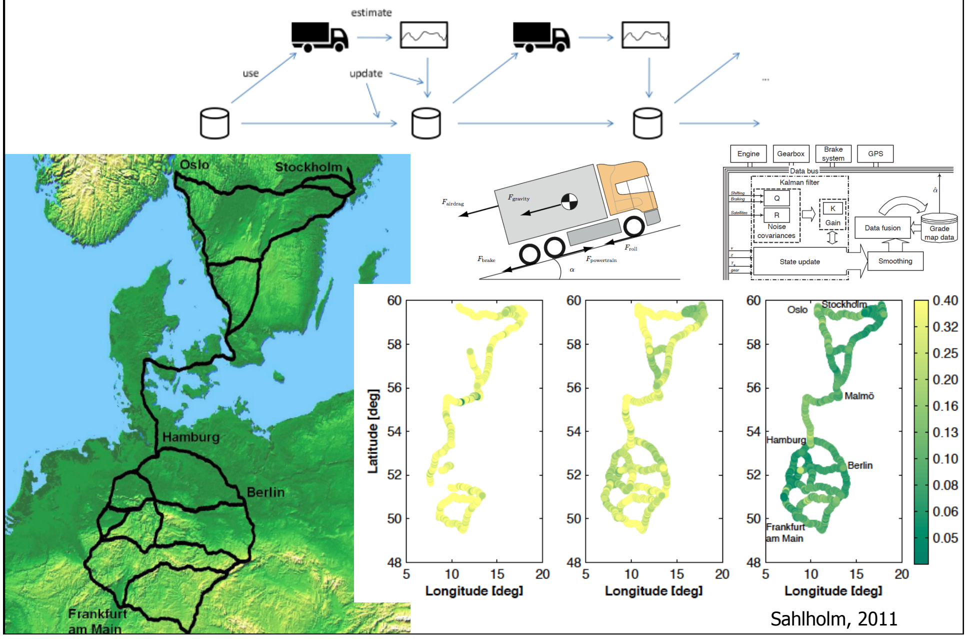
- Vehicle-to-vehicle and vehicle-to-infrastructure communications enable **new** set of **transport applications**
- Sensor data collection, information fusion, decision-making
- Design and management tools to handle operation complexity



Traffic Prediction from Large Mobile Sensor Network



Collaborative Road Grade Estimation

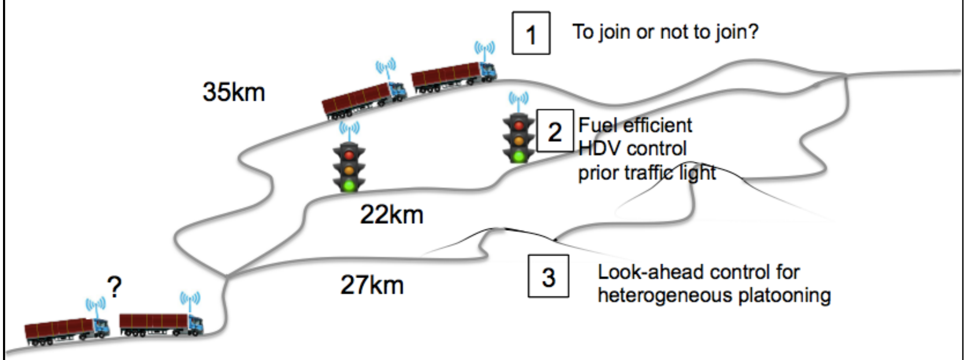


Sahlholm, 2011

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

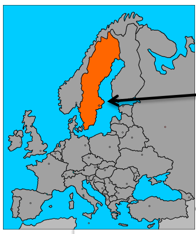


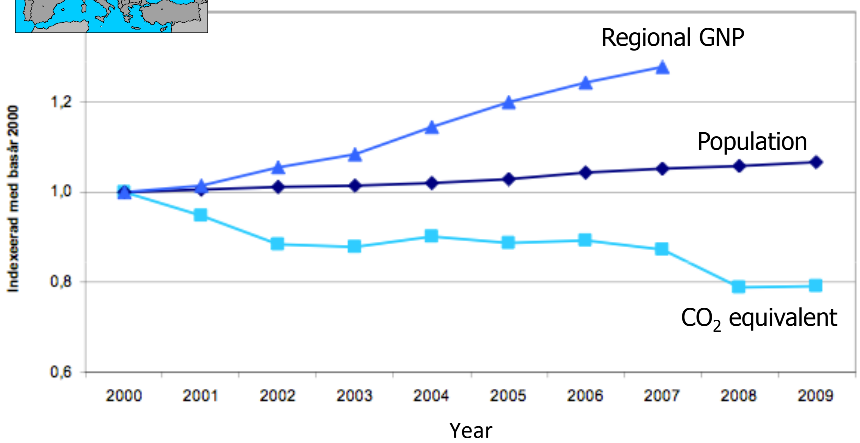
Liang et al., 2012

An IoT Agenda

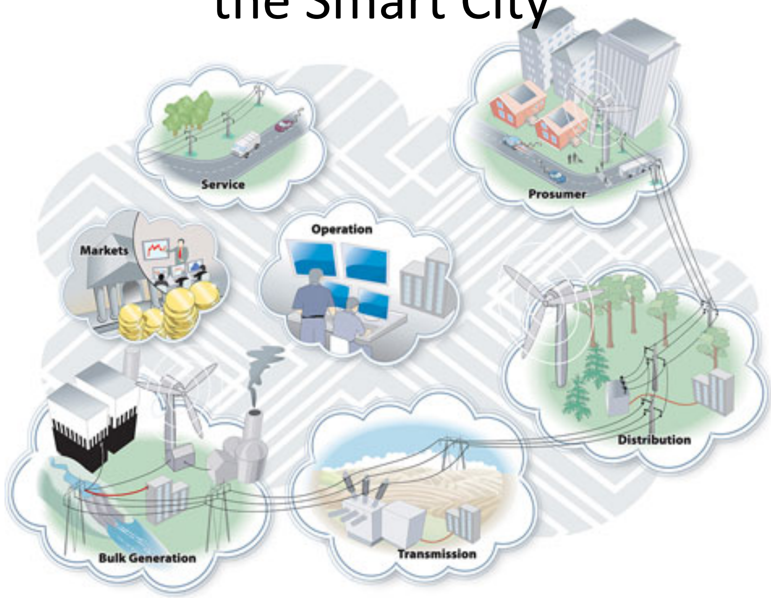
Smart City

Stockholm Challenge





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

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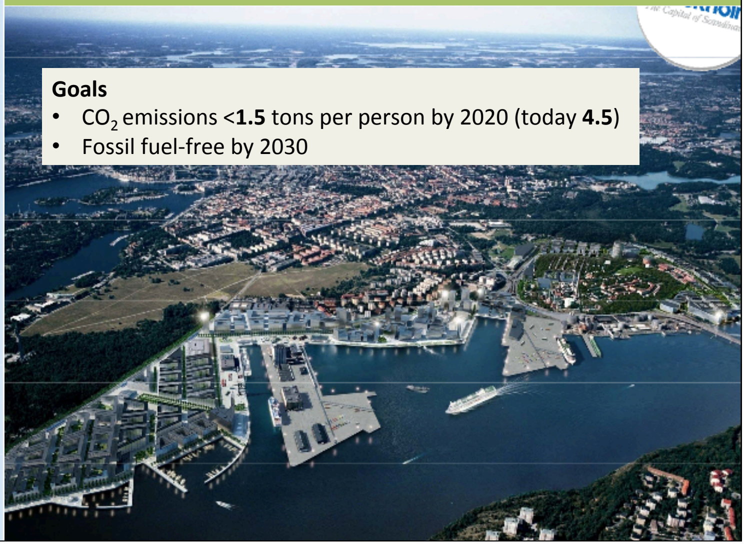
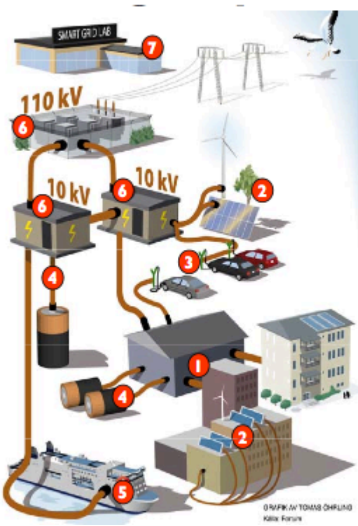
From a brown field area to a sustainable city district

Goals
- CO_2 emissions <**1.5** tons per person by 2020 (today **4.5**)
- Fossil fuel-free by 2030

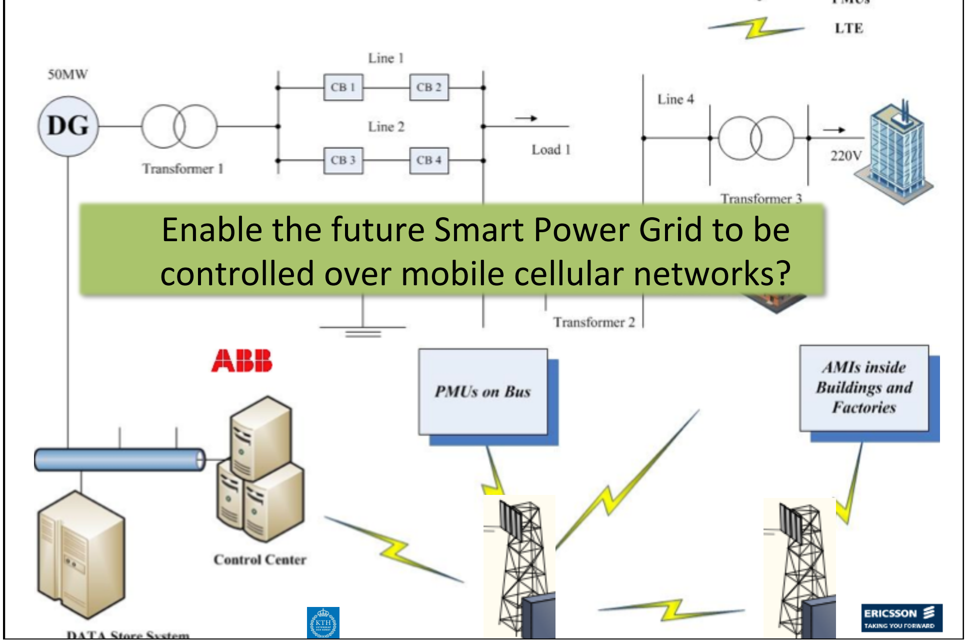


Smart Grid in the Stockholm Royal Seaport

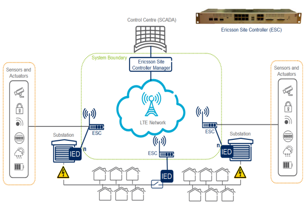


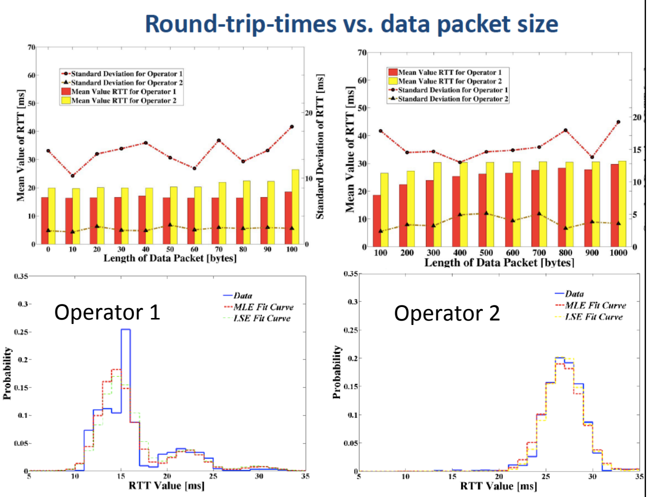
1. Smart homes/Buildings and Demand Response
2. Distributed Energy Systems
3. Integration and Use of electric vehicles
4. Energy Storage for customers and the grid
5. Smart electrified harbour
6. Smart Primary Substations
7. Smart Grid Lab (part of an innovation Center)

Smart Grid Communications over 4G LTE



Smart Grid Communications over 4G LTE



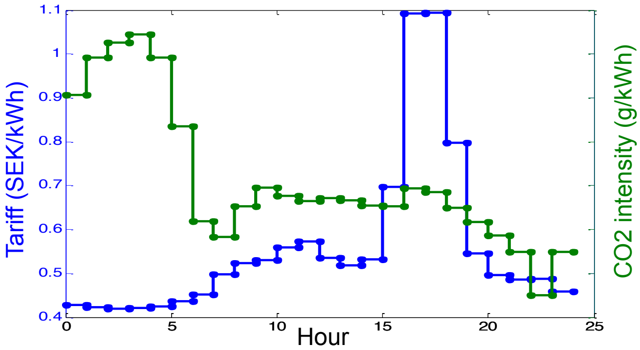


Experiments
- 2 Stockholm LTE services
- Off-the-shelf modems
- ICMP response times

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

Weimer et al., 2012

Smart Home Appliances Scheduling



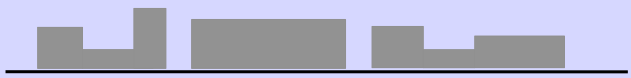
basic home gateway

smart home gateway

smart appliance

Optimal power profile scheduling for smart appliances

Decision: **when** to run? **How much power** to assign?

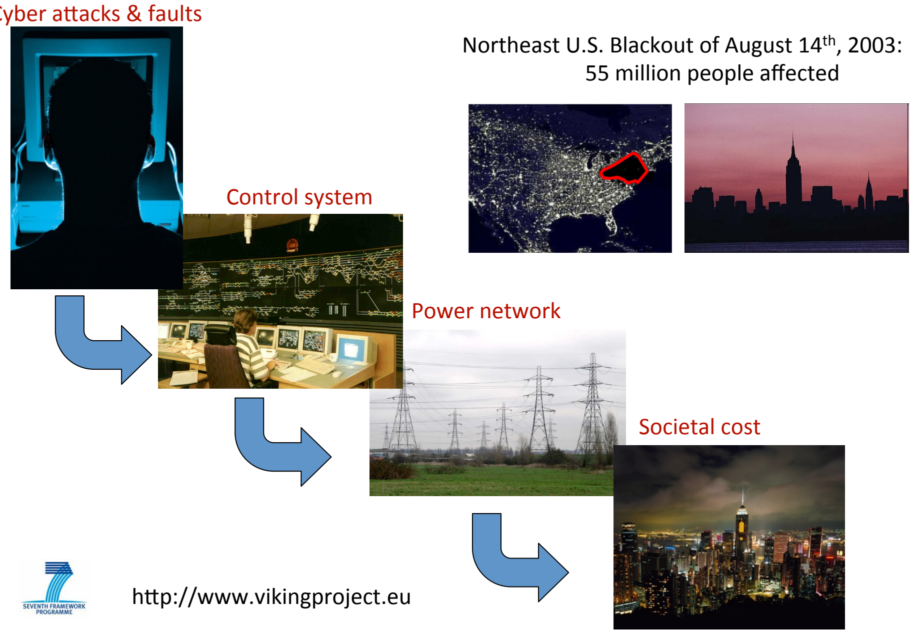


Seu et al., 2012

An IoT Agenda

Cyber-Security

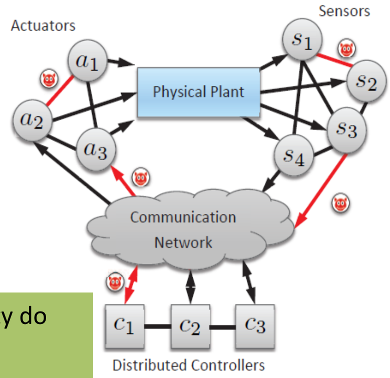
From Resilience and Security to Societal Cost



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



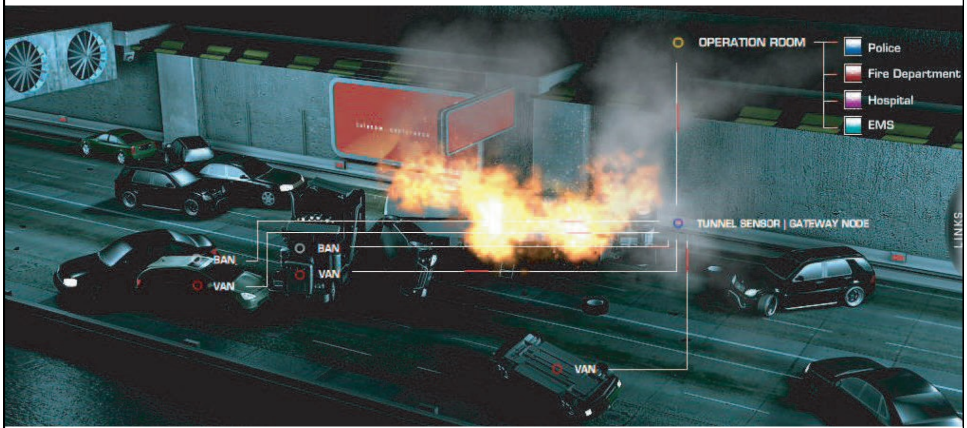
- How to model attacks?
- How to measure vulnerability?
- How to compute consequences?
- How to design secure control systems

- 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



VIDEO

RUNES

An IoT Agenda

Intelligent Transportation

SCANIA

Smart City

ABB

Cyber-Security

ERICSSON

Summary: Internet of Things Research Challenges

Societal Scale
- Global and dense instrumentation of physical phenomena
- Interacting with a computational environment: closing the loop
- Security, privacy, usability

Distributed Services
- Self-configuring, self-optimization
- Reliable performance despite uncertain components, resilient aggregation

Programming the Ensemble
- Local rules with guaranteed global behavior
- Distributed and networked control

Network Architectures
- Heterogeneous systems: local sensor/actuator networks and wide-area networks
- Self-organizing multi-hop, resilient, energy-efficient routing
- Limited storage, noisy channels

Real-Time Operating Systems
- Extensive resource-constrained concurrency
- Modularity and data-driven physics-based modeling

1000 Radios per Person
- Low-power processors, radio communication, encryption
- Coordinated resource management, spectrum efficiency

Sastry & J, 2010

http://www.ee.kth.se/~kallej