Challenges in Wireless Control Networks for Cyber-Physical Systems

Chenyang Lu
Cyber-Physical Systems Laboratory
Department of Computer Science and Engineering
Wireless Control Networks

Real-time
Reliability
Control performance

Need drastically different network design from best-effort sensor networks!
Wireless for Process Automation

- World-wide adoption of wireless in process industries

- 1.5+ billion hours operating experience

- 100,000s of smart wireless field devices

- 10,000s of wireless field networks

Courtesy: Emerson Process Management

Onshore

Offshore
WirelessHART

- Industrial-grade reliability
  - Multi-channel TDMA MAC
  - Redundant routes
  - Over IEEE 802.15.4 PHY

- Centralized network manager
  - Collects topology information
  - Generates routes and transmission schedule
  - Changes when devices/links break

Industrial wireless standard for process monitoring and control
Real-Time Scheduling for Wireless

Goals
- Real-time transmission scheduling → meet end-to-end deadlines
- Fast delay analysis → online admission control and adaptation

Approach
- Leverage real-time scheduling theory for multiprocessors
- Incorporate wireless characteristics: transmission conflicts

Results
- Dynamic priority scheduling [RTSS'10][IWQoS'14]
- Fixed priority scheduling [RTAS'11][ECRTS'11]
- Wireless control network testbed
Wireless-Control Co-Design [ICCPS'13]

- Wireless Cyber-Physical Simulator (WCPS)
  - Capture dynamics of both physical plants and wireless networks
  - TOSSIM + Simulink/MATLAB
  - Open source: http://wcps.cse.wustl.edu

- Wireless structural control experiments
  - Wireless traces collected from Jindo bridge
  - Structural models of bridge over Mississippi
  - Excited by CA earthquake traces

- Wireless-control co-design
  - End-to-end scheduling + optimal control
  - Improved control with delay and loss
Challenge: Scalability

- **Centralized** network architecture does not scale
  - WirelessHART: a gateway can support up to 80 devices

- **Approach**
  - Local adaptation to wireless dynamics
  - Hierarchical network management
  - SNOW: sensor network over White Spaces
  - **Key**: Scale up without losing predictability!
Challenge: Control over Wireless

- Wireless resource is scarce and dynamic
- Cannot afford separating scheduling and control

Wireless-control co-design

- Optimize control, not to meet deadlines
  - Rate selection for wireless control [RTAS'12]
  - Civil structural control [ICCPS'13]
- Wireless and control co-design for resilient control
Summary

- Real-time wireless is a **reality** today
  - Industrial standards: WirelessHART, ISA100
  - Real deployments in the field

- Real-time scheduling theory for wireless

- Challenges and **opportunities** ahead
  - Scale to 10,000+ nodes
  - Wireless-control co-design