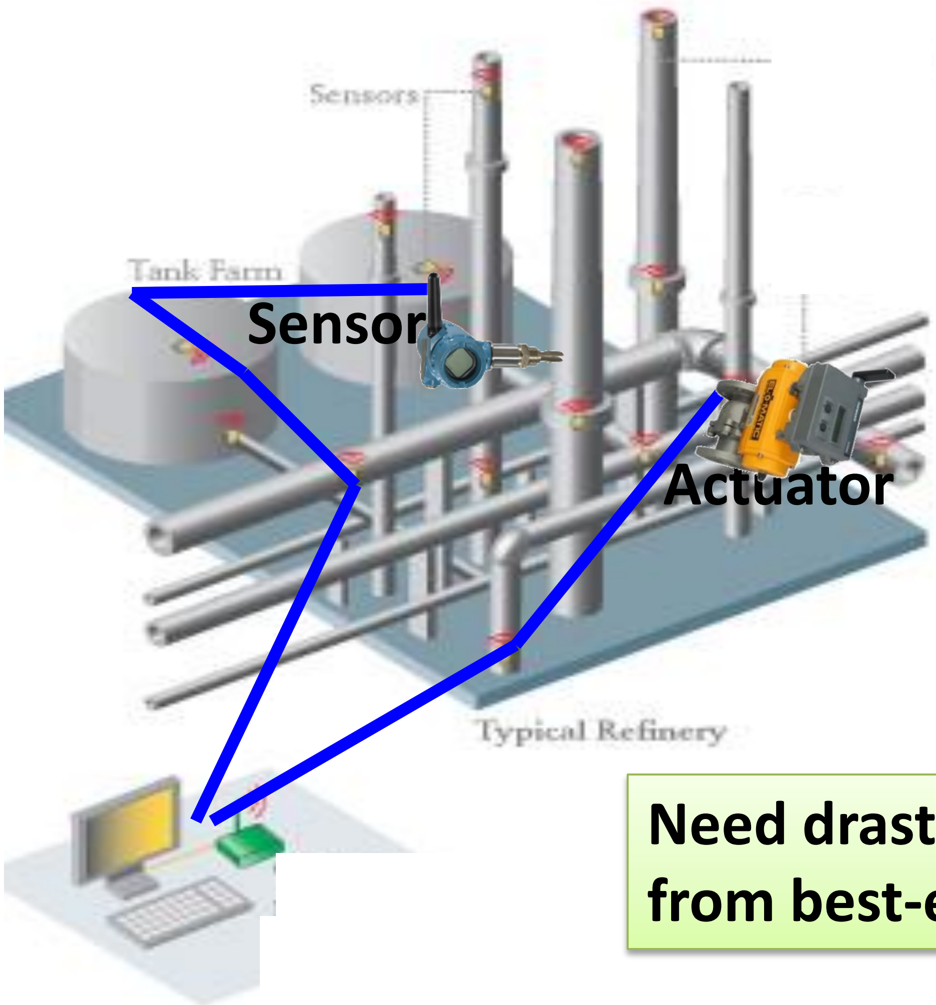
CPSL
Cyber-Physical Systems Laboratory

Real-Time Wireless Control Networks for Cyber-Physical Systems

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

Washington University in St.Louis

Wireless Control Networks



Real-time

Reliability

Control performance

Need drastically different network design from best-effort sensor networks!

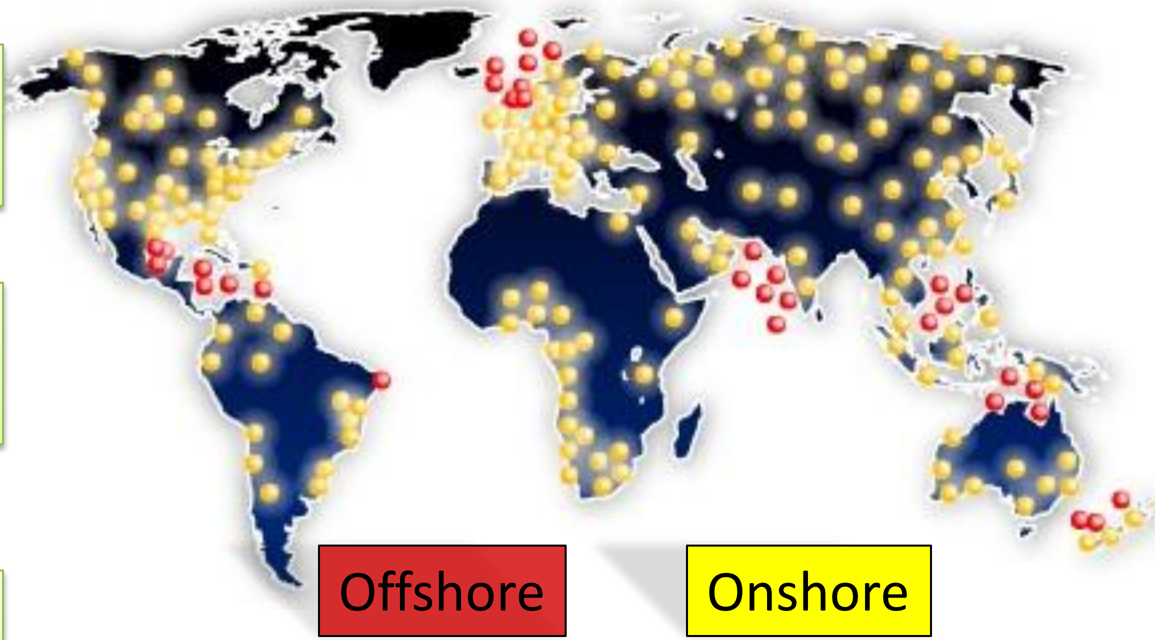
Wireless for Process Automation

- World-wide adoption of wireless in process industries

1.5+ billion hours operating experience

100,000s of smart wireless field devices

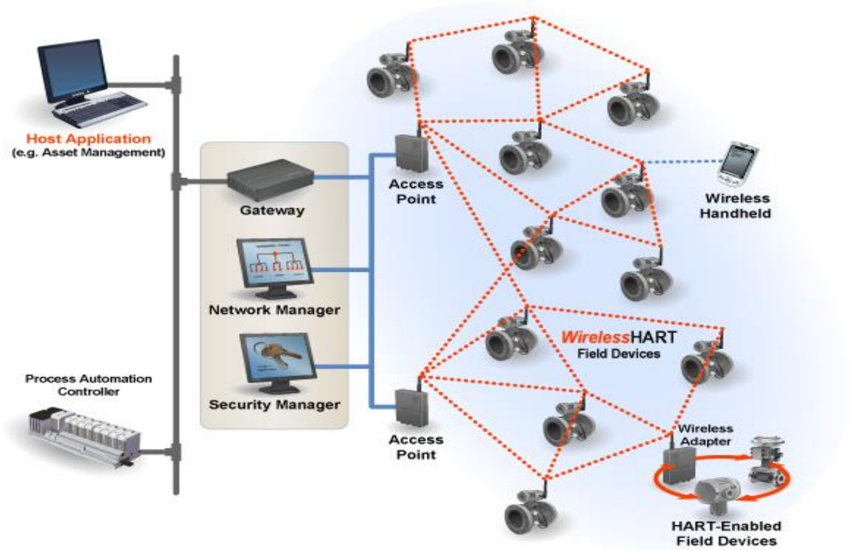
10,000s of wireless field networks



Courtesy: Emerson Process Management

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

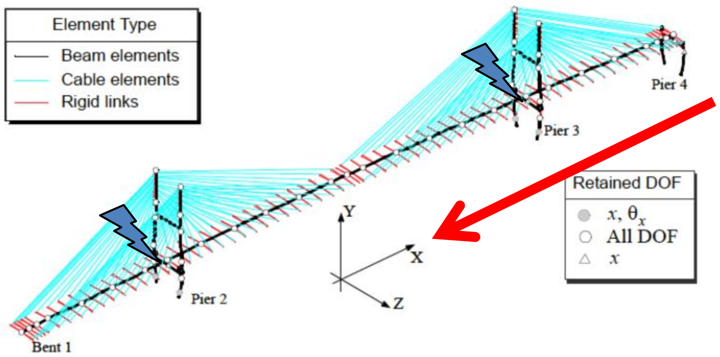
Results

- 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

(a)



(b)

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