

Real-Time Wireless Control Networks

Challenges and Directions

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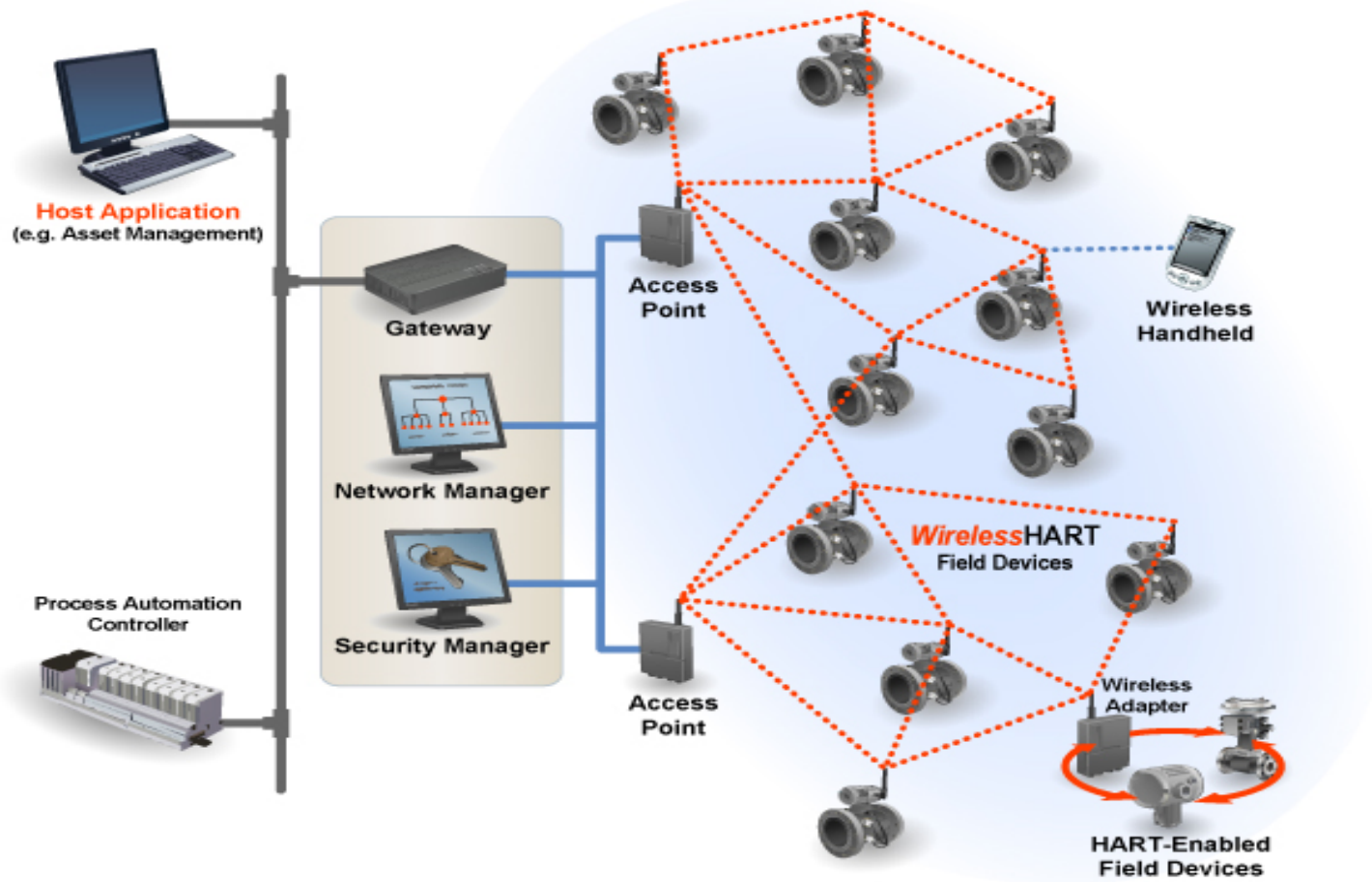


Outline

- WirelessHART: a starting point
- Real-time scheduling for WirelessHART
- Challenges and directions of wireless control networks

WirelessHART

Industrial wireless standard for process monitoring & control



Characteristics

- Real-time and reliable in hash industrial environments
- Time Division Multiple Access (10ms slot)
- Multi-channel
- Route diversity
- No spatial reuse of the same channel

- Centralized network manager
 - ❑ Collect topology information from the network
 - ❑ Generate routes and global transmission schedule
 - ❑ Recalculate when devices/links break

Time Synchronization

- WirelessHART protocol
 - ❑ Gateway is the root source of time.
 - ❑ When a device receives a packet
 - Δt = time of arrival – expected arrival time based on own clock.
 - sends Δt to the sender via ACK.
 - ❑ The sender adjusts time.

- Benefits of accurate clocks
 - ❑ Reduce guard time used to accommodate clock skew
 - ✓ Shorter slot
 - ❑ Reduce frequency of clock sync
 - ✓ Lower overhead
 - ✓ Better scalability

Real-Time Scheduling for WirelessHART

Goals

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

Approach

- Leverage real-time scheduling theory for processors
- Incorporate wireless characteristics

Initial Results

- Dynamic priority transmission scheduling [RTSS'10]
- Fixed priority transmission scheduling
 - ❑ End-to-end delay analysis [RTAS'11]
 - ❑ Priority assignment [ECRTS'11]
- Rate selection for wireless control [RTAS'12]

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Real-Time Flows

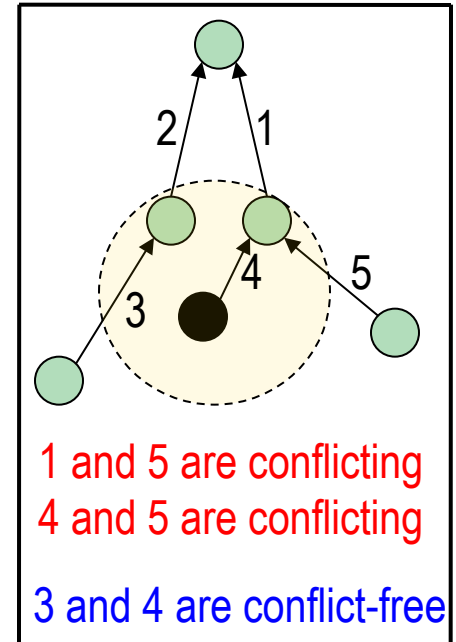
- Flow: sensor->controller->actuator over multi-hops
- A set of flows $F = \{F_1, F_2, \dots, F_N\}$ ordered by priorities
 - highest
 - lowest priority
- Each flow F_i is characterized by
 - ❑ A **source** (sensor), a **destination** (actuator), **route** through the gateway (where controller is located)
 - ❑ A **period** P_i
 - ❑ A **deadline** D_i ($\leq P_i$)
 - ❑ Total number of **transmissions** C_i along the route

Scheduling Problem

- Fixed priority scheduling
 - ❑ Transmissions ordered based on the priorities of their flows
- Flows are **schedulable** if $R_i \leq D_i \quad \forall F_i \in F$
 - end-to-end delay of F_i (pointing to R_i)
 - deadline of F_i (pointing to D_i)
- **Goal: efficient end-to-end delay analysis**
 - ❑ Give an upper bound of the end-to-end delay for each flow
 - ❑ Used for online admission control and adaptation

End-to-End Delay Analysis

- A lower priority flow is delayed due to
 - ❑ **channel contention:** when all channels are assigned to higher priority flows in a slot
 - ❑ **conflict:** its transmission and a transmission of a higher-priority flow involve a same node
- Each type of delay is analyzed separately
- Combine both delays → end-to-end delay bound

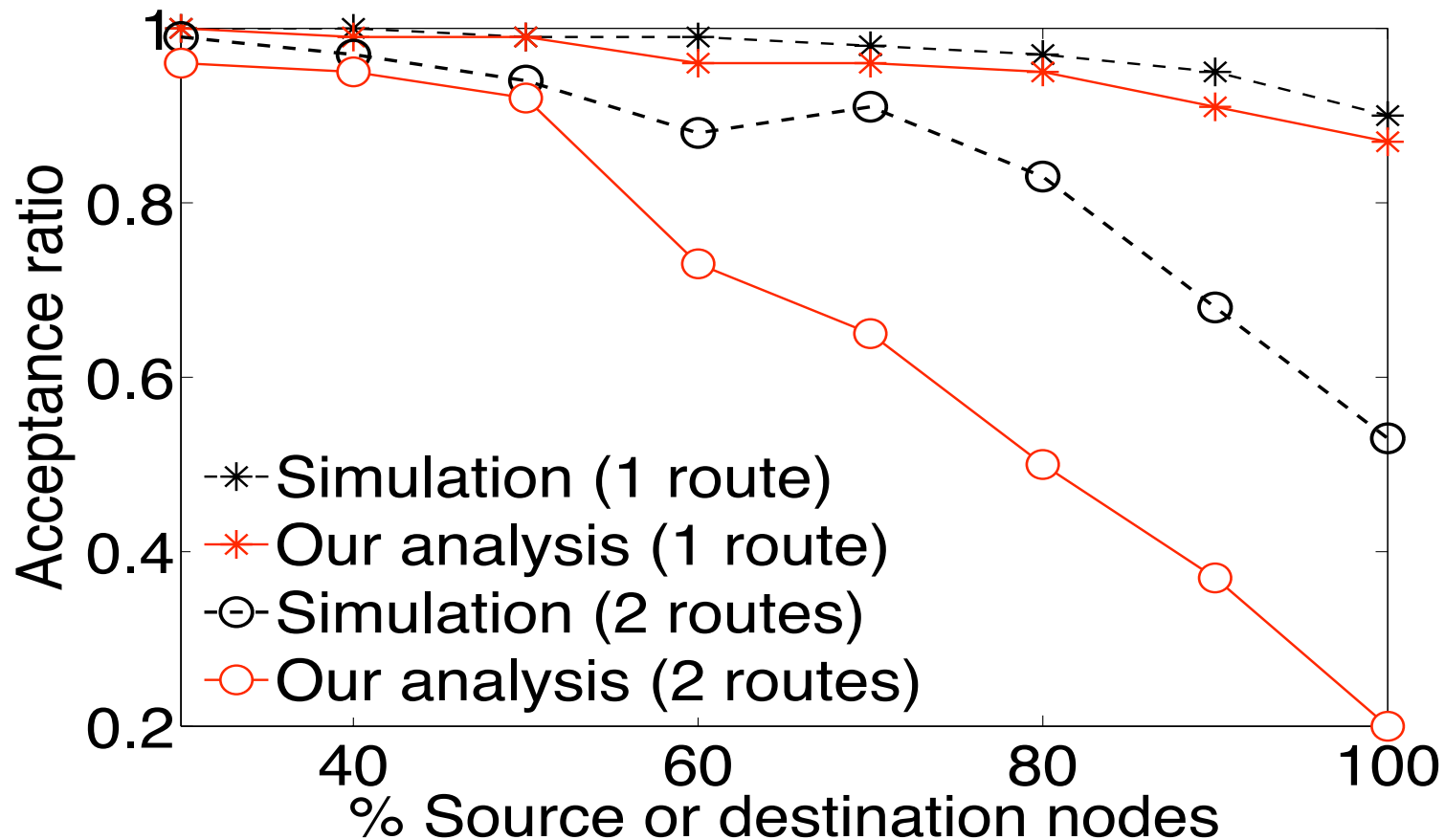


Insights

- **Transmission vs. multiprocessor scheduling**
 - ❑ Similar: channel contention
 - ❑ Different: transmission conflicts
- **Channel contention → multiprocessor scheduling**
 - ❑ A **channel** → a **processor**
 - ❑ **Flow** F_i → a **task** with period P_i , deadline D_i , execution time C_i
 - ❑ Leverage existing **response time analysis for multiprocessors**
- Account for delays due to conflict with high-priority flows

Acceptance Ratio (Testbed Topology)

- Number of channels=12
- Priority assignment policy: Deadline Monotonic



What we have so far...

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

- Starting a **real-time scheduling theory for wireless**
 - ❑ Leverage real-time processor scheduling
 - ❑ Incorporate unique wireless properties

- What's next?

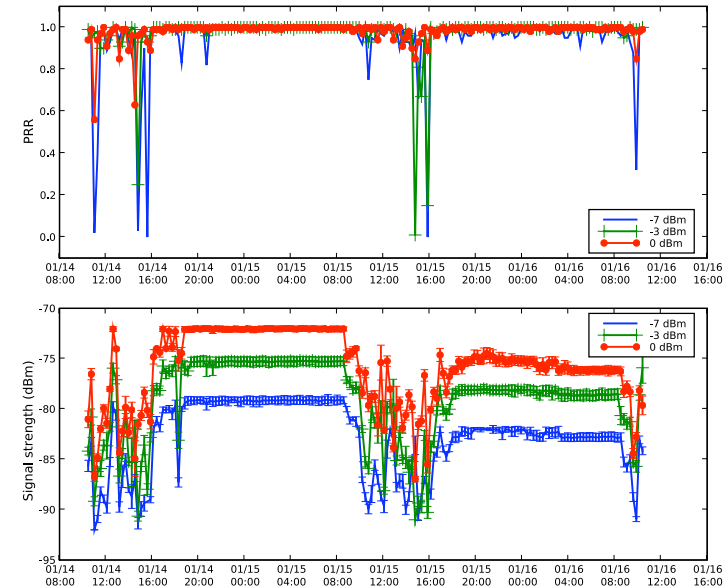
Wireless Dynamics

Challenges

- Wireless links change dynamically.
- Requires global rescheduling.
- Current approach too rigid?

Approaches

- Flexible and dynamic scheduling
 - ❑ Ex: RTQS avoids conflicts by enforcing inter-release times locally [RTSS'07]
- Mixed criticality in wireless
 - ❑ Sacrifice non-critical flows when links break
 - ❑ Maintain guarantees to critical flows



Scheduling-Control Co-Design

Challenge

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

Approaches

- Scheduling to optimize control objectives, not to meet deadlines
 - Ex: Rate selection for wireless control [RTAS'12]
- Achieve fault tolerance through wireless and control co-design
- Scheduling for self-triggered and event-based control

Scalability

Challenges

- **Centralized** approach does not scale
 - ❑ Network management
 - ❑ Feedback control loop
- WirelessHART: A gateway can support up to 80 devices

Approaches

- Hierarchical network management
- Local adaptation
- Peer-to-peer control
- Synchronized distributed clocks as time sources
- **Key: Scale without losing predictability!**

Summary

- Real-time wireless is a **reality** today
 - ❑ Industrial standards: WirelessHART, ISA100
 - ❑ Real deployments in the field
- Starting a **real-time scheduling theory for wireless**
 - ❑ Leverage real-time processor scheduling
 - ❑ Incorporate unique wireless properties
- Tremendous **opportunities** ahead
 - ❑ Optimize for control
 - ❑ Robust under wireless dynamics
 - ❑ Scale to 10,000+ nodes
- **Integrate** protocol design and scheduling theory

References

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http://wsn.cse.wustl.edu/index.php/Real-Time_Wireless_Control_Networks