Real-Time Wireless Control Networks
Challenges and Directions

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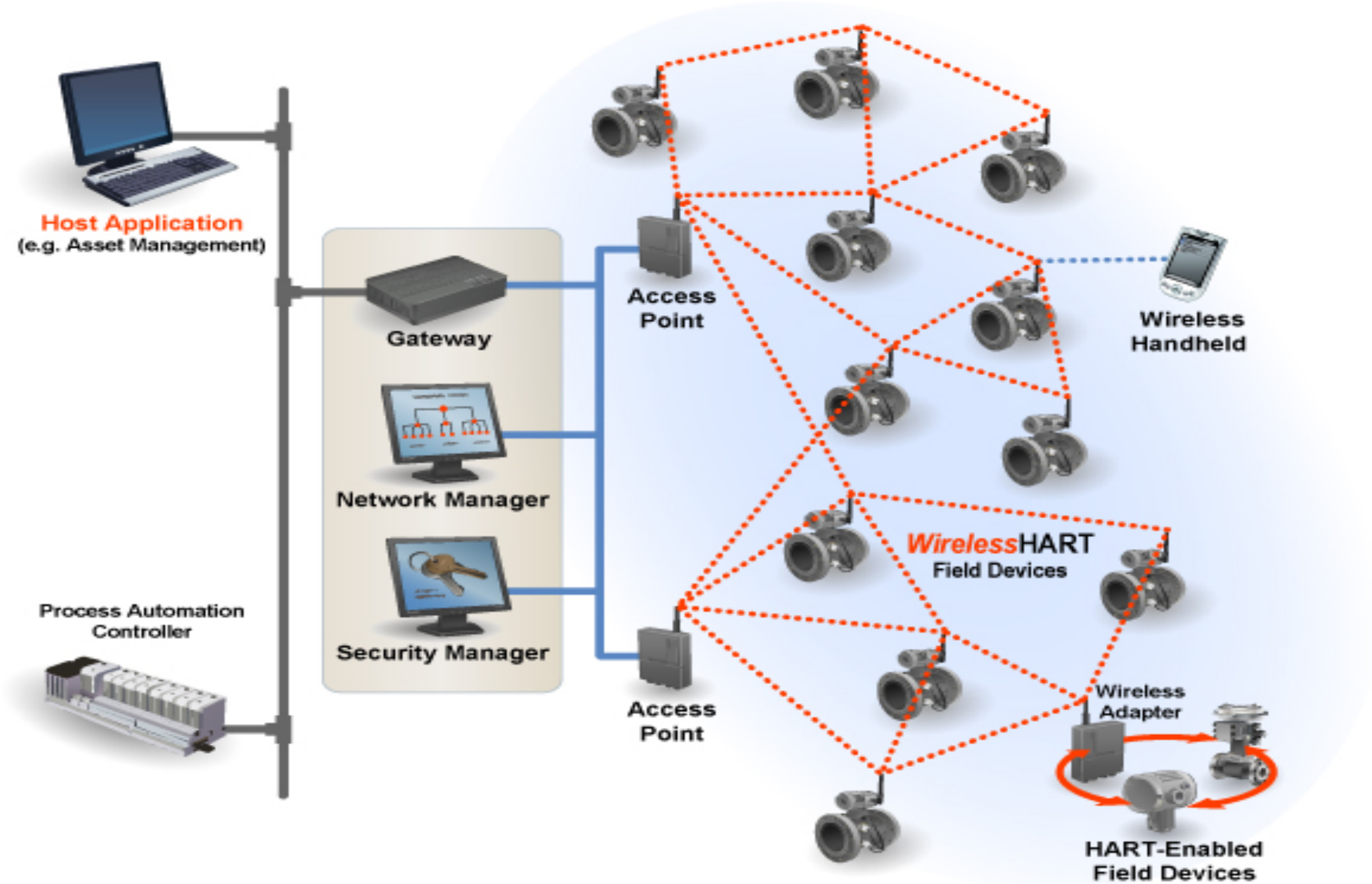
Outline

- 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

highest ... lowest priority

- A set of flows $F=\{F_1, F_2, \ldots, F_N\}$ ordered by priorities

- 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

end-to-end delay of F_i

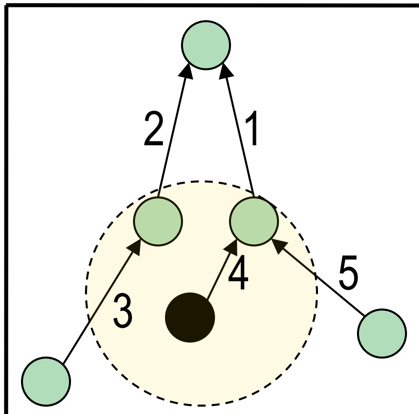
- Flows are schedulable if $R_i \leq D_i \quad \forall F_i \in F$

deadline of F_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



1 and 5 are conflicting
4 and 5 are conflicting

3 and 4 are conflict-free

- Each type of delay is analyzed separately

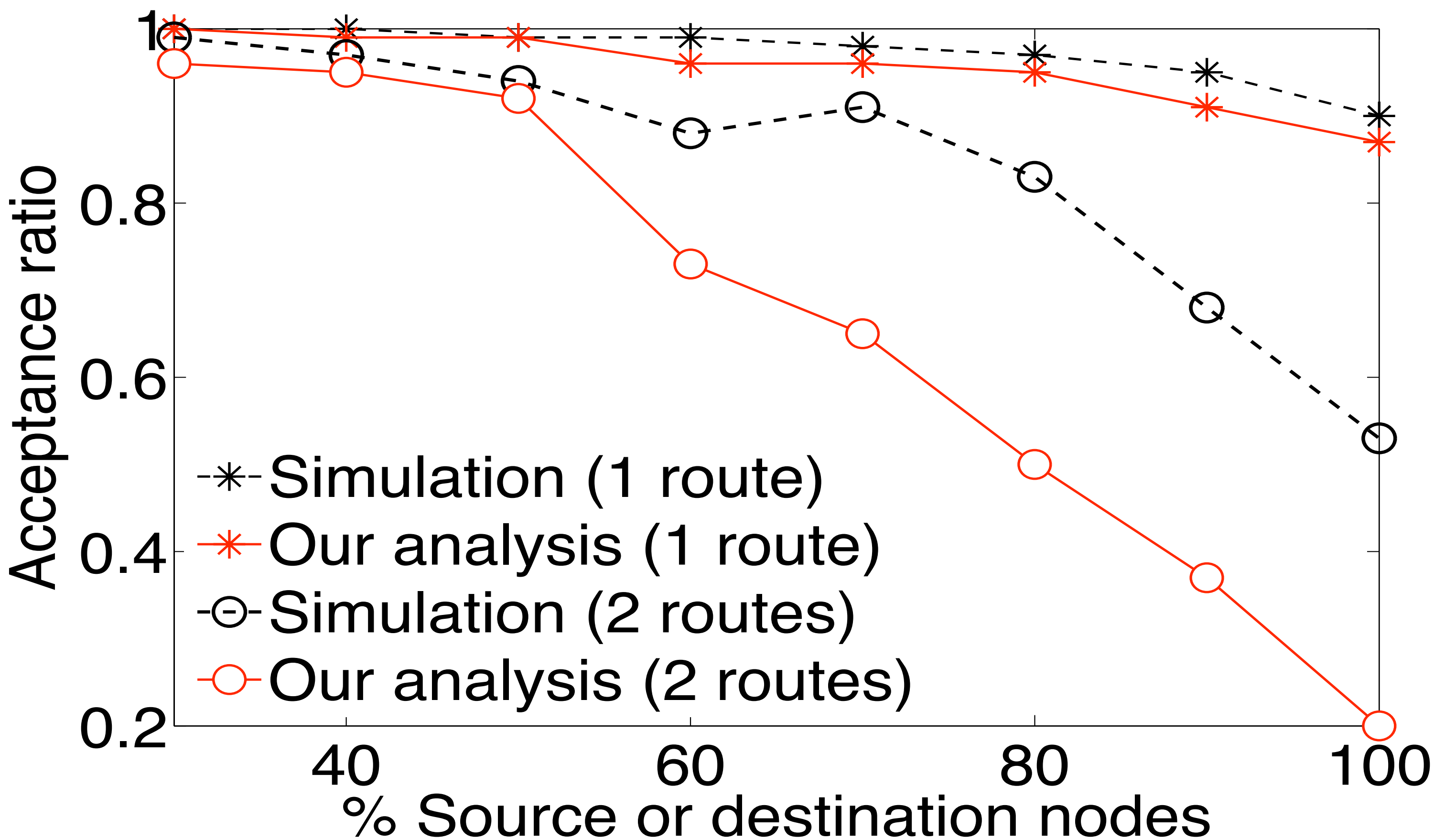
- Combine both delays → end-to-end delay bound

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



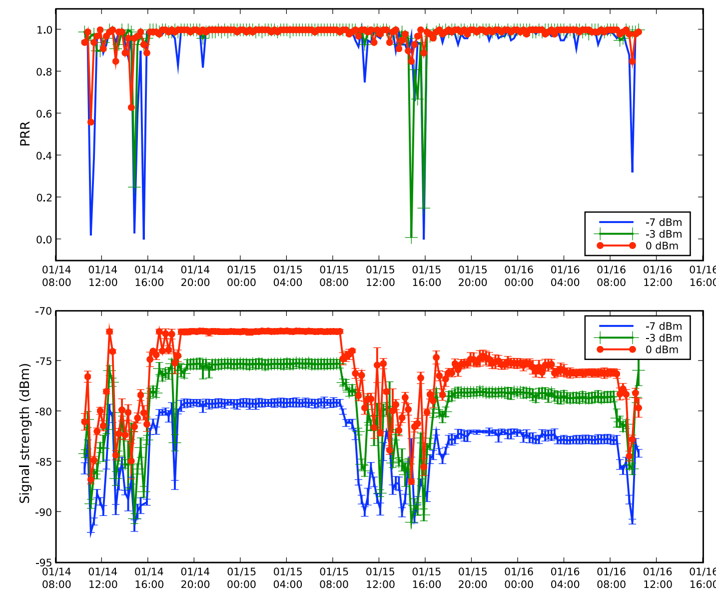
What we have so far…

- 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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