End-to-end Delay Analysis for Fixed Priority Scheduling in WirelessHART networks


WirelessHART (Highway Addressable Remote Transducer)

- Specifically designed for real-time communication between sensor and actuator devices.
- Supports operation in the 2.4 GHz ISM Band using IEEE 802.15.4 standard radios.
- Self-configurable and have no strict requirements on timing and communication reliability.
- Open WSAN standard which has been specifically designed for monitoring and control applications in process industries.
- Centralized network management architecture
- Multi-channel Time Division Multiple Access (TDMA)
- Redundant routes
- Avoidance of spatial reuse of channels
- Channel blacklisting
- Channel hopping.

WirelessHART Architecture

- Physical layer

  Based mostly on the IEEE STD 802.15.4-2006 2.4GHz DSSS physical layer.
  This layer defines radio characteristics, such as:
  - signaling method
  - signal strength
  - device sensitivity
WirelessHART Architecture

Data Link Layer

- defines a strict 10ms time slot and utilizes TDMA technology to provide collision free and deterministic communications.
- concept of super frame is introduced to group a sequence of consecutive time slots.
- introduces the idea of channel blacklisting.

Network Layer and Transport Layer

- (1) Field Devices that are attached to the plant process
- (2) Handheld which is a portable WirelessHART-enabled computer used to configure devices, run diagnostics, and perform calibrations
- (3) A gateway that connects host applications with field devices
- (4) A network manager that is responsible for configuring the network, scheduling and managing communication between WirelessHART devices.

Application Layer

- Defines various device commands, responses, data types and status reporting.
- Communication between the devices and gateway is based on commands and responses.
- Responsible for parsing the message content, extracting the command number, executing the specified command, and generating responses.

Security Architecture

- Public Keys which are used to generate MICs on the MAC layer by the joining devices.
- Network Keys which are shared by all network devices and used by existing devices in the network to generate MAC MIC’s.
- Join Keys that are unique to each network device and is used during the joining process to authenticate the joining device with the network manager.
- Session Keys that are generated by the network manager and is unique for each end-to-end connection between two network devices. It provides end-to-end confidentiality and data integrity.
WirelessHART network

* A flow is something a field device sends to someone at the network
* Multiple flows on the same system
* Node can only transmit or receive one transmission at a timeslot
* Time divided into fixed length slots
* Flows have a fixed priority, lower priority flows are delayed by higher priority

Delay analysis

* Arbitrary network topologies with no constraint for route length
* Authors derive an upper bound for the delays caused by higher priority flows transmitting
* Used to calculate maximum time it takes to transmit

Channel contention

* Each channel can transmit only one transmission per timeslot
* Channel usage based on priority
* Lower priority flows have to wait for a free channel

Channel contention

- 4 channel system
- Arrows depict transmission paths
Channel contention

- WirelessHART scheduling equal to the problem of Multiprocessor scheduling if no conflicts
- Channels mapped to processors, flows mapped to tasks with a priority and constant execution time
- Multiprocessor scheduling has been studied so authors could use existing literature to calculate upper bound

Transmission conflict

- Causes a delay to a lower priority flow when using the same path with a higher priority flow
- Unique to wirelessHART, not in multiprocessor scheduling
- Authors derived an equation to calculate the delay

Transmission conflict

Green flow will have to wait for red

Calculating total end-to-end delay

- Composed of channel contention and transmission conflicts
- First calculate upper bound for delay without conflicts for every flow
- Authors derived an equation for End-to-end delay considering transmission conflicts
- Use an iterative algorithm to find a minimal time needed to schedule
EVALUATION

• Priority assignment policies.
  • 1) Deadline Monotonic (DM): the flow with the shortest deadline being assigned the highest priority.
  • 2) Proportional Deadline monotonic (PD): PD assigns priorities to flows based on relative subdeadline defined for a flow as its relative deadline divided by the total number of transmissions along its route.
  • For both of them if there is a tie, then the flow with the smallest ID is assigned the highest priority.

Metrics.

• Acceptance ratio: This is defined as the proportion of the number of test cases deemed to be schedulable to the total number of test cases.

• Pessimism ratio: For a flow, this metric is defined as the proportion of the analyzed theoretical upper bound to its maximum end-to-end delay observed in simulations.

Simulation Setup

• n : Number of nodes in the network
• m : Number of channels
• ρ : Edge-density of the network
• θ : Fraction of total nodes which are sources and destinations
• γ : Number of routes between every source and destination
• P~ : Period range
• α : Deadline parameter (i.e., route length≤deadline≤α*period)
• β : Rate factor (i.e., new rate = β*old rate)

Simulations with Testbed Topologies

The testbed topology with a transmission power of 0 dBm
Varying sources and destinations.

The flows are generated in the network by randomly selecting the sources and destinations.

![Graph](image)

(b) Priority assignment: PD
Acceptance ratio under varying number of sources and destinations

Varying deadlines

- Deadlines become longer as $\alpha$ increases.
- Most of the schedulable cases are accepted analysis when $\Upsilon = 1$ under DM priority assignment policy.
- The difference is larger for $\Upsilon > 0.5$
- The difference between EDA and SIM is much smaller when the priorities are assigned using PD.

Varying rates

- By changing $\beta$ we tune rates of each flow.
- There are no schedulable cases with $\beta$ higher than 4.
- The acceptance ratios of our analysis decrease sharply with the increase of rates.
Varying rates

Random Topologies

- The edges are chosen randomly.
- We change only number of nodes while other parameters are chosen as number of sources=number of destinations.

Performance under DM

- up to 50 nodes

Random Topologies

- 75th percentile of the pessimism ratios is less than 1.6 for all cases up to 260 nodes
Random Topologies

• 75th percentile is less than 1.8 for all test cases up to 110 nodes when $\gamma = 2$.

Performance under PD.

• The difference between $EDA$ and $SIM$ remains less than 0.13 up to 160 nodes when $\gamma = 1$
• 75th percentile is less than 1.74 for all test cases up to 100 nodes when $\gamma = 2$.

Performance under PD.

• The results indicate that analysis is effective even for very large networks under various fixed priority assignment policies.
• All test cases accepted by our analysis meet their deadlines in the simulations which demonstrates that the estimated bounds are safe. So it’s possible to use this test for real-time flows

Conclusion

• We have mapped the scheduling of real-time data flows between sensors and actuators in a WirelessHART network.
• Simulation results demonstrate that end-to-end analysis is very effective in term of ratio acceptance under priority scheduling policies.
Thank you for your attention!

Questions?