Dwarf: Delay-aWAre Robust Forwarding for Energy-Constrained Wireless Sensor Networks

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NCCR MICS National Competence Center in Research Mobile Information and Communication Systems

FNSNF Fonds National Suisse Schweizerischer Nationalfonds Fondo Nazionale Svizzero Swiss National Science Foundation

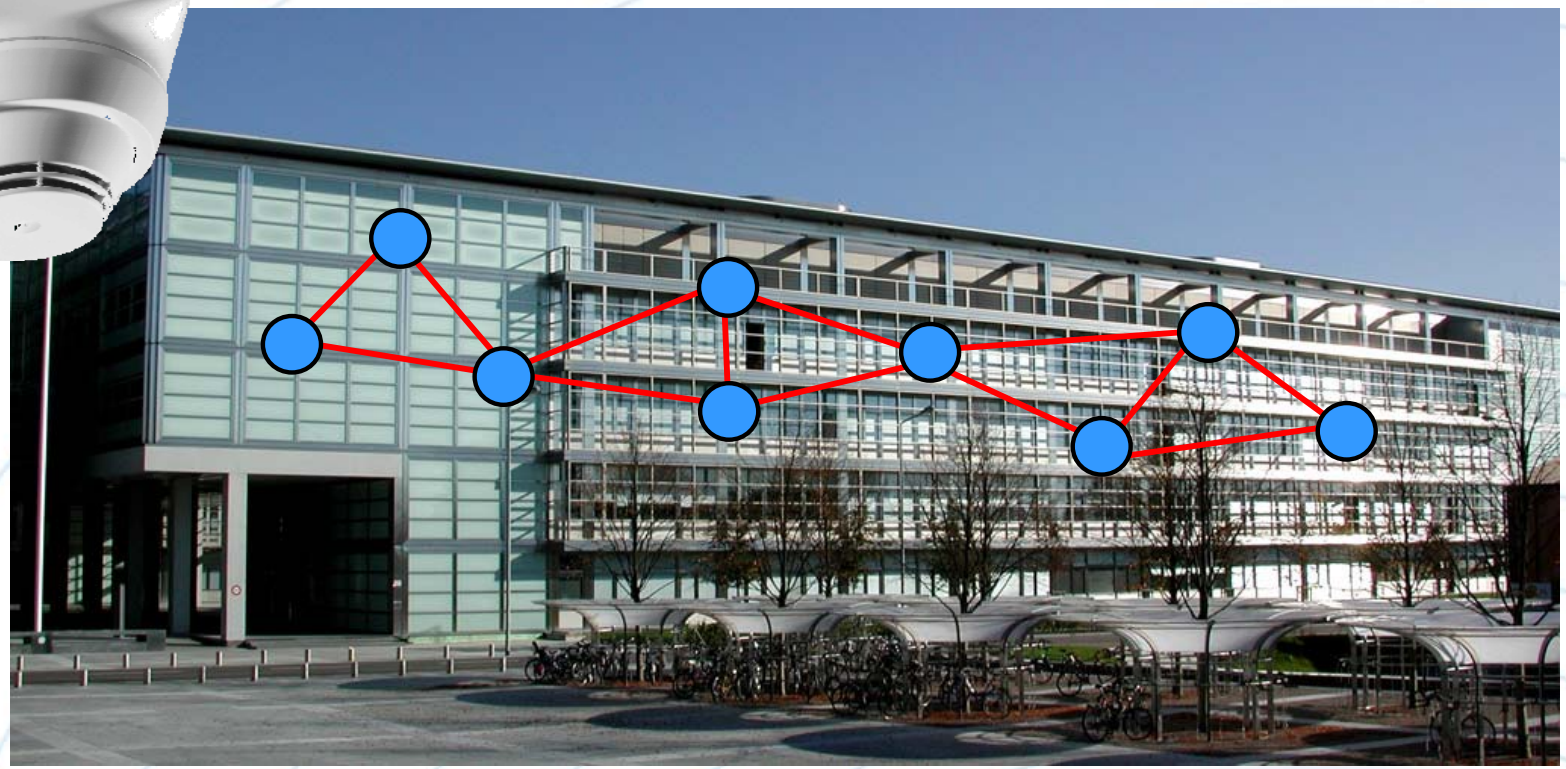
ETH Eidgenössische Technische Hochschule Zürich Swiss Federal Institute of Technology Zurich

TU Delft

SIEMENS

Motivation – Smart Buildings

- Wireless fire-alarm system
  - Wiring a building is cumbersome/costly or not even possible
- Large buildings requires scalable (multi-hop) solution
  - Existing products/solutions are single hop only



Requirements for Fire-Alarm System

1. Event reporting:
   - Alarm delay: ≤ 10 seconds (node to sink)
   - Robust and reliable

2. Status monitoring:
   - Node failure report: ≤ 5 minutes (at the sink)

3. Energy efficiency:
   - Lifetime greater than 3 years (on 2xAA): < 1% duty cycle

→ Large deployments require multi-hop solution

Related Work

- Event detection
  - Reliable transport protocols: ESRT, RMST, PSFQ
  - Flooding based approaches: GRAB, DFRF

Latency
Power

- Energy Efficiency
  - Data gathering protocols: Dozer [IPSN'07]

Latency
Reliability

- Status monitoring
  - Wang [DSN'03], Tai [DSN'04], Memento [SECON'06]

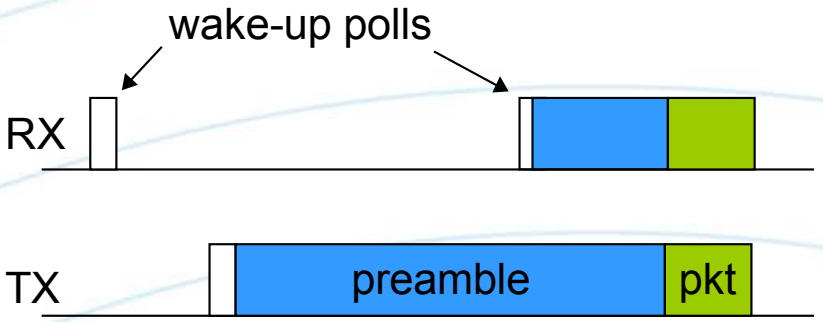
Latency
(Power)

anising

- No solution available for guaranteed:
  - Reliability and low latency and energy efficiency
  - Combination of monitoring with alarm forwarding

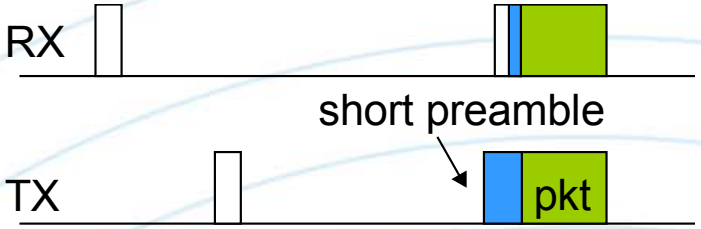
LPL based MACs are suited well for duty cycles < 1%

- B-MAC
  - Requires very long preambles



[Polastre et al. 2004]

- WiseMAC
  - Link based synchronization
  - High channel utilization and short preambles
  - Packet time (~5ms) much smaller than polling time (~1s)



[El-Hoiydi et al. 2004]

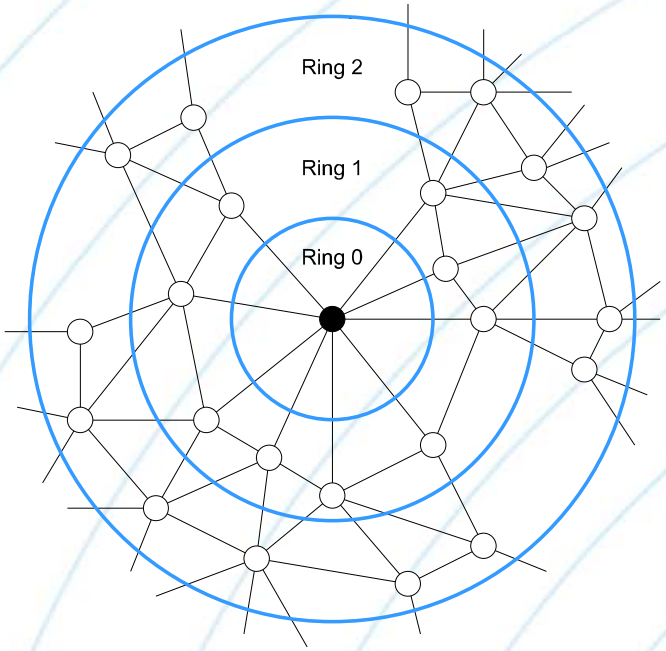
Dwarf Algorithm

Idea: Constrained flooding in combination with a delay-aware node-selection strategy

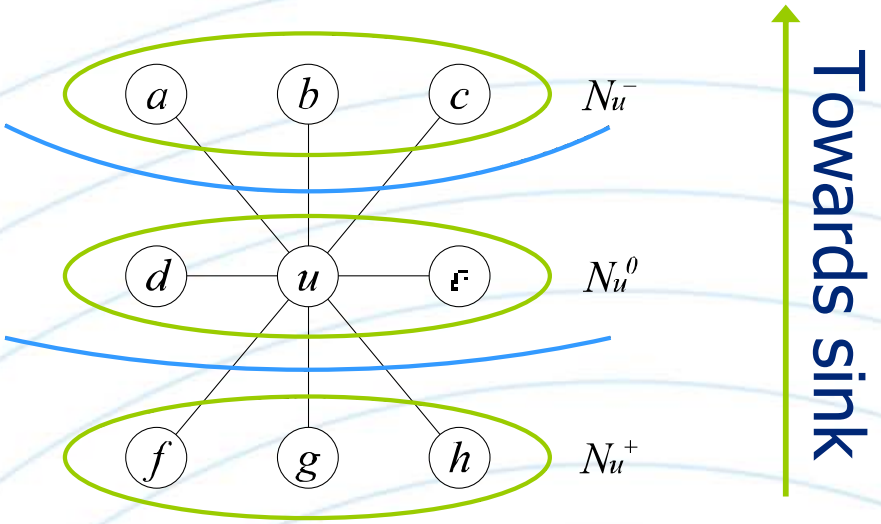
- Alarm is forwarded to *k* neighbors
  - Degree k: redundancy vs. message complexity (costs)
- Select forwarding nodes according their wake-up times and relative positions
  - Reduce alarm notification time

Dwarf's Network Structure

- Nodes are organized in rings
  - According to their distance to the nearest sink
  - We assume a topology manager selecting/maintaining high quality links only

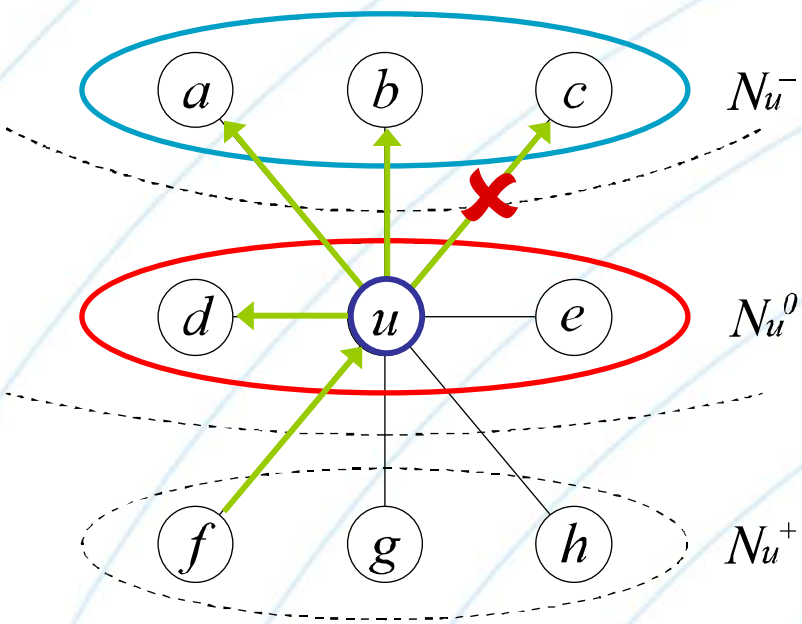


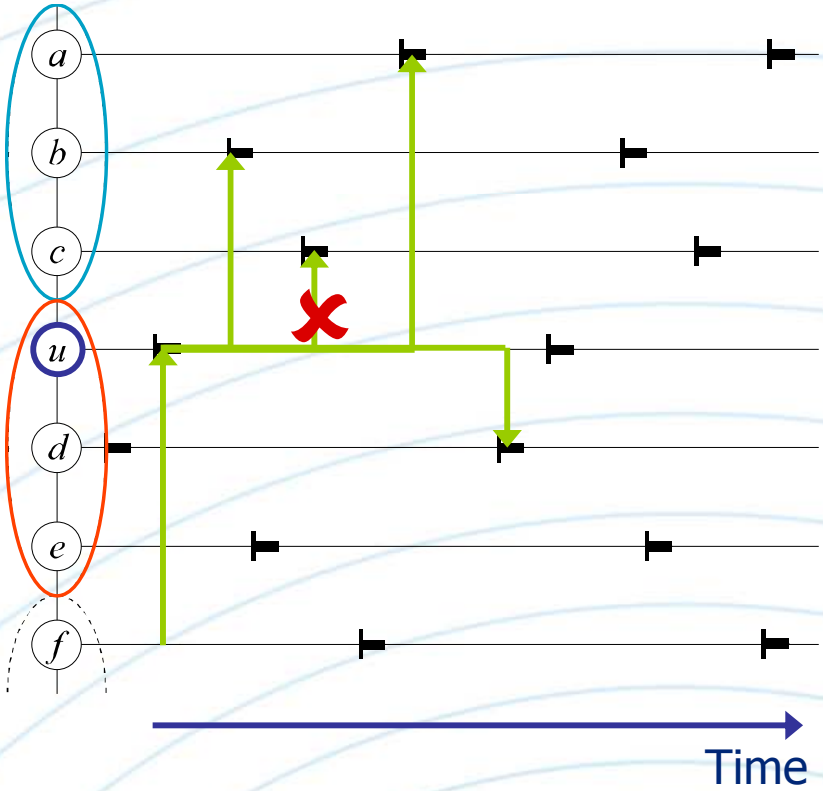
- The neighbors of node u are divided into
  - parents N_u^-, peers N_u^0, and children N_u^+
  - depending on the ring they belong to



Dwarf Algorithm: Example for $k = 3$ (Typical Value)

- Increasing k increases robustness but also the link maintenance costs
  - Analysis shows that k=2,3 already performs well



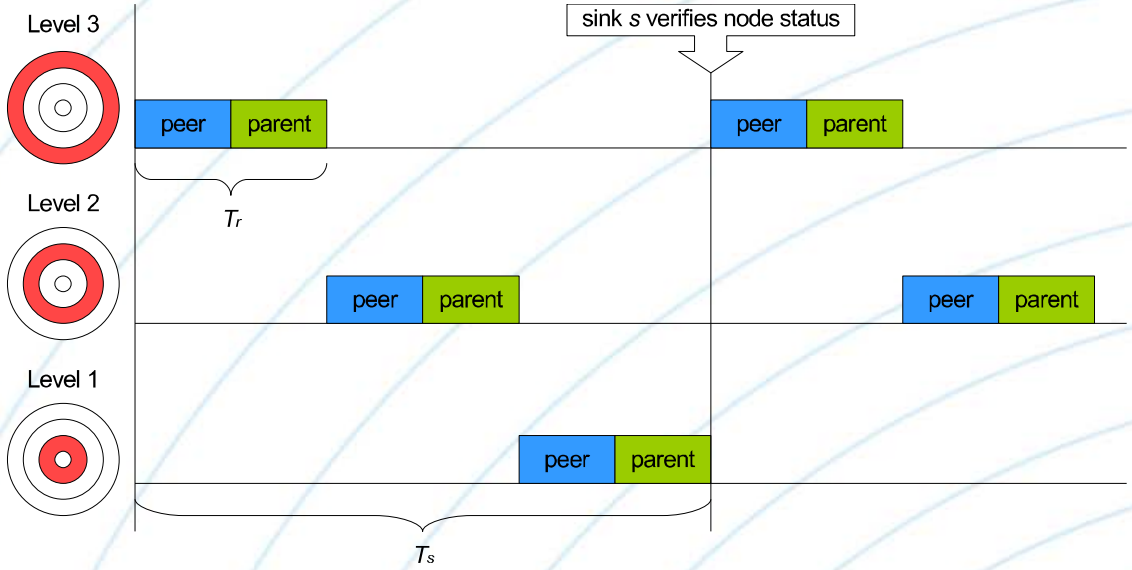


Dwarf Algorithm: Status Messages

- Exchange status messages
  - A) Detect node and link failures
    - Topology management
  - B) Keep wake-up schedules up to date

May interfere with alarm forwarding

- Ring based status-information aggregation towards the sink



Dwarf Algorithm: Analytic Analysis

Statement 1:

- Robustness and performance of a particular network can easy be assessed (based on network characteristic)

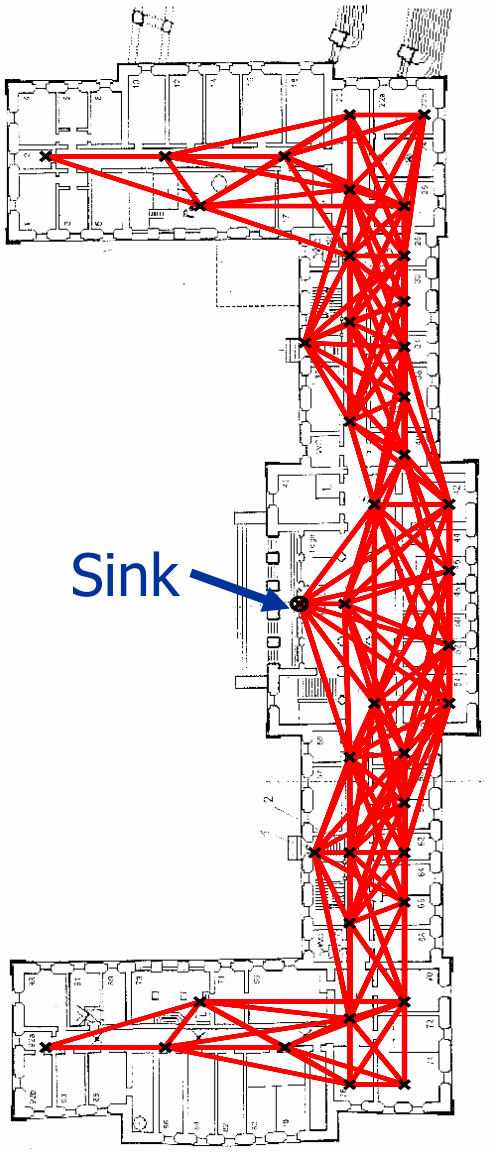
Statement 2:

- It is sufficient to have local knowledge of the one-hop neighborhood only

→ Proofs in paper

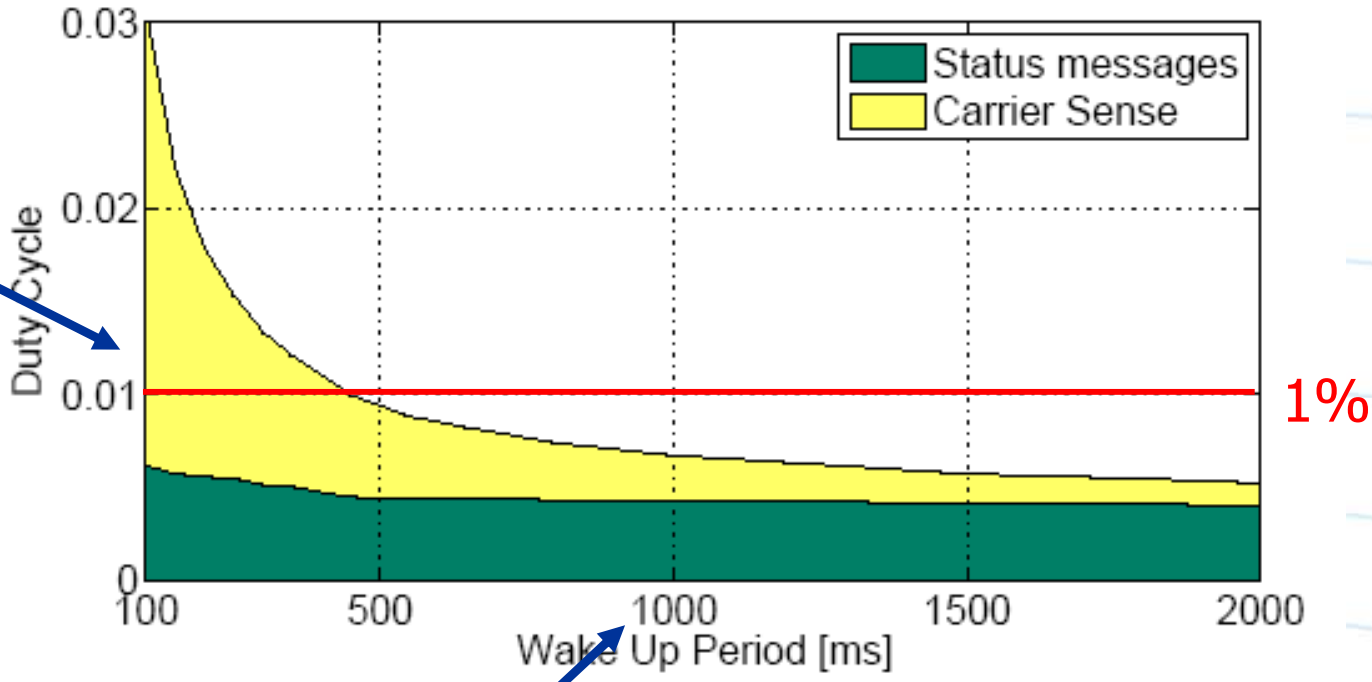
Performance Evaluation

- Connectivity Measurements
  - 80 nodes in real building (2 floors)
  - based on wired placement
  - provided by Siemens
  - 1-5 hops (3 on avg.)
- Used as input to GloMoSim simulation
  - Fed with link measurements
  - SINR radio model
  - CC1000 radio (switching times)
- No artificial topology and communication range



Performance Evaluation: Energy Consumption

Targeted Duty Cycle < 1%

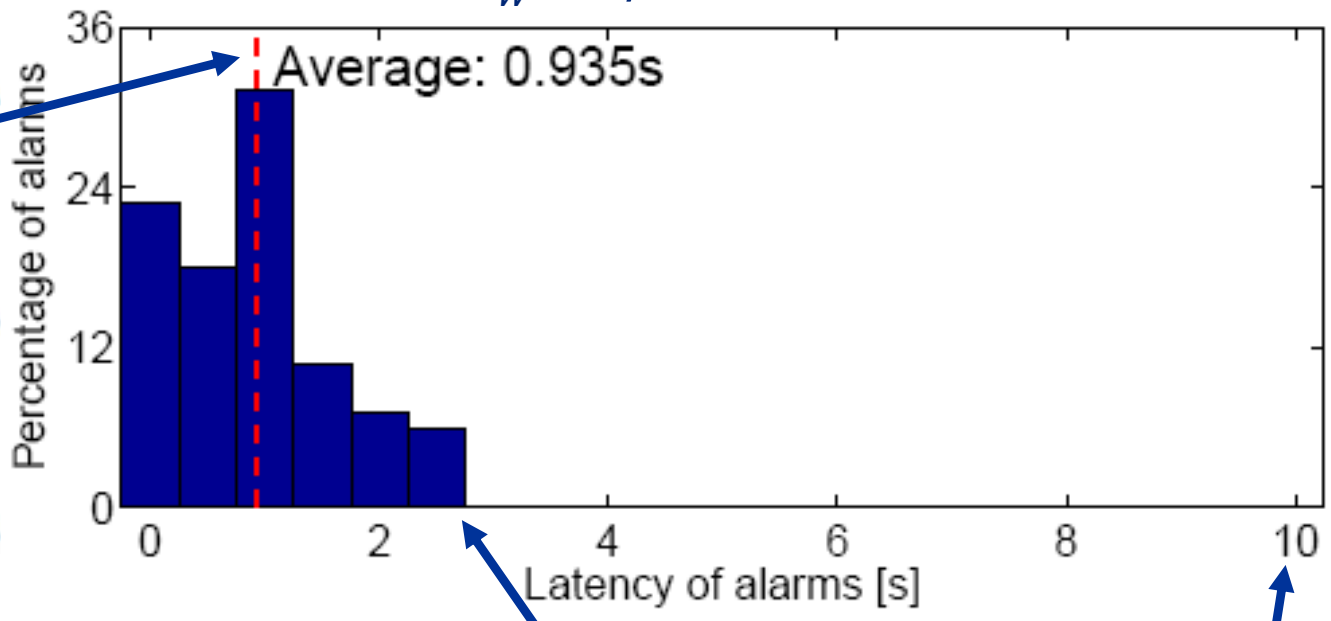


T_W=1s provides additional flexibility
– Maintenance, initialization...

Alarm Delay for Wake-up Time T_W=1s

More sensitive, less redundancy

T_w=1s, k=2

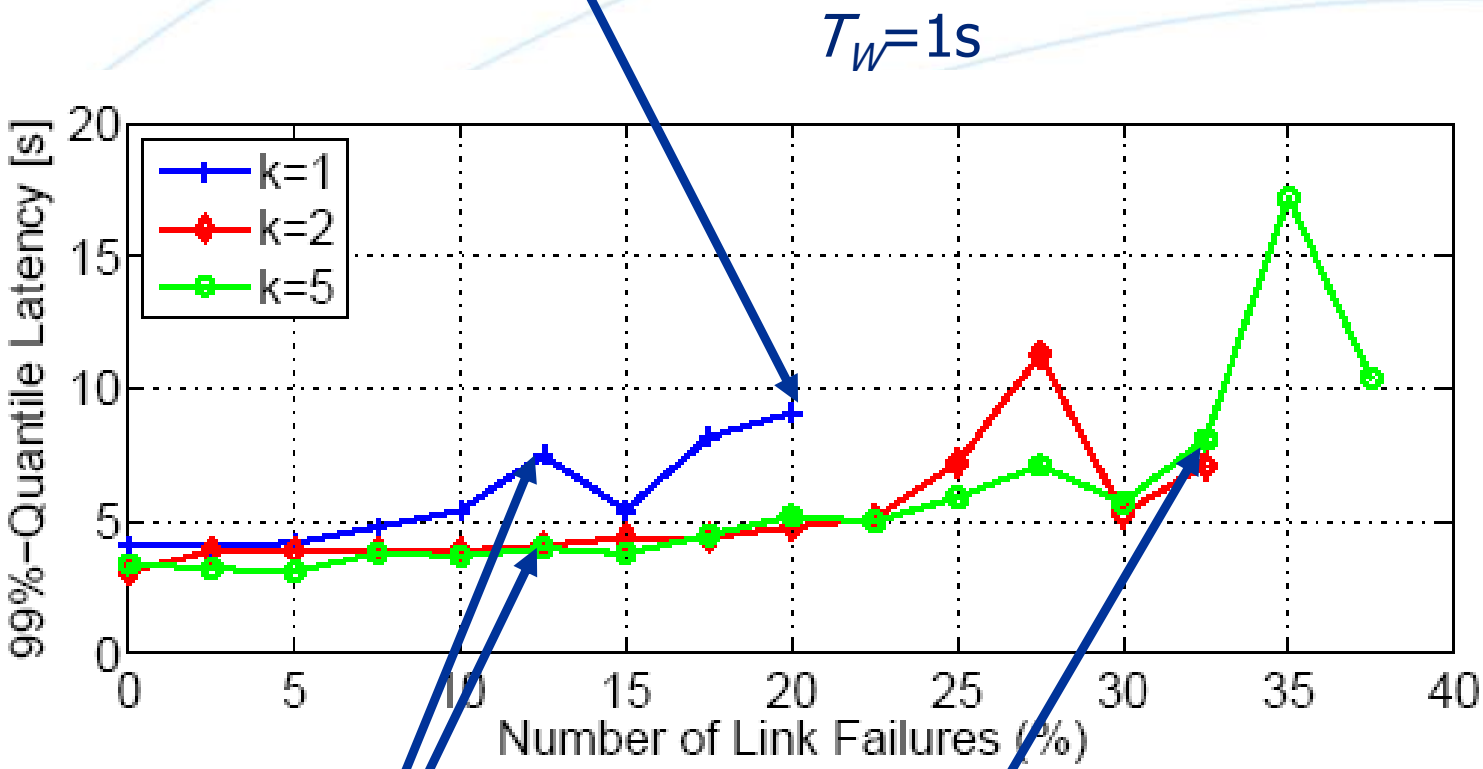


Average latency smaller than T_W
– 3 hops in avg.

Maximum latency well within 10s
– Up to 5 hops

Performance Evaluation: Robustness

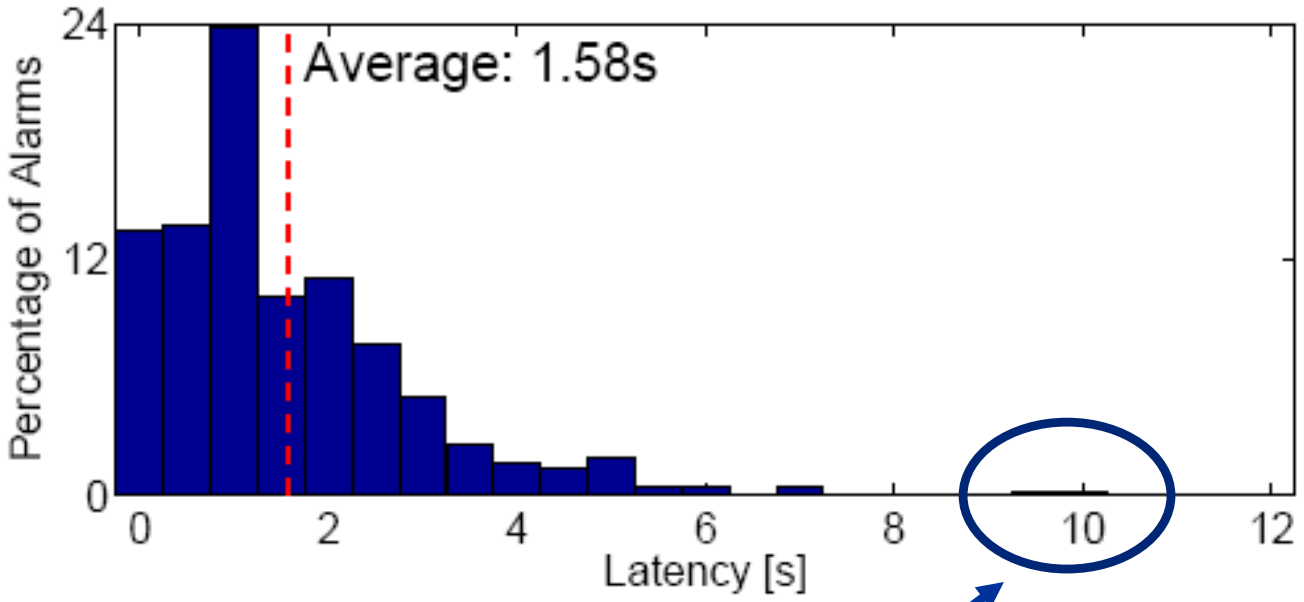
k = 1 not robust
– Messages lost in dead ends



k ≥ 2
– Messages overtake each other
– Less dead ends due to redundancy

Performance Evaluation: Robustness Detailed

T_W=1s, k=2, 25% link failures



Few outliers
– Combination of link failures and status message interference
– Alarm performance within the required 10s

Conclusion

- Problem: Safety critical alarm reporting requires
  - Robustness and timeliness and energy efficiency and monitoring
- Solution: Dwarf
  - Constrained flooding with delay-aware node selection
  - Ring based monitoring
- Dwarf provides robust and timely alarm reporting
  - Evaluation based on real world scenario
  - Duty cycle of about 0.5%
  - Even in combination with status monitoring
- Consider application as a whole
  - Status messages may interfere with alarm

Thank you for your attention

Questions?

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