Reliable Routing for Low-Power Smart Space Communications

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CONTENTS

Smart Space (SS)

❖ Smart Space (SS)

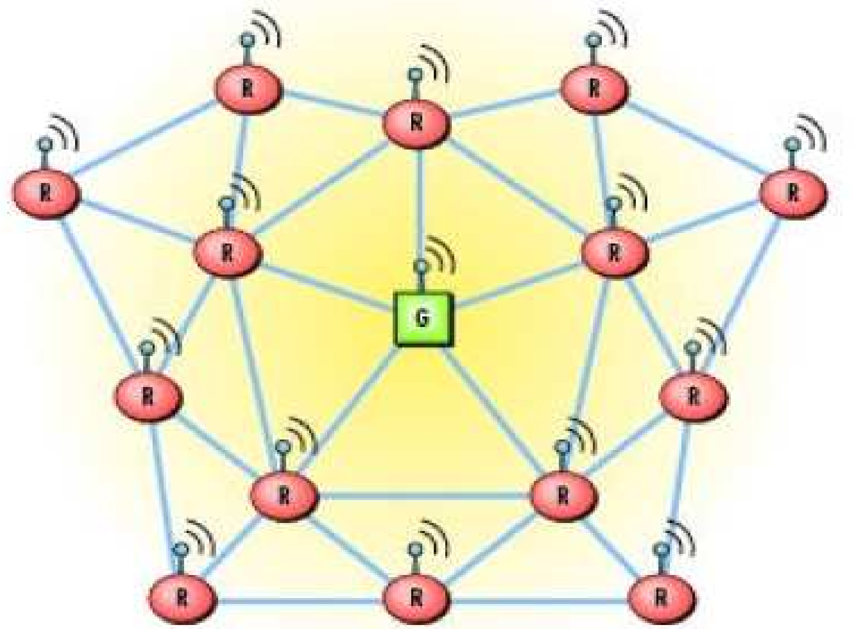
- **Embedded technology** [1]
  - Smart nodes: sensing, actuating, communicating, computing
- **Wirelessly networked** [2]
  - Low-power RF
  - Low data rate
- **Collaborative networking** [3]
  - Autonomous operation
  - Adaptive data collection
- **Examples** [4]
  - Smart sensor networks for home automation
  - Medical body sensor networks

BACKGROUND (Cont.)

Wireless Sensor Networks

❖ Definition

- WSN is a collection of distributed autonomous wireless sensor nodes which can self-organize to form an unattended network to cooperatively monitor physical or environmental conditions [3]



❖ Features [3][4]

- Multihop communication
- Dynamic topology
- Nodes work as routers

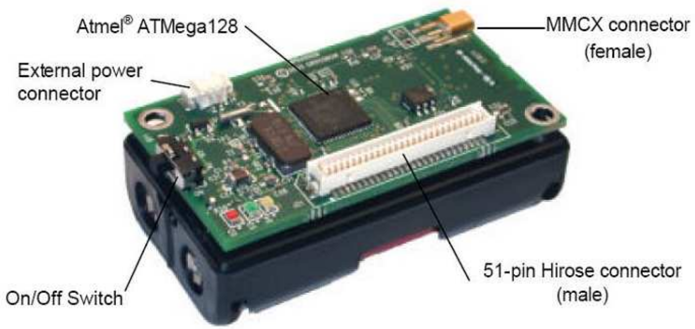
❖ Limitations [1]

- Constrained resources

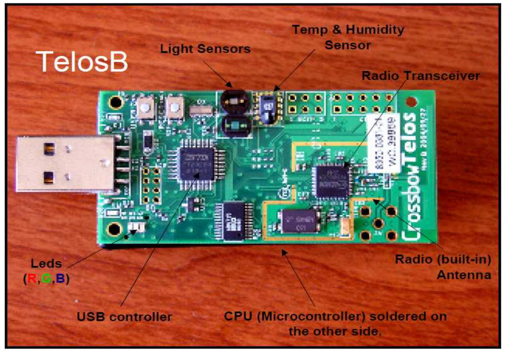
BACKGROUND (Cont.)

Wireless Sensor Networks

- ❖ Sensor networks are gaining popularity due to their wide variety of applications, e.g., military, industrial, environmental, etc.
- ❖ Tiny, low-cost, low-power wireless sensor nodes [1]



Mica2 [1]



TelosB [1]

- ❖ Wireless sensor nodes can
  - Sense a physical phenomenon
  - Process the sensed values
  - Communicate the sensed values among neighbors
  - Respond to physical phenomenon using actuators

Challenges in Sensor Networks

❖ Resource limitations

- Limited power
- Limited computation capabilities
- Limited bandwidth ~ 250 Kbps (TelosB motes) [1]

❖ Nature of communication

- Time-varying dynamic links
- Local broadcast with collisions
- Wireless radio multipath fading effects [4]

Problem Statement

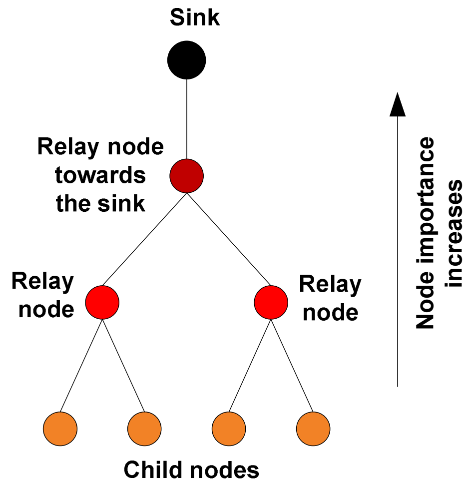
❖ Reliability-Oriented Routing Protocols

- Pure reliance on reliability metrics: Channel State Information (CSI) such as RSSI and LQI [2], or on delivery cost estimates such as ETX [5]
- Existing TinyOS-based collection tree routing protocols [6] do not explicitly employ energy or load balancing in their routing schemes

❖ Problems

Frequent use of optimal routes lead to:

- Imbalanced workload on relay nodes
- Topological bottleneck tree-based routing
- Network partitioning and routing-hole problem [9]

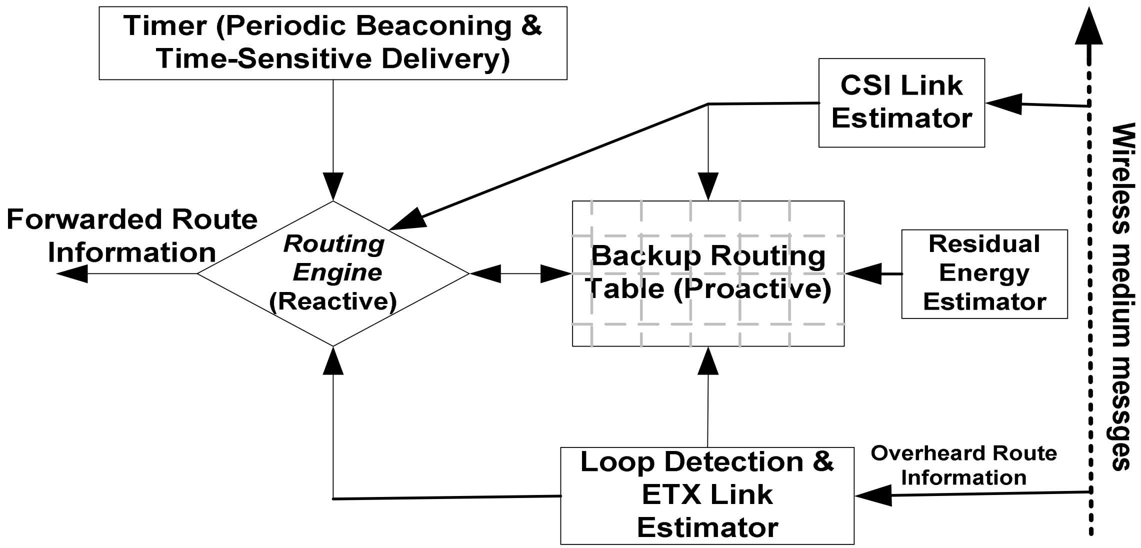


Topological bottleneck with respect to upstream nodes [9]

The Proposed Scheme

❖ Reliable Multiple-Metric Routing

- Remaining battery capacity (energy-aware)
- Channel state information (reliability-oriented)
- Number of hops (minimum end-to-end delay)
- Aggregated packets (minimum transmissions)

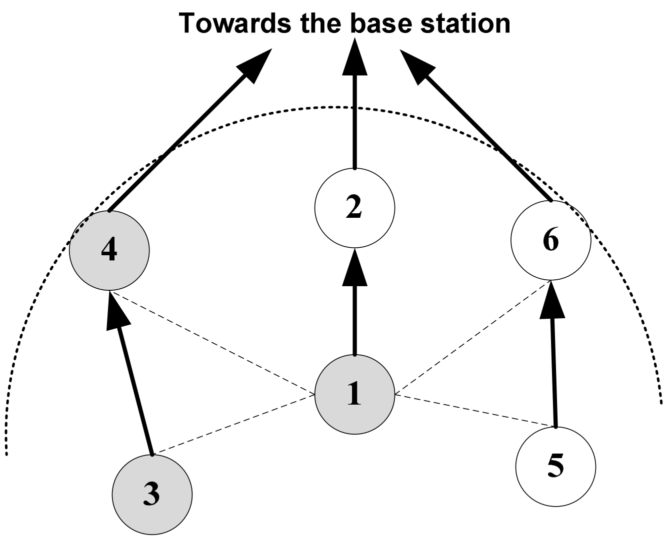


Proposed Routing Scheme Framework

The Proposed Scheme

❖ Overhearing-Based Packet Aggregation

- Adjacent nodes can exploit unavoidable overhearing of neighboring nodes' traffic to improve the selection of parent nodes and uncongested data aggregators. In this case, node 1 can move to node 4.
- Since more than one data packet being aggregated, the resulting aggregated packet must be dispatched to ensure the aggregated packets' with minimum deadlines.



Overhearing of Neighborhood Traffic

Performance Evaluation

Evaluation Methodology

❖ **Experimental Testbed**

- Outdoor interference-prone environment
- 30 static randomly deployed TelosB motes
- Single fixed perimeter sink
- Network stack: TinyOS IEEE802.15.4 (CSMA) on CC2420 2.4GHz radio

❖ **Large-Scale Simulations**

- 100 static sensor nodes in a square sensor field of 10x10 grid
- Various scenarios of 30, 50 and 70 source nodes
- IEEE 802.15.4 with bandwidth of 250Kbps
- Multipath shadowing propagation model [7]
- CC2420 radio energy model [8]

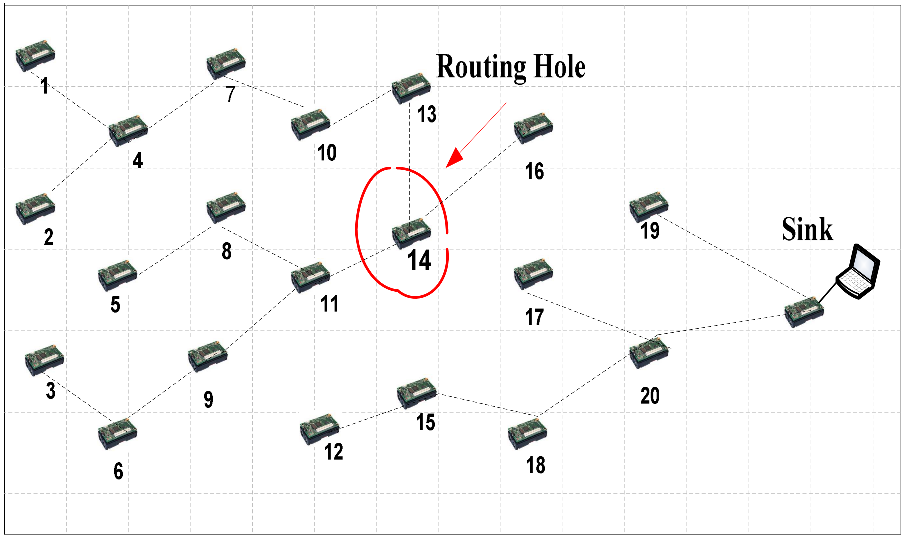
❖ **Benchmarking**

- Comparisons with TinyOS-2.x MultihopLQI collection routing protocol [6]
- Simulations validate the experiments

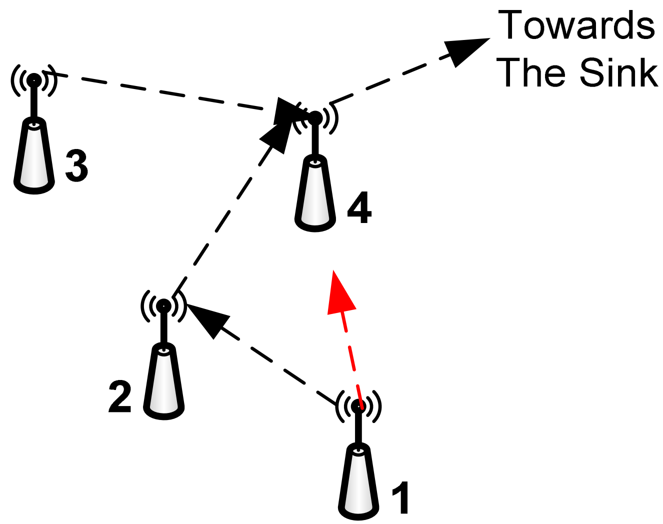
Experimental Observations

❖ Network Connectivity and Link Dynamics

- Due to pure reliance on link quality, MultihopLQI deals inappropriately with the asymmetric link problem as child sensor nodes might not get their packets acknowledged



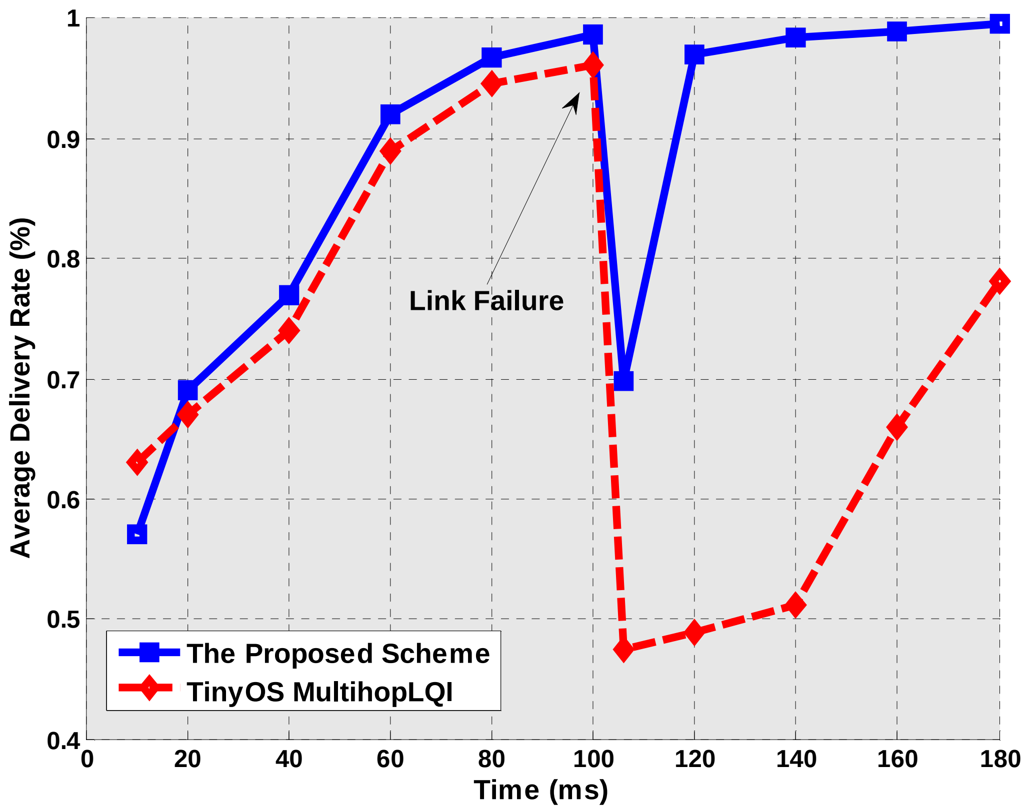
Based on LQI, sensor node 14 is in the opposite direction of where the sink is located but it is selected as a parent for node 16 instead of selecting node 19 and constructs the optimal route



Using averaged link quality values allows node 1 to switch to reachable node, e.g., node 2, to be its new valid parent after maximum transmission failures due to link asymmetry and transmission range between nodes 1 and 4.

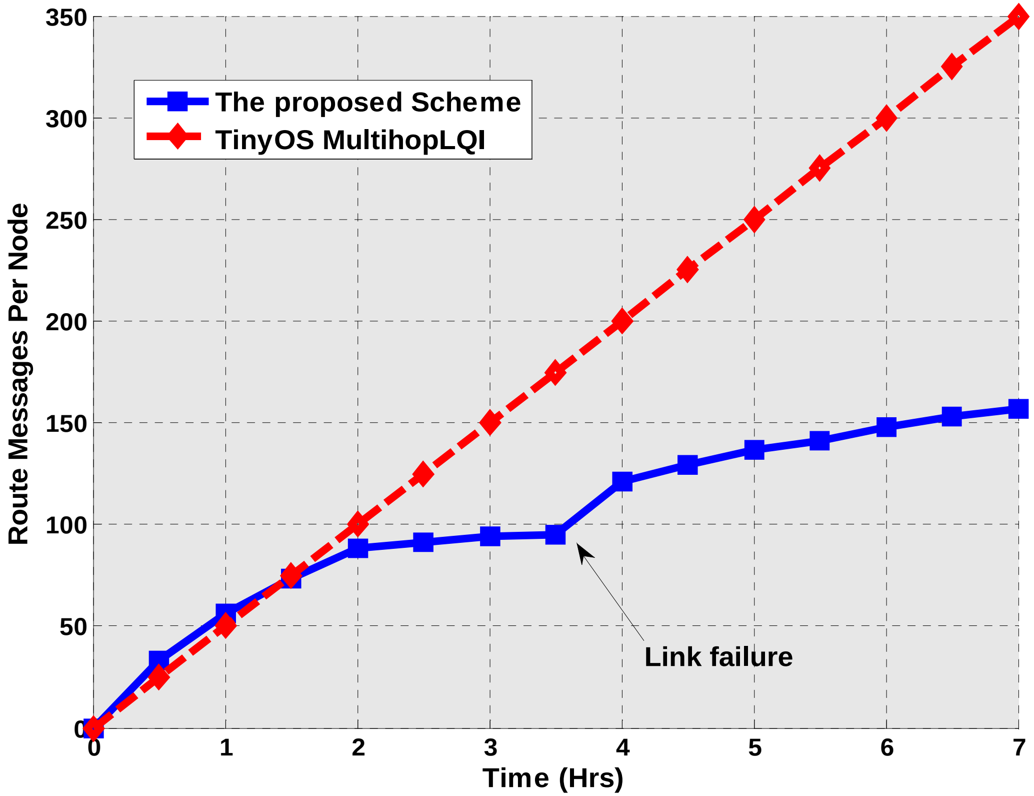
❖ Recovery from Link Failures

When a link is broken at 100ms within a short-term transmission period, the proposed scheme provides a faster recovery from broken links.



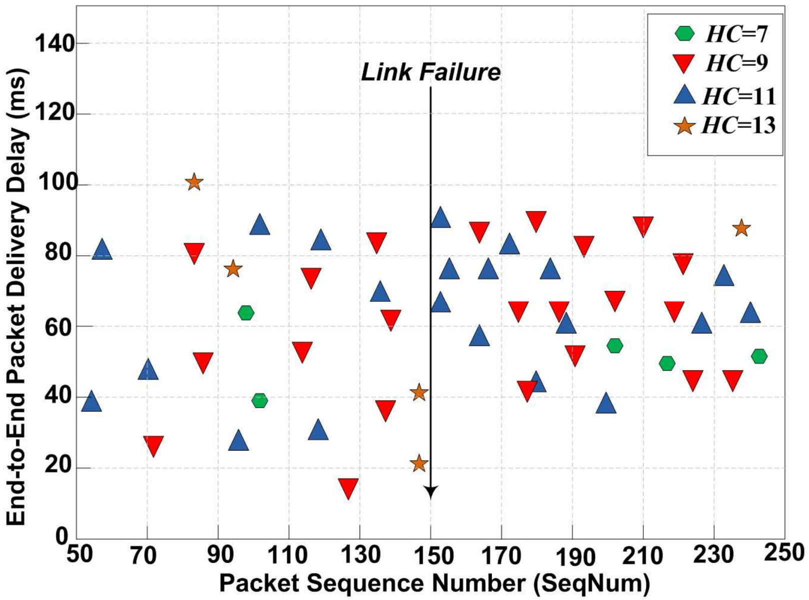
❖ Route Messages vs. Link Failure

During long-term transmission periods, the beaconing rate of route messages in the proposed scheme is slightly increased compared to MultihopLQI due to destroyed route. It rapidly reconstruct a routing path on an alternative route

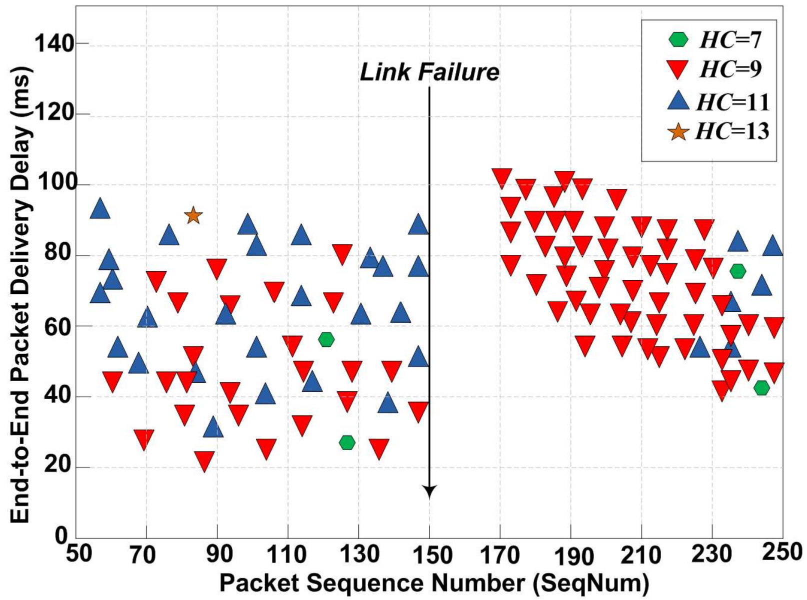


❖ End-to-End Packet Delivery Delay

- Since MultihopLQI keeps a state of one parent at a time, it is incapable of rapidly recovering from a broken route
- The proposed responds quickly to recover from a broken route as it maintains an alternative route to compensate the failed one. This new constructed route is used temporarily as a backup route to deliver source-originated data packets in timely manner towards the base station. However, the hop count (*hc*) might increase



Route Recovery Delay in the Proposed Scheme

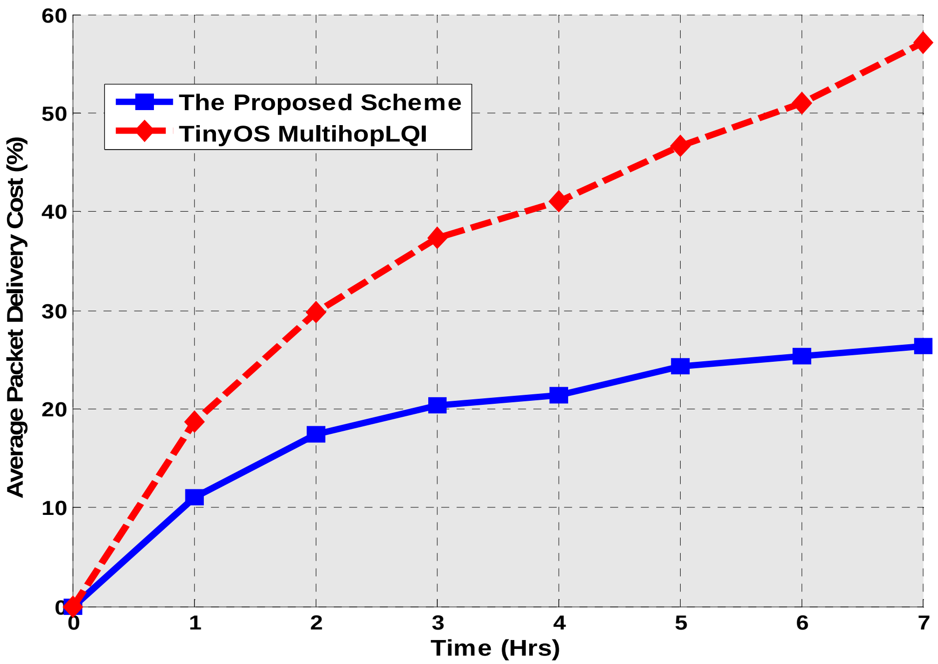


Route Recovery Delay in MultihopLQI

Experimental Observations (Cont.)

❖ Routing Overhead

- Over long run, the proposed scheme broadcasts fewer route/control messages as a result of minimising route message transmissions using adaptive beaconing. This leads to less energy consumed for route messages transmissions required for delivering data packets successfully towards the sink.

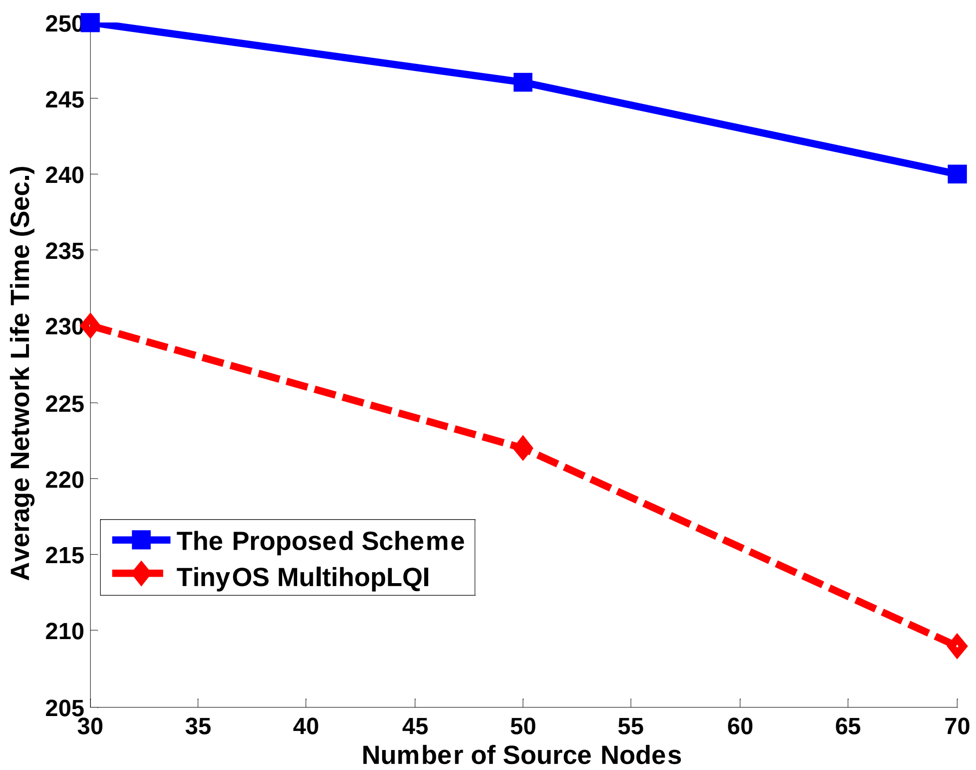


$$Average\ \ Packet\ \ Delivery\ \ Cost\ = \frac{Sent\ \ data\ \ and\ \ control\ \ packets}{received\ \ of\ \ data\ \ packets}$$

Simulations Results

❖ Functional Network Lifetime

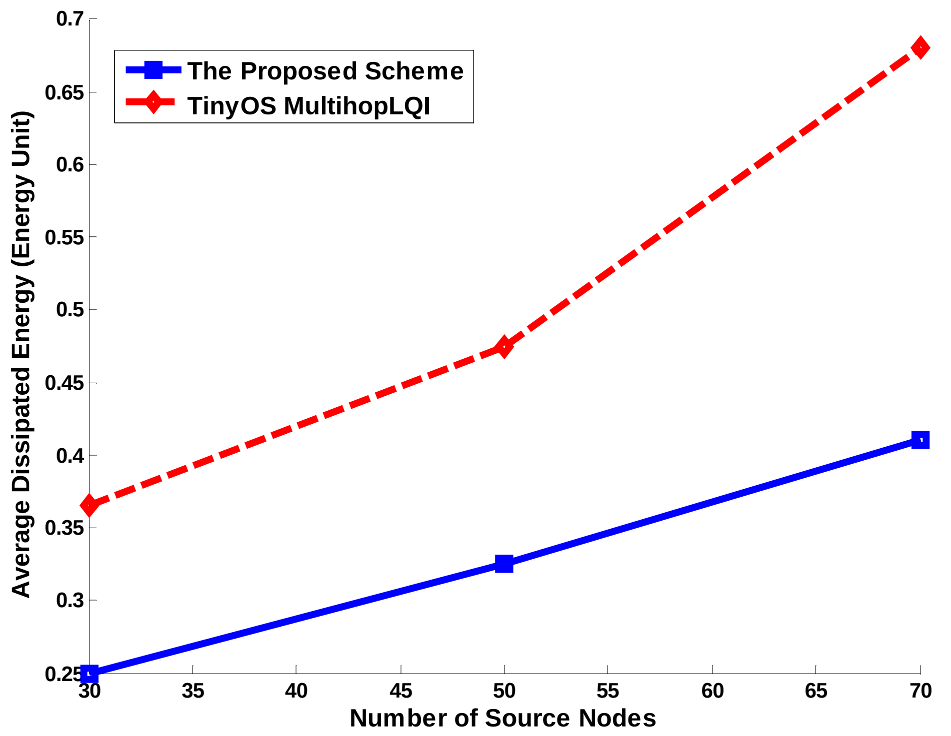
- Due to the low volume of control and data packets transmitted throughout the network, the proposed scheme results in a slower and a more graceful linear degradation of the network lifetime.



Simulations Results (Cont.)

❖ Average Dissipated Energy

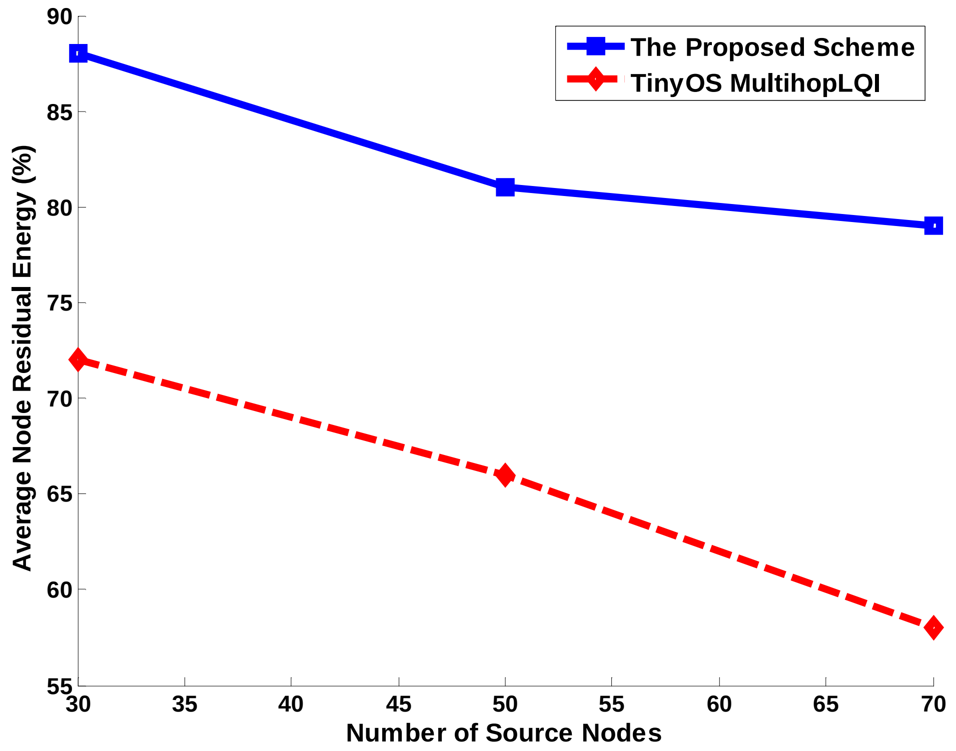
- The proposed scheme dissipates less energy for the same number of source nodes. The energy dissipation increases gradually as the number of generating nodes grows.



Simulations Results (Cont.)

❖ Average Node Residual Energy

- The proposed scheme reduces the redundant data copies in the network which results in lower traffic load handled by each individual forwarding node .



CONCLUSION AND FUTURE WORK

Conclusion

- Improved reliability and packet delivery
- Improved energy usage and efficient utilization of sensor node's resources
- Energy balance is beneficial for network lifetime extension
- The proposed scheme consumes less energy while reducing topology repair latency and supports various aggregation weights by redistributing packet relaying loads
- It allows for adapting the amount of traffic to the fluctuations in network connectivity and energy expenditure

Ongoing work

- Comparisons with energy-aware routing protocols
- Adaptability to mobile wireless sensor networks

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