Fault Tolerance

CS 447– Wireless Embedded Systems
Outline

• Overview
• Mechanisms for Fault Tolerance
• Disjoint Multipath
• Braided Multipath
• Retransmission
• Replication
Overview

• Focus on fault tolerant routing protocols

• Multipath routing should be designed to handle if / when nodes go down
Overview

Wireless sensor networks of unique constraints

- Energy consumption
- Node deployment
- QoS – Quality of Service
- Data Aggregation
- Node Mobility
Overview

Careful resource management is critical

A node or link could fail due to:
• Limited battery
• Hardware malfunction
• Communication errors
• Malicious attacks
Overview

A single failure could affect entire WSN

Routing protocols should be designed to provide fault tolerance
  • And needs to be scalable

This lecture: focus on using multipath routing to increase WSN reliability..
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Mechanisms for Fault Tolerance

Fault tolerance – ensures system is available for use without interruption in the presence of faults

Fault tolerance increases system:
• Reliability
• Availability
• Dependability
Mechanisms for Fault Tolerance

Multipath routing is most popular to provide fault tolerance
• Set of multiple paths between source and sink nodes
Mechanisms for Fault Tolerance

Multipath routing tradeoffs:
• Increased power consumption
• Increased network traffic

Benefits:
• Load balancing
• Bandwidth aggregation
Mechanisms for Fault Tolerance

Three types of multipath routing methods

1. Paths *precomputed*, stored in routing table
2. Reactive routing- paths created *on demand*
3. Hybrid- mix of both
Mechanisms for Fault Tolerance

How to establish paths:

- Disjoint multipath
- Braided multipath
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Disjoint Multipath

- Construct number of alternate paths
- Nodes (and links) disjoint with primary path
- Any failure on primary path will not harm alternatives
Disjoint Multipath

But...

- Alternate paths may require more energy (more hops)
- Requires global knowledge of network topology
Disjoint Multipath

S

primary path

D
Disjoint Multipath

S

D

primary path
alternate paths
Disjoint Multipath

If node in **primary path** goes down, packet can still reach destination.
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Braided Multipath

• Construct alternate path for each node in primary path
• Alternate paths in a braid partially overlay primary path
• Not as expensive as disjoint
• Provides alternative if node in primary path fails
Braided Multipath

But...

• If most or all nodes in primary path fail, new path discovery is required
• Can be costly
Braided Multipath

S

D

primary path
Braided Multipath

S

primary path
alternate path

D

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Braided Multipath

There should be an alternate route for each node in primary path.
Braided Multipath

If node in primary path goes down, packet can still reach destination.
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Retransmission

- Most popular method
- *Retransmit data packets to destination*
- Use one of multiple paths
- Try to minimize hop count or energy consumption
Retransmission

- Retransmit a predetermined number of times

Basic premise:
- Destination sends ACK to sender
- Sender does not receive ACK before timeout
- Data transmitted via another path
Retransmission

Drawbacks:
• Increased network traffic
• Transmitting ACK back to sender may increase:
  • Delivery delay
  • Packet loss due to collisions

• Requires more memory per node
  • Must buffer new packets until ACK received
Retransmission

Example algorithm: *Energy Efficient Multiple Routing Protocol for WSNs*

- Uses *directed diffusion* to create routing table
- WSN finds several *braided multipaths*
- WSN picks primary path between source and destination
- If failure in primary path, node recovers by retransmitting along another path
- How to detect failure? Sender does not receive ACK
Aside: **directed diffusion**

- Destination sends “interest” packet
- Received interest packet flooded to all neighbors
- Each receiver generates a *gradient* (direction where interest packet came from)
- Information used to create routing table
Aside: **directed diffusion** (cont’d)

- Source sends dummy packet along multiple paths
- Reaches destination (from multiple paths), destination picks one route (e.g., with fewest hops)
- Path will be reinforced to use with sensor data
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Replication

• Introduce redundancy into packet delivery
• One method- transmit multiple copies of same packet along different paths

Drawbacks:
• Increased overhead when packet Tx through each node
• Each node must maintain path state
• Not adaptive to channel errors
Replication

Another method- _erasure coding_

- Source decodes packet (size bM bits) into
- M fragments each of size b
- Generates another K coding fragments
- M + K total fragments
- Fragments sent as sub packets \( x_1, x_2, \ldots, x_n \) for n paths from source to destination
Replication

Erasure coding (cont’d)

• Allocation of fragments on each path determined by load balancing algorithm where

\[ \sum_{i=1}^{n} x_i = M + K. \]

• At least M fragments must be received by destination to reconstruct original packet
• At most K fragments can be lost
Erasure coding (cont’d)

• Several algorithms that provide erasure coding
  • Reed—Solomon codes
  • Rateless codes
  • (Similar to how RAID 5 and 6 work)

• Erasure coding is more reliable and energy efficient than retransmission
Replication

\[
\sum_{i=1}^{n} x_i = M + K
\]

\[
\sum_{i=1}^{n} z_i \geq M
\]

Data fragments
Parity fragments
Replication

Example algorithm: ReinForm (Reliable Information Forwarding)

- Destination periodically broadcasts routing update packet to network
- Each node knows: its neighbors and # hops to destination
Replication

ReinForm algorithm (cont’d)

• Source has data to send, generates packet with some level of desired reliability

• Depending on reliability parameter by source, multiple copies of data packet created and sent on multiple paths to destination

• Number of multipaths function of reliability parameter
Replication

ReinForm algorithm (cont’d)
• Each intermediate node uses reliability information to determine:
• Number of copies to make
• Number of multipath to forward packet
• Which neighbors to forward packet to
Replication

ReinForm algorithm (cont’d)

• Process continues until packet reaches destination

Fault tolerance:

• Multiple copies of same packet sent over randomly chosen paths to destination

• Duplication not only at source node, but every intermediate node in WSN
Replication

ReinForm algorithm (cont’d)

Drawbacks-
• High energy consumption
• Packet is copied, transmitted, and reconstructed among each node in WSN