Wireless Sensor Networks

5. Routing

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- Perkins, Royer
  - Ad hoc On-Demand Distance Vector Routing, IEEE Workshop on Mobile Computing Systems and Applications, 1999

- Reaktives Routing-Protokoll

- Reactive routing protocol
  - Improvement of DSR
  - no source routing
  - Distance Vector Tables
    - but only for nodes with demand
  - Sequence number to help identify outdated cache info
  - Nodes know the origin of a packet and update the routing table
Algorithm

- Route Request (RREQ) like in DSR
- Intermediate nodes set a reverse pointer towards the sender
- If the target is reached, a Route Reply (RREP) is sent
- Route Reply follow the pointers

Assumption: symmetric connections
Route Reply
Data Packet[F]
Route Reply in AODV

- Intermediate nodes
  - may send route-reply packets, if their cache information is up-to-date

- Destination Sequence Numbers
  - measure the up-to-dateness of the route information
  - AODV uses cached information less frequently than DSR
  - A new route request generates a greater destination sequence number
  - Intermediate nodes with a smaller sequence number may not generate a route reply (RREP) packets
Timeouts

- Reverse pointers are deleted after a certain time
  - RREP timeout allows the transmitter to go back
- Routing table information to be deleted
  - if they have not been used for some time
  - Then a new RREQ is triggered
Link Failure Reporting

- Neighbors of a node X are active,
  - if the routing table cache are not deleted
- If a link of the routing table is interrupted,
  - then all active neighbors are informed
- Link failures are distributed by Route Error (RERR) packets to the sender
  - also update the Destination Sequence Numbers
  - This creates new route request
Detection of Link Failure

- **Hello messages**
  - neighboring nodes periodically exchange hello packets
  - Absence of this message indicates link failure

- **Alternative**
  - use information from MAC protocol
Sequence Numbers

- When a node receives a message with destination sequence number N
  - then this node sets its number to N
  - if it was smaller before

- In order to prevent loops
  - If A has not noticed the loss of link (C, D)
    - (for example, RERR is lost)
  - If C sends a RREQ
    - on path C-E-A
  - Without sequence numbers, a loop will be constructed
    - since A "knows" a path to D, this results in a loop (for instance, CEABC)
Sequence Numbers
Optimization
Expanding Ring Search

- Route Requests
  - *start with small time-to-live value (TTL)*
  - if no Route Reply (RREP) is received, the value is increased by a constant factor and resent

- This optimization is also applicable for DSR
\[ \text{Traffic: } 1^2 + 2^2 + 3^2 + \ldots + d^2 = \Theta(d^3) \]

\[ \text{Time: } 2(1 + 2 + 3 + \ldots + d) = \frac{d(d+1)}{2} = \Theta(d^2) \]

\[ \text{Traffic: } 1 + (2^2 + 3^2 + 4^2 + \ldots + d^2) = \Theta(d^{1.5}) \]

\[ \text{Time: } 1 + 2^2 + 3^2 + 4^2 + \ldots + d^2 = \Theta(d^2) \]
exponential expanding ring search

\[ 1, 2, 4, 8, 16, \ldots, d \]

Time: \[ 2 \cdot \left( 1 + 2 + 4 + 8 + \ldots + d \right) \]
\[ \leq 2d < 3d \]

Traffic: \[ D \cdot \left( 1 + 2^2 + 4^2 + 8^2 + \ldots + d^2 \right) \]
\[ \leq \frac{d^4}{2} \]

\[ 1, 2, 2^2, 2^2, 2^2, 2^2, 2^2, 2^2, \ldots, 2^n, 3^n \]
DYMO - Dynamic MANET On-demand (AODVv2) Routing

- Literature

- Improvement of AODV
  - RREQ, RREP to construct shortest length paths
  - Path accumulation
    - a single route request creates routes to all the nodes along the path to the destination
  - Unreliable links can be assigned a cost higher than one
  - Sequence numbers to guarantee the freshness routing table entries
Routing in MANETs

- **Routing**
  - Determination of message paths
  - Transport of data

- **Protocol types**
  - **proactive**
    - Routing tables with updates
  - **reactive**
    - repair of message paths only when necessary
  - **hybrid**
    - combination of proactive and reactive
Routing Protocols for MANETs

- **Proactive**
  - Routes are demand independent
  - Standard Link-State and Distance-Vector Protocols
    - Destination Sequenced Distance Vector (DSDV)
    - Optimized Link State Routing (OLSR)

- **Reactive**
  - Route are determined when needed
    - Dynamic Source Routing (DSR)
    - Ad hoc On-demand Distance Vector (AODV)
    - Dynamic MANET On-demand Routing Protocol
    - Temporally Ordered Routing Algorithm (TORA)

- **Hybrid**
  - combination of reactive und proactive
    - Zone Routing Protocol (ZRP)
    - Greedy Perimeter Stateless Routing (GPSR)
Optimized Link State Routing

- Literature
  - First published 1999

- Most proactive protocols are based on
  - Link-state routing
  - Distance-Vector routing
Link State Routing

- Connections are periodically published throughout the network
- Nodes propagate information to their neighbors
  - i.e. flooding
- All network information is stored
  - with time stamp
- Each node computes shortest paths
  - possibly also other route optimizations
- Each node broadcasts its neighborhood list
  - Each node can determine its 2-hop neighborhood
- Reducing the number of messages
  - Fewer nodes participate in flooding
- Multipoint relay node (MPRs)
  - Are chosen such that each node has at least one multipoint relay node as in its 2-hop neighborhood
  - Only multipoint relay nodes propagate link information
- Node sends their neighborhood lists
  - Such that multipoint relay nodes in the 2-hop neighborhood can be chosen
Optimized Link State Routing (OLSR)

- Combines Link-State protocol and topology control
- Topology control
  - Each node chooses a minimal dominating set of the 2 hope neighborhood
    - *multipoint relays (MPR)*
      - Only these nodes propagate link information
      - More efficient flooding
  - Link State component
    - Standard link state algorithm on a reduced network
Optimized Link State Routing (OLSR)
Optimized Link State Routing (OLSR)
Optimized Link State Routing (OLSR)
Selection of MPRs

- Multipoint Relaying for Flooding Broadcast Messages in Mobile Wireless Networks, Amir Qayyum, Laurent Viennot, Anis Laouiti, HICCS 2002
- Problem is NP-complete
- Heuristics
  - recommended for OLSR
- Notations
  - $N(x)$: 1 hop neighborhood of $x$
  - $N^2(x)$: 2 hop neighborhood of $x$
  - Alle connections are symmetrical

$N^2(x) = N(N(x))$
Selection of MPRs

- At the beginning there is no MPR
  - Each node chooses its MPRs

- Rule 1: A node of x is selected as MPR, if
  - it in N(x) and
  - it is the only neighborhood node in the node N^2(x)

- Rule 2: If nodes in N^2 (x) are not covered:
  - Compute for each node in N(x) the number of uncovered nodes in N^2(x)
  - Select as MPR the node that maximizes the value
Rule 1
Rule 2
OLSR

- OLSR is flooding link information using MPRs
  - Multipoint-Relays
- Receivers choose their own MPRs for propagating
  - Each node chooses its own MPRs
- Routes use only MPRs as intermediate nodes
Zone Routing Protocol (ZRP)

- **Haas 1997**

- **Zone Routing Protocol combine**
  - **Proactive protocol**
    • for local routing
  - **Reactive protocol**
    • for global routing
ZRP

- **Routing zone of a node x**
  - Nodes in a given maximum hop-distance $d$

- **Peripheral nodes**
  - all nodes have exactly the hop-distance $d$
  - within the routing zone $x$
ZRP

- **Intra zone routing**
  - proactive update the connection information in the routing zone of node
    - e.g. with link state or distance vector protocols

- **Inter zone routing**
  - Reactive route discovery is used for distant / unknown nodes
  - Procedure similar to DSR
  - Only peripheral nodes reach further information
ZRP: Example with radius $d=2$

Routing zone of $x$

Peripheral nodes
ZRP: Example with radius $d=2$

route discovery for blue node
ZRP: Example with radius $d=2$

route discovery for blue node
ZRP: Example with radius $d=2$

route discovery for blue node

Route Reply
ZRP: Example with radius $d=2$

route discovery for blue node

Data transfer
Routing Protocols for WSNs

- Literature
Types of Communication

- **Single Hop**
  - Two participants, sender/receiver, e.g. outdoor temperature sensor
  - Base stations: master/slave, e.g. Bluetooth
  - Many participants, i.e. data mule

- **Multihop**
  - Local Communication
  - Point-to-Point/Unicast
  - Convergence
  - Aggregation
  - Divergence

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Data Aggregation

- In multi-hop networks combining messages can improve networking
- Concatenation of messages
  - overall number of headers is reduced
    - especially for Preamble Sampling
  - smaller costs for collision avoidance
- Recalculation of contents
  - e.g. If the minimum temperature is required, then it satisfies to forward the smallest value
  - For this purpose, collect the input over some time
Convergence
Data Aggregation by Concatenation
Real Data Aggregation by Recalculation

17°C

19°C

20°C

= min(17, 19, 20)

minimum temperature 17°C
Simple Functions for Data Aggregation

- **Minimum**
  - inner node computes the minimum of input values

- **Maximum**
  - like Minimum

- **Number of sources**
  - inner node adds input values

- **Sum**
  - addition at inner nodes

\[
\min \left( \max \{x, y\} \right) = - \min \{-x, -y\}
\]
Aggregable Functions

- **Mean**
  - compute the number of sensors: \( n \)
  - compute the sum of sensor values: \( S \)
  - mean = \( \frac{S}{n} \)

- **Variance**
  - Compute average and the average of squares of values
  - \( V(X) = E(X^2) - E(X)^2 \)

\[ \text{Median} \left( 10, 0, 0, 15, 24 \right) = 10 \]
Hard Aggregable Functions

- The following functions cannot be aggregated easily
  - median 50%
  - p-quantile 25%
    - if p is not very small or large
  - number of different values
    - only for large data sets an approximation is possible

- Approximate solution
  - was presented in „Medians and Beyond: New Aggregation Techniques for Sensor Networks, Shrivastava et al. Sensys 04
  - using k words in each message an approximation ratio of $\log{n}/k$ can be achieved
Routing Models for Data Aggregation

- Address Centric Protocol
  - each sensor sends independently towards the sink
  - not suitable for (real) aggregation

- Data Centric Protocol
  - Forwarding nodes can read and change messages
Communication Graphs for Aggregation

- **Tree Structure**
  - If there is only a single sink
  - and every source uses only a single path
  - then every communication graph in a WSN is a tree

- **DAG (directed acyclic graph)**
  - general case
  - caused by changing routing paths to the sink
  - may complicate data aggregation
    - e.g. sum

- **General graph**
  - Population protocols
  - are not used in WSNs
\[ \frac{1}{n} + \frac{1}{2} = \frac{3}{16} \]

\[ \frac{1}{n} + \frac{5}{16} = \frac{9}{16} \]

\[ S_1 + S_2 = \frac{S_1 + S_2}{2} \]

\[ S_1 + S_2 \]
\[ \frac{3 + \frac{2}{8}}{2} = \frac{\frac{5}{16}}{2} \rightarrow \left( \frac{1}{3} \right) \]
Probabilistic Counting for Data Aggregation

- Hard problems for Data Aggregation
  - Counting of different elements in a multiset
  - Computation of Median
- Exact computation needs complete knowledge
  - therefore we compute approximations

Main Technique
- probabilistic counting
  - "Counting by Coin Tossings“, Philippe Flajolet, ASIAN 2004
- probabilistic sampling
Types of WSN Routing

- MANET Routing
  - Flooding Based Routing (MANET)
    - Flooding, DSR, AODV, DYMO
  - Cluster-Based Hierarchical Routing
    - Low-Energy Adaptive Clustering Hierarchy (LEACH)

- Geographic Routing
  - Greedy Routing
  - Face Routing

- Self-Organizing Coordinate Systems
  - Inferring Location from Anchor Nodes, Virtual Coordinates
  - Gradient Routing
    - Gradient-Based Routing (GBR)
    - Routing Protocol for Low Power and Lossy Networks (RPL)

Algorithms for Radio Networks

Routing

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