A Taxonomy for Routing Protocols in Mobile Ad Hoc Networks

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Overview

- mobile ad hoc networks
- routing protocols
  - communication model
  - structure
  - state information
  - scheduling
- performance analysis
- ongoing and future work
Mobile Ad hoc Network

- mobile, multi-hop wireless network
- autonomous operation; independent of any fixed infrastructure
- nodes must cooperate to provide network infrastructure
- contrast
  - mobile IP
  - wireless LAN
  - cellular
Applications

• tactical communication

• ubiquitous computing

• sensor networks
MANET characteristics

- highly dynamic topology, with frequent and unpredictable connectivity changes
- bandwidth-constrained, variable-capacity links
- hidden/exposed terminals
- energy-constrained nodes
Infrastructure

- routing
- service location
- naming
- security
MANET routing

• routes are dynamically discovered
MANET routing

- route errors occur frequently
MANET routing

- new routes are discovered
MANET routing

- fixed network routing protocols aren’t effective

- proposed protocols -- “alphabet soup”

### UNICAST

<table>
<thead>
<tr>
<th>Protocol</th>
<th>Protocol</th>
</tr>
</thead>
<tbody>
<tr>
<td>AODV</td>
<td>LAR</td>
</tr>
<tr>
<td>CEDAR</td>
<td>RDMAR</td>
</tr>
<tr>
<td>ABR</td>
<td>DSR</td>
</tr>
<tr>
<td>TORA</td>
<td>CBRP</td>
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<tr>
<td>GSR</td>
<td>DSDV</td>
</tr>
<tr>
<td>OLSR</td>
<td>CGSR</td>
</tr>
<tr>
<td>ZRP</td>
<td>WRP</td>
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### MULTICAST

<table>
<thead>
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<tr>
<td>MCEDAR</td>
<td>AODV</td>
</tr>
<tr>
<td>AMRIS</td>
<td>ODMRP</td>
</tr>
</tbody>
</table>

- IETF MANET WG
Taxonomy

- communication model
- structure
- state information
- scheduling
Example: AODV

- variant of conventional distance vector
- on-demand routing
- source/destination sequence number
- claim - loop free

- route discovery via “flooding” establishes (temporary) reverse routes

- route reply activates forward route

- sequence number ensures route freshness
AODV- route discovery

- route_request
  rreq_id = 12345
  src = 2, src_seq# = 76
  dest = 13, dest_seq# = 1, hopcount = 0
AODV - route discovery

- route_request
  - rreq_id = 12345
  - src = 2, src_seq# = 76
  - dest = 13, dest_seq# = 1, hopcount = 1
AODV - route discovery

- route_request
  - rreq_id = 12345
  - src = 2, src_seq# = 76
  - dest = 13, dest_seq# = 1, hopcount = 2
AODV - route discovery

- route_request
  - rreq_id = 12345
  - src = 2, src_seq# = 76
  - dest = 13, dest_seq# = 1, hopcount = 3
AODV - route reply

• route_reply
  src = 2
  dest=13, dest_seq# = 1, hopcount = 1
AODV- route reply

- route_reply
  src = 2
  dest=13, dest_seq# = 1, hopcount = 2
AODV - route reply

- route_reply
  
  src = 2
  
  dest=13, dest_seq# =1, hopcount = 3
AODV- route reply

- route_reply
  - src = 2
  - dest=13, dest_seq# = 1, hopcount = 4
AODV - route reply

- route
  dest = 13, dest_seq# = 1, hopcount = 4, 3, 2, 1
AODV - route maintenance

• route_reply
  src = 2
  dest = 13, dest_seq# = 2, hopcount = inf.
AODV - route discovery

- route_request
  rreq_id = 12346
  src = 2, src_seq# = 77
  dest = 13, dest_seq# = 2, hopcount = 0
Communication model

- single logical communication channel
  - CSMA/CA (e.g. 802.11)
  - network-layer (often w/link-layer support)
  - IETF MANET WG

- multi-channel
  - *DMA
  - combine e.g. code separation, channel assignment with routing
  - non-uniform structure
Structure

- **uniform**
  - all nodes participate equally
  - + no cost/complexity to maintain structure
  - - all nodes participate

- **non-uniform(1)**
  - each node designates “re-broadcasters” (MPR)
  - + reduce broadcast load
  - - cost to maintain structure
  - - limited scalability
  - - disproportionate load on re-broadcasters
Structure

- non-uniform (2)
  define clusters (MDS or clique), clusterheads negotiate routes via gateways or tunnels
  + simplifies routing (easier QoS)
  + increased scalability
  - cost/complexity to maintain structure
  - disproportionate load on critical nodes
Example: CEDAR

- core nodes negotiate routes, maintain and disseminate QoS information

- “core broadcast” using unicast tunnels
State information

• topology-oriented
  maintain (some) network-wide topology information
  + cached information is useful
  + optimal (QoS optimal) routes
  - cost to maintain information
  - stale cache is very bad

• destination-oriented
  next-hop information, possibly local topology
  + less cost to maintain cached information
  - much less cached information
Scheduling

• proactive
  continuously maintain routes for all source/destination pairs
  + low latency
  - pay for routes that are never used

• reactive
  “route_discovery” - find routes on demand
  + only pay for active routes
  - higher latency
  - “broadcast storm” problem
Taxonomy

- single channel protocols
  - uniform
  - topology-based
    - proactive
      - GSR
    - reactive
      - DSR
  - destination-based
    - proactive
      - DSDV
    - reactive
      - WRP
      - AODV
      - TORA
      - ABR

- non-uniform
  - neighbor selection
    - ZRP
    - OLSR
  - partitioning
    - CEDAR
    - CBRP
Performance Analysis

- simulation (mobility model, wireless propagation model)
  - PARSEC(UCLA)
  - ns-2 (UCB/LBL & CMU Monarch project)
- protocol-protocol comparison (IETF)
  - ns-2 w/ various mobility and traffic scenarios
  - CMU Monarch project (MobiCom’98)
  - Ericsson Research (MobiCom’99)
- realism???
Effectiveness

- avoid routing loops

- avoid implosion

- fraction of traffic delivered
  - probes
  - TCP
Efficiency

- route latency
- route optimality (secondary goal)
- load distribution
- packet/bandwidth overhead
- energy considerations
Energy

• synonymous with bandwidth -- NOT!
  • non-renewable
  • cost at both sender and receiver
  • cost to idle, discard, drop

• issues
  • broadcast vs unicast
  • incremental cost of data
  • distribution of routing load

• no centralized energy management
Energy consumption model

- Basic model:
  - $Cost = m \times \text{size} + b$
  - fixed cost - acquire channel
  - incremental cost - proportional to pkt size

- Costs
  - broadcast traffic
    sender + all receivers
  - unicast traffic
    data: sender + destination + all non-destination
    control: sender + all receivers
Energy consumption data

- receive significant compared to send
e.g. ratio 3:1, 2:1, 1:1

- incremental cost of data is relatively low for many interfaces

- energy-sensitive comparison of AODV and DSR using CMU ns-2
Observations

• receiving counts!
  • traffic received not proportional to traffic sent

• discarding counts!
  • it had better be cheap

• broadcast traffic associated with flooding is very expensive

• cost of MAC control negotiation is significant

• cost is not very dependent on mobility
Observations

- **DSR**
  - cost of source routing headers isn’t too high
  - operating the network interface in promiscuous mode is potentially expensive

- **AODV**
  - sends more broadcast traffic than DSR
  - cost of broadcast traffic is very high
  - initiates route discovery more often
Ongoing and Future work

• testbed
  • small IPv6 stacks for appliances
  • manet <-> fixed network interoperability (IPv6)

• energy consumption
  • QoS resource
  • idle nodes

• spontaneous networks
  issue: lack of centralized administration
  • naming, security
  • “spontaneous VPN”
More information

- http://www.sics.se/~lmfeeney/
  -- my home page, SICS home page

  -- IETF MANET WG

- http://monarch.cs.cmu.edu/
  -- CMU Monarch project ns-2 source code, scenarios, etc.