A Performance Comparison of Multi-Hop Wireless Ad Hoc Network Routing Protocols

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Outline

• Introduction

• NS-2 Simulator Environment

• Ad Hoc Routing Protocols
  – DSDV
  – TORA
  – DSR
  – AODV

• Simulation Methodology

• Simulation Results

• Conclusions
Introduction

- **Mobile Ad Hoc Networks (MANETs)**
  - Have useful applications
    - Battlefields, mobile robots, vehicular networks
  - Each mobile node acts both as a **host** but also as a **router**.
  - Ad hoc routing protocols provide **multi-hop paths** through the network to any other node.
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NS-2 Simulator Environment

• Mobile nodes have **position** and **velocity**.
  – Needed to extend simulator to model attenuation of radio waves, propagation delays, capture effects and carrier sense.

• Added simulation of DCF for 802.11 MAC layer (including **RTS/CTS**).

• Simulated nodes have **50** packet drop-tail queues for packets awaiting transmission and **50** additional packets of buffer for awaiting route discovery.
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Studying Ad Hoc Routing (circa 1998)

- Authors implemented the four protocols according to specifications.
- However, while simulating they made improvements:
  - Broadcast ACKs deliberately jittered.
  - Routing packets were inserted at the front of the queue.
  - Used ‘link breakage detection’ feedback from MAC layer when packet could not be forwarded (except for DSDV).
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Destination-Sequenced Distance Vector (DSDV)

- DSDV is a hop-by-hop distance vector routing protocol requiring each node to periodically broadcast routing updates.
- DSDV (unlike DV) is guaranteed loop free.
DSDV Mechanism

• Each node maintains a routing table listing the “next hop” for each reachable destination.

• Routes are tagged with a sequence number.
  – Higher sequence number indicates a better route.
  – Sequence number ties broken by lower metric.

• Each node periodically broadcasts routing updates.

• Implemented both full and incremental updates.
DSDV Implementation

• Route updates are used to broadcast changes in the topology (i.e. broken link) and triggered by:
  – Receipt of a new sequence number for a destination (the DSDV-SQ variation).
  – Receipt of a new metric for a destination (DSDV).

• Link layer breakage notification was not used due to a significant performance penalty.
## DSDV-SQ Constants

<table>
<thead>
<tr>
<th>Constant</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Periodic route update interval</td>
<td>15 s</td>
</tr>
<tr>
<td>Periodic updates missed before link declared broken</td>
<td>3</td>
</tr>
<tr>
<td>Initial triggered update weighted settling time</td>
<td>6 s</td>
</tr>
<tr>
<td>Weighted settling time weighting factor</td>
<td>7/8</td>
</tr>
<tr>
<td>Route advertisement aggregation time</td>
<td>1 s</td>
</tr>
<tr>
<td>Maximum packets buffered per node per destination</td>
<td>5</td>
</tr>
</tbody>
</table>

*Table I* Constants used in the DSDV-SQ simulation.
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Temporally-Ordered Routing Algorithm (TORA)

• TORA is a distributed routing protocol based on a “link reversal” algorithm.
• Routes are discovered on demand.
• Provides multiple routes to destination.
• Designed to minimize communication overhead by localizing algorithmic reaction to topological change.
• Tries to avoid the overhead of discovering new routes.
TORA Mechanism

• Described in terms of water flowing downhill towards a destination node.
• Links between routers conceptually viewed as a **height**.
• Link is directed from the higher router to the lower router.
• Height adjustments occur when topology changes.
TORA Mechanism

- A logically separate copy of TORA exists at each node and is run for each destination.
- A node needing a route broadcasts a QUERY packet containing the destination address.
- Packet propagates through network until it reaches the destination or to a node having a route to the destination.
TORA Mechanism

- Node with route to destination broadcasts an **UPDATE packet** listing its height with respect to destination.
- Nodes receiving **UPDATE** sets its height greater than that of neighbor from which **UPDATE** was received.
- The effect is to create a series of directed links from the original sender of the query to the node that generated the **UPDATE**.
TORA Mechanism

• Layered on top of IMEP (Internet MANET Encapsulation Protocol) for reliable in-order delivery of all routing control messages, and link state notifications.
  – Periodic BEACON / HELLO packets.

• IMEP - implemented to support TORA.
  – Attempts to aggregate TORA and IMEP control messages (**objects**) into a single packet (**object block**) to reduce overhead.
  – Chose to aggregate only HELLO and ACK packets.

• Parameters are chosen through experimentation.
### TORA Constants

Table II  Constants used in the TORA simulation.

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>BEACON period</td>
<td>1 s</td>
</tr>
<tr>
<td>Time after which a link is declared down if no BEACON or HELLO packets were exchanged</td>
<td>3 s</td>
</tr>
<tr>
<td>Time after which an object block is retransmitted if no acknowledgment is received</td>
<td>500 ms</td>
</tr>
<tr>
<td>Time after which an object block is not retransmitted and the link to the destination is declared down</td>
<td>1500 ms</td>
</tr>
<tr>
<td>Min HELLO and ACK aggregation delay</td>
<td>150 ms</td>
</tr>
<tr>
<td>Max HELLO and ACK aggregation delay</td>
<td>250 ms</td>
</tr>
</tbody>
</table>
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Dynamic Source Routing (DSR)

- DSR uses *source routing* rather than hop-by-hop routing with each packet carrying in its header the complete ordered list of nodes through which the packet must pass.
  - Eliminates the need for periodic route advertisement and neighbor detection packets.
  - Designed specifically for multi-hop wireless ad hoc networks.
- Two mechanisms: Route Discovery and Route Maintenance.
DSR Route Discovery

- Node S wishes to send a packet to destination D obtains a source route to D.
- S broadcasts a **ROUTE REQUEST** packet that is **flooded** through the network and is answered by a **ROUTE REPLY** packet from either the destination node or another node that knows the route to the destination.

![Diagram of network route discovery](image)

**Figure 1:** Route Discovery example: Node A is the initiator, and node E is the target.
DSR Route Discovery

• To reduce the cost of Route Discovery, each node maintains a cache of source routes learned or overhead.

• Cache significantly reduce the number of ROUTE REQUESTs sent.
DSR Route Maintenance

• Route Maintenance is the mechanism by which a packet’s sender S detects if the network topology has changed such that it can no longer use its route to the destination.

• When route is broken, S is notified with a ROUTE ERROR packet.

• S can use another route in cache or invoke route discovery.

Figure 2: Route Maintenance example: Node C is unable to forward a packet from A to E over its link to next hop D.
DSR Constants

DSR is bidirectional due to 802.11. This means **ROUTE REPLY** uses reverse path.

**Table III**  Constants used in the DSR simulation.

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time between retransmitted ROUTE REQUESTs (exponentially backed off)</td>
<td>500 ms</td>
</tr>
<tr>
<td>Size of source route header carrying $n$ addresses</td>
<td>$4n + 4$ bytes</td>
</tr>
<tr>
<td>Timeout for nonpropagating search</td>
<td>30 ms</td>
</tr>
<tr>
<td>Time to hold packets awaiting routes</td>
<td>30 s</td>
</tr>
<tr>
<td>Max rate for sending gratuitous REPLYs for a route</td>
<td>1/s</td>
</tr>
</tbody>
</table>
DSR Advantages/Disadvantages

Advantages: uses a reactive approach which eliminates the need to periodically flood the network with table update messages which are in the table-driven approach. The intermediate nodes also utilize the route cache information efficiently to reduce the control overhead.

Disadvantage: The route maintenance mechanism does not locally repair a broken link. Stale route cache information can produce inconsistencies during the route reconstruction phase.
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Ad Hoc On-Demand Distance vector (AODV)

- **AODV combines DSR and DSDV**
  - Uses on-demand Route Discovery and Route Maintenance from DSR plus hop-by-hop routing, sequence numbers and periodic beacons from DSDV.

- **When S needs a route to D, it broadcasts a ROUTE REQUEST message to its neighbors**, including last known sequence number for that destination.
AODV

• ROUTE REQUEST is control-flooded until it reaches a node that has a route to the destination D and each node that forwards a ROUTE REQUEST creates a reverse route back to S.

• Node that has route to D generates a ROUTE REPLY that contains number of hops to reach D and sequence number for D most recently seen.

• Each node that forwards the REPLY back towards S creates a forward route to D.
AODV

• This scheme is hop-by-hop in that each node remembers only next hop.

• To maintain routes, each node periodically transmits a HELLO message. Failure to receive three consecutive HELLO messages is an indicator that the link to neighbor is down.

• Alternatively, use link layer feedback (AODV-LL). Since this eliminates need for HELLO messages, only AODV-LL reported in the paper.
AODV

• When a link goes down, any upstream node that recently forwarded packets through that link is notified via an **UNSOLICITED ROUTE REPLY** with an infinite metric.

• Upon receiving this reply, the node must use Route Discovery to find a new route to the destination.
## AODV Constants

**Table IV** Constants used in the AODV-LL simulation.

<table>
<thead>
<tr>
<th>Constant</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time for which a route is considered active</td>
<td>300 s</td>
</tr>
<tr>
<td>Lifetime on a ROUTE REPLY sent by destination node</td>
<td>600 s</td>
</tr>
<tr>
<td>Number of times a ROUTE REQUEST is retried</td>
<td>3</td>
</tr>
<tr>
<td>Time before a ROUTE REQUEST is retried</td>
<td>6 s</td>
</tr>
<tr>
<td>Time for which the broadcast id for a forwarded ROUTE REQUEST is kept</td>
<td>3 s</td>
</tr>
<tr>
<td>Time for which reverse route information for a ROUTE REPLY is kept</td>
<td>3 s</td>
</tr>
<tr>
<td>Time before broken link is deleted from routing table</td>
<td>3 s</td>
</tr>
<tr>
<td>MAC layer link breakage detection</td>
<td>yes</td>
</tr>
</tbody>
</table>
AODV Advantages/Disadvantages

• Advantages: AODV routes established on demand with destination sequence numbers used to find the latest route to destination. The connection setup delay is less.

• Disadvantages: intermediate nodes can yield inconsistent routes if the source sequence number is very old and the intermediate nodes have a higher but not the latest destination sequence number (stale entries). Also multiple ROUTE REPLY packets in response to a single ROUTE REQUEST packet can lead to heavy control overhead.
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Simulation Methodology

- Simulations focused on routing protocols ability to react to topology changes and viewing performance under a range of conditions.
- 50 wireless nodes in ad hoc network over a 1500m x 300m grid for 900 simulated seconds of time.
- Physical characteristics meant to model WaveLAN DSSS (Note – this is old technology now!).
Simulation Methodology

• Simulations driven by input scenario file describing exact motion and sequence of packets originated by nodes. 210 different scenarios were pre-generated and ran all four protocols against each scenario file.

• Movement is characterized by a **pause time** whereby a node remains stationary for **pause time** seconds.
Simulation Methodology

• At the end of pause time, the node selects a random destination and moves at a speed uniformly distributed between 0 and some maximum (1m/s or 20m/s).

• Simulation alternates between pause times and movement times for each node.

• 10 movement patterns were generated for each pause time of 0, 30, 60, 120, 300, 600, & 900 seconds (total of 70 movement patterns for each protocol tested).

• 0 pause time corresponds to continuous motion.

• 900 second pause time is no movement.
Communication Model Issues

- Experimented with 1, 4 and 8 packets per second and then fixed rate at 4 packets/sec.
- 10, 20 and 30 CBR (constant bit rate) sources with peer-to-peer conversations.
- Tried 64 and 1024-byte packets
  - 1024-byte packets caused congestion.
  - Packet size fixed at 64 bytes because they wanted to factor out congestion effects.
Scenario Characteristics

- Internal mechanism determines shortest path (in hops) assuming 250m transmission range.
- Average data packet made 2.6 hops and farthest reachable node was 8 hops away.
Figure 1 Shortest Path Distribution

Figure 1  Distribution of the shortest path available to each application packet originated over all scenarios.
Table V  Link Connectivity Changes

Table V  Average number of link connectivity changes during each 900-second simulation as a function of pause time.

<table>
<thead>
<tr>
<th>Pause Time</th>
<th># of Connectivity Changes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 m/s</td>
</tr>
<tr>
<td>0</td>
<td>898</td>
</tr>
<tr>
<td>30</td>
<td>908</td>
</tr>
<tr>
<td>60</td>
<td>792</td>
</tr>
<tr>
<td>120</td>
<td>732</td>
</tr>
<tr>
<td>300</td>
<td>512</td>
</tr>
<tr>
<td>600</td>
<td>245</td>
</tr>
<tr>
<td>900</td>
<td>0</td>
</tr>
</tbody>
</table>
Metrics

• **Packet Delivery Ratio ::** The ratio between the number of packets originated by the application layer CBR sources and the number of packets received by the CBR sink at the final destination.

• **Routing Overhead ::** The total number of routing packets transmitted during the simulation.
  - Note, each transmission hop counts as one transmission.

• **Path Optimality ::** The difference between the number of hops taken to reach destination and the length of the shortest path that physically existed through the network when the packet was originated.
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Figure 2 Packet Delivery Ratio (as a function of pause time)

DSDV does not converge

20 Sources
Figure 3 Routing Packets Sent (as a function of pause time)
Figure 4: Packet Delivery Ratio

Figure 4  Packet delivery ratio as a function of pause time. TORA is shown on a different vertical scale for clarity (see Figure 2).
Figure 5: Routing Overhead

Routing overhead as a function of pause time. TORA and AODV-LL are shown on different vertical scales for clarity (see Figure 3).
Figure 6: Path Length Excess

Results are averaged over all mobility levels.
Figure 7: Application Packets Sent (as a function of pause time)

Speed = 1m/s
20 Sources
Figure 8: Routing Packets Sent (as a function of pause time)

Speed = 1m/s
20 Sources
Figure 9 Routing Overhead

20 Sources

(a) Routing overhead in packets.

(b) Routing overhead in bytes.

accounts for extra bytes in DSR packets
Figure 10 Packet Delivery Ratio
DSDV vs DSDV-SQ
Figure 11 Routing Overhead
DSDV vs DSDV-SQ
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• Paper Contributions:
  – Modifications to the ns-2 simulator to model 802.11 MAC layer issues.
  – Detailed simulation results that compared four protocols.
• Each protocol performs well in some cases and has drawbacks in others.
Conclusions

- **TORA** was the worst.
- **DSR** was the best.
- **DSDV-SQ** performs well when load and mobility is low, poorly as mobility increases.
- **AODV-LL** performs nearly as well as **DSR**, but has high overhead at high mobility levels.
Critique

• Well written.
• Good scientific method.

Comments !!
Acknowledgments

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Questions ??

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