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 (VANETs)**
  - **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 ONLY a new metric for a destination (DSDV).**
- **Link layer breakage notification was not used due to a significant performance penalty.**

DSDV-SQ Constants

Table I Constants used in the DSDV-SQ simulation.

Periodic route update interval	15 s
Periodic updates missed before link declared broken	3
Initial triggered update weighted settling time	6 s
Weighted settling time weighting factor	7/8
Route advertisement aggregation time	1 s
Maximum packets buffered per node per destination	5

All reported results in the paper use DSDV_SQ (except for section 6.2)

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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 to a destination 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.**
- **Each node receiving an 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
- Authors chose parameters through experimentation.

TORA Constants

Table II Constants used in the TORA simulation.

BEACON period	1 s
Time after which a link is declared down if no BEACON or HELLO packets were exchanged	3 s
Time after which an object block is retransmitted if no acknowledgment is received	500 ms
Time after which an object block is not retransmitted and the link to the destination is declared down	1500 ms
Min HELLO and ACK aggregation delay	150 ms
Max HELLO and ACK aggregation delay	250 ms

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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 the 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

- **Route Discovery** is the mechanism by which Node S wishing 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.

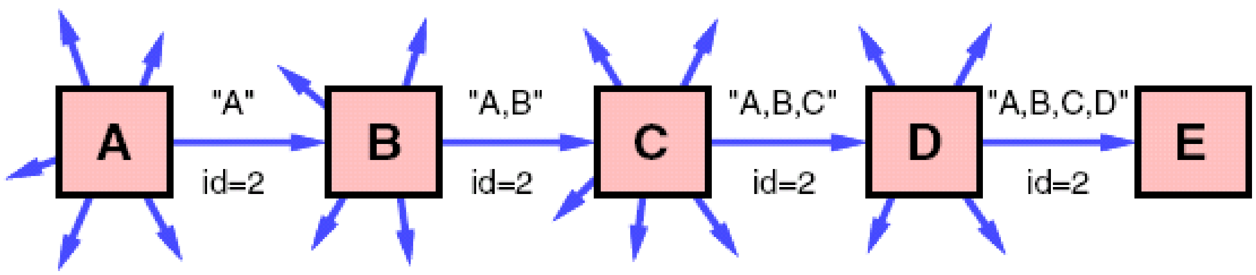

Figure 1: Route Discovery example: Node **A** is the initiator, and node **E** is the target.

DSR Route Discovery

- A ROUTE REQUEST is answered by a ROUTE REPLY packet from either the destination node or another node that knows a route to the destination.

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

- The 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 a route is broken, S is notified with a ROUTE ERROR packet.
- S can use another route in cache or invoke route discovery.

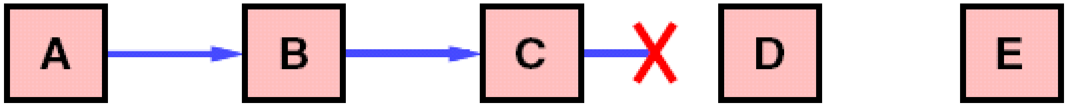

Figure 2: Route Maintenance example: Node C is unable to forward a packet from A to E over its link to next hop D.

DSR Constants

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

Table III Constants used in the DSR simulation.

Time between retransmitted ROUTE REQUESTs (exponentially backed off)	500 ms
Size of source route header carrying n addresses	$4n + 4$ bytes
Timeout for nonpropagating search	30 ms
Time to hold packets awaiting routes	30 s
Max rate for sending gratuitous REPLYs for a route	1/s

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-LL Constants

Table IV Constants used in the AODV-LL simulation.

Time for which a route is considered active	300 s
Lifetime on a ROUTE REPLY sent by destination node	600 s
Number of times a ROUTE REQUEST is retried	3
Time before a ROUTE REQUEST is retried	6 s
Time for which the broadcast id for a forwarded ROUTE REQUEST is kept	3 s
Time for which reverse route information for a ROUTE REPLY is kept	3 s
Time before broken link is deleted from routing table	3 s
MAC layer link breakage detection	yes

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 they 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

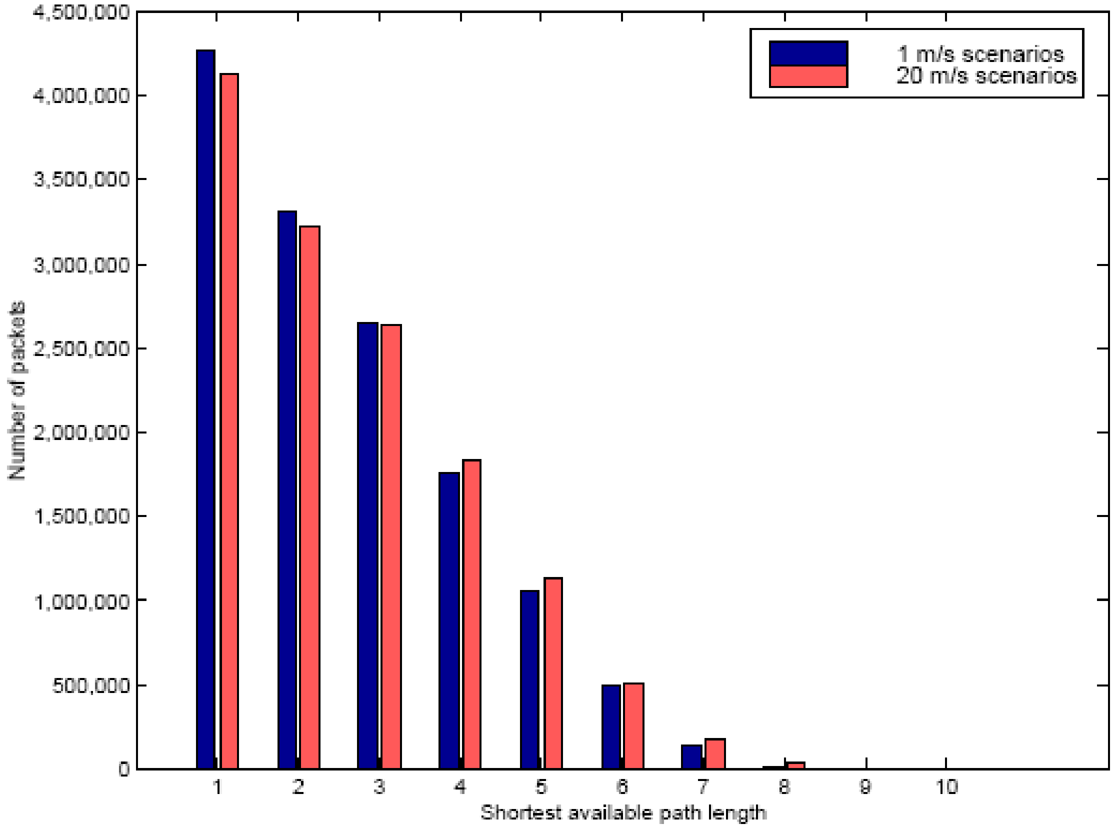

Figure 1 Distribution of the shortest path available to each application packet originated over all scenarios.

Table V
Link Connectivity Changes

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

Pause Time	# of Connectivity Changes	
	1 m/s	20 m/s
0	898	11857
30	908	8984
60	792	7738
120	732	5390
300	512	2428
600	245	1270
900	0	0

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)

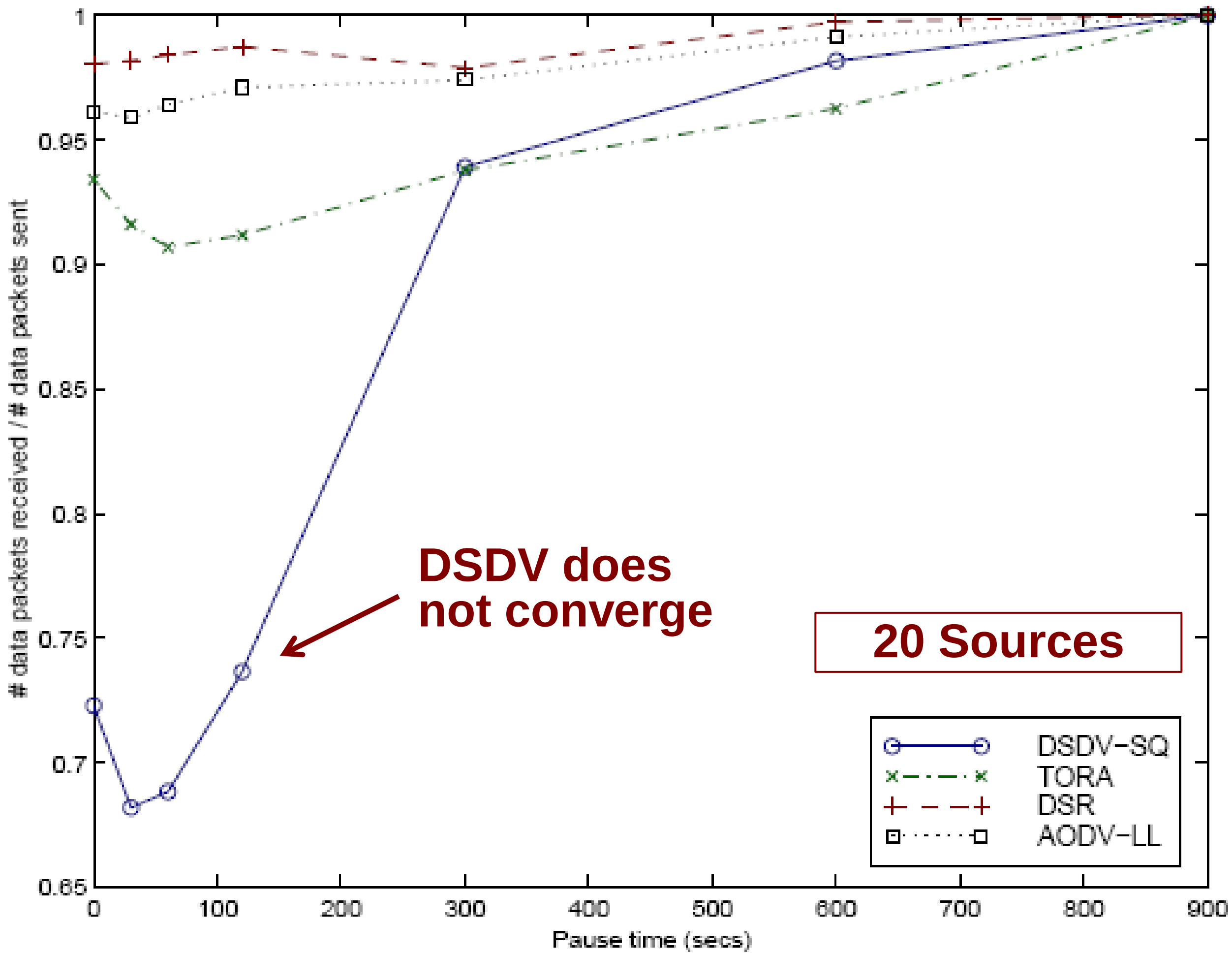


Figure 3 Routing Packets Sent (as a function of pause time)

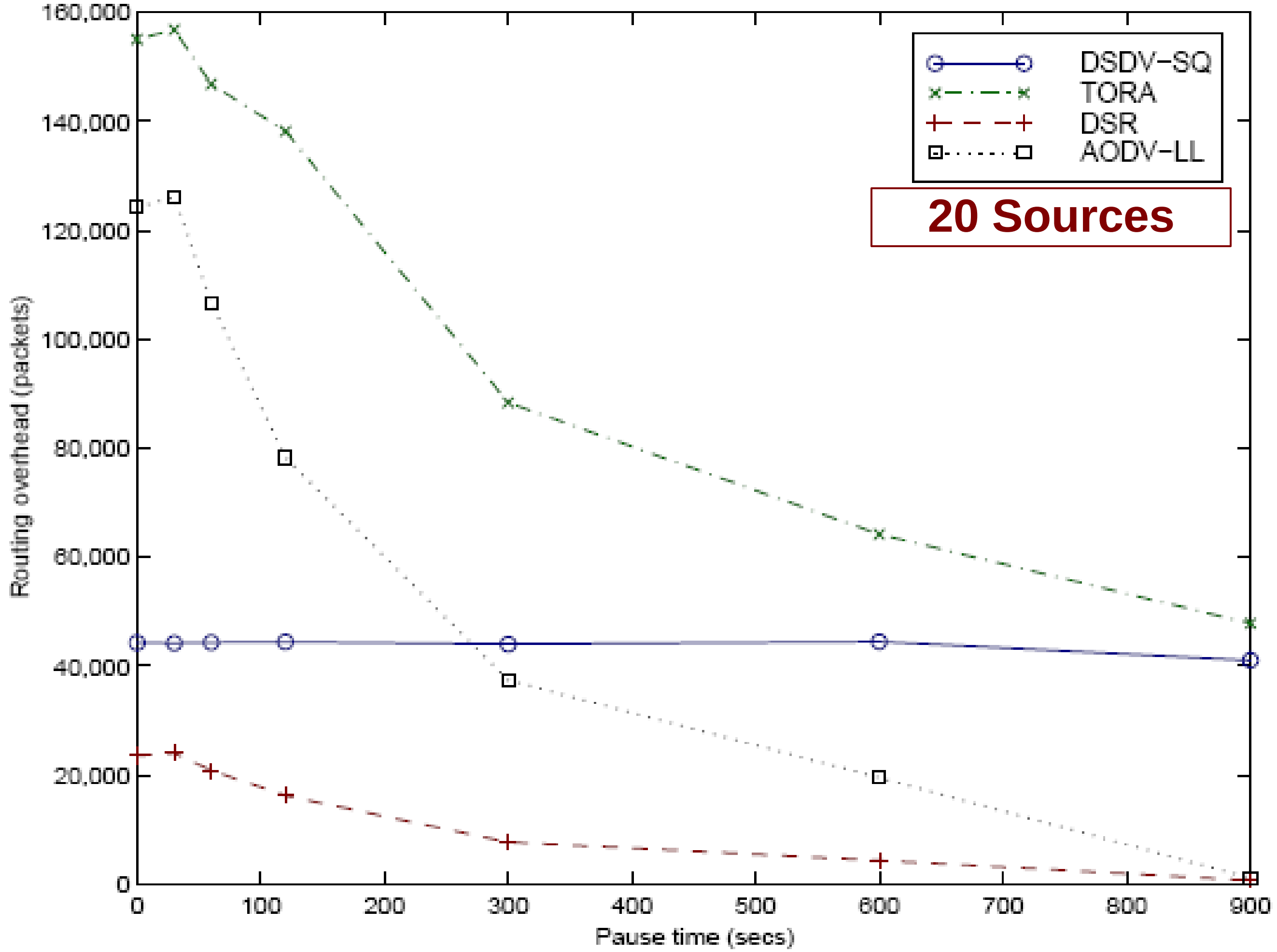


Figure 4: Packet Delivery Ratio

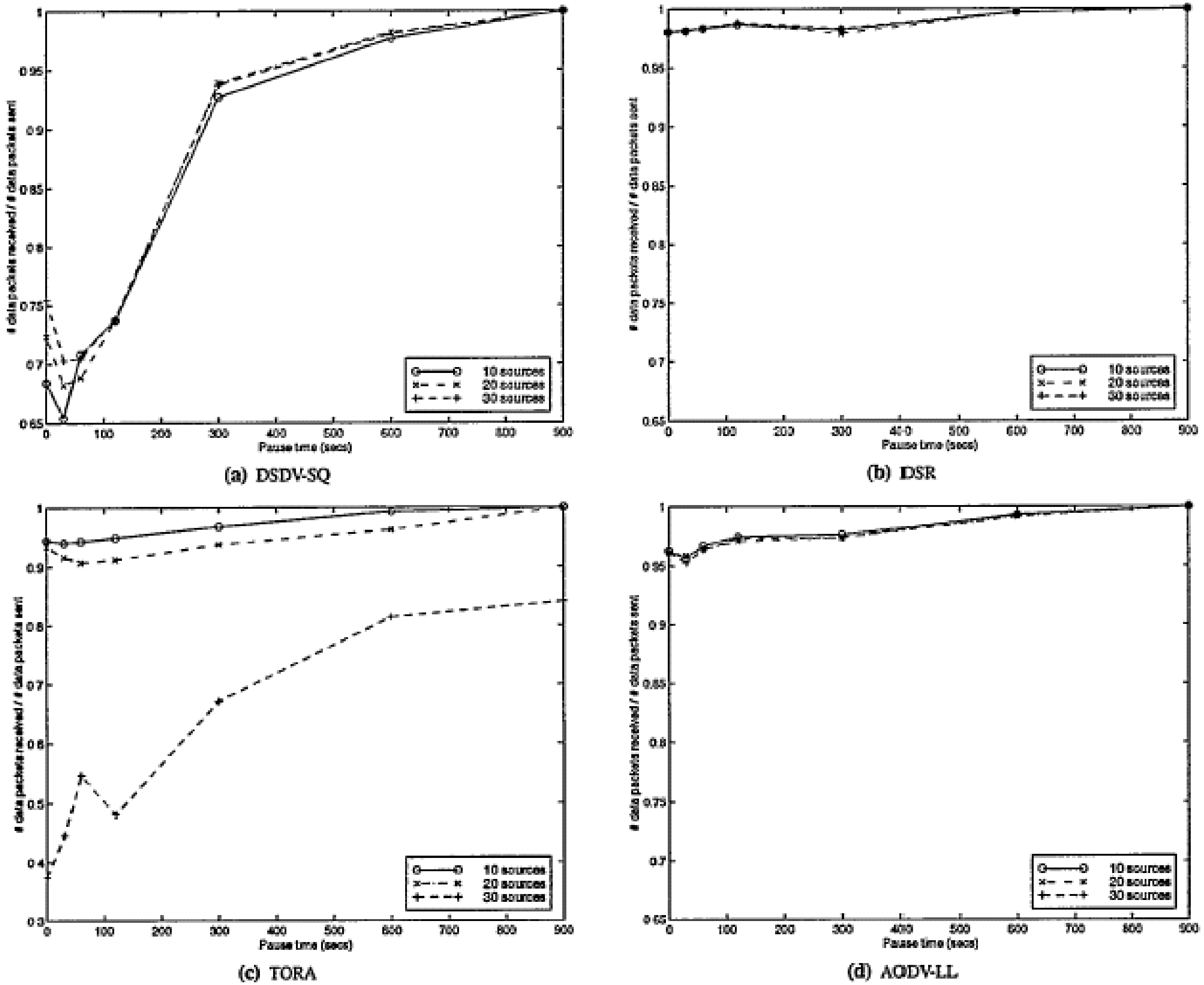


Figure 4 Packet delivery ratio as a function of pause time. TORA is shown on a different vertical scale for clarity (see Figure 2).

Figure 5: Routing Overhead

different scales

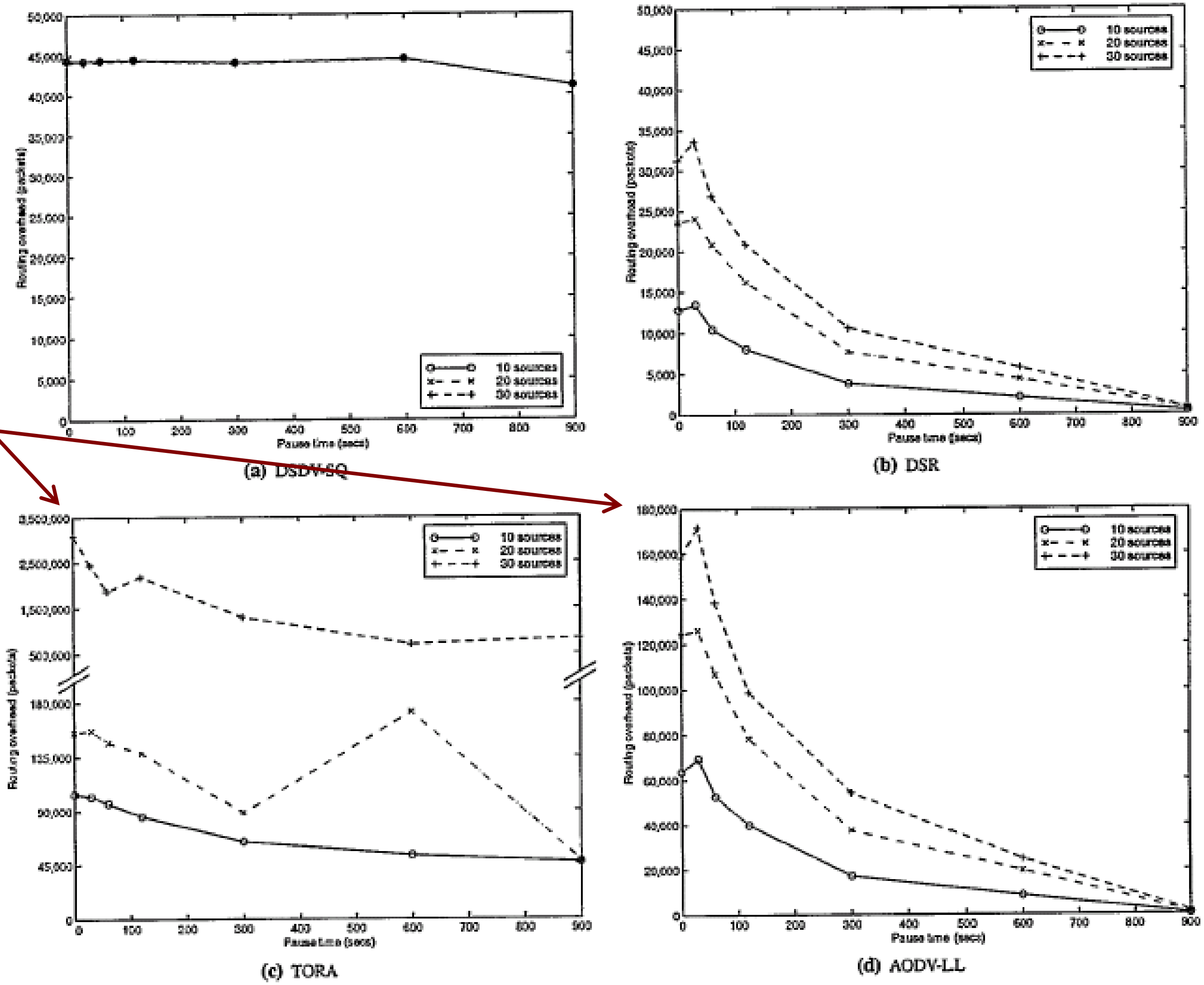
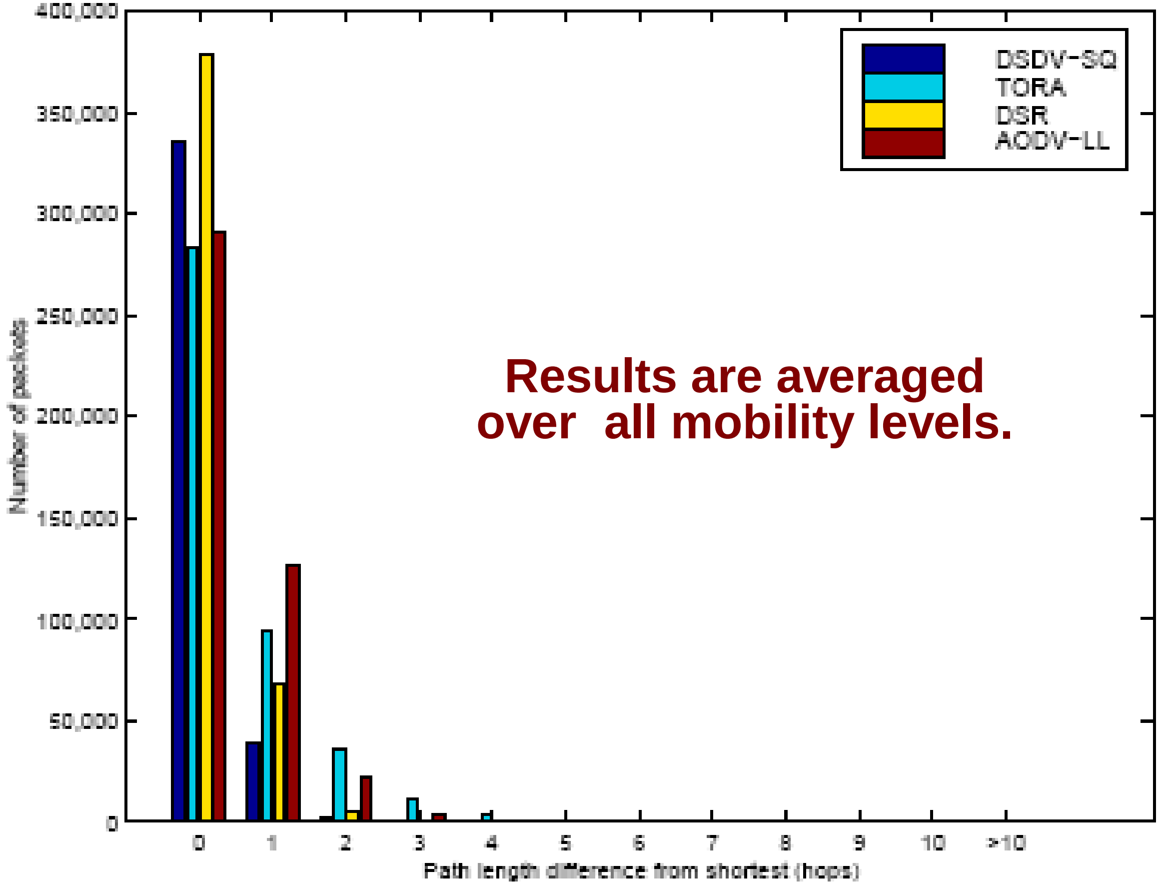


Figure 5 Routing overhead as a function of pause time. TORA and AODV-LL are shown on different vertical scales for clarity (see Figure 3).

Figure 6: Path Length Excess



Results are averaged over all mobility levels.

Figure 7: Application Packets Sent (as a function of pause time)

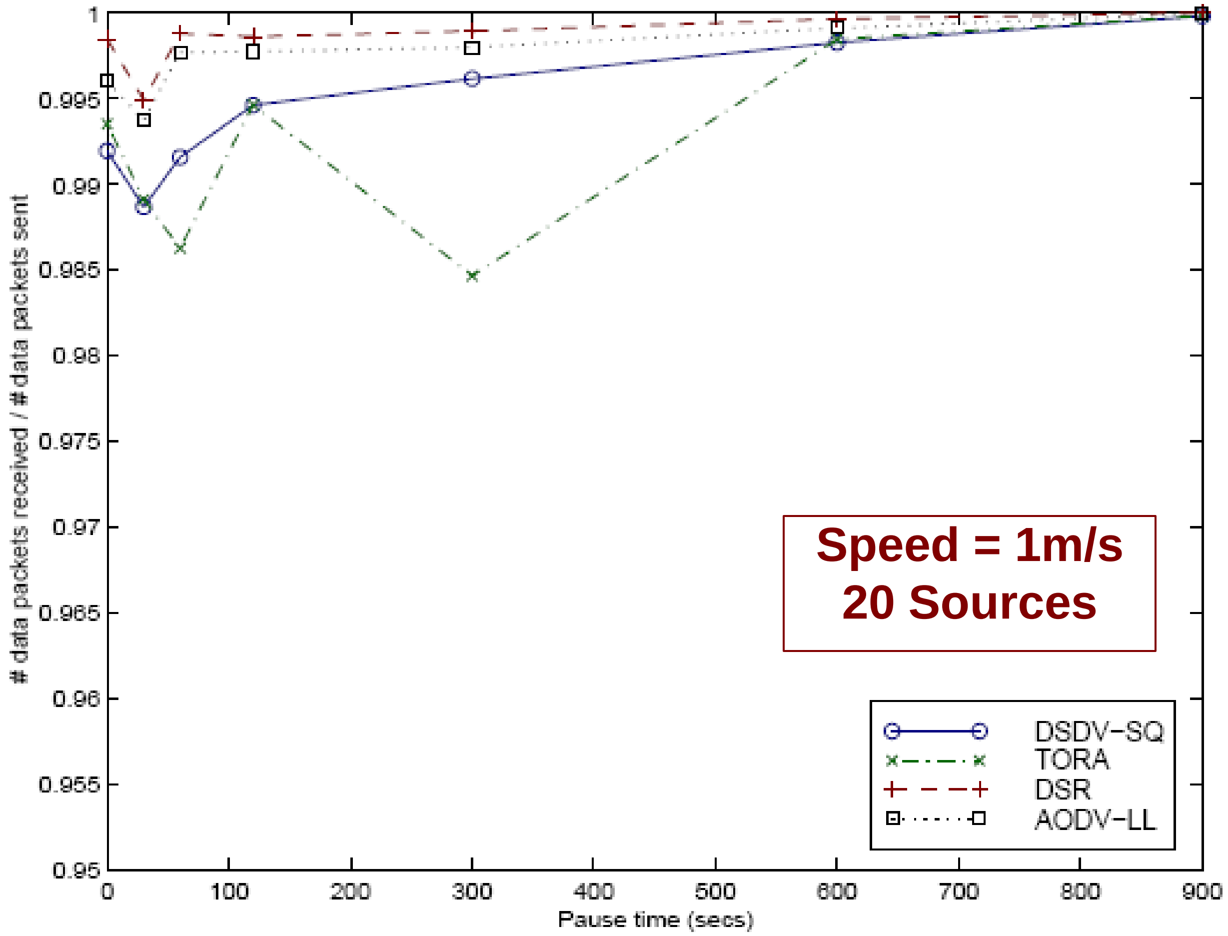


Figure 8: Routing Packets Sent (as a function of pause time)

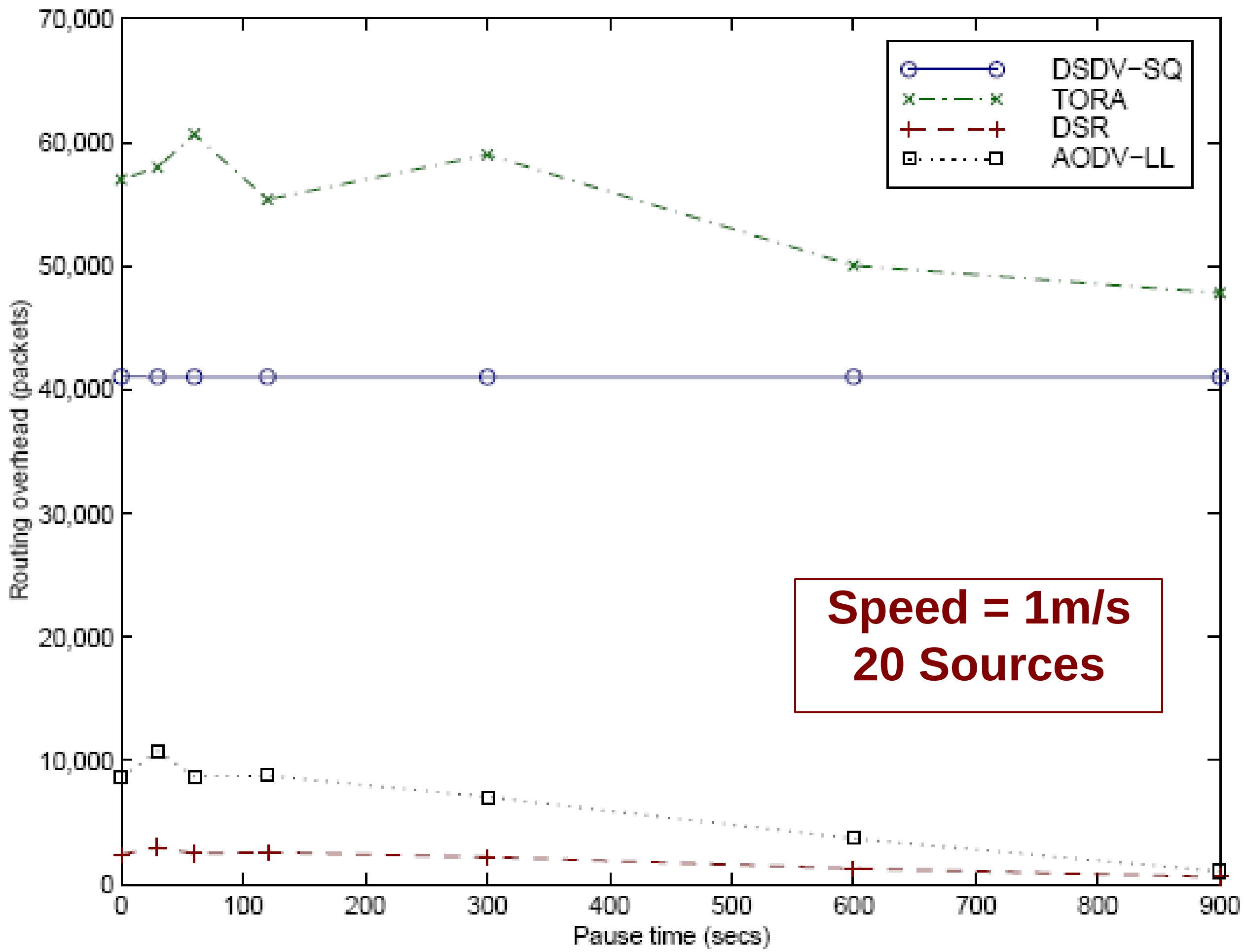
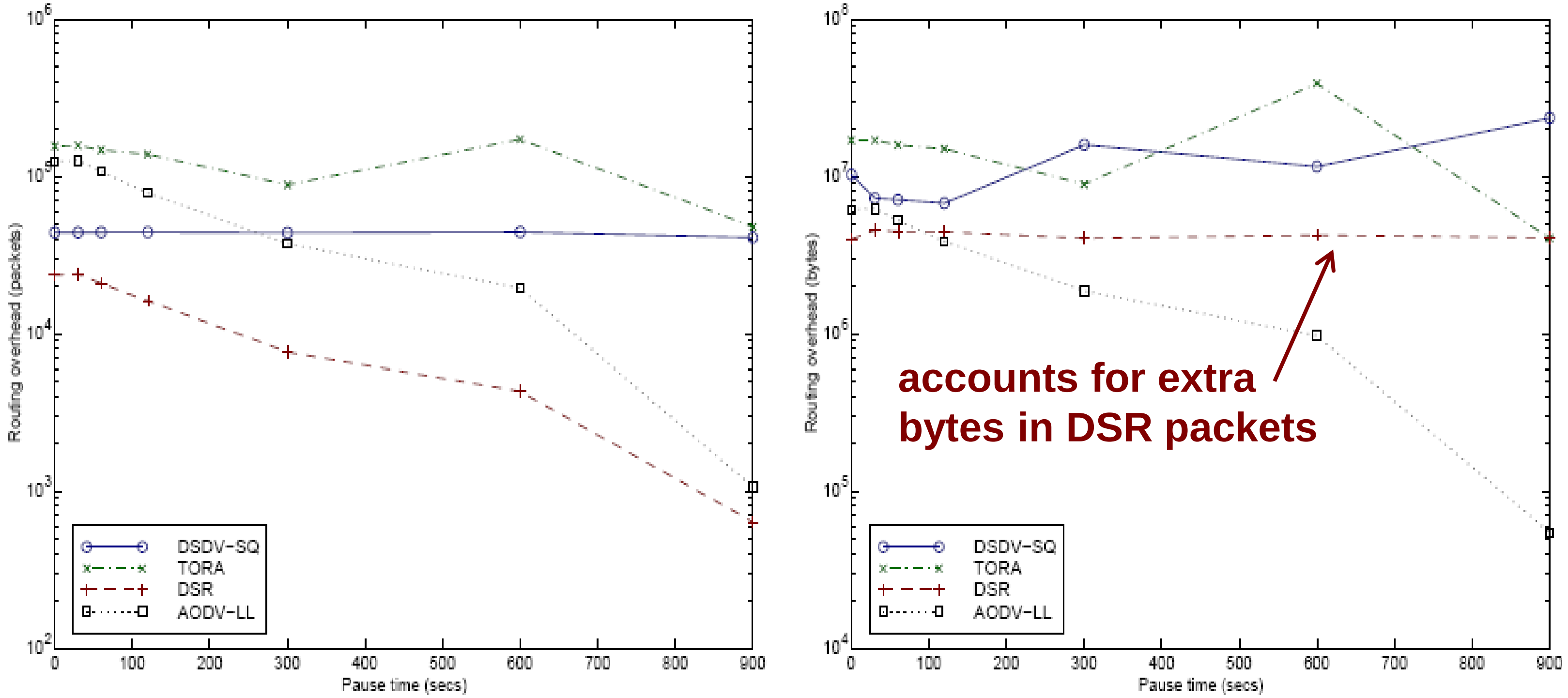


Figure 9 Routing Overhead

20 Sources



(a) Routing overhead in packets. (b) Routing overhead in bytes.

Figure 10 Packet Delivery Ratio DSDV vs DSDV-SQ

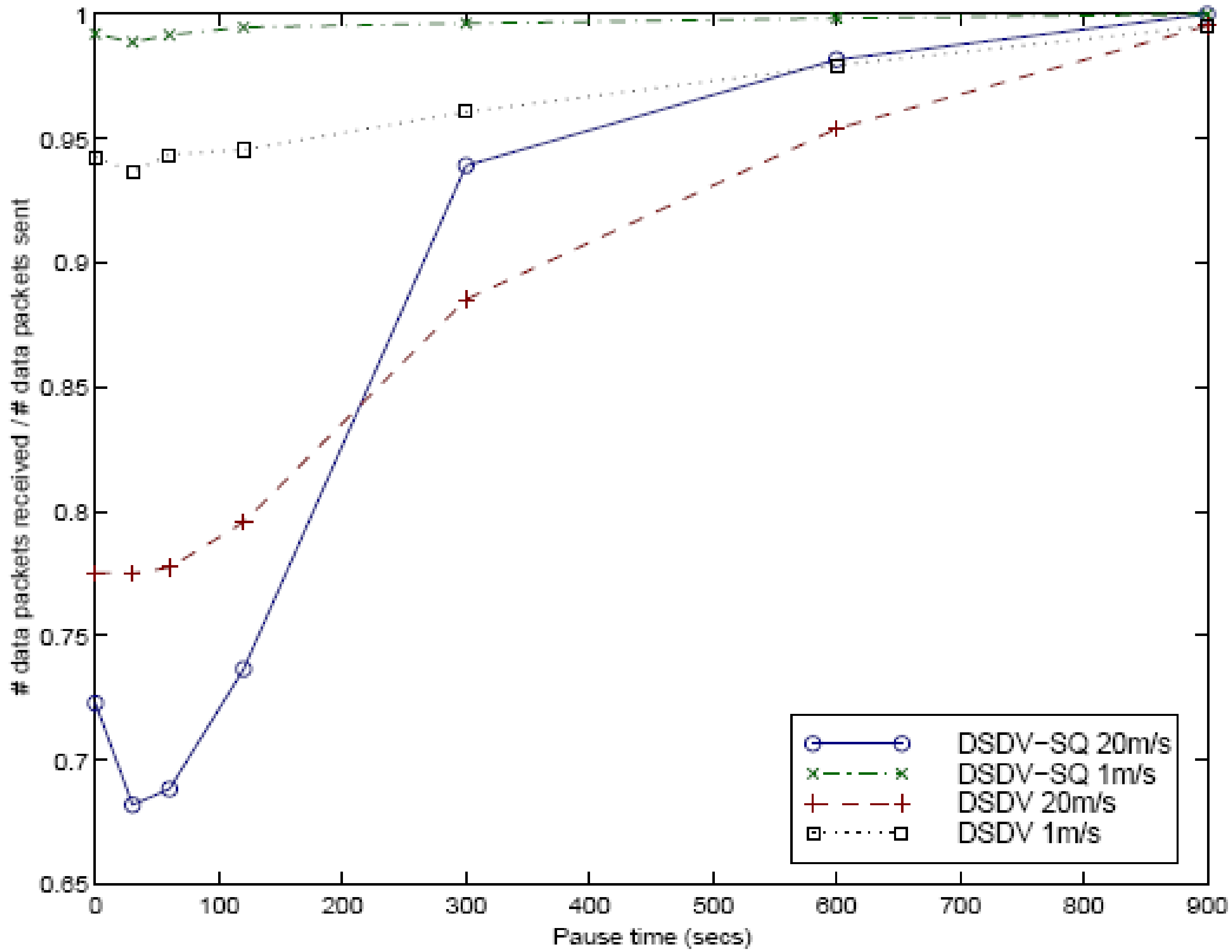
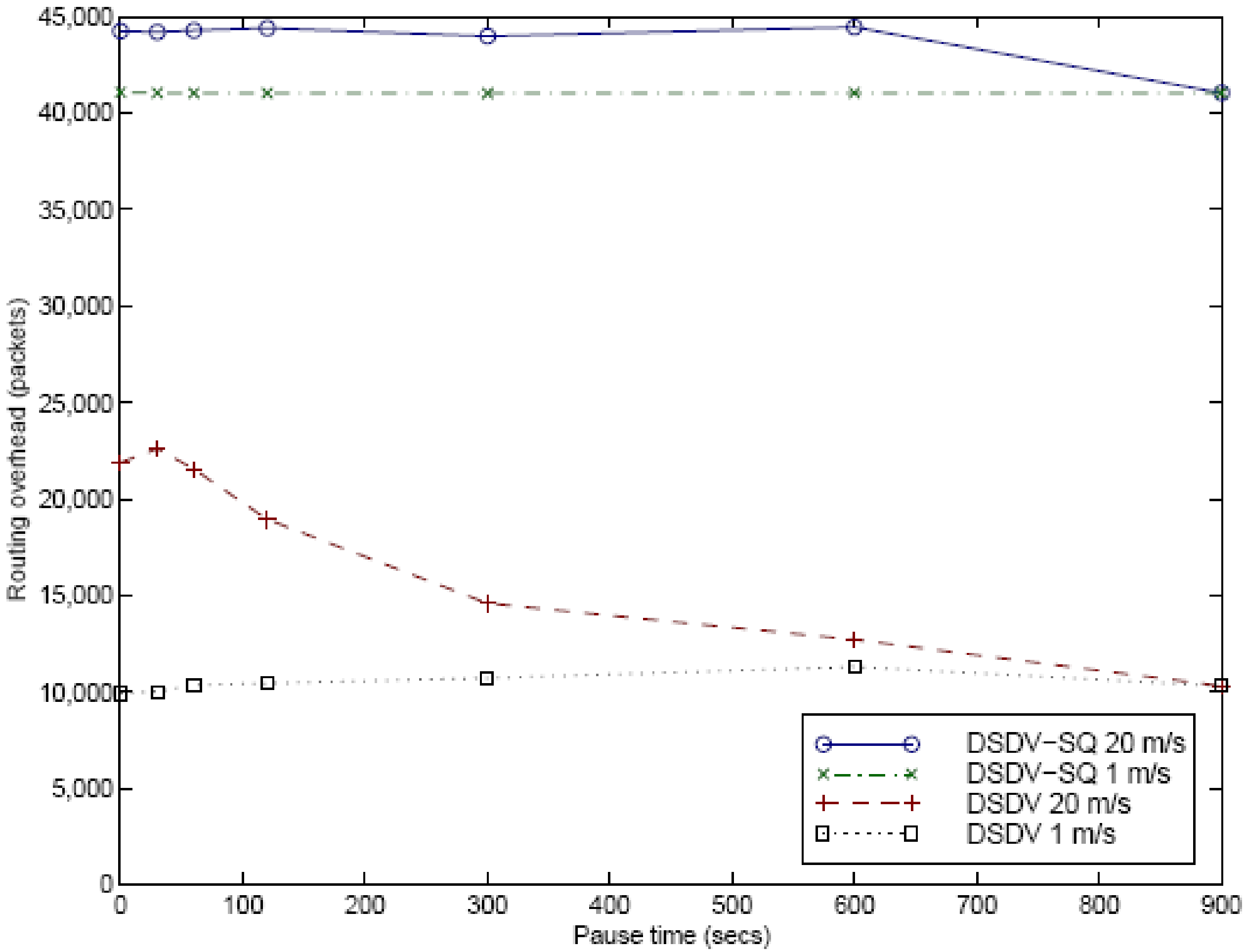


Figure 11 Routing Overhead DSDV vs DSDV-SQ



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Conclusions

- **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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from the original paper.

Questions ??

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