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

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Outline

- Compare four protocols
  - DSDV
  - TORA
  - DSR
  - AODV
- Simulation
  - *ns* extensions
  - Protocol implementations
- Simulation results

ns-2 extensions

The *ns*-2 network simulator was extended to include:

- Node mobility
- A realistic physical layer
  - propagation delay, capture effects, carrier sense
- Radio network interfaces
  - transmission power, antenna gain, receive sensitivity
- IEEE 802.11 MAC protocol using Distributed Coordinated Function (DCF)
  - node contention for wireless medium

Simulation Environment

- Routing protocol models
  - DSDV, TORA/IMEP, DSR, AODV
- Physical model
  - Attenuation of radio waves (free propagation and two-ray ground reflection model)
- Data link layer model
  - IEEE 802.11 MAC
- Address Resolution Protocol (ARP) model
  - IP address resolution
- Packet buffering in each node
  - 50 packet queue size in network interface. Additional 50 by routing protocol
- Ad hoc network
  - 50 wireless mobile nodes moving about and communicating with each other

Protocol improvements

During protocol implementation and early tests general improvements were discovered and implemented.

- Broadcasts and broadcast responses were jittered using a random delay uniformly distributed between 0 and 10 ms.
- Routing packets where queued at the head of the queue
- Each protocol, except DSDV, used 802.11 MAC layer link breakage detection.

DSDV

- Destination-Sequenced Distance Vector
  - designed by Charles E. Perkins and Pravin Bhagwat.
  - Presented SIGCOMM94
  - variant of distance vector routing suitable for mobile ad hoc networks
  - address drawbacks of poor looping properties in conventional distance vector routing

DSDV mechanism

- Each node maintains a routing table listing the “next hop” for each reachable destination.
- Each node advertises a sequence number which is recorded in the table.
  - A higher sequence number is a more favorable route
  - Equal sequence number resorts to favoring lower metrics
- Each node periodically broadcasts routing updates.

DSDV Simulation

- Triggered route updates are used to broadcast changes in the topology(i.e. broken link).
  - Receipt of a new sequence number for a destination. Labeled DSDV-SQ in the paper.
  - Receipt of a new metric for a destination. Labeled DSDV in the paper.
  - Link layer notification – not used due to signification performance penalty.

DSDV constants

- Reported results are for DSDV-SQ.
  – Later DSDV-SQ is compared to DSDV
- Constants used in simulation

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

TORA features

- Temporally-Ordered Routing Algorithm
  - Developed by Vincent Parks and M. Scott Corson
  - Appeared in IEEE INFCOM'97
  - Distributed routing protocol based on a "link reversal" algorithm.
  - Routes discovered on demand.
  - Reaction to topological changes are localized to minimize communication overhead.
  - Shortest path considered secondary to avoid overhead of discovering newer routes.

TORA mechanism

- 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.
- 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.

TORA/IMEP

- **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 chosen through experimentation.**

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

Dynamic Source Routing

- ## Source routing:

  Source routing is a technique whereby the sender of a packet can specify the route that a packet should take through the network. The “source” makes some or all of these decisions.

- ## Dynamic Source Routing:

  Dynamic Source Routing protocol is a simple and efficient routing protocol designed specifically for use in multi-hop wireless ad hoc networks of mobile nodes. The use of source routing allows packet routing to be trivially loop-free, avoids the need for up-to-date routing information in the intermediate nodes through which packets are forwarded, and allows nodes forwarding or overhearing packets to cache the routing information in them for their own future use.

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DSR mechanism (1)

- **Route discovery:**

  When some node S originates a new packet destined to some other node D, it places in the header of the packet a source route giving the sequence of hops that the packet should follow on its way to D. Normally, S will obtain a suitable source route by searching its Route Cache of routes previously learned, but if no route is found in its cache, it will initiate the Route Discovery protocol to dynamically find a new route to D. In this case, we call S the initiator and D the target of the Route Discovery.

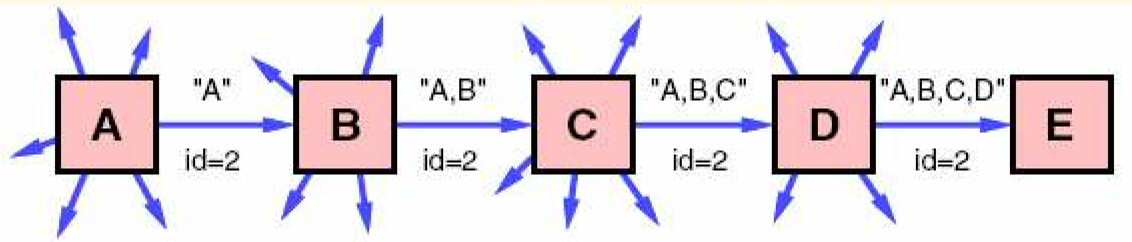


Figure 1: Route Discovery example: Node **A** is the initiator, and node **E** is the target.

DSR mechanism 2

- ## Route maintenance:

When originating or forwarding a packet using a source route,each node transmitting the packet is responsible for confirming that the packet has been received by the next hop along the source route; the packet is retransmitted (up to a maximum number of attempts) until this confirmation of receipt is received.

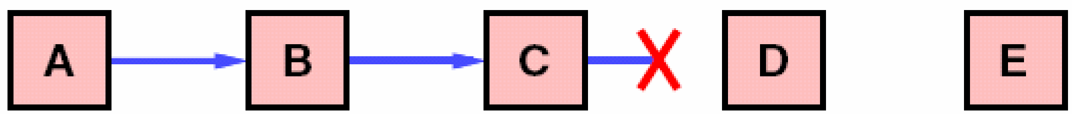


Figure 2: Route Maintenance example: Node **C** is unable to forward a packet from **A** to **E** over its link to next hop **D**.

Implementation and Constant

DSR using only bidirectional links in delivering data packets. It does not currently support true multicast routing, but does support and approximation of this that is sufficient in many network contexts.

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

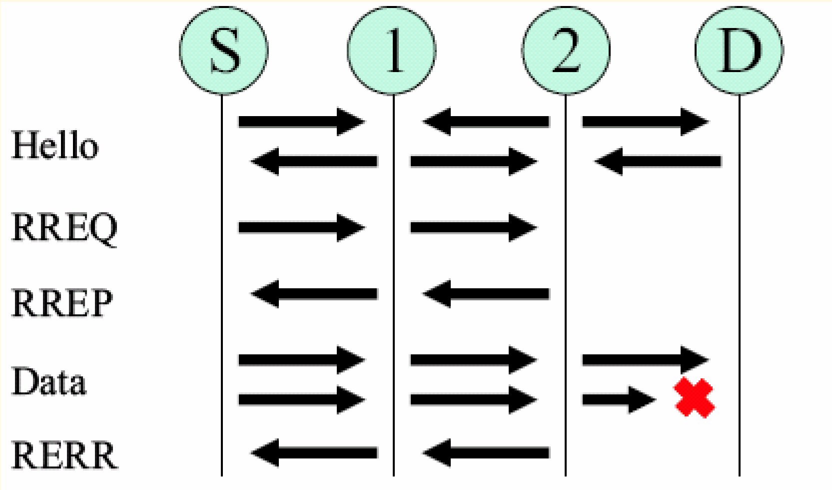
Advantages and disadvantages

Advantage: This protocol used a reactive approach which eliminates the need to periodically flood the network with table update messages which are in 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 could also result in inconsistencies during the route reconstruction phase.

AODV Protocol

The AODV routing protocol is a reactive routing protocol. Therefore, routes are determined only when needed. The figure shows the message exchange of the AODV protocol



Implementation and constant

Using AODV-LL protocol instead of the standard AODV routing protocol. The AODV-LL uses no hello mechanism by utilizing link layer feedback from 802.11.

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 Vs DSR

The major difference between AODV and DSR stems out from the fact that DSR uses source routing in which a data packet carries the complete path to be traversed. However, in AODV, the source node and the intermediate nodes store the next-hop information corresponding to each flow for data packet transmission.

AODV Advantage and Disadvantage

- **Advantage:**

  The main advantage of this protocol is that routes are established on demand and destination sequence numbers are used to find the latest route to destination. The connection setup delay is less.

- **Disadvantage:**

  One disadvantage is that intermediate nodes can lead to inconsistent routes if the source sequence number is very old and the intermediate nodes have a higher but not the latest destination sequence number, thereby having stale entries. Also multiple Route Request packets in response to a single Route Request packet can lead to heavy control overhead.

Movement Patterns

- *Pause times* included in simulation scenario files.
  - Node remains stationary for pause time seconds.
  - 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).
  - 10 scenario files for each pause time of 0, 30, 60, 120, 300, 600, & 900 seconds. Total of 70 movement patterns for each protocol tested.

Traffic Pattern

- Traffic sources
  – CBR
- Traffic rate
  – 4 packets/second
  – 64 bytes packets
- Source count
  – 10, 20 and 30 sources
- Connections
  – Peer-to-peer connections started at times uniformly distributed between 0 and 180 seconds

Scenario Characteristics

- Measured shortest-path hop count provided by simulation scenarios
  - Average data packet had to cross 2.6 hops
  - Farthest node to which routing protocol had to deliver a packet was 8 hops.

Distribution of Shortest-path

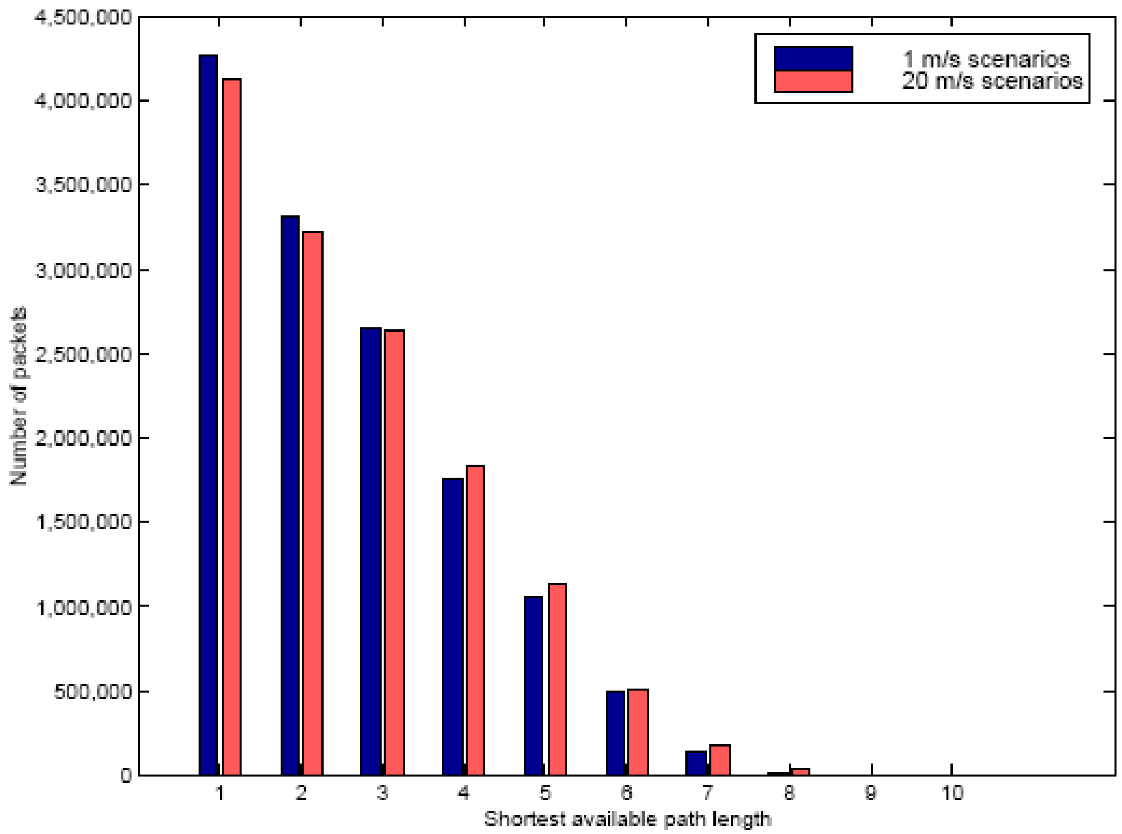


Figure 1 Distribution of the shortest path available to each application packet originated over all scenarios.

WPI

Connectivity Changes

- **A connectivity change occurs when a node goes into or out of direct communication range with another node.**

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 CBR sources and the number of packets received by the CBR sink at the final destination
  - Describes the loss rate seen by the protocol

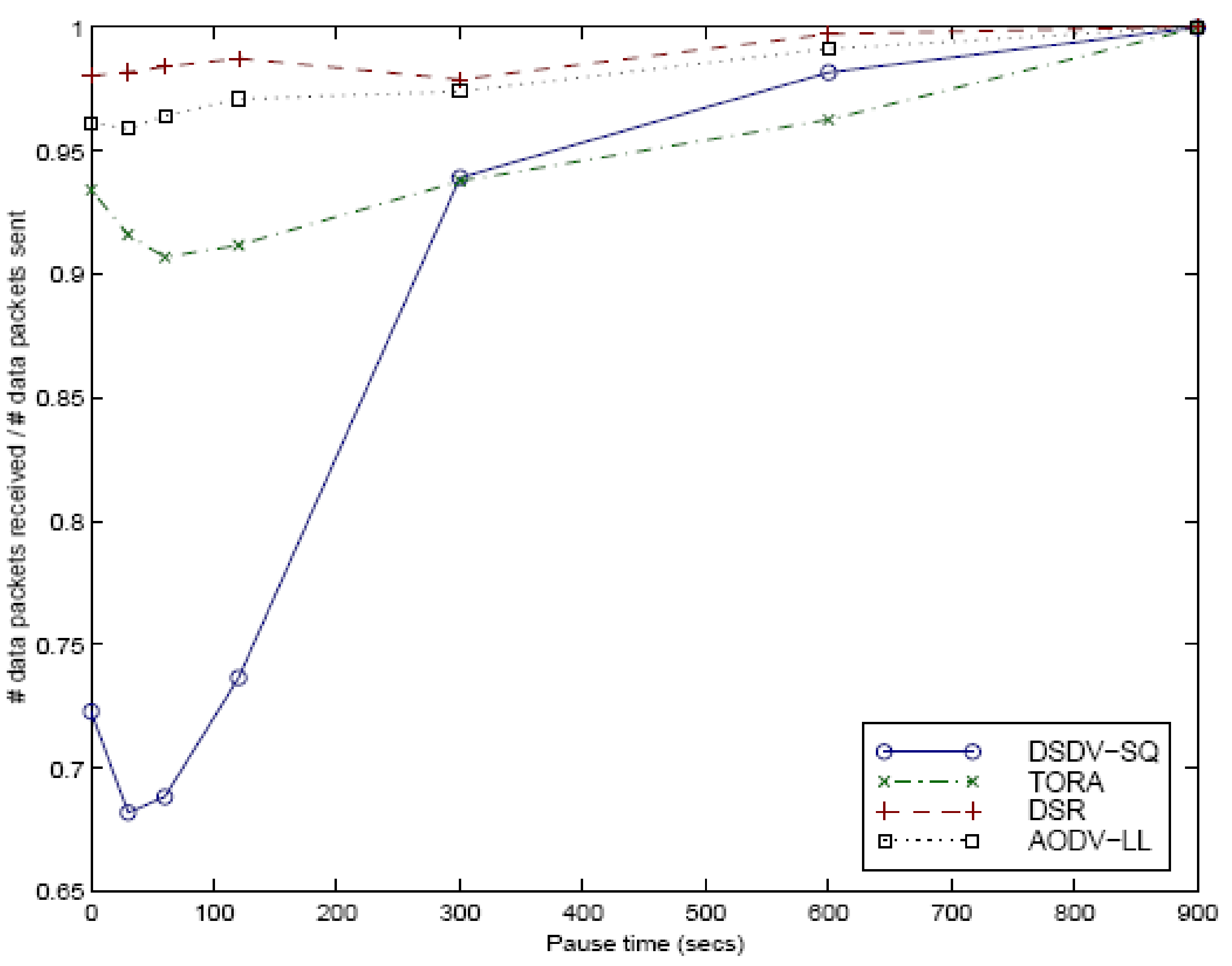
Metrics

- **Routing Overhead**
  - The total number of routing packets transmitted during the simulation
  - Measures the scalability of the protocol
  - Measures the degree to which protocol will function in congested or low-bandwidth environment
  - Measures the protocol efficiency in terms of consuming node battery power

Metrics

- Path Optimality
  - The difference between the number of hops a packet took to reach its destination and the length of the shortest path that physically existed through the network when the packet was originated
  - Measures the ability of the routing protocol to efficiently use network resources by selecting the shortest path to a destination

Packet delivery ratio vs pause time

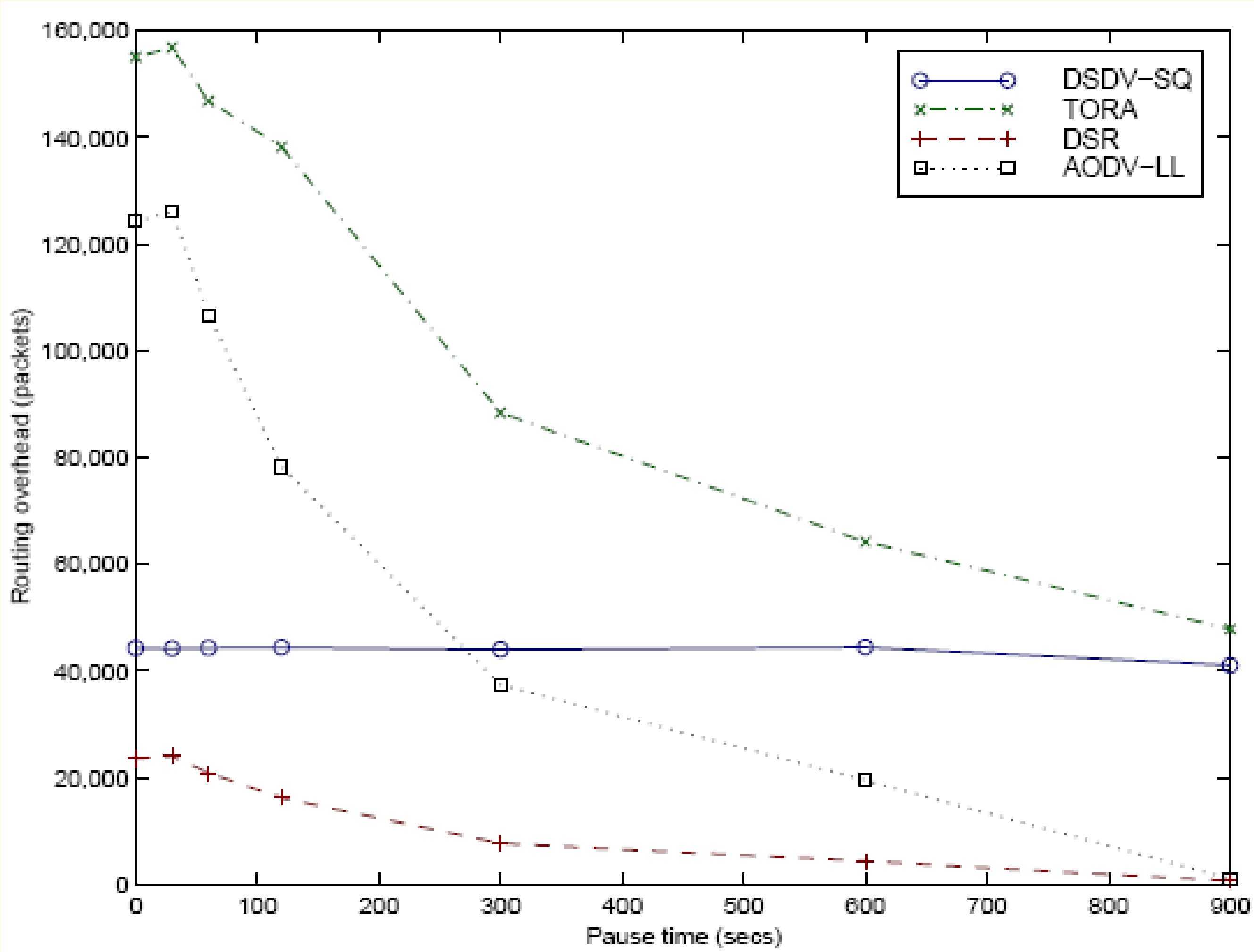


Speed: 20 m/s

Source count: 20

- DSDV-SQ: fails to converge at pause times less than 300 sec.
- All converge to 100% when there is no node motion.

Routing overhead vs pause time



Speed: 20 m/s

Source count: 20

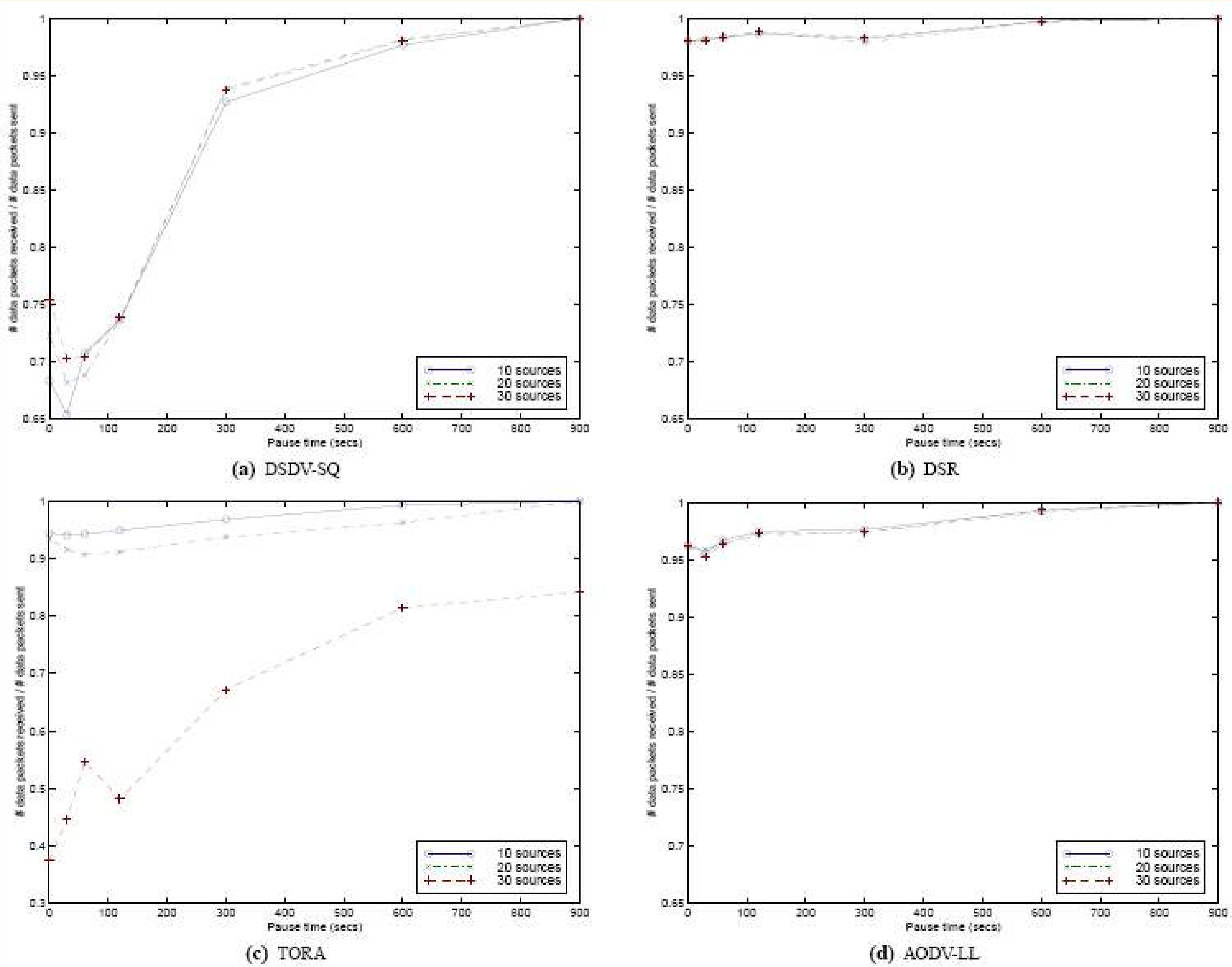
•DSR has the least overhead.

•TORA has the most overhead.

•DSDV-SQ is mostly a periodic protocol resulting in a constant overhead.

WPI

Packet delivery ratio vs pause time and load



Speed: 20 m/s

- DSDV-SQ lost packets at high mobility because of stale routing table.
- With 30 sources, TORA's average packet delivery ratio drops to 40% at pause time 0 because of increased congestion.

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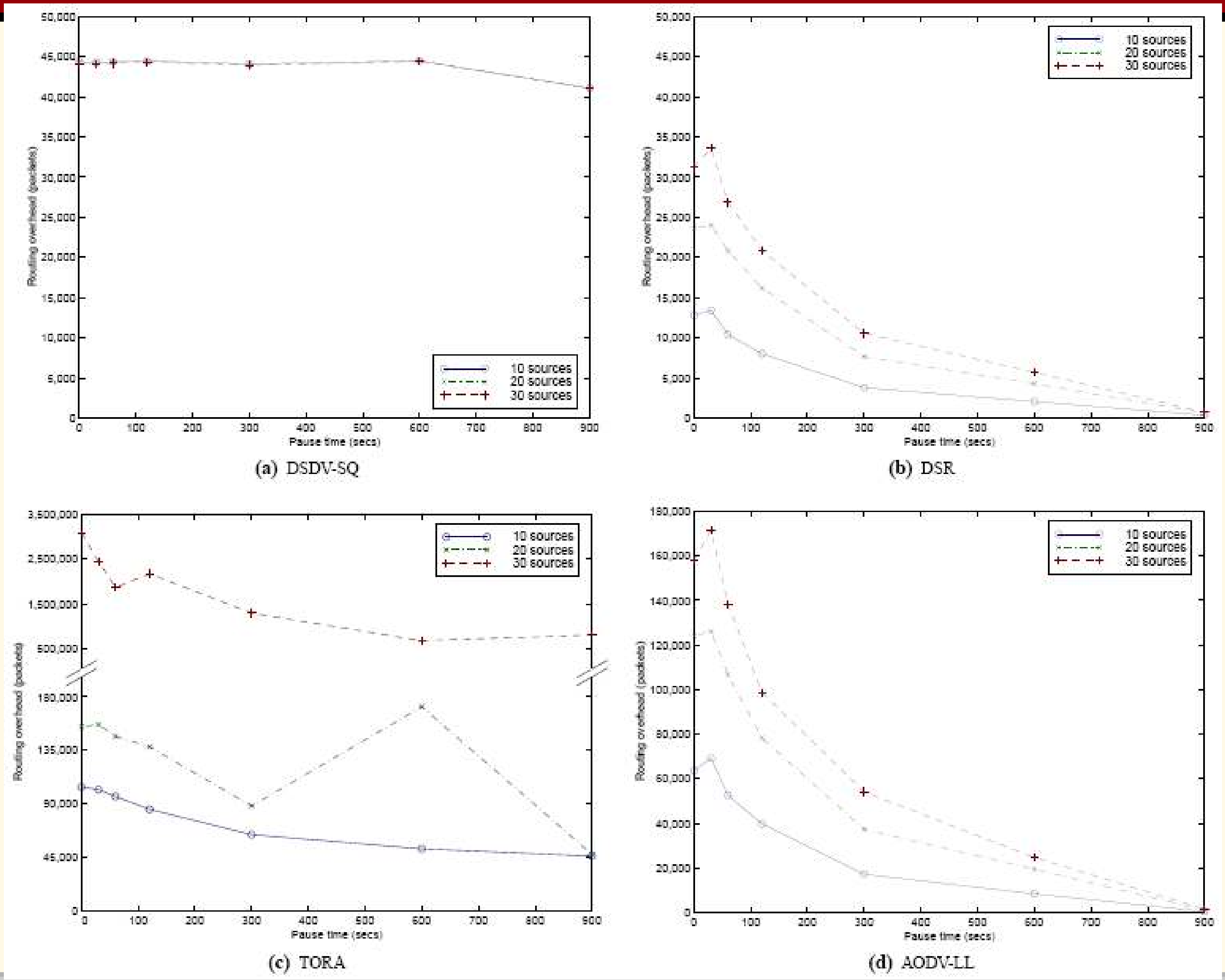
Routing overhead vs pause time and load

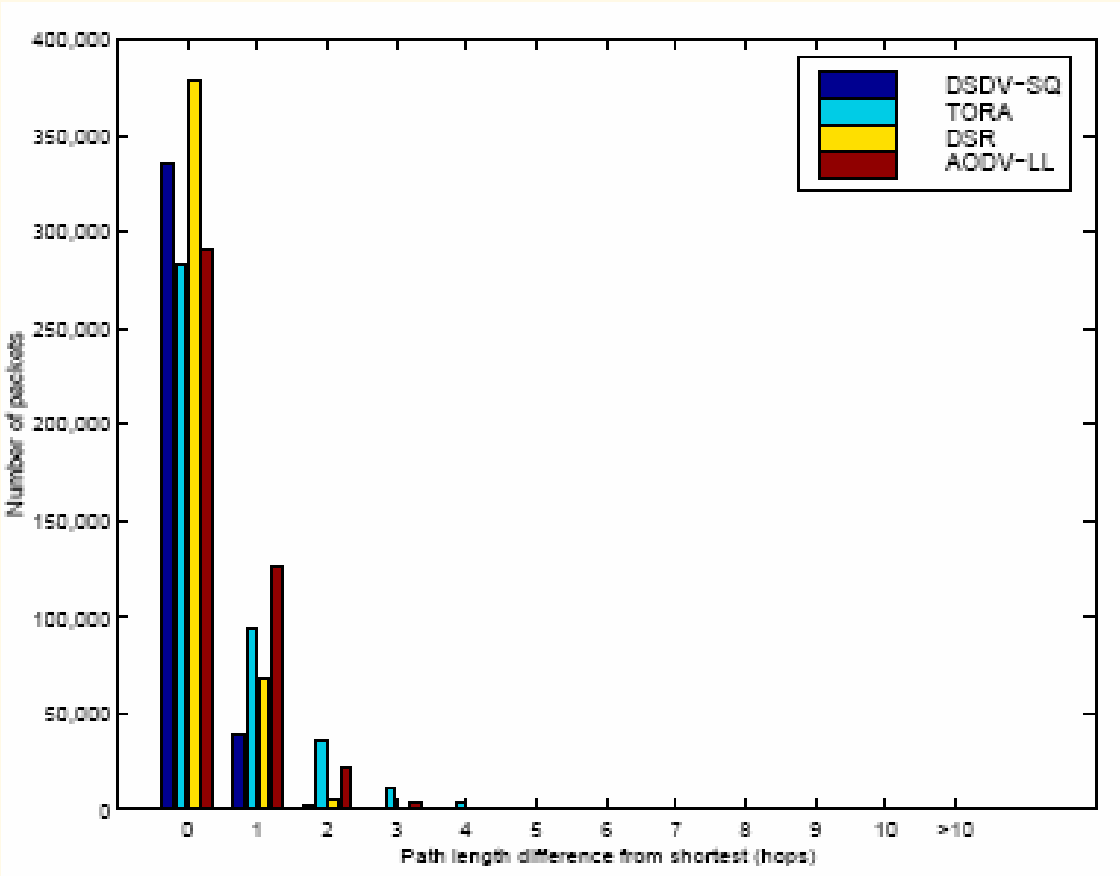


Speed: 20 m/s

- On demand routing protocols TORA, DSR, and AODV-LL increase routing packets as load increases due to an increase in the number of destinations.

Path Optimality

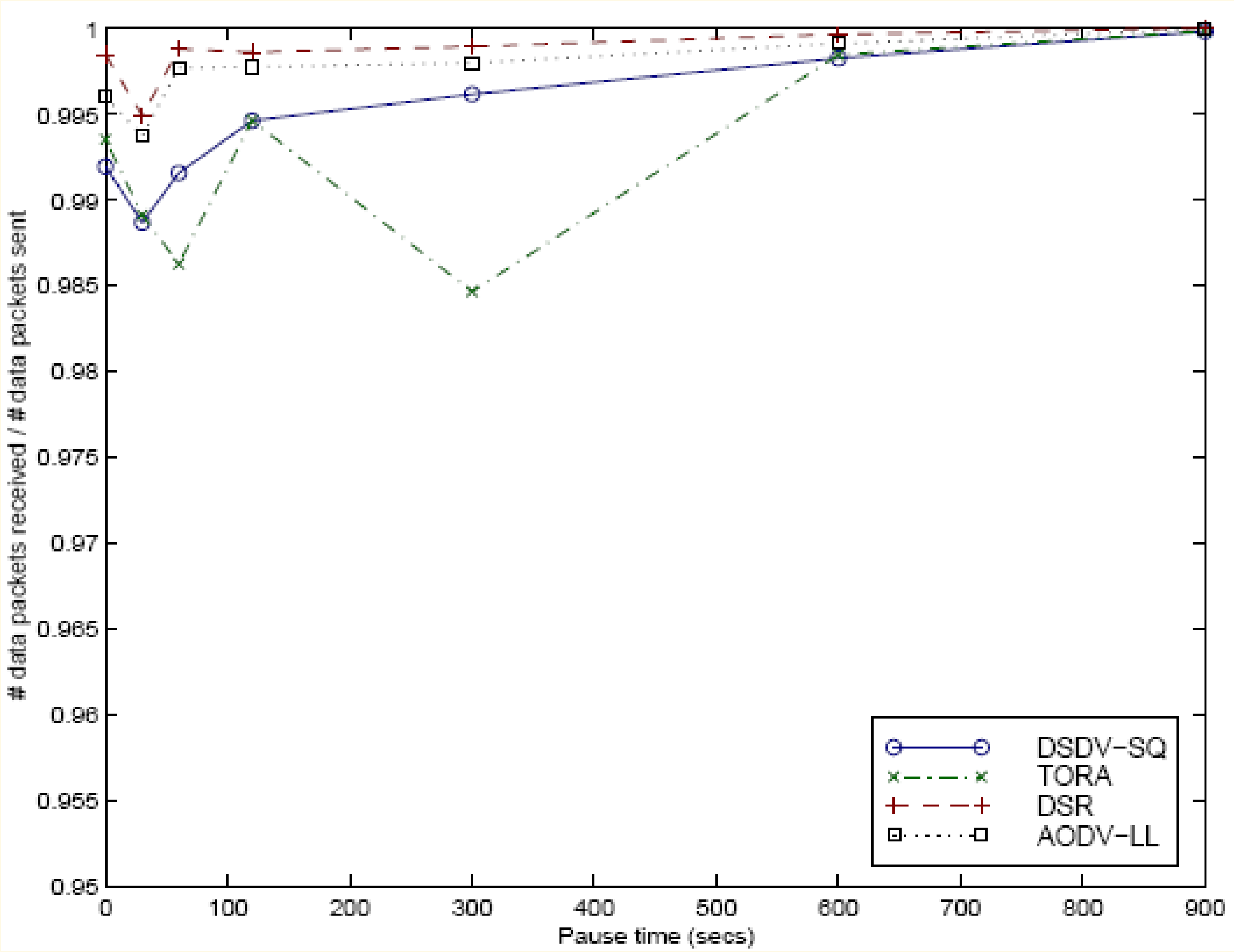
The difference between the shortest path length and the length of the paths actually taken by data packet.



- Both DSDV-SQ and DSR use routes close to optimal
- TORA and AODV-LL have a significant tail.
- Note, TORA is not designed to find shortest path to destination.

Lower speed of node movement

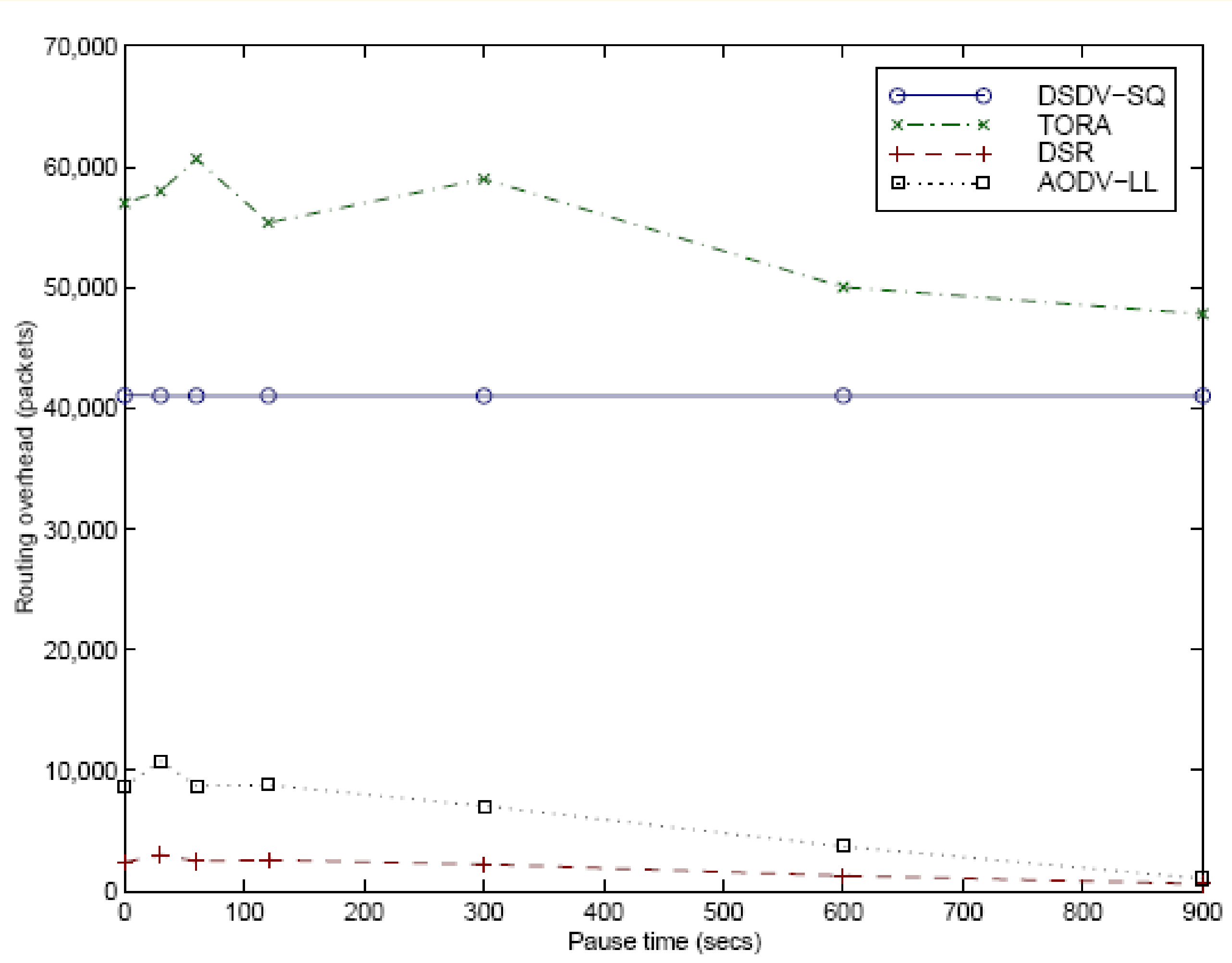
Packet delivery ratio versus pause time at movement speed of 1m/s with 20 sources



- All the protocols deliver more than 98.5% of their packets at this movement speed

Lower speed of node movement

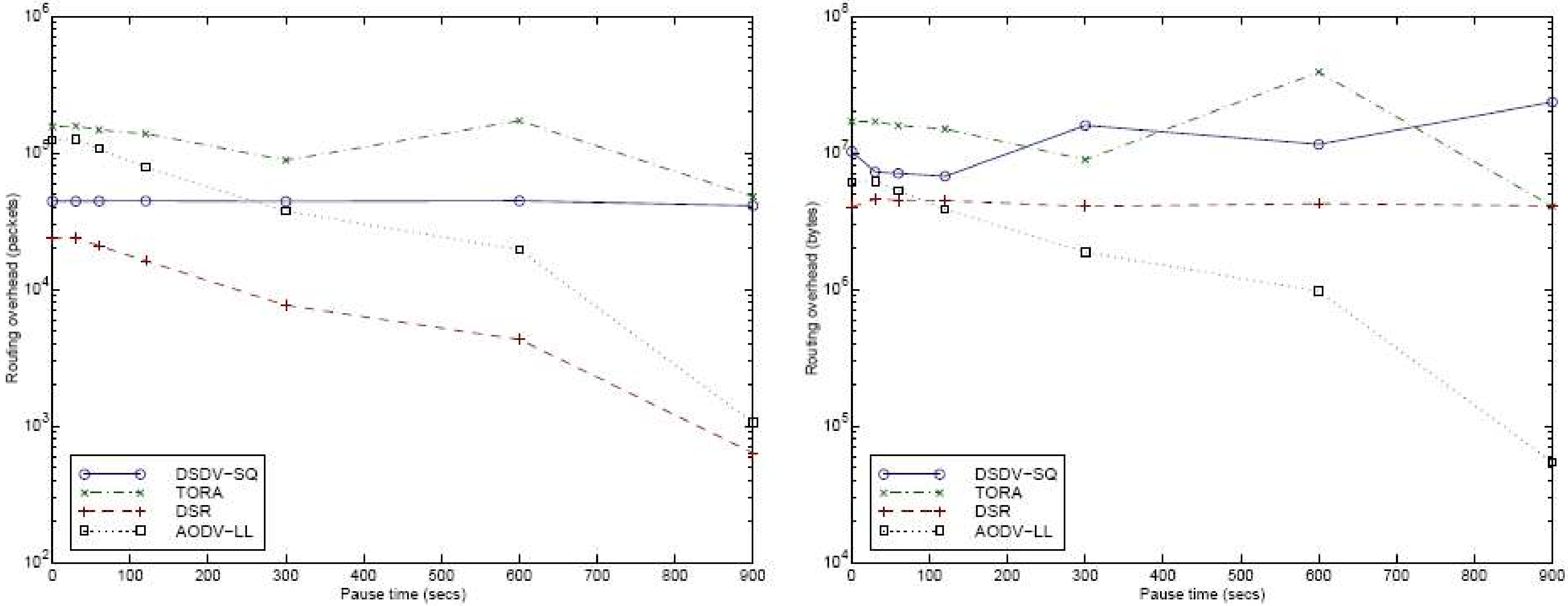
Routing overhead versus pause time for movement speed of 1m/s with 20 sources.



- Separation between DSR and AODV-LL is a factor of 10 vs a factor of 5 due to DSR's caching going stale more slowly.
- DSDV-SQ continues to have a constant overhead.
- TORA's overhead is dominated by the link/status sensing mechanism of IMEP.

Overhead in bytes

If routing overhead is measured in bytes and includes the bytes of the source route header that DSR replaces in each packet, DSR becomes more expensive than AODV-LL.

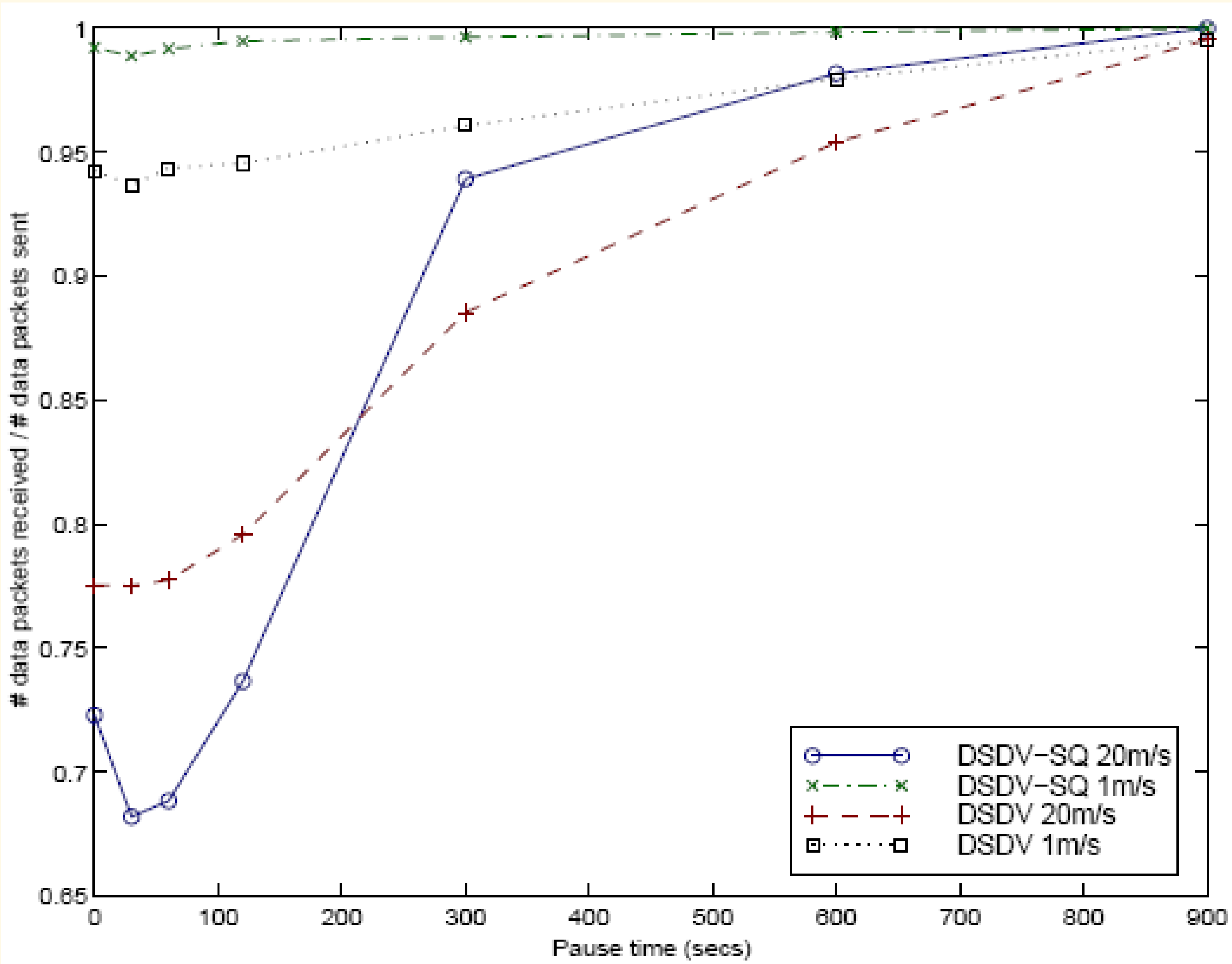


(a) Routing overhead in packets.

(b) Routing overhead in bytes.

DSDV-SQ vs DSDV

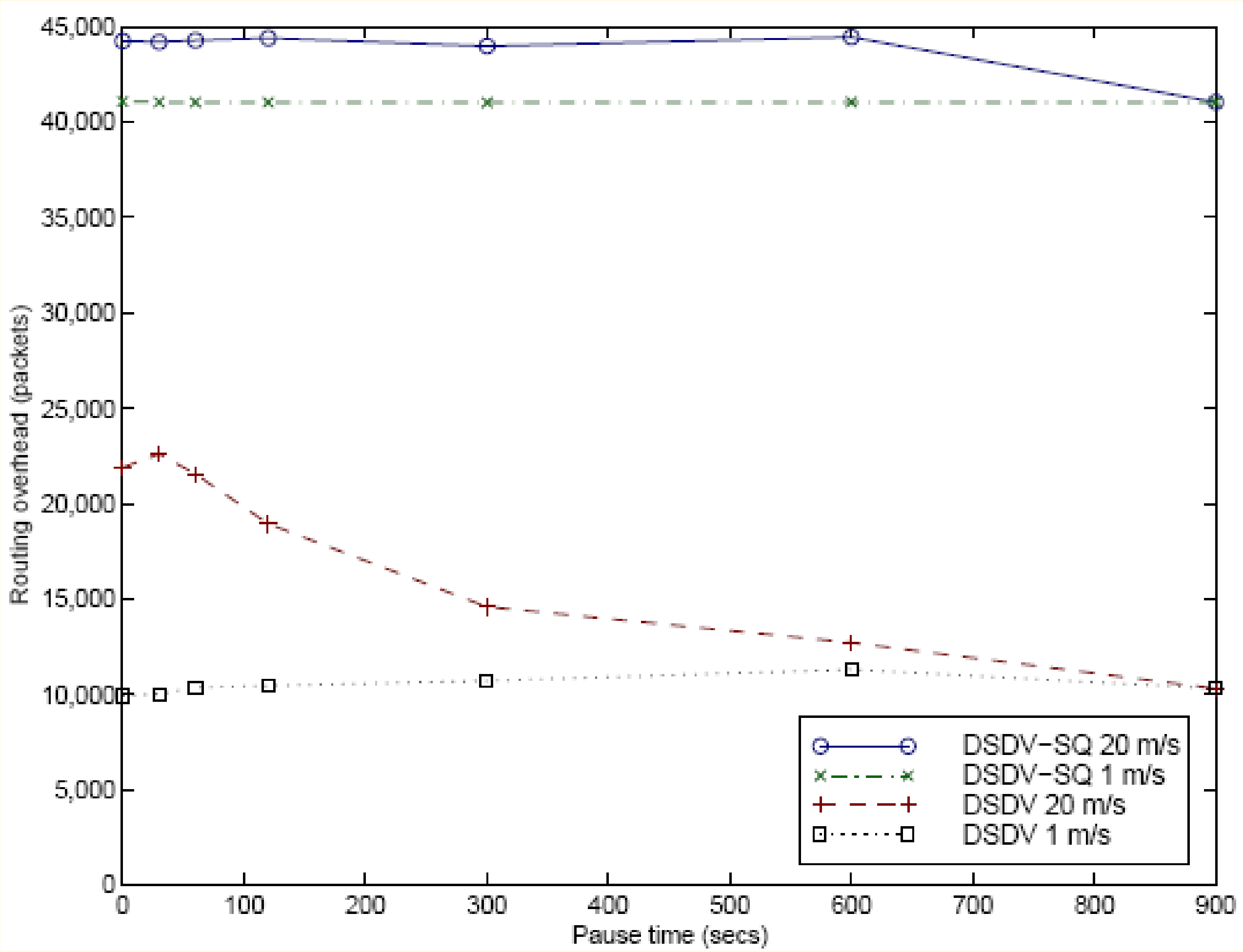
Packet delivery ratio versus pause time with 20 CBR sources.



- At 1m/s DSDV delivers fewer packets than DSDV-SQ. DSDV dropped packets are caused by link breakages not detected as quick as DSDV-SQ
- At 20m/s both fail to converge below 300 seconds of pause time causing a large percentage of data packets to be dropped.

DSDV-SQ vs DSDV

Routing overhead versus pause time with 20 CBR sources.



- At 1m/s DSDV routing overhead is a factor of 4 smaller than DSDV-SQ
- At 20m/s DSDV triggering scheme reduces the relative routing overhead by a factor of 4 at pause time 900 and by a factor of 2 at pause time 0.

Conclusion

- Contributions
  - ns network simulator extension
  - This new simulation environment provides a powerful tool for evaluating ad hoc networking protocols.

WPI

Conclusion

- **Using ns, results were presented of a detailed packet-level simulation of four protocols.**
  - **DSDV performs predictably. Delivered virtually all packets at low node mobility, and failing to converge as node mobility increases.**
  - **TORA worst performer. Still delivered 90% of the packets in scenarios with 10 or 20 sources.**
  - **DSR was very good at all mobility rates and movement speeds.**
  - **AODV performs almost as well as DSR, but still requires the transmission of many routing overhead packets. At higher rates of node mobility its actually more expensive than DSR.**