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

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CS 577 – Prof. Bob Kinicki

Outline

- Introduction
- Simulation Environment
- Ad Hoc Network Routing Protocols
  - DSDV
  - TORA
  - DSR
  - AODV
- Methodology
- Simulation Results & Observations
- Conclusions

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Introduction

- What is ad hoc?
  - Ad hoc is a Latin phrase meaning "for this". It generally signifies a solution designed for a specific problem or task, non-generalizable, and not intended to be able to be adapted to other purpose.

Introduction

- What is ad hoc network?
  - each mobile node operates not only as a host but also as a router
  - ad hoc routing protocol allows each node to discover "multi-hop" paths through the network to any other node
  - infrastructureless networking
  - dynamically establish routing

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Simulation Environment

- ns
  - Node mobility
  - A realistic physical layer including:
    - a radio propagation model
    - supporting propagation delay
    - capture effects
    - carrier sense
  - Radio network interfaces with properties such as:
    - transmission power
    - antenna gain
    - **receiver sensitivity**
  - IEEE 802.11 MAC protocol using DCF

Some details on simulation

- Attenuates the power of a signal:
  - $1/r^2$ at short distance
  - $1/r^4$ at long distance
- Reference distance
  - 100 meters for outdoor
  - low-gain antennas 1.5 m above the ground plane
  - operating in the 1–2 GHz band
- ARP
- 50 packets with drop-tail

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Ad Hoc Network Routing Protocols

- Improvements to all of the protocols:
  - To prevent synchronization, periodic broadcasts and packets sent in ACK were jittered using a random delay uniformly distributed between 0 and 10 milliseconds.
  - To insure that routing information propagated in a timely fashion, routing packets were queued for transmission at the head of the network interface.
  - Each of the protocols use link breakage detection feedback from the 802.11 MAC (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 periodically broadcast routing updates
  - it guarantees loop-freedom (traditional DV doesn't)
- Based on the Bellman-Ford algorithm

DSDV

- Each node maintains a routing table listing the "next hop" for each reachable destination.
- DSDV tags each route with a sequence number. (the higher, the better)
- Each node in the network advertises a monotonically increasing even sequence number for itself.
- Each node periodically broadcasts update.

DSDV Implementation

- Does not use link layer breakage detection.
- Uses both full and incremental updates.
- Trigger an update when:
  - receipt of a new sequence number for a destination will cause a triggered update (DSDV-SQ)
  - receipt of a new metric (simply DSDV).

Constants in DSDV

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

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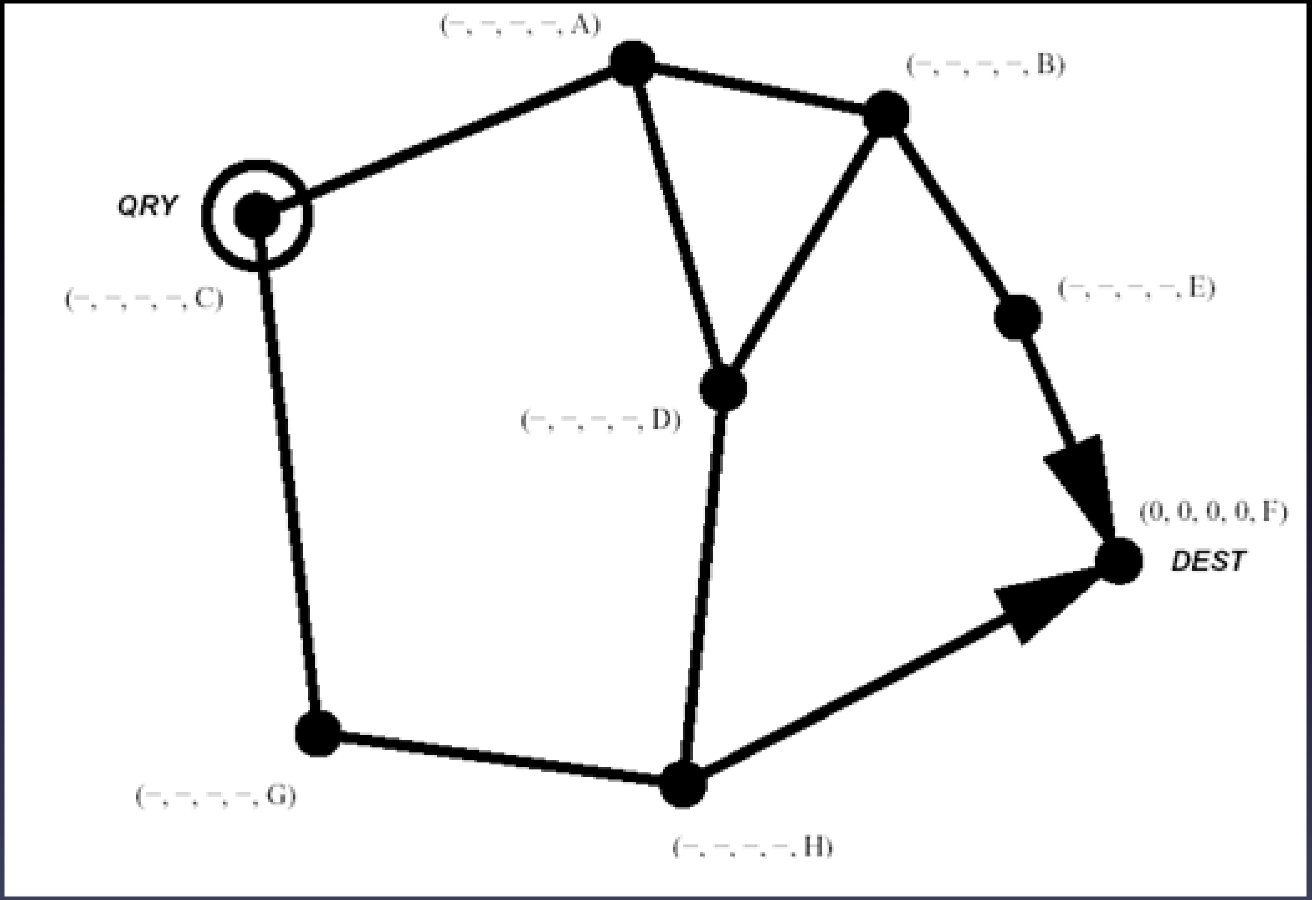
Temporally-Ordered Routing Algorithm (TORA)

- A distributed routing protocol based on a "link reversal" algorithm.
- Discovers routes on demand.
- Provides multiple routes to a destination.
- Minimizes communication overhead by localizing algorithmic reaction to topological changes.
- Route optimality is considered of secondary importance.
- Longer routes are often used to avoid the overhead of discovering newer routes (what?!).

TORA

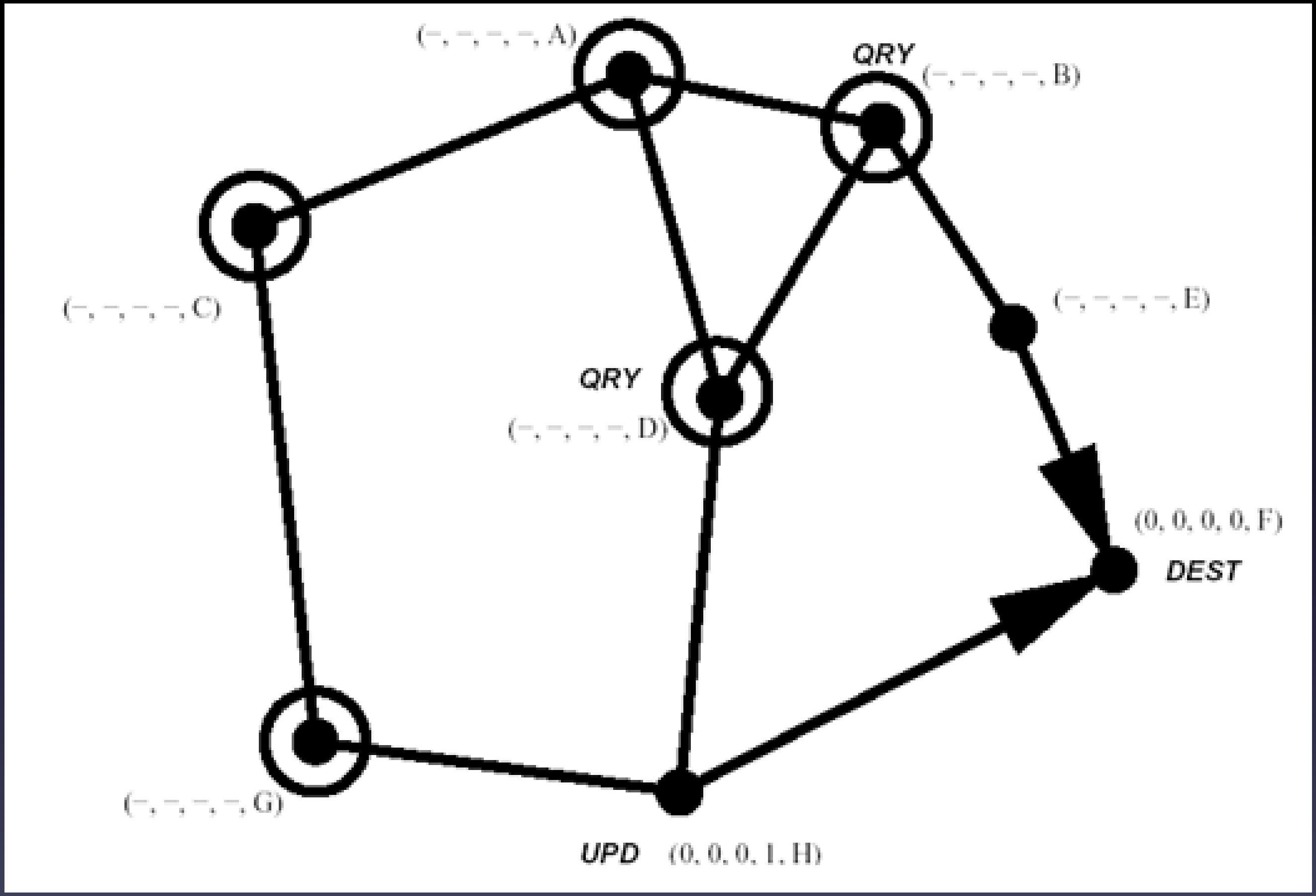
- Start: when a node needs a route to a particular destination, it broadcasts a QUERY packet.
- Propagate: QUERY packet stops at the destination or an intermediate node having a route to the destination.
- Response: the recipient then broadcasts an UPDATE packet listing its height with respect to the destination.
- End: each node that receives the UPDATE sets its height to a value greater than it received.

TORA Example



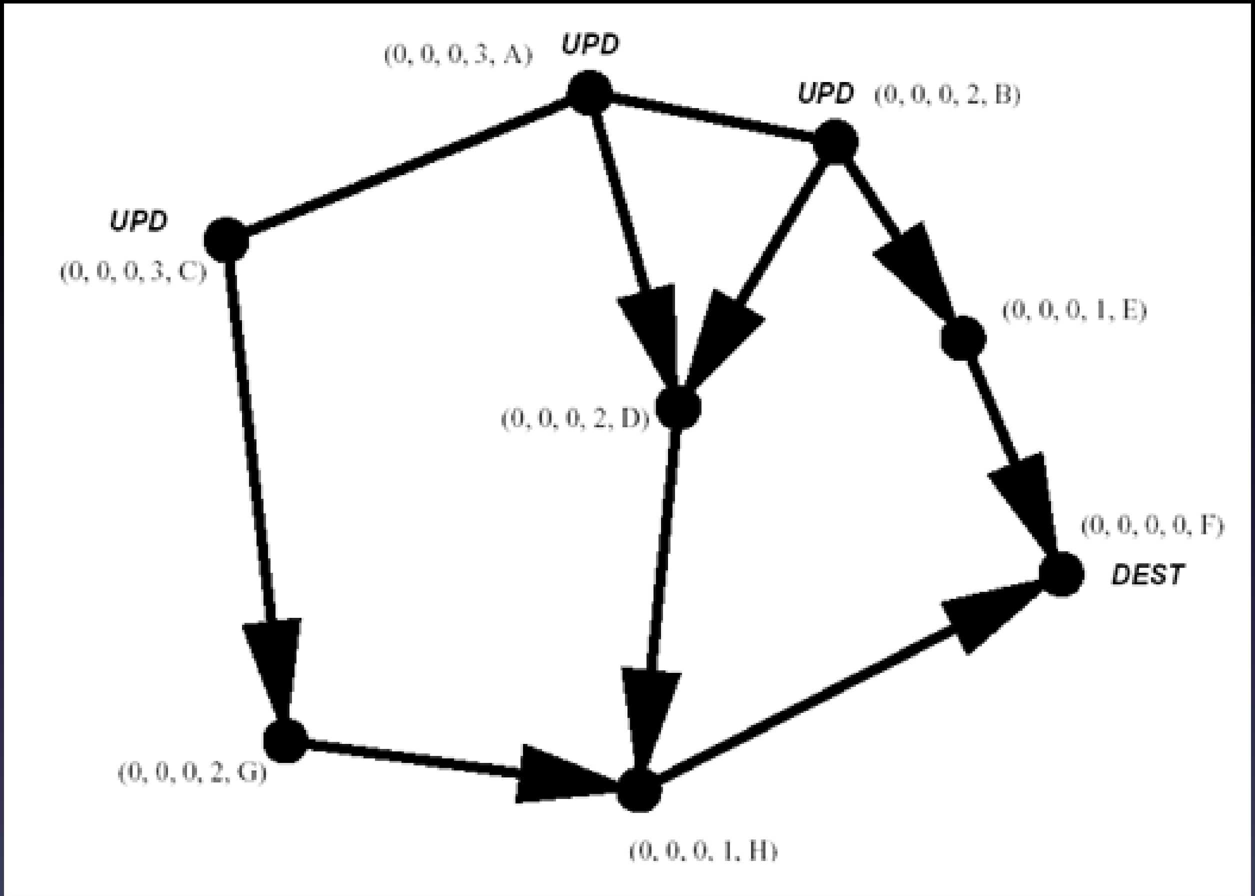
Node C requires a route, so it broadcasts a QRY

TORA Example



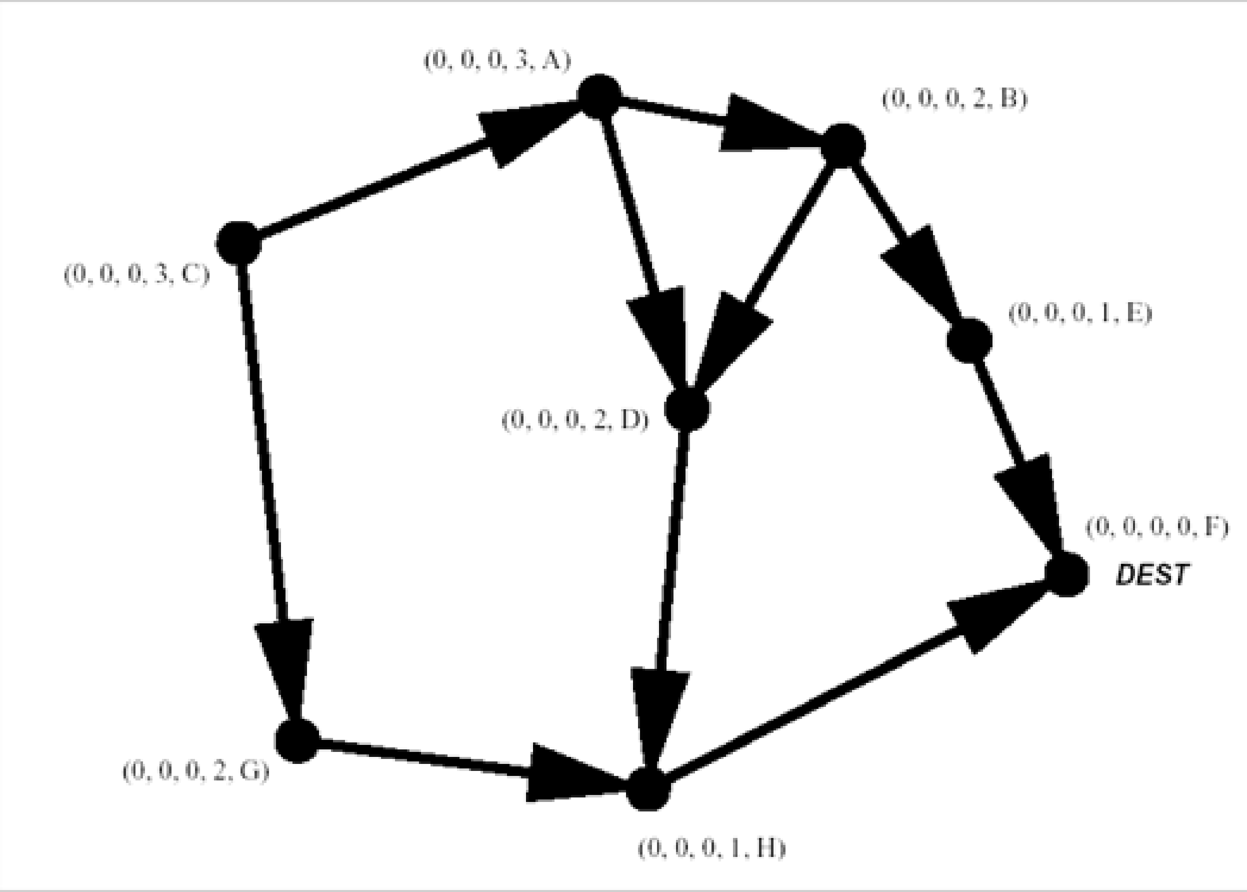
The QRY propagates until it hits a node which has a route to the destination

TORA Example



The UPD is also propagated, while node E sends a new UPD

TORA Example



Finally, every node gets its height

TORA

- TORA can be described in terms of water flowing downhill towards a destination node through a network of tubes that models the routing state of the real network.

TORA Implementation

- TORA is layered on top of IMEP (Internet MANET Encapsulation Protocol).
- IMEP attempts to aggregate many TORA and IMEP control together into a single packet.
- Each IMEP node periodically transmits a BEACON, which is answered by each node hearing it with a HELLO.
- Uses ARP instead of IMEP in network layer address resolution.

TORA Implementation

- Balance overhead and routing protocol convergence:
  - aggregate HELLO and ACK packets for a time uniformly chosen between 150 ms and 250 ms.
  - Does not delay TORA routing messages for aggregation.
  - * transmission delay of TORA routing messages + any queuing delay at the network interface, allows these routing loops to last long enough that significant numbers of data packets are dropped.

Constants in TORA

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)

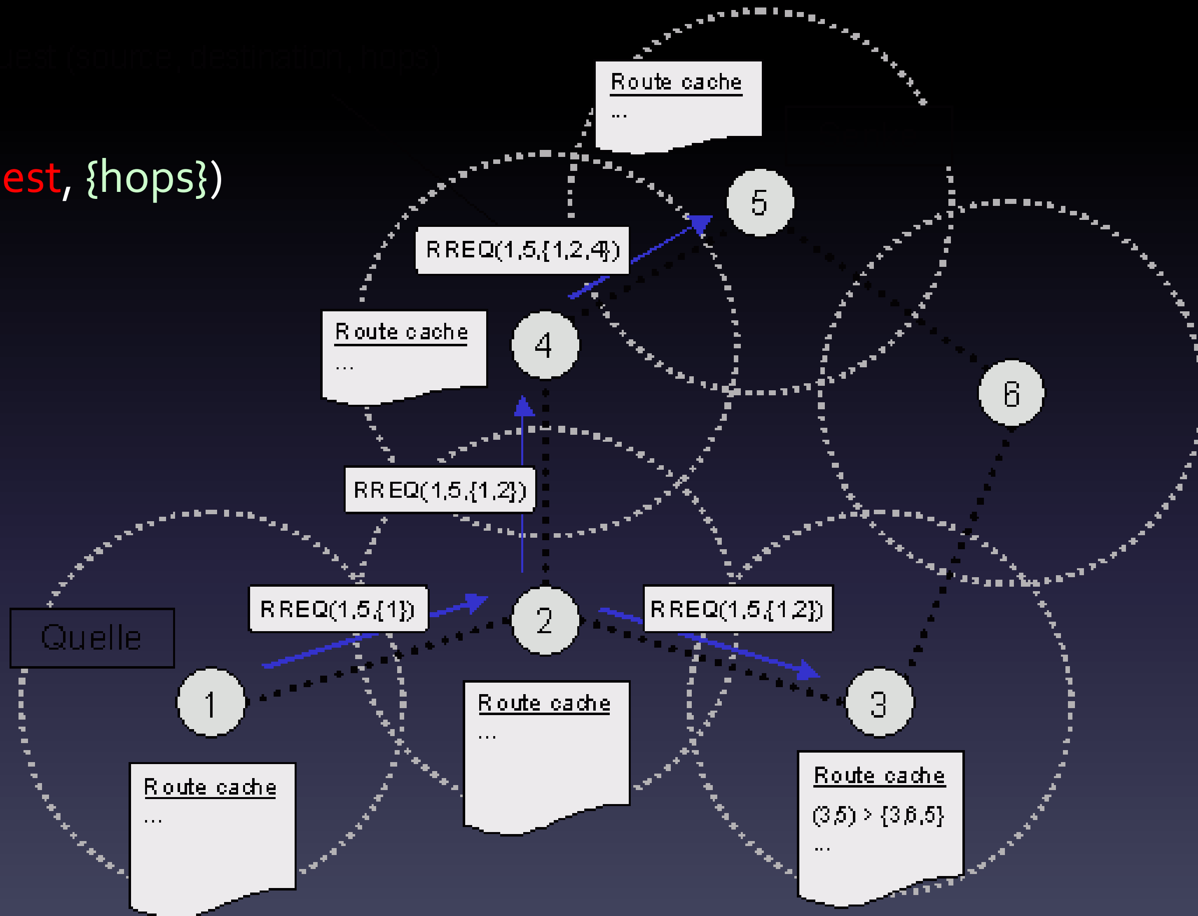
- DSR uses source routing rather than hop-by-hop routing. Each packet carries an ordered list of nodes, which the packet must pass.
  - intermediate nodes do not need to maintain up-to-date routing information in order to route the packets.
  - periodic route advertisement and neighbor detection packets are not needed.
- DSR protocol consists of two mechanisms:
  - Route Discovery
  - Route Maintenance.

DSR - Route Discovery

- Start: the source node broadcasts a REQUEST packet that is flooded through the network. (same as TORA, except the content of REQUEST).
- Propagate: the destination node or another node that knows a route to the destination will answer with a REPLY. (same as TORA, except the content of REPLY).

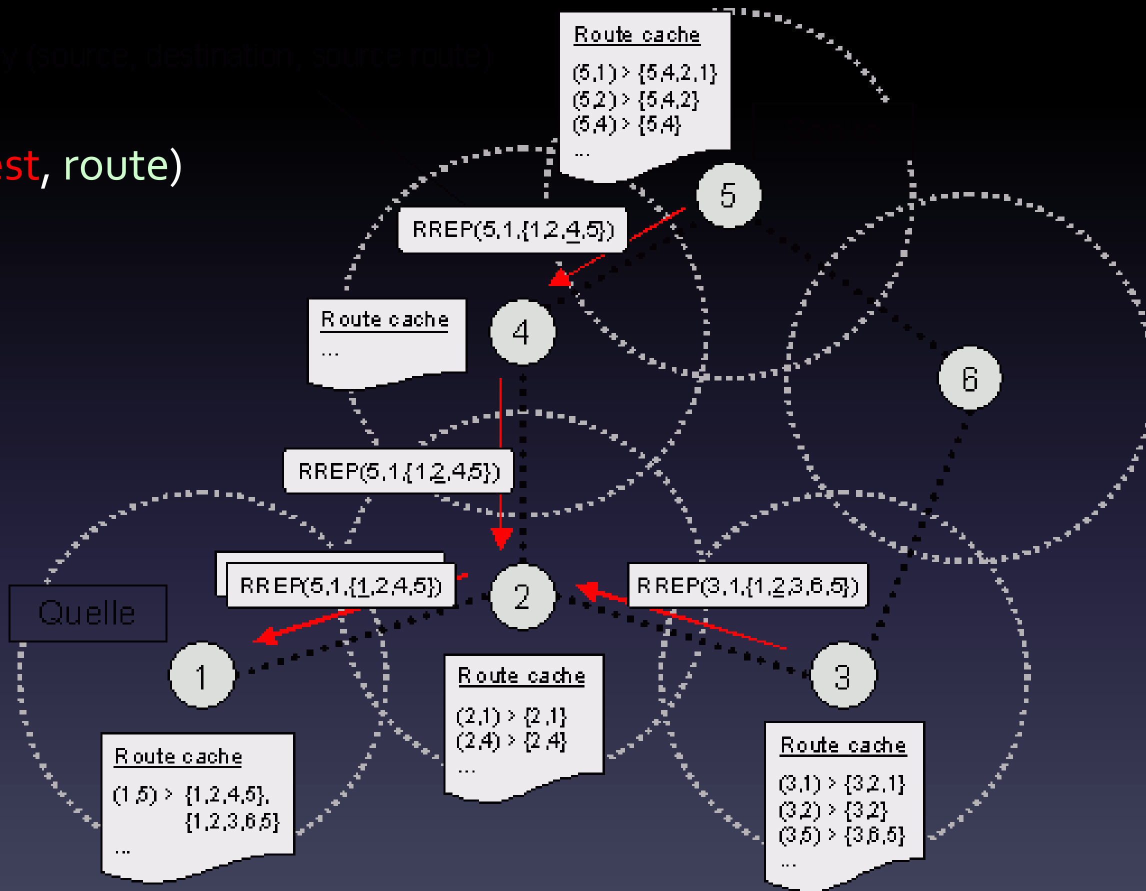
DSR – Route Discovery

Request:
(source, request, {hops})



DSR – Route Discovery

Reply:
(source, request, route)



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DSR - Maintenance

- Detects when the topology of the network has changed:
  - source node is notified with a ROUTE ERROR packet.
- Decides:
  - if an alternative route can be used.
  - if the Route Discovery protocol must be started to find a new path.

DSR Implementation

- Discovers only routes composed of bidirectional links
  - by requiring nodes to return ROUTE REPLY messages to where ROUTE REQUEST packet came.
- A node sends a ROUTE REQUEST with TTL=0. If this non-propagating search times out, it will send a propagating ROUTE REQUEST.

Constants in DSR

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

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Ad Hoc On-Demand Distance Vector (AODV)

- AODV is essentially a combination of both DSR and DSDV.
  - It borrows the basic on-demand mechanism of Route Discovery and Route Maintenance from DSR.
  - It uses hop-by-hop routing, sequence numbers, and periodic beacons from DSDV.

AODV

- Start & propagate: same as DSR, except the REQUEST contains the last known sequence number for that destination.
- Response: when the REQUEST reaches a node with a route to D, it generates a REPLY that contains:
  - the number of hops necessary to reach D
  - the sequence number for D most recently seen it.
- End: Each node that participates in forwarding this REPLY back toward S, creates a forward route to D by remembering only the next hop (same as DSDV).

AODV - Maintenance

- Each node periodically transmit a HELLO message with a default rate of once per second.
- Failure to receive three consecutive HELLO messages from a neighbor ?= the neighbor is down.
  - Alternatively, may use physical layer or link layer methods to detect link breakages.
- UNSOLICITED REPLY containing an infinite metric for that destination will be sent to any upstream node that has recently forwarded packets to a destination using that link.

AODV Implementation

- also implemented a version of AODV that we call AODV-LL (link layer), using only link layer feedback from 802.11 as in DSR.
- Changed AODV implementation to use a shorter timeout of 6 seconds before retrying a REQUEST for which no REPLY has been received (RREP WAIT TIME).

Constants in AODV

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

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Methodology

- The overall goal of our experiments was to measure the ability of the routing protocols to react to network topology changes while continuing to successfully deliver data packets to their destinations.

Methodology

- 50 wireless nodes, moving about over a rectangular (1500m * 300m) flat space, simulated 900 s
- 210 different scenario files with varying movement patterns and traffic loads
- Physical radio characteristics: Lucent WaveLAN direct sequence spread spectrum radio.

Methodology

- Movement Model
- Communication Model
- Scenario Characteristics
- Metrics

Movement Model

- "random waypoint" model
  1. begins by remaining stationary for a pause time
  2. selects a random destination
  3. moves to that destination at a speed distributed uniformly 0~MAX
  4. upon reaching, pauses again for a pause time
  5. repeats from 2

Movement Model

- 7 different pause times: 0, 30, 60, 120, 300, 600, and 900 s.
- 70 different movement patterns, 10 for each value of pause time
- 2 different maximum speeds:
  - 20 m/s
  - 1 m/s

Methodology

- Movement Model
- Communication Model
- Scenario Characteristics
- Metrics

Communication Model

- Constant Bit Rate (CBR)
  - sending rates of 1, 4, and 8 packets per second
  - networks containing 10, 20, and 30 CBR sources
  - packet sizes of 64 and 1024 bytes
- did not use TCP (because it's so GOOD!!)

Methodology

- Movement Model
- Communication Model
- Scenario Characteristics
- Metrics

Scenario Characteristics

- An internal mechanism of the simulator calculates the shortest path between the originated packet's sender and its destination.
- The shortest path is calculated based on a range of 250m for each radio without congestion and interference.
- The average hops is 2.6, and the farthest is 8.

Scenario Characteristics

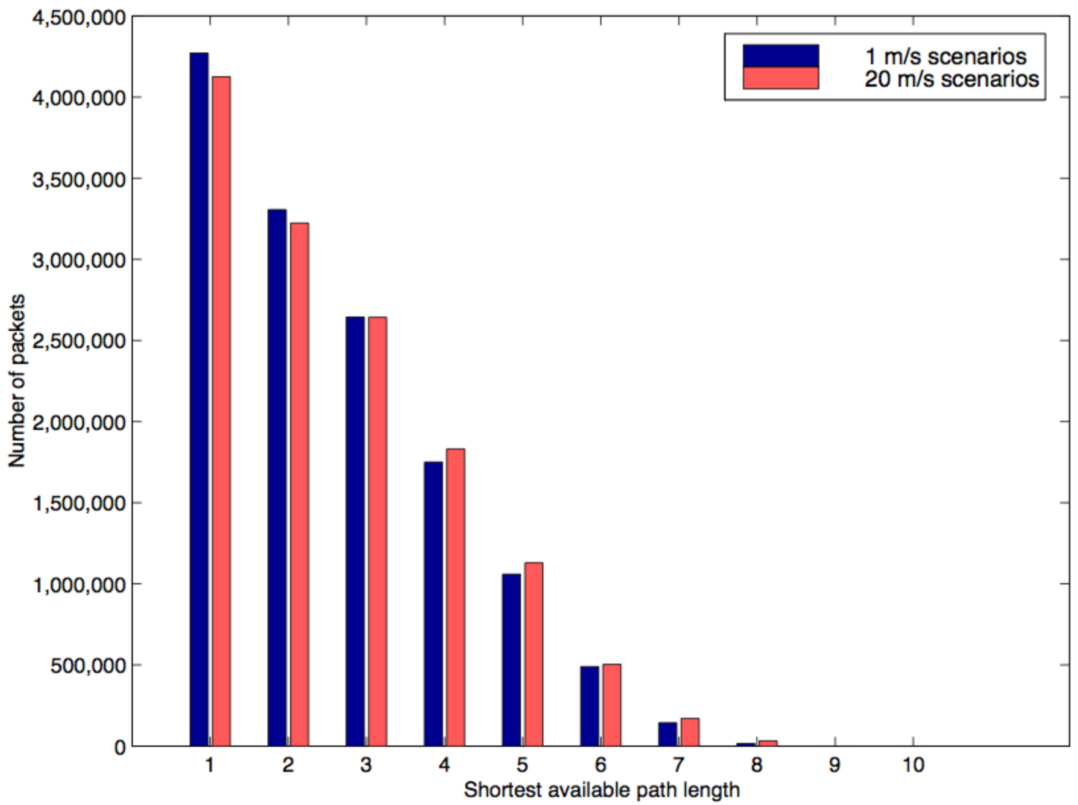

Figure 1 Distribution of the shortest path available to each application packet originated over all scenarios.

Scenario Characteristics

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

Methodology

- Movement Model
- Communication Model
- Scenario Characteristics
- Metrics

Metrics

- Packet Delivery Ratio
  - the ratio between the number of packets originated and number of packets received
- Routing Overhead
  - the total number of routing packets transmitted during the simulation (each hop counts)
- Path Optimality
  - the difference between the number of hops a packet took and the length of the shortest path

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delivery ratio - pause time

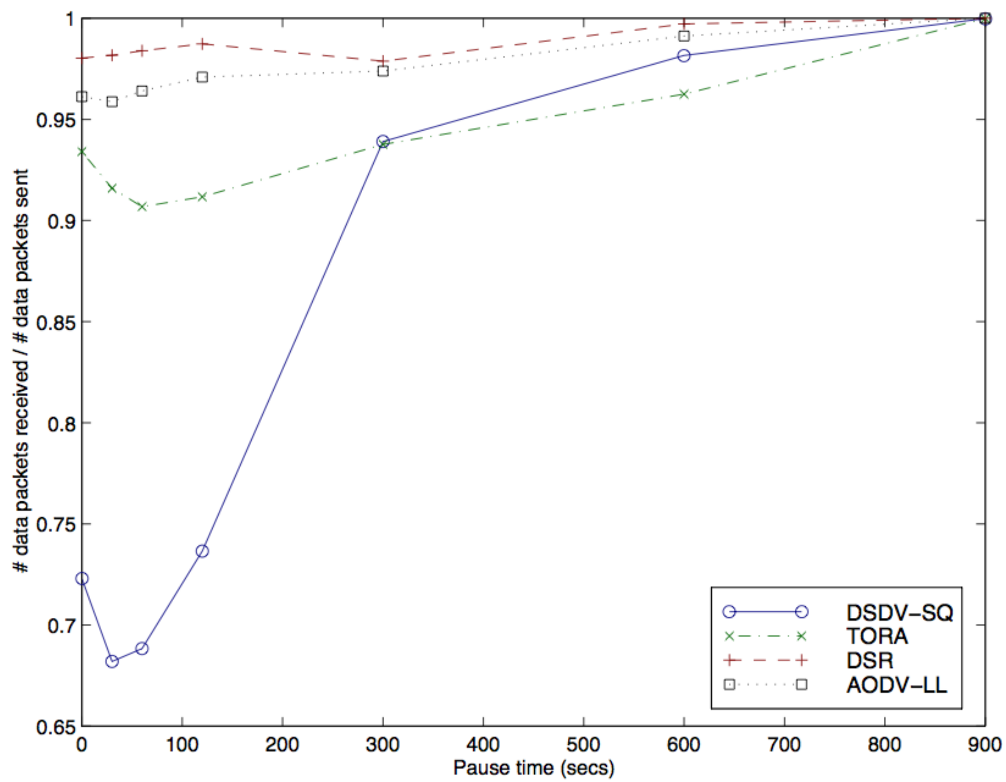


Figure 2 Comparison between the four protocols of the fraction of application data packets successfully delivered (packet delivery ratio) as a function of pause time. Pause time 0 represents constant mobility.

20 sources

overhead - pause time

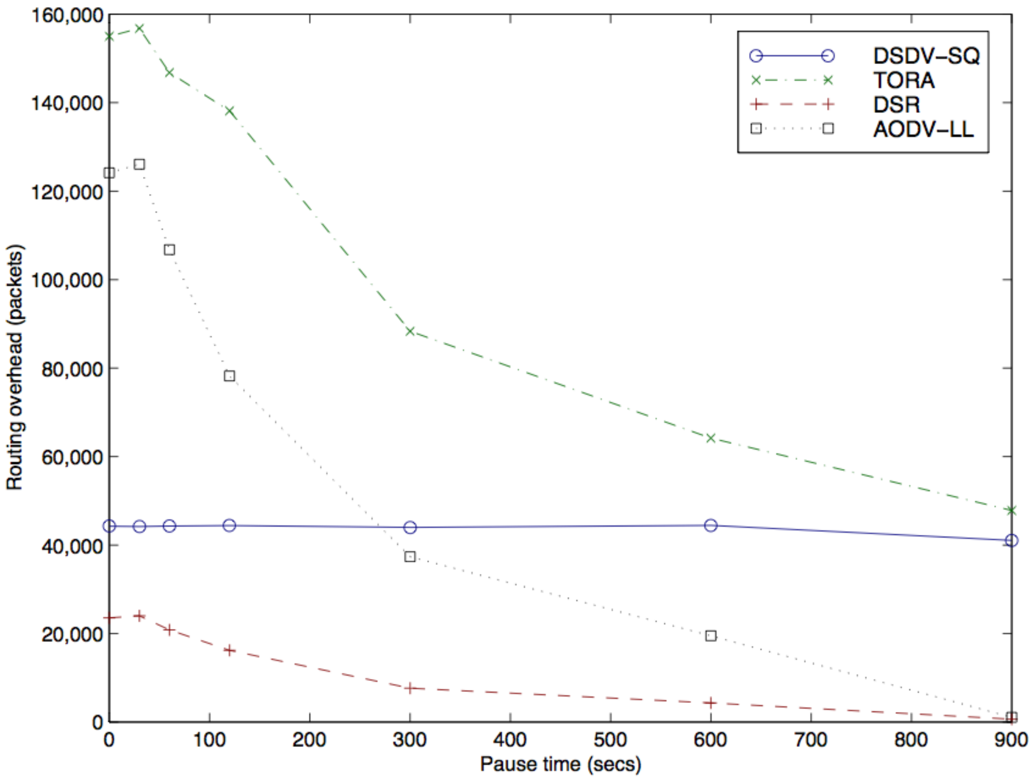


Figure 3 Comparison between the four protocols of the number of routing packets sent (routing overhead) as a function of pause time. Pause time 0 represents constant mobility.

20 sources

delivery ratio - pause time

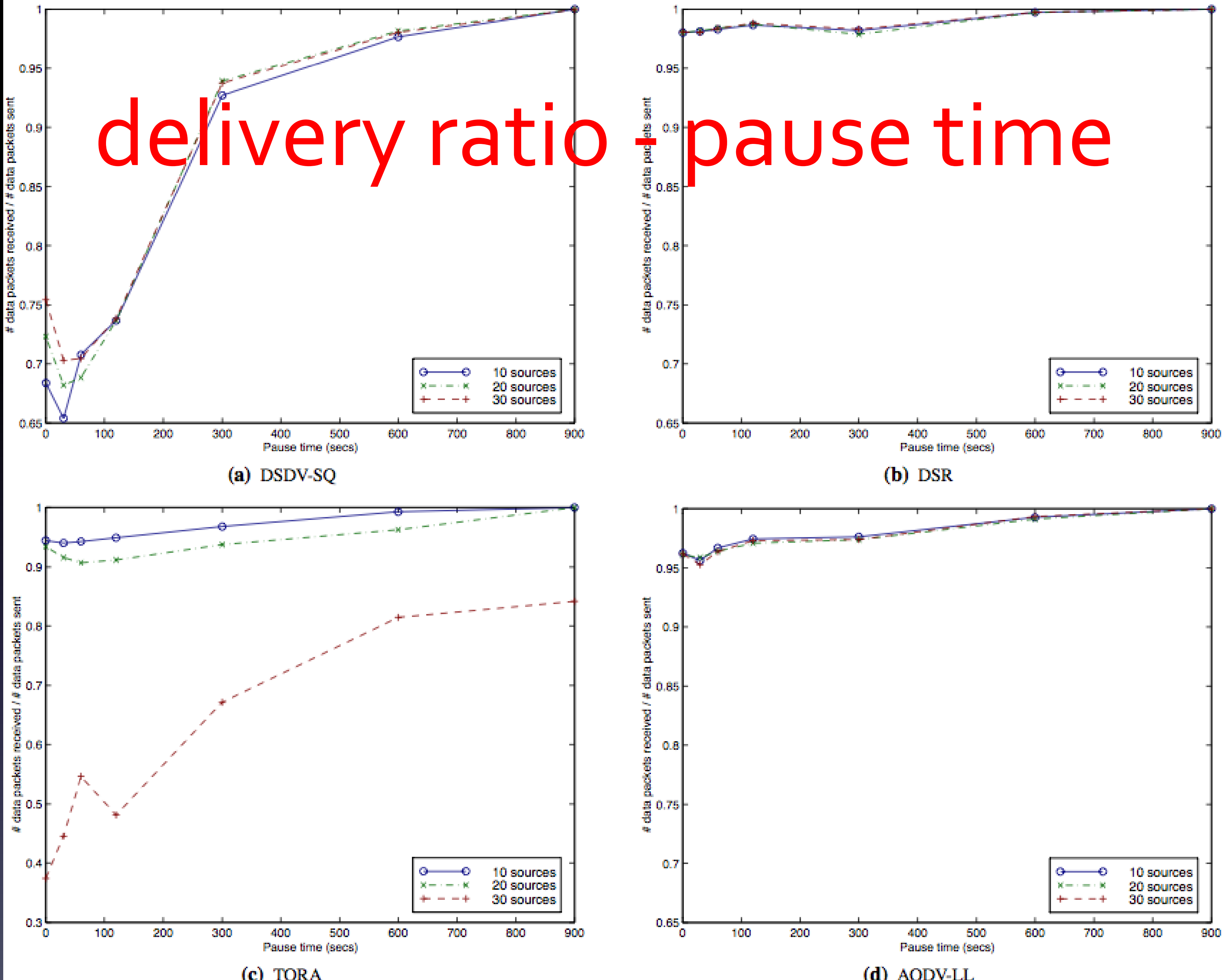


Figure 4 Packet delivery ratio as a function of pause time. TORA is shown on a different vertical scale for clarity (see Figure 2).

overhead – pause time

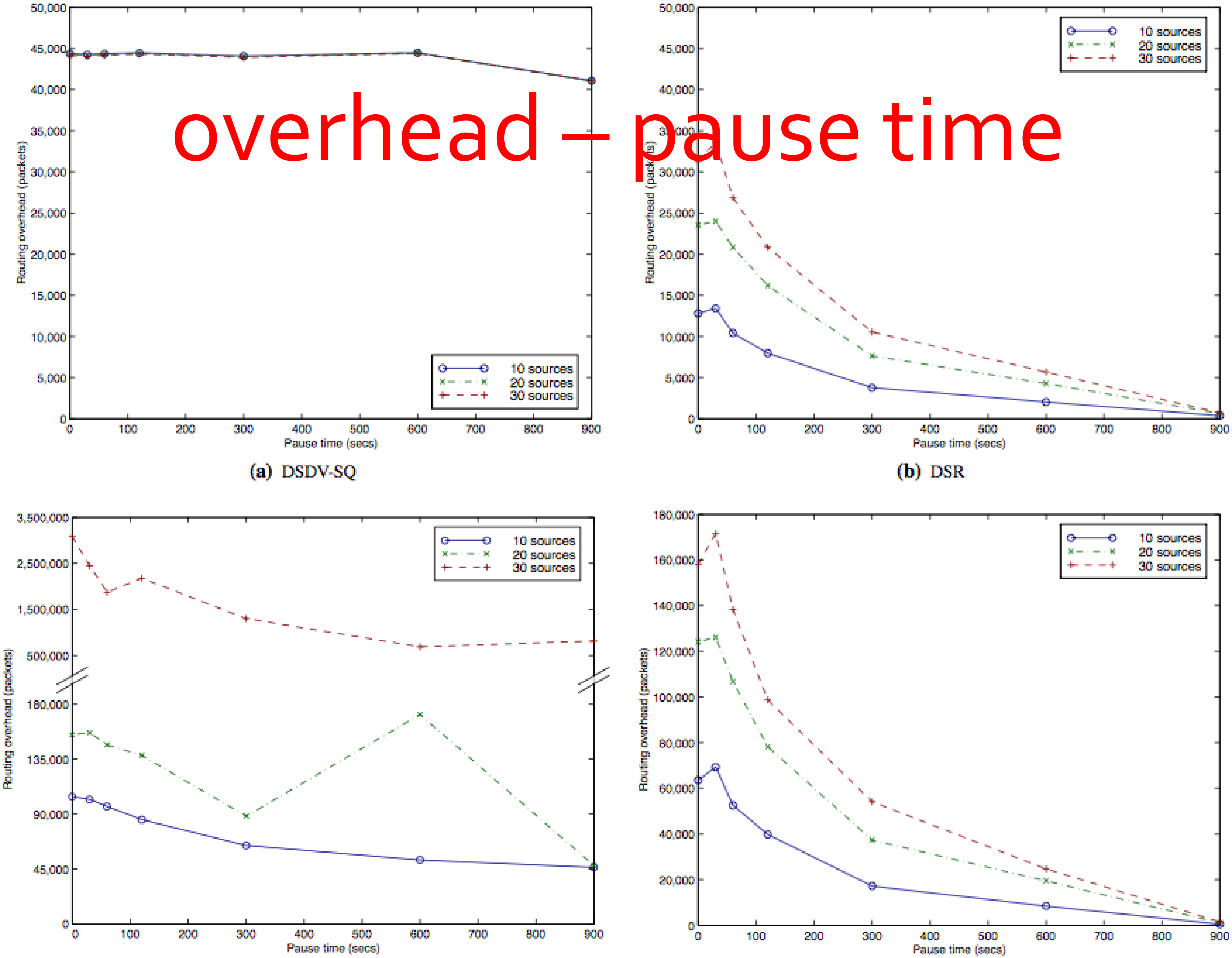


Figure 5 Routing overhead as a function of pause time. TORA and AODV-LL are shown on different vertical scales for clarity (see Figure 3).

difference from shortest

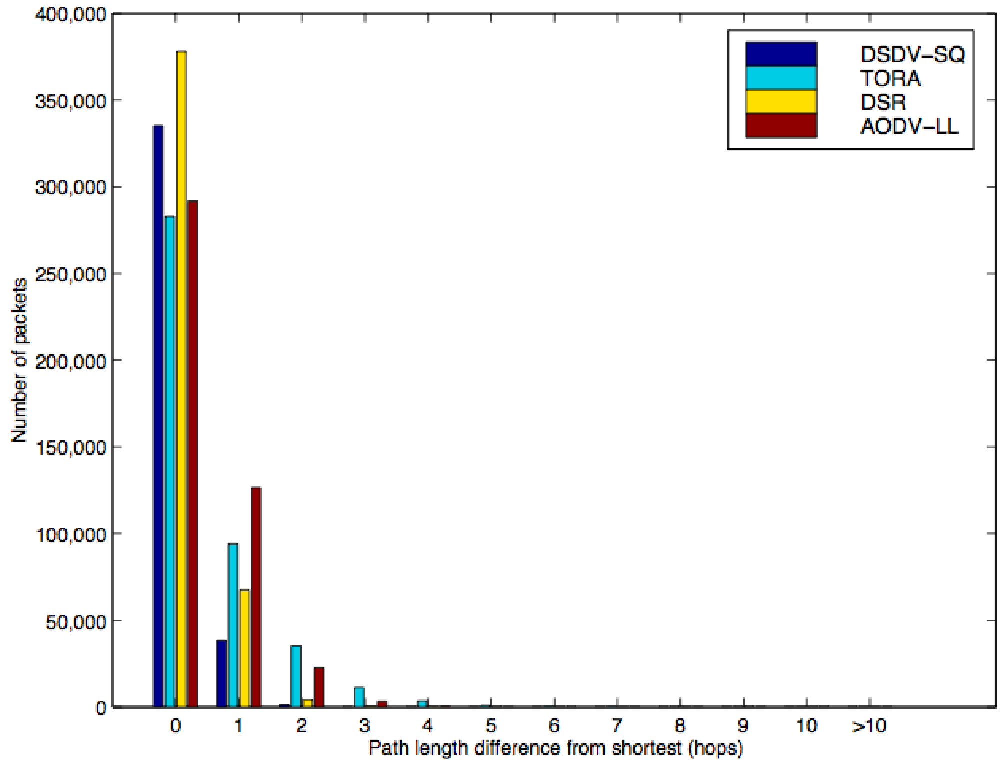


Figure 6 Difference between the number of hops each packet took to reach its destination and the optimal number of hops required. Data is for 20 sources.

20 sources

Lower Speed of Node Movement

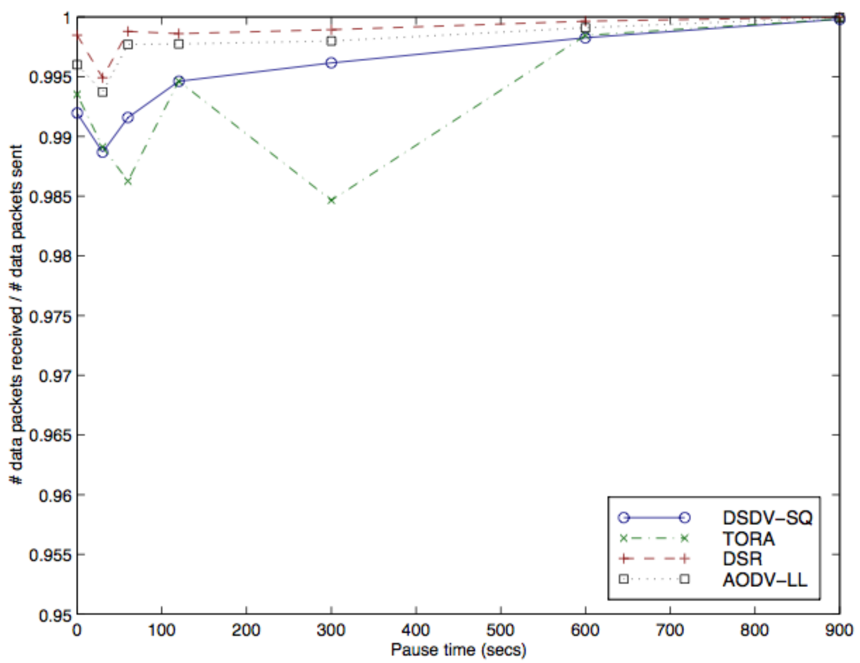


Figure 7 Comparison of the fraction of application data packets successfully delivered as a function of pause time. Speed is 1 m/s.

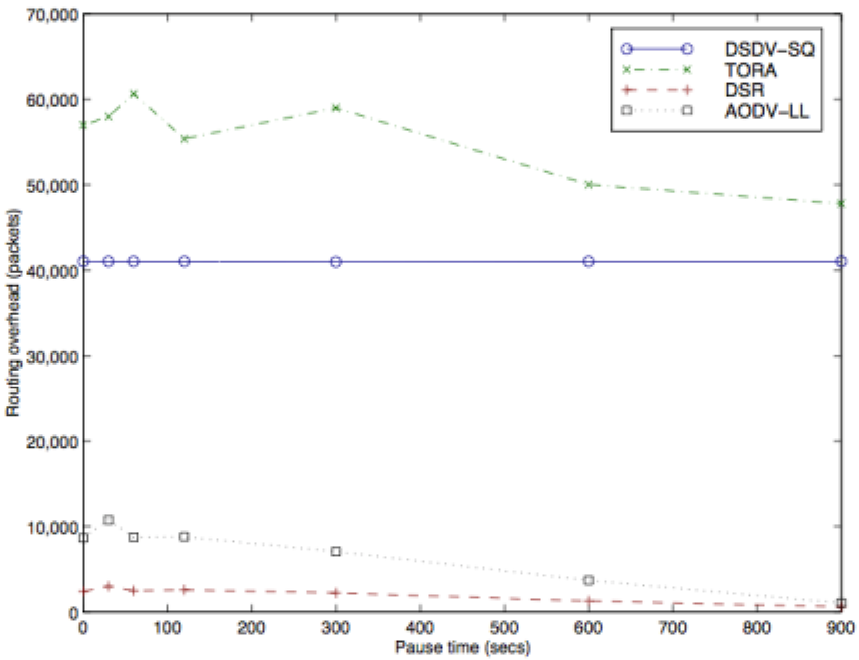
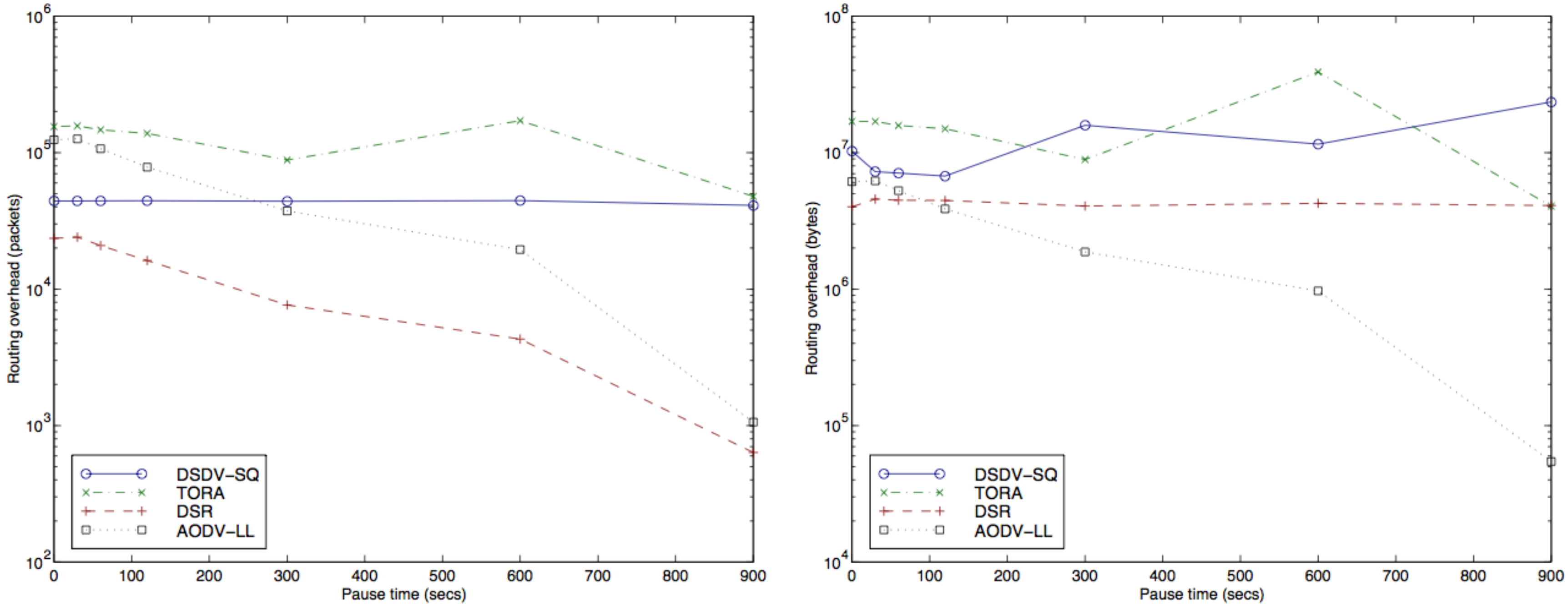


Figure 8 Comparison of the number of routing packets sent as a function of pause time. Speed is 1 m/s.

1 m/s, 20 sources

Overhead in Source Routing Protocols



(a) Routing overhead in packets.

(b) Routing overhead in bytes.

Figure 9 Contrasting routing overhead in packets and in bytes. Both graphs use semi-log axes.

measured in bytes

includes the bytes of the source route header that DSR places in each packet

DSDV vs. DSDV-SQ

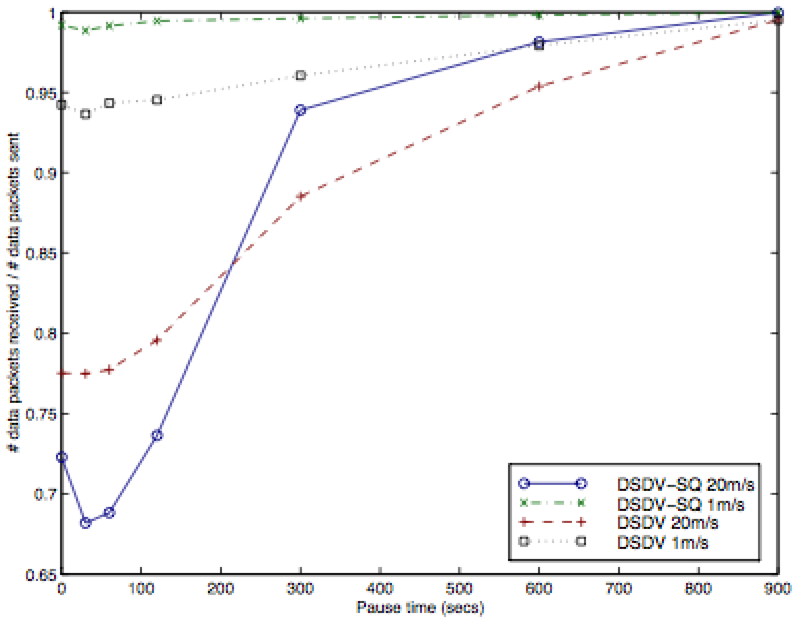


Figure 10 Fraction of originated data packets successfully delivered by DSDV-SQ and DSDV.

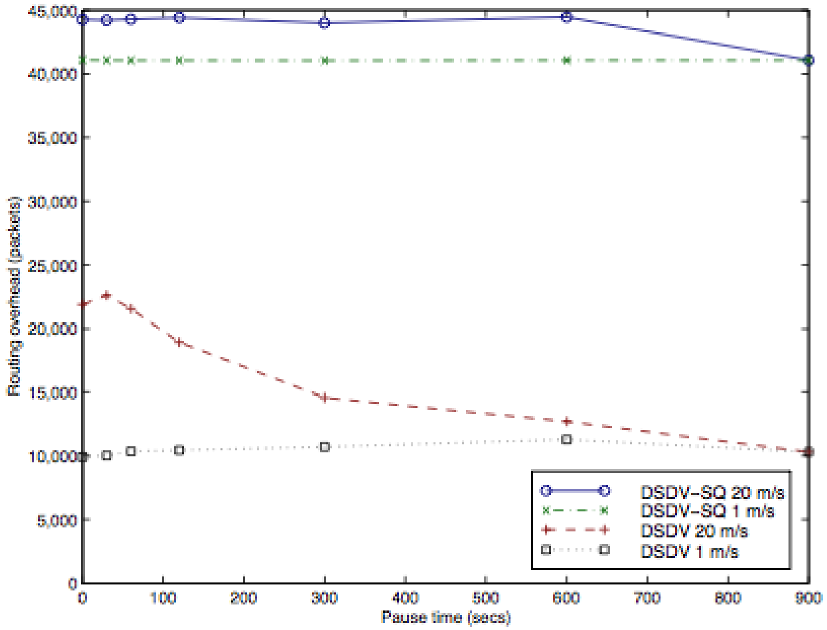


Figure 11 Routing overhead as a function of pause time for DSDV-SQ and DSDV.

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Conclusions

- This paper:
  - provides an accurate simulation of the MAC and physical-layer behavior of the IEEE 802.11 wireless LAN standard with modifications to the ns network simulator. (a powerful tool)
  - detailed packet-level simulation comparing DSDV, TORA, DSR, and AODV
- Each of the protocols studied performs well in some cases yet has certain drawbacks in others.

Conclusions

- DSDV
  - performs quite predictably, delivering virtually all data packets when node mobility rate and movement speed are low
  - failing to converge as node mobility increases.

Conclusions

- TORA
  - the worst performer in routing packet overhead.
  - still delivered over 90% of the packets in scenarios with 10 or 20 sources.
  - at 30 sources, the network was unable to handle all of the traffic generated by the routing protocol and a significant fraction of data packets were dropped.

Conclusions

- DSR
  - very good at all mobility rates and movement speeds.
  - its use of source routing increases the number of routing overhead bytes required by the protocol.

Conclusions

- AODV
  - performs almost as well as DSR at all mobility rates and movement speeds.
  - accomplishes its goal of eliminating source routing overhead.
  - but still requires the transmission of many routing overhead packets and at high rates of node mobility is actually more expensive than DSR.

Brief Conclusions

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

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Q & A

Thanks