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

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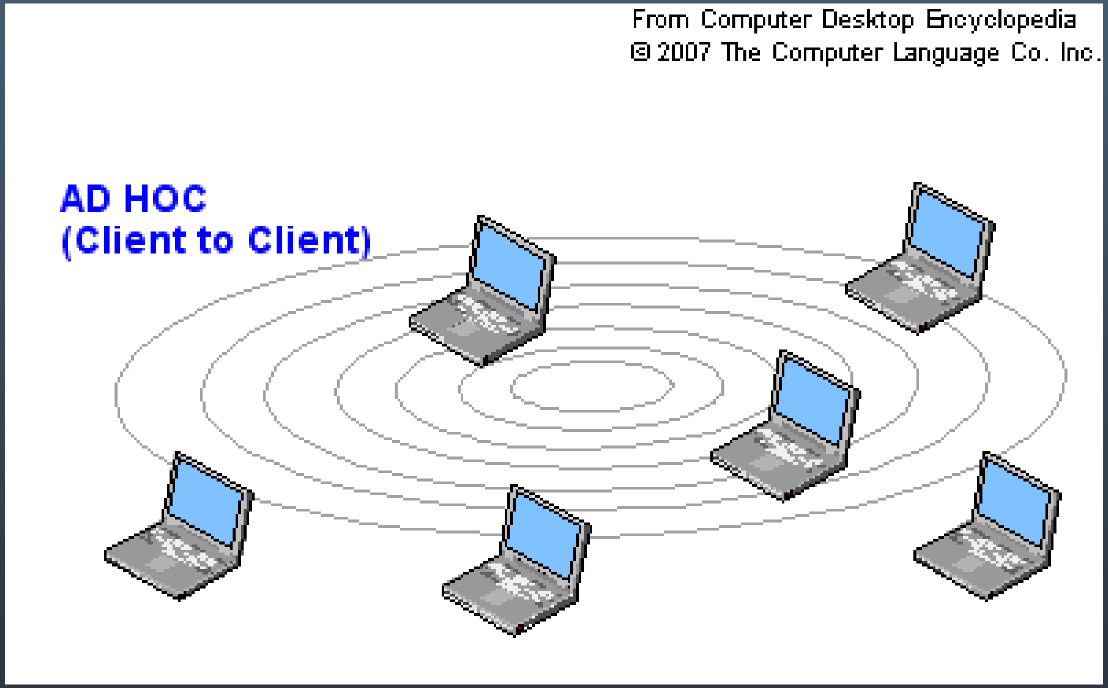
SECTION 1: INTRODUCTION

Introduction

MANET (Mobile Ad-Hoc NETworks)



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SECTION 2: SIMULATOR DETAILS

Simulator: Layers

- Network Layer
  - Routing protocols!
- Data Link Layer
  - MAC sublayer
  - Collisions
- Physical Layer
  - Attenuation
  - Node movement

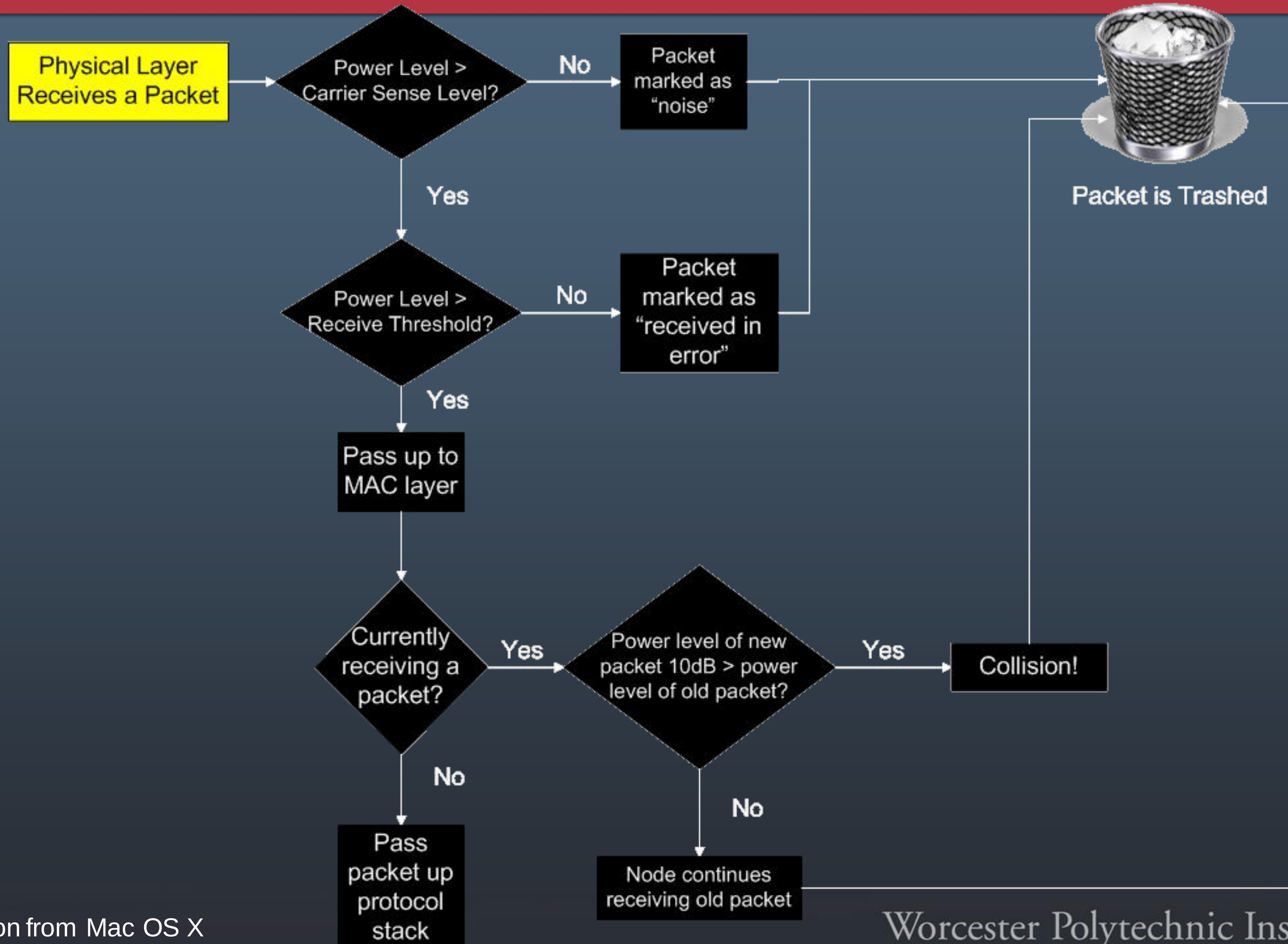
Simulator Details

Physical Characteristics

- Nodes can have:
  - Position
  - Velocity
  - Elevation (not used)

$$Attenuation = \begin{cases} \frac{1}{r^2} \text{ if } r \leq 100m \\ \frac{1}{r^4} \text{ if } r > 100m \end{cases}$$

Simulator: Receiving a Packet



Trash icon from Mac OS X

Simulator: Sending a Packet

Uses **DCF** (**D**istributed **C**oordination **F**unction)

- Physical Carrier Sense
- Virtual Carrier Sense **RTS**/**CTS** (**R**equest-**T**o-**S**end/**C**lear-**T**o-**S**end)
- Positive Acknowledgement
- Broadcast packets are special
  - Waits for physical/virtual channel to be clear
  - Not preceded by a RTS/CTS

Simulator Details

- IP addresses used at network layer
- ARP used to translate MAC addresses to IP addresses
  - ARP requests are **broadcast**
- NIC has a 50 packet drop-tail buffer
  - **On Demand** protocols have an additional 50 packet buffer

SECTION 3:
ROUTING PROTOCOLS

Routing Protocols

Tested Four Routing Protocols:

- DSDV
- TORA
- DSR
- AODV

Routing Protocols

General improvements for all protocols:

- Periodic broadcasts/broadcast responses delayed randomly from 0-10 milliseconds
- Routing packets inserted **first** in NIC buffer!
  - Other types of packets (ARP, data) queued at the end of buffer
- Used MAC layer link breakage detection
  - Not used in DSDV

Destination-Sequenced Distance Vector (DSDV)

- Hop-by-hop distance vector protocol
- Loop freedom!
- Each node has a sequence number
- Routes on routing table:
  - Next hop to destination
  - Sequence number of destination
  - Metric

DSDV: Sequence Numbers

- Nodes advertise even sequence numbers
  - Numbers ***increase*** over time
- Greater sequence numbers = newer data
  - Route with greatest sequence number is used
  - Ties determined by metric
- ***Odd*** sequence number advertised for broken routes with infinite metric
  - Bad news will travel fast
  - Link Layer link breakage not needed

DSDV: Flavors

DSDV-**SQ** (Used for paper results)

- New **s**e**q**uence numbers trigger updates
- Broken links detected faster
  - Increases packet delivery ratio
- More overhead

DSDV

- New metrics trigger updates
- Less overhead
- Broken links not detected as fast
  - Decreased packet delivery ratio

Temporally-Ordered Routing Algorithm (TORA)

- Distributed routing protocol based on "link reversal" algorithm
- Quickly discover routes **on demand**
- Algorithm focused to minimized communication overhead

- Layered on **IMEP (Internet MANET Encapsulation Protocol)**
  - Provides reliable and in-order control message delivery
  - Periodic BEACON / HELLO packets

TORA Mechanisms

- Links between each nodes measured in “heights”
- Direction of link goes from **higher** → **lower** heights
- As the nodes move, the heights between each node changes, causing new routes

- Node sends a QUERY with destination address
- UPDATE sent back from destination or intermediate node
  - Contains height from node to destination
- Each node receiving UPDATE sets its height greater than neighbor it received from
- Creates a graph of directed links from source to destination

TORA Implementation Decisions

- IMEP queues objects to allow aggregation
  - Reduce overhead
  - Only aggregate HELLO and ACK packets

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

Constants were chosen through experimentation

Dynamic Source Routing (DSR)

- Uses *source routing* instead of hop-by-hop routing
  - Each packet carries complete route in header
- Designed for multi-hop wireless ad hoc networks

- **Advantages:**
  - Intermediate nodes do not need to maintain up-to-date routing information
  - Eliminates need of periodic route advertisements
  - Eliminates need of periodic neighbor detection

- Requires two mechanisms: **Route Discovery** and **Route Maintenance**

DSR Route Discovery

- Node looking for route broadcasts ROUTE REQUEST
  - Packet is *flooded* through network
- ROUTE REPLY sent back from destination or intermediate node
- Each node maintains cache of routes
- Source route put in header

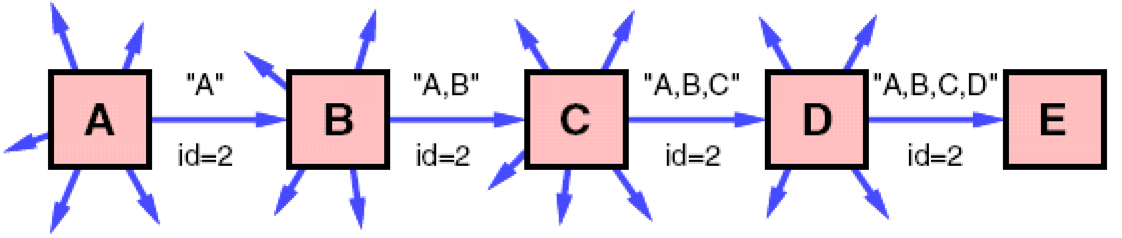


Figure 1: Route Discovery example: Node **A** is the initiator, and node **E** is the target.

DSR Route Maintenance

- Used to detect change in network topology causing route to fail
- Node is notified with ROUTE ERROR packet
  - Uses valid route from cache
  - Invoke Route Discovery

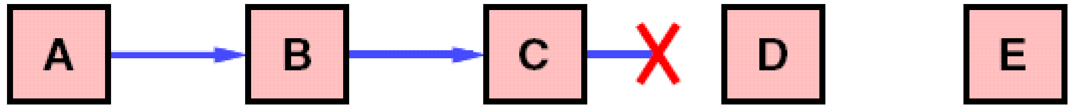


Figure 2: Route Maintenance example: Node **C** is unable to forward a packet from **A** to **E** over its link to next hop **D**.

DSR Implementation Decisions

- Required use of *Bidirectional* links
  - ROUTE REPLY uses reverse of ROUTE REQUEST route
- Nodes listen to all packets
  - Hear ROUTE ERROR packets
  - Used to cache additional routes
  - Create potentially better routes

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

Ad-Hoc On Demand Distance Vector (AODV)

- Combination of DSR and DSDV
- Broadcasts ROUTE REQUEST
- Receives ROUTE REPLY with routing information
- Nodes remember only the next hop
- HELLO msgs maintain link state

AODV Implementation

- Removed HELLO messages
  - Added link layer feedback
  - Called AODV-LL
- Shorter timeout for ROUTE REQUEST

SECTION 4:
TESTING & RESULTS

Methodology

- Simulated network
  - Took scenario files as input
  - 210 total scenario files
- 50 wireless nodes
- Flat rectangular area (1500m x300m)
- 900 seconds test time

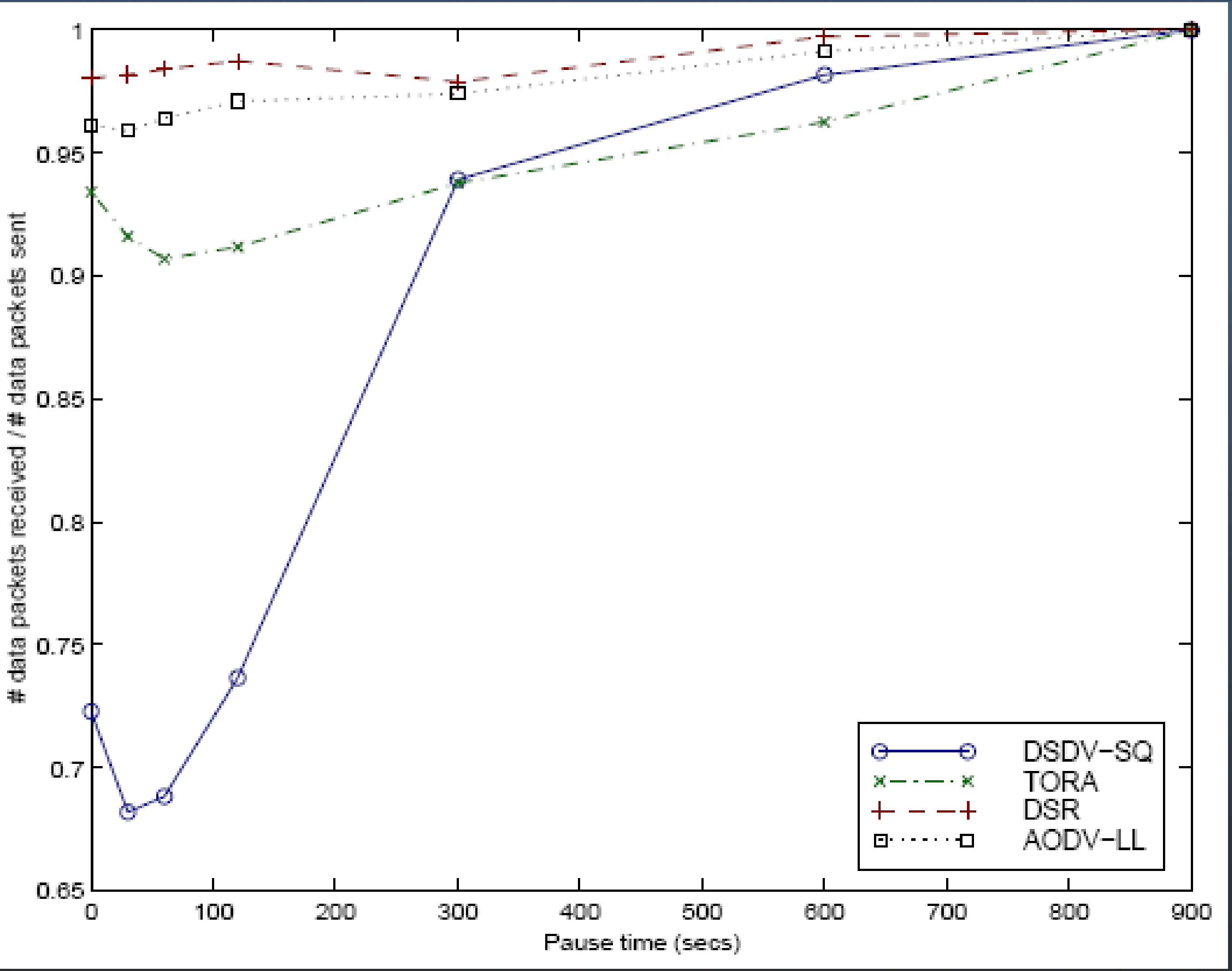
Movement Model and Communication

- 7 different pause times
- Nodes moved with a speed from 0-20m/s
  - Also use simulations with max 1m/s for comparison
- Networks contained 10,20,30 CBR sources
  - Did not use TCP
- 4 packets per second
- 64 byte packets
- Connections started uniformly between 0-180s

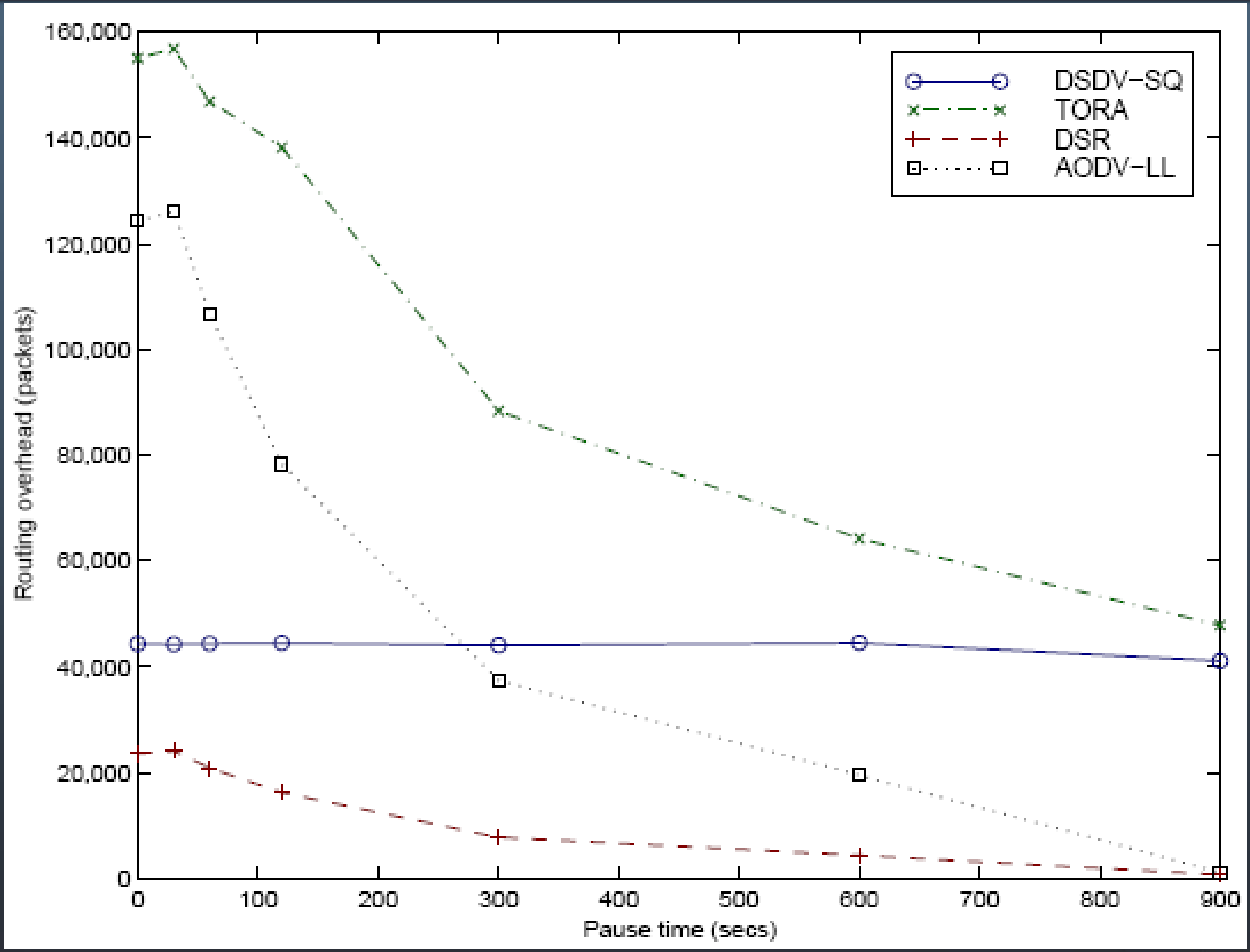
Metrics

- Packet Delivery Ratio
  - Loss rate of transport protocols
- Routing Overhead
  - Measures scalability
- Path Optimality
  - Effective use of network resources

Packet Delivery Ratio
(function of pause time)



Routing Packets Sent
(function of pause time)



Packet Delivery Ratio

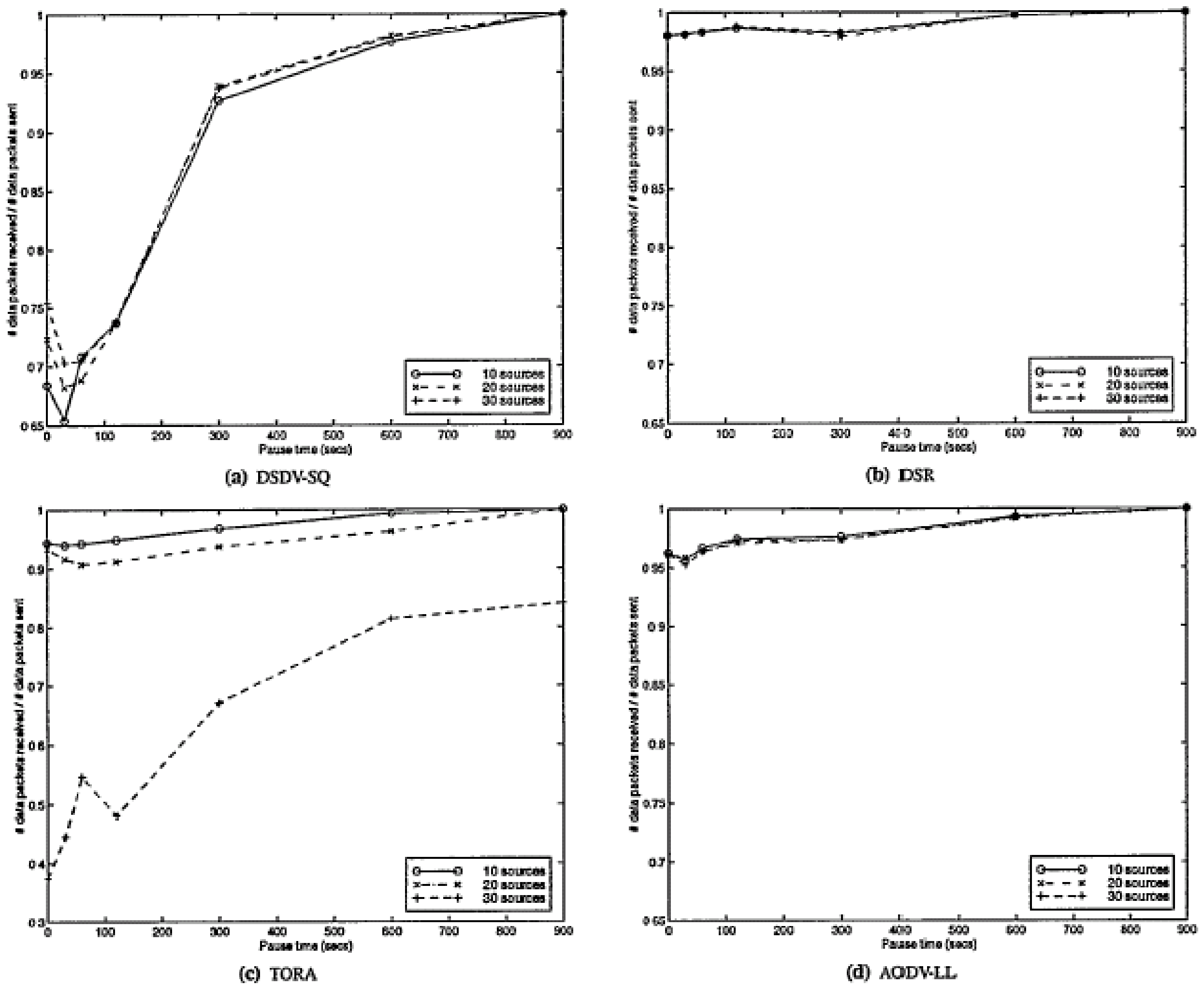


Figure 4 Packet delivery ratio as a function of pause time. TORA is shown on a different vertical scale for clarity (see Figure 2).

Routing Overhead

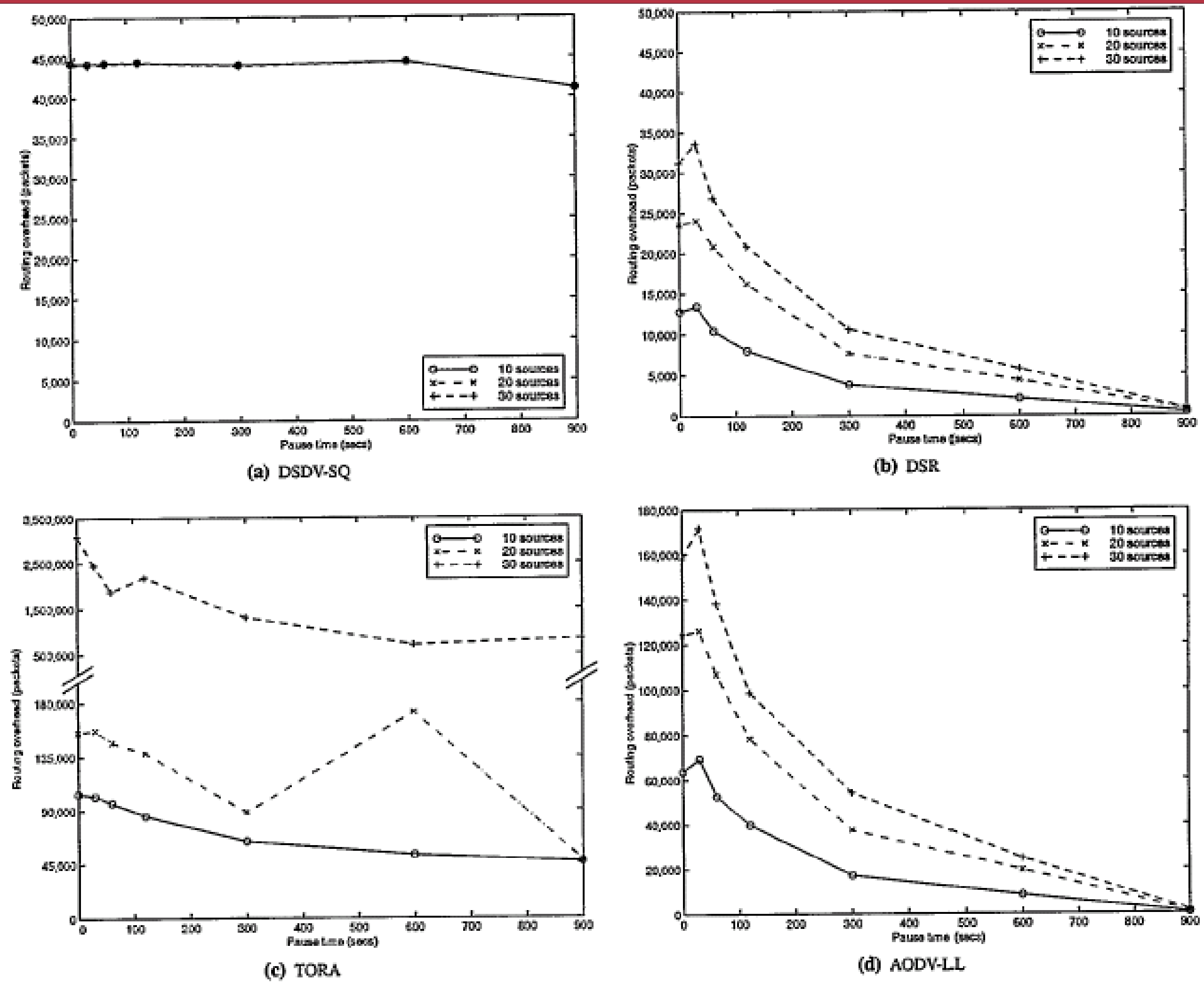
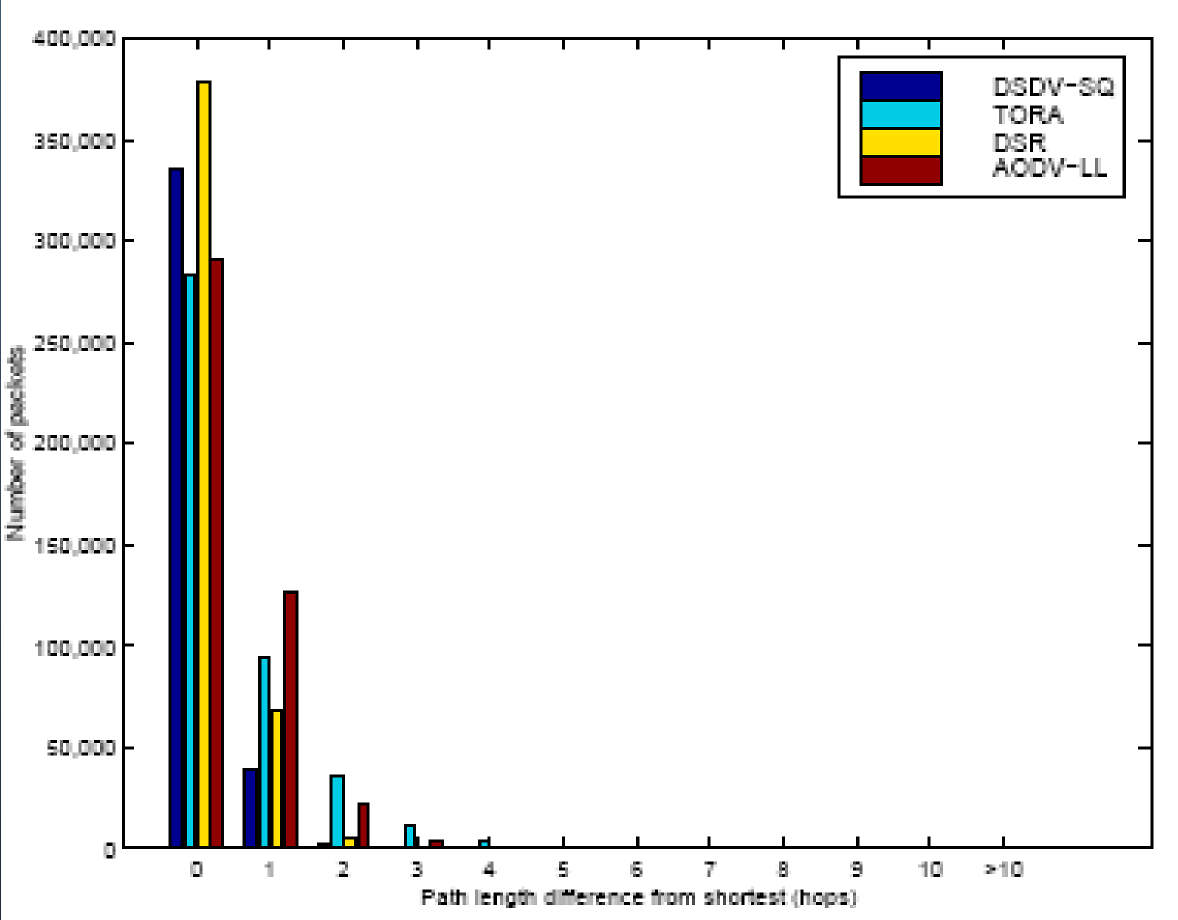


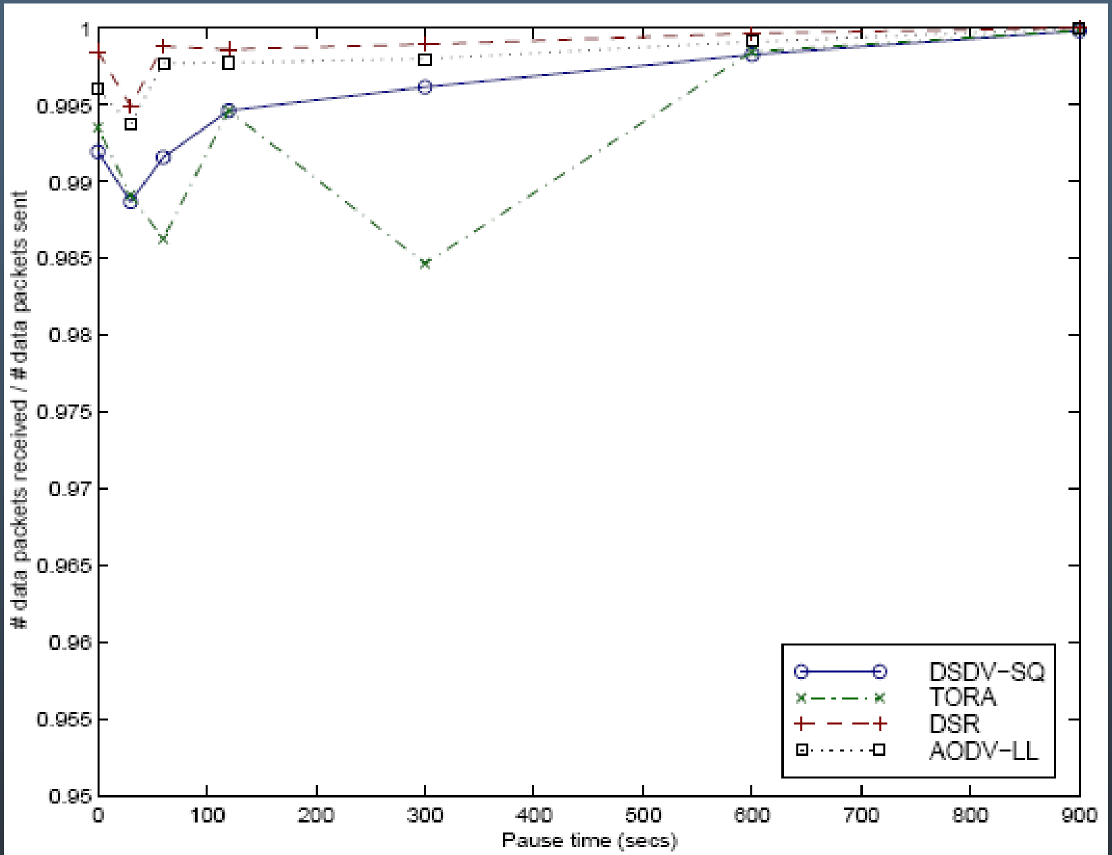
Figure 5 Routing overhead as a function of pause time. TORA and AODV-LL are shown on different vertical scales for clarity (see Figure 3).

Path Optimality Details



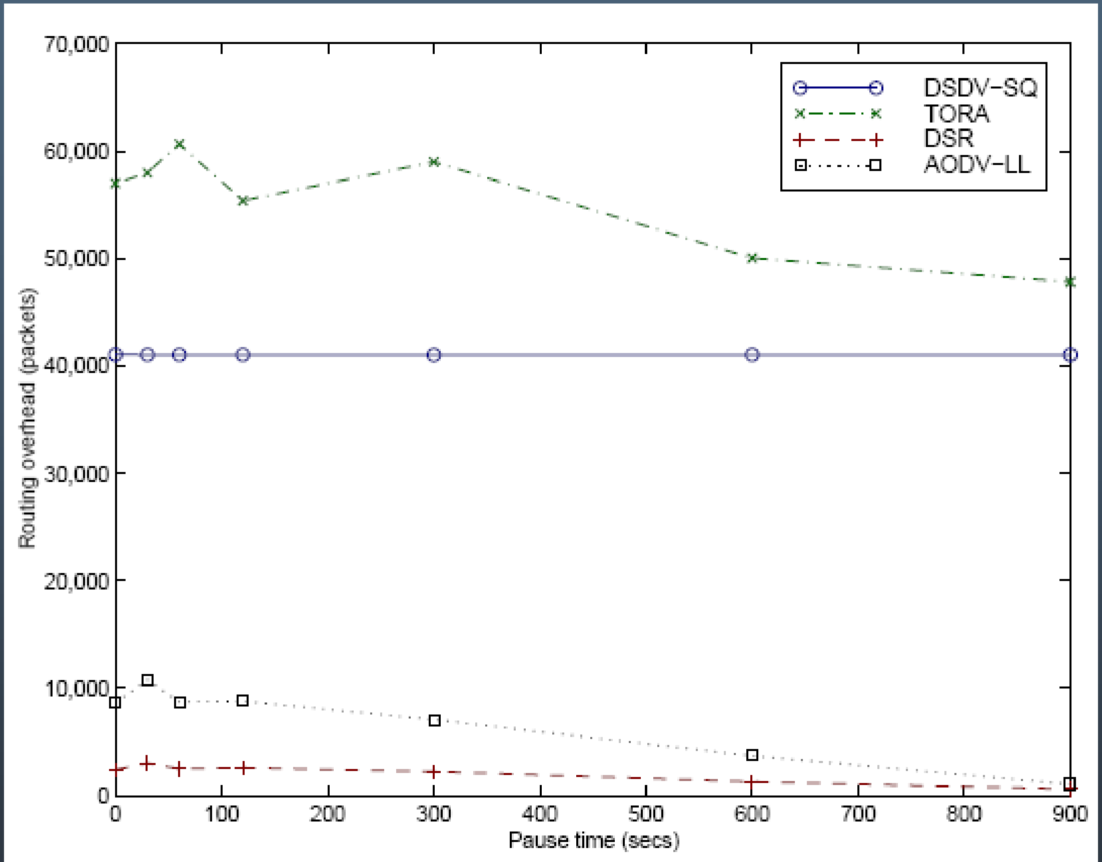
- DSR and DSDV-SQ close to optimal
- Doesn’t take into account pause time

Lower Speed of Node Movement



"application" data successfully delivered as a function of pause time (packet delivery ratio)

Lower Speed of Node Movement



Routing packets sent as a function of pause time (routing overhead)

Conclusions

- *ns* network simulator can now evaluate ad-hoc routing protocols
- DSDV
  - Good with low mobility.
- TORA
  - Large overhead; fails to converge with 30 sources
- DSR
  - Very good at all rates + speed, but large packet overhead
- AODV
  - Almost as good as DSR, but has more transmission overhead

Acknowledgements

- Thanks to Professor Kinicki for the colored graphs.

Questions?