RoMR: Robust Multicast Routing in Mobile Ad-Hoc Networks

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Outline

- About the Dissertation
- Introduction
- Review of Ad-Hoc Routing Protocols
- ROMR Architecture
- ROMR Link Availability
- Simulation Results
- Conclusions

Next . . .

- **About the Dissertation**
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The Dissertation

- Title:
  - *"RoMR: Robust Multicast Routing in Mobile Ad-Hoc Networks"*
- Author:
  - Lynn, Gretchen H.
- URL:
  - http://etd.library.pitt.edu/ETD/available/etd-12152003-093515/

The Goal

- To develop a multicast protocol to deliver the multicast with high degree of reliability in a dynamic multicast group in a mobile ad hoc network
- The protocol should be able to adapt to a variety of circumstances
  - Proactive Components
    - To anticipate the future events
  - Reactive Components
    - To deal with events that have not been foreseen
- The protocol should use the network resource efficiently

Challenges

- There are three source of challenges
  - Network-centric challenges
    - Infrastructureless network
  - Device-centric challenges
    - Limited transmission range, memory, storage, and power
  - Medium-centric challenges
    - Limited bandwidth, interference and packet collision
  - Challenges due to the "*Multicasting Problem*"
    - Complex problem

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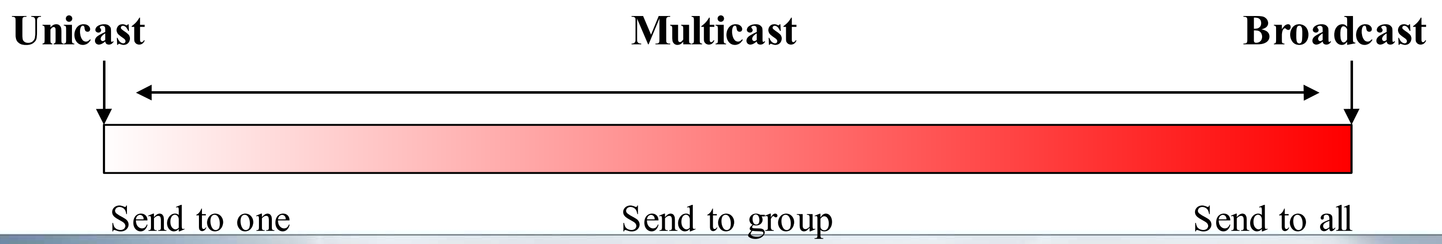
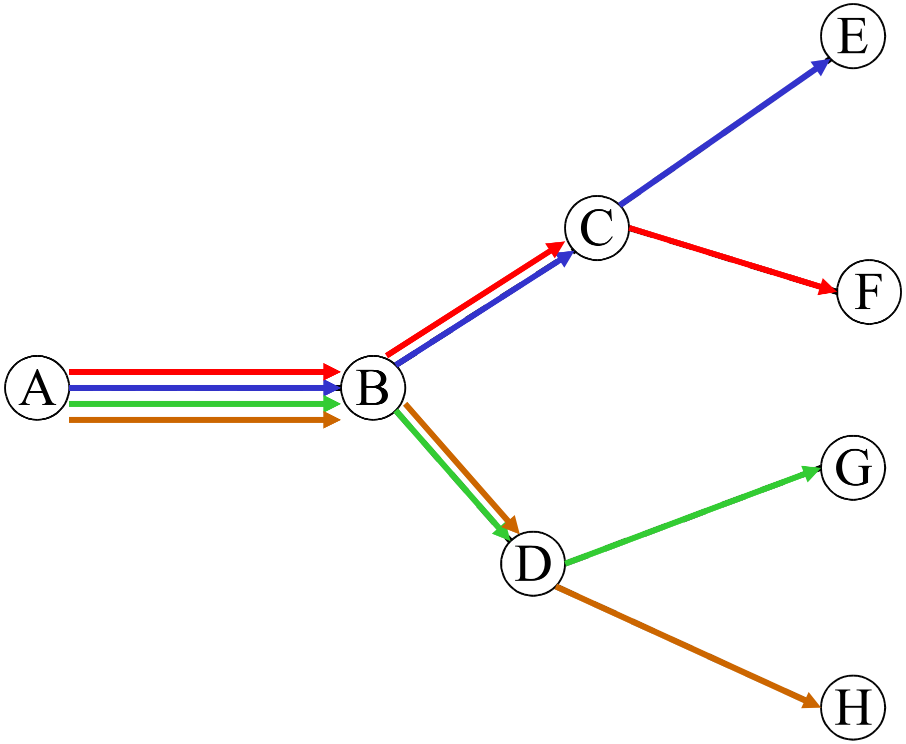
Communications Categories

- Based on the number of senders and receivers, communications can be categorized into:
  - Unicast
    - One-to-One communication
  - Broadcast
    - One-to-All communication
  - Multicast
    - One-to-Many communication
    - Many-to-Many communication



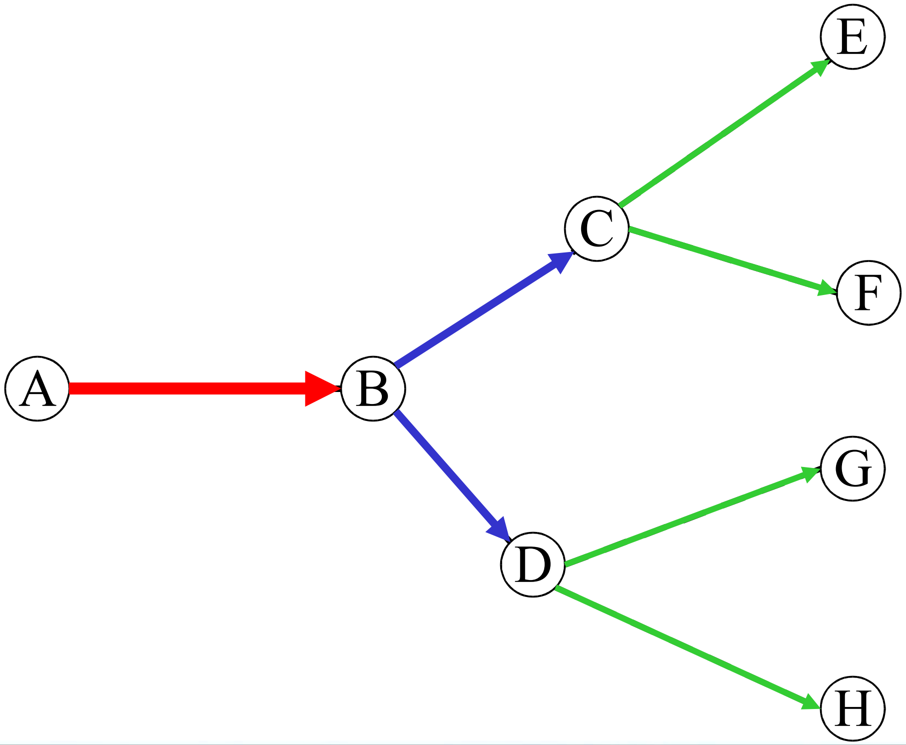
Basic Multicasting Techniques (1/3)

- Node A sends a message for every individual node
  - Intermediate nodes do not keep any copy of the routed message
  - Link A-B carries 4 copies of the message
  - 12 messages has been transmitted over the individual links



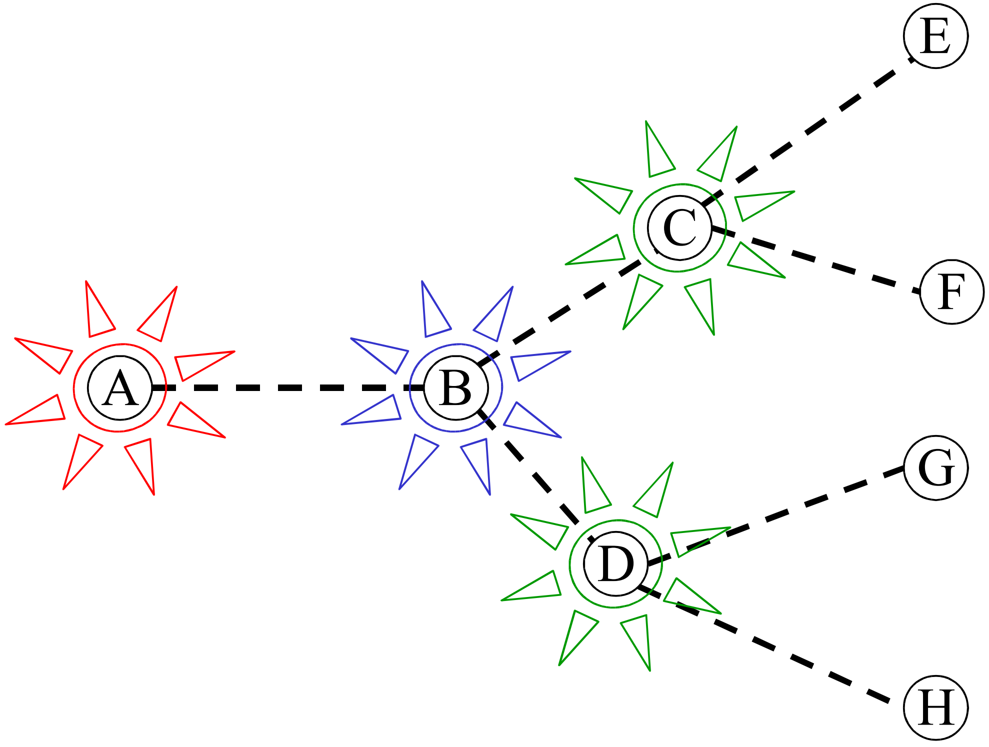
Basic Multicasting Techniques (2/3)

- Each node forwards a copy of the incoming message to the receivers
  - Assuming that intermediate nodes keep a copy of the routed message
  - Total number of transmitted message is 7
  - Each link carries one copy of the message



Basic Multicasting Techniques (3/3)

- Send multiple messages in one transmission burst . . .
  - Assuming that multiple nodes can receive a message as long as each is in the transmission range of the sender
  - Total number of transmitted message is 4



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Classification of Routing Protocols

- Table-Driven (Proactive) Protocols
  - Maintain current information on all reachable destinations
  - Nodes are required to maintain one or more tables for routing information

- On-Demand (Reactive) Protocols
  - When route is needed
    - Route Discovery
    - Route Maintenance

Table Driven Routing

- Referred to as "Proactive Routing"
- Maintain current information on all reachable destinations
  - Nodes are required to maintain one or more tables for routing information
  - Tables are exchanges between nodes
- Pros.
  - Routing info is immediately available
- Cons.
  - Requires periodic updating of routing tables

On-Demand Routing

- Referred to as “Reactive Routing”
- When a route is needed
  - Route Discovery
  - Route Maintenance
- Pros.
  - Less overhead to discover the needed routes
- Cons.
  - Longer delay in getting packets to the destination

Source Routing Routing

- Lists each hop to the path in the packet header
- Requires no information to be kept in the nodes

- Pros.
  - Less overhead to the intermediate nodes
- Cons.
  - Larger packet size

Link State Routing

- Each node in the network maintains a database describing the network topology
- Message are regularly exchanged between neighbors to determine the local neighborhood

- Pros.
  - Routing decisions can be made easily
- Cons.
  - High amount of information is exchanged between nodes

Distance-Vector Routing

- Keeps the distance to reachable nodes in order to determine the next hop
- Pros.
  - Only next hop information is passed between nodes
- Cons.
  - Only one route is known from a node to each of the accessible nodes instead of the entire or localized topology

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Multicasting and OSI Model

Multicasting Applications:
The applications that rely on the multicast network services to establish and maintain communication

Multicasting Session:
Keeping track of multicasting groups

Multicasting Transport:
TCP is not adequate to support multicasting because of the acknowledgements. UDP is widely used for multicasting

Multicasting Network Layer:
Multicast group addressing

Multicasting and Data Link Layer:
IP is used.
ATM and Frame-relay are not adequate to for multicasting

Multicasting Physical Layer:
Not affected.

ROMR Efficiency Techniques

- ROMR address efficiency in two ways
  - ROMR waits until the number of intact trees reaches a threshold before recalculating and redistributing the trees
    - Reduces the number of tree set packets that must be distributed
  - ROMR uses Forward Error Correction (FEC) to encode *k* packets from the sender as *n* packets where n is the number of multicast trees
    - The receiver needs to receive any k of the packets

ROMR Parameters

- The actual number of trees created is a function of
  - The specified reliability level
  - The topology of the network
- Three values have to be specified
  - *Minimum Number of Trees* to be formed *(*μ*)*
  - The *Reliability Threshold (*τ*)*
  - *Link Reuse Factor (*ρ*)*

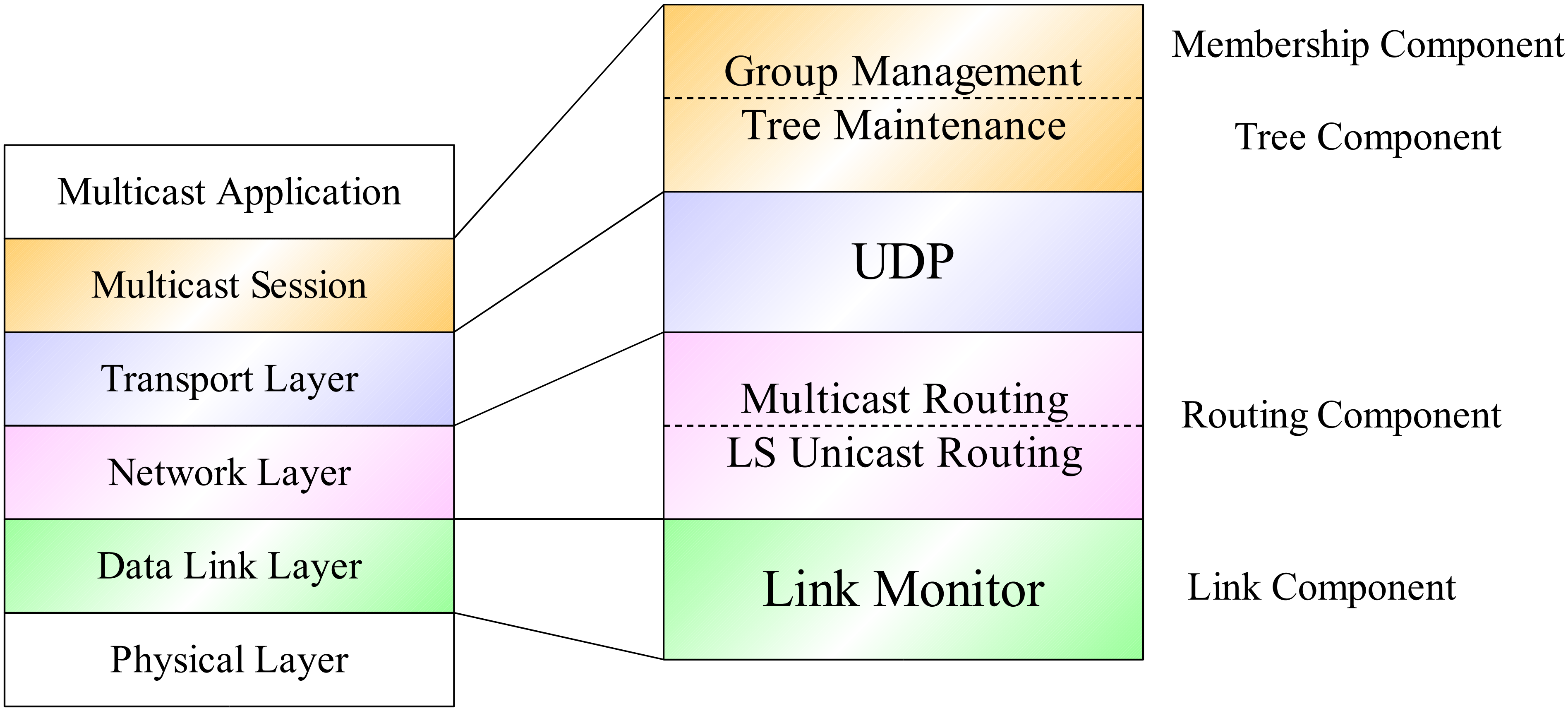
ROMR Reliability Level

- The desired reliability level can be set using the following parameters
  - Reuse Factor (RF)
    - The percentage of links in a tree that are eligible to be used in the next tree (0 < RF < 1)
      - RF = 0 ➔ disjoint trees ➔ increasing the use of network resources
  - Weight Threshold (WT)
  - Minimum Number of Tress

ROMR Group Management

- Group Types
  - Open Group
    - Non-members may send messages to the group members
  - Closed Group
    - Restricted to only the members of the group
- Joining and Leaving
  - Nodes are allowed to join or leave the group
- Group Destruction
  - Can be executed by the group owner

ROMR Layered Architecture



ROMR Link Component

- Monitors the strength of the radio signal from neighboring nodes
- Determines the weights associated with adjacent links
- The probability that the link will exist during the next time interval given that it existed in the most recent time interval

ROMR Tree Component

- ROMR computes multiple multicast trees that may be interconnected through the sharing of reliable links
- Maintains the trees as the group membership and network topology changes
- The target is to have a set of *n* possibly interconnected multicast trees connecting a single source to a set of receivers
- Tree Component determines two values
  - *n*: the number of trees to be created
  - *k*: to be used in *(n,k)* encoding scheme

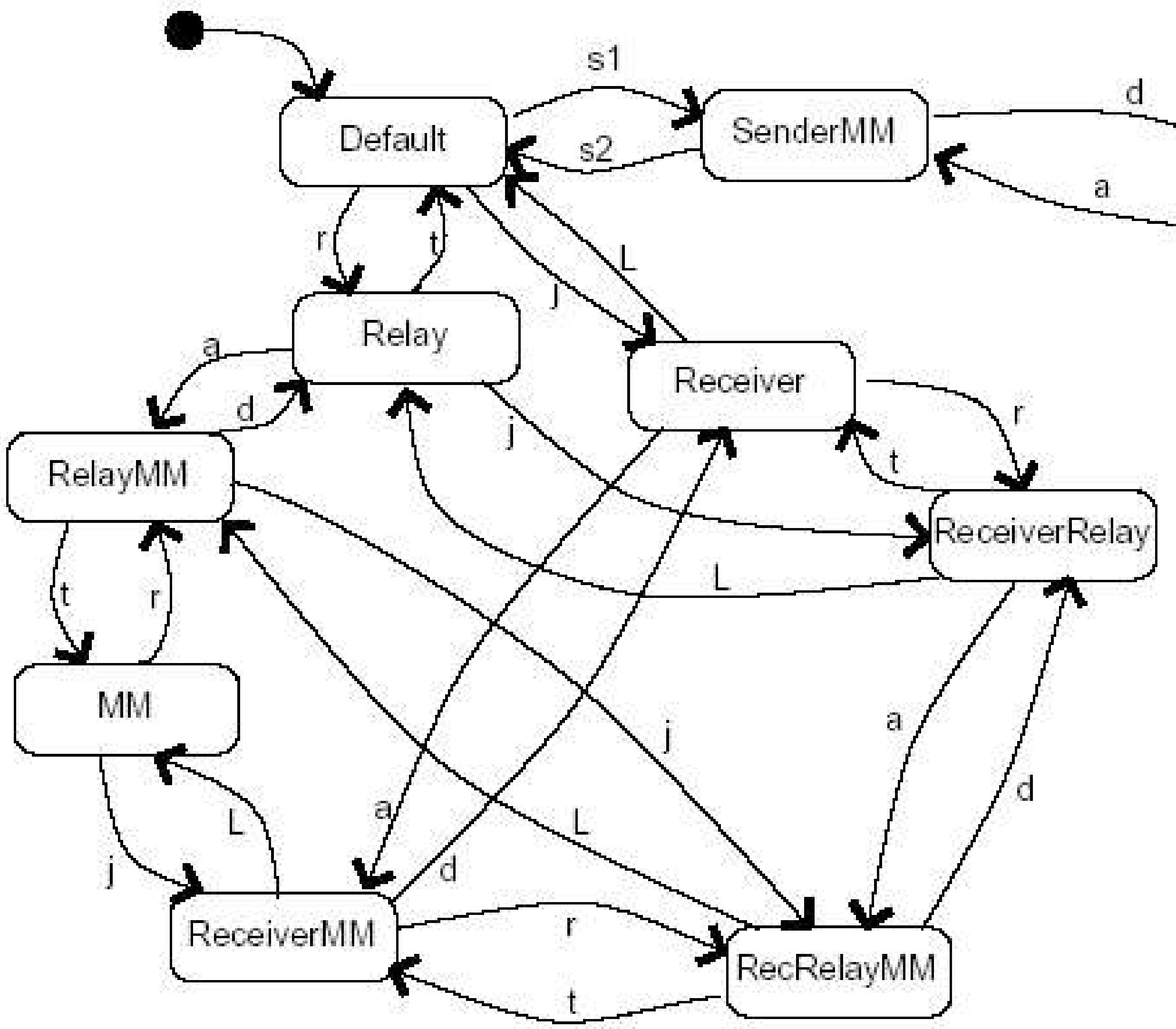
ROMR Routing Component

- Has two complementary parts
  - Process packets that come from upper layers addressed to the group address
    - Buffers *k* of the packets addressed to the group
    - Applies *(n,k)* FEC before sending the n encoded packets to MAC layer
  - Examine the data packets that are received from the MAC layer from another node
    - If the nodes is Relay node
      - then it forwards the packet
      - Caches the sequence number to prevent routing loops
    - If the node is a group member
      - Buffers incoming packets addressed to group until k packets have been received
      - Decodes the packets and passes them to the upper layer

ROMR Membership Component

- Services the join and leave requests
- Keeps the tree component informed of the current membership lists
- The major duty of the Multicast Manager (MM) node
- The MM duties can be handed over to another node
- Any node may join the group by contacting the MM
- The MM address can be looked up from the DNS (or similar registration system)

Node States (1/2)



Events:
a: accept MM duties
d: delegate MM duties
j: join the group
L: leave the group
r: get tree packet designating node as relay
s1: start the session
s2: stop the session
t: relay time out

Node States (2/2)

- Node Basic States
  - Default
    - The node is not associated with a multicast group in any way
  - Multicast Manager
    - The node is responsible for performing the duties of two components
      - Tree component
      - Membership component
  - Sender
    - Source node
  - Receiver
    - Detect the duplicate pacekts
    - Decode the received packet
  - Relay
    - Intermediate nodes

Composite States

- Sender + Multicast Manager
- Receiver + Multicast Manager
- Relay + Multicast Manager
- Receiver + Relay
- Receiver + Relay + Multicast Manager

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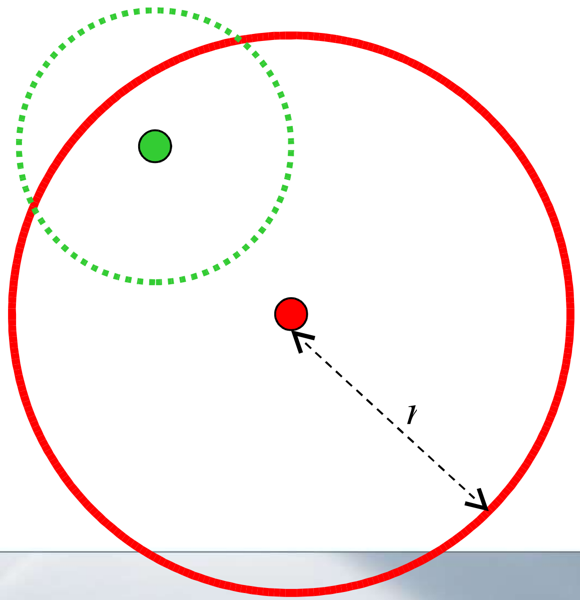
ROMR Link Availability

- The ROMR approach
  - A node computes the area in which a neighboring node is likely to be in the near future
  - The node examines the portion of that area which overlaps the transmission range of itself
  - A weight is assigned to the link is the ratio of the overlap area to the possible location area



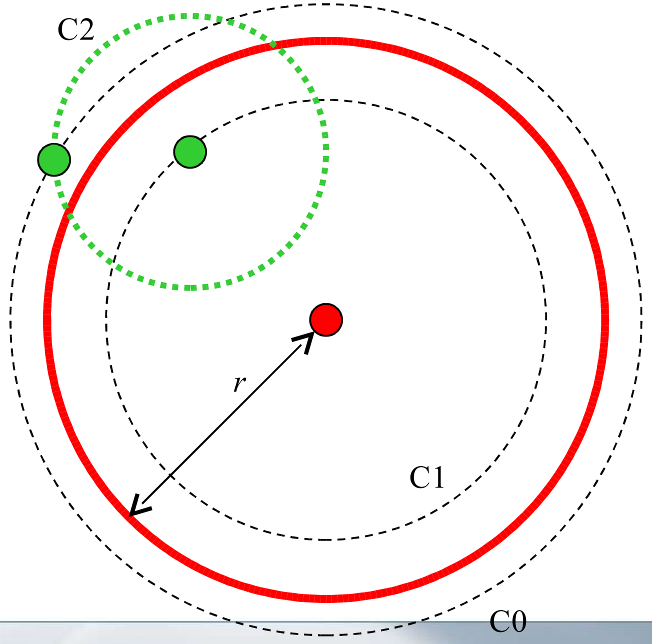
Link Availability Weights (1/2)

- Link Weight is a function of
  - The average signal strength received from the transmitting node at time t_i
  - The average signal strength received from the transmitting node at time $t_i + \Delta t$
- The power of the transmitted signal at the sender is assumed to be constant over Δt
- The intersection of the locus of next possible locations with the transmission range locus gives the link weight estimate

Link Availability Weights (2/2)

- Path Loss model has to be incorporated in the link availability calculations

$$P_r = P_t \left(\frac{1}{4\pi rf} \right)^n g_t g_r$$



Link Availability Estimation (1/4)

Theorem 1 *If p_0 is the power of the signal received by node n from node m at time t_i,*

p_1 is the power of the signal received by node n from node m at time $t_i + \Delta t$,

p_m is the minimum power level that node n can receive,

$p_0 < p_1$, and $\frac{1}{4}\frac{4p_0p_m + p_1p_m - p_1p_0}{p_m\sqrt{p_0p_1}} \in [-1, +1]$, then the probability that link (m, n) will exist at time $t_i + 2\Delta t$ is

$$-\Big(-4\beta p_0p_m - 8\sqrt{p_0}\sqrt{p_1}(\cos\beta)p_m + 2(\cos\beta\sin\beta)p_1p_m - 2\beta p_1p_m + 4\gamma p_0p_m + 8\sqrt{p_0}\sqrt{p_1}(\cos\gamma)p_m - 2(\cos\gamma\sin\gamma)p_1p_m + 2\gamma p_1p_m - \sqrt{p_m}\sqrt{p_0}(\sin\alpha)p_1 - p_1p_0\pi + p_1p_0\alpha\Big)$$

$$/\Big(p_m\Big(4\beta p_0 + 8\sqrt{(p_1p_0)}\cos\beta - 2(\cos\beta\sin\beta)p_1 + 2\beta p_1 + 2\pi p_0 + \pi p_1\Big)\Big)$$

where $\beta = \arcsin\sqrt{\frac{p_0}{p_1}}$

$$\gamma = \arcsin\left(\frac{1}{4}\frac{4p_0p_m + p_1p_m - p_1p_0}{p_m\sqrt{p_0p_1}}\right)$$

$$\alpha = \arccos\left(\frac{1}{8}\frac{-p_1p_m^2 + 2p_1p_0p_m - p_1p_0^2 + 4p_0p_m^2 + 4p_0^2p_m}{\left(\sqrt{p_0}\right)^3\left(\sqrt{p_m}\right)^3}\right)$$

Link Availability Estimation (2/4)

Theorem 2 *If* p_0 *is the power of the signal received by node* n *from node* m *at time* t_i*,* p_1 *is the power of the signal received by node* n *from node* m *at time* $t_i + \Delta t$*,* p_m *is the minimum power level that node* n *can receive,* $p_0 < p_1$*, and* $\frac{1}{4}\frac{4p_0p_m + p_1p_m - p_1p_0}{p_m\sqrt{p_0p_1}} \notin [-1, +1]$*, then the probability that link* (m, n) *will exist at time* $t_i + 2\Delta t$ *is 1.0.*

Link Availability Estimation (3/4)

Theorem 3 *If* p_0 *is the power of the signal received by node* n *from node* m *at time* t_i, p_1 *is the power of the signal received by node* n *from node* m *at time* $t_i + \Delta t$, p_m *is the minimum power level that node* n *can receive,* $p_1 \leq p_0$, *and* $\frac{1}{4}\frac{4p_0p_m+p_1p_m-p_1p_0}{p_m\sqrt{p_0p_1}} \in [-1,+1]$, *then the probability that link* (m,n) *will exist at time* $t_i + 2\Delta t$ *is*

$$= \frac{1}{2p_m\pi\left(2p_0+p_1\right)}(2\pi p_0p_m + \pi p_1p_m - 4\gamma p_0p_m - 8\sqrt{p_0}\sqrt{p_1}\left(\cos\gamma\right)p_m$$

$$+2\left(\cos\gamma\sin\gamma\right)p_1p_m - 2\gamma p_1p_m + \sqrt{p_m}\sqrt{p_0}\left(\sin\alpha\right)p_1 + p_1p_0\pi - p_1p_0\alpha)$$

$$\textit{where } \gamma = \arcsin\left(\frac{1}{4}\frac{4p_0p_m + p_1p_m - p_1p_0}{p_m\sqrt{p_0p_1}}\right)$$

$$\alpha = \arccos\left(\frac{1}{8}\frac{-p_1p_m^2 + 2p_1p_0p_m - p_1p_0^2 + 4p_0p_m^2 + 4p_0^2p_m}{\left(\sqrt{p_0}\right)^3\left(\sqrt{p_m}\right)^3}\right)$$

Link Availability Estimation (4/4)

Theorem 4 *If* p_0 *is the power of the signal received by node* n *from node* m *at time* t_i, p_1 *is the power of the signal received by node* n *from node* m *at time* $t_i + \Delta t$, p_m *is the minimum power level that node* n *can receive,* $p_1 \le p_0$, *and* $\frac{1}{4}\frac{4p_0p_m + p_1p_m - p_1p_0}{p_m\sqrt{p_0p_1}} \notin [-1, +1]$, *and* $p_m < \frac{p_0p_1\sqrt{p_0p_1}}{4p_0\sqrt{p_0p_1} - 4p_0p_1 + p_1\sqrt{p_0p_1}}$ *then the probability that link* (m, n) *will exist at time* $t_i + 2\Delta t$ *is 1.0*

Theorem 5 *If* p_0 *is the power of the signal received by node* n *from node* m *at time* t_i, p_1 *is the power of the signal received by node* n *from node* m *at time* $t_i + \Delta t$, p_m *is the minimum power level that node* n *can receive,* $p_1 \le p_0$, $p_m > \frac{p_0p_1\sqrt{p_0p_1}}{4p_0\sqrt{p_0p_1} - 4p_0p_1 + p_1\sqrt{p_0p_1}}$ *and* $\frac{1}{4}\frac{4p_0p_m + p_1p_m - p_1p_0}{p_m\sqrt{p_0p_1}} \notin [-1, +1]$, *then the probability that link* (m, n) *will exist at time* $t_i + 2\Delta t$ *is* $\frac{p_0p_1}{p_m(4p_0 + 2p_1)}$

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- ROMR Algorithms
- **Simulation Results**
- Conclusions

Simulation Setup: Fixed Parameters

- Simulation Area: 1000 m × 1000 m
- Mobility Model: Random Waypoint
- Speed: constant
- Radio Frequency: 2.4 GHz
- Bandwidth: 11 Mbps
- Transmit Power: 20 dBm
- SNR: 10
- Receiver Sensitivity: -78 dBm
- Traffic Model: CBR (0.5 packet /sec, 512 bytes)
- Simulation Time: 10 minutes

Simulation Setup: Variable Parameters

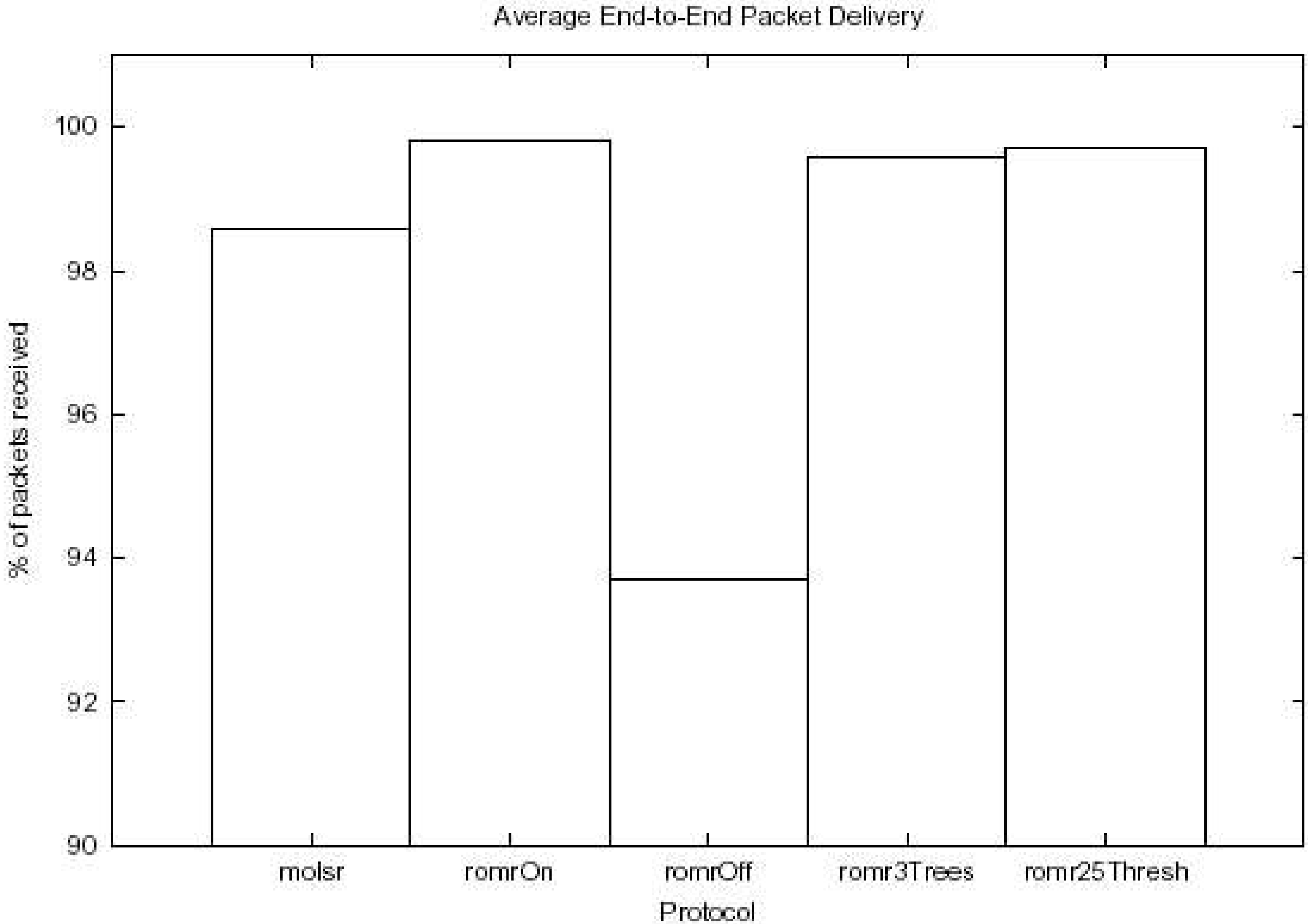
- Network Density:
  - 10 nodes (sparse)
  - 30 nodes (medium)
  - 50 nodes (dense)
- Group size: 50% , 20% or 10% of the network size
- Speed: 0 to 30 m/sec
- Minimum Number of Trees (μ): 2
- Minimum Cumulative Weight Threshold (τ): 0.15
- Reuse Factor (ρ): 0.5

Simulated Protocols

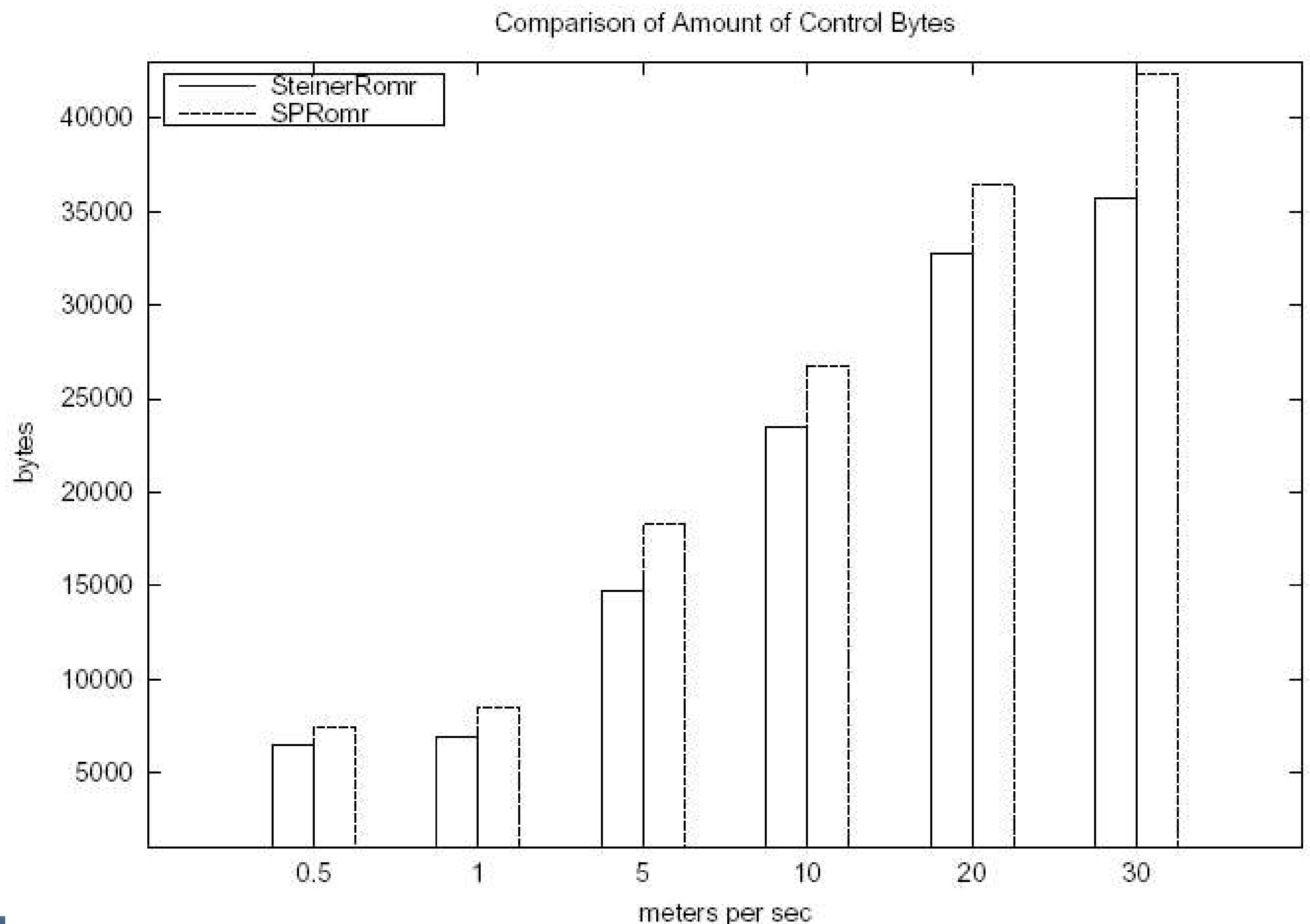
- The following protocols were simulated
  - molsr: Multicast version of OLSR
  - romrOff: All links were assumed to have equal weights
  - romrOn: $\mu = 2$, $\tau = 0.15$, $\rho = 0.5$
  - romr25Thresh: $\mu = 2$, $\tau = 0.25$, $\rho = 0.5$
  - romr3Trees: $\mu = 3$, $\tau = 0.15$, $\rho = 0.5$

- Simulation Tool: GloMoSim

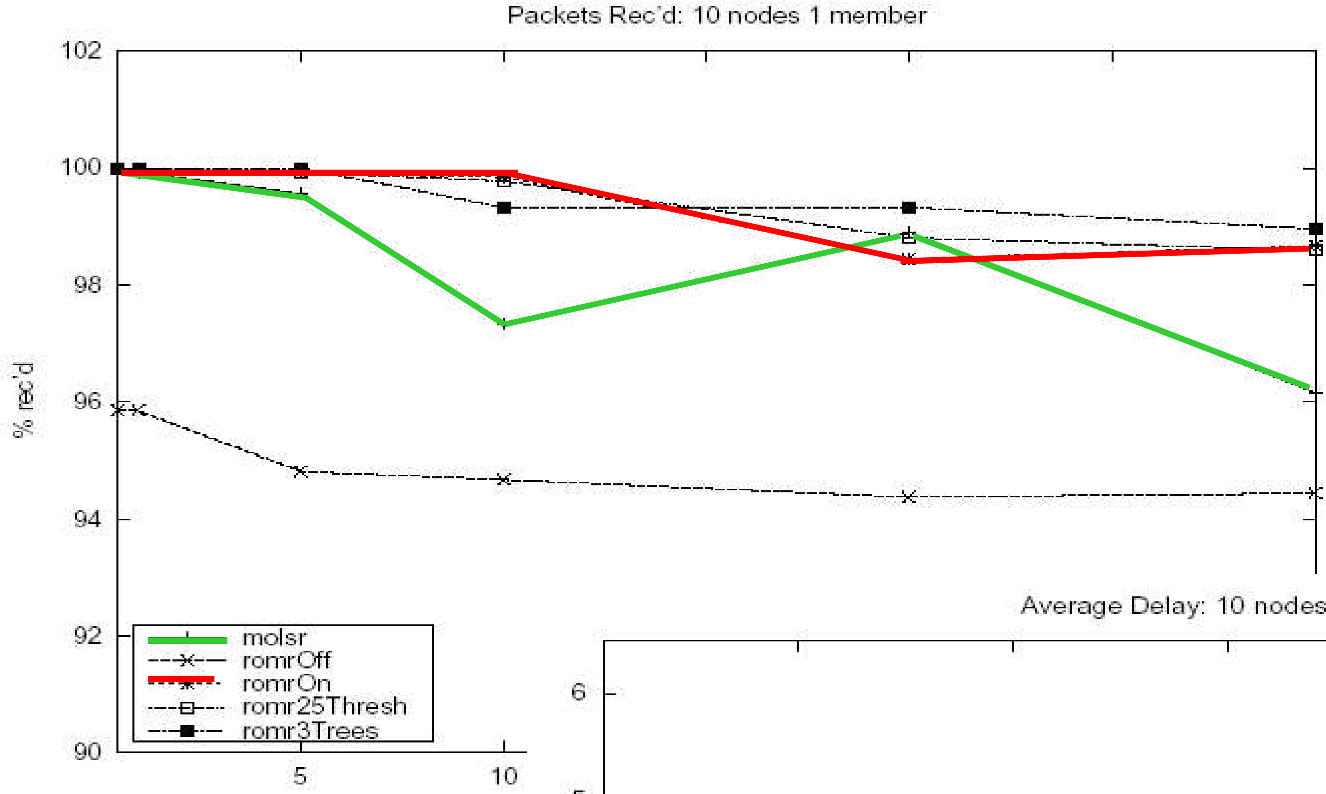
Simulation Results: Packet Delivery

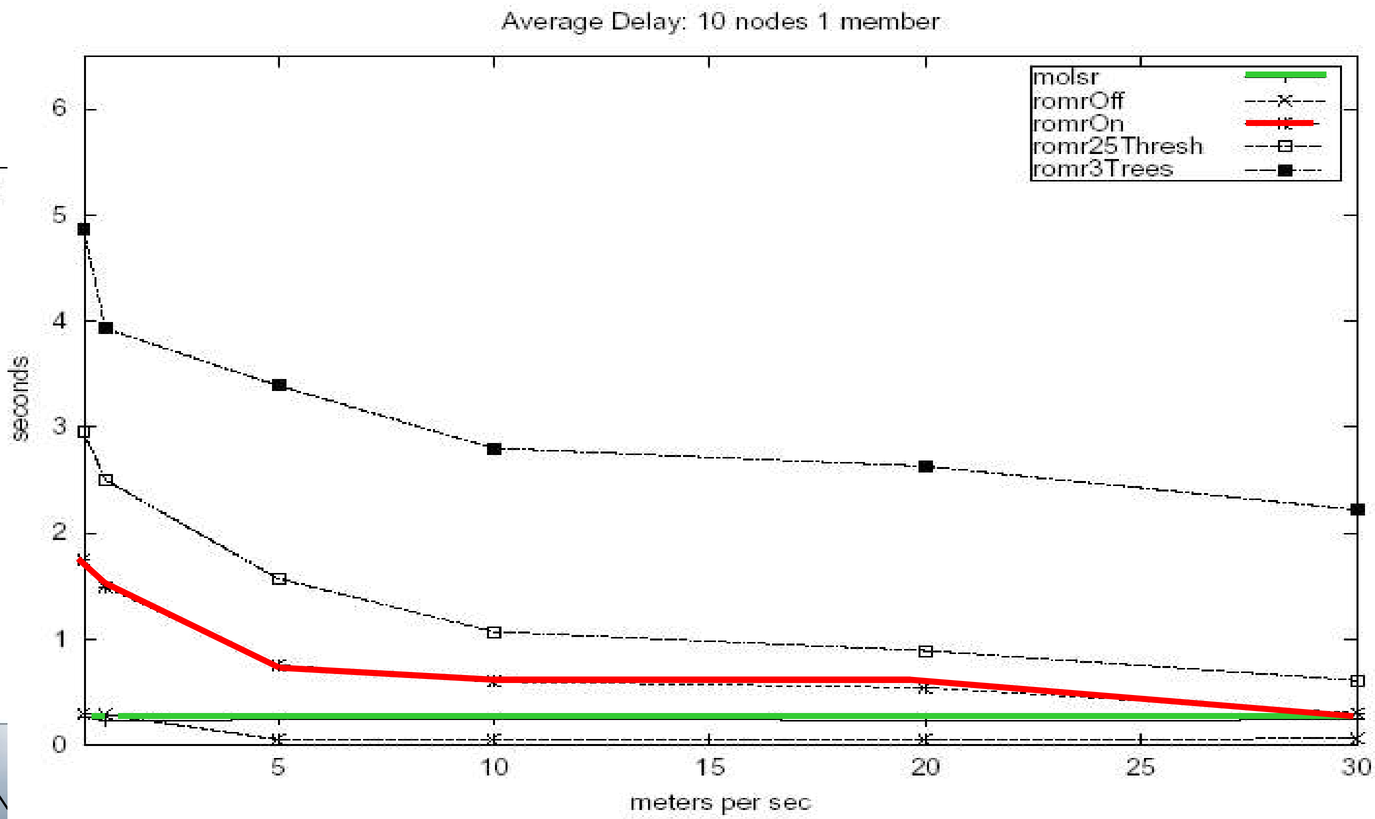


Simulation Results: Protocol Overhead



Detailed Results





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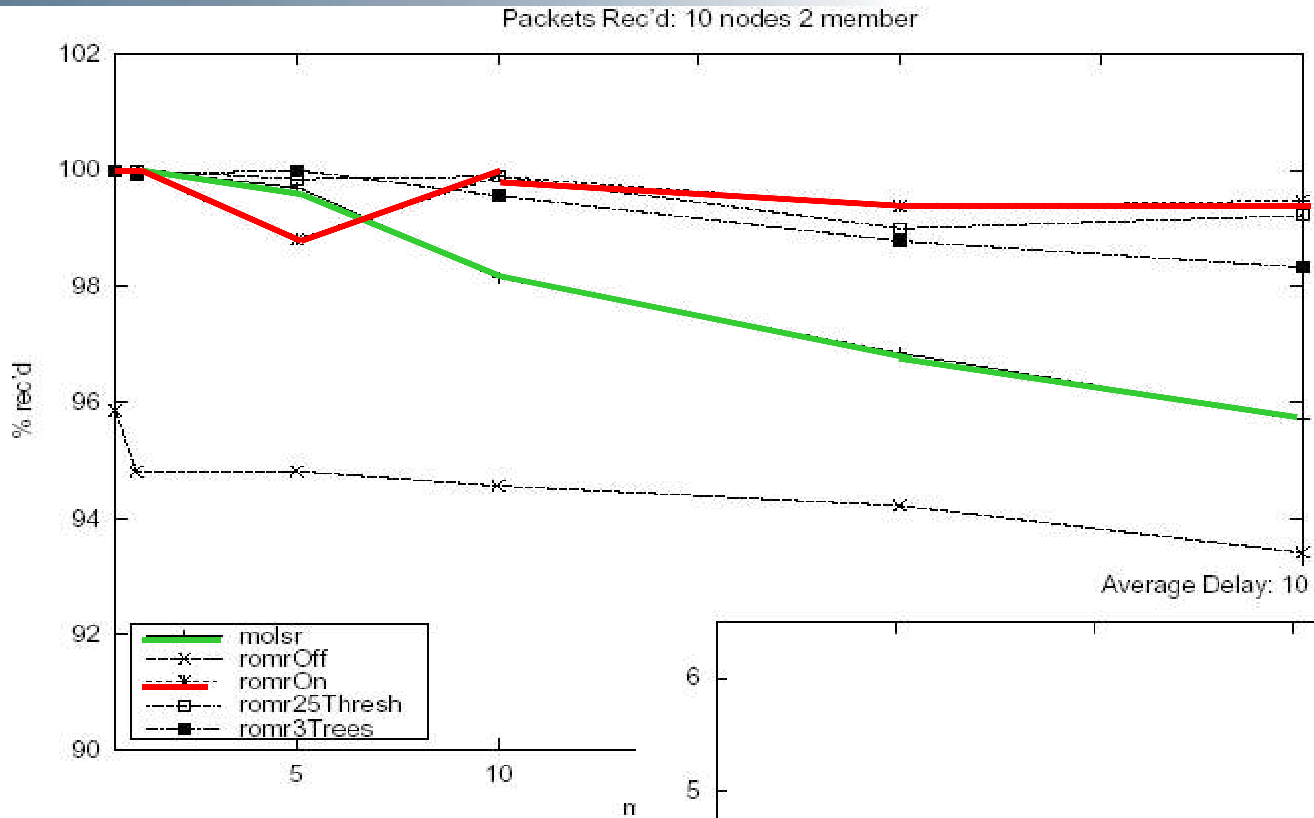

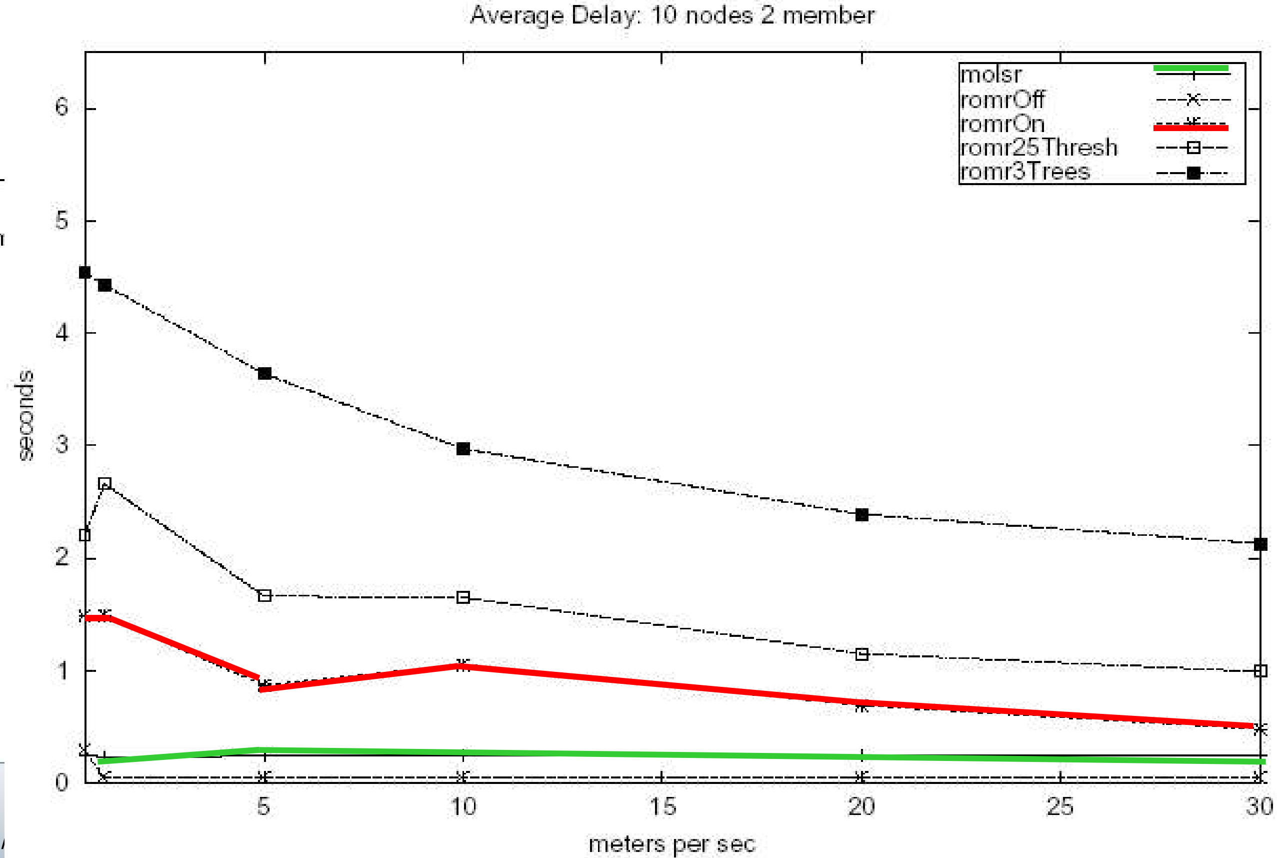

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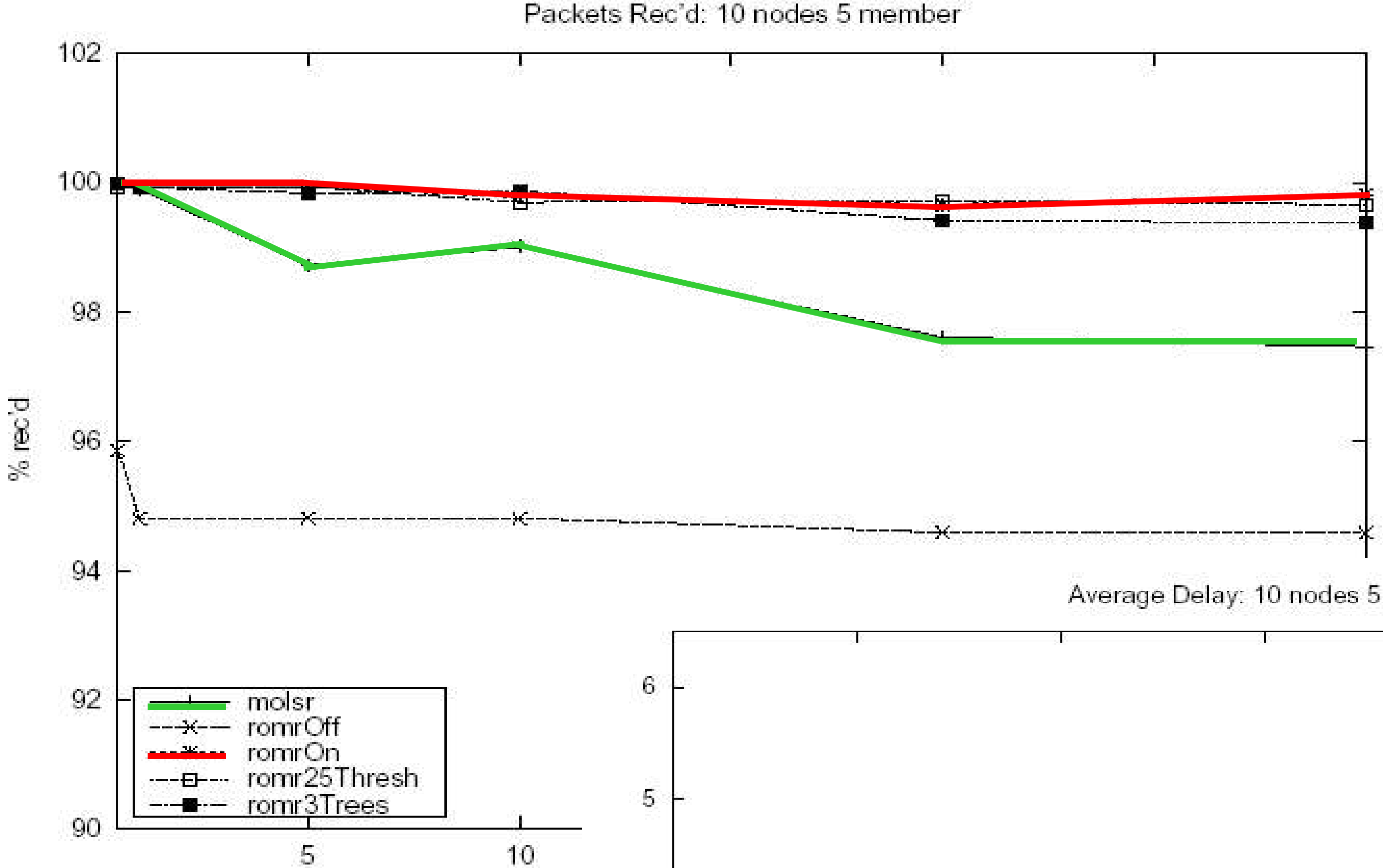

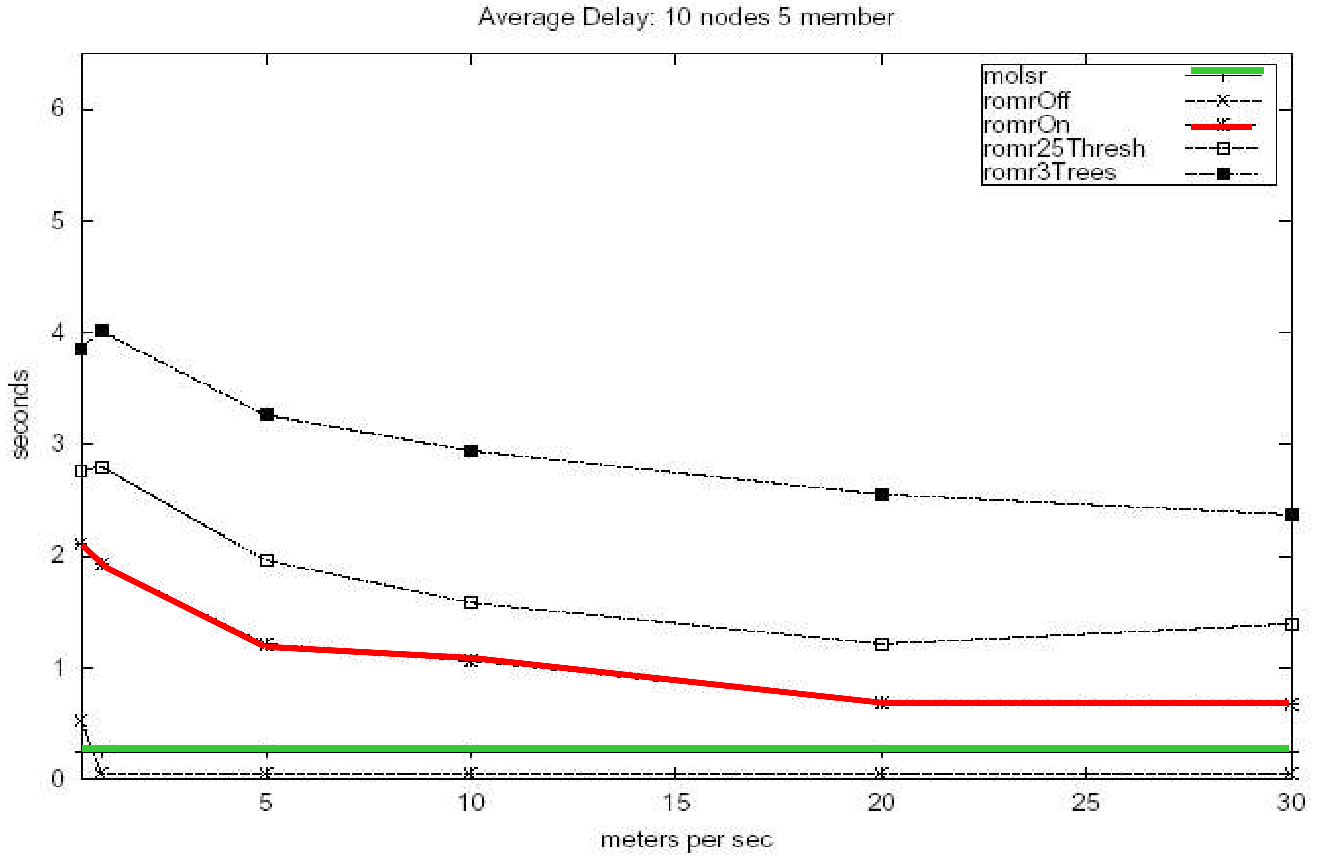

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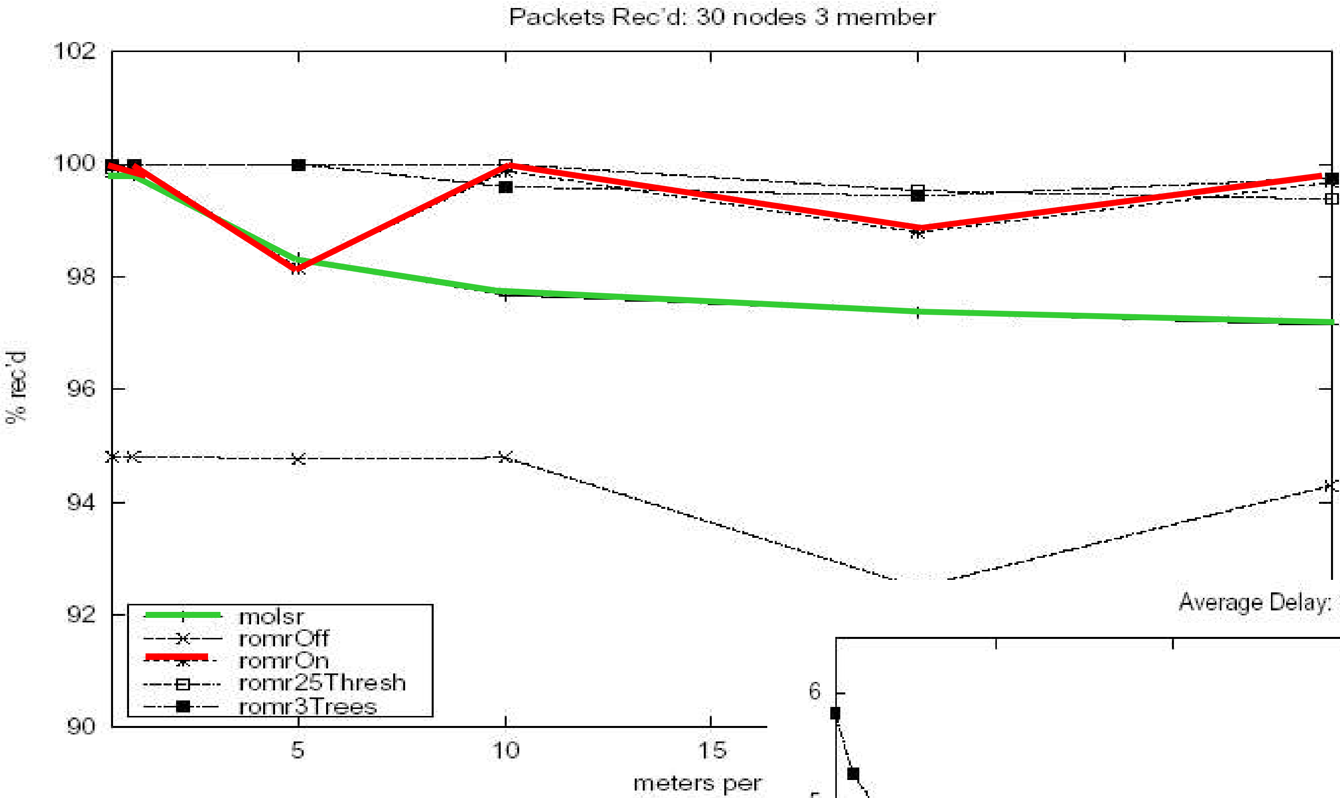

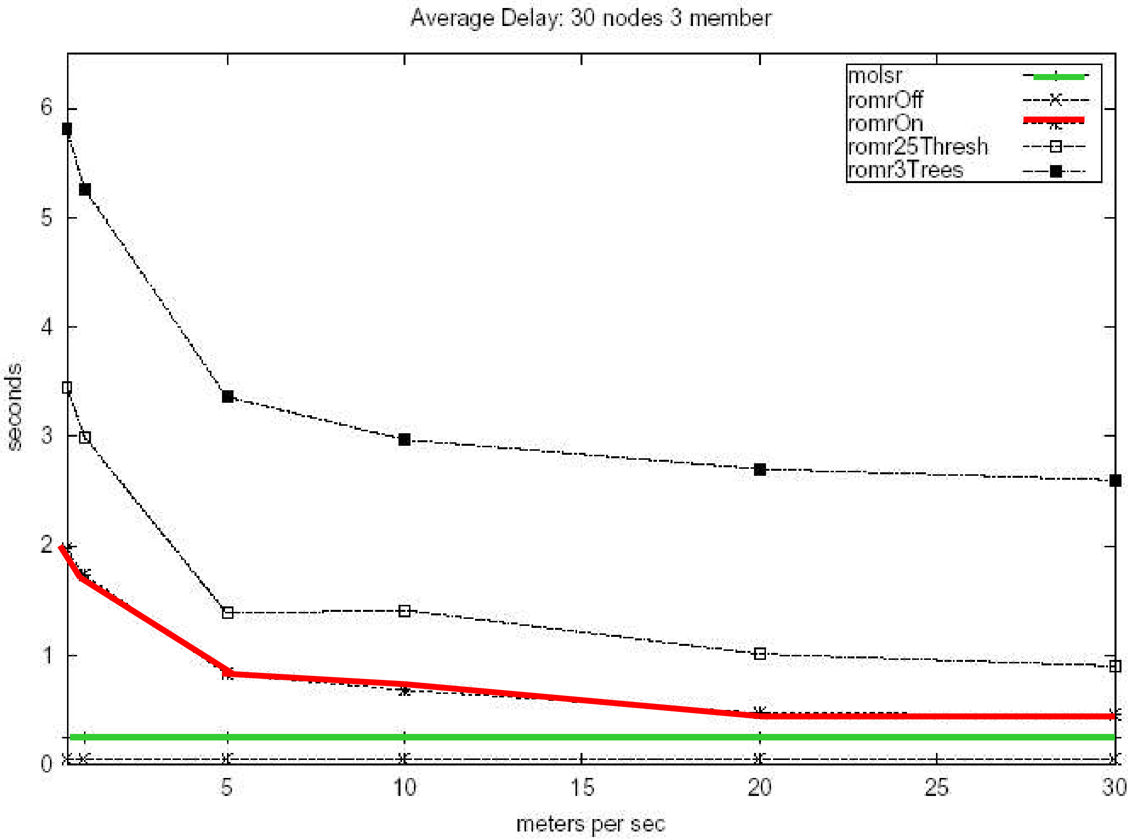

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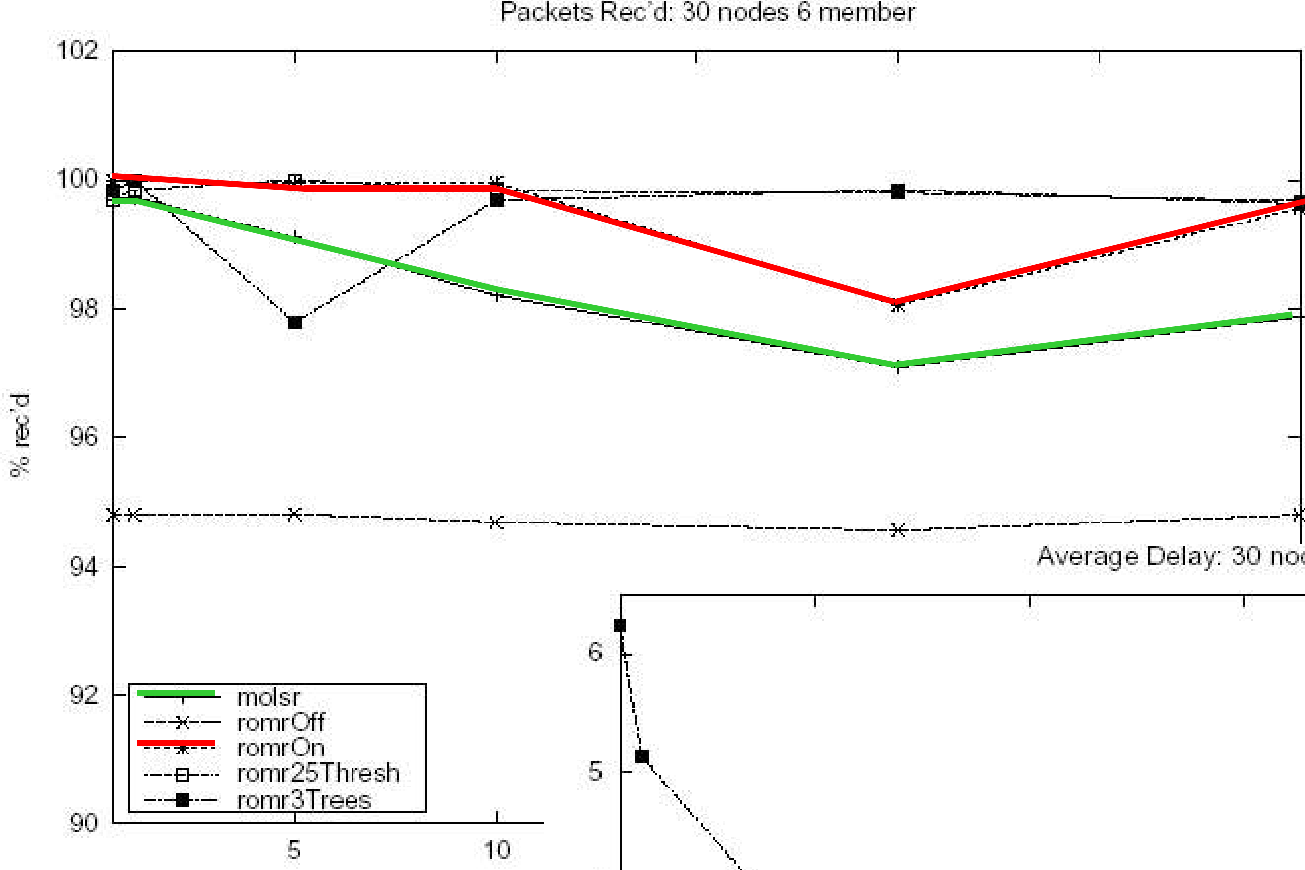

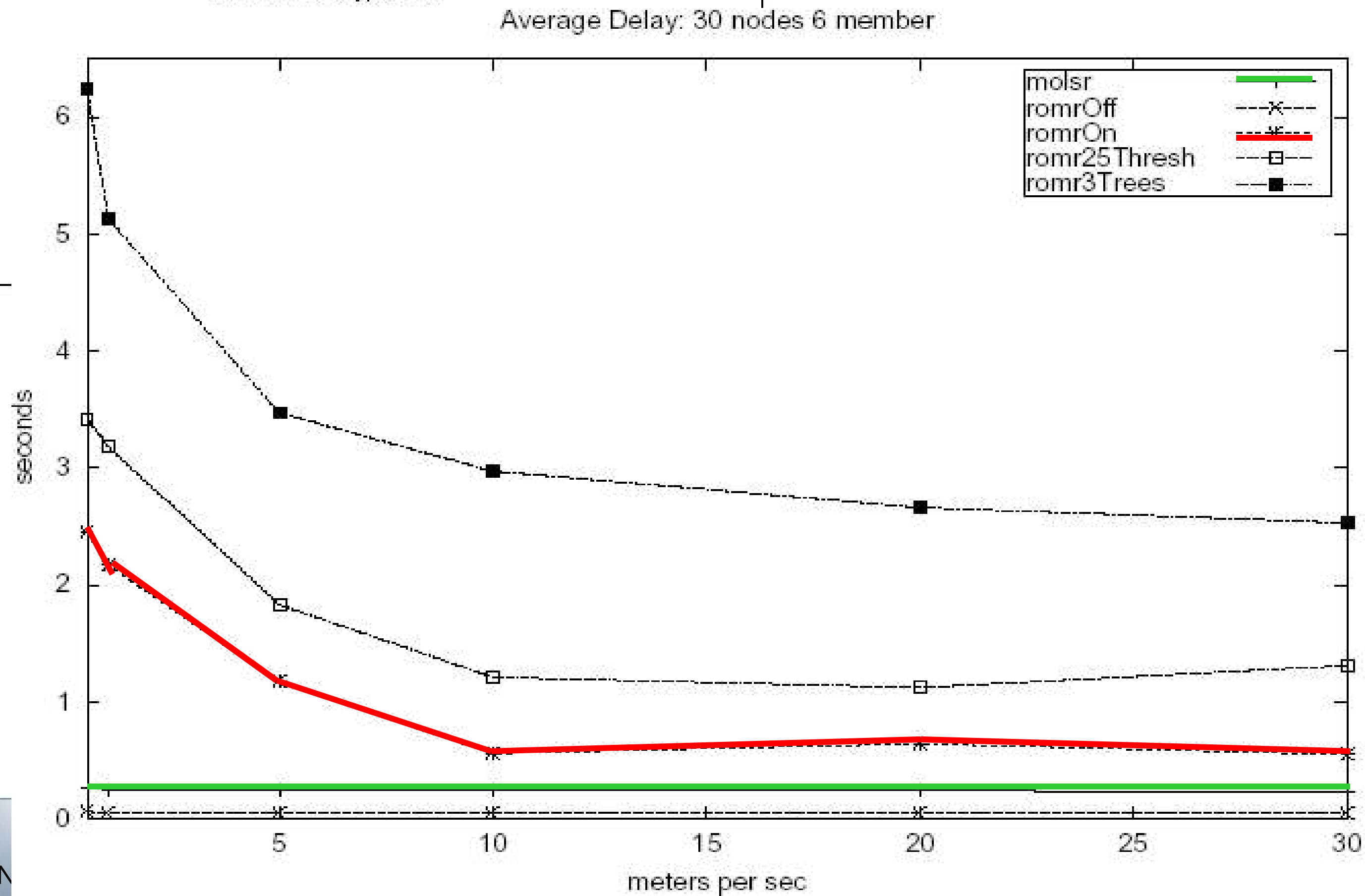

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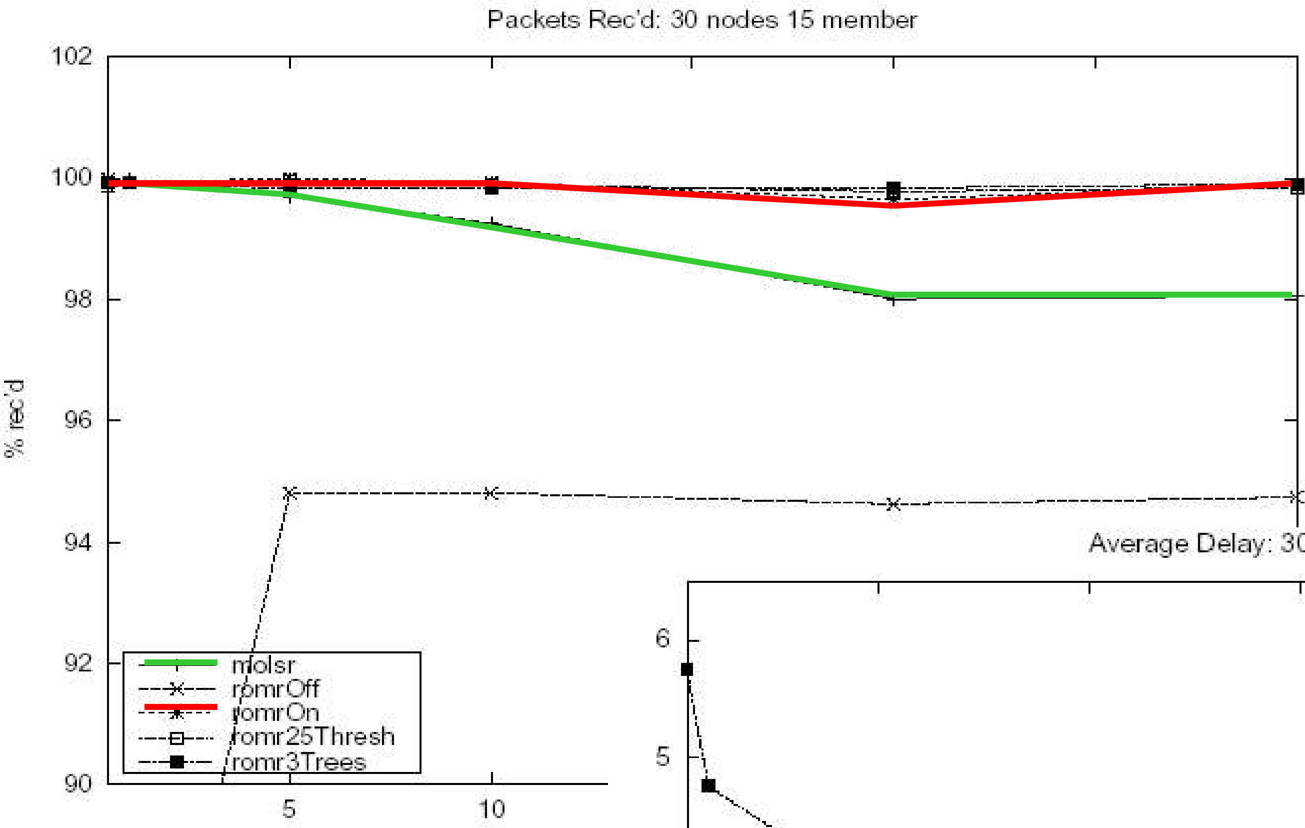

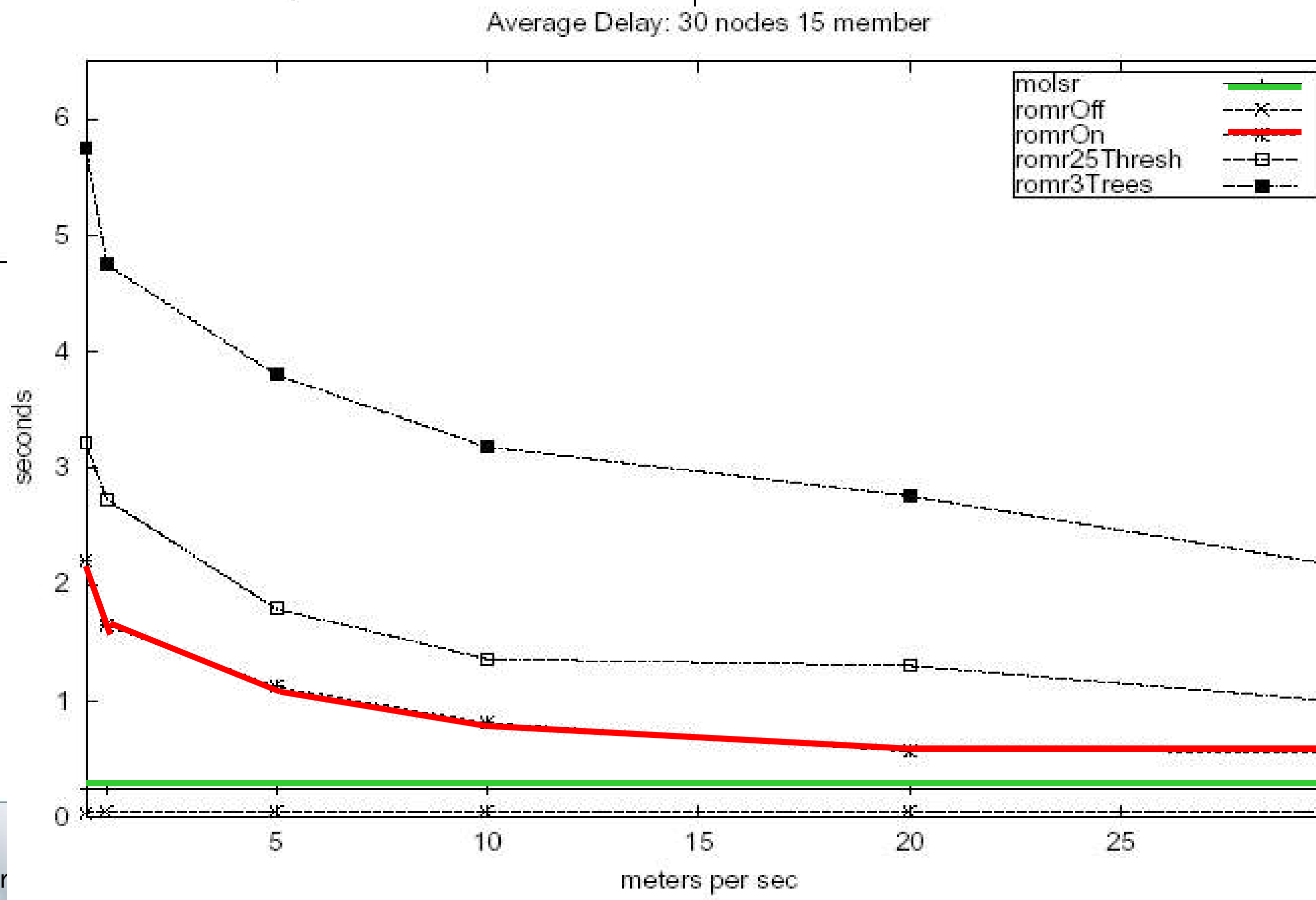

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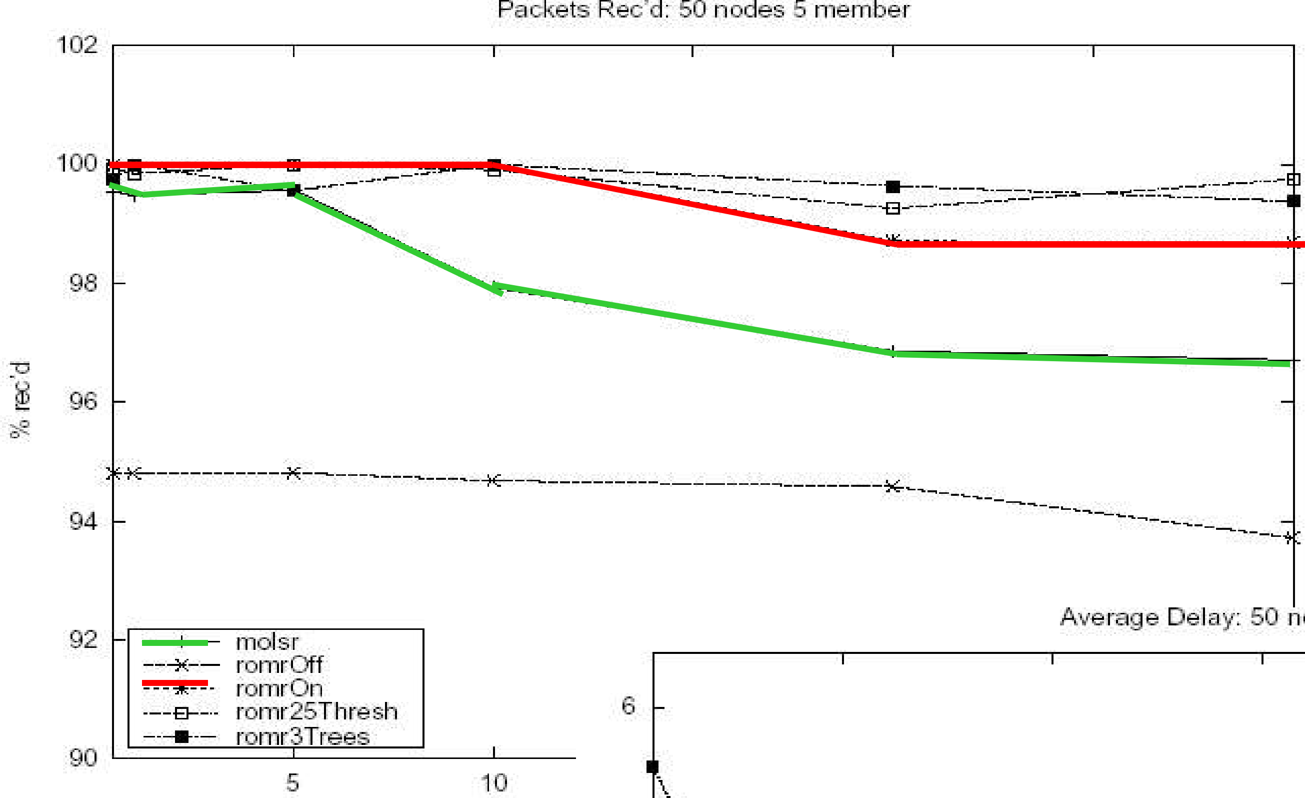

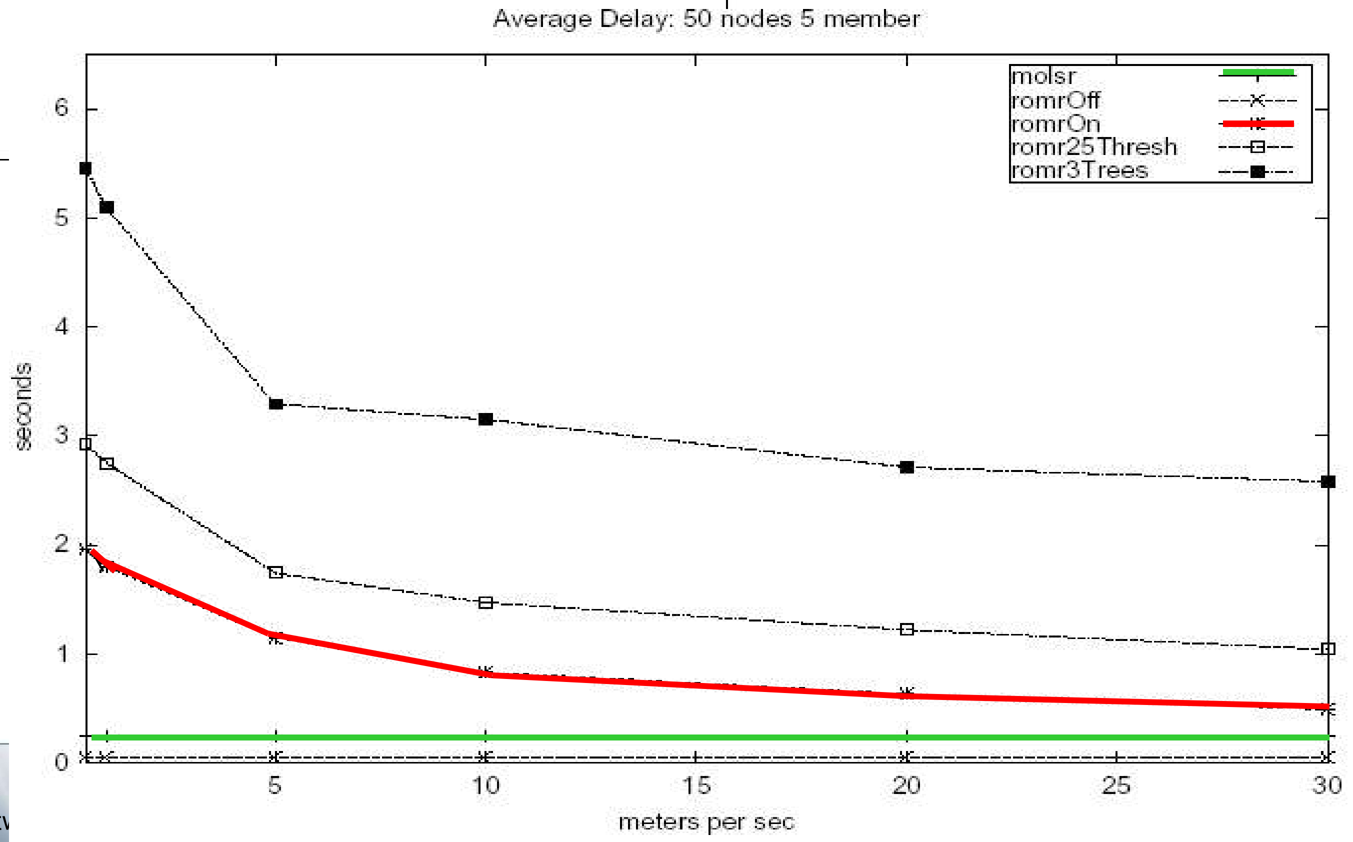

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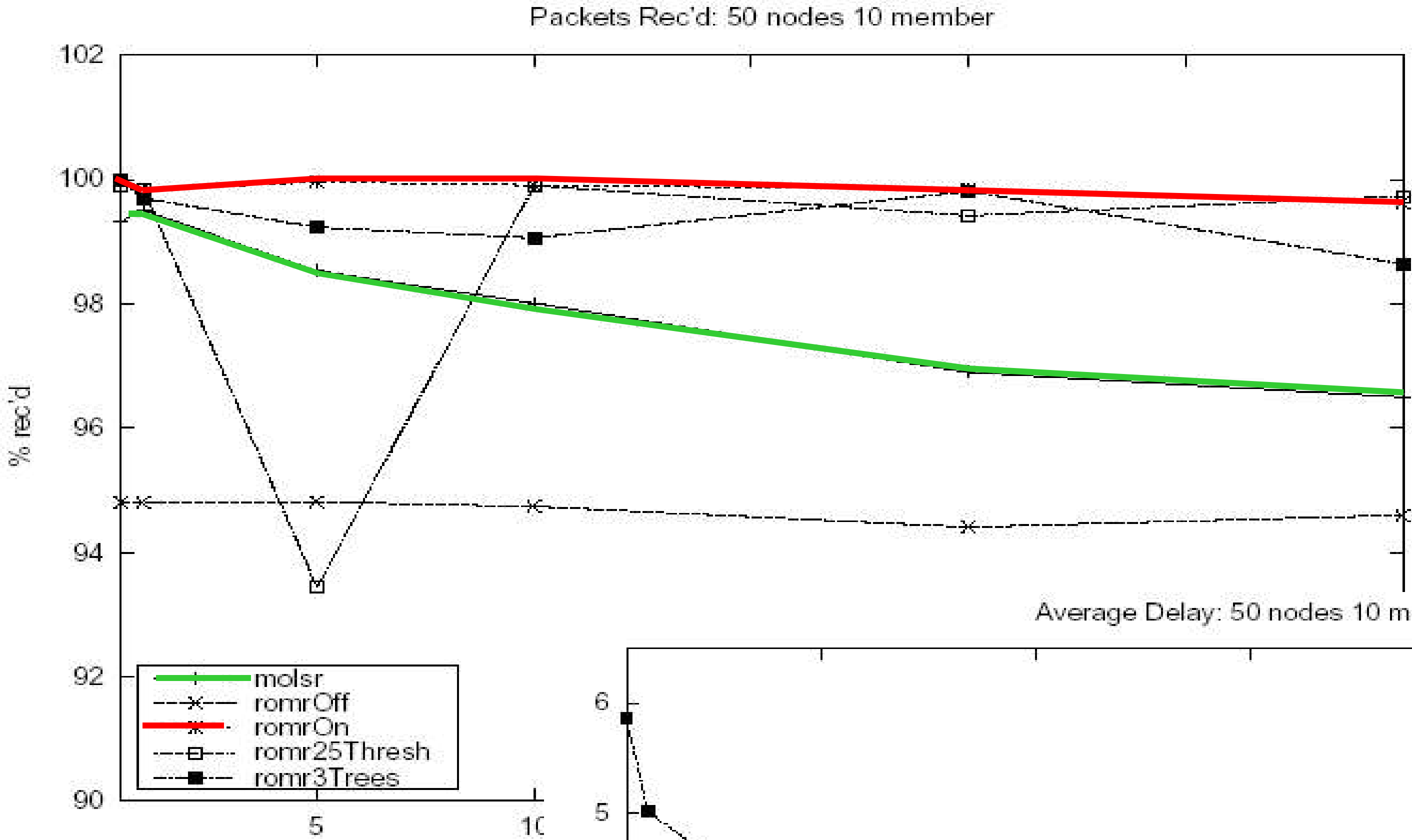

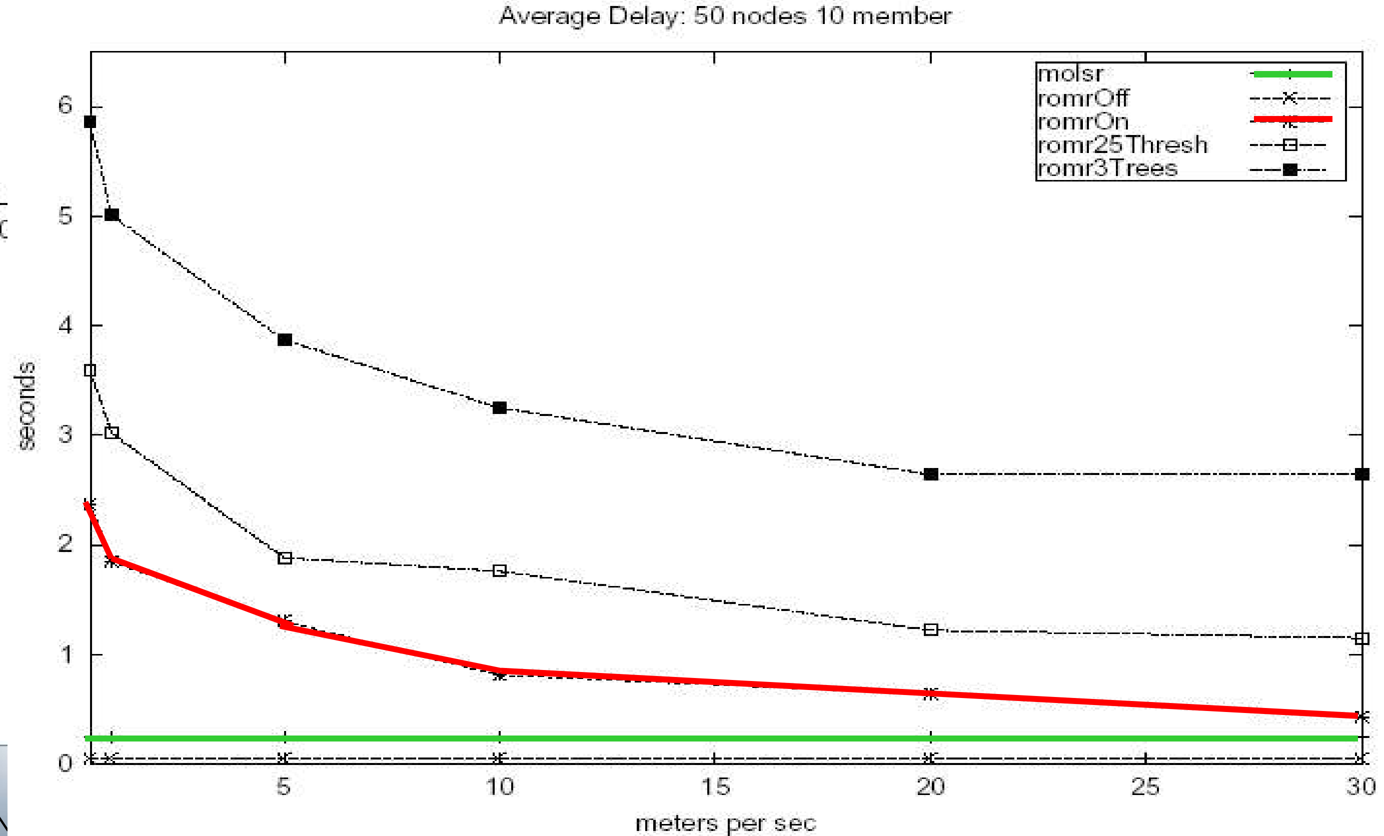

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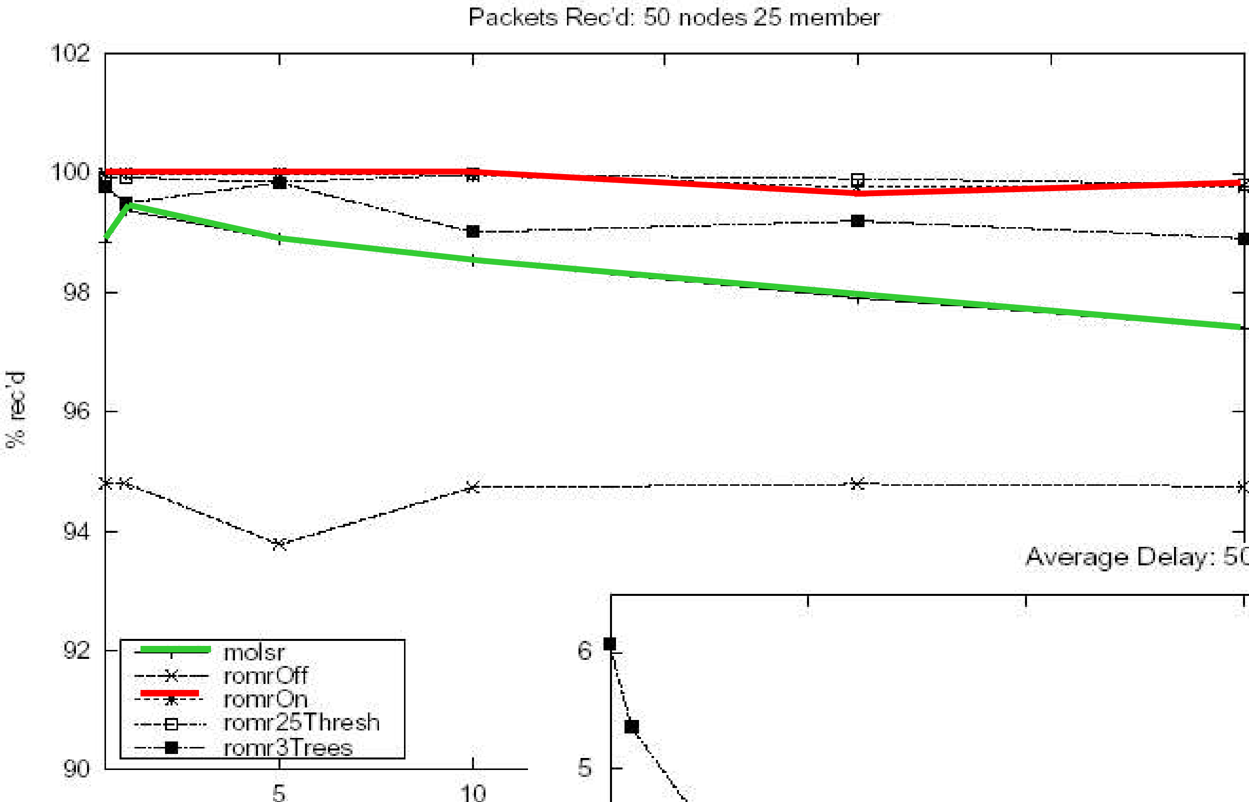

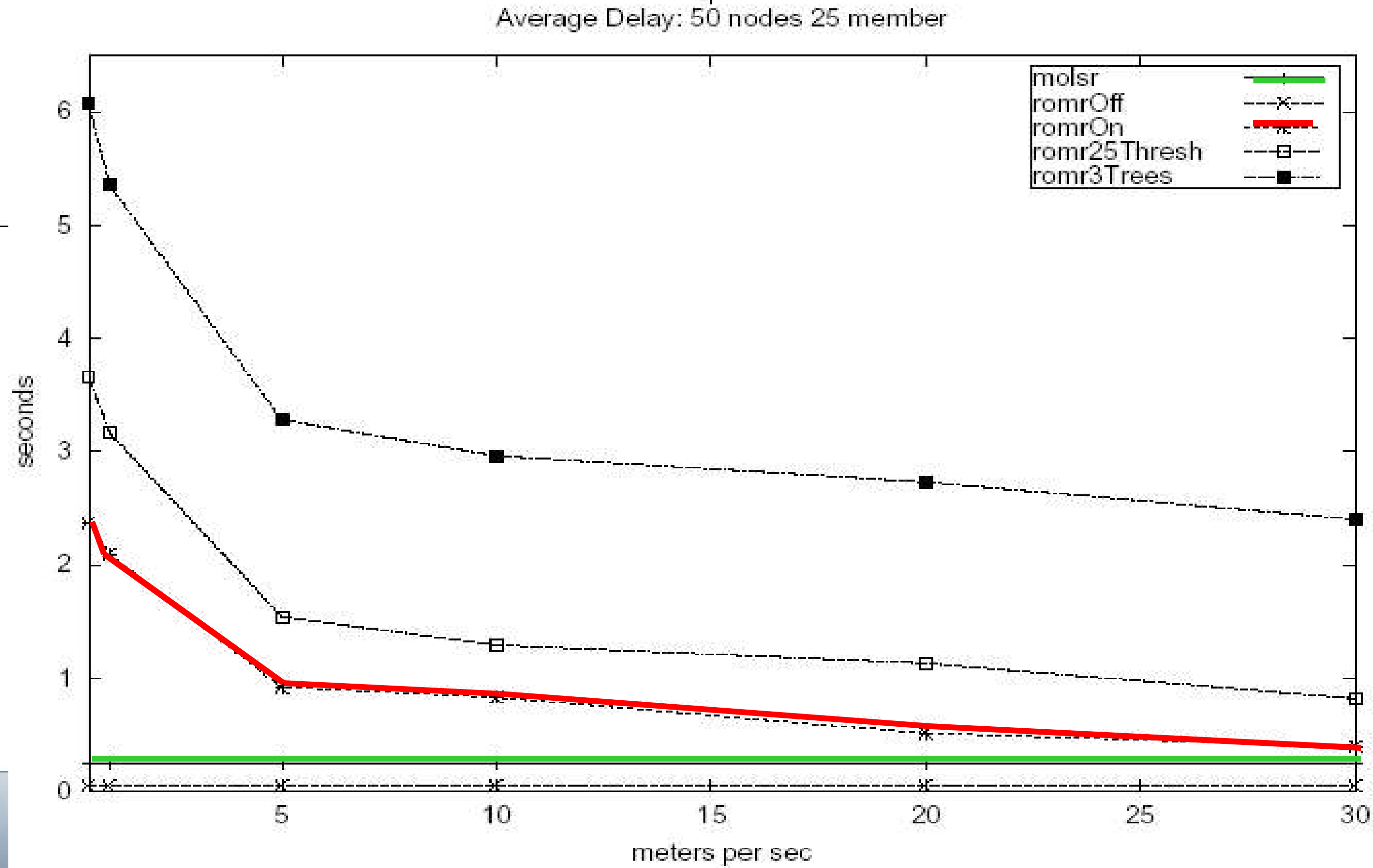

Results Comparison

RomrOn vs RomrOff	RomrOn PktsRec	RomrOff PktsRec
Mean	269.50	253.04
Variance	4.50	553.92
Observations	2160	2160

RomrOn vs MOLSR	RomrOn PktsRec	MOLSR PktsRec
Mean	269.50	266.19
Variance	4.50	26.45
Observations	2160	2160

RomrOn vs Romr3Trees	RomrOn PktsRec	Romr3Trees PktsRec
Mean	269.50	268.82
Variance	4.50	9.01
Observations	2160	2160

RomrOn vs Romr25Thresh	RomrOn PktsRec	Romr25Thresh PktsRec
Mean	269.50	269.18
Variance	4.50	40.66
Observations	2160	2160

Romr3Trees vs Romr25Thresh	Romr3Trees PktsRec	Romr25Thresh PktsRec
Mean	268.82	269.18
Variance	9.01	40.66
Observations	2160	2160

Next . . .

- Introduction
- About the Dissertation
- Review of Ad-Hoc Routing Protocols
- ROMR Architecture
- ROMR Link Availability
- Simulation Results
- **Conclusions**

Conclusions

- The overall packet delivery (to members) ratio has increased
- ROMR incorporates a number novel algorithms
  - Forward Error Correction
  - Steiner-Tree Approximations
  - Link-Availability Estimates

Critique (1/2)

- The increase in the packet delivery ratio comes with high cost
  - High overhead
  - High end-to-end delay
  - Power and Memory consumption
    - Due to the complex link-availability algorithms
- The link availability calculations were based on a simplified path loss model $P_r = P_t \left(\frac{1}{4\pi fd} \right)^n g_t g_r, \ where\ n = 2$
  - However, the situation is not so simple when it comes to the path loss in the real life
    - Many path loss models are different propagation conditions

Critique (2/2)

- No explanation of simulation results
  - No comments on the fluctuation of the results!

- Personal Opinion
  - Not so "*beautiful*" dissertation !

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Thank You!

Abbreviations

ABR	Associativity-Based Routing
AODV	Ad-hoc On-Demand Distance Vector
CGSR	Clusterhead Gateway Switch Routing
DSDV	Destantion-Sequenced Distance Vector
DSR	Dynamic Source Routing
FSR	Fisheye State Routing
LAR	Location-Aided Routing
OLSR	Optimized Link State Routing
SSA	Signal Stability-based Adaptive Routing
STAR	Source-Tree Adaptive Routing
TBP	Ticket Based Routing
TORA	Temporally Ordered Routing Algorithm
WRP	Wireless Routing Protocol
RoMR	Robust Multicast Routing