Ad-hoc On-Demand Distance Vector Routing

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Ad-hoc Networks

- Infrastructureless networks
- All nodes capable of movement
- Links appear and disappear dynamically
- Special constraints:
  - limited bandwidth
  - limited power
  - high error rates
- Protocol needed to create and maintain routes
- Conventional routing protocols not applicable

Desired Characteristics of an Ad-hoc Routing Protocol

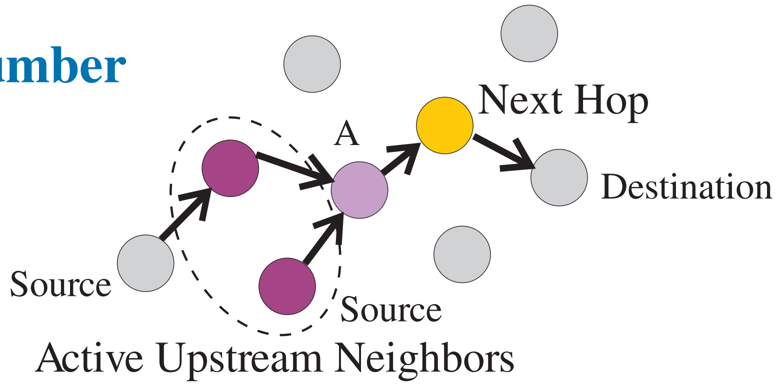
- Ability to find multi-hop paths
- Unicast, broadcast, and multicast routing ability
- Dynamic topology maintenance
- Ability to self-start
- Loop-freedom and rapid route convergence
- Low consumption of memory, bandwidth
- Scalable to large ($\geq$ 1000) populations of nodes
- Minimal control overhead
- No data overhead

Ad-hoc On-Demand Distance Vector Routing (AODV)

- **Primary Objectives**
  - **Provide unicast, broadcast, and multicast capability**
  - **Initiate forward route discovery only on demand**
  - **Disseminate changes in local connectivity to those neighboring nodes likely to need the information**
- **Characteristics**
  - $On\ demand$ **route creation, resulting in localized effect of topology changes, and minimized control traffic.**
  - **Two dimensional routing metric:** $<Seq\#, Hop\_Count>$
  - **Storage of routes in Route Table**

Route Table

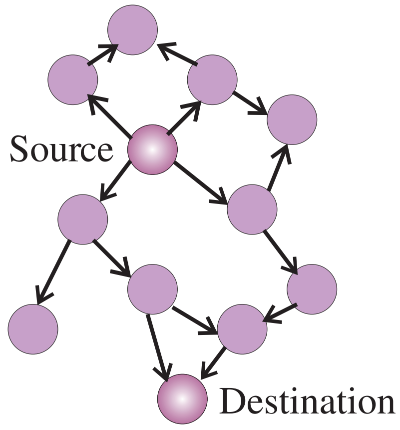
- **Fields:**
  - **Destination IP Address**
  - **Destination Sequence Number**
  - **Hop Count**
  - **Next Hop IP Address**
  - **Active Neighbors**
  - **Expiration time**



- **Each time a route entry is used to transmit data, the expiration time is updated to** $current\_time + \texttt{active\_route\_timeout}$
- **Route entries may be updated if a route with greater sequence number or smaller hopcount is discovered**

Route Discovery

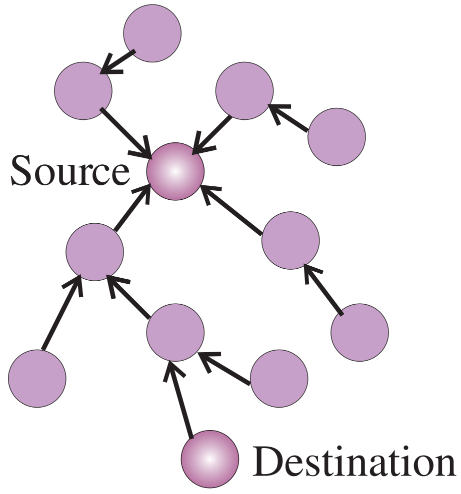
- **Source broadcasts** *Route Request* **(RRREQ)**
- **RREQ contains:** $<$*Source_Addr, Source_Seq#, Broadcast_ID, Dest_Addr, Dest_Seq#, Hop_Count*$>$
- **A node can reply to the RREQ if**
  - **It is the destination**
  - **It has a "fresh enough" route to the destination**
- **Otherwise it rebroadcasts the RREQ**
- **Nodes keep track of** $<$*Source_Addr, Broadcast_ID*$>$ **and discard redundant broadcasts**



Route Request Propagation

Reverse Path Setup

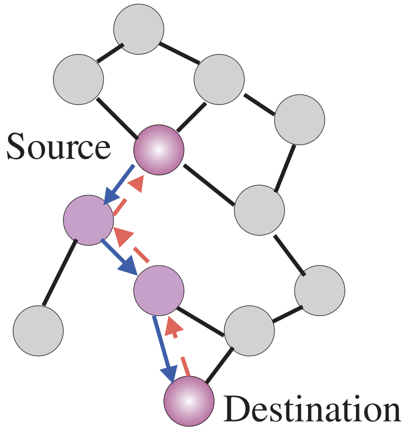
- **Nodes update their Route Table with source node information before forwarding RREQ**
- **Reverse path entry used to forward** *Route Reply* **(RREP) back to source if one is received**
- **Expiration time is long enough for a RREP to be received and forwarded**



Reverse Path Formation

Forward Path Setup

- **Destination, or intermediate node with current route to destination, unicasts** *Route Reply* **(RREP) back to source**
- **RREP contains:**
  $<Source\_Addr,\ Dest\_Addr,\ Dest\_Seq\#,\ Hop\_Count,\ Lifetime>$
- **Nodes along path record** *forward route* **in Route Table, use** *reverse route* **to forward RREP**
- **Source can begin sending data when it receives first RREP**
- **If it later receives a RREP with better metric, it updates its route entry**

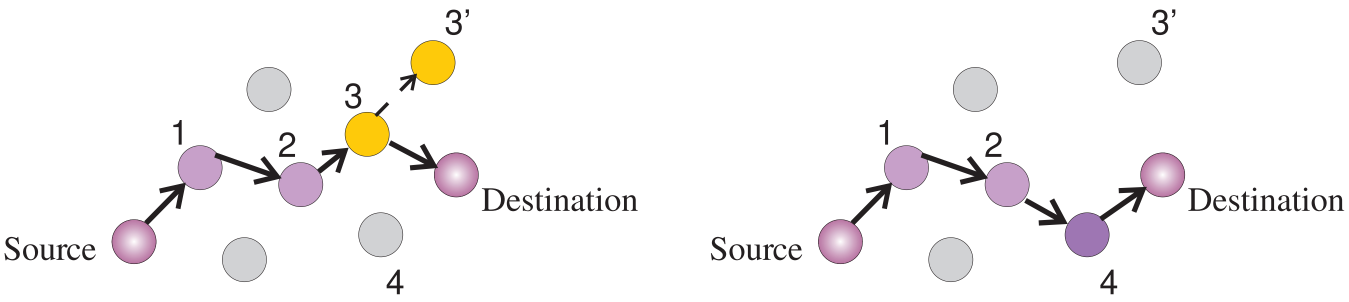


Forward Path Formation

Path Maintenance

- Movement of nodes not along active path does not trigger protocol action
- If source node moves, it can reinitiate route discovery
- When destination or intermediate node moves, node upstream of break sends $unsolicited\ RREP$ to all active upstream neighbors
  - ∞ metric, incremented Seq#
  - Used to flush stale routes
- RREP is propagated to their active neighbors, and so on back to source
- Source can reinitiate route discovery if route is still needed
- RREQs for reinitiated route discovery contain destination sequence number of one greater than last known number

Path Maintenance (cont.)



The Initial Route After Route Reconstruction

- Node 3 moves to new location 3'
- Node 2 notices loss of link, sends link failure to Node 1
- Node 1 forwards link failure to Source
- Source reinitiates route discovery, finds new route through Node 4

Local Connectivity Management

- **Node must periodically hear from** *active* **neighbors to know they are still within range**
- **Eavesdrop on neighbor transmissions**
- **If no other transmissions within** `hello_interval`**, broadcast** *Hello* **packet**
- **Failure to hear from a neighbor for** $(1 + \texttt{allowed\_hello\_loss}) * \texttt{hello\_interval}$ **indicates loss of link**

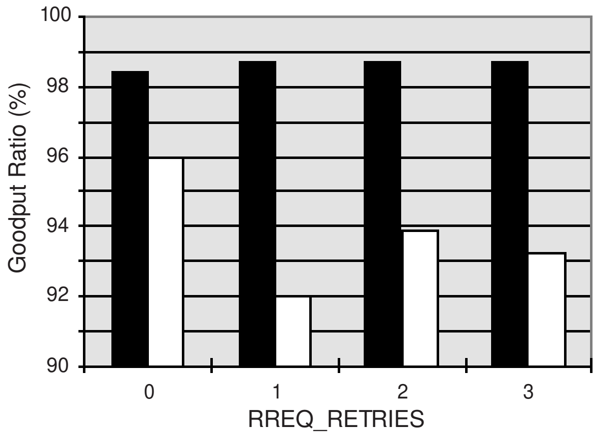
Simulation Environment

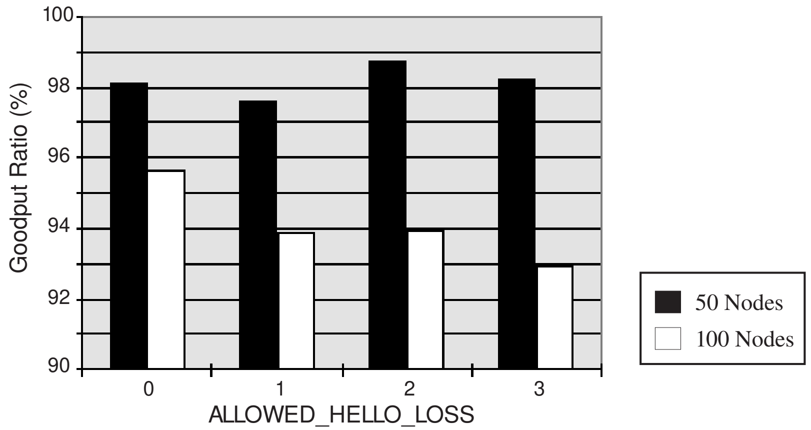
- Objectives
  - AODV route establishment is quick and accurate
  - AODV scales to networks with large numbers of nodes
  - Determine optimal value for `allowed_hello_loss` and `rreq_retries` parameters
- All simulations executed in PARSEC
- Each node chooses destination, speed
- After reaching destination, node rests, then selects new destination, speed
- Carrier Sensing performed before each transmission

Simulation Environment (cont.)

- Simulated Length of Time: 600 seconds
- Data Rate: 1.0 Mbit/sec
- Transmission Radius: 10m
- Session Types
  - 64 byte data packets
  - 170 byte data packets
- Room Size
  - 50, 100 Nodes: 50m$\times$50m
  - 500 Nodes: 100m$\times$100m
  - 1000 Nodes: 150m$\times$150m

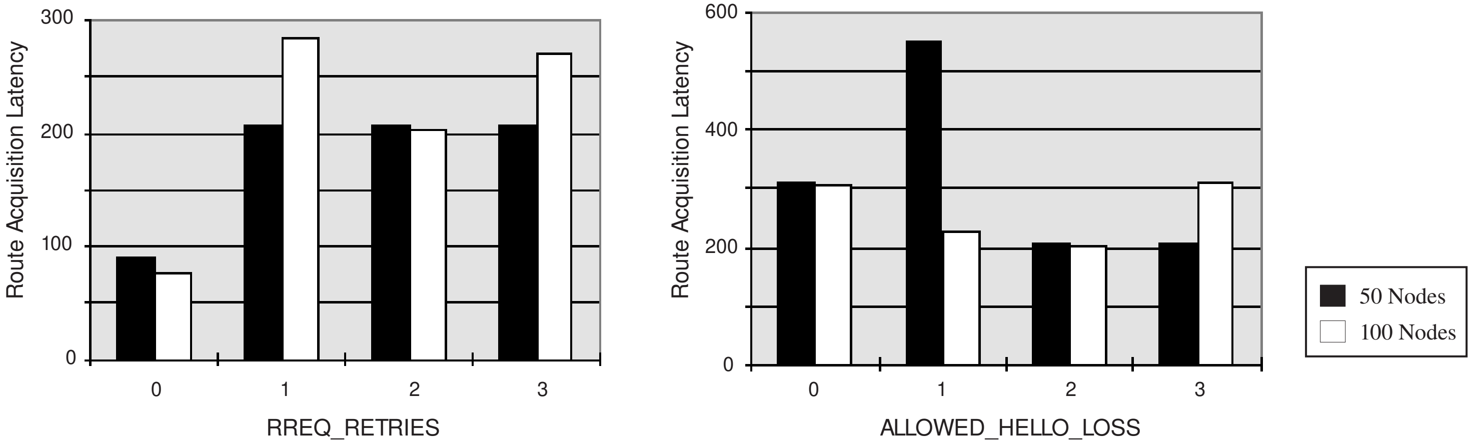
Goodput Ratio





- 50 Nodes - over 98%
- 100 Nodes - approximately 94%
- Optimal Values:
  - `rreq_retries` = 2
  - `allowed_hello_loss` = 2

Route Acquisition Latency



- **50 Nodes - approximately 200 msec**
- **100 Nodes - approximately 200 msec**
- **Optimal Values:**
  - `rreq_retries` = 2
  - `allowed_hello_loss` = 2

Comparison of Network Sizes

# of Nodes	50	100	500	1000
Goodput Ratio at Sim End	98.75%	93.92%	87.46%	70.53%
Goodput Ratio Avg	97.98%	95.91%	86.43%	72.32%
Bandwidth Overhead Ratio	1.14	1.11	1.31	1.49
Avg Rte Acq Latency (msec)	206	202	454	548
Avg Path Length (hops)	3.94	4.57	6.83	10.45
Loss to Collision	1.43%	5.74%	22.80%	26.37%

- **50, 100 Nodes - high goodput, low bandwidth overhead**
- **500, 1000 Nodes - lower goodput, higher bandwidth overhead**
- **Reasons for degraded performance:**
  - **Greater likelihood of collision**
  - **Greater chance of mid-session route rebuilding**

Comparison of Session Types

# of Nodes	50		100	
Data Packet Size	64 bytes	170 bytes	64 bytes	170 bytes
Goodput Ratio at sim end	98.75%	86.18%	93.92%	83.38%
Bandwidth Overhead Ratio	1.14	1.06	1.11	1.06
Avg Rte Acq Latency (msec)	206	388	202	580
# Generated Sessions	24	45	62	89

- **Longer packet lengths of voice session $\Rightarrow$ greater likelihood of collision**
- **Better bandwidth overhead ratio $\Rightarrow$ same amount of control overhead but more data bytes**
- **Longer wait between transmissions $\Rightarrow$ longer route acquisition latency**

Conclusion

- On-demand route establishment
- Minimum delay for route discovery
- Quick response to link breakage in active routes
- Maintenance of loop-free routes by use of destination sequence numbers
- Scalable to large populations of nodes

Within the limits imposed by mobile, wireless networks, AODV is an effective protocol for routing within ad-hoc networks.

Future Work

- Multicast
  http://www.ietf.org/internet-drafts/draft-ietf-manet-aodv-02.txt
- Elimination of *Hello* Messages
- Quality of Service
  - Delay
  - Bandwidth
- Local Repair
  - RREQ sent by intermediate node with small TTL
  - Tradeoff between route reconstruction time and number of packets dropped?
- Authentication and Security

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