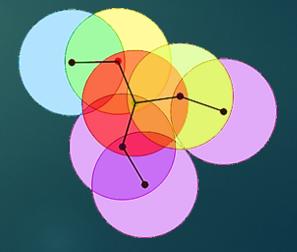


Mobile Ad-Hoc Networks & Routing Algorithms

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Introduction



An ad-hoc network is a collection of mobile nodes (ad hoc means "for this" or "for this purpose only."), that :

> connect over the wireless/wired medium

without the need of any pre-deployed existing infrastructure.

Nodes in a MANET can dynamically self-organize into temporary and arbitrary and network topologies

Multi-hop flexible low cost last mile-extensions of wired infrastructure

Why Ad Hoc Networks?



Ease and Speed in deployment

Decreased dependence on infrastructure

Only possible solution to interconnect a group of nodes

Many Commercial Products available today

Mobile Ad-Hoc network Applications



Body Area Networking

- body sensors network,
- Personal area Networking
 - cell phone, laptop, ear phone, wrist watch
- Disaster Recovery Areas
- Emergency operations
 - search-and-rescue (earthquakes, boats, airplanes...)
 - policing and fire fighting

- Military environments
 - soldiers, tanks, planes,
 battlefield
- Civilian environments
 - vehicle networks
 - meeting rooms
 - sports stadiums
 - boats, small aircraft
- eHealth/mHealth/uHealth

What's unique about a mobile adhoc network ?

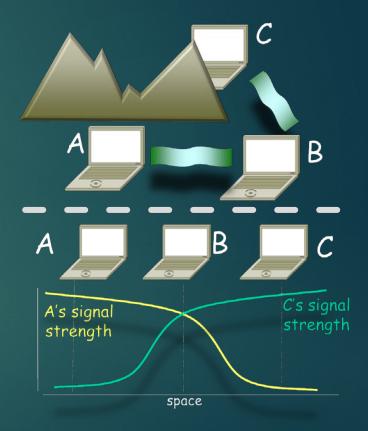


Traffic characteristics may differ in different ad hoc networks

- various and volatile wireless link quality
- bit rate, reliability requirements, unicast, multicast,
- host-based/ content-based/ capability-based addressing
- Co-exist and Co-operate with infrastructure-based networks
- Mobility characteristics may be different
 - speed, direction of movement, pattern of movement
- Symmetric vs. Asymmetric (nodes' capabilities and responsibilities)
- Pervasive (cheap) devices: Power constraints
- Security/Confidentiality issues

Issues in Mobile Ad-hoc Networks

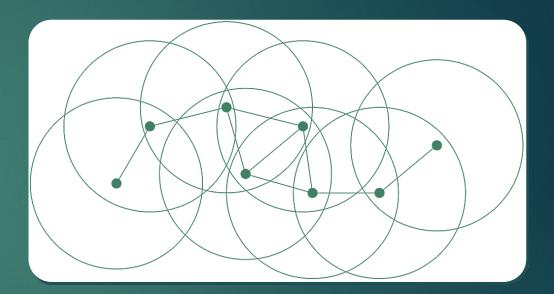
- Limited wireless transmission range
- Broadcast nature of the wireless medium
 - Hidden terminal problem
- Packet losses due to transmission errors
- Mobility-induced route changes
- Mobility-induced packet losses
- Battery constraints
- Potentially frequent network partitions
- Ease of snooping on wireless transmissions (security hazard)







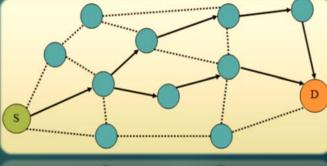
Routing in Mobile Ad-Hoc Networks



Mobile Ad Hoc Networks (MANETs)

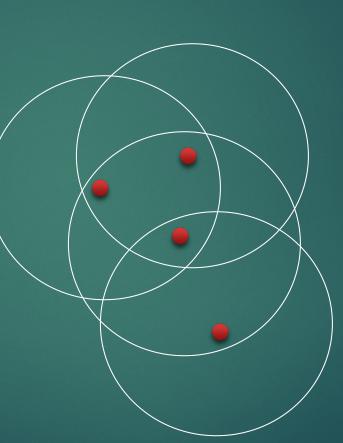


Formed by a collection of wireless mobile hosts
Without any pre-existing infrastructure or the aid of any centralized administration
Network characteristics change over time
Routes between nodes may potentially contain multiple hops
Number of hosts in the network

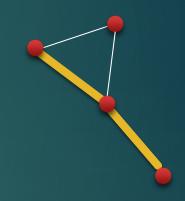


Mobile Ad Hoc Networks

- Mobile wireless hosts
 - Only subset within range at given time
 - Want to communicate with any other node
- May need to traverse multiple links to reach a destination



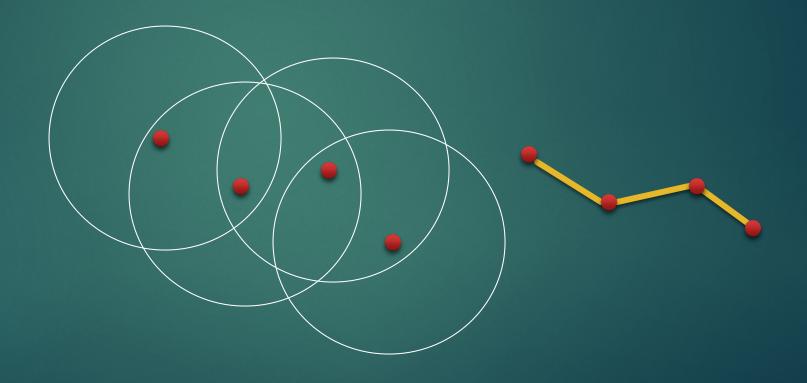






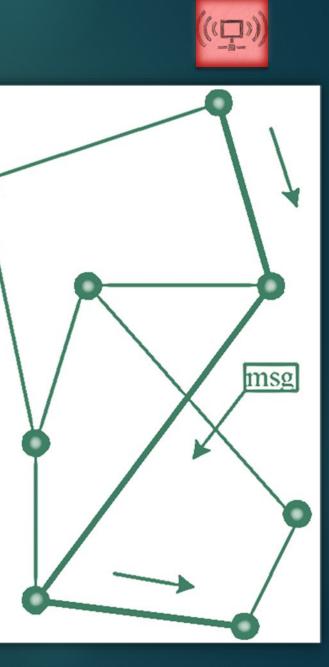


Mobility causes route changes



Routing Overview

Network with nodes, edges ► Goal: transfer message from one node to another → Which is the *best path*? \rightarrow Who *decides* source, intermediate or *destination* node(s)



Which path?



Generally try to optimize one of the following:

- Shortest path (fewest hops)
- Shortest time (lowest latency)
- Shortest weighted path (utilize available bandwidth, battery)

Who determines route?



Source ("path") routing [Like airline travel]
 Source specifies entire route
 Intermediate nodes just forward to specified next hop

Destination ("hop-by-hop") routing [Like postal service]
 Source specifies only destination in message header
 Intermediate nodes look at destination in header, consult internal tables to determine appropriate next hop

IETF MANET Working Group



The Mobile Ad-hoc Networking (manet) Working Group is a chartered working group within the Internet Engineering Task Force (IETF) to investigate and develop candidate standard Internet routing support for mobile, wireless IP autonomous segments.

The charter and official IETF Home Page for manet are found at : <u>https://datatracker.ietf.org/wg/manet/charter/</u>

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Description of Working Group



- The purpose of the MANET working group is to <u>standardize IP routing protocol</u> <u>functionality suitable for wireless routing application within both static and dynamic</u> <u>topologies</u> with increased dynamics due to node motion or other factors.
- Approaches are intended to be
 - lightweight in nature,
 - suitable for multiple hardware and wireless environments, and
 - ▶ address scenarios where MANETs are deployed at the edges of an IP infrastructure.
- Hybrid mesh infrastructures (e.g., a mixture of fixed and mobile routers) should also be supported by MANET specifications and management features.
- Using mature components from previous work on experimental reactive and proactive protocols, the WG will develop two Standards track routing protocol specifications:
 - Reactive MANET Protocol (RMP)
 - Proactive MANET Protocol (PMP)

MANET Research Topics



- Routing
 - Better metrics, higher throughput
- Transport Layer
 - TCP performance: throughput, fairness, etc.
- MAC Layer
 - MAC performance, channel utilization
- Security
 - Reliable routing against malicious nodes
- Power Management
 - Power saving and power control

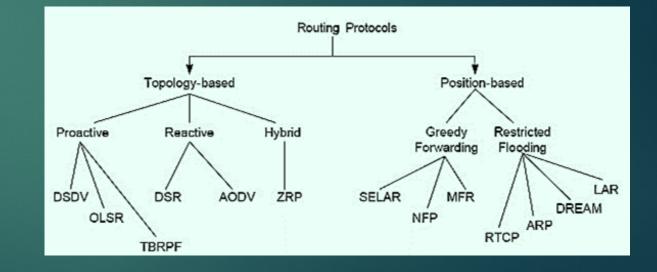
MANET Protocol Zoo

Topology based routing

- Proactive approach, e.g., DSDV.
- Reactive approach, e.g., DSR, AODV, TORA.
- ► Hybrid approach, e.g., Cluster, **ZRP**.

Position based routing

- ► Location Services:
 - DREAM, Quorum-based, GLS, Home zone etc.
- Forwarding Strategy:
 - Greedy, GPSR, RDF, Hierarchical, etc.





MANET Routing Properties



Qualitive Properties

- Distributed operation
- Loop Freedom
- Demand Based Operation
- Security
- Sleep period operation
- Unidirectional link support

Quantitative Properties

- End-to-End data throughput
- Delays
- Route Acquisition time
- Out of order delivery (percentage)
- ► Efficiency

MANET Routing Properties



No distinction between "routers" and "end nodes": all nodes participate in routing

- No external network setup: self-configuring
- Efficient when network topology is dynamic (frequent network changes – links break, nodes come and go)
- Self Starting
- Adapt to network conditions

Why is Routing in MANET different?



Host mobility

- Ink failure/repair due to mobility may have different characteristics than those due to other causes
- Rate of link failure/repair may be high when nodes move fast
- New performance criteria are used
 - route stability despite mobility
 - energy consumption
 - host position

Dynamic Solutions much more difficult to be deployed

Routing Protocols



- **No Routing:** Plain Flooding (PF)
- Proactive protocols: determine routes independent of traffic pattern, traditional link-state and distancevector routing protocols are proactive.
 - Destination Sequence Distance Vector (DSDV), Link State Routing
- Reactive protocols: discover routes and maintain them only if needed.
 - Dynamic Source Routing (DSR)
 - Ad-hoc On-Demand Distance Vector Routing (AODV)
- ► Hybrid protocols: Zone Based Routing (ZBR)

Trade-Offs



Latency of route discovery

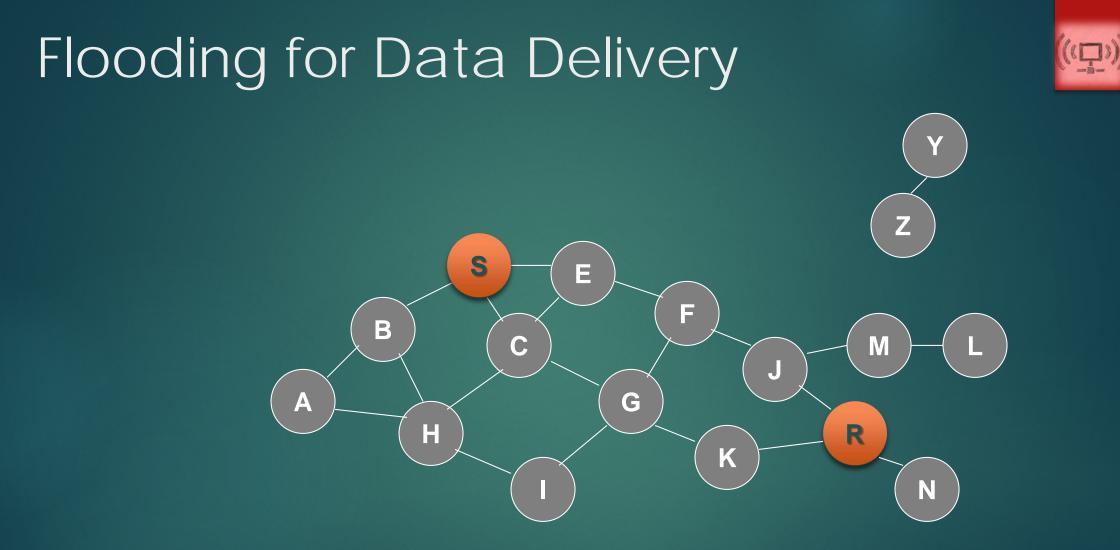
- Proactive protocols may have lower latency since routes are maintained at all times
- Reactive protocols may have higher latency because a route from X to Y will be found only when X attempts to send to Y

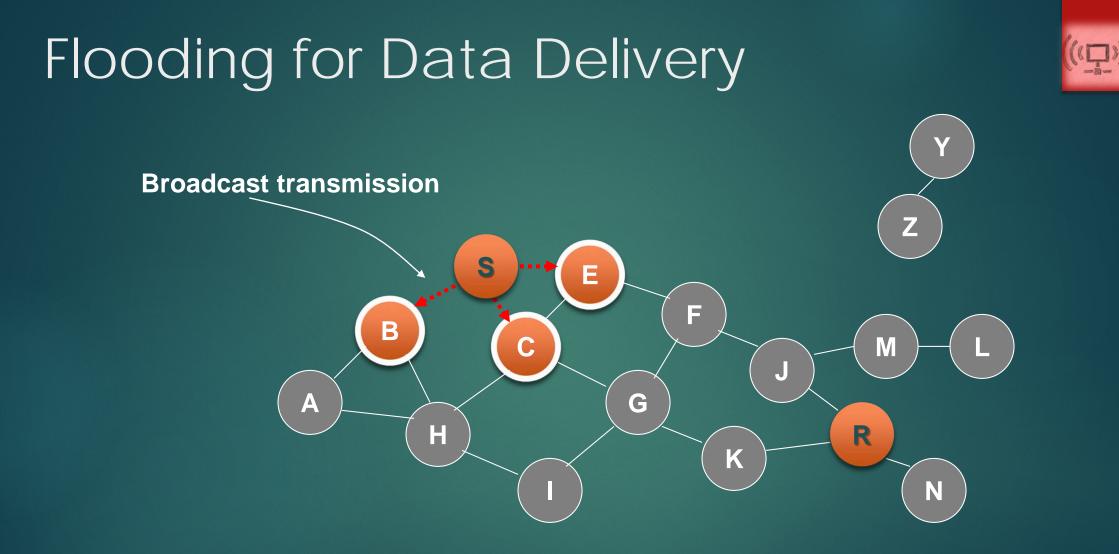
Overhead of route discovery/maintenance

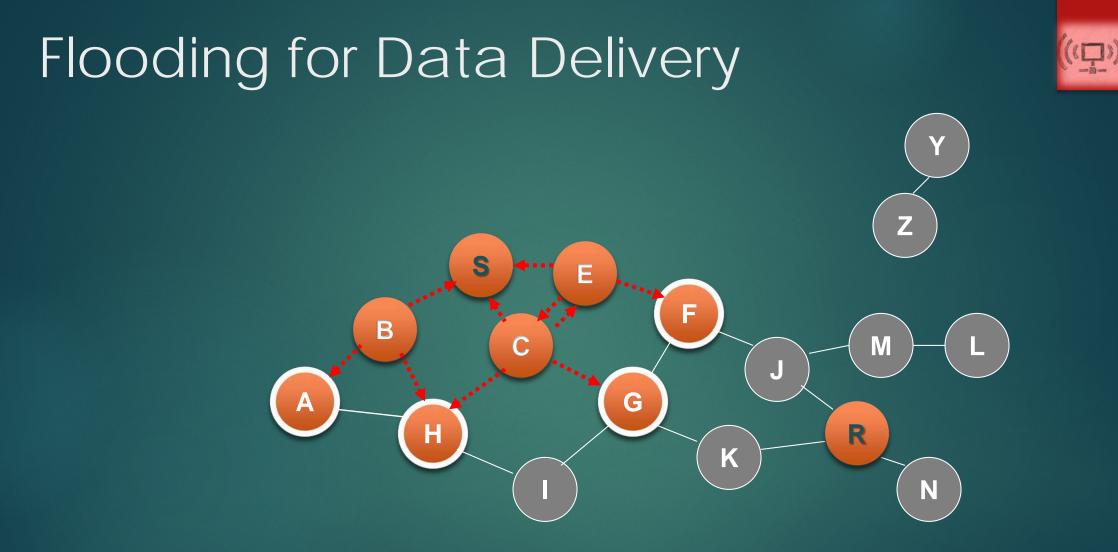
- Reactive protocols may have lower overhead since routes are determined only if needed
- Proactive protocols can (but not necessarily) result in higher overhead due to continuous route updating
- Which approach achieves a better trade-off depends on the traffic and mobility patterns

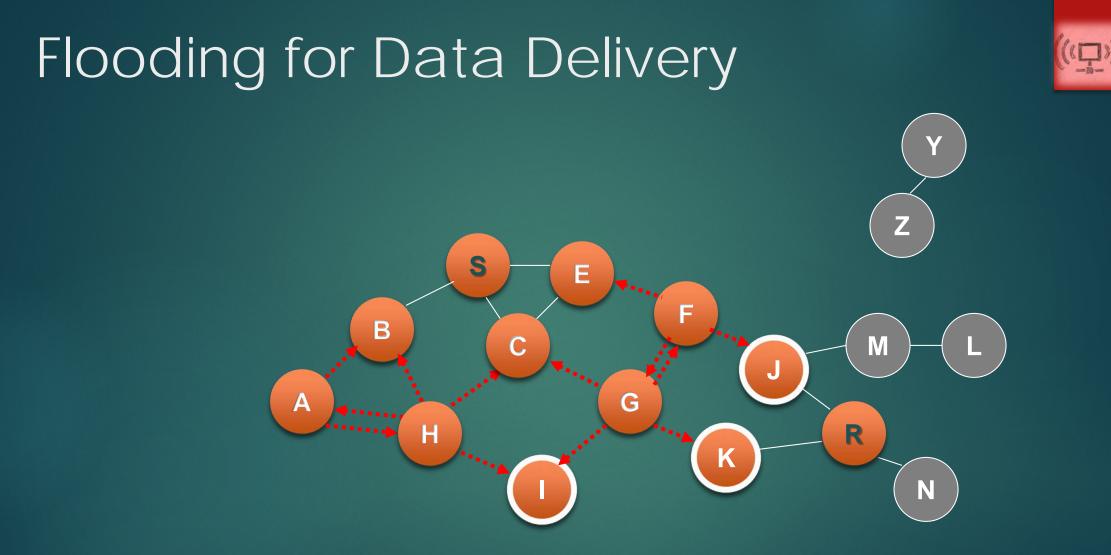


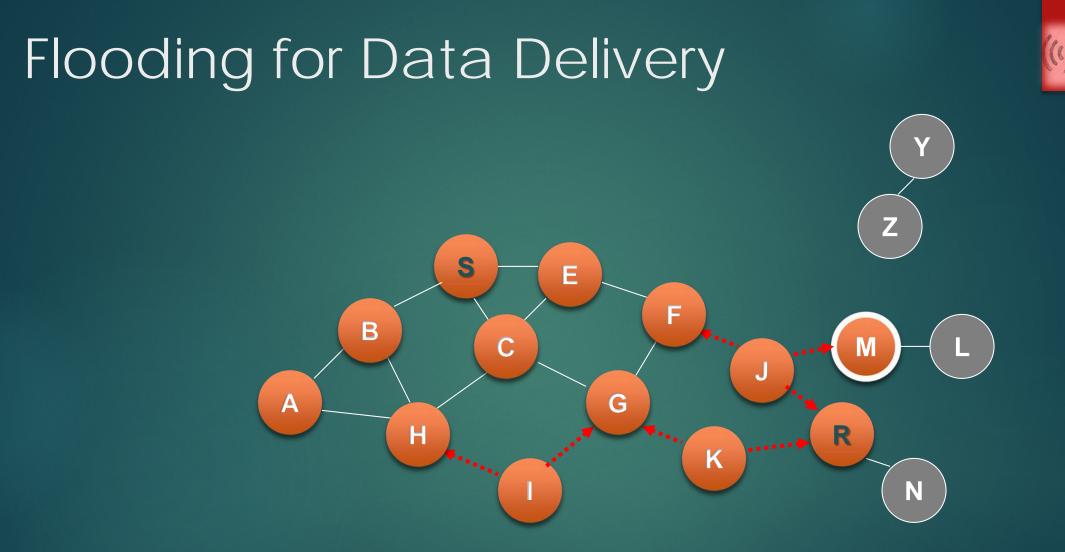
Routing Protocols Description



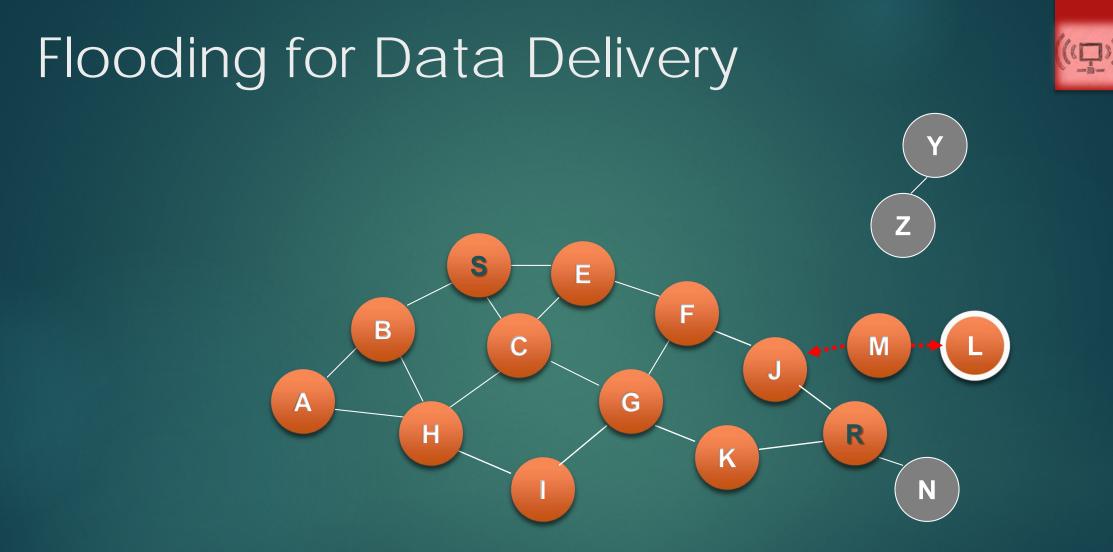


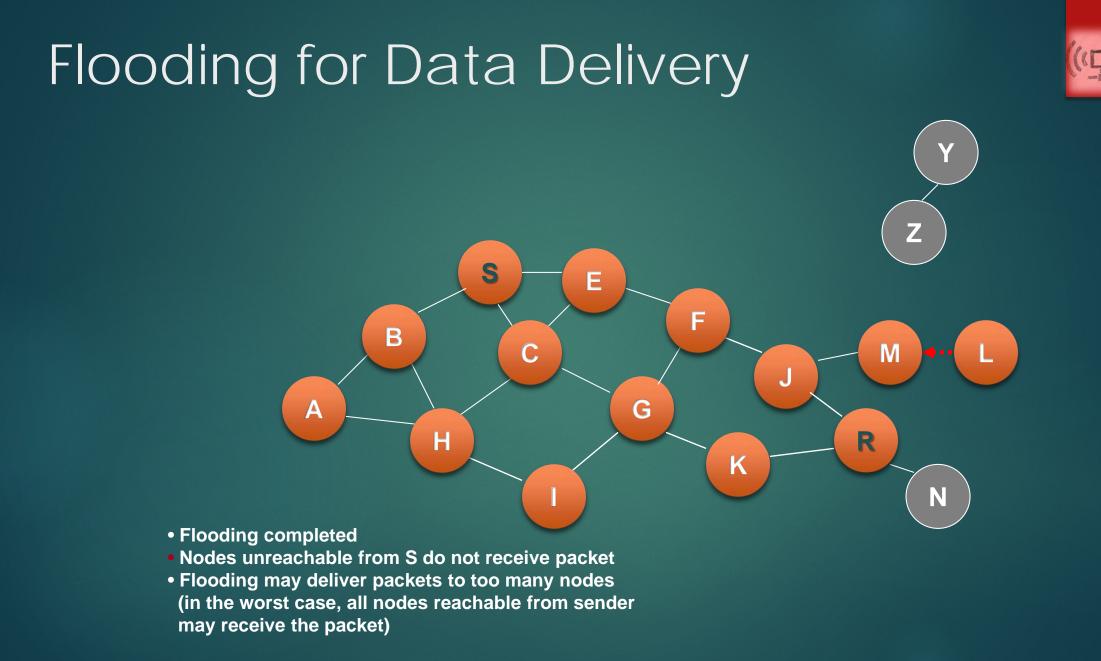






- Nodes J and K both broadcast packet P to node R
- Since nodes J and K are hidden from each other, their transmissions may collide
 - => Packet P may not be delivered to node R at all, despite the use of flooding





Flooding for Data Delivery: Advantages



- Simplicity
- Efficient than other protocols when rate of information transmission is low enough
 - overhead of explicit route discovery/maintenance incurred is higher
 - small data packets
 - infrequent transfers
 - many topology changes occur between consecutive packet transmissions
- Potentially higher reliability of data delivery

Flooding for Data Delivery: Disadvantages



High overhead Data packets may be delivered to too many nodes who do not need to receive them Lower reliability of data delivery

▶If Broadcasting is unreliable (ie. 802.11 MAC)

Flooding of Control Packets



Many protocols perform (potentially limited) flooding of control packets, instead of data packets

The control packets are used to discover routes

Discovered routes are subsequently used to send data packet(s) Dynamic Source Routing (DSR)



Source routing: entire path to destination supplied by source in packet header

Utilizes extension header following standard IP header to carry protocol information (route to destination, etc.)

DSR Protocol Activities



Route discovery

- Undertaken when source needs a route to a destination
- Route maintenance
 - Detect network topology changes
 Used when link breaks, rendering specified path unusable
- Routing (easy!)

Details



Intermediate nodes cache overheard routes "Eavesdrop" on routes contained in headers Reduces need for route discovery Intermediate node may return Route Reply to source if it already has a path stored Encourages "expanding ring" search for route

Details (cont.)



- Destination may need to discover route to source to deliver Route Reply
 - piggyback Route Reply onto new Route Request to prevent "infinite loop"
- Route Request duplicate rejection:
 - Source includes identification number in Route Request
 - Partial path inspected for "loop"

Route Maintenance



- Used when link breakage occurs
- Link breakage may be detected using link-layer ACKs, "passive ACKs", DSR ACK request
- Route Error message sent to source of message being forwarded when break detected
- Intermediate nodes "eavesdrop", adjust cached routes
- Source deletes route; tries another if one cached, or issues new Route Request
 - Piggybacks Route Error on new Route Request to clear intermediate nodes' route caches, prevent return of invalid route

Issues



Scalability

Discovery messages broadcast throughout network

Broadcast / Multicast

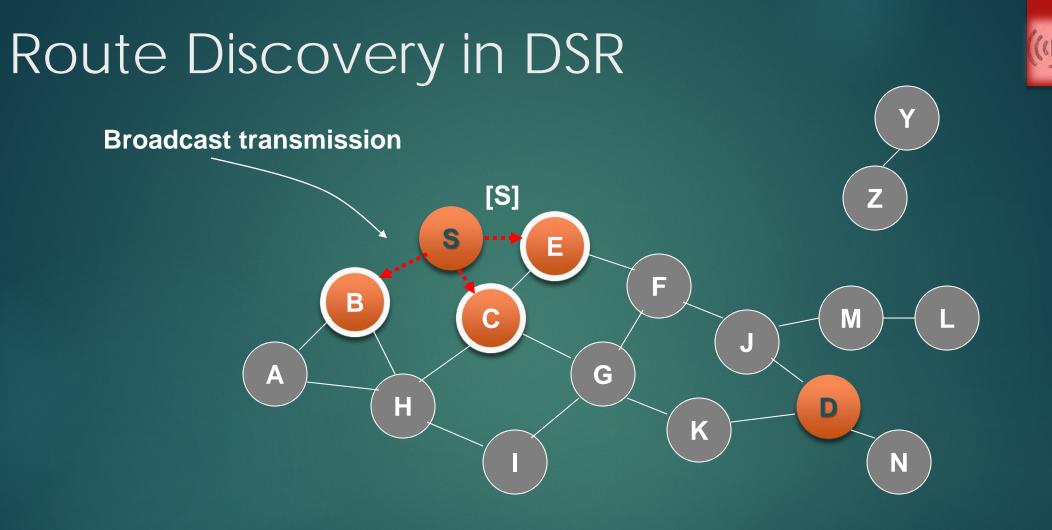
- Use Route Request packets with data included
 - Duplicate rejection mechanisms prevent "storms"

Multicast treated as broadcast; no multicast-tree operation defined

Scalability issues

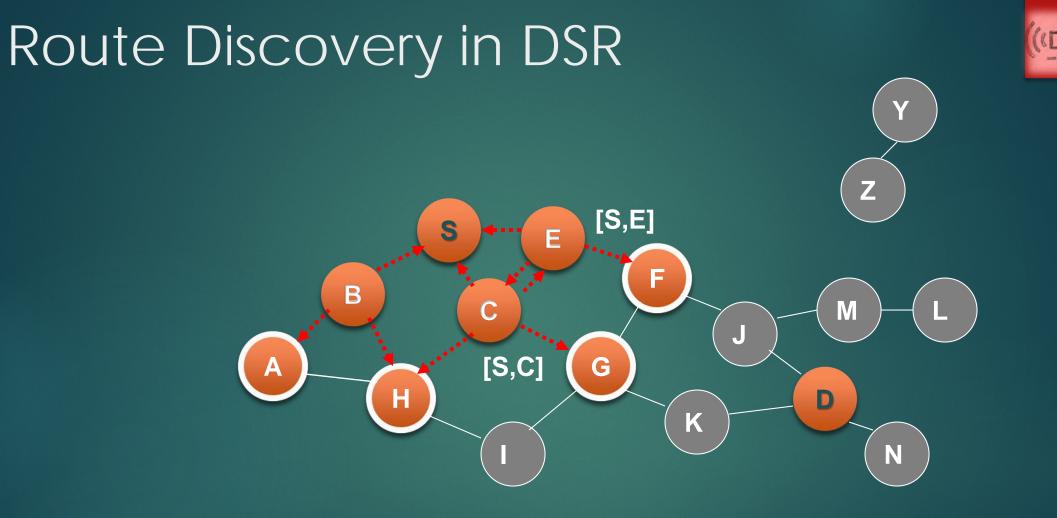




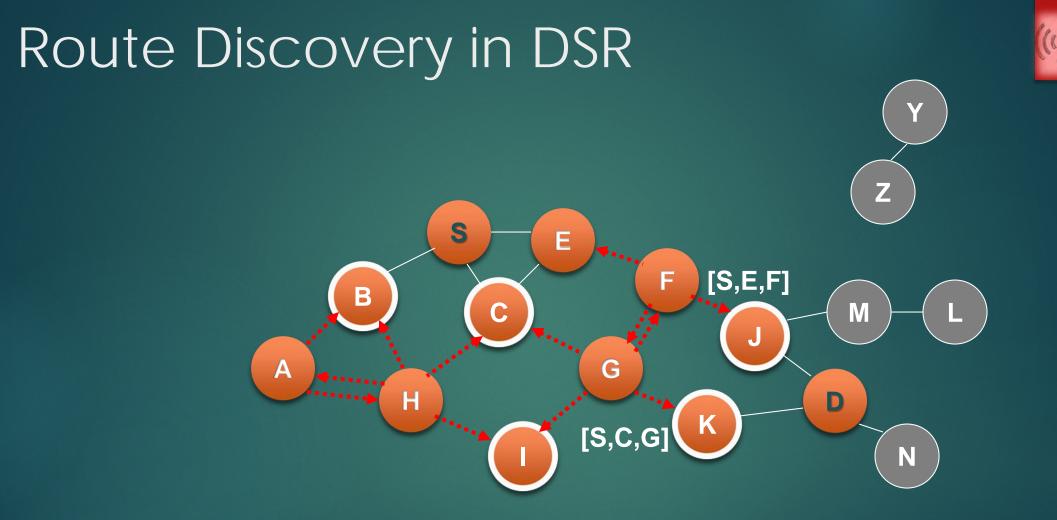


Represents transmission of RREQ

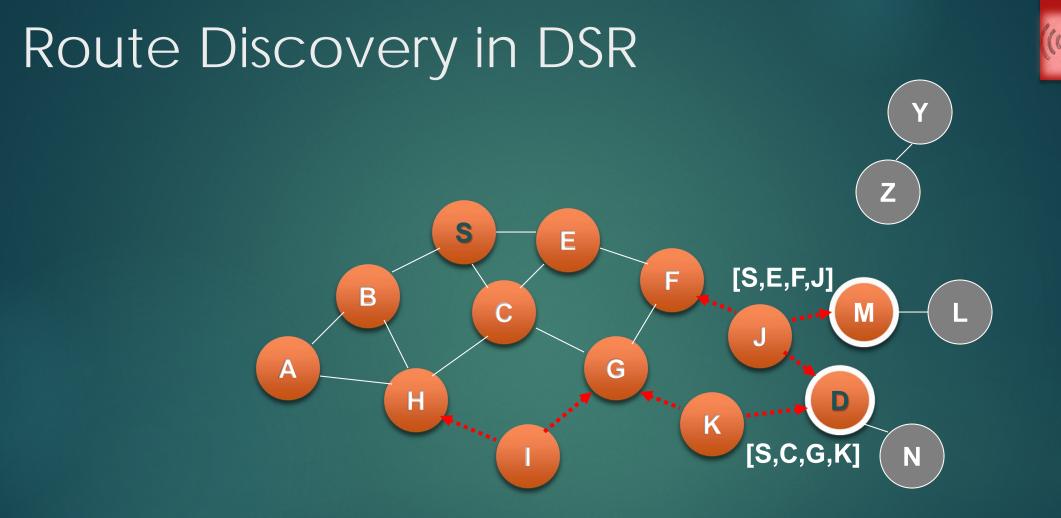
[X,Y] Represents list of identifiers appended to RREQ



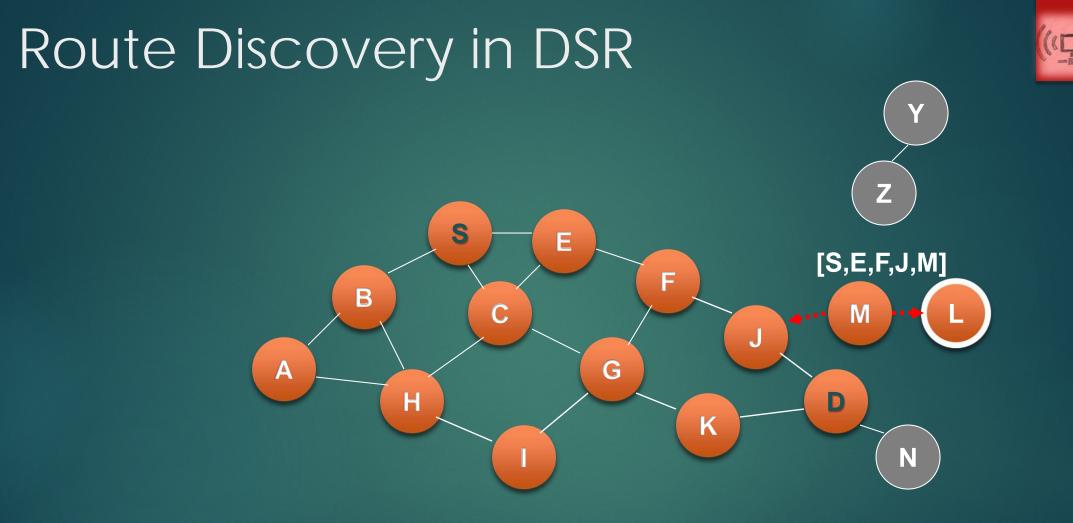
• Node H receives packet RREQ from two neighbors: potential for collision



• Node C receives RREQ from G and H, but does not forward it again, because node C has already forwarded RREQ once



- Nodes J and K both broadcast RREQ to node D
- Since nodes J and K are hidden from each other, their transmissions may collide



• Node D does not forward RREQ, because node D is the intended target of the route discovery

Route Reply in DSR



Route Reply can be sent by reversing the route in Route Request (RREQ) only if links are guaranteed to be bi-directional

- To ensure this, RREQ should be forwarded only if it received on a link that is known to be bi-directional
- If unidirectional (asymmetric) links are allowed, then RREP may need a route discovery for S from node D
 - Unless node D already knows a route to node S
 - If a route discovery is initiated by D for a route to S, then the Route Reply is piggybacked on the Route Request from D.
- If IEEE 802.11 MAC is used to send data, then links have to be bidirectional (since Ack is used)

Dynamic Source Routing (DSR)

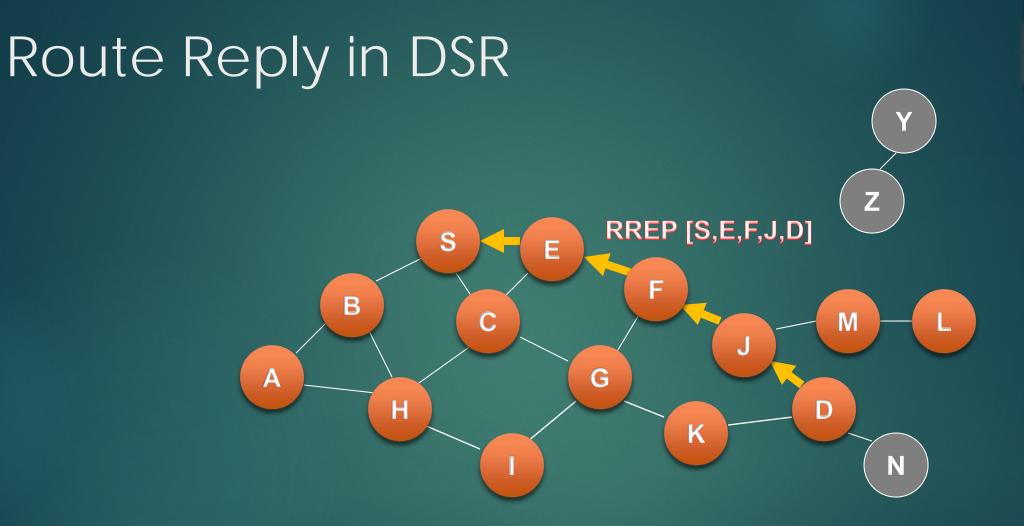


Node S on receiving RREP, caches the route included in the RREP

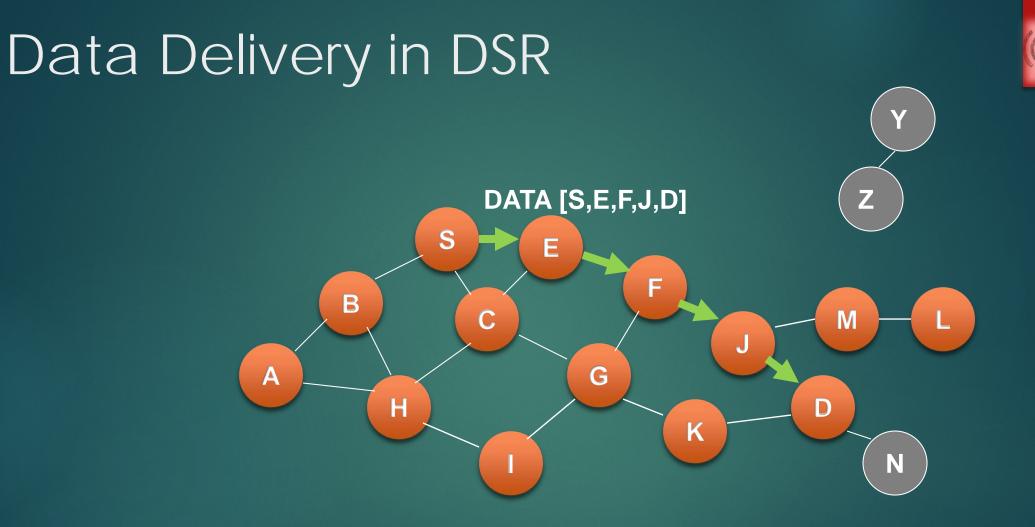
When node S sends a data packet to D, the entire route is included in the packet header

hence the name source routing

Intermediate nodes use the source route included in a packet to determine to whom a packet should be forwarded



• Node D sends back a Reply (RREP) to S with the path NOTE: If node D does not know a rout back to S it might be necessary to start it's own rout discovery to S.



Packet header size grows with route length

DSR: Advantages



Routes maintained only between nodes who need to communicate

- reduces overhead of route maintenance
- Route caching can further reduce route discovery overhead

A single route discovery may yield many routes to the destination, due to intermediate nodes replying from local caches

DSR: Disadvantages



- Packet header size grows with route length due to source routing
- Flood of route requests may potentially reach all nodes in the network
- Care must be taken to avoid collisions between route requests propagated by neighboring nodes

Insertion of random delays before forwarding RREQ

DSR: Disadvantages



 An intermediate node may send Route Reply using a stale cached route, thus polluting other caches
 Solution – Cached Route invalidation (root lifetime estimation)

- Increased contention, too many route replies using their local cache node caches
 - Route Reply Storm problem
 - Solution preventing a node from sending RREP if it hears another RREP with a shorter route

Ad-hoc On-demand Distance Vector Routing



"Hop-by-hop" protocol: intermediate nodes use lookup table to determine next hop based on destination

Utilizes only standard IP header

AODV Protocol Activities



Route discovery

Undertaken whenever a node needs a "next hop" to forward a packet to a destination

Route maintenance

Used when link breaks, rendering next hop unusable

Routing (easy!)

Route Discovery



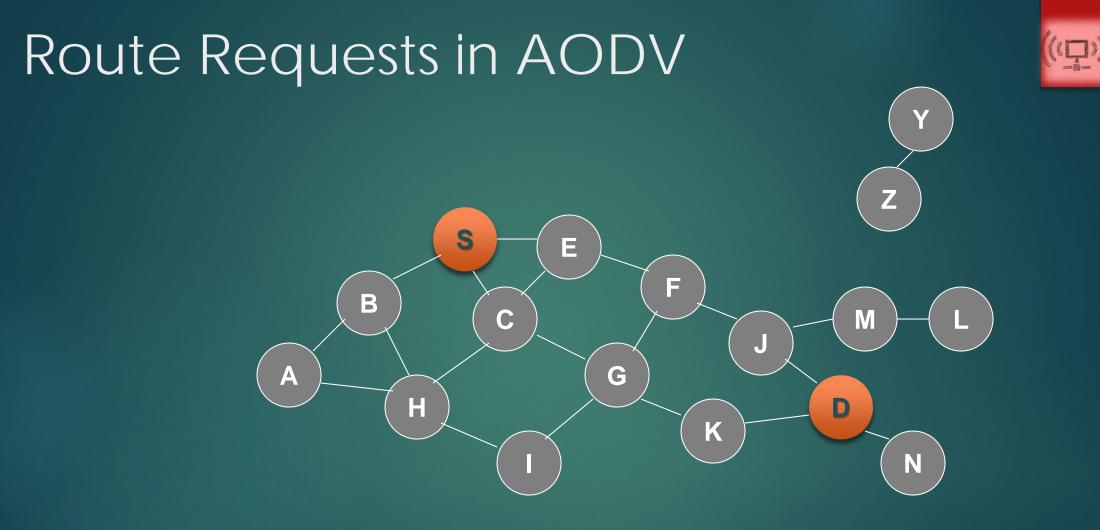
Route Request:

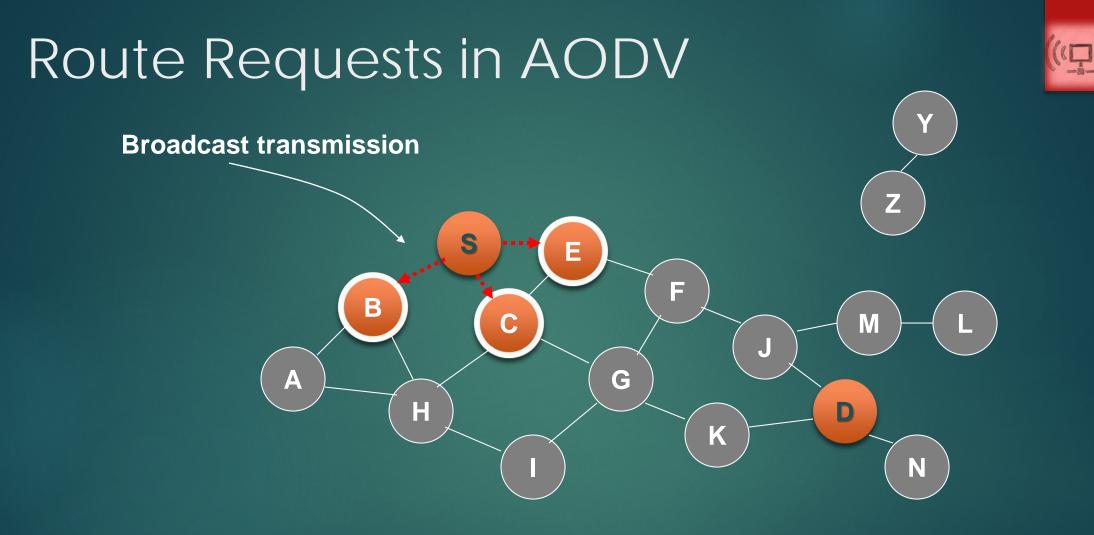
- Source broadcasts Route Request (RREQ) message for specified destination
- Intermediate node Forward message toward destination
- Route Reply
 - Destination unicasts Route Reply msg to source
 - Intermediate node create next-hop entry for destination and forward the reply
 - If source receives multiple replies, uses one with lowest hop count

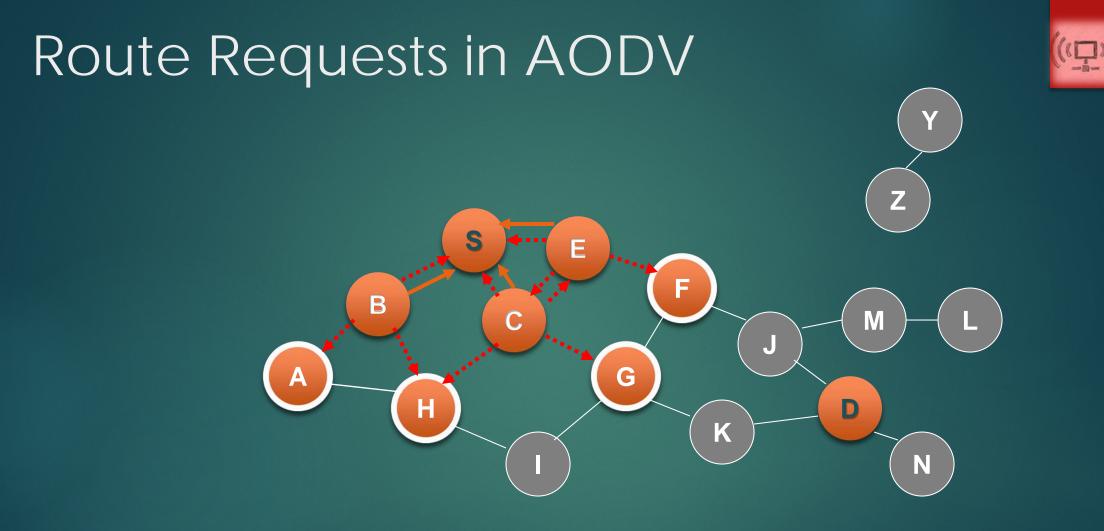
Route Maintenance

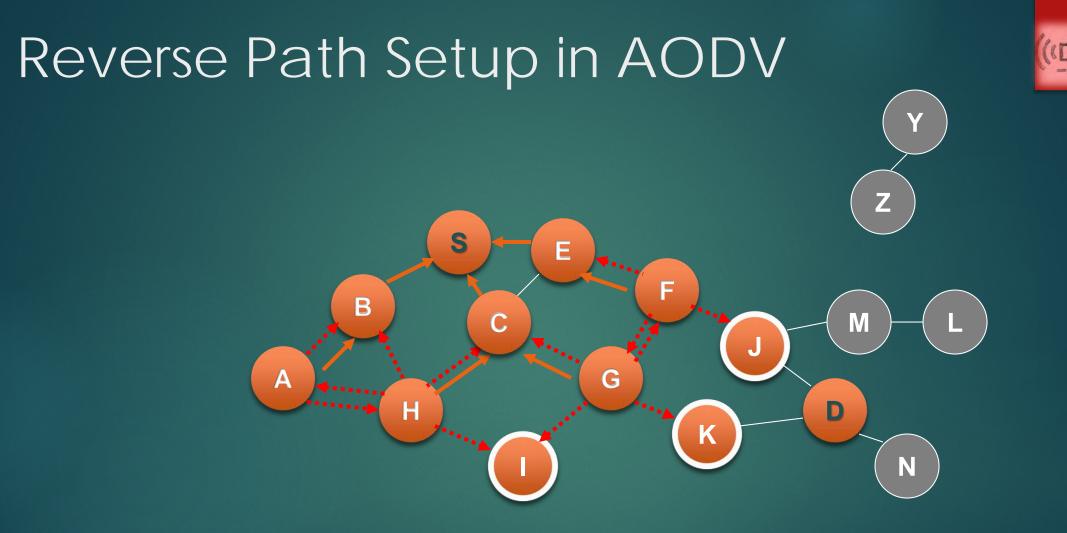


Used when link breakage occurs Detecting node may attempt "local repair" Route Error (RERR) message generated Contains list of unreachable destinations Sent to "precursors": neighbors who recently sent packet which was forwarded over broken link Propagated recursively

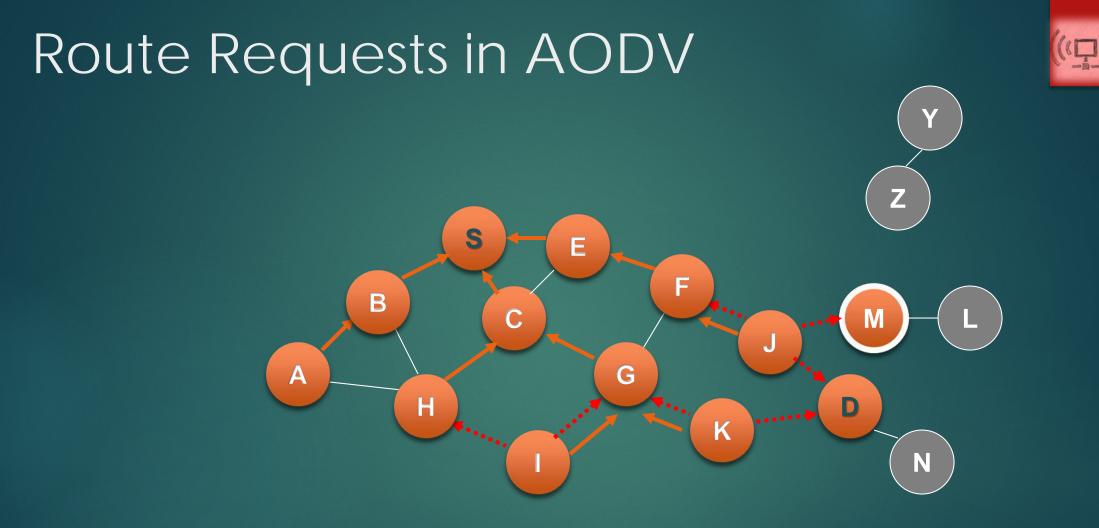


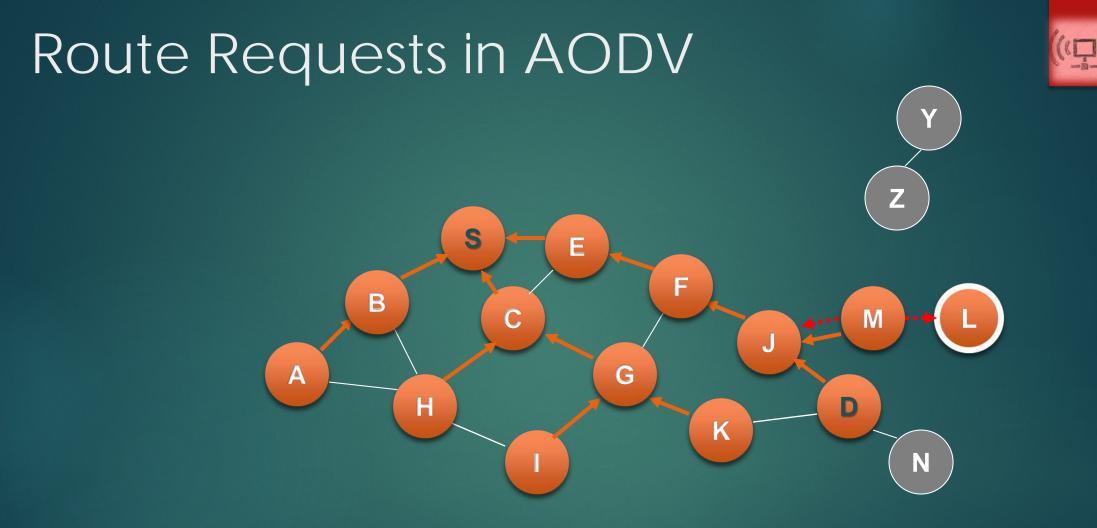




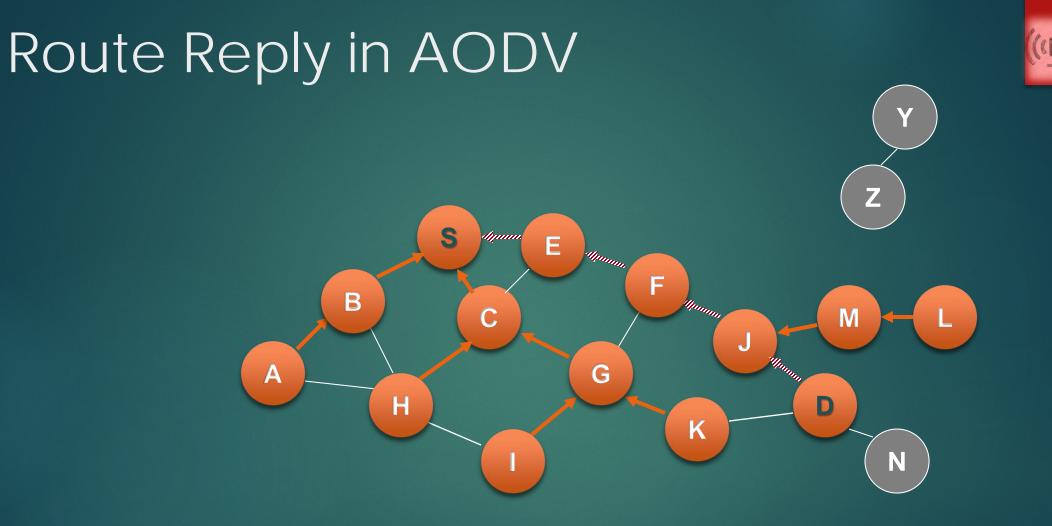


• Node C receives RREQ from G and H, but does not forward it again, because node C has already forwarded RREQ once





• Node D does not forward RREQ, because node D is the intended target of the RREQ



Represents links on path taken by RREP

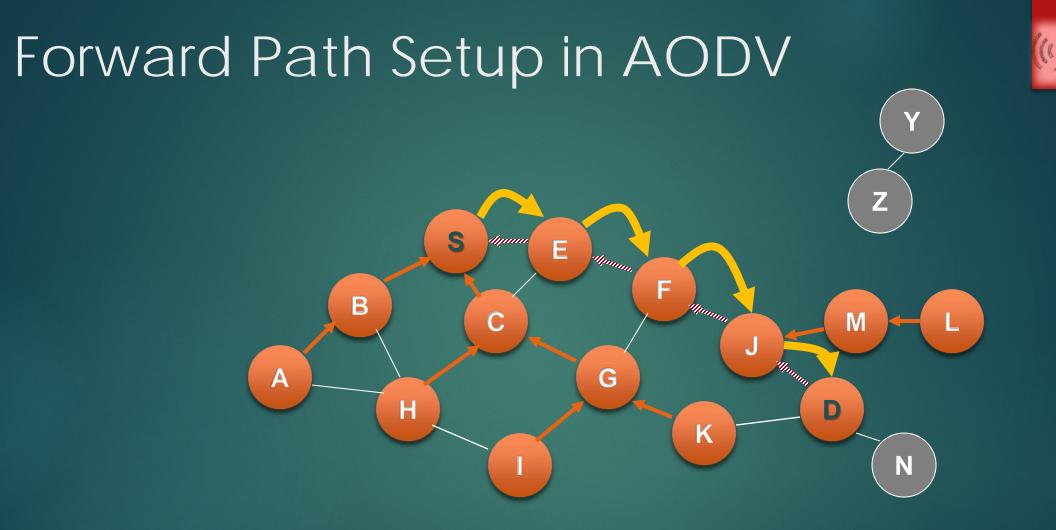
Route Reply in AODV



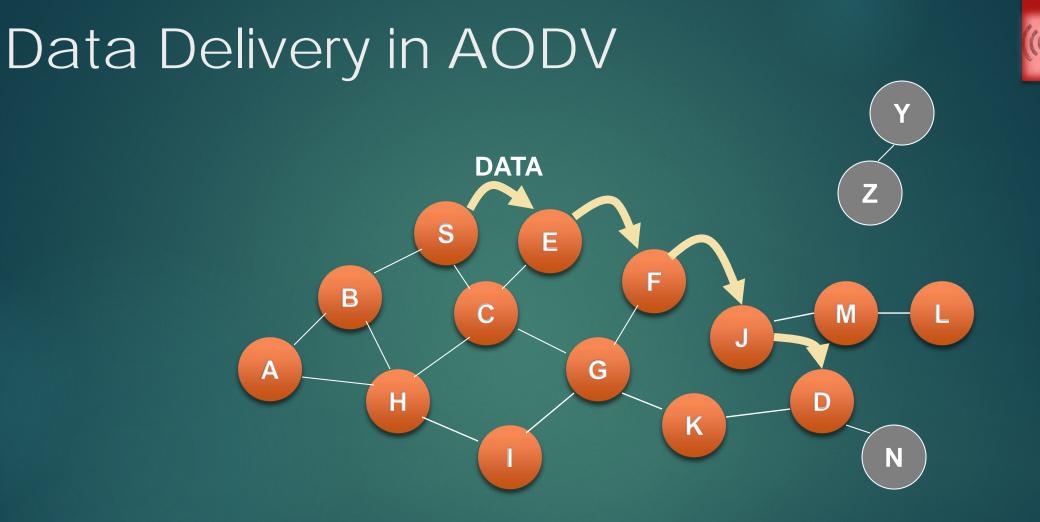
An intermediate node (not the destination) may also send a Route Reply (RREP) provided that it knows a more recent path than the one previously known to sender S

To determine whether the path known to an intermediate node is more recent, destination sequence numbers are used

The likelihood that an intermediate node will send a Route Reply when using AODV is not as high as DSR



Forward links are setup when RREP travels along the reverse path
 Represents a link on the forward path



• Routing table entries used to forward data packet.

Route is not included in packet header.

Why Sequence Numbers in AODV



- To avoid using old/broken routes
 - ► To determine which route is newer
- To prevent formation of loops
 - Assume that A does not know about failure of link C-D because RERR sent by C is lost
 - Now C performs a route discovery for D. Node A receives the RREQ (say, via path C-E-A)
 - Node A will reply since A knows a route to D via node B
 - Results in a loop (for instance, C-E-A-B-C)

Summary: AODV



- Routes need not be included in packet headers
- Nodes maintain routing tables containing entries only for routes that are in active use
- At most one next-hop per destination maintained at each node

DSR may maintain several routes for a single destination

Unused routes expire even if topology does not change

Overview / Comparizon



On-Demand	AODV	DSR
Overall	Medium	Medium
complexity		
Overhead	Low	Medium
Loop-free	Yes	Yes
Beaconing	No	No
requirements		
Multiple	No	Yes
route support		
Routes	Route table	Route cache
maintained in		
Route	Erase route;	Erase route;
reconfigurati	notify source	notify source
on		
methodology		
Routing	Freshest and	Shortest path
metric	shortest path	



Hybrid Protocols

Zone Routing Protocol (ZRP)

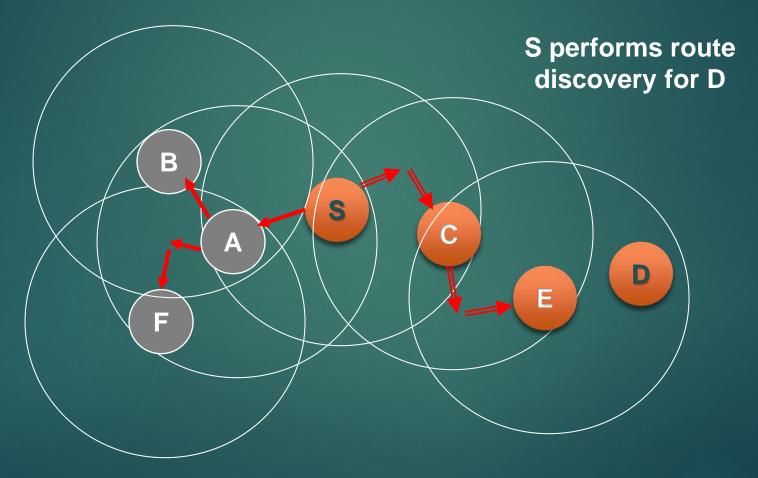


Zone routing protocol combines

Proactive protocol: which pro-actively updates network state and maintains route regardless of whether any data traffic exists or not

Reactive protocol: which only determines route to a destination if there is some data to be sent to the destination

ZRP: Example with Zone Radius = d = 2

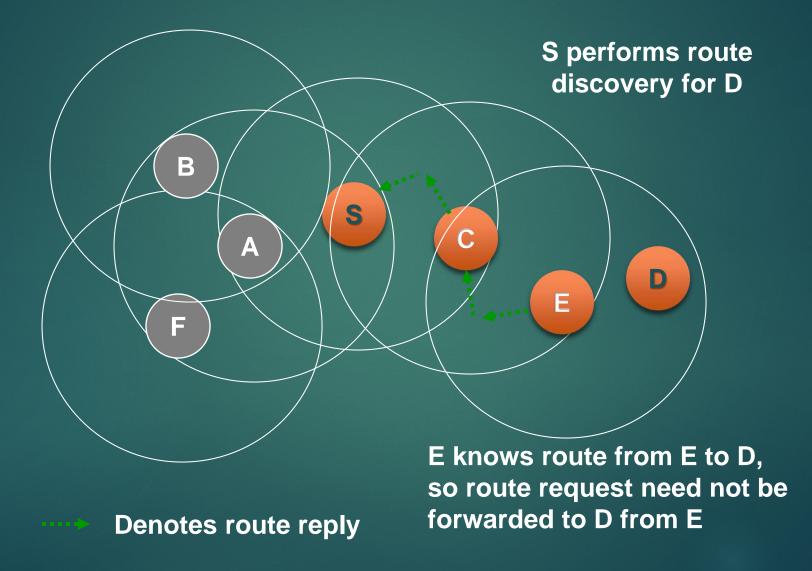


Denotes route request



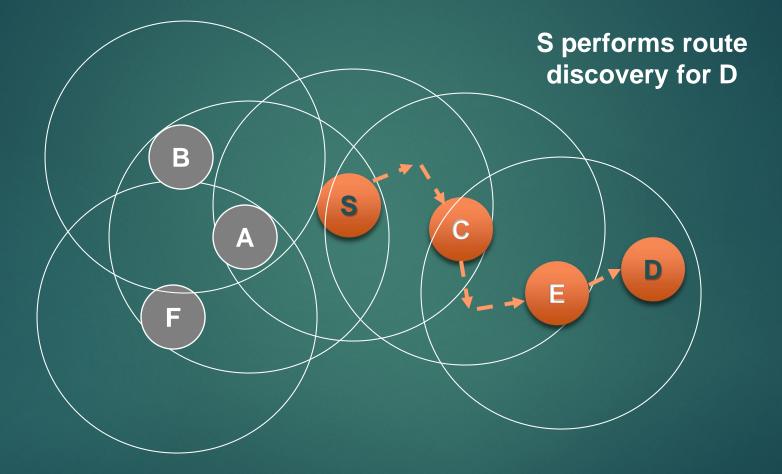
ZRP: Example with d = 2





ZRP: Example with d = 2





→ Denotes route taken by Data



hank you.

