Sensor Net Routing

Presented by Fatemeh Saremi and Nadia Tkach

Slides are based on information from original papers

Paper Reviews

- A Review of Current Routing Protocols for Ad Hoc Mobile Wireless Networks, E.M. Royer et al, IEEE Personal Communications 1999
- Directed Diffusion: A Scalable and Robust Communication Paradigm for Sensor Networks, C. Intanagonwiwat et al, Mobicom 2000
- Learn on the Fly: Data-Driven Link Estimation and Routing in Sensor Network Backbones, Hongwei Zhang et al, Infocom 2006

A Review of Current Routing Protocols for Ad Hoc Mobile Wireless Networks

Elizabeth M. Royer, UCSB

Chai-Keong Toh, Georgia Institute of Tech.

IEEE Personal Communications, April 1999

Presented By: Fatemeh Saremi

Nadia Tkach

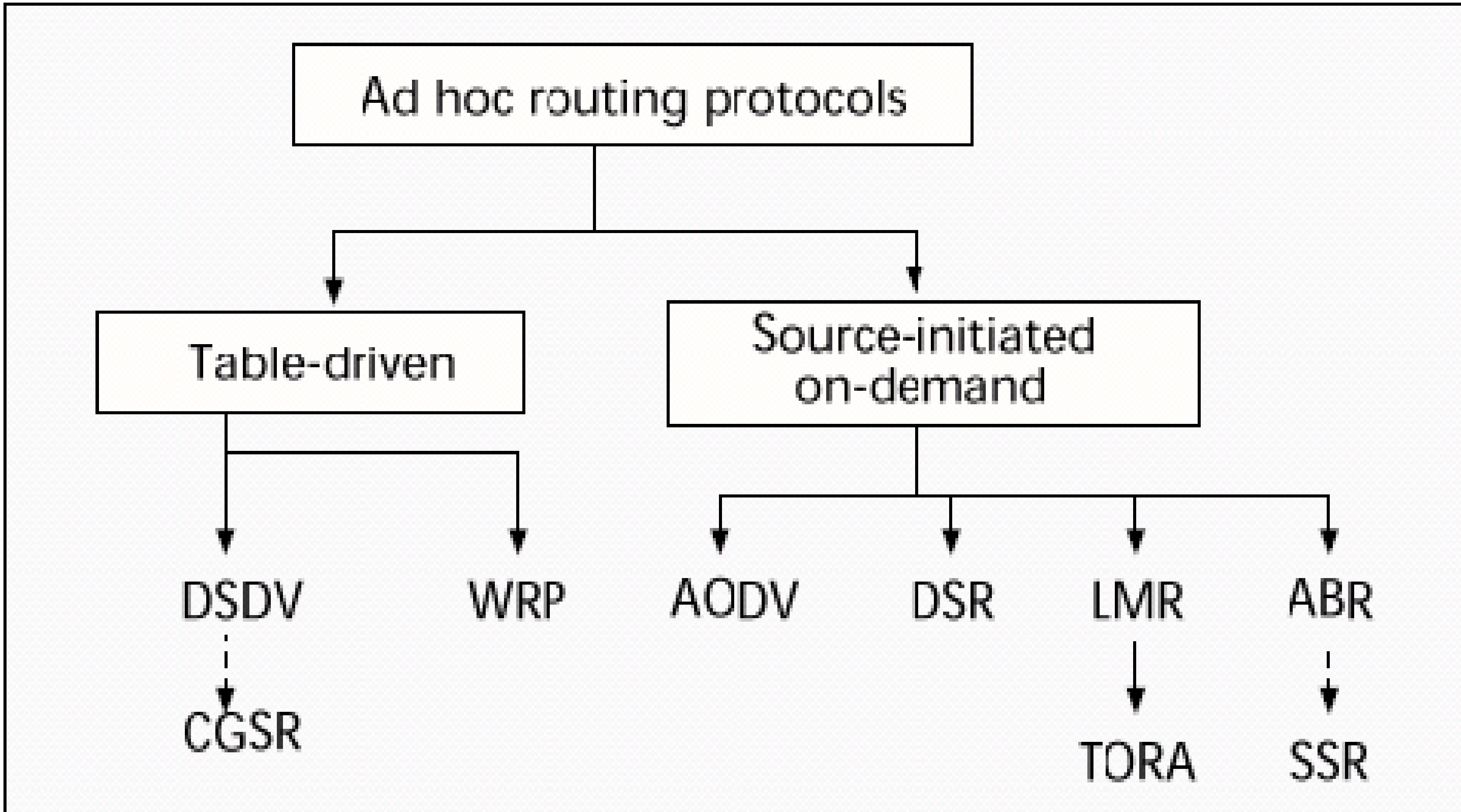
Introduction

- Wireless Mobile Networks
  - Infrastructured Network
    - Base stations
  - Ad hoc Network (Infrastructureless)
    - No fixed router
- Routing Protocol

Existing Ad Hoc Routing Protocols

- Table-Driven Routing Protocols (Proactive)
  - Maintain consistent and up-to-date routing info
    - The number of necessary routing tables
    - The broadcast methods for propagating changes
- Source-Initiated On-Demand Routing Protocols (Reactive)
  - Route discovery when needed

Classification of Routing Protocols in Ad Hoc Networks



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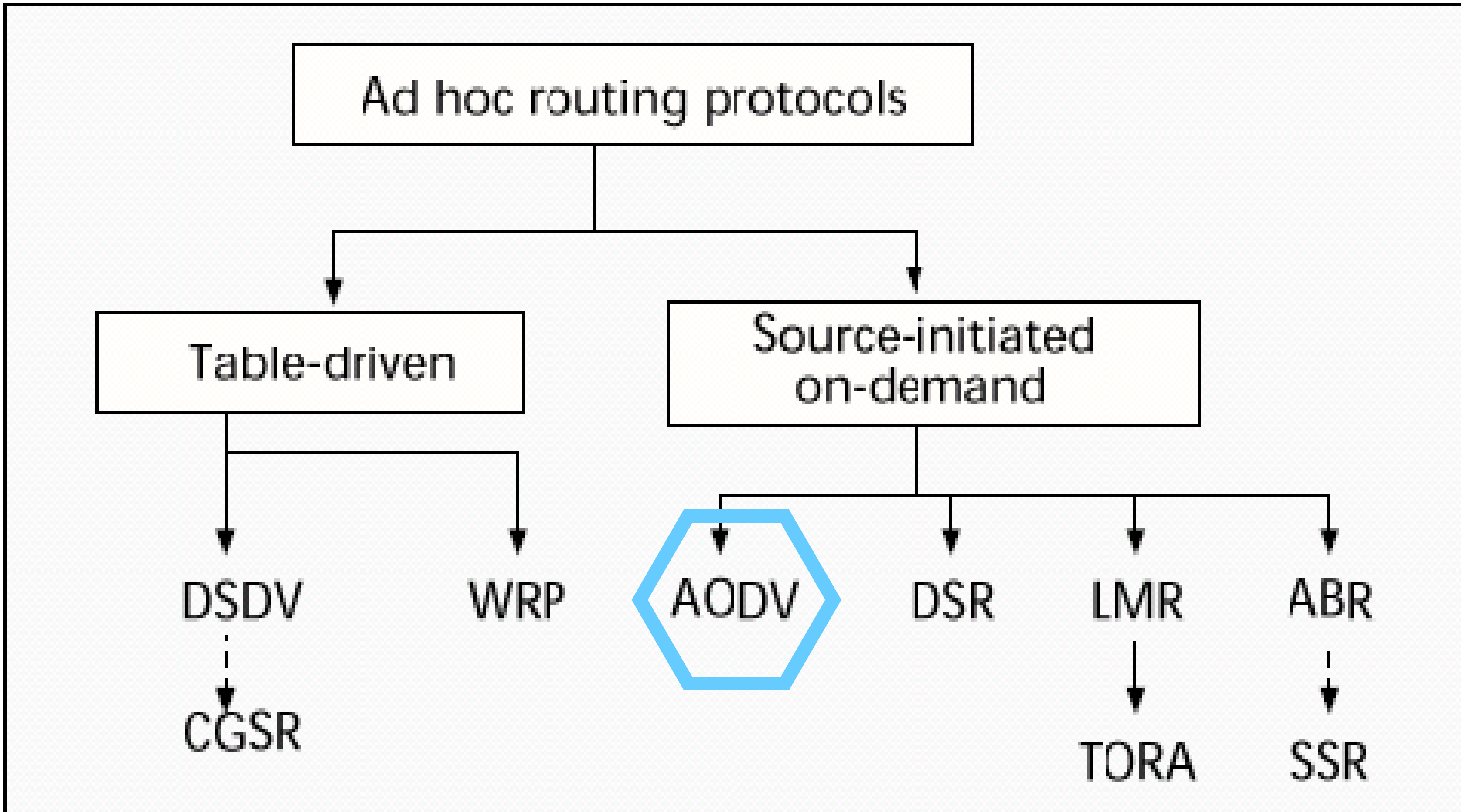
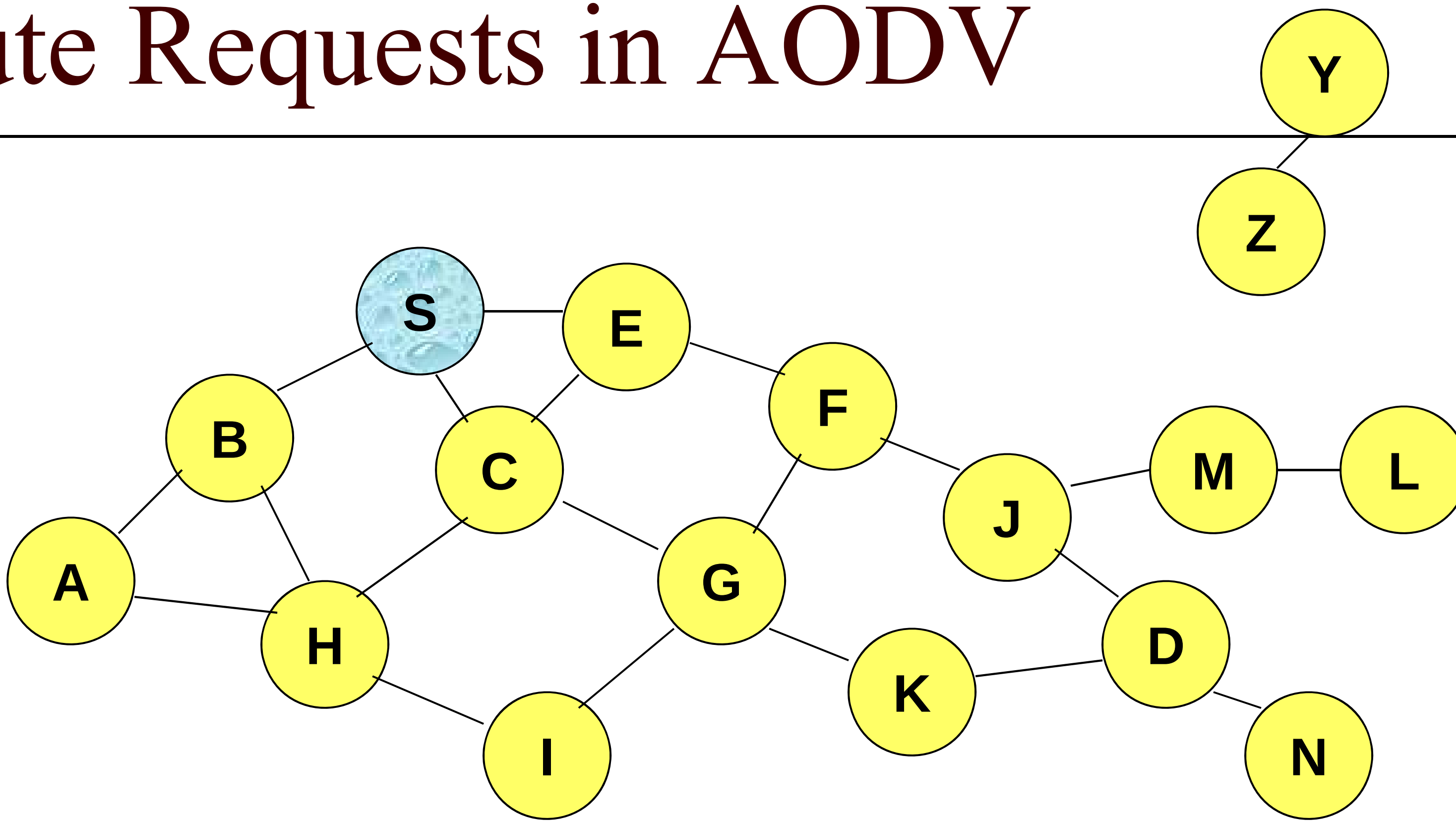


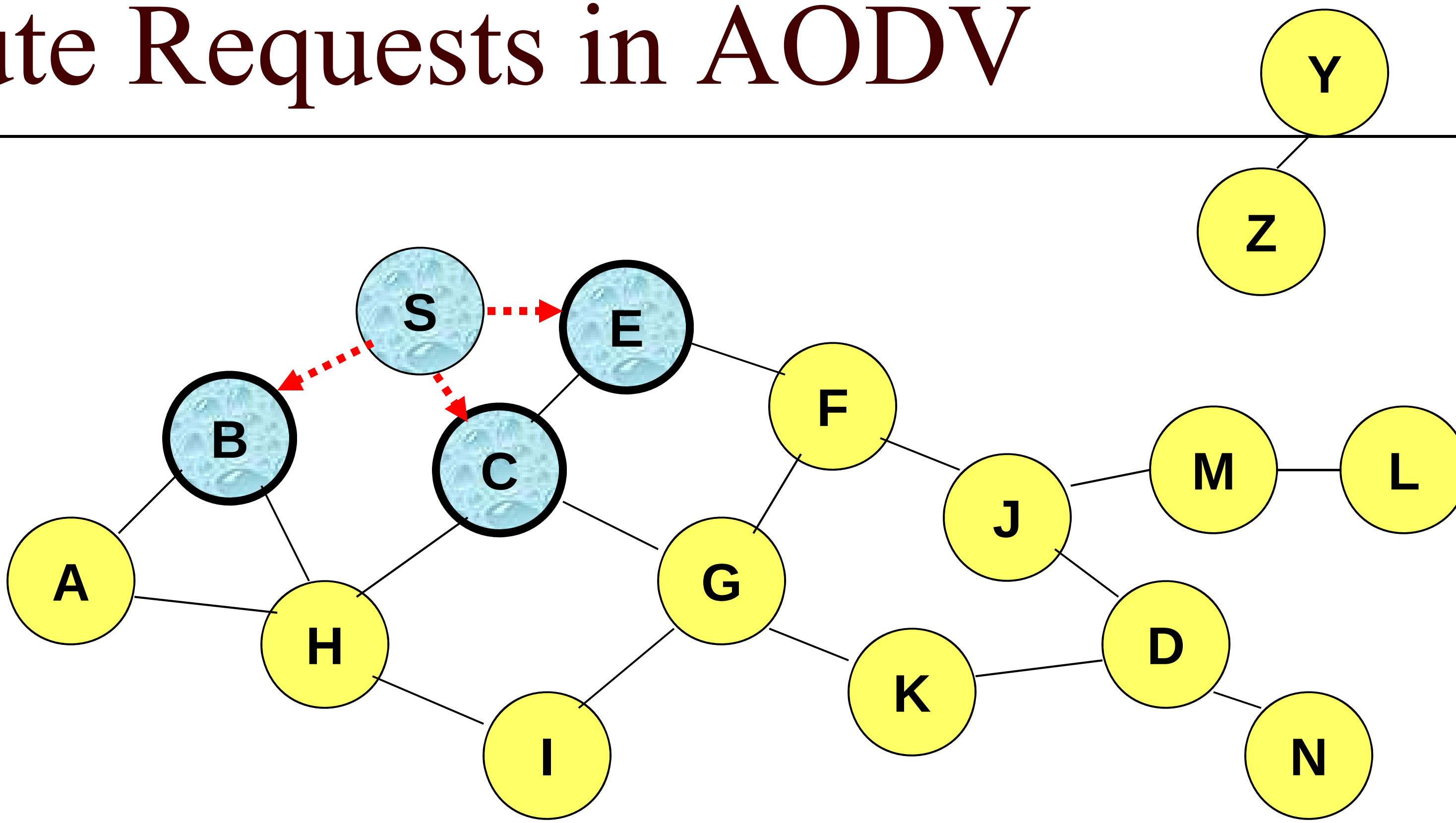
Ad Hoc On-Demand Distance Vector (AODV)

- On-demand version of the DSDV
- Distance Vector based
  - Unlike link state routing does not disseminate the state of all the links to all the hosts
  - Each host periodically broadcasts (to its neighbors) a distance vector
    - A digest of the info available to that host

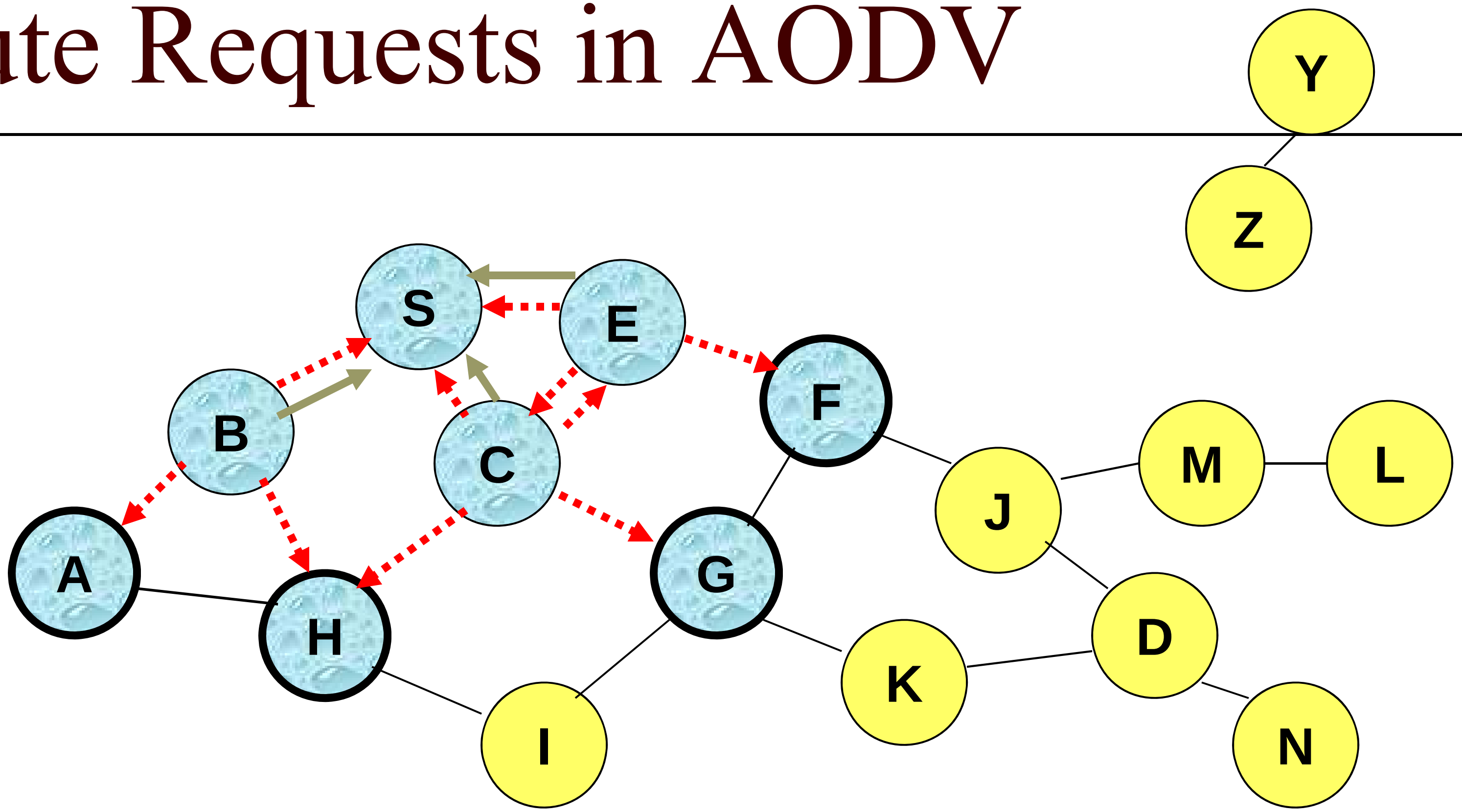
Route Requests in AODV



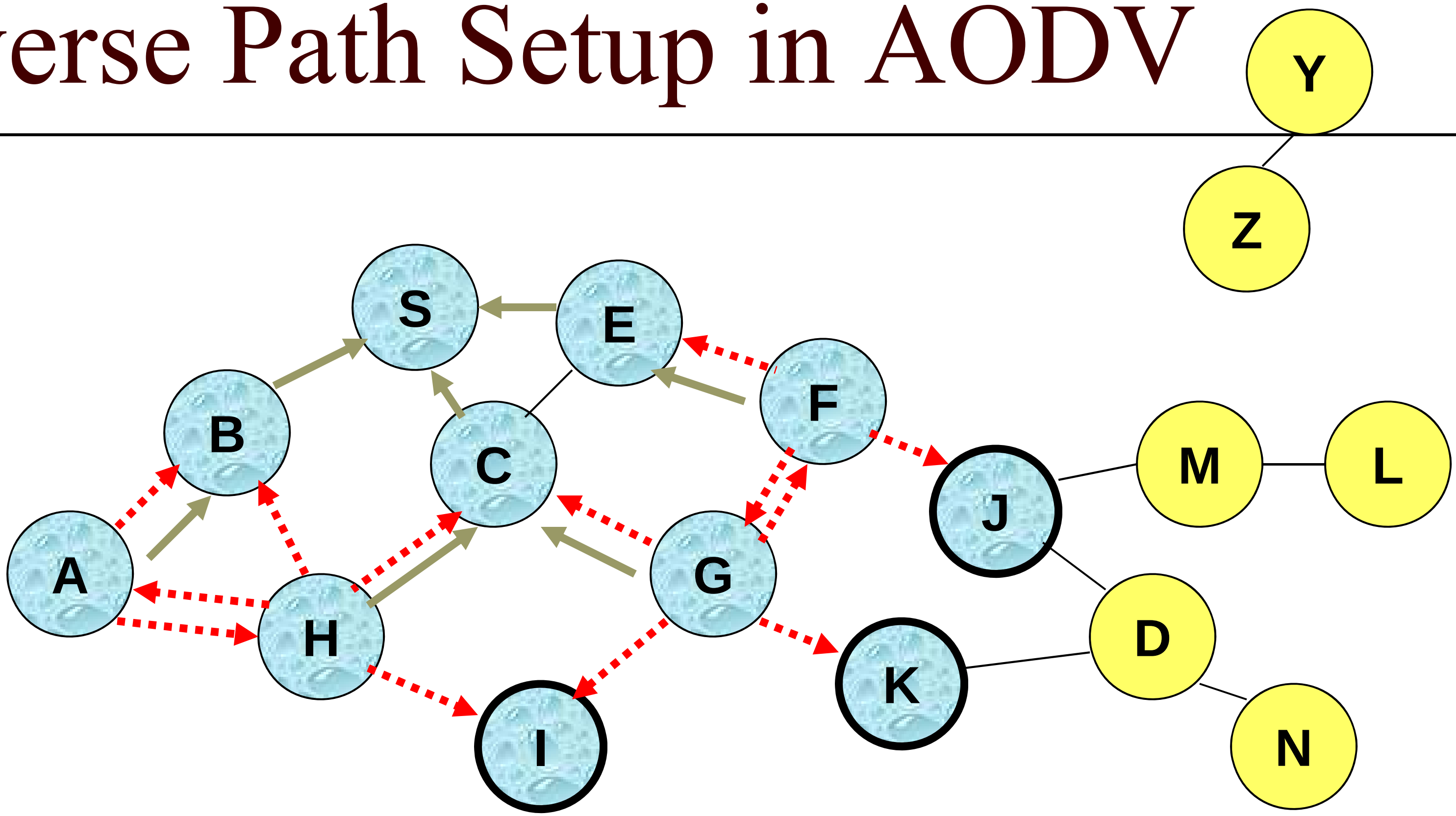
Route Requests in AODV



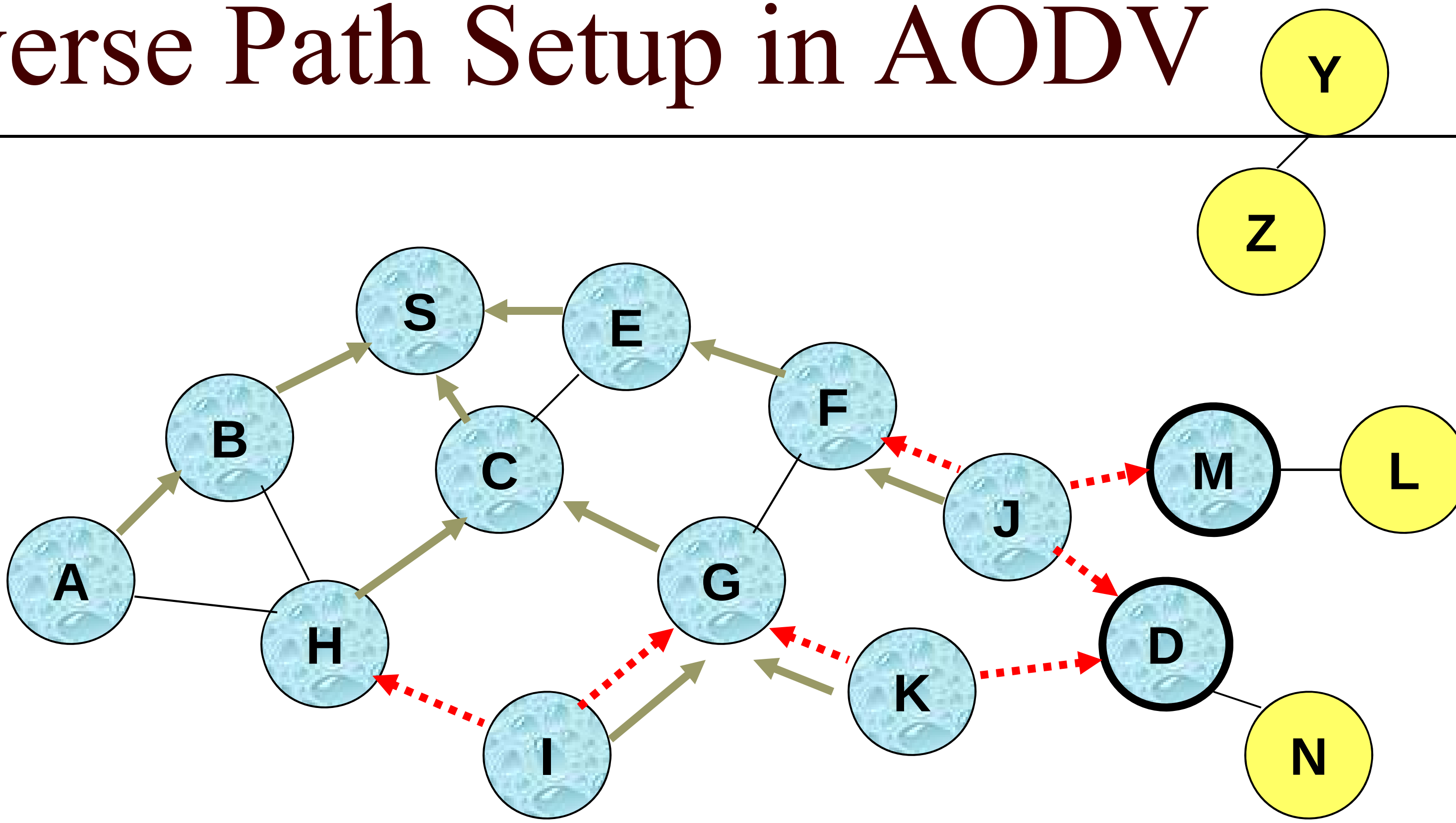
Route Requests in AODV



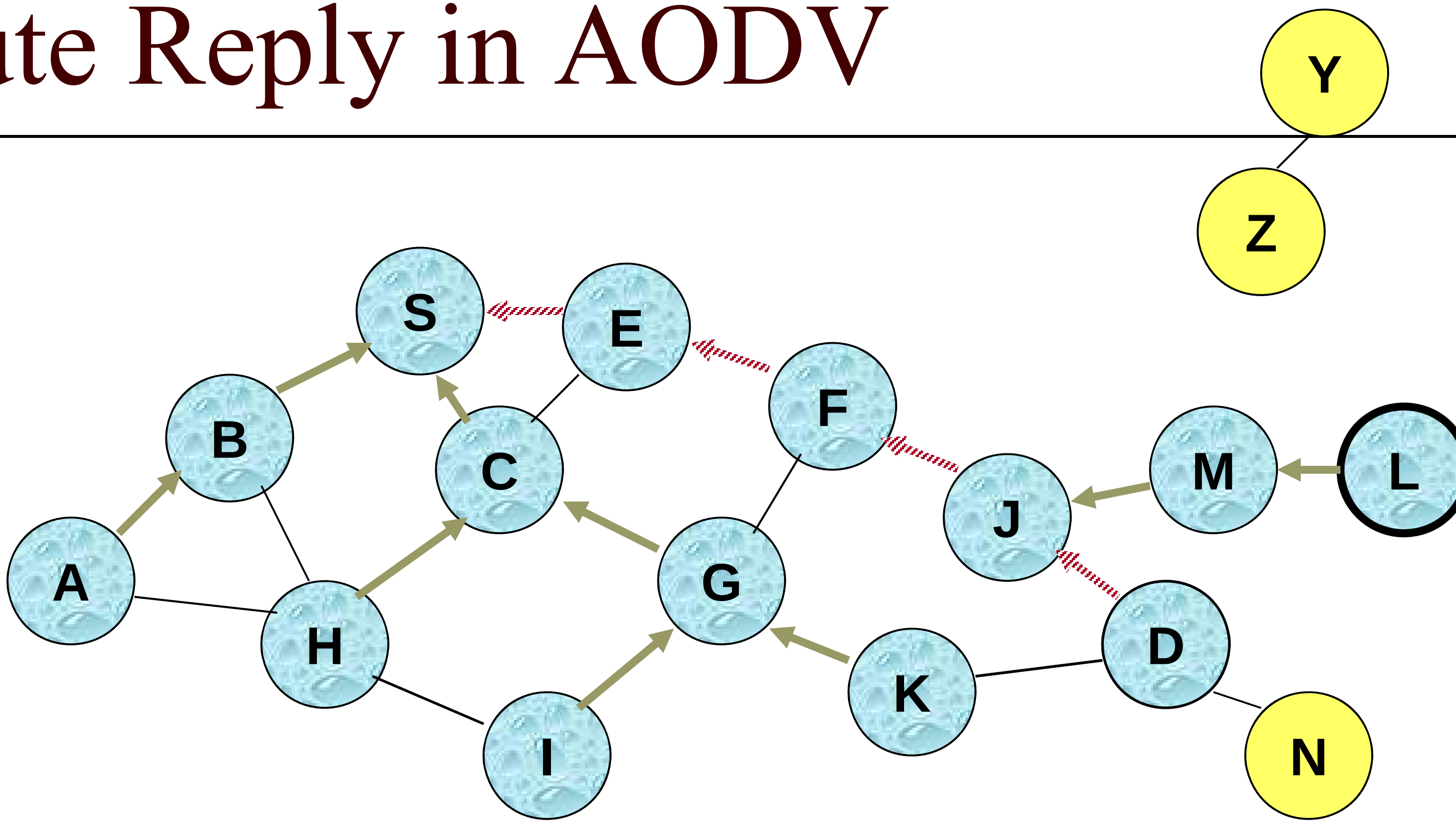
Reverse Path Setup in AODV



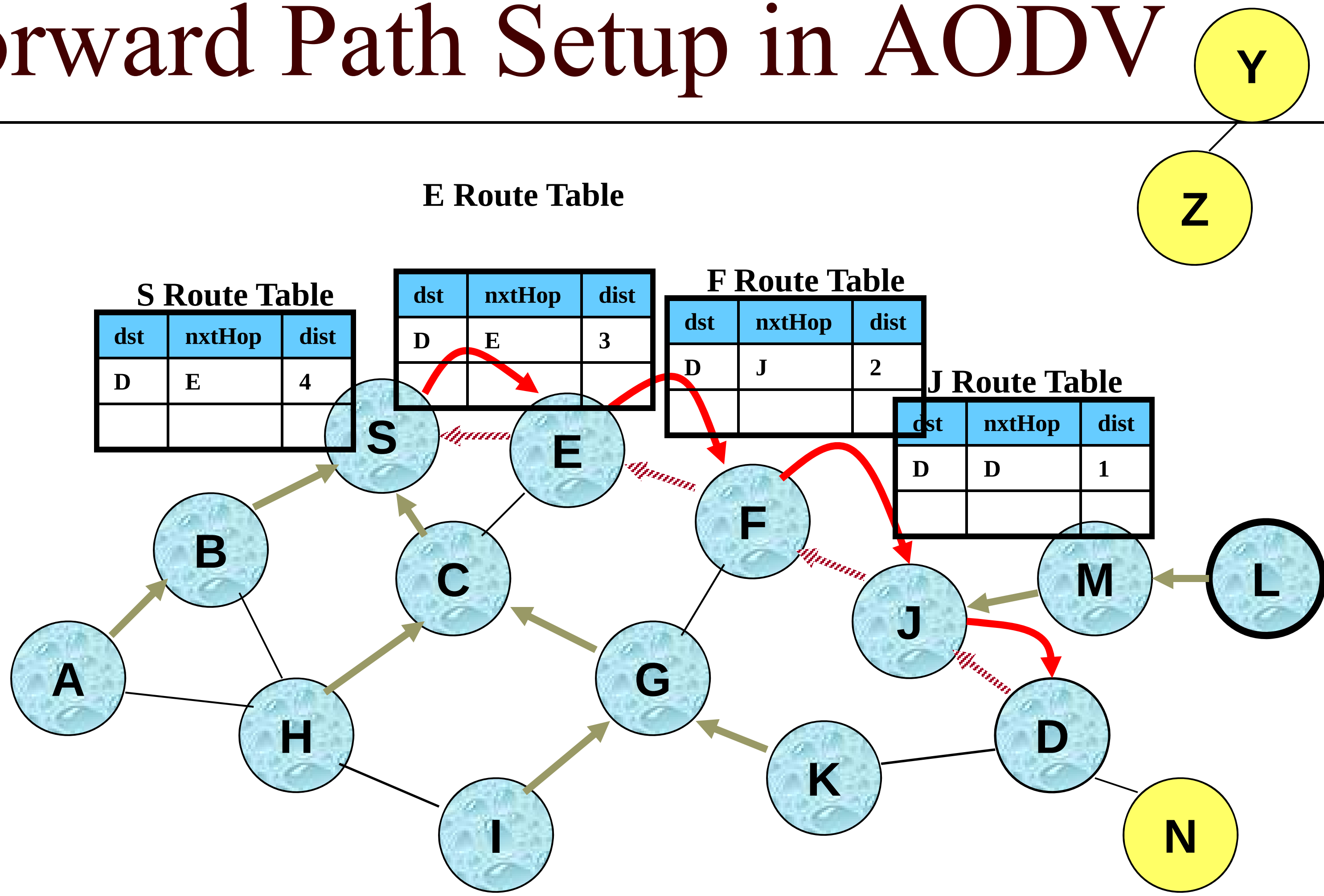
Reverse Path Setup in AODV



Route Reply in AODV



Forward Path Setup in AODV



S Route Table

dst	nxtHop	dist
D	E	4

E Route Table

dst	nxtHop	dist
D	E	3

F Route Table

dst	nxtHop	dist
D	J	2

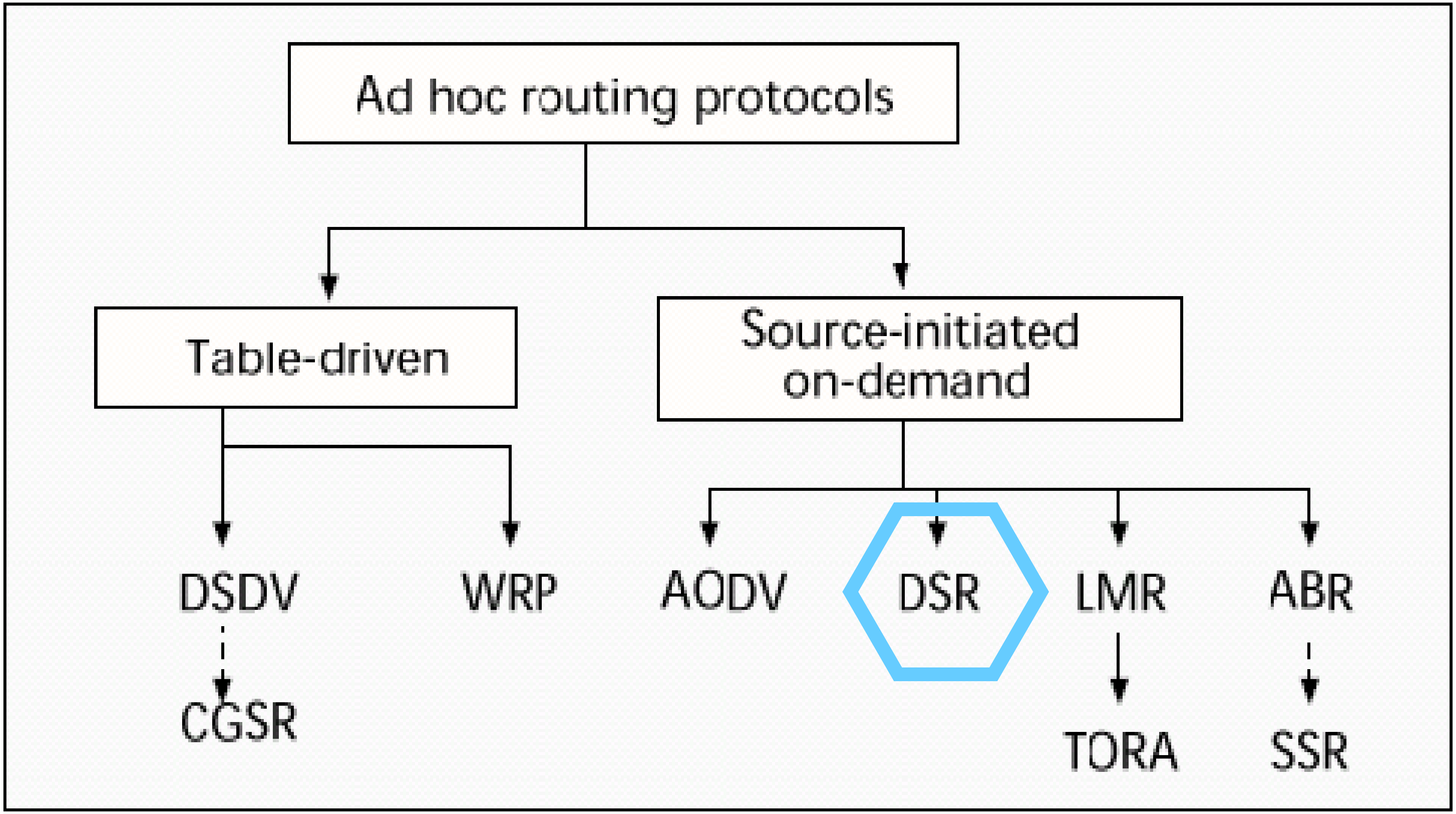
J Route Table

dst	nxtHop	dist
D	D	1

AODV

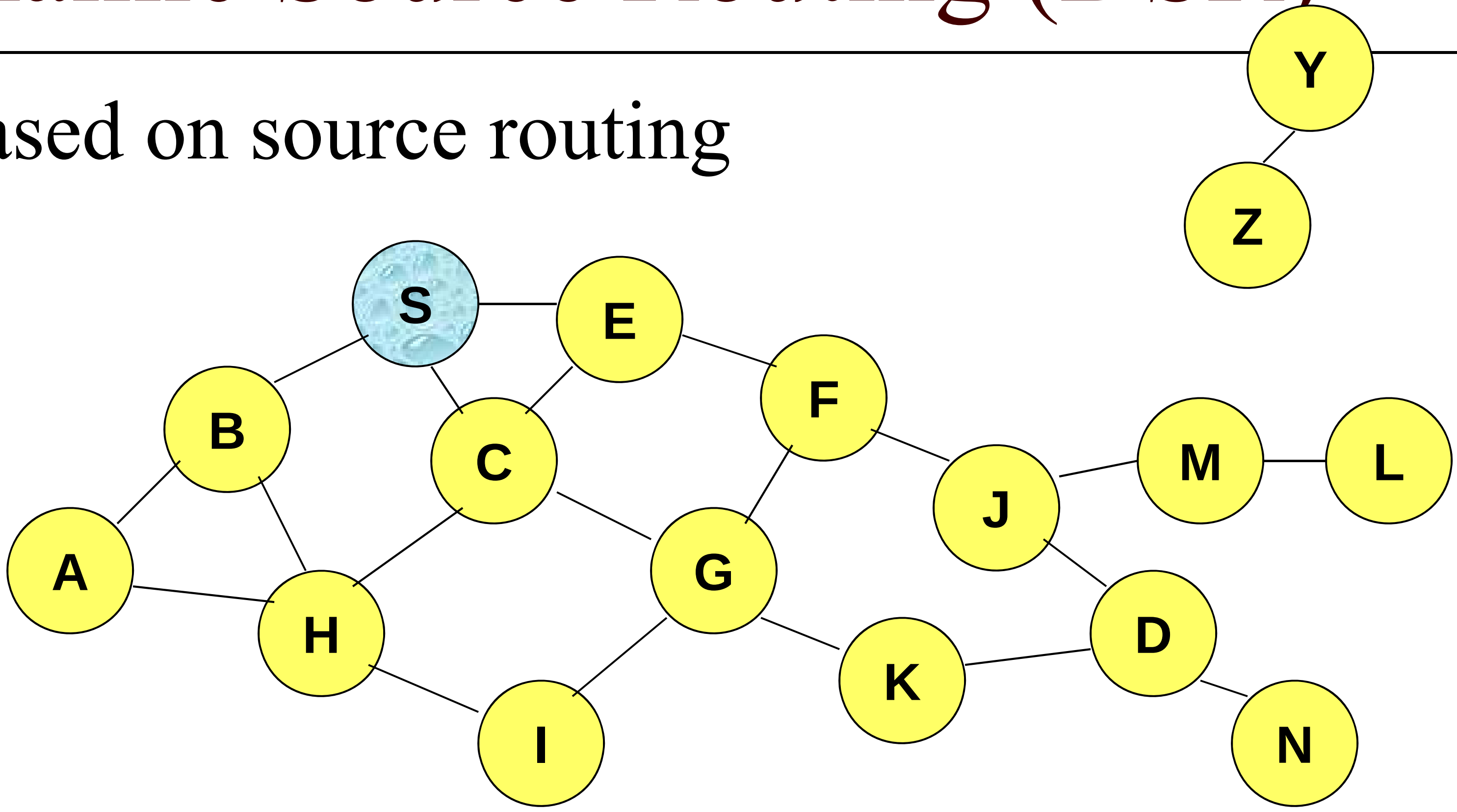
- Destination Sequence Number
  - To ensure all routes are loop-free
  - To identify the most recent route info
- Route Maintenance
  - Route Timer
    - For deletion of entries which are not used within the specified lifetime
  - Link Failure Notification
- Only the use of symmetric links supported, why?
- Hello messages
  - Really required?

Classification of Routing Protocols in Ad Hoc Networks

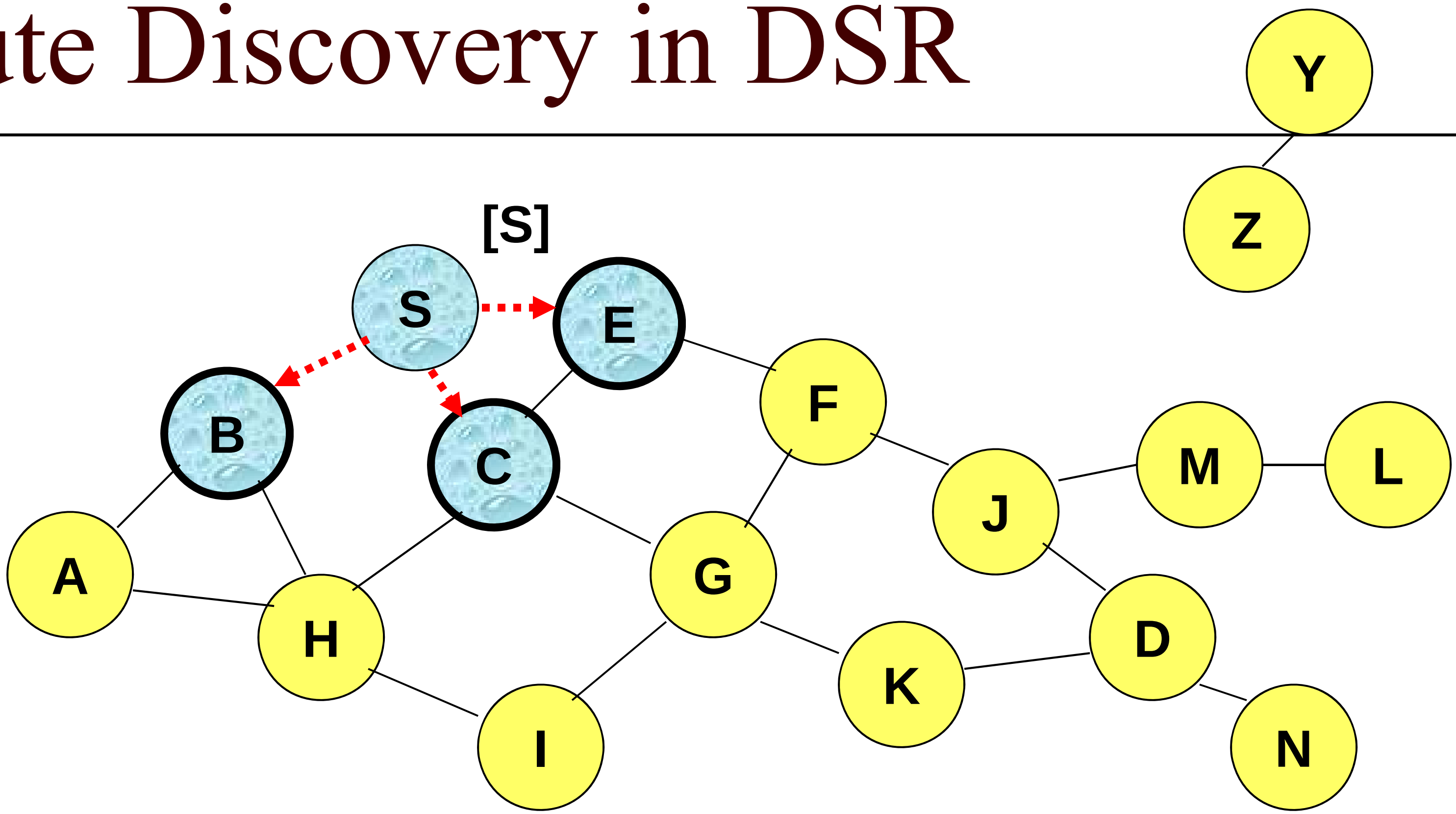


Dynamic Source Routing (DSR)

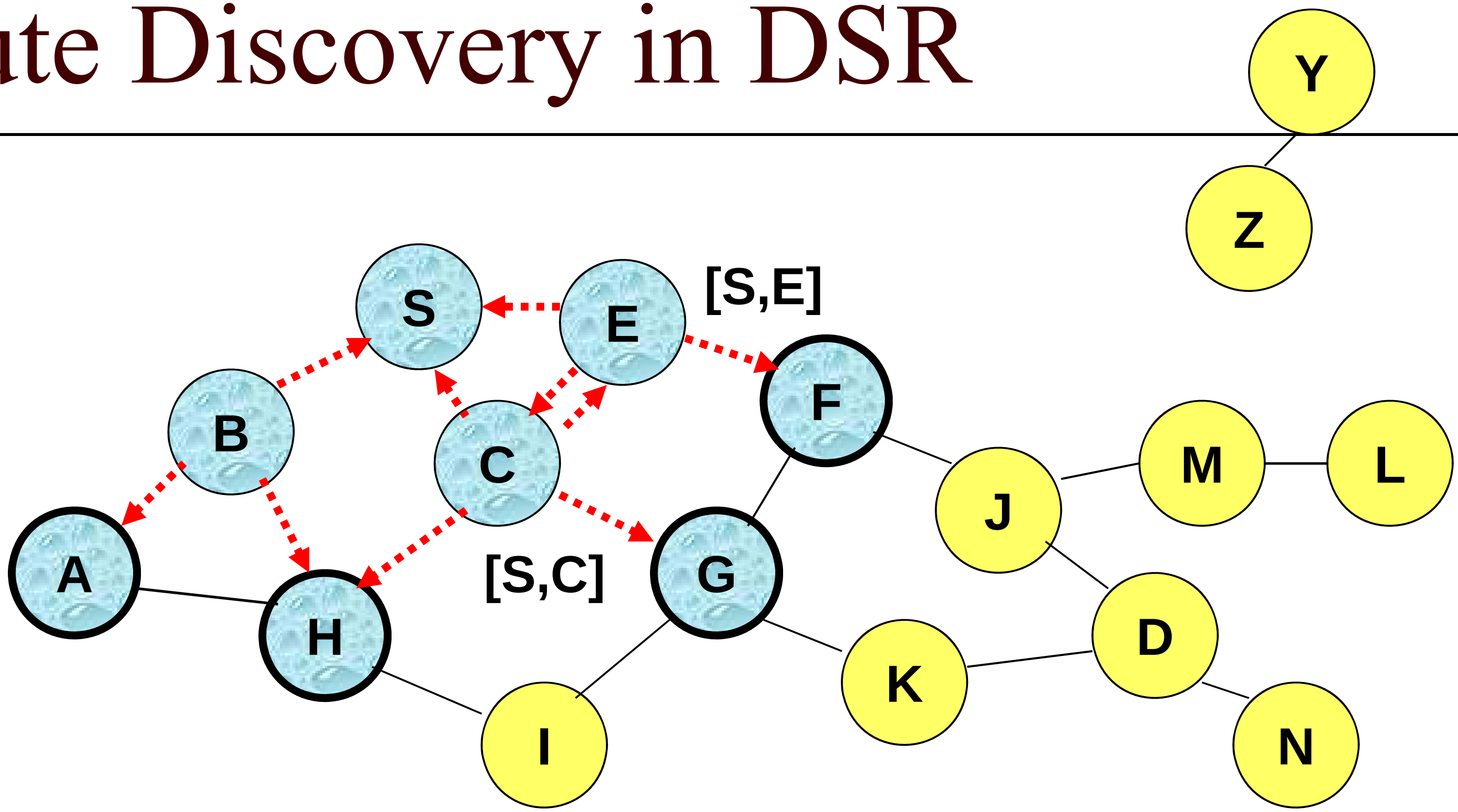
- Based on source routing



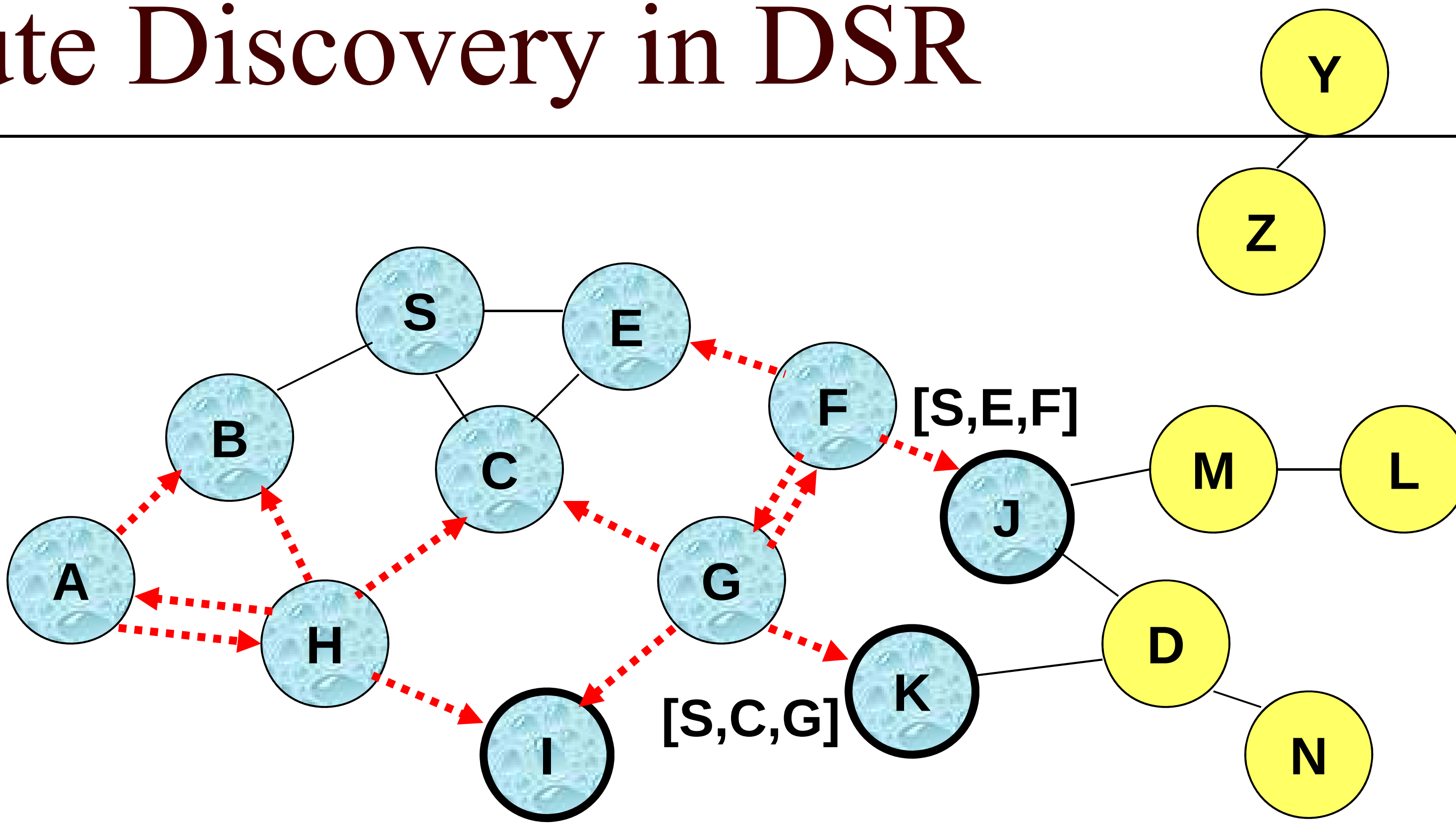
Route Discovery in DSR



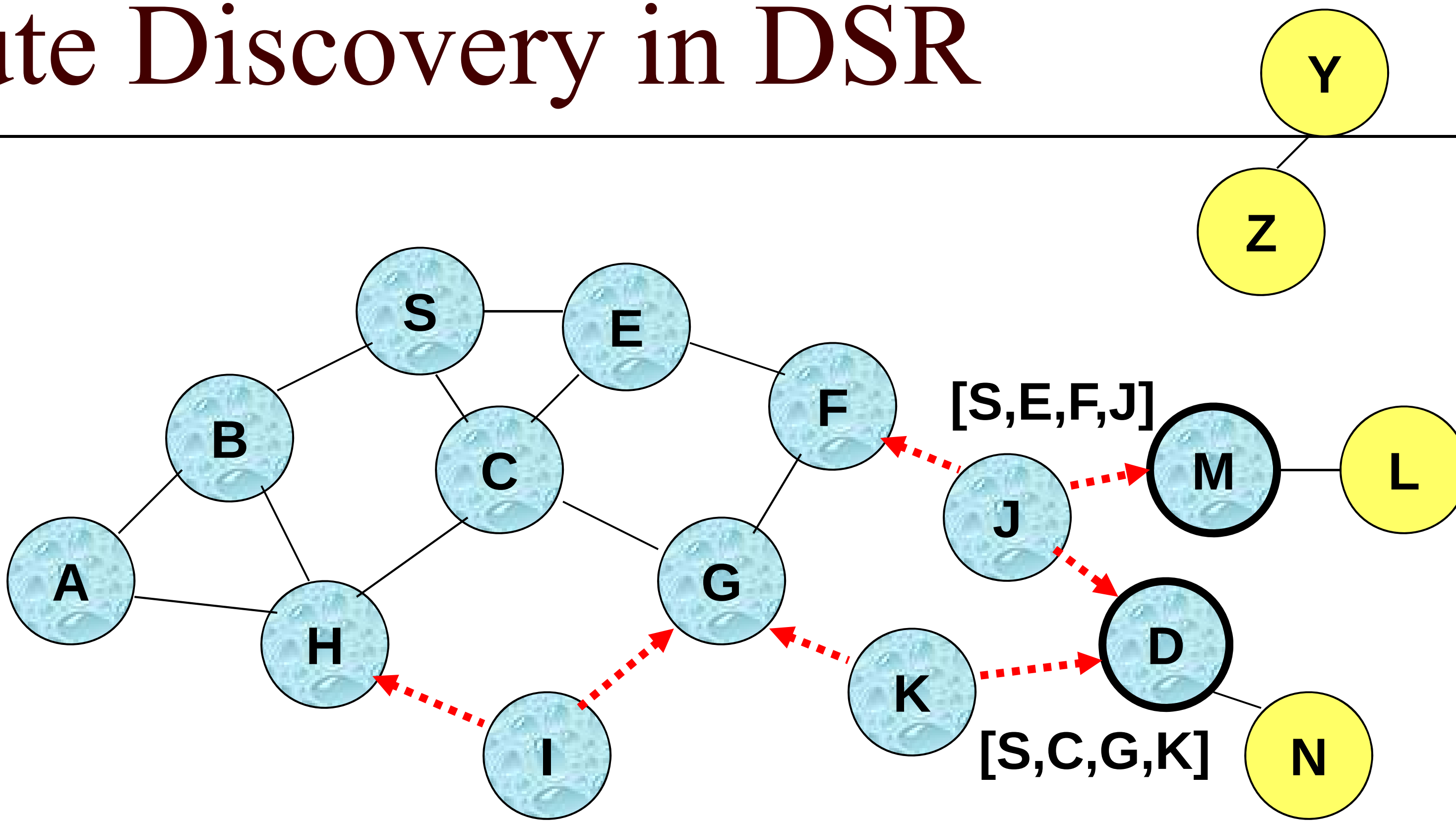
Route Discovery in DSR



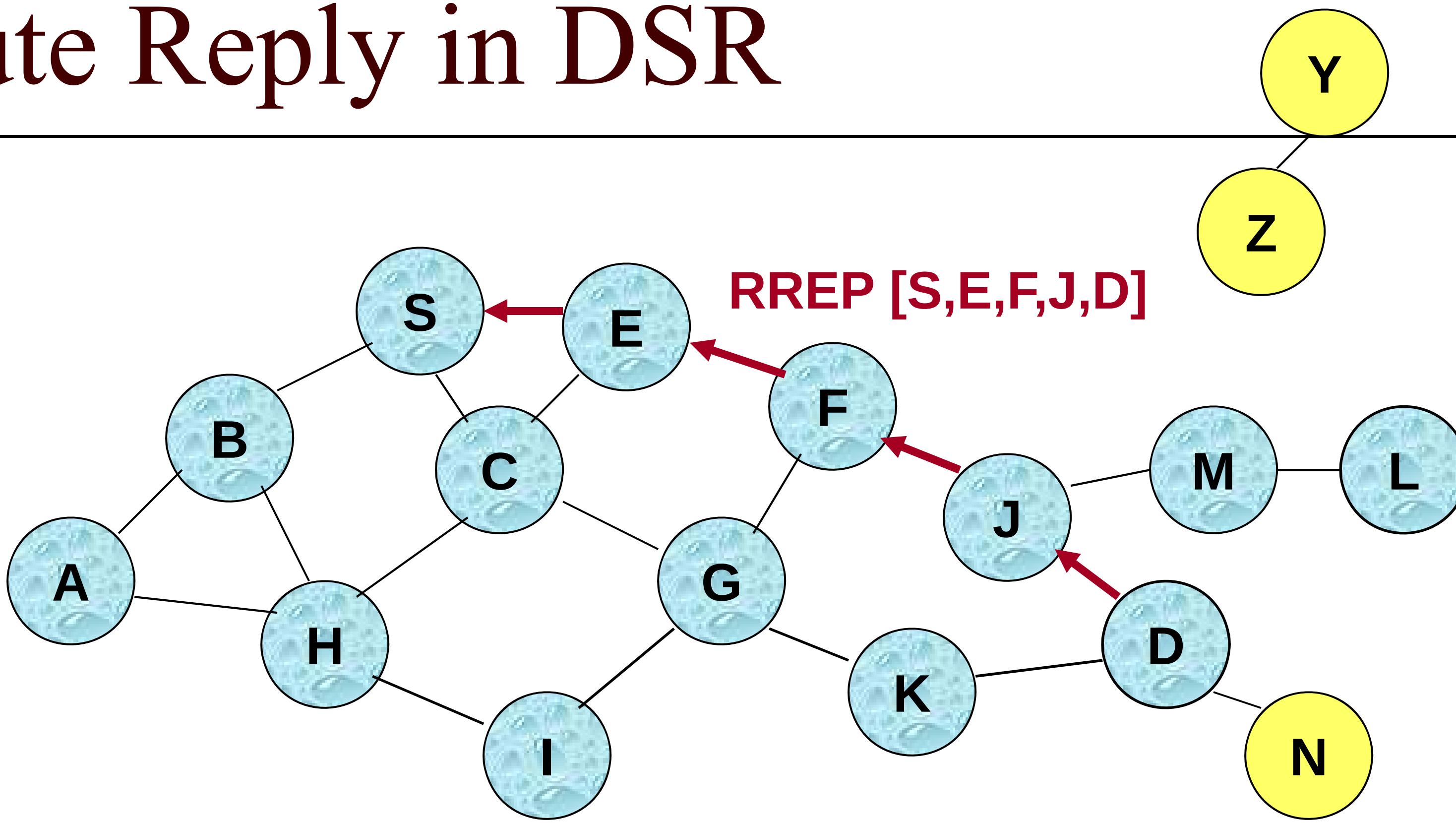
Route Discovery in DSR



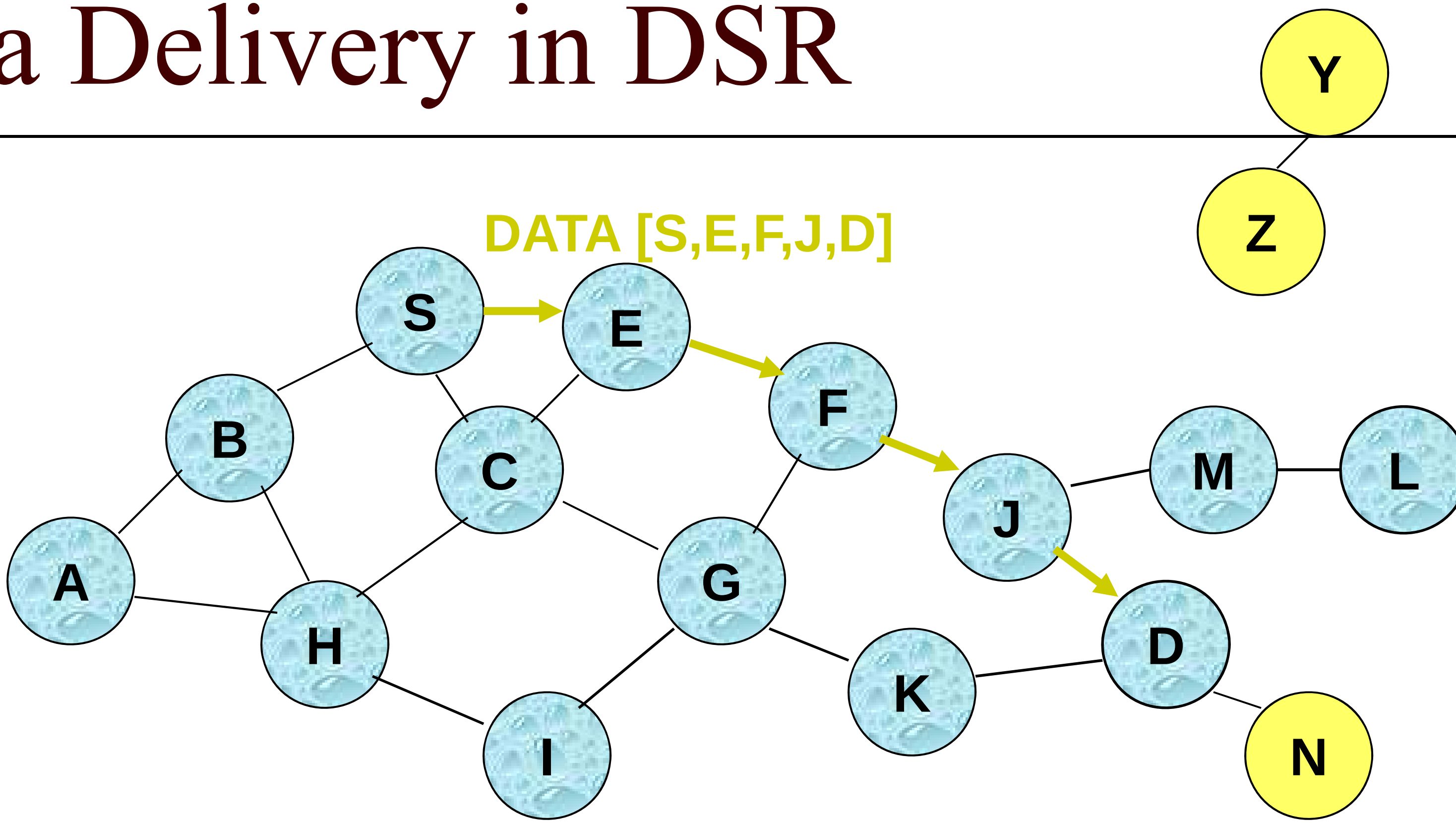
Route Discovery in DSR



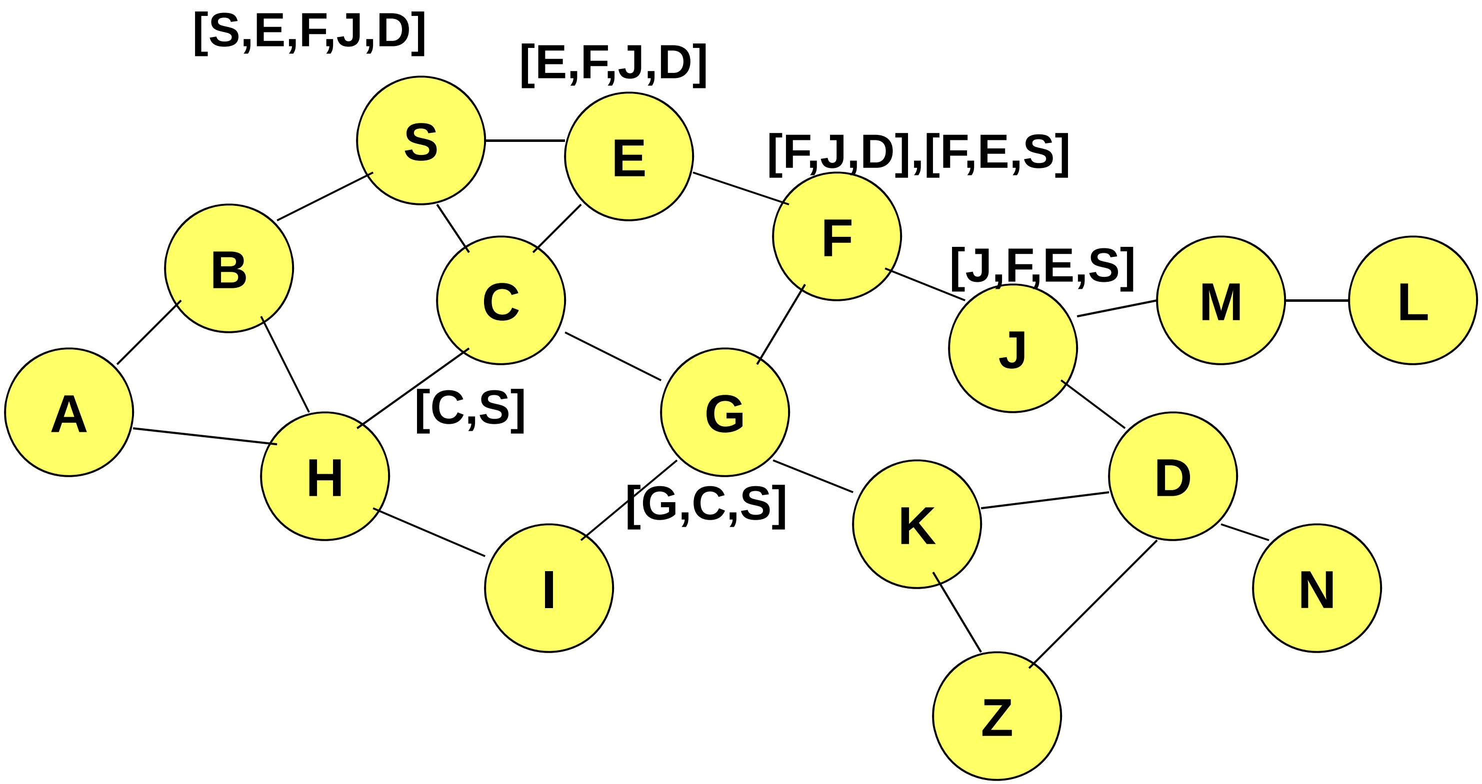
Route Reply in DSR



Data Delivery in DSR



Route Caching in DSR



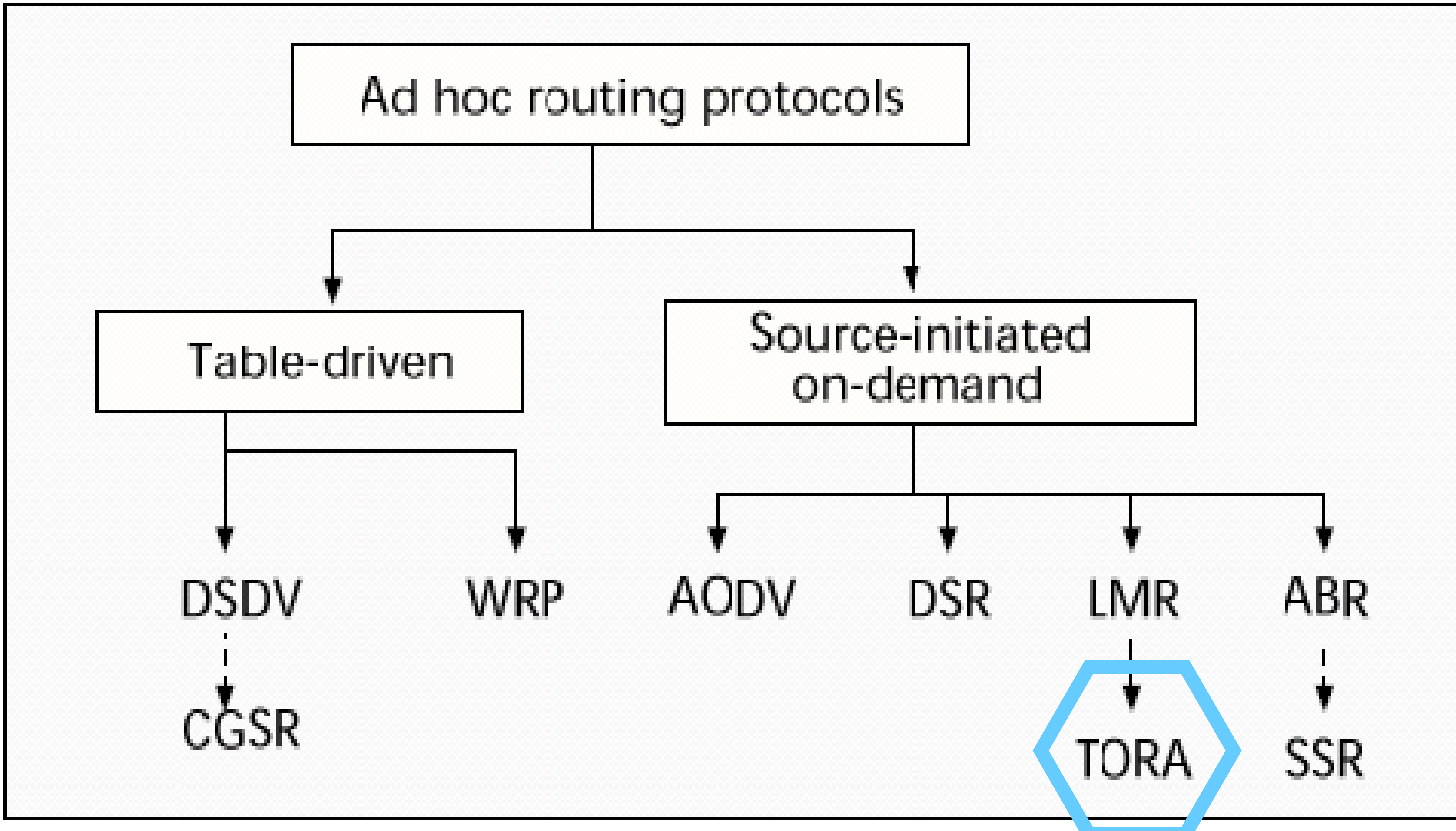
DSR

- Route maintenance
  - RERR
  - ACK, Passive ACK

- DSR main problem?

- Does DSR work in a network of anonymous nodes? what about AODV?

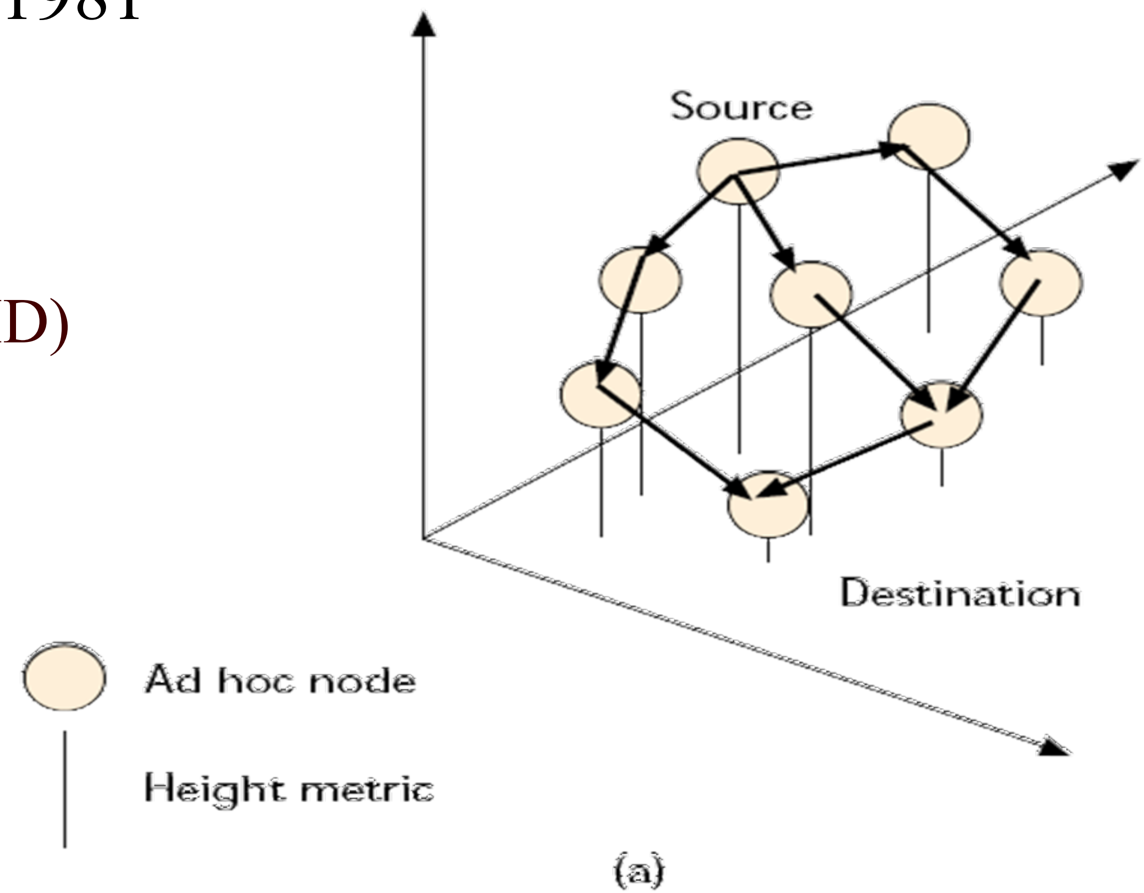
Classification of Routing Protocols in Ad Hoc Networks



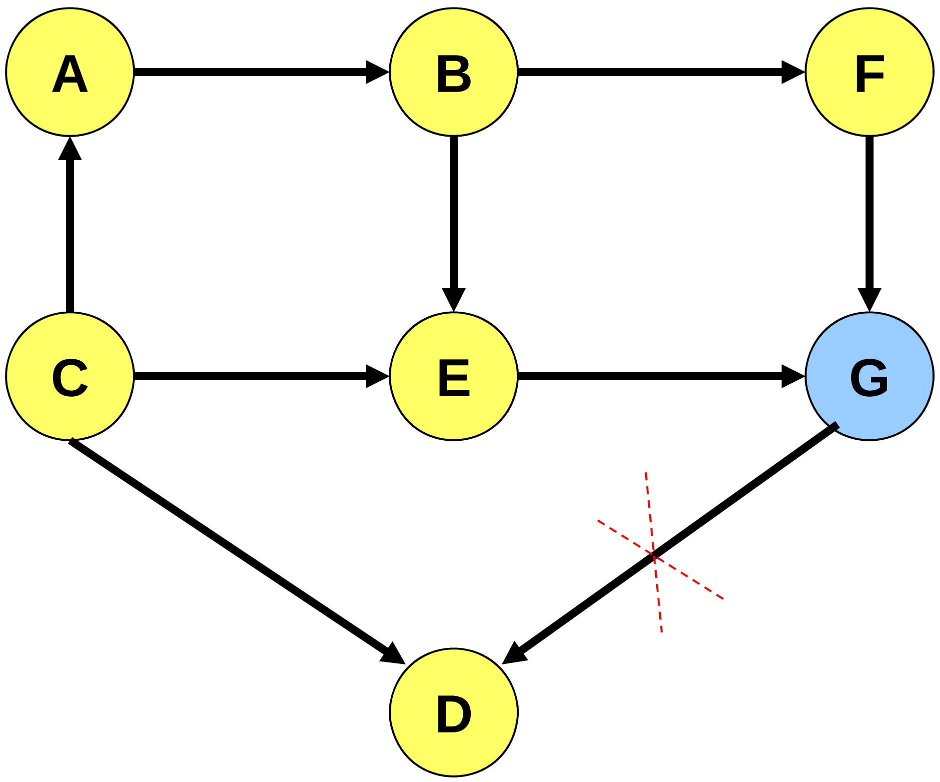
Temporally-Ordered Routing Algorithm (TORA)

- Based on Link Reversal method by Gafni and Bertsekas, 1981

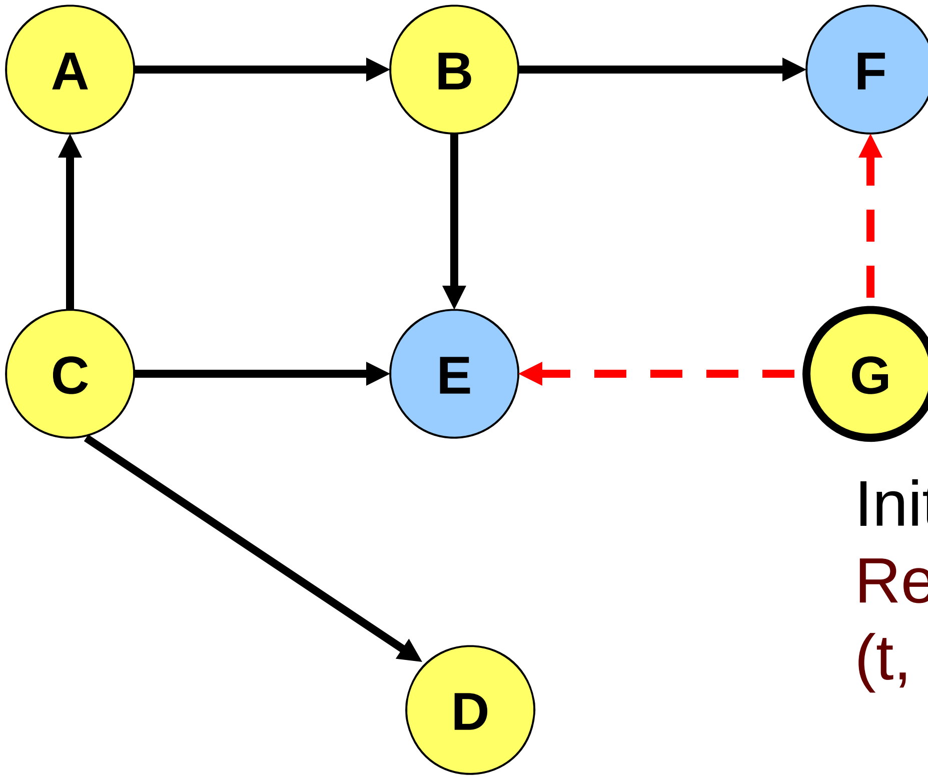
Height:
(t, oid, r, δ, ID)



TORA – Route Maintenance

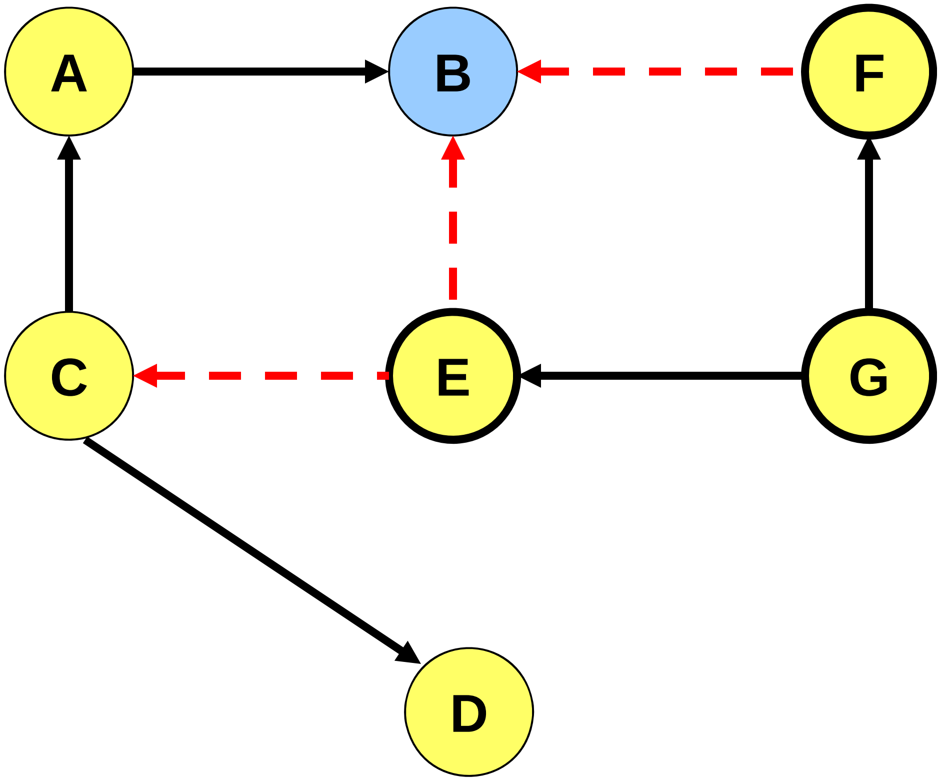


TORA – Route Maintenance

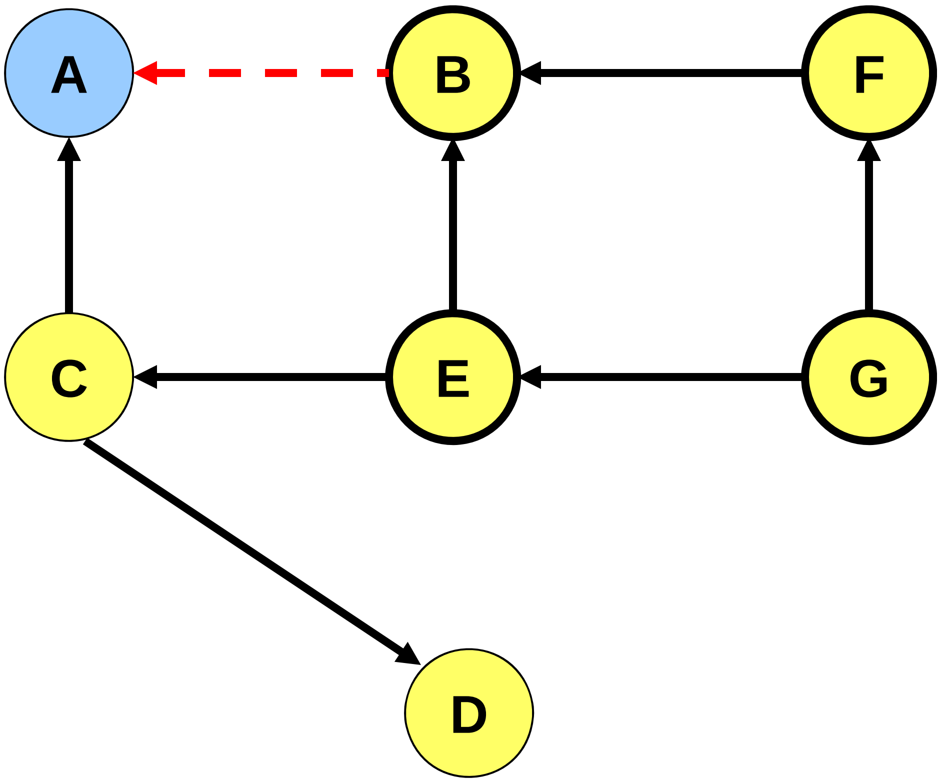


Initiating a new Reference Level (t, oid, r)

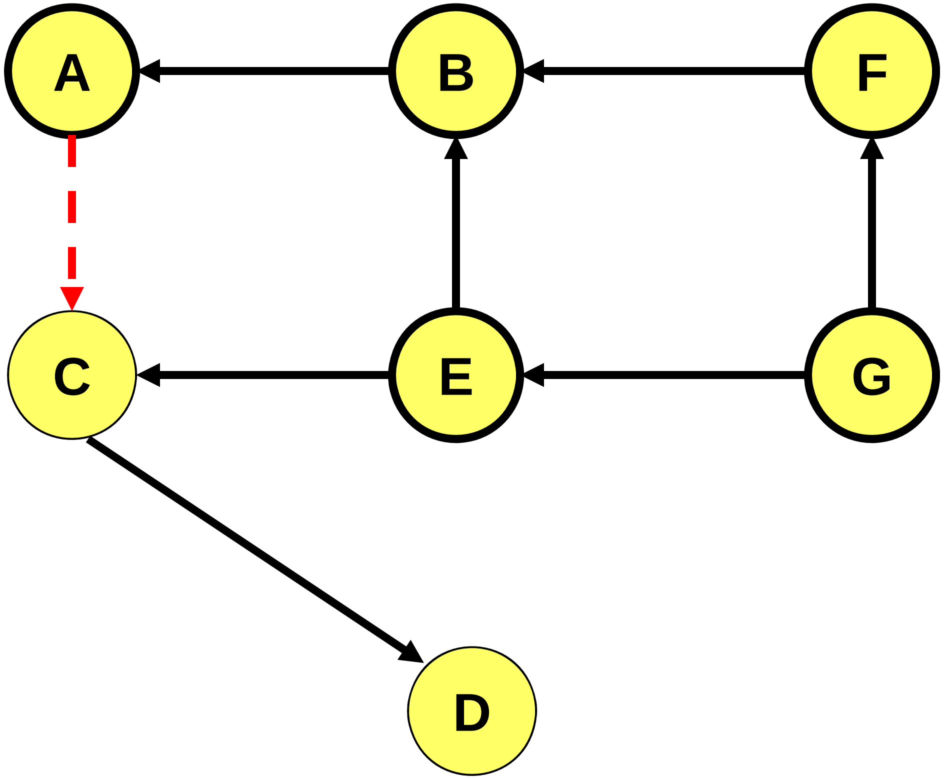
TORA – Route Maintenance



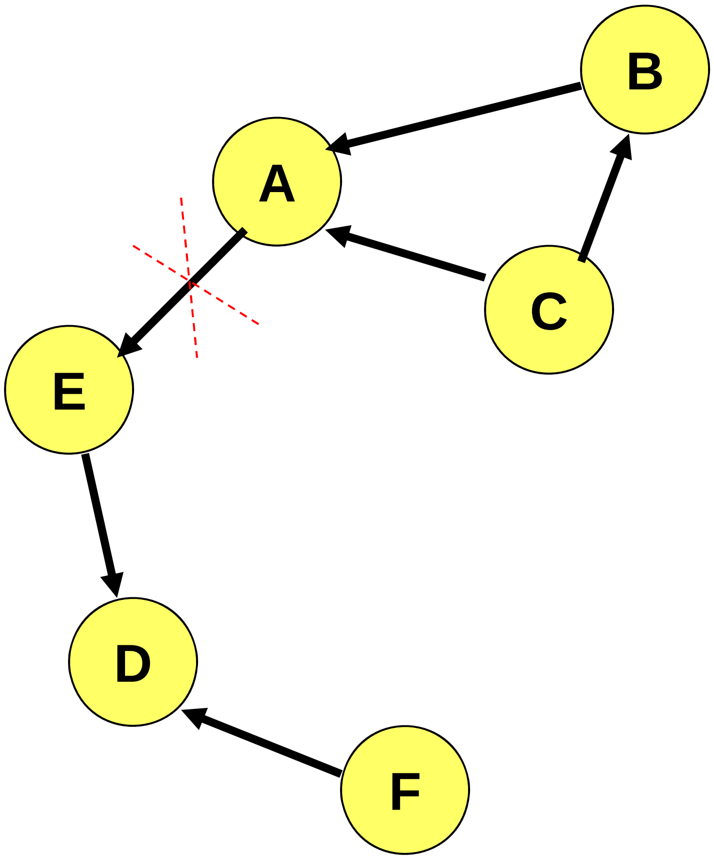
TORA – Route Maintenance



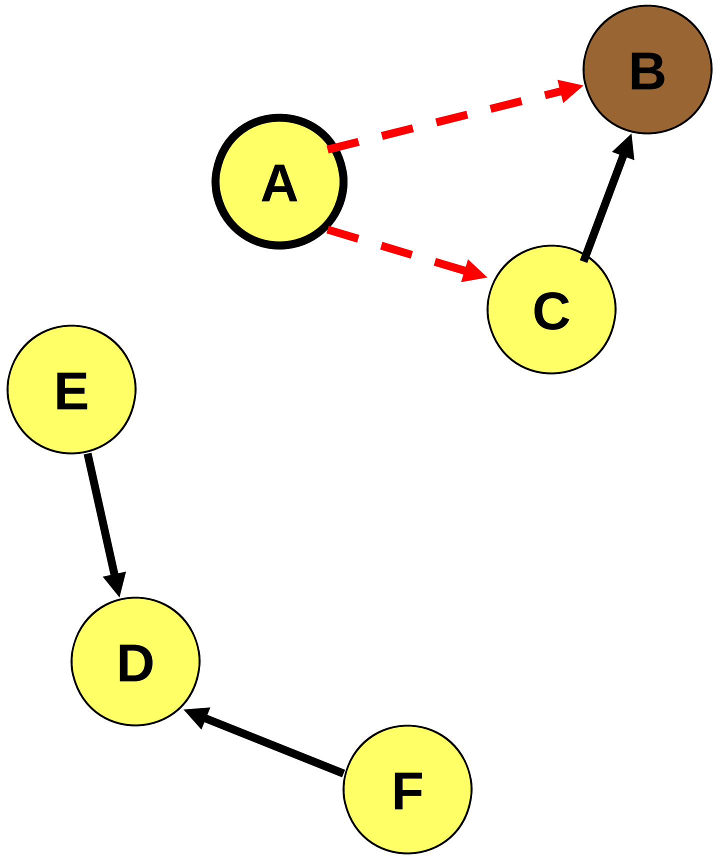
TORA – Route Maintenance



TORA - Partition Detection

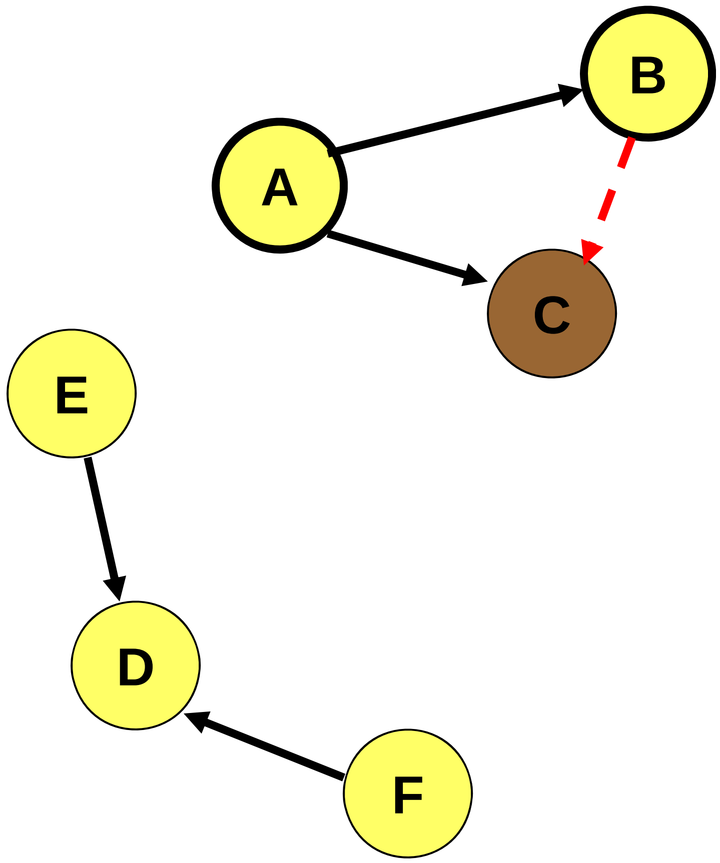


TORA - Partition Detection

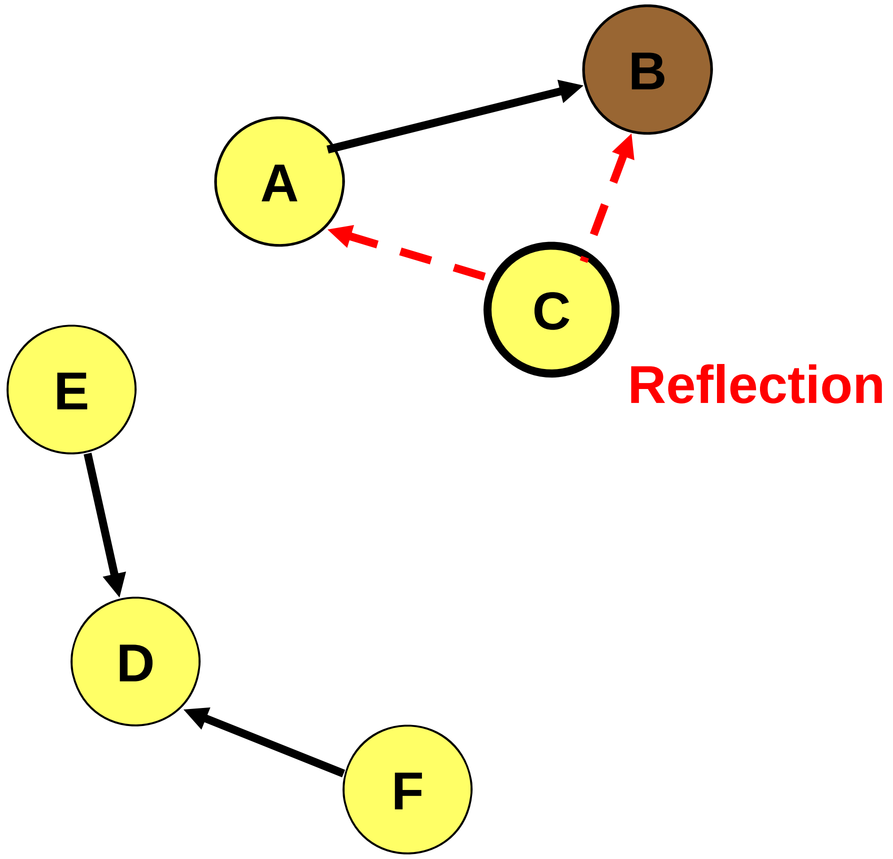


Node A:
Initiates a new
Reference Level
(t, oid, r)

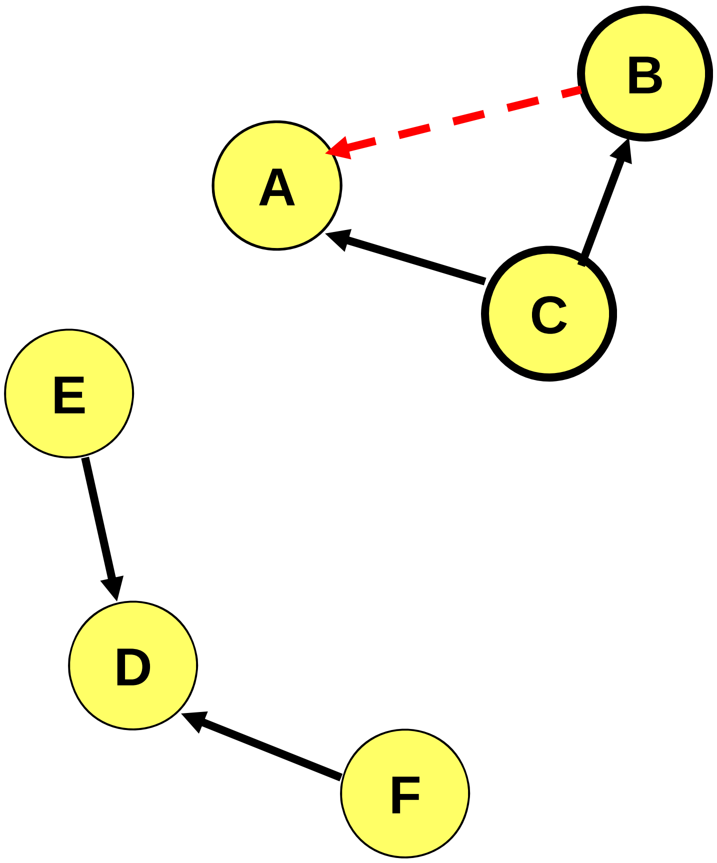
TORA - Partition Detection



TORA - Partition Detection

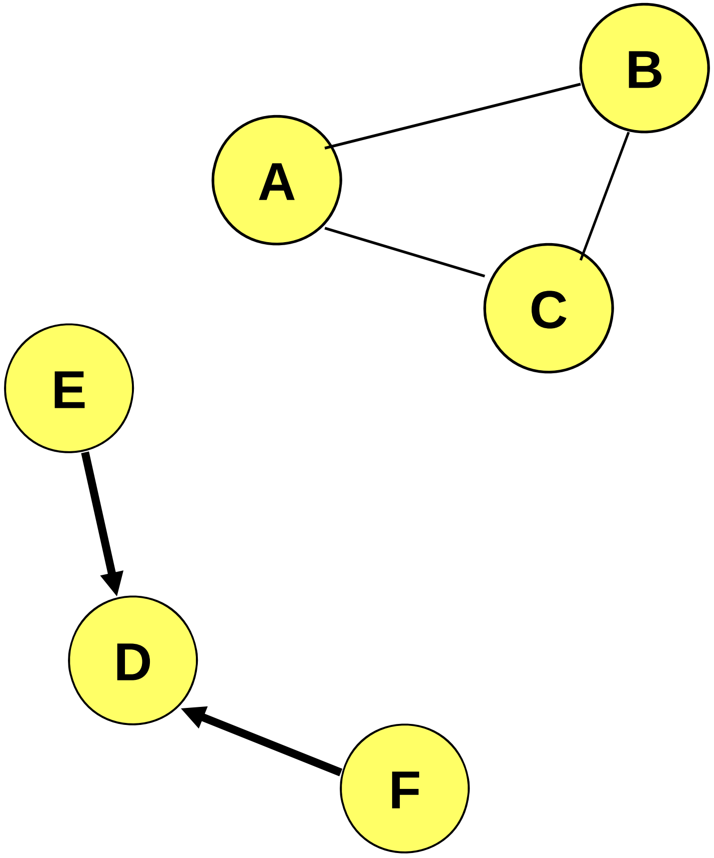


TORA - Partition Detection



A has received Reflection from all neighbors → Partition!

TORA – Route Erasure

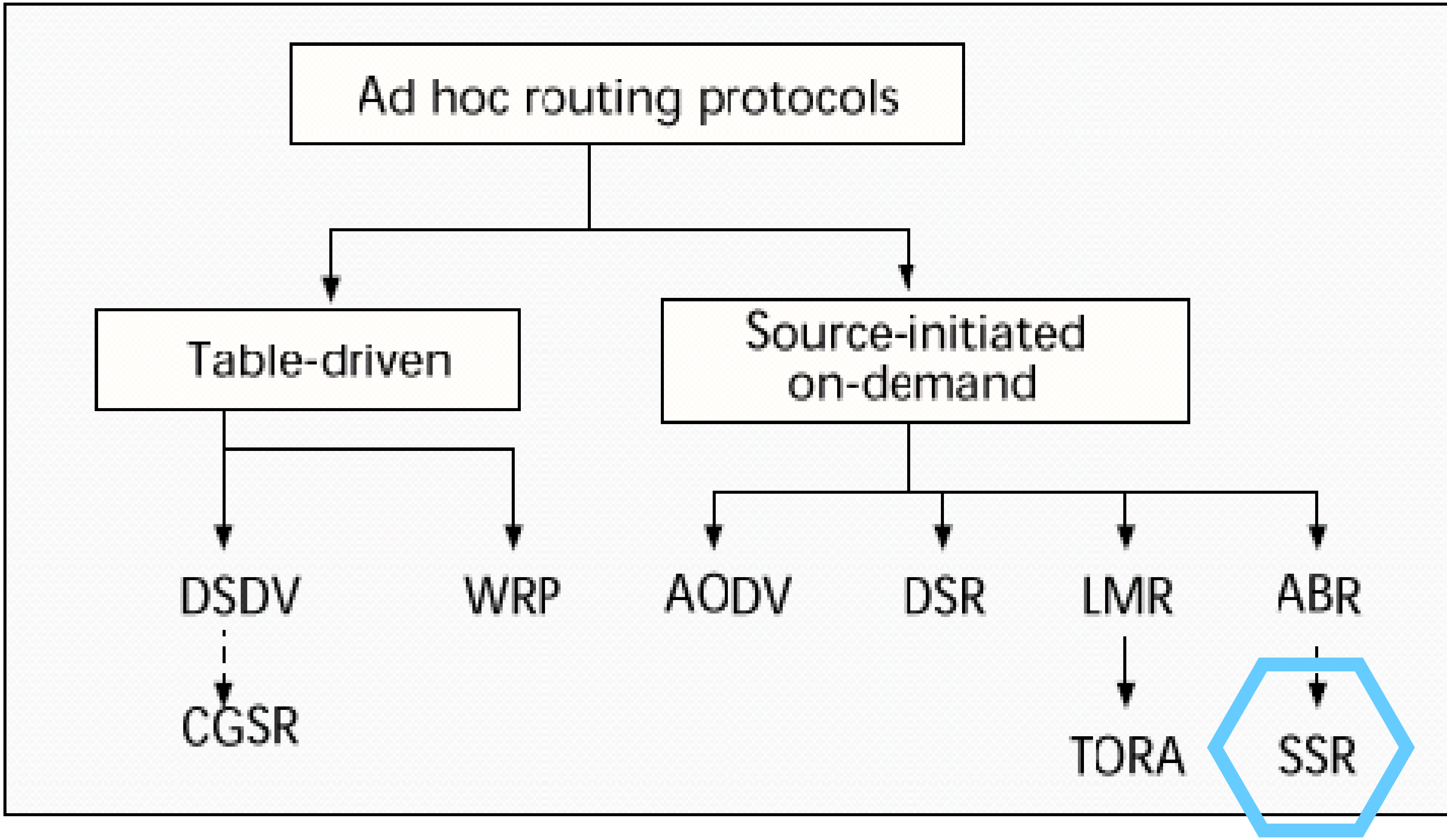


A sends a CLR packet that purges all directed links in that partition

TORA

- Beneficial when many hosts want to communicate with a single destination
- Localization of control messages
  - Suitable for highly dynamic networks
- Oscillations!
  - Eventually converges ☺
- Paths may not be shortest
- All nodes have synchronized clocks!

Classification of Routing Protocols in Ad Hoc Networks



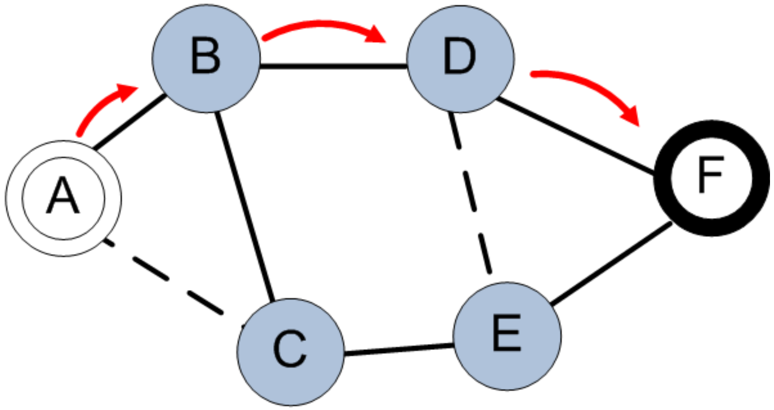
Signal Stability-Based Adaptive Routing (SSR)

- Selects routes based on the signal strength and node's location stability
- Dynamic Routing Protocol (DRP) maintains via periodic beacons
  - Signal Stability Tables (SST), and
  - Routing Tables (RT)
- Static Routing Protocol (SRP) handles
  - Packet forwarding routines, and
  - Route search

Signal Stability-Based Adaptive Routing (SSR)

The Signal Stability Table (SST)

Host	Signal Strength	Last	Clicks	Set
Y				
Z				



The Routing Table (RT)

Destination	Next Hop
Y	
Z	

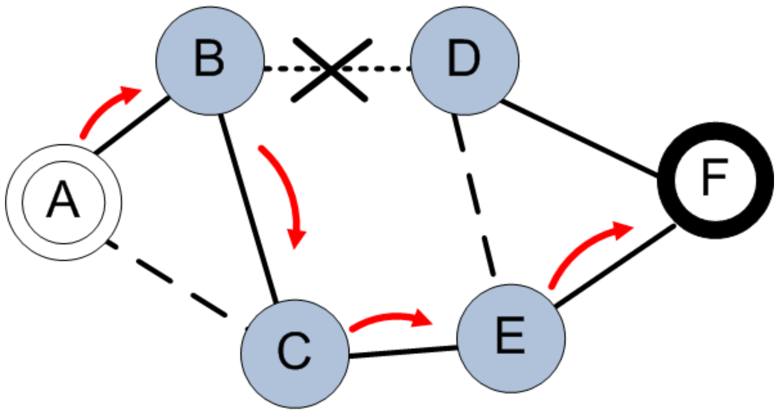
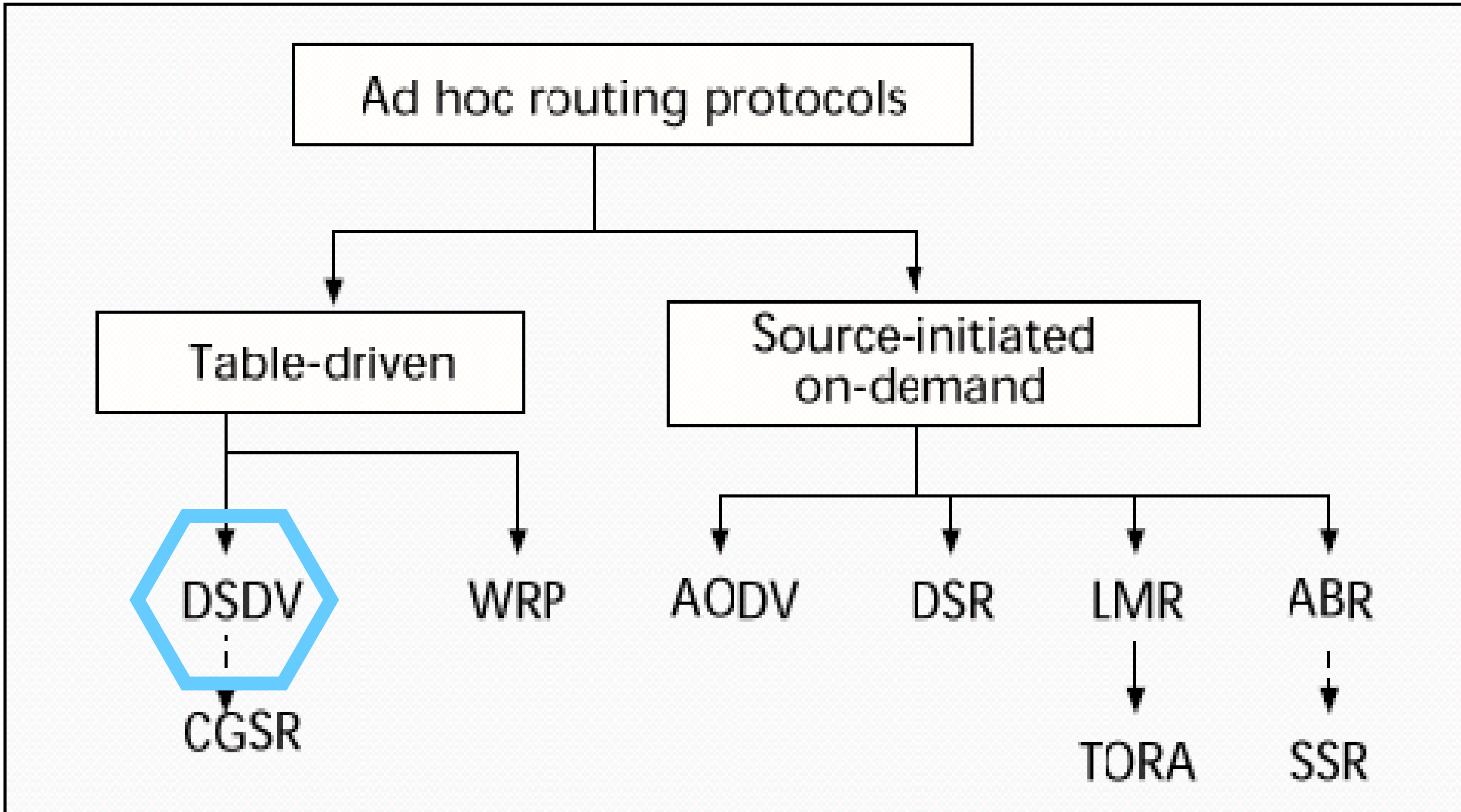


Table-Driven Routing Protocols

- Each node maintains one-to-all routing information
- Changes are propagated through the entire network
  - Destination-Sequenced Distance-Vector Routing
  - Clusterhead Gateway Switch Routing
  - Wireless Routing Protocol

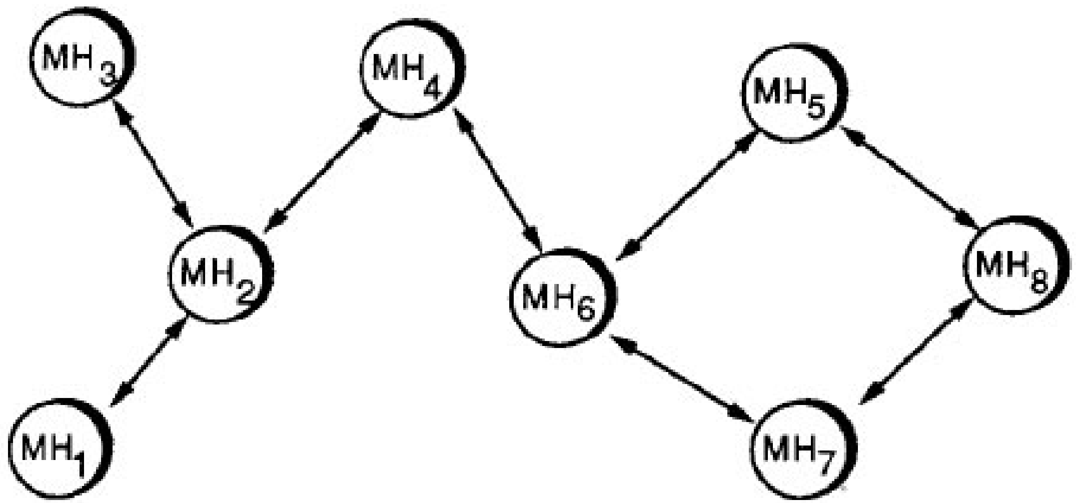
Classification of Routing Protocols in Ad Hoc Networks



Destination-Sequenced Distance-Vector Routing (DSDV)

- Uses Distributed Bellman-Ford (DBF) algorithm as a basis
- Modified to prevent looping in the network architecture by usage of sequence numbers
- Each node periodically shares its routing table with its neighbors

Destination-Sequenced Distance-Vector Routing (DSDV)

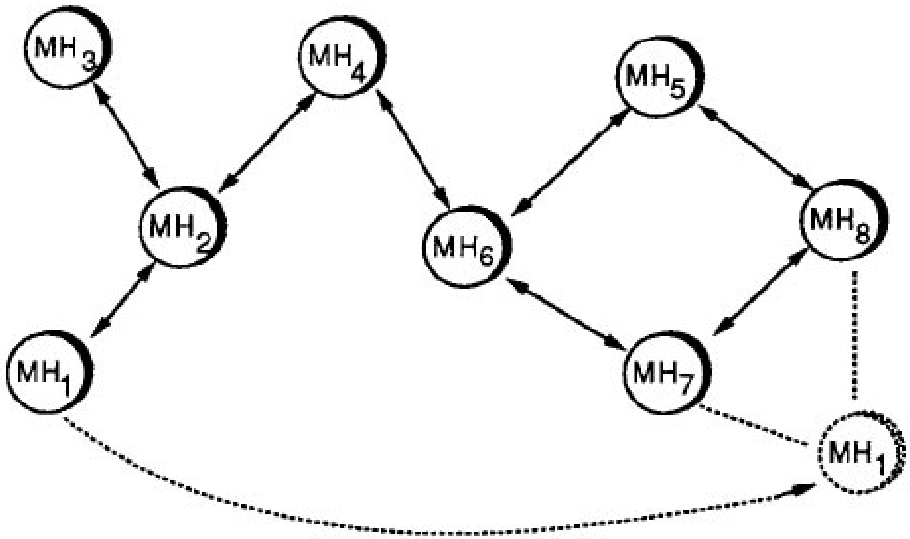


Destination	NextHop	Metric	Sequence number	Install	Flags	Stable_data
MH_1	MH_2	2	S406_MH_1	T001_MH_4		Ptr1_MH_1
MH_2	MH_2	1	S128_MH_2	T001_MH_4		Ptr1_MH_2
MH_3	MH_2	2	S564_MH_3	T001_MH_4		Ptr1_MH_3
MH_4	MH_4	0	S710_MH_4	T001_MH_4		Ptr1_MH_4
MH_5	MH_6	2	S392_MH_5	T002_MH_4		Ptr1_MH_5
MH_6	MH_6	1	S076_MH_6	T001_MH_4		Ptr1_MH_6
MH_7	MH_6	2	S128_MH_7	T002_MH_4		Ptr1_MH_7
MH_8	MH_6	3	S050_MH_8	T002_MH_4		Ptr1_MH_8

Destination-Sequenced Distance-Vector Routing (DSDV)

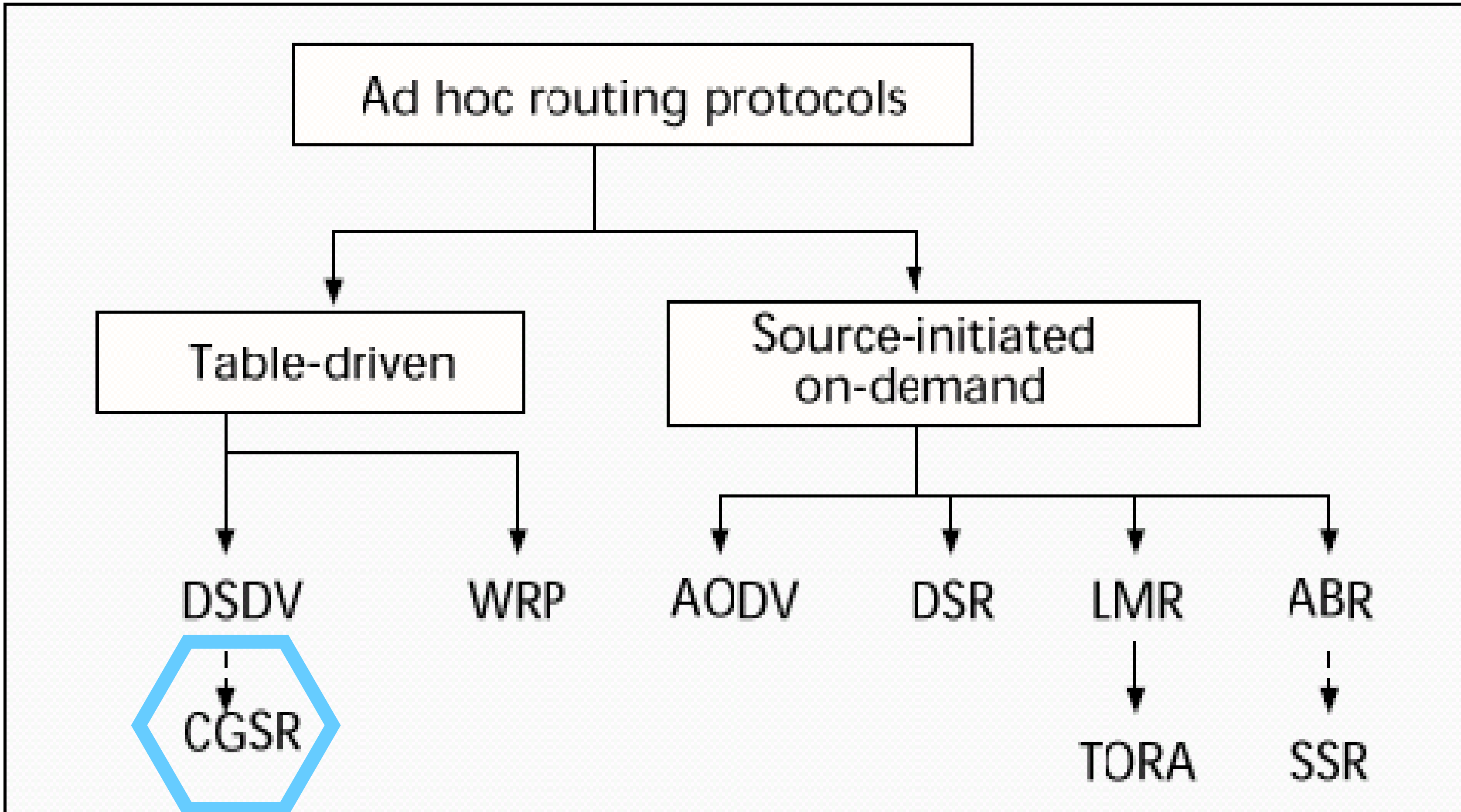
- Delays advertisement of unstable routes to reduce fluctuations of the routing tables
- Employs 2 types of maintenance messages: full dump and incremental packets to reduce the amount of traffic
- DSDV works even with nodes in a sleep node or is not in the range of direct communication at the moment

Destination-Sequenced Distance-Vector Routing (DSDV)



Destination	NextHop	Metric	Sequence number	Install	Flags	Stable_data
MH_1	MH_6	3	S516_MH_1	T810_MH_4	M	Ptr1_MH_1
MH_2	MH_2	1	S238_MH_2	T001_MH_4		Ptr1_MH_2
MH_3	MH_2	2	S674_MH_3	T001_MH_4		Ptr1_MH_3
MH_4	MH_4	0	S820_MH_4	T001_MH_4		Ptr1_MH_4
MH_5	MH_6	2	S502_MH_5	T002_MH_4		Ptr1_MH_5
MH_6	MH_6	1	S186_MH_6	T001_MH_4		Ptr1_MH_6
MH_7	MH_6	2	S238_MH_7	T002_MH_4		Ptr1_MH_7
MH_8	MH_6	3	S160_MH_8	T002_MH_4		Ptr1_MH_8

Classification of Routing Protocols in Ad Hoc Networks

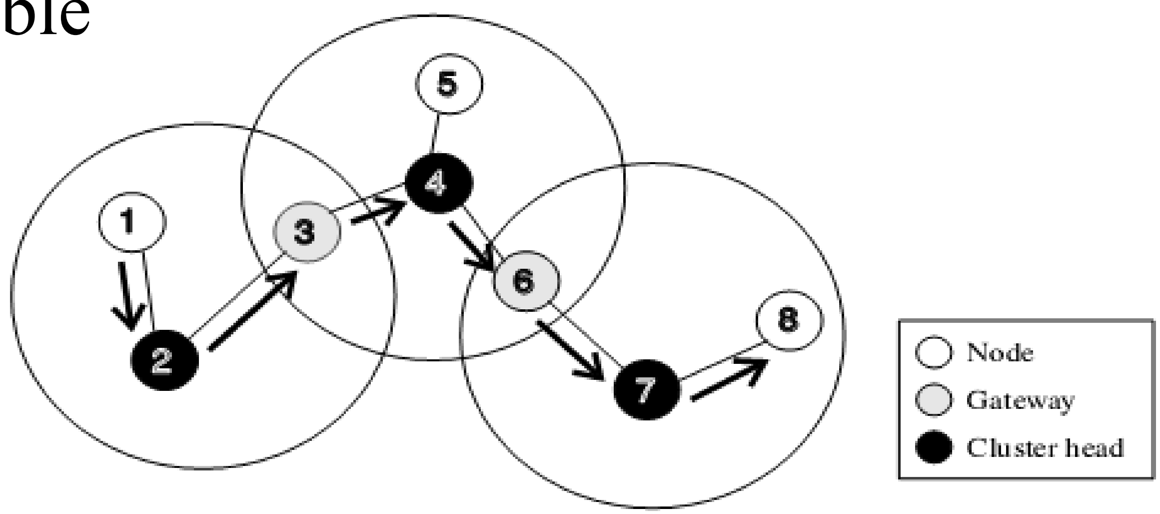


Clusterhead Gateway Switch Routing (CGSR)

- Uses DSDV routing scheme on a clustered multihop mobile wireless network
- Cluster head selection algorithm
- Least Cluster Change (LCC) reduces the frequency of head re-elections, performs only when
  - Two cluster heads come into contact
  - Node moves out of reach of all cluster heads

Clusterhead Gateway Switch Routing (CGSR)

- Two types of nodes: cluster heads and gateway nodes
- Each node contains Cluster Member Table that includes the cluster heads of all destination nodes and Routing Table



Goals

- Low communication overhead
- As little time for path finding
- As few maintenance messages
- No centralized host
- Scalable
- Loop-free
- Small memory overhead

Comparison for On-Demand Routing

Performance Parameters	AODV	DSR	TORA	ABR	SSR
Time Complexity (initialization)	O(2d)	O(2d)	O(2d)	O(d+z)	O(d+z)
Time Complexity (postfailure)	O(2d)	O(2d) or 0 (cache hit)	O(2d)	O(l+z)	O(l+z)
Communication Complexity (initialization)	O(2N)	O(2N)	O(2N)	O(N+y)	O(N+y)
Communication Complexity (postfailure)	O(2N)	O(2N)	O(2x)	O(x+y)	O(x+y)
Routing Philosophy	Flat	Flat	Flat	Flat	Flat
Loop Free	Yes	Yes	Yes	Yes	Yes
Multicast Capability	Yes	No	No[3]	No	No
Beaconing Requirements	No	No	No	Yes	Yes
Multiple Route Possibilities	No	Yes	Yes	No	No
Routes Maintained in	route table	route cache	route table	route table	route table
Utilizes Route Cache/Table Expiration Timers	Yes	No	No	No	No
Route Reconfiguration Methodology	Erase Route; Notify Source	Erase Route; Notify Source	Link Reversal; Route Repair	Localized Broadcast Query	Erase Route; Notify Source
Routing Metric	Freshest & Shortest Path	Shortest Path	Shortest Path	Associativity & Shortest Path & others[4]	Associativity & Stability

Comparison for Table-Driven Routing

Parameters	DSDV	CGSR	WRP
Time Complexity (link addition / failure)	O(d)	O(d)	O(h)
Communication Complexity (link addition / failure)	O(x=N)	O(x=N)	O(x=N)
Routing Philosophy	Flat	Hierarchical	Flat[1]
Loop Free	Yes	Yes	Yes, but not instantaneous
Multicast Capability	No	No[2]	No
Number of Required Tables	Two	Two	Four
Frequency of Update Transmissions	Periodically & as needed	Periodically	Periodically & as needed
Updates Transmitted to	Neighbors	Neighbors & cluster head	Neighbors
Utilizes Sequence Numbers	Yes	Yes	Yes
Utilizes "Hello" Messages	Yes	No	Yes
Critical Nodes	No	Yes (cluster head)	No
Routing Metric	Shortest Path	Shortest Path	Shortest Path

Table-Driven vs. On-Demand

Parameters	On-demand	Table-driven
Availability of routing information	Available when needed	Always available regardless of need
Routing philosophy	Flat	Mostly flat, except for CGSR
Periodic route updates	Not required	Required
Coping with mobility	Use localized route discovery as in ABR and SSR	Inform other nodes to achieve a consistent routing table
Signaling traffic generated	Grows with increasing mobility of active routes (as in ABR)	Greater than that of on-demand routing
Quality of service support	Few can support QoS, although most support shortest path	Mainly shortest path as the QoS metric

Discussion

- Energy efficiency vs. high throughput?
  - What trade-off relationship is most reasonable and why?
- High throughput vs. high traffic?
  - High packet replication guarantee high probability of packet delivery, but can result in network congestion. How to choose the best option?

Directed Diffusion: A Scalable and Robust Communication Paradigm for Sensor Networks

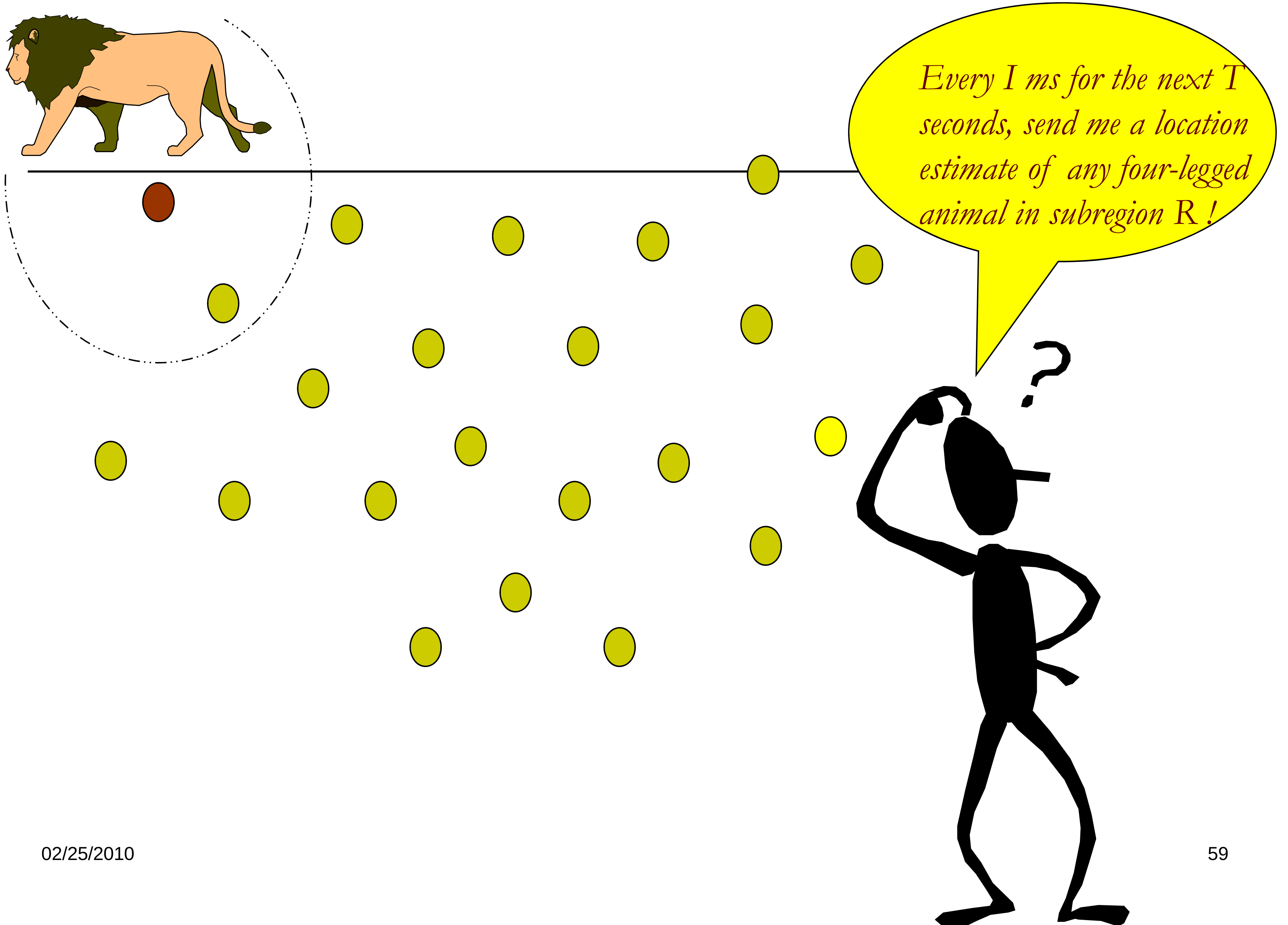
Chalermek Intanagonwiwat, USC

Ramesh Govindan, USC

Deborah Estrin, UCLA

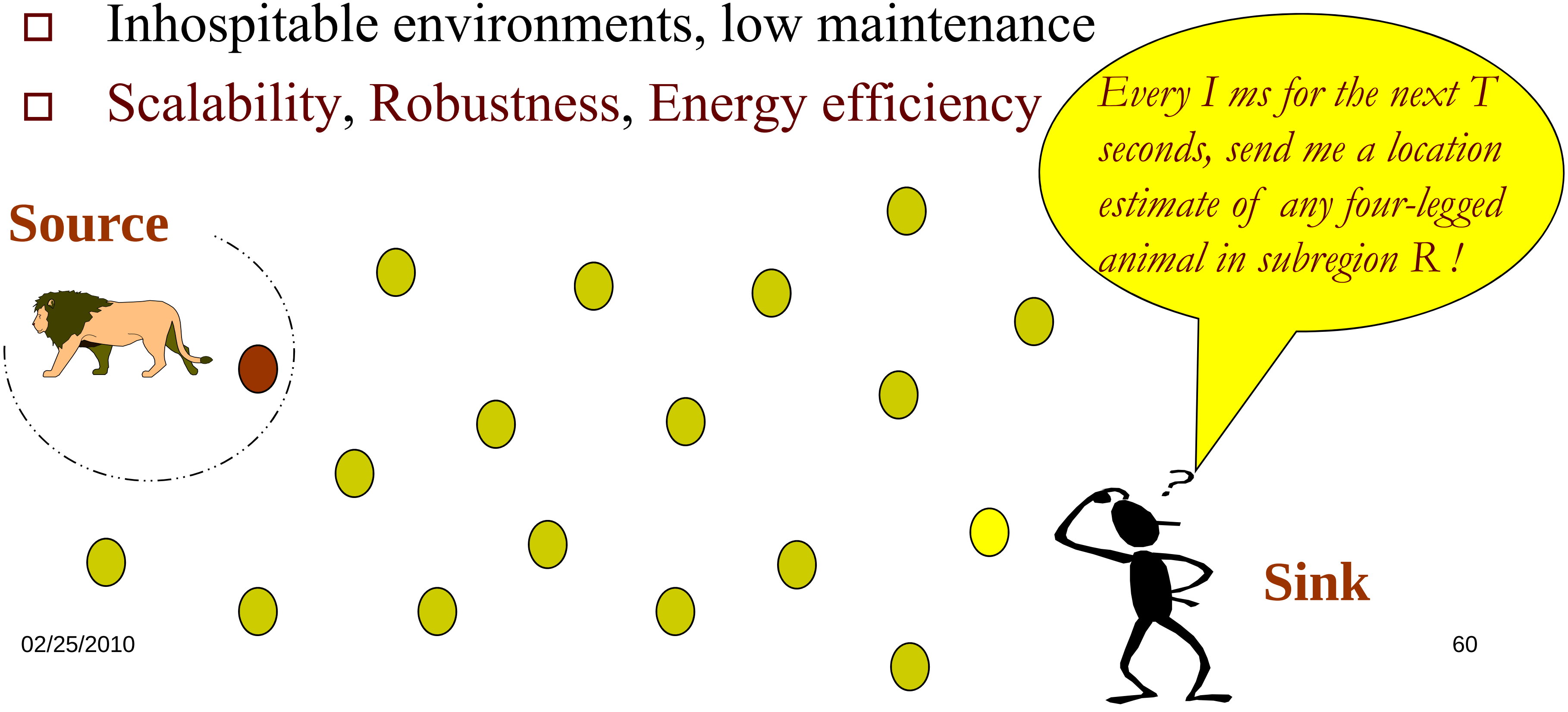
Mobicom 2000

Presented By: Fatemeh Saremi


Every I ms for the next T seconds, send me a location estimate of any four-legged animal in subregion R !

Sensor Networks

- Distributed sensing
- Large scale, dynamically changing
- Inhospitable environments, low maintenance
- Scalability, Robustness, Energy efficiency



Directed Diffusion Elements

- Naming
- Interests
- Gradients
- Data Propagation
- Reinforcement

Naming

- Task descriptions are named by a list of attribute-value pairs
- Task description (interest)

```
type = four-legged animal
interval = 20 ms
duration = 10 seconds
rect = [-100, 100, 200, 400]
```

- Sensed data description

```
type = four-legged animal
instance = lion
location = [125, 250]
intensity = 0.6
confidence = 0.85
timestamp = 01:20:40
```

Interests and Gradients

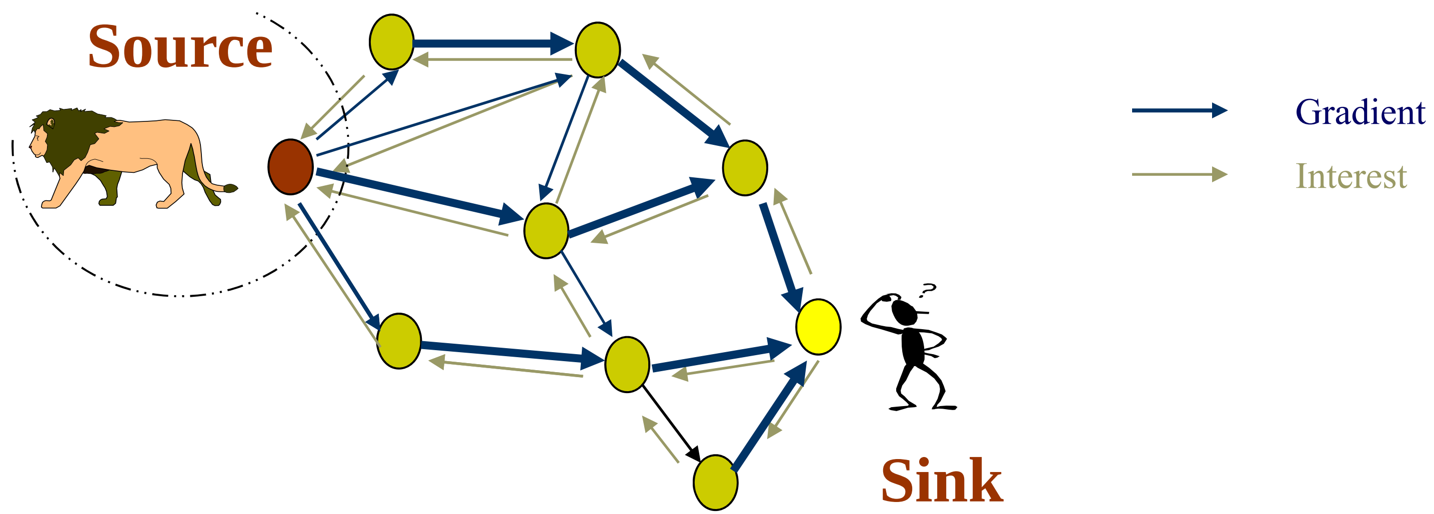
- Interest – sensing task
- Sink broadcasts interest
  - The interest contains much larger interval
  - Periodically refreshed

type = four-legged animal
interval = 1 s
rect = [-100, 200, 200, 400]
timestamp = 01:20:40
expiresAt = 01:30:40

Interests and Gradients

- Every node maintains an interest cache
  - Each item corresponds to a distinct interest
  - Each entry has a timestamp and a list of gradients
    - Each gradient contains locally unique neighbor id, data rate and duration fields
  - Entries do not contain info about the sink
- Interest aggregation

Interests and Gradients



- After receiving an interest, a node may resend or suppress it (if it has already resent the interest)

Data Propagation

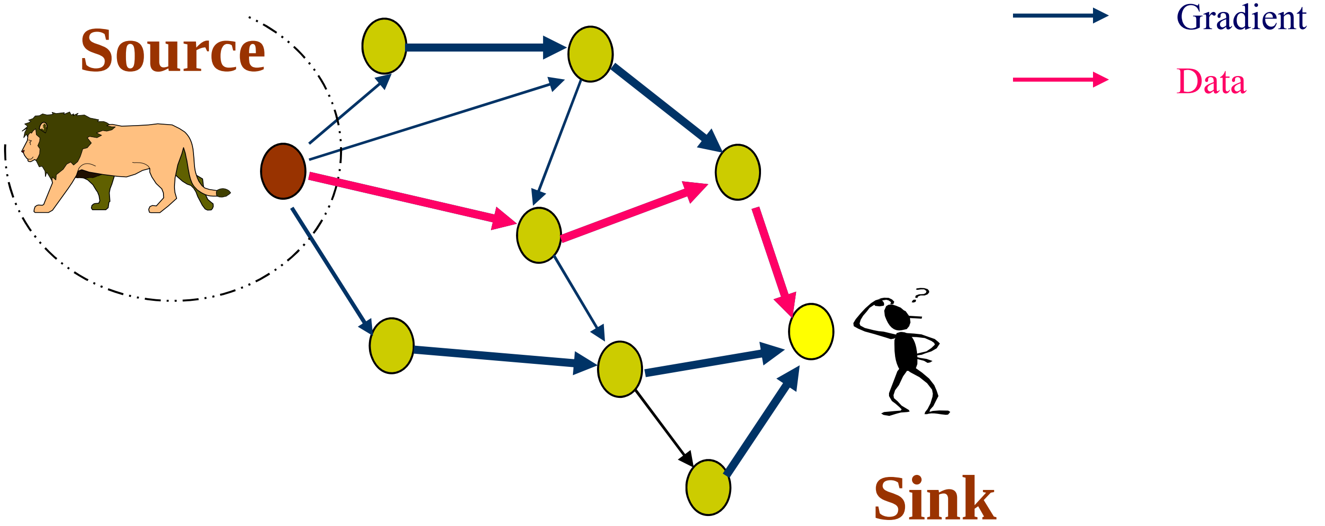
- Detecting a target, the sensor node generates event samples at the highest requested rate
- Data messages will be unicast individually to the relevant neighbors

type = four-legged animal
Instance = lion
interval = 1 s
Location = [125, 220]
Intensity = 0.6
Confidence = 0.85
timestamp = 01:20:40

- A node that receives a data message from its neighbors attempts to find a matching interest in its interest cache

Data Propagation

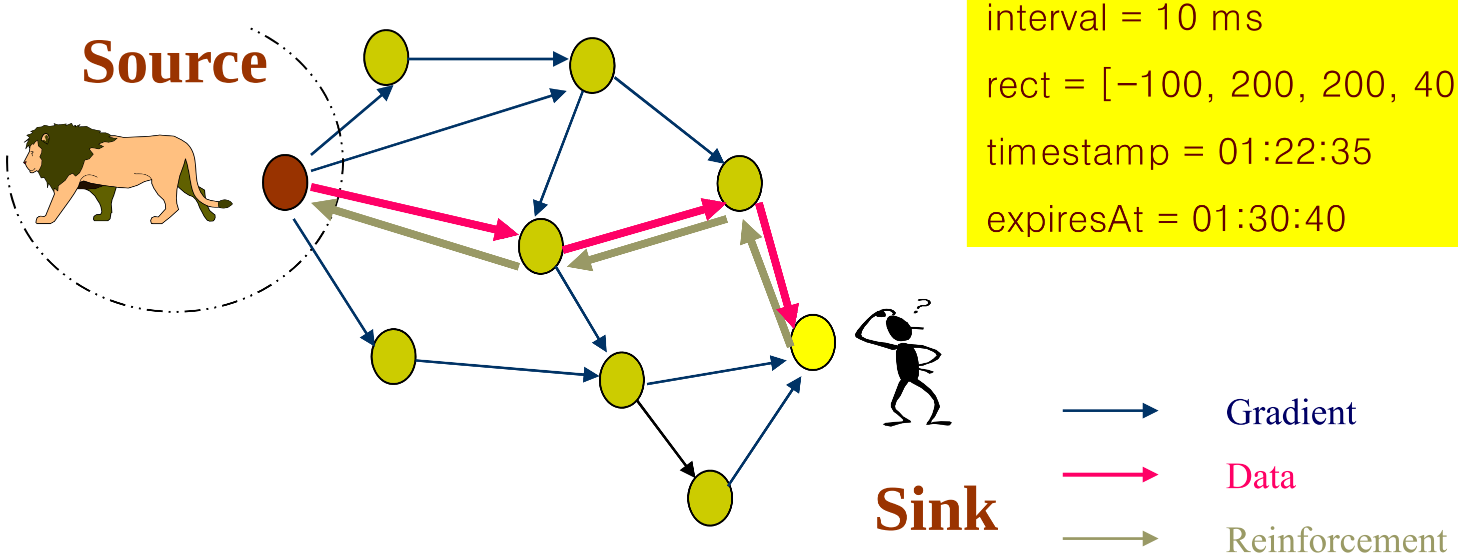
- If a match exists, it checks the data cache associated with the matching interest
  - Data cache keeps track of recently seen data items
  - Loop prevention and downconversion



Reinforcement

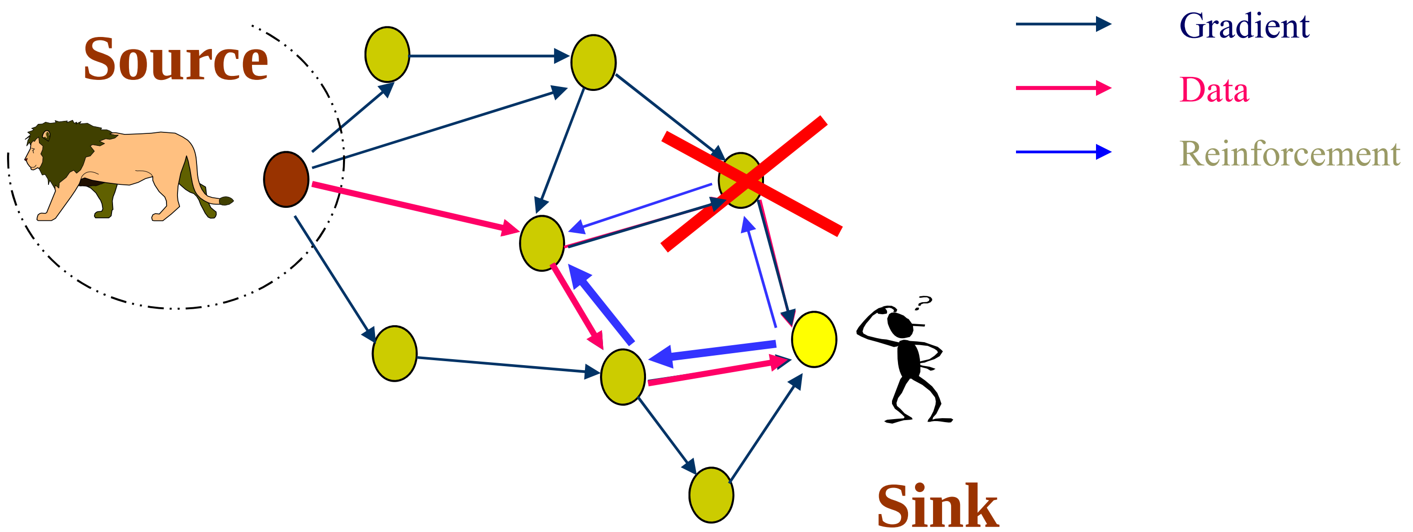
- Sink reinforces one particular neighbor to drawn down higher quality events
- If the neighboring node realizes that the new data rate is higher than any existing gradient in its cache, the node must reinforce at least one neighbor

type = four-legged animal
interval = 10 ms
rect = [-100, 200, 200, 400]
timestamp = 01:22:35
expiresAt = 01:30:40

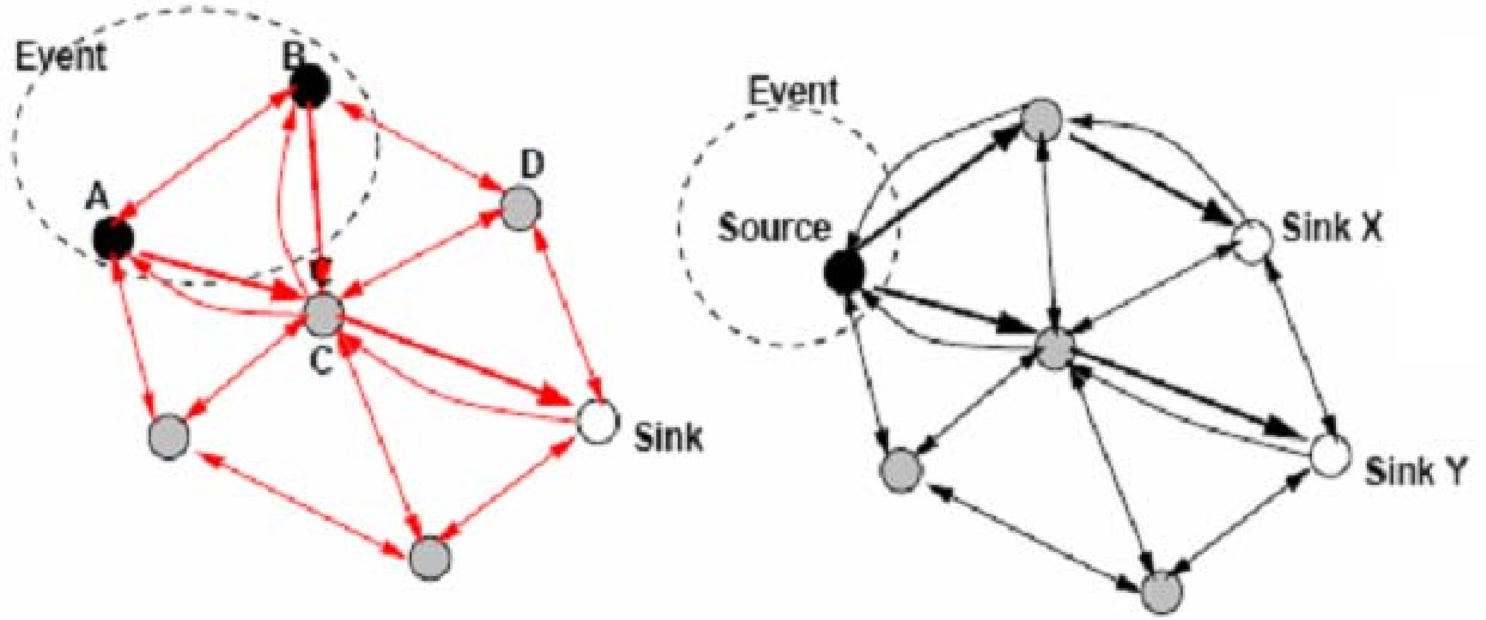


Negative Reinforcement

- Different mechanisms
  - Timeout all high data rate gradients unless they are explicitly reinforced
  - Explicitly degrade the path by resending the interest with the lower data rate



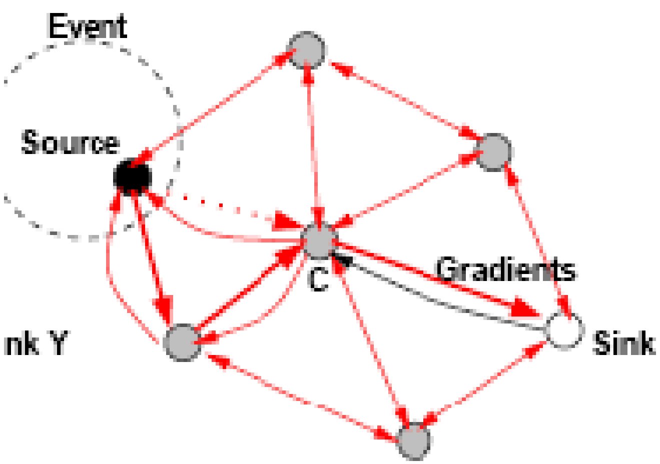
Discussion



Multiple sources   Multiple sinks

Discussion (Cont.)

- Local repair



- Novel features
  - Data-centric dissemination
  - Data caching
  - In-network interest/data aggregation
  - (Negative) Reinforcement based path adaptation

Discussion (Cont.)

- Would it be better if interest entries in the cache contain info about the sink?

- How would you compare Directed Diffusion with reactive routing protocols?

Discussion (Cont.)

- "Routes" are established on-demand
- No attempt is made to find loop-free path before data transmission commences
- Soon thereafter reinforcement attempts to reduce the multiplicity of paths to a small number
- Message cache is used to perform loop avoidance

Discussion (Cont.)

- Could the features be applied to traditional networks? Why or why not?

Discussion (Cont.)

- Data-centric
- Neighbor-to-neighbor
- No “routers”
  - Sensor networks are not general-purpose communication networks
- No need for globally unique IDs
- Possibility of performing coordinated sensing close to the sensed phenomena (vs. what IP-based sensor networks do)

Discussion (Cont.)

- Nodes may propagate data in the absence of interests
  - Provides the ability to spontaneously propagate an important event to some region

- Robust, Scalable, and Energy Efficient
  - Local interactions and rules, (negative) reinforcement based path adaptation

Learn on the Fly: Data-driven Link Estimation Routing in Sensor Network Backbones

Hongwei Zhang, Ohio State U

Anisha Arora, Ohio State U

Prasun Sinha, Ohio State U

Infocom 2006

Presented By: Nadia Tkach

Wireless Sensor Networks - Overview

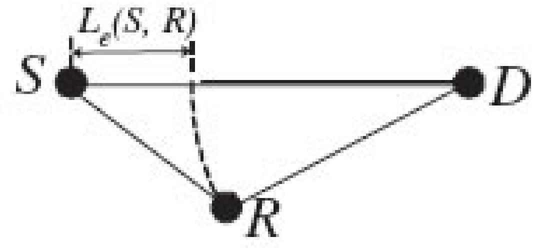
- Wireless sensor nodes are disconnected and require regular beacon messaging
- Existing protocols can estimate the quality of a link at any given point, but they don't offer continuity in time
- Events on the network usually represent a sudden burst of data traffic
- Link quality can significantly drop in the presence of such events
- Conclusion:
  - Beaconing is not efficient
  - Beaconing require high energy consumption

Learn on the Fly (LOF) Routing

- Does not use periodic beacons
- Employs information diffusion and data-driven link quality estimation
- Uses routing metric ELD – the expected media-access-control (MAC) latency per unit-distance to the destination

Learn on the Fly (LOF) Routing

- Based on timing feedback of MAC frame transmission, or MAC latency, and geographic location
- Initializes the node on boot up via few beacons (identifying base station location)
- Performs MAC latency sampling, adaptive estimations and probabilistic selection of a forwarder



Learn on the Fly (LOF) Routing

- LOF specifies a certain threshold for ELD metric for route selection
- The nodes/links that fall below this value are considered dead
- If the node loses all reliable links/forwarders, it initiates withdrawing and rejoining process
- LOF supports probabilistic neighbor switching to try different forwarders over time

Learn on the Fly (LOF) Routing

- Analysis and evaluation shows
  - LOF reduced end-to-end MAC latency
  - Reduces energy consumption in packet delivery
  - Improves route stability
  - Outperforms existing protocols in the events of bursty traffic as well as periodic traffic
- Based on adaptive routing concept and probabilistic exploration

Discussion

- Local network vs. large network?
  - Can LOF scale to large networks?

- Loops in LOF protocol?
  - Can there exist loops in LOF network?