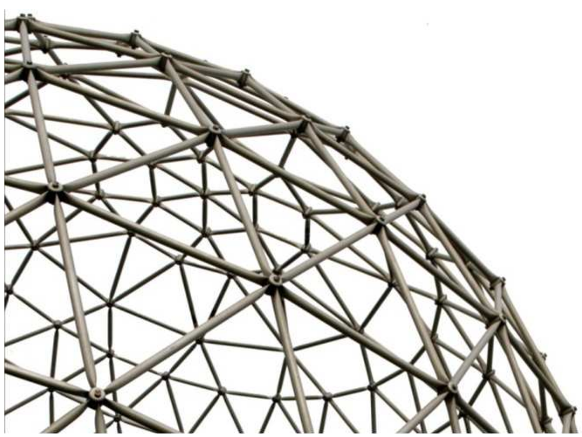
EEEM048- Internet of Things

Lecture 4: Network



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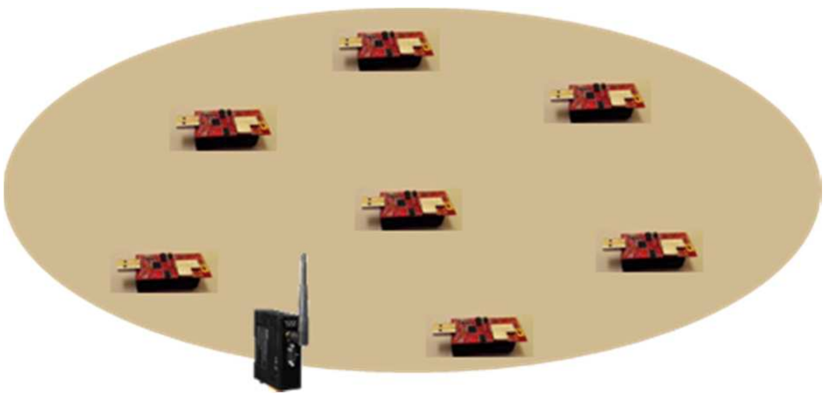
Overview

- Network Module
- Routing Technologies
- Performance Issues

Network Module



Network Module

RF-based IoT applications

- Communication module only provides data link solution
  - i.e. transmitting a packet between nodes within the radio range
- Network module is needed to provide a solution for end-to-end packet delivery
  - Since source/destination pair may not be within each other radio range, intermediate nodes are needed to forward packet
  - It is a distributed system. All nodes need to perform networking related tasks.
  - It is often software implementation.

Network Module

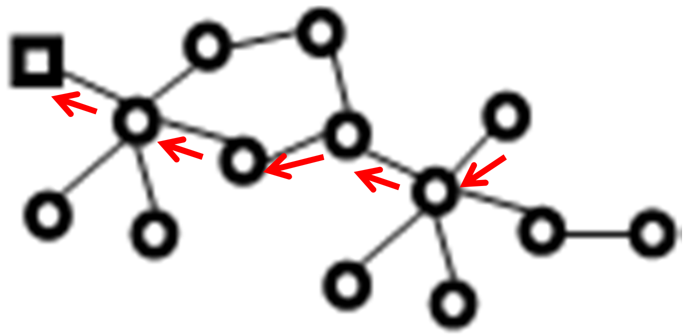
- RF-based IoT applications: Multi-hop Wireless Network. Some examples:
  - Wireless Sensor Networks (WSNs)
  - Mobile Wireless Ad hoc Networks (MANETs)
  - Wireless Mesh Networks (WMNs)
  - Vehicular Ad Hoc Networks (VANETs)
  - and others...

- Main concern: Reliability & Performance

Network Module: Roles

- Management:
  - Packet: Adapting the packet sizes and formats
  - Address: Adapting and/or resolving addresses
  - Device: Joining/leaving of nodes
  - Service: Providing adds-on services such as security
- Operational:
  - Route discovery & maintenance
  - Packet forwarding

Routing Technologies



Common Routing Techniques

- Flooding
  - When receiving a packet, each node rebroadcasts the packet
  - No memory is kept in a node
  - Very wasteful in bandwidth usage

- Source Routing
  - A source node partially or completely specifies the route that a packet should be forwarded
  - Source node is responsible for finding the route to the destination
  - Implementation: DSR

Common Routing Techniques

- Distance Vector
  - Exchange distance vectors only with neighbours to establish routing tables
  - Less traffic for table maintenance makes it suitable for wireless networks
  - Implementation: RIP, AODV, etc

- Link State
  - Flood link information in the network and use Dijkstra's algorithm to compute routing tables
  - Popular solution in wired network. Not adequate for wireless, as it requires network-wide flooding
  - Implementation: OSPF, OLSR, etc

Common Routing Techniques

- Path Vector
  - Based on distance vector, path information is used instead of distance
  - Permit implementation of some policy to take control of the route
  - Used in inter-domain routing
  - Implementation: BGP

Route Establishment & Maintenance

- Proactive (table-driven):
  - Nodes maintain a table describing how a packet should be forwarded to destinations
  - It is more suitable for networks with static topology
- Reactive (on-demand):
  - Upon a request, nodes flood the network to find the destination
  - It is more suitable for networks with changing topology
- Mixed:
  - Hybrid: Operate both proactive and reactive routing
  - Hierarchical: Separate nodes into different levels and use different routing techniques in different levels

Routing in IoT

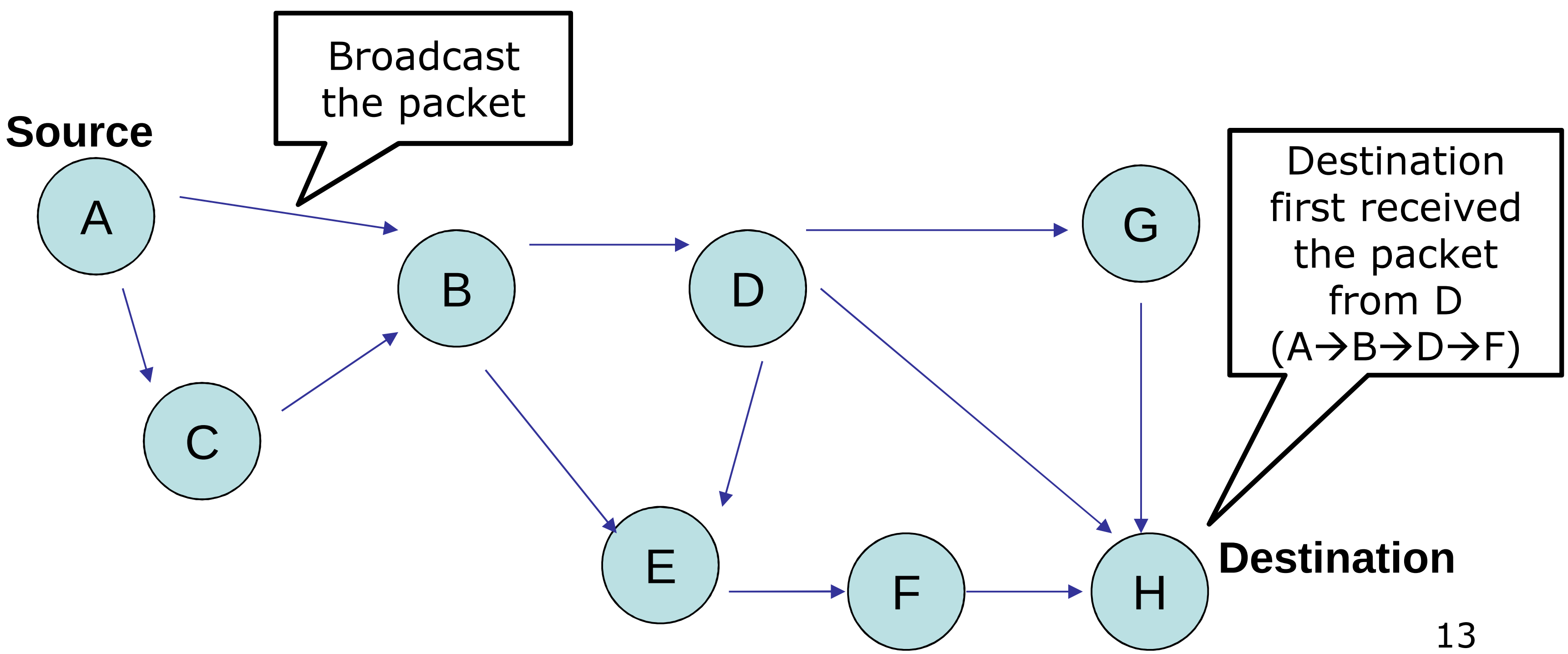
- Ad hoc On-demand Distance Vector (AODV)
  - Specified in RFC 3561
  - Implemented in ZigBee

- IPv6 Routing Protocol for Low-Power and Lossy Networks (RPL)
  - Specified in RFC 6550
  - Implemented in ContikiOS, TinyOS

NOTE: We'll also review Flooding & Source Routing

Flooding

- When receiving a packet
  - If it is not seen before, broadcast the packet
  - Else discard the packet

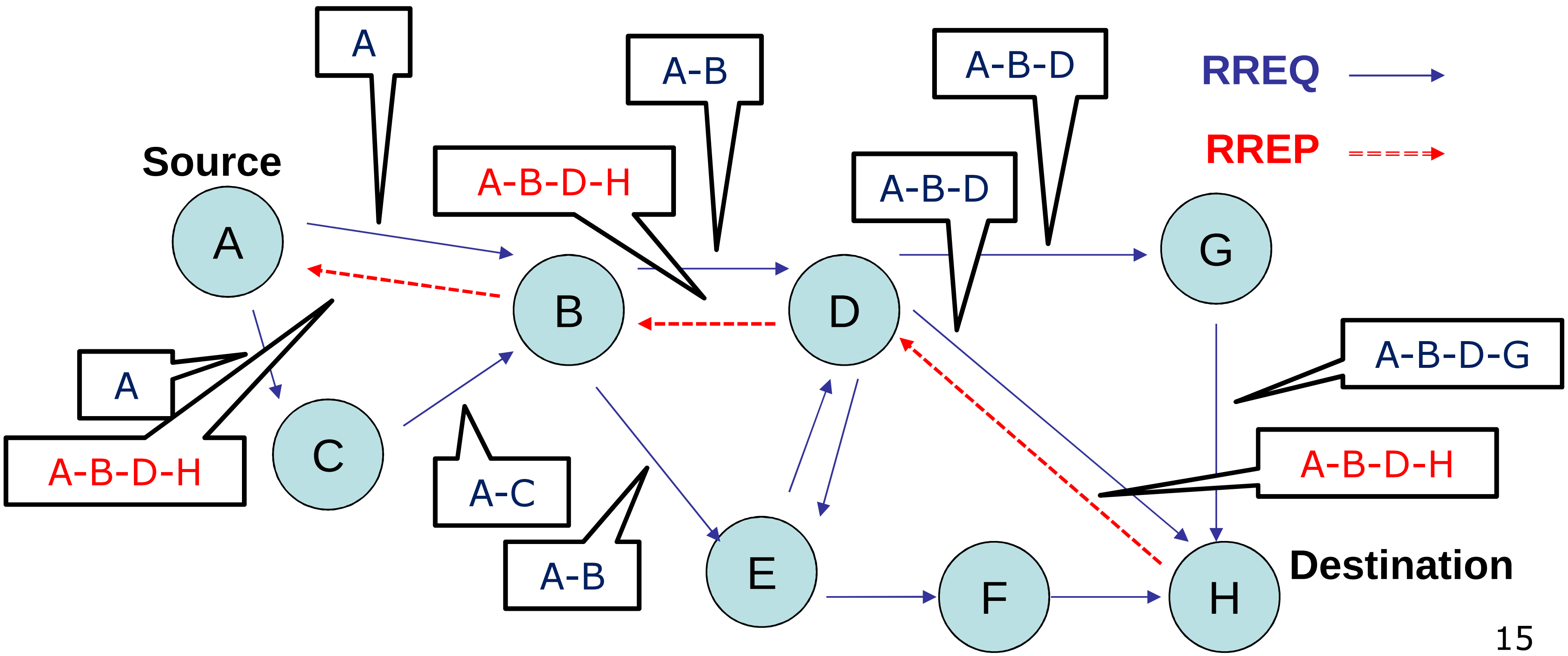


Source Routing

- In source routing, the source takes control of the forwarding
  - Basic idea:
    - The SOURCE broadcasts a REQUEST
    - Each node include the path information in the REQUEST
    - When the REQUEST reaches the DESTINATION, the DESTINATION unicasts a REPLY with the path info
    - When the REPLY reaches the SOURCE, it may transmit data packet with the received path info included in the header
    - Each intermediate node uses the path info in the header to forward the data packets
    - Each node maintains route cache to improve route discovery performance

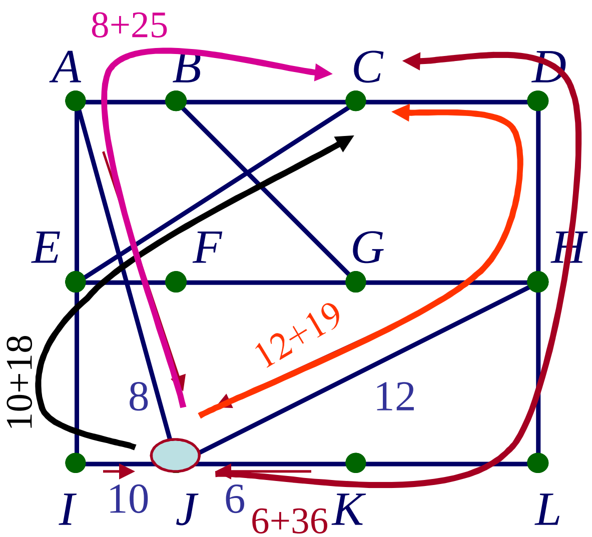
Source Routing: Example

- RREQ: Route Request
- RREP: Route Reply



Distance Vector

Node *J* has been switched on



The distance vector published by *A*, *I*, *H*, *K* to *J*:

	A	B	C	D	E	F	G	H	I	J	K	L
A	0	12	25	40	14	23	18	17	21	8	24	29
I	24	36	18	27	7	20	31	20	0	10	22	33
H	20	31	19	8	30	19	6	0	14	12	22	9
K	21	28	36	24	22	40	31	19	22	6	0	9

J's new distance vector and routing table:

	A	B	C	D	E	F	G	H	I	J	K	L
J	8	20	28	20	17	30	18	12	10	0	6	15
via	A	A	I	H	I	I	H	H	I	---	K	K

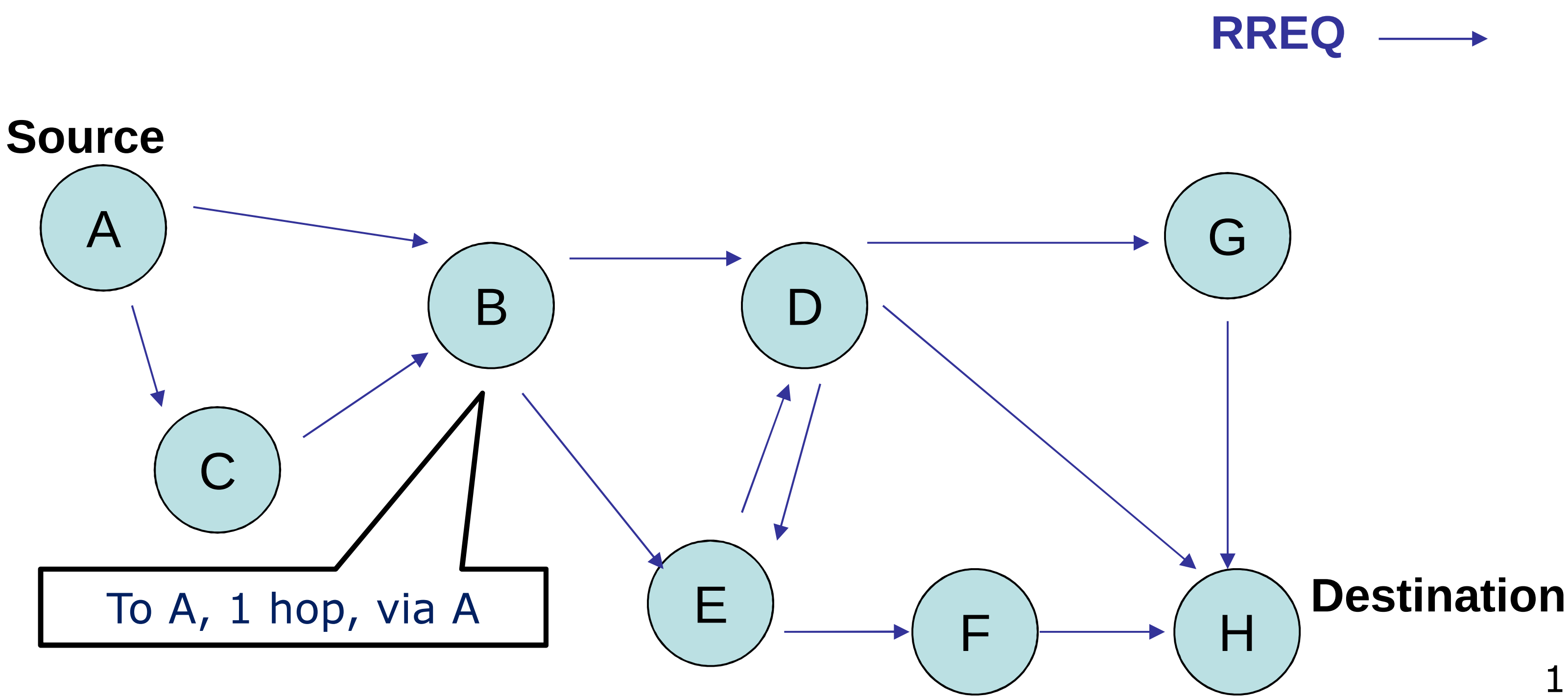
(source, distance, next hop)
C 28 I

AODV

- Ad hoc On-demand Distance Vector (AODV)
  - Reactive Routing using Distance Vector
  - Basic idea:
    - Activity starts when there is a demand for transmission
    - The SOURCE broadcasts a REQUEST
    - Each node rebroadcasts the REQUEST & creates DISTANCE VECTOR for the reverse path
    - When the REQUEST reaches the DESTINATION, the DESTINATION unicasts a REPLY
    - Each participated node forwards the REPLY & creates DISTANCE VECTOR for the forward path
    - When the REPLY reaches the SOURCE, data transmission may start

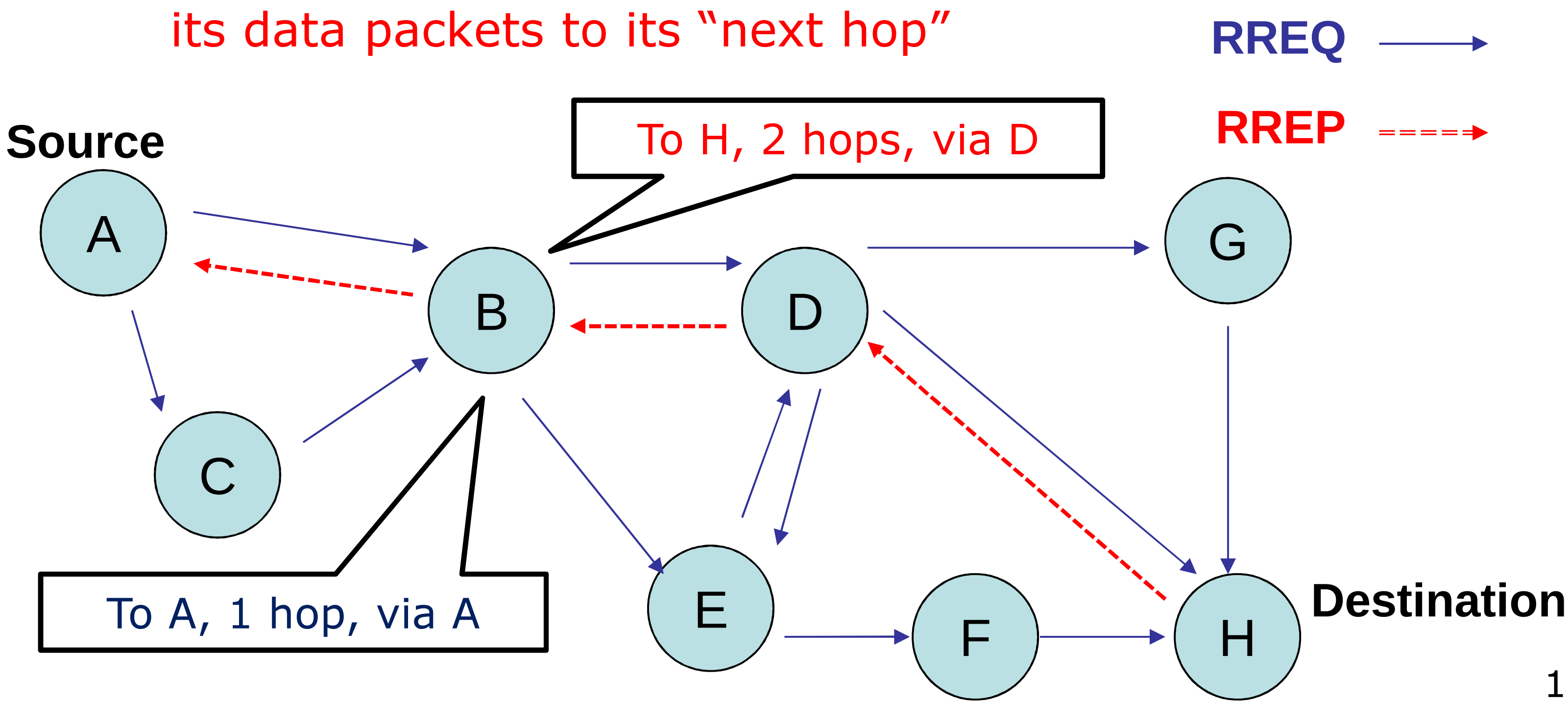
AODV: RREQ

– Route Request (RREQ) broadcasting
  - The source broadcasts a RREQ to find a connection
  - Intermediate nodes rebroadcast the RREQ to others
  - While rebroadcasting, intermediate nodes create a temporary route information recording the reverse path (i.e. source, number of hops, next hop)



AODV: RREP

- Returning of Route Reply (RREP)
  - Once RREQ reaches the destination, the destination unicasts RREP to its "next hop"
  - Each participated node forwards RREP to its "next hop" and record the forward path
  - Once the RREP reaches the source, the source can transmit its data packets to its "next hop"



AODV: Some management issues

- Distance Vector maintenance
  - A reverse path is purged after a timeout interval (to make sure the interval is long enough for RREP unicasting to complete)
  - A forward path is purged after it is not used for some time

- Enhancements
  - Intermediate nodes with information to the destination can reply RREP
  - Add sequence numbers to packets to avoid duplicate rebroadcasting
  - Use "time to live" to limit the rebroadcasting of RREQ

IPv6 Routing Protocol for Low-Power and Lossy Networks (RPL)

- Background:
  - Need for Low power and Lossy Networks (LLN)
  - IETF formed a Working Group called Routing Over Low power and Lossy Networks (ROLL) in 2008
  - ROLL developed “Ripple” routing protocol (RPL)

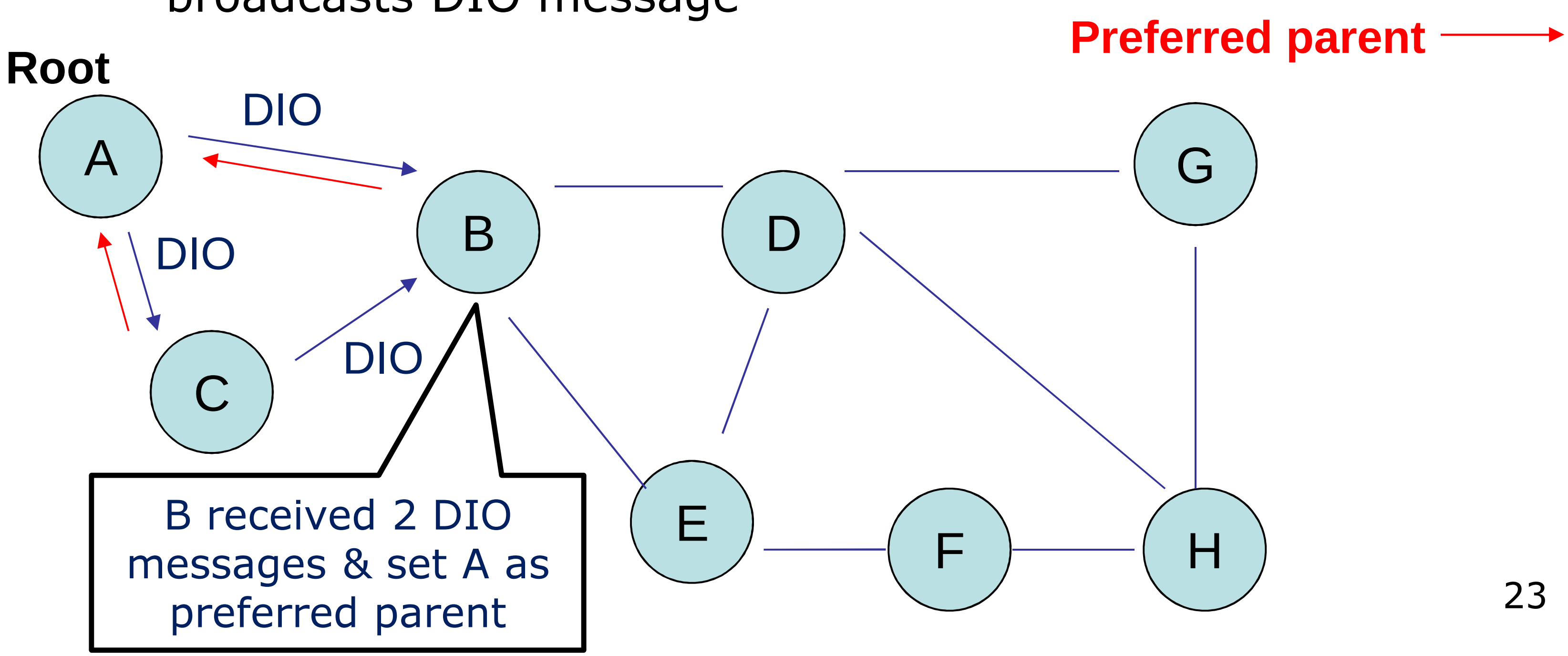
- RPL is a Distance Vector IPv6 routing protocol for LLNs
- RPL is a proactive routing protocol (periodic activity to construct route)
- RPL permits multiple routes (or graphs), each with some specific objective

RPL

- PRL is about building a Destination Oriented Directed Acyclic Graph (DODAG) with some objectives
- DOGAG building process
  - A node is designated as a root
  - A set of new ICMPv6 control messages is created
    - DIS: DODAG Information Solicitation
    - DIO: DODAG Information Object
    - DAO: DODAG Destination Advertisement Object
  - An Objective Function (OF) is specified for each node to compute its rank in the graph

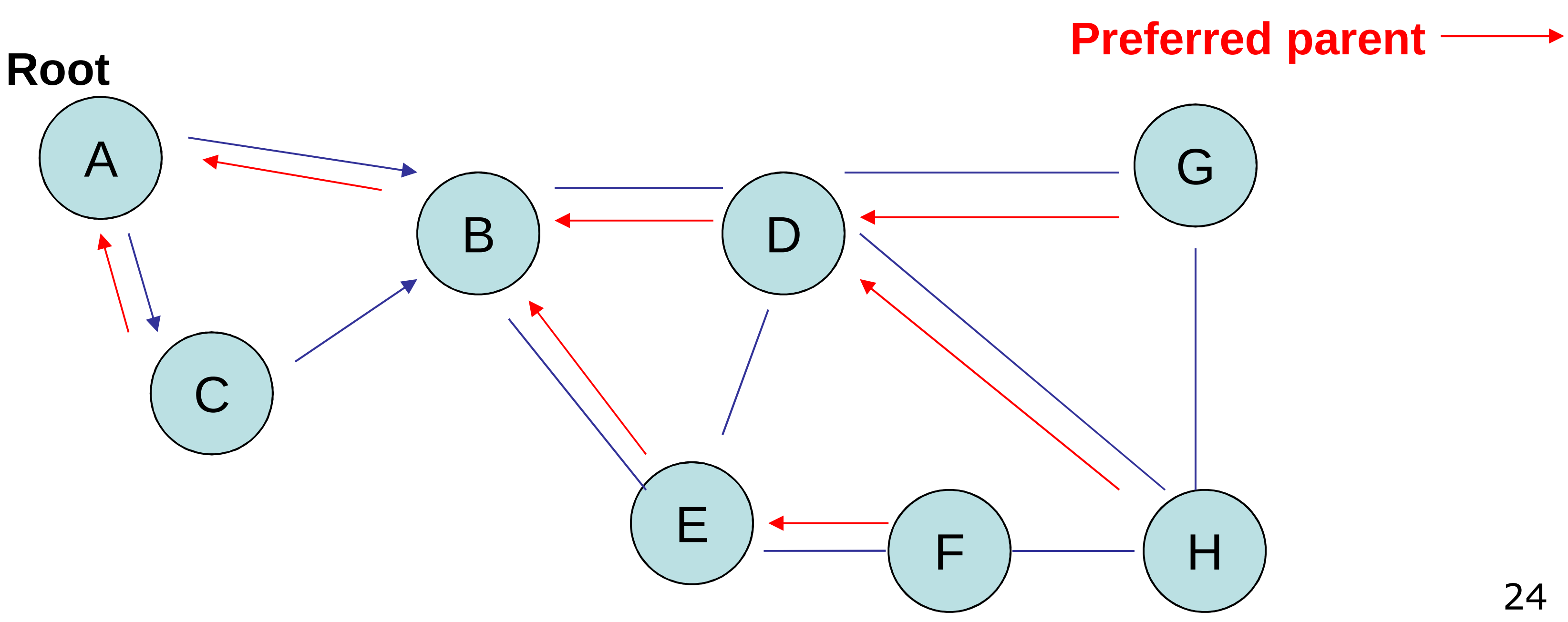
RPL: DOGAG Building Process

– Procedure:
  – The root starts broadcasting DIO
  – Upon receiving DIO, each node
    – computes its rank based on the OF
    – chooses a neighbour with a rank lower than itself as preferred parent
    – broadcasts DIO message



RPL: DOGAG Building Process

- Procedure (cont'd):
  - The broadcasting of DIO continues until all nodes have seen the DIO
  - By now, each node should have nominated one of its neighbours to be its preferred parent
  - A tree is built for UPWARD routing (or MP2P traffic)



RPL: P2MP & P2P

- Point-to-Multi-Point (P2MP) for Downward traffic
  - Each node transmits a DAO message to the root
  - Each intermediate node appends its ID and relays DAO to the root
  - Each node can make use of the passing DAO messages to build a subtree for downward traffic
    - This type of node is called a storing node
    - A node without this storing capability is called a non-storing node
  - The root will build and store a complete tree for downward traffic
  - Downward traffic can be routed using source routing
- Point-to-Point (P2P) traffic
  - P2P is done by upward+downward transmissions

RPL: Other Issues

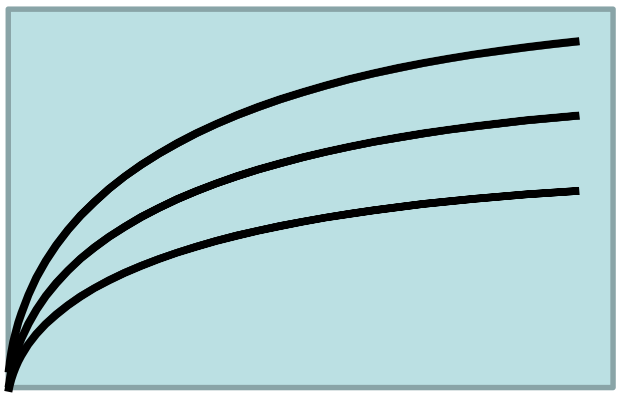
- Topology maintenance
  - A Trickle timer to control the sending rate of DIO
  - When routing inconsistencies are detected (e.g. loops, loss of a parent, etc), Trickle timer is reset to the minimum value to get the problems fixed quickly

- Supporting multiple topologies
  - RPL uses RPLInstanceID to label a graph
  - RPLInstanceID is included in graph building process

Mesh-under versus Route-over

- Relaying of packets can be performed at Layer 2 (mesh-under) or layer 3 (route-over)
- Layer-2 packet switching
  - It creates a single layer-2 domain, all nodes appear to be directly connected to each other somehow
  - It may offer simpler solution
  - It may offer lower transmission delay
- Layer-3 packet routing
  - It separates data link and routing operations
  - It may offer better management of a large network

Performance Issues



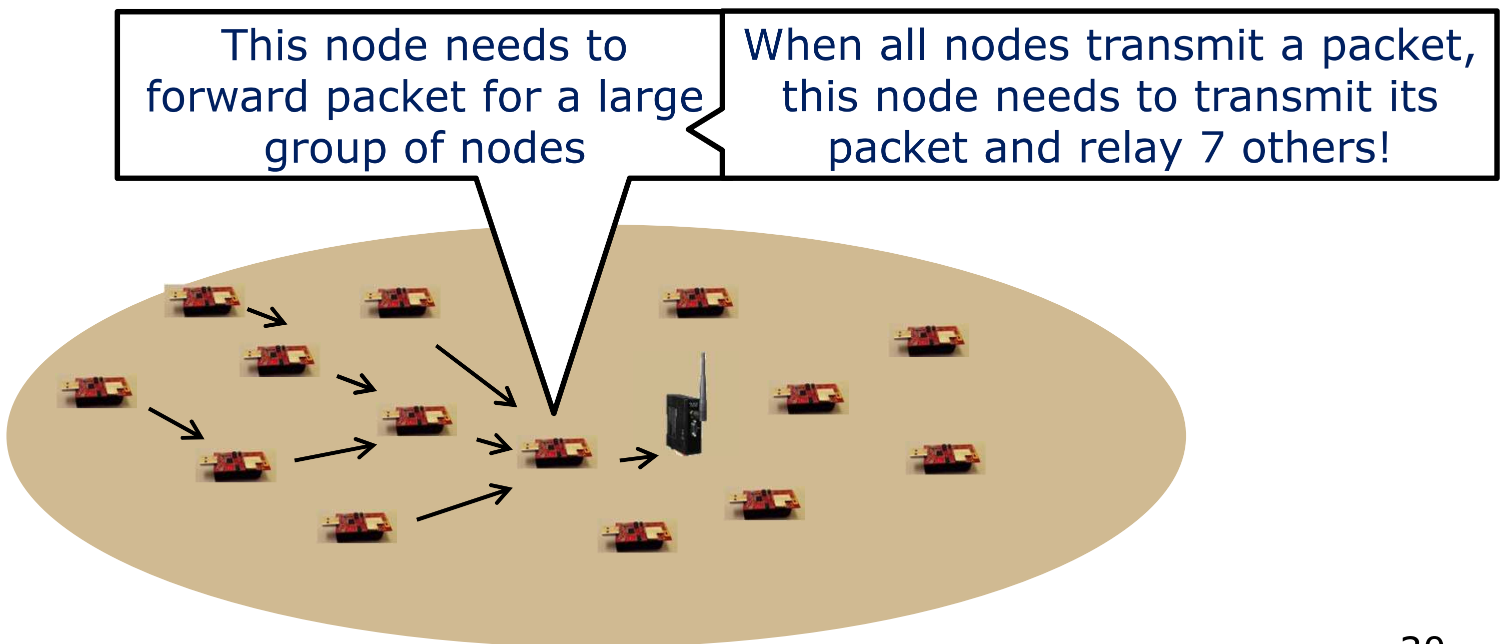
Network Performance

- Power Supply:
  - limited power supply

- Power Consumption:
  - Power consumption of communications is relatively high
  - Network establishment and maintenance need communications
  - Departure of some nodes may cause the network to fail partially or totally (e.g. nodes connecting to the gateway, nodes connecting two islands of networks, etc)

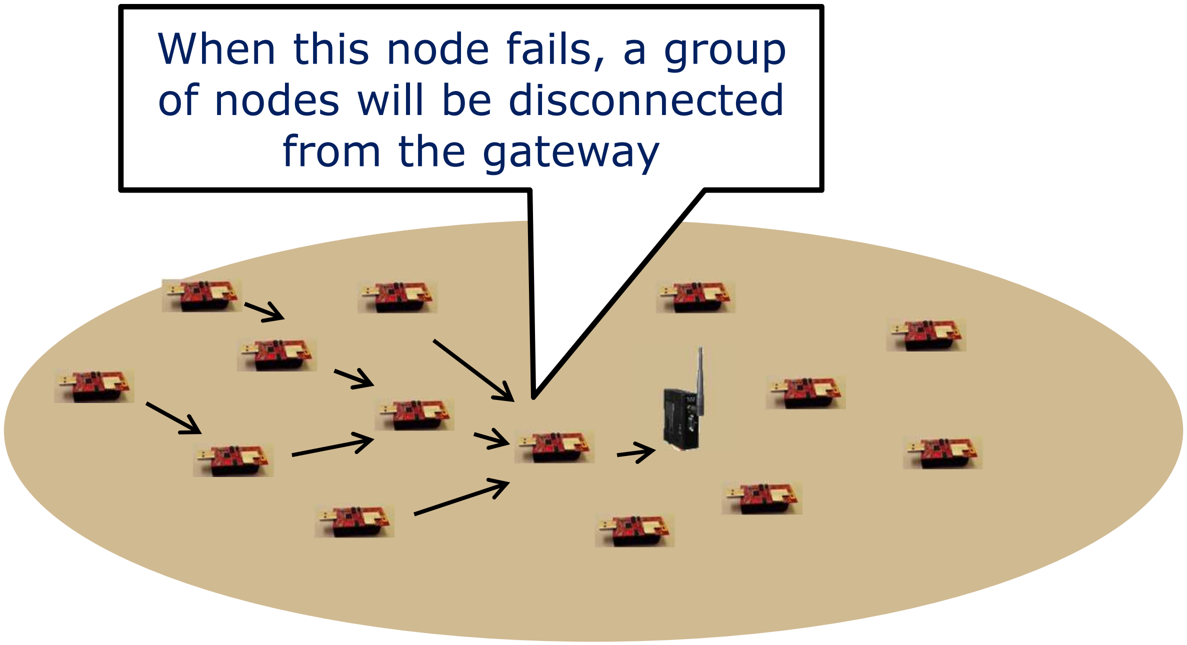
Performance:

- Deployment of nodes:
  - Bottleneck: When all flows aggregate at a particular node, the node may represent the bottleneck of the network
  - Possible solutions: add more nodes to create other paths; add gateways to divert traffic flows



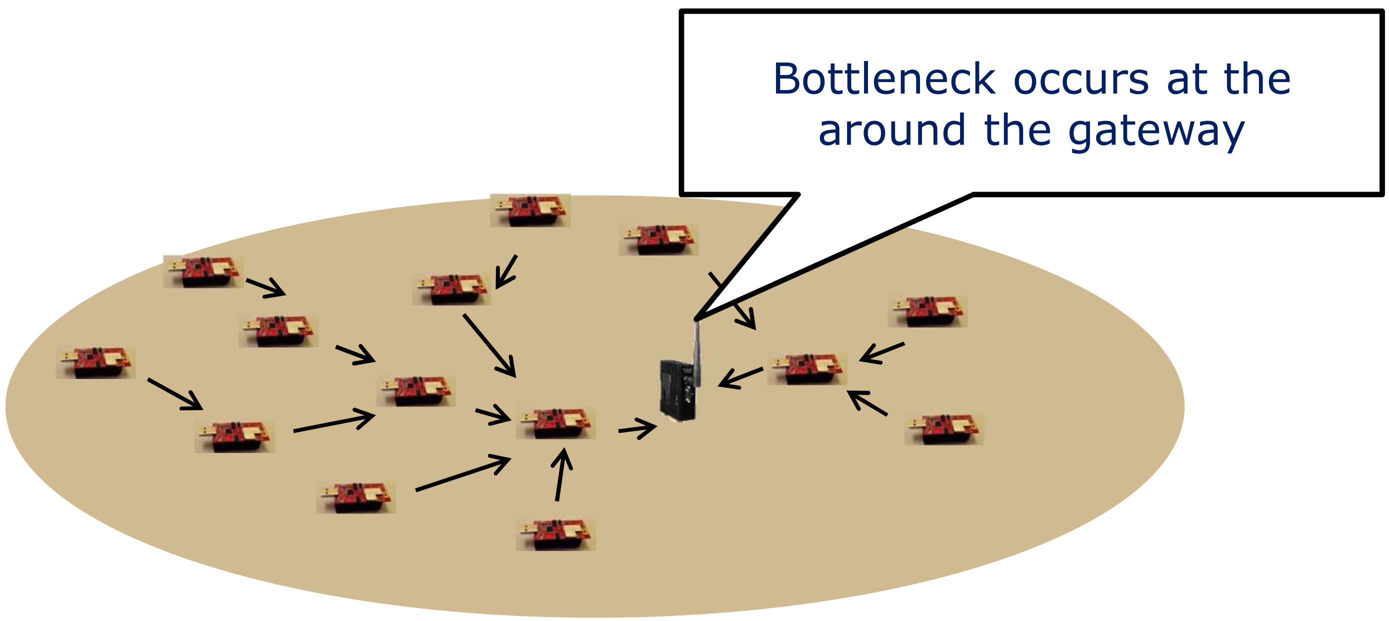
Performance:

- Deployment of nodes:
  - Network lifetime: Nodes nearer to the gateway perform more packet forwarding tasks. Their departures (due to flat battery) may cause the network to fail.
  - Possible solutions: add more nodes around the gateway; use higher capacity battery



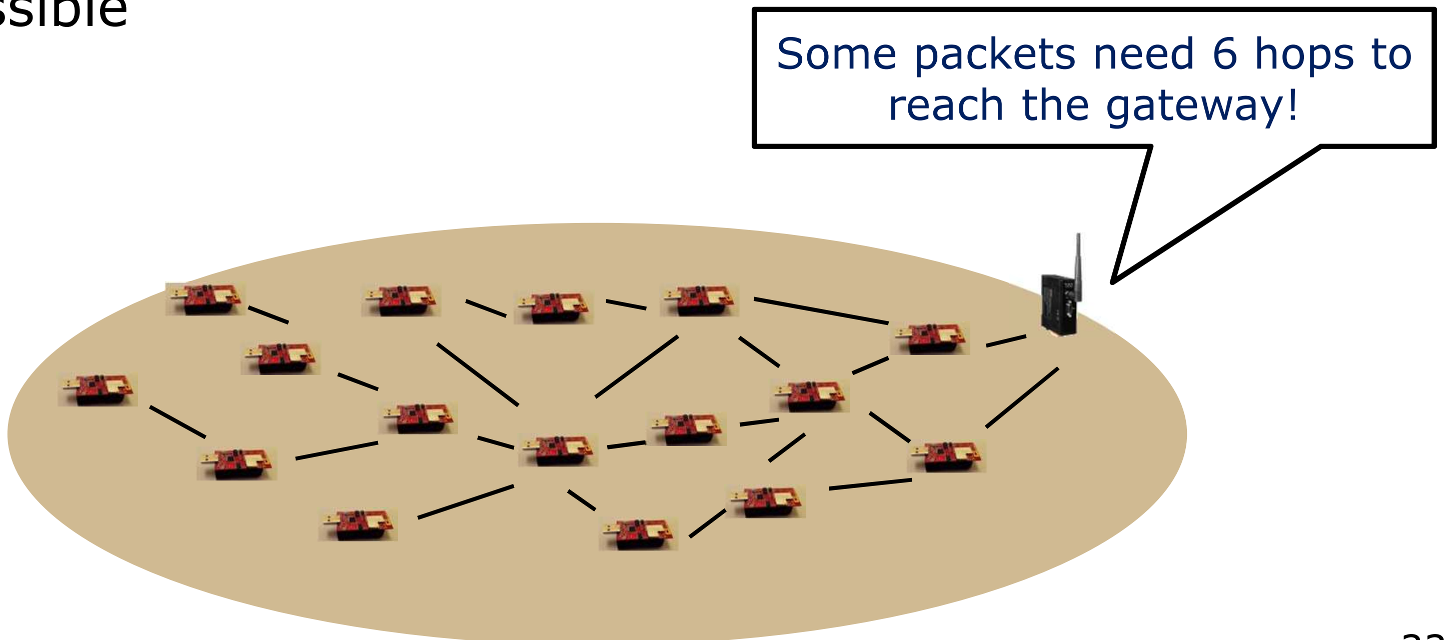
Performance:

- Position of a gateway:
  - Bottleneck: Gateway may become bottleneck of traffic flows if not adequately positioned in the network
  - Possible solutions: reposition the gateway or nodes around it and/or add more gateways to ease the congestion



Performance:

– Position of a gateway:
  – Delay: Nodes far away from the gateway may result in long end-to-end transmission delay
  – Possible solutions: relocating the gateway and/or place more gateways. Ideally, we should keep the number of hops between a node and the gateway as low as possible



Summary

- Understand the roles and functions of network module
- Understand various routing technologies related to IoT applications
- Understand the impact of nodes/gateway deployment on network performance

Questions?