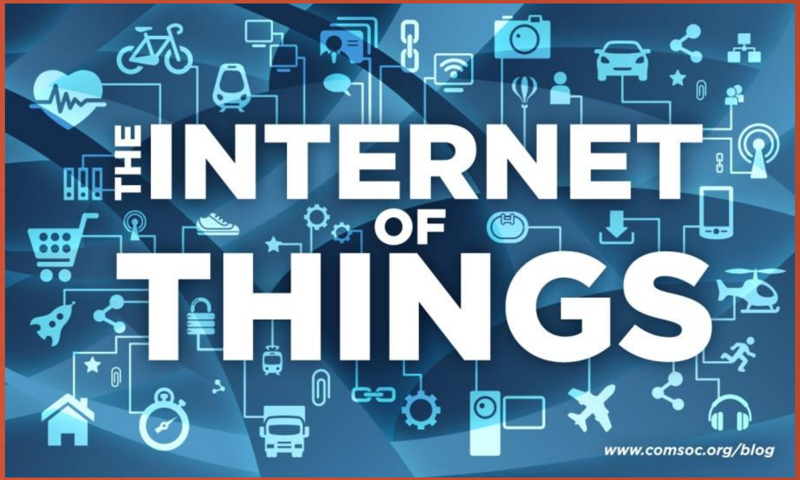
Routing in the
Internet of Things (IoT)



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IoT challenges

- IoT nodes are heterogeneous
  - Some have important resources
    - Smart phones, cars, coke machines
    - Connected to electricity, or easy to recharge
    - No size limitation
    - Big computing capacity, much memory
    - Many different radio interfaces, direct connection to the Internet

  - Nodes with limited resources
    - Sensors, smart tags
    - Limited CPU, memory, **battery life**
    - Usually only 1 radio interface, mostly in sleep mode
    - No direct connection to the Internet

IoT routing

- The nodes with limited resources also have to connect somehow to the Internet
  - To send their data (to the cloud)
  - To be queried from distance
- Multi-hop communication and routing
  - Traditional routing solutions are too resource-hungry
  - The goal is the fast and reliable transmission
- LLN – Low Power and Lossy Networks
  - Connections are by default unreliable, low transmission speed, high packet loss rate
    - Small capacity antennas, unfriendly environment (rain, snow, frost), interferences, mobility
  - The goal is energy efficiency, not communication efficiency
    - No problem is no continuous connection or packets are lost
    - Unattended operation for years – self-configuration, self-management

IoT routing

- In traditional networks if a connection is broken, a new path has to be found rapidly
  - To minimize packet loss
  - E.g., IP/MPLS Fast Reroute in OSPF
- **In LLN, link failures are usual, but transient**
  - If we would react to them, the network would become unstable (too much control plane overhead)

- In traditional networks big data traffic (video, VoIP),no possibility for buffering if a link is broken
- **In LLNs low data traffic, a transient loss can be easily handled with buffering or local redirection**
  - No need to reconfigure the entire topology

- In traditional networks static metrics, to ensure path stability
- **In LLNs dynamic metrics, changing in time**
  - The networks can adapt

LLN vs. WSN

- A wireless sensor network is a special type of LLN

WSN	LLN
Homogeneous network, similar sensors	Heterogeneous network, different nodes
Devices deployed with a specific goal, based on the needs of a specific application	Devices with different tasks, cooperating to find a gateway to the Internet
P2MP or MP2P communication (between sink and sensors)	P2MP, MP2P or P2P communication (between two IoT devices
Usually no IP support	IP based communication

RPL – IPv6 Routing Protocol for Low Power Lossy Networks

- IETF ROLL WG – **R**outing **O**ver **L**ow power **L**ossy (2008)
  - RPL protocol (say Ripple) – RFC 6550 (2012)

- IPv6 distance vector routing protocol
  - Builds a **DODAG-ot (Destination Oriented Directed Acyclic Graph**)
  - Using an objective function (OF) that takes into account several metrics and/or constraints
  - Several different OFs might be used in the same time, each building its own DODAG

    E.g.,1) The smallest ETX*, but only over nodes supporting encryption

    2) The lowest delay, but only over nodes that have solar panels

* ETX – Expected Transmission Count

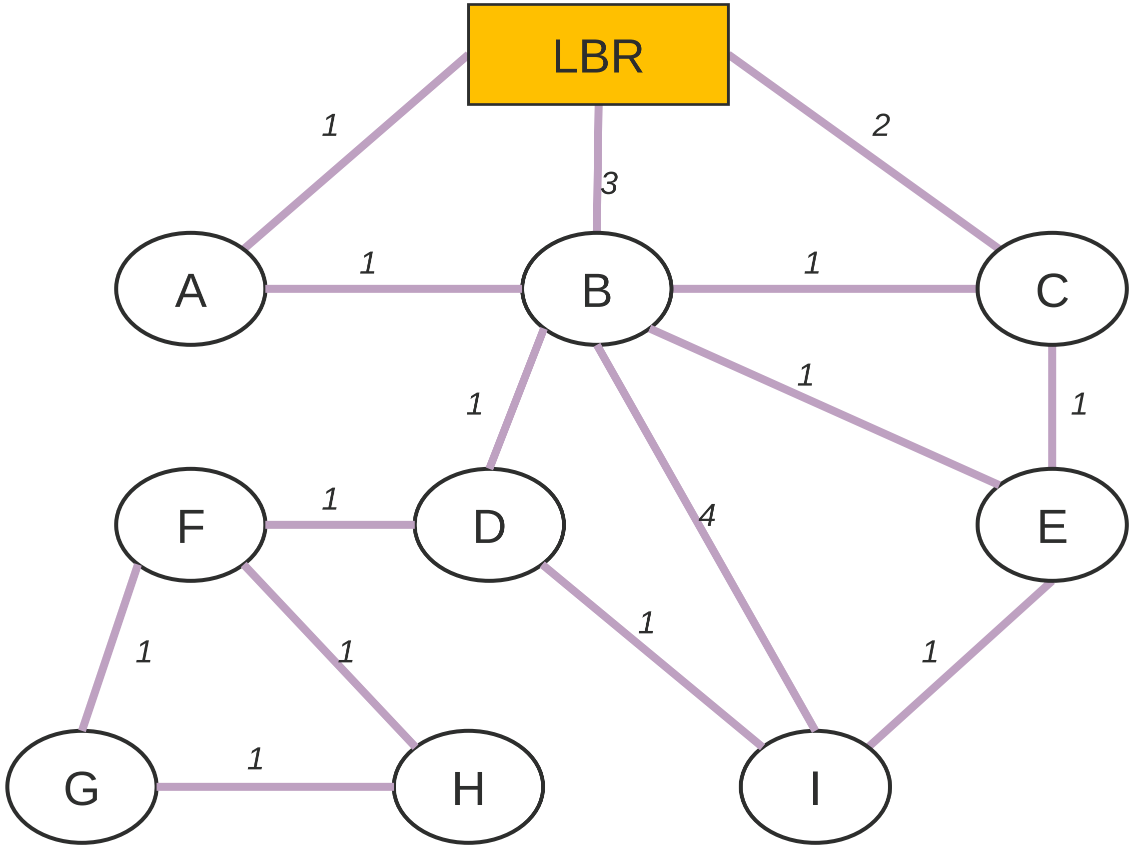
- Shows the quality of a radio connection – how many times should I **probably** send a packet to be sure that it is received
- Value between 1 and ∞, expected value based on past experience

Building a DODAG

- Starts at the root node – LBR (LLN Border Router)
  - Gateway to the Internet
  - Many LBRs can exist in the same network

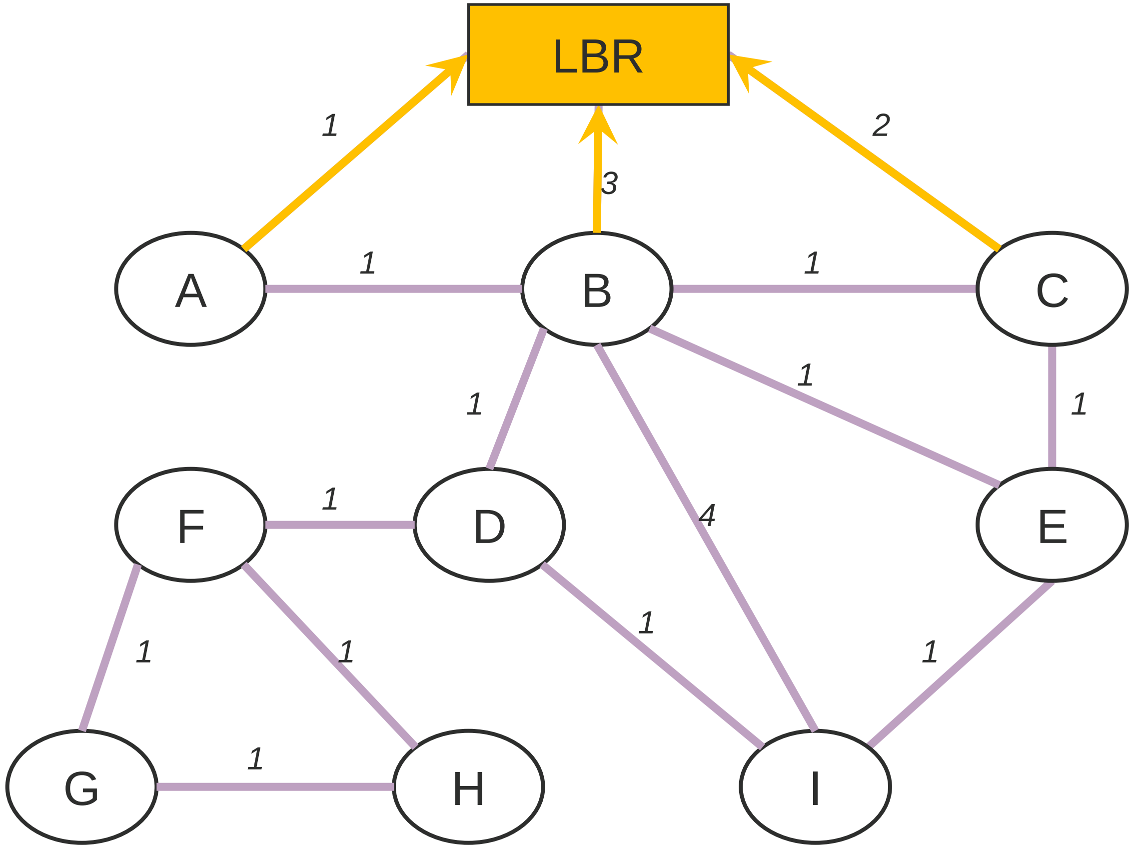
- New ICMPv6 control messages for RPL
  - DIO – DODAG Information Object
  - DAO – DODAG Destination Advertisement Object
  - DIS – DODAG Information Solicitation

Building the DODAG



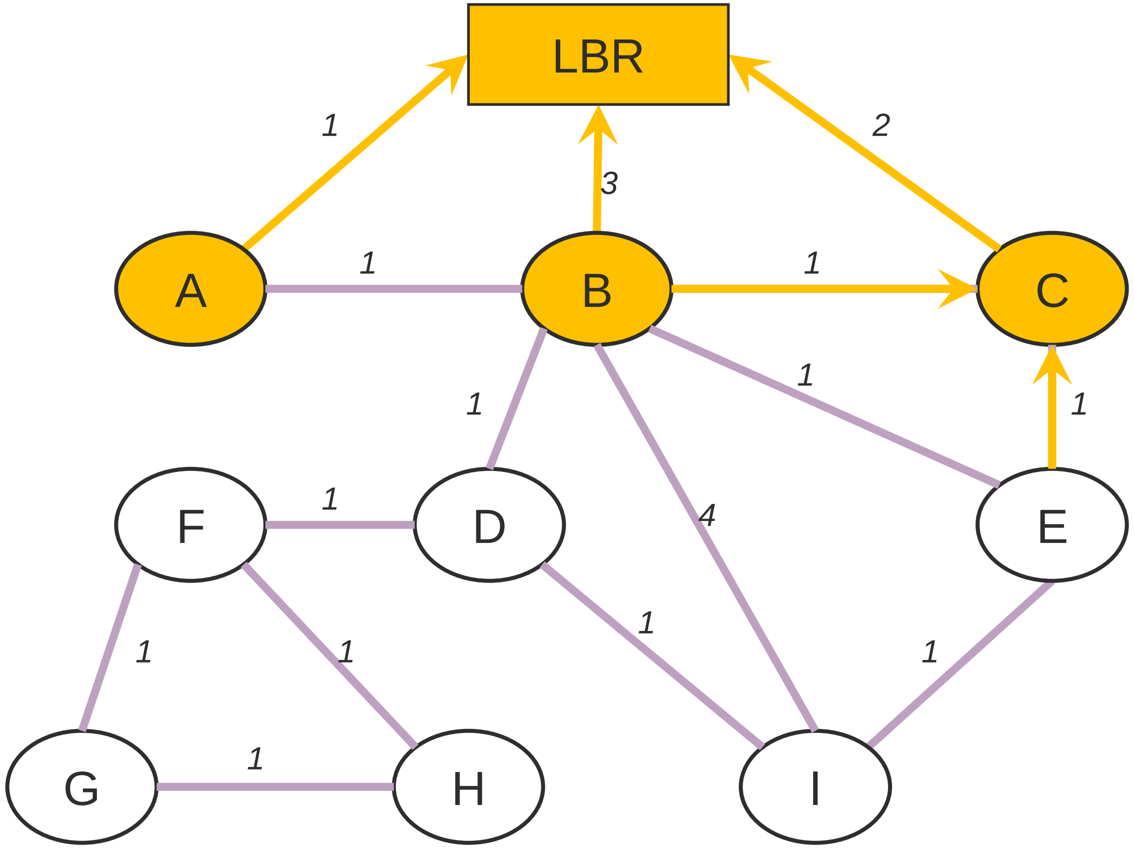
- Edges – LLN connections
- Values – e.g. ETX
  - Can change in time
  - Using an average value some stability can be ensured
- Goal (OF) – minimize ETX

Building the DODAG



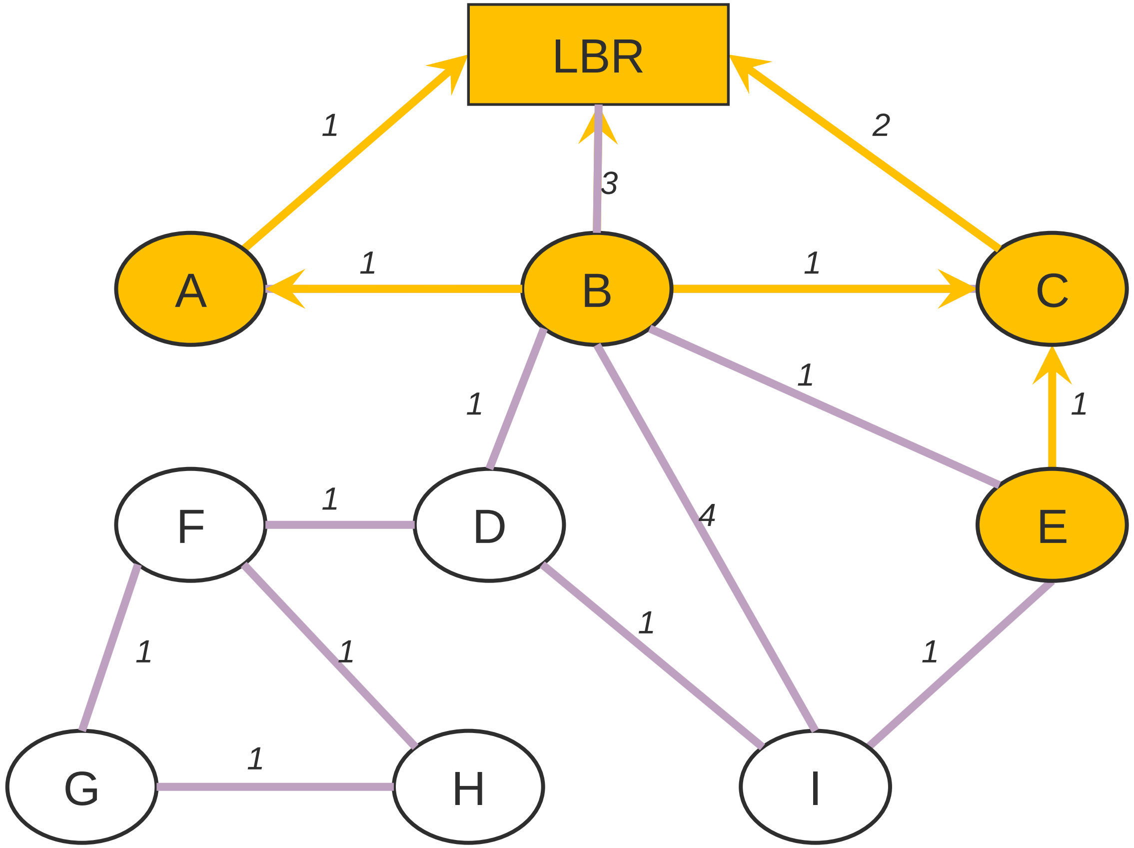
- The LBR sends a DIO message to its neighbors
  - Link local multicast
- Nodes A, B, C receive and handle it
  - Many DIOs can be received in the same time, from different LBRs
  - Based on the OF and other criteria, they decide to join the DODAG or not
  - If yes, the LBR is marked as parent

Building the DODAG



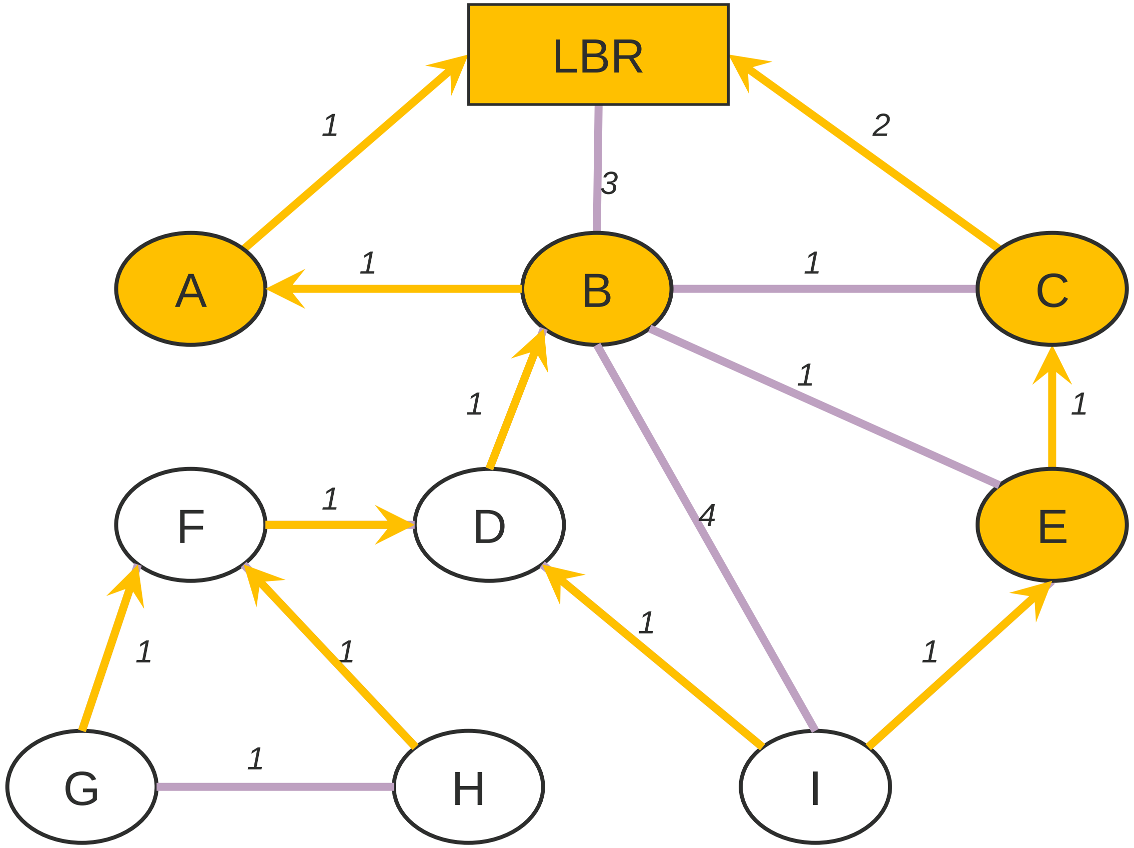
- The DIO timer of node C expires
- C sends a multicast DIO message to its neighbors
- The LBR ignores it, as it come from a higher ranked node
  - Rank(LBR) = 0, Rank(C) = 1
  - Needed to avoid loops
- B marks C as an alternative parent
- E joins the DODAG, marks C as a parent

Building the DODAG



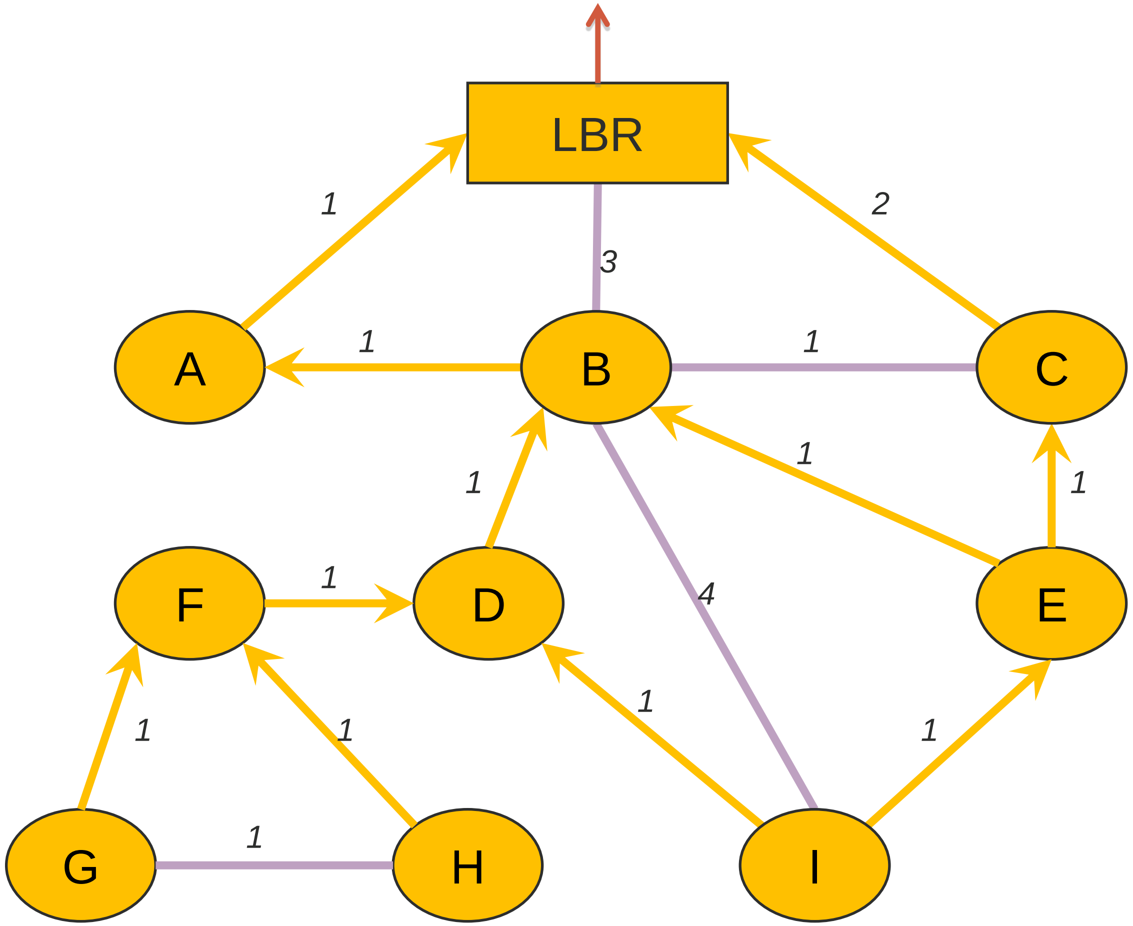
- The DIO timer of node A expires
- Sends a multicast DIO message to its neighbors
- The LBR ignores it
- B marks A as an alternative parent
- As the OF (ETX) value is better if B connects through A, B deletes the LBR and C from its parents

Building the DODAG



- The construction of the DODAG is continuous
- The DODAG is continuously maintained

MP2P (Multi-Point to Point) traffic



- MP2P traffic along the DODAG, from each node to the LBR
  - UPWARD routing
- The LBR connects to the Internet
- A node can participate in parallel in several DODAGs

P2MP (Point to Multi-Point) traffic

- DOWNWARD routing
  - Routing information has to be built

- **DAO (DODAG Destination Advertisement)** messages
  - If a node joins a DODAG, sends a DAO to its parents
  - Can be initiated by the LBR as well, or any intermediate node in the DODAG
    - Marked in the DIO message going downwards
    - The DAO timers (DelayDAO) are set so as to expire first at higher ranked nodes in the DODAG
  - The advertise in the DAO message the network prefix reachable through them

P2MP (Point to Multi-Point) traffic

- LLN nodes sometimes are not able to store routing entries

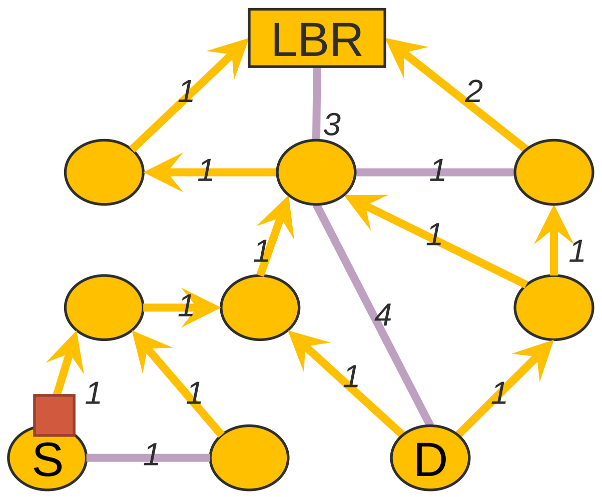
  - If yes – **storing mode**
    - If possible, it aggregates the prefix of its children with his own prefix, and send this aggregated value forward

  - If not – **non-storing mode**
    - Source-routing: the DAO message contains the path

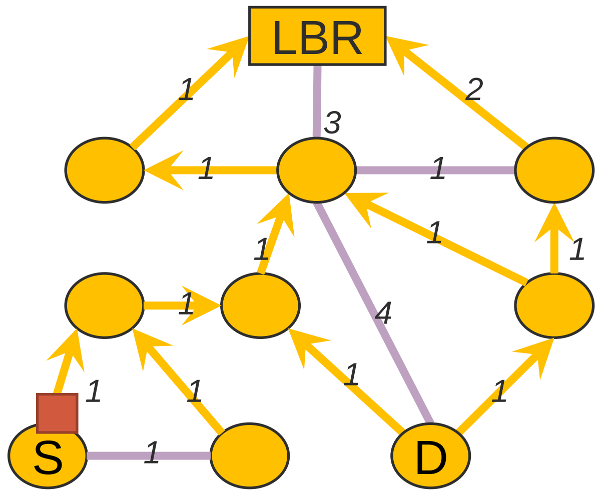
  - Either storing mode or non-storing, the hybrid solution was not standardized
    - Even if it was included in the first drafts
  - Advantages end drawbacks
    - In storing mode routing entries have to be stored, but short messages
    - In non-storing mode nothing has to be stored but long messages, increased energy consumption

P2P (Point-to-Point) traffic

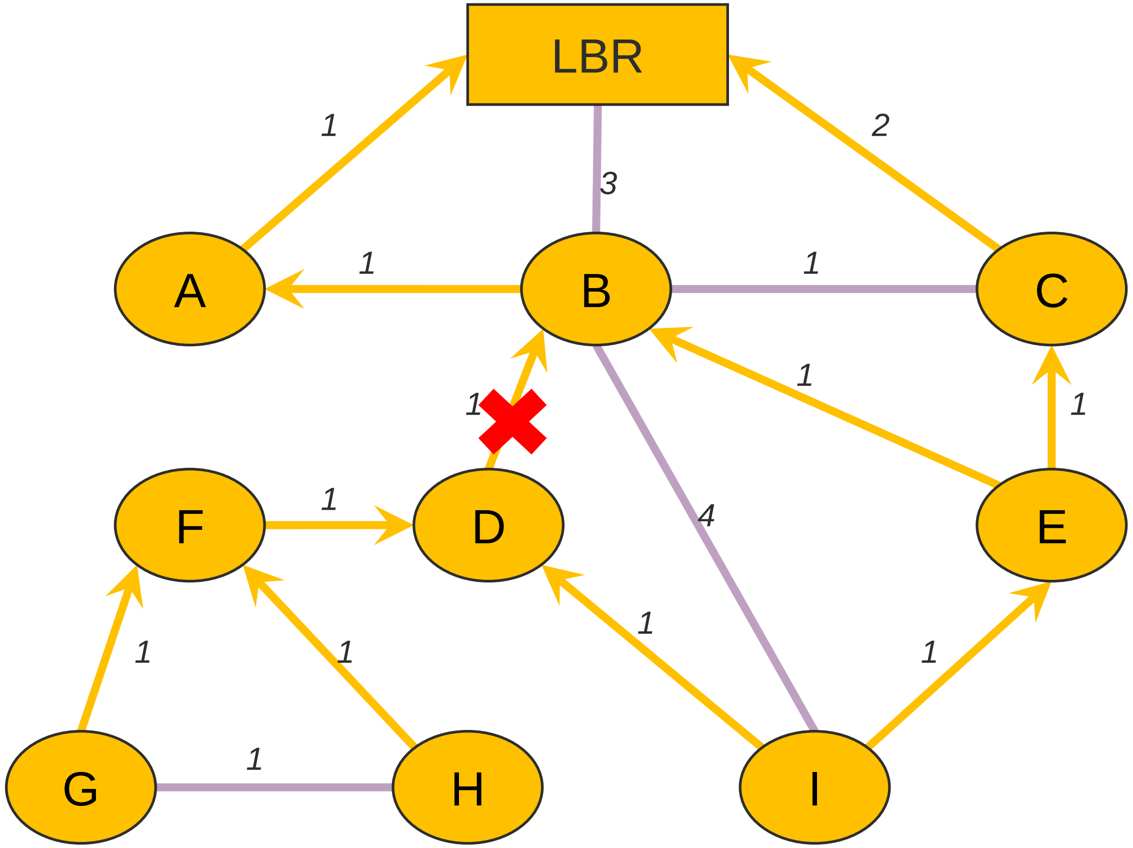
- Between any two S (Source) and D (Destination) nodes
  - If non-storing mode:
    - From S, we have to go towards the LBR along the DODAG
    - Then source routing from the LBR to D



  - If storing mode:
    - Shortcut at the first common ancestor



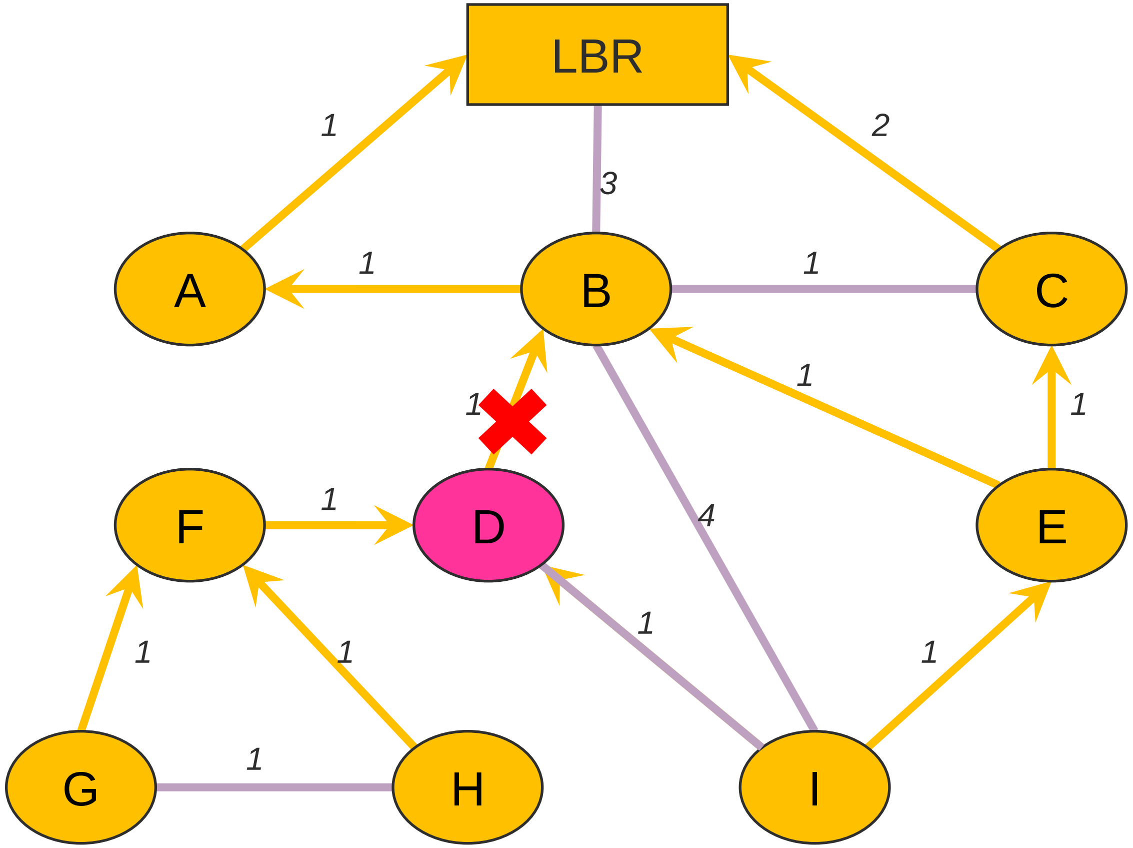
DODAG maintenance



- **Grounded DODAG**
  - A DODAG that corresponds to an OF and the given constraints
- **Floating DODAG**
  - A DODAG that does not meet the necessary criteria
  - Transient state, marked in the DIO message by setting the G (Grounded) bit

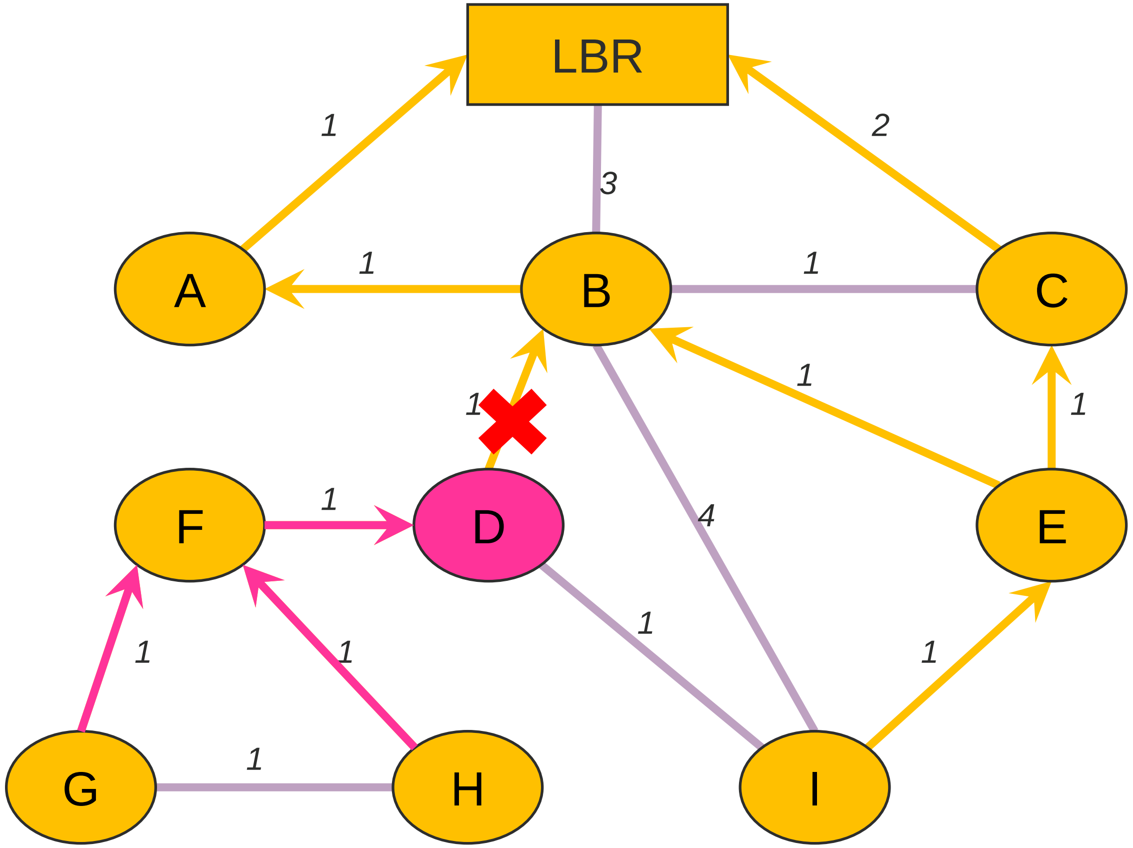
- What happens if the connection breaks between B and D?
- D deletes B from its parents
- As D does not have other parents, it becomes the root of a floating DODAG

DODAG maintenance



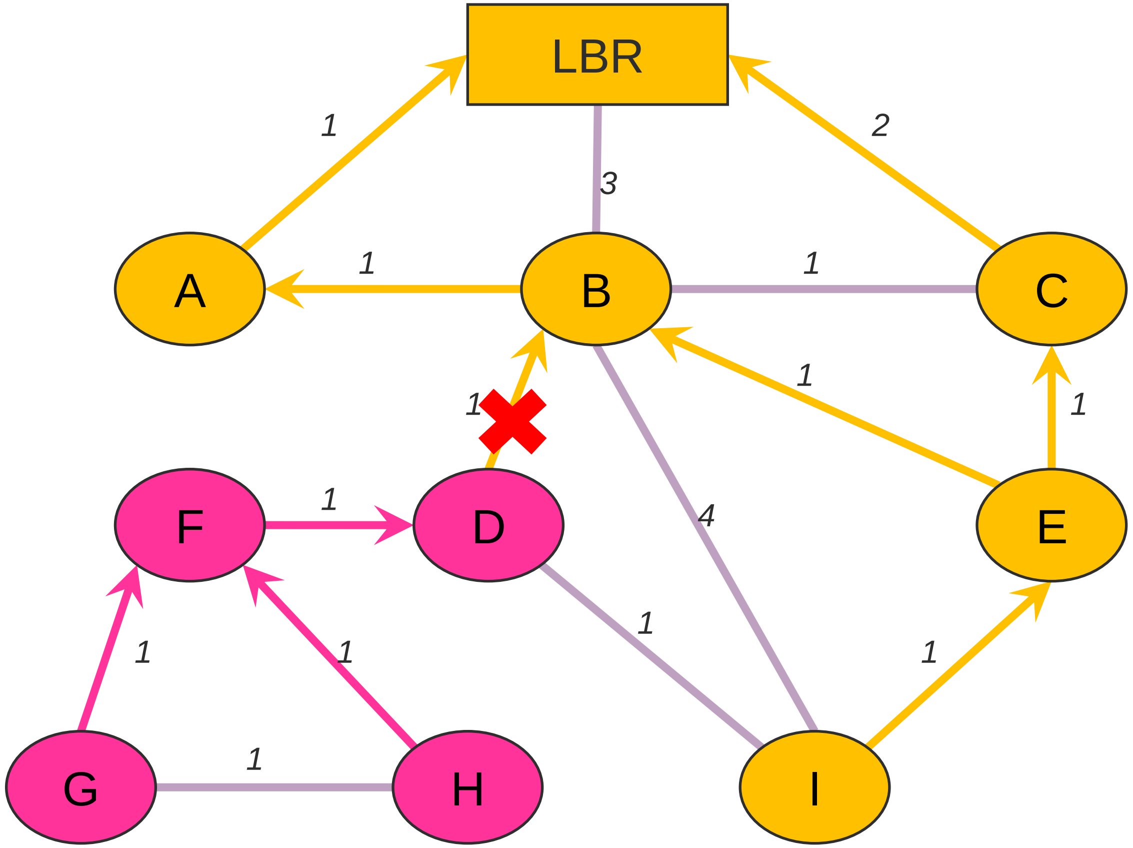
- D sends a multicast DIO message to its neighbors, letting them know about the change
- Node I has an alternative parent (E), still connected through it to the grounded DODAG
- As D is not part of the DODAG anymore, I deletes it from its parents

DODAG maintenance



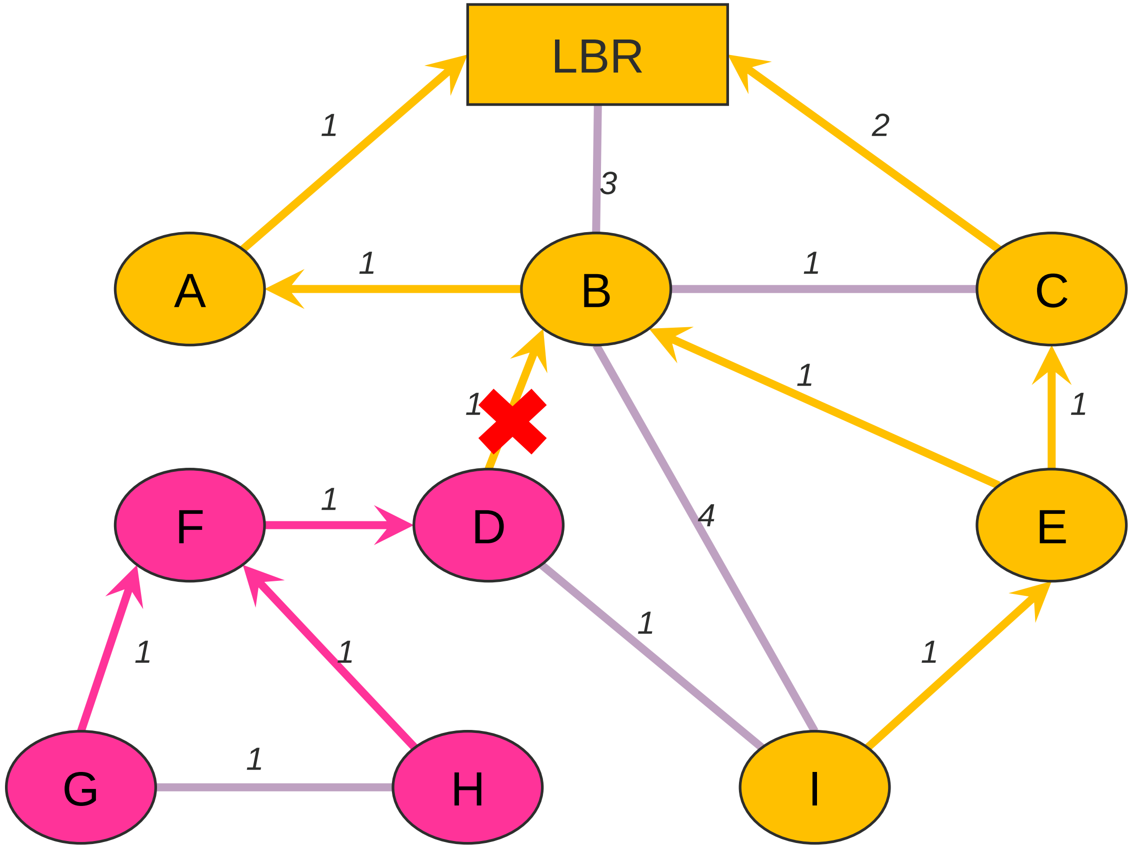
- F does not have an alternative parent, so it stays in the floating DODAG of D
- F sends a multicast DIO message to its neighbors
- G and H do the same and follow F in the floating DODAG of D

DODAG maintenance



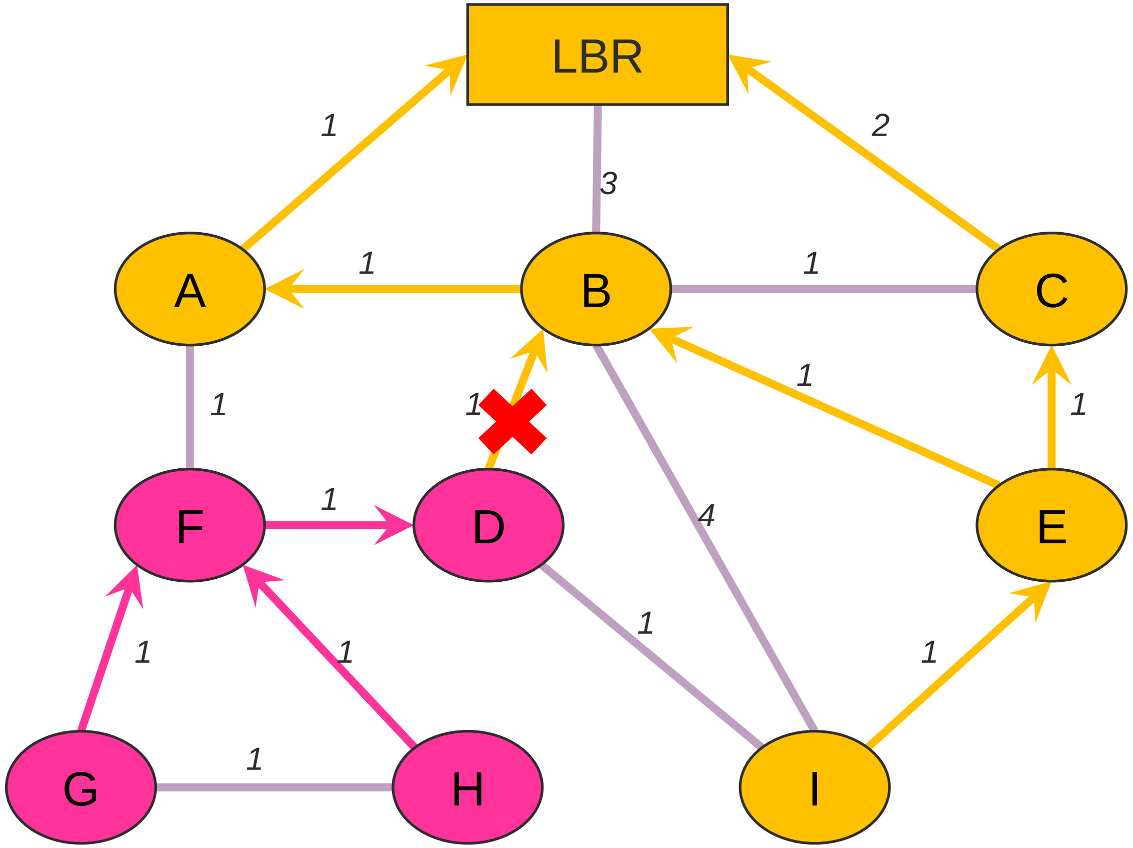
- A floating DODAG was formed, with D being the root
- They delete all the paths related to LBR
- The floating DODAG tries to rejoin the grounded DODAG…

DODAG maintenance



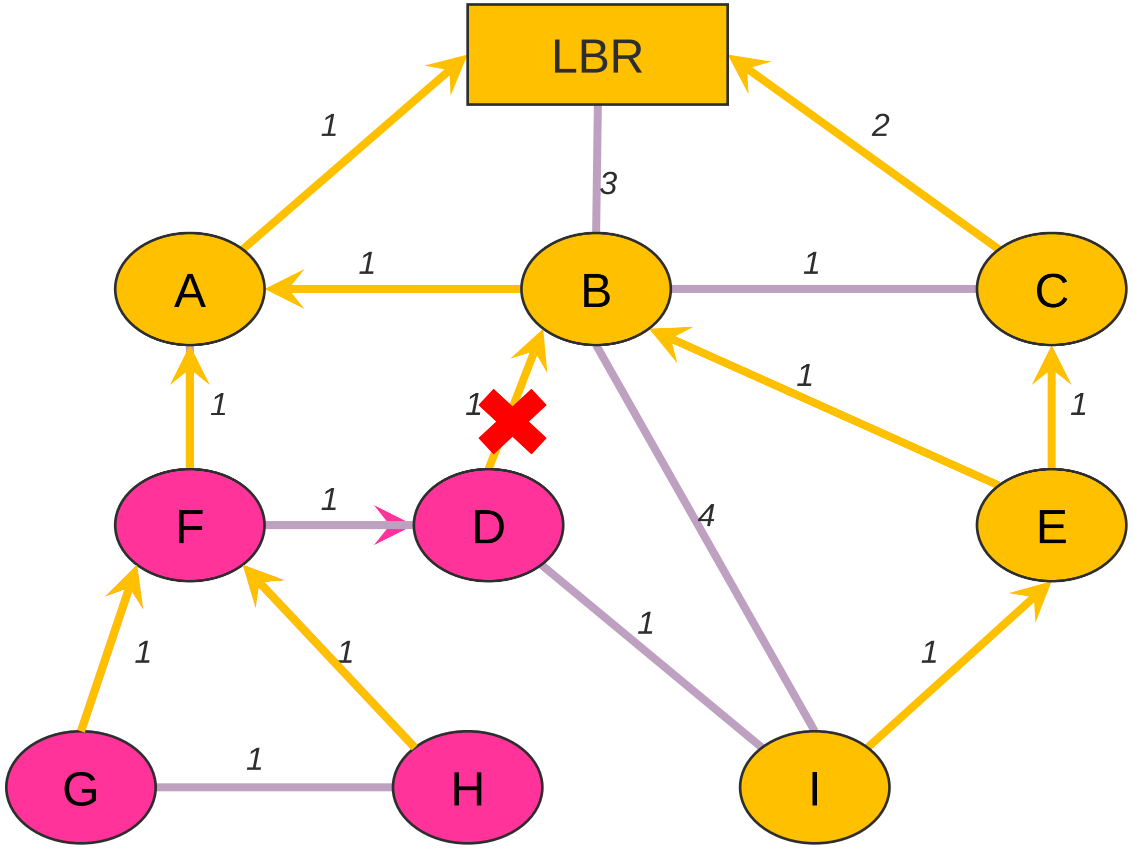
- I sends a multicast DIO message
- D receives it, learns that it could join the LBR DODAG through I
- D starts a timer related to node I
  - The setting of the timer depends on the rank of node I
  - D wants to be as close to LBR as possible

DODAG maintenance



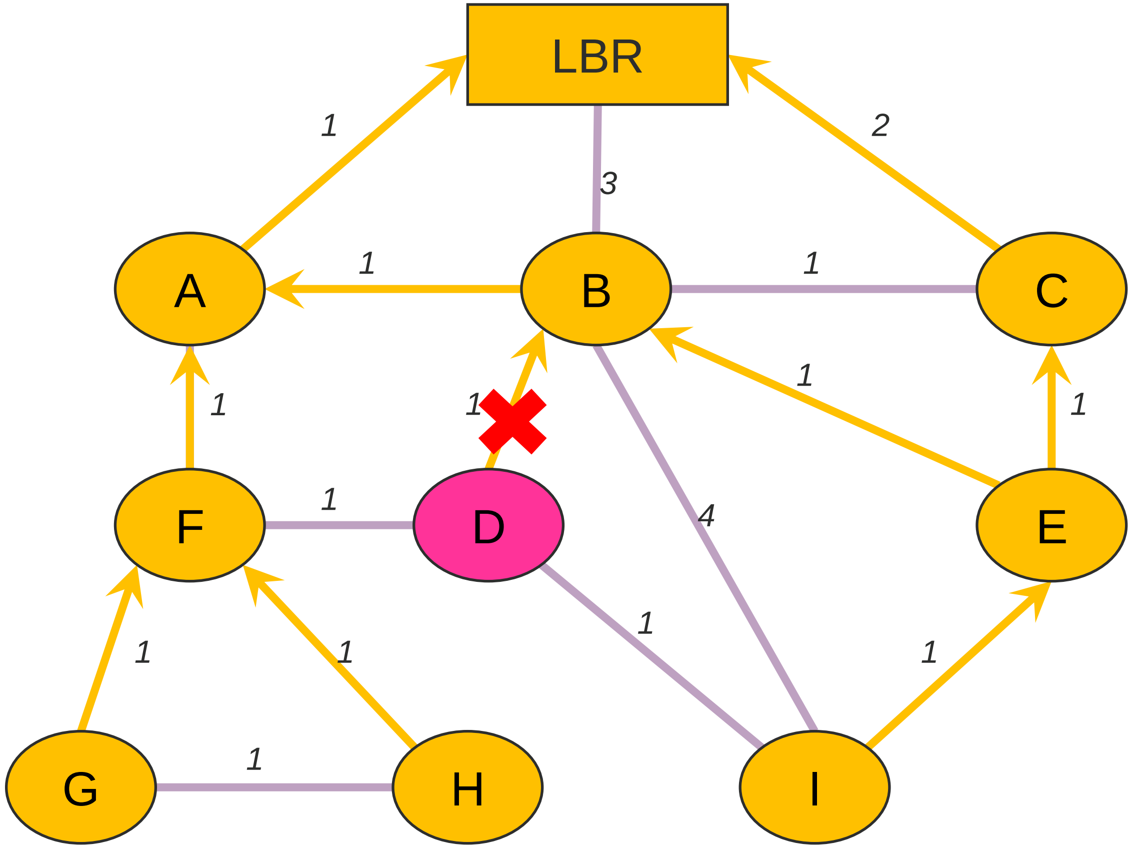
- Suppose that A radio link is established between A and F
- A sends a multicast DIO message
- F receives it, starts a timer related to node A

DODAG maintenance



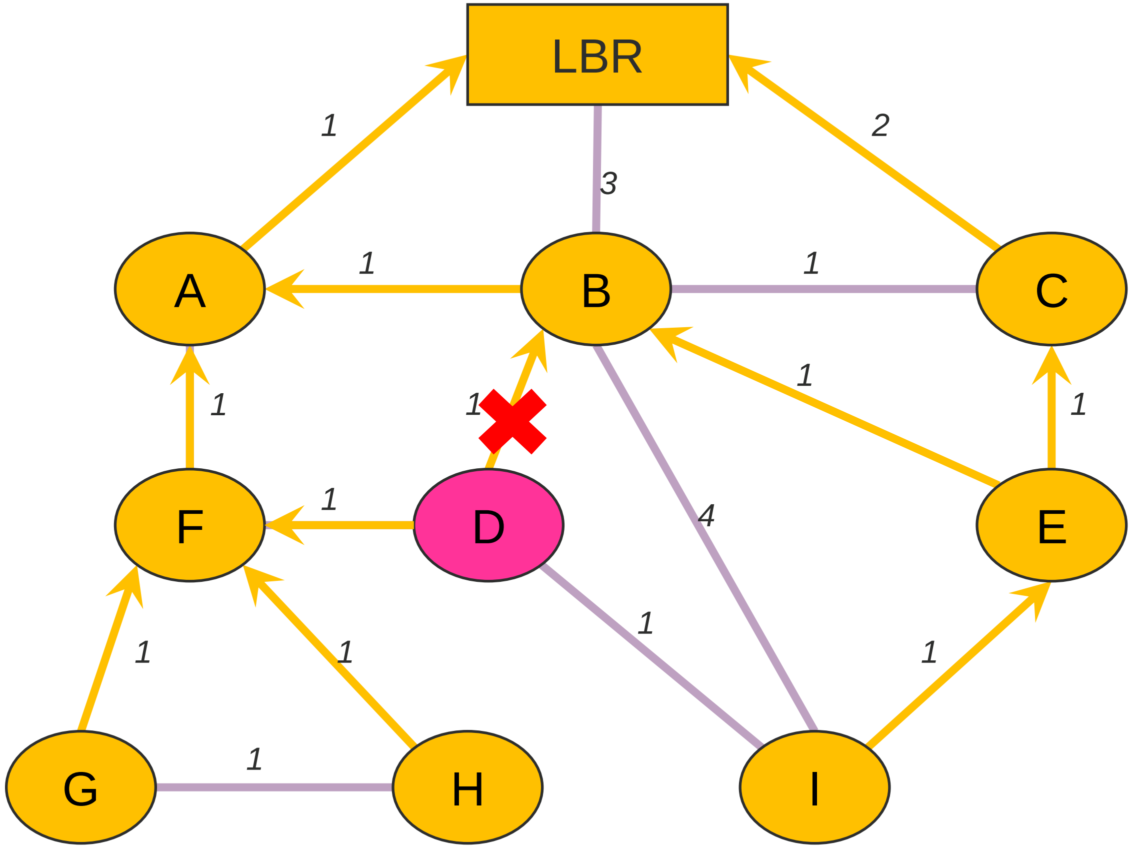
- The timer of node F expires
- F joins the grounded DODAG through A, deletes D from its parents
- F sends a multicast DIO message
- G and H join the grounded DODAG through F

DODAG maintenance



- D sees that it could join the grounded DODAG through F
- D starts a timer related to F, besides the already running time related to I

DODAG maintenance



- The timer related to F expires first
- D joins the grounded DODAG through F
- The floating DODAG disappears, the problem was handled without forming cycles

Joining

- When a node appears (it is switched on, or it moves the the given area), it starts listening to DIO messages
  - If it receives such messages, it decides which DODAG to join
  - If it receives nothing, or if it wants to speed up the process, it sends a DIS message
    - **DODAG Information Solicitation**
    - Triggers the sending of DIO messages from its neighbors
  - If still no DIO is received, it has the choice to become the root of a floating DODAG
    - Starts sending its own multicast DIO messages

Further details

Add	Document	Title	Date	Status
Active Internet-Drafts				
	draft-ietf-roll-admin-local-policy-03	Forwarder policy for multicast with admin-local scope in the Multicast Protocol for Low power and Lossy Networks (MPL)	2015-02-06	RFC Ed Queue (for 25 days) RFC Editor State: MISSREF Submitted to IESG for Publication
	draft-ietf-roll-applicability-ami-10	Applicability Statement for the Routing Protocol for Low Power and Lossy Networks (RPL) in AMI Networks	2015-01-30	I-D Exists In WG Last Call Oct 2012
	draft-ietf-roll-applicability-home-building-09	Applicability Statement: The use of the RPL protocol suite in Home Automation and Building Control	2015-03-25 new	IESG Evaluation (for 9 days) IESG Telechat: 2015-04-09 Submitted to IESG for Publication Oct 2012
	draft-ietf-roll-applicability-template-06	ROLL Applicability Statement Template	2014-11-10	I-D Exists WG Document Jan 2013
	draft-ietf-roll-mpl-parameter-configuration-03	MPL Parameter Configuration Option for DHCPv6	2015-01-20	I-D Exists In WG Last Call
	draft-ietf-roll-trickle-mcast-11	Multicast Protocol for Low power and Lossy Networks (MPL)	2014-11-24	IESG Evaluation::Revised I-D Needed (for 57 days) Submitted to IESG for Publication
RFCs				
	RFC 5548 *(was draft-ietf-roll-urban-routing-reqs)*	Routing Requirements for Urban Low-Power and Lossy Networks	2009-05	RFC 5548 (Informational)
	RFC 5673 *(was draft-ietf-roll-indus-routing-reqs)*	Industrial Routing Requirements in Low-Power and Lossy Networks	2009-10	RFC 5673 (Informational)
	RFC 5826 *(was draft-ietf-roll-home-routing-reqs)*	Home Automation Routing Requirements in Low-Power and Lossy Networks	2010-04	RFC 5826 (Informational) Errata
	RFC 5867 *(was draft-ietf-roll-building-routing-reqs)*	Building Automation Routing Requirements in Low-Power and Lossy Networks	2010-06	RFC 5867 (Informational)
	RFC 6206 *(was draft-ietf-roll-trickle)*	The Trickle Algorithm	2011-03	RFC 6206 (Proposed Standard)
	RFC 6550 *(was draft-ietf-roll-rpl)*	RPL: IPv6 Routing Protocol for Low-Power and Lossy Networks	2012-03	RFC 6550 (Proposed Standard) Errata
	RFC 6551 *(was draft-ietf-roll-routing-metrics)*	Routing Metrics Used for Path Calculation in Low-Power and Lossy Networks	2012-03	RFC 6551 (Proposed Standard) Errata
	RFC 6552 *(was draft-ietf-roll-of0)*	Objective Function Zero for the Routing Protocol for Low-Power and Lossy Networks (RPL)	2012-03	RFC 6552 (Proposed Standard)
	RFC 6719 *(was draft-ietf-roll-minrank-hysteresis-of)*	The Minimum Rank with Hysteresis Objective Function	2012-09	RFC 6719 (Proposed Standard)
	RFC 6997 *(was draft-ietf-roll-p2p-rpl)*	Reactive Discovery of Point-to-Point Routes in Low-Power and Lossy Networks	2013-08	RFC 6997 (Experimental)
	RFC 6998 *(was draft-ietf-roll-p2p-measurement)*	A Mechanism to Measure the Routing Metrics along a Point-to-Point Route in a Low-Power and Lossy Network	2013-08	RFC 6998 (Experimental)
	RFC 7102 *(was draft-ietf-roll-terminology)*	Terms Used in Routing for Low-Power and Lossy Networks	2014-01	RFC 7102 (Informational)
	RFC 7416 *(was draft-ietf-roll-security-threats)*	A Security Threat Analysis for the Routing Protocol for Low-Power and Lossy Networks (RPLs)	2015-01	RFC 7416 (Informational)