Wireless Sensor Networks

6. WSN Routing

Christian Schindelhauer
Technische Fakultät
Rechnernetze und Telematik
Albert-Ludwigs-Universität Freiburg
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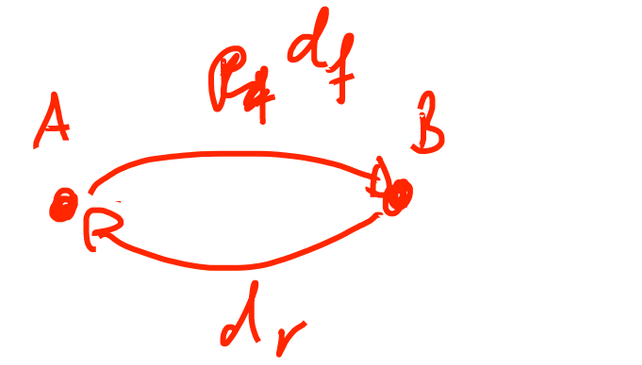
Routing Protocol for Low power and Lossy Networks (RPL)

- Literature
  - IETF RFC 6550, RPL: IPv6 Routing Protocol for Low-Power and Lossy Networks, Winter, Thubert, Brandt, Hui, Kelsey, Levis, Pister, Struik, Vasseur, Alexander, March 2012
- Designed for Low-power and Lossy Networks (LLN)
  - limited processing power, memory, energy
  - interconnected by lossy links, low data rates
  - traffic patterns
    - Multipoint to point (convergecast)
    - Point to multipoint (multicast)
    - point to point (unicast)
- Design Principles
  - Routing Metric is variable
  - bidirectional links required
  - uses Trickle for data dissemination
  - uses DAG as basic topology

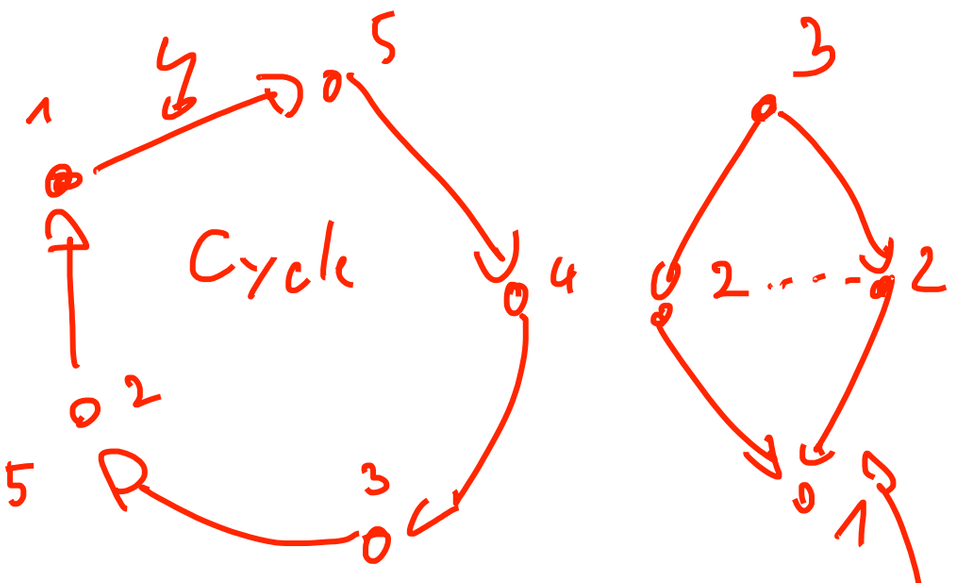


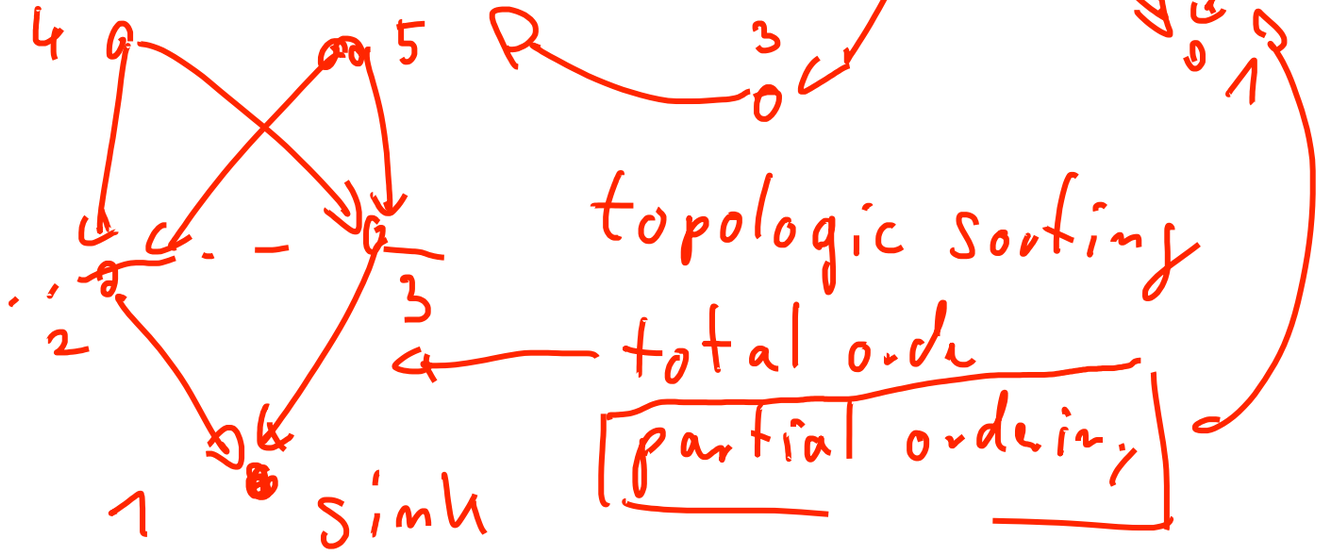
$$ETX(A,B) = \frac{1}{d_f \cdot d_r}$$

DAG

directed acyclic graph

non-cyclic





topologic sorting

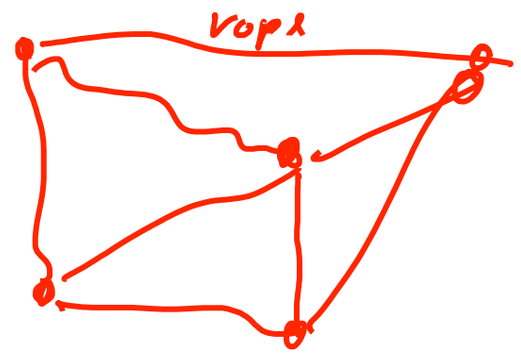
total order

partial ordering

set of nods / vertices

set of edges / rays ..

knot nods



undirected

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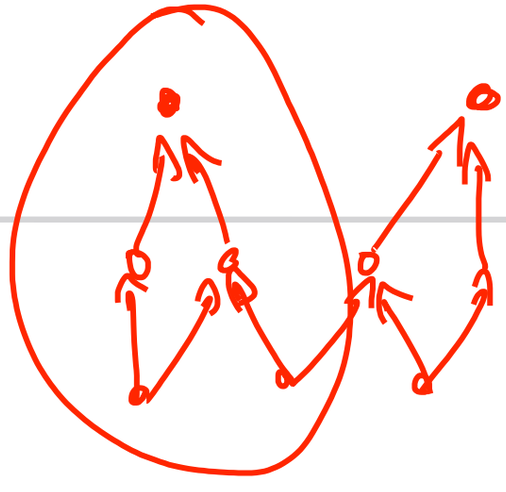
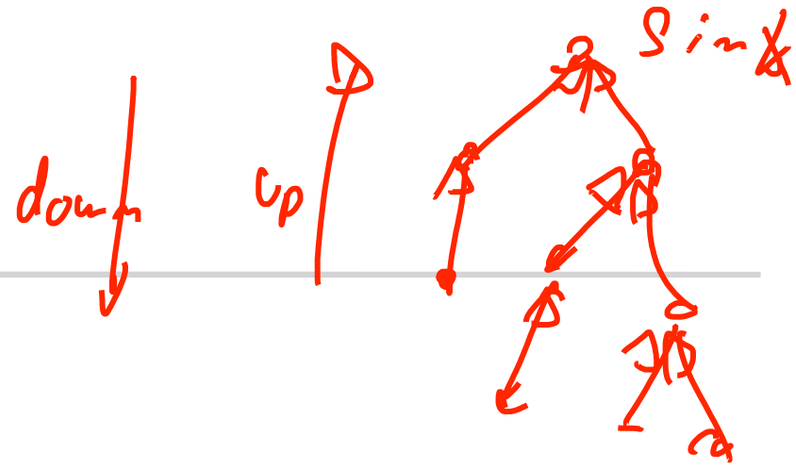
RPL: Terms



- DAG: directed acyclic graph
  - routed towards root nodes
- DAG root = sink of a DAG = LBR (LLN Border Router)
- DODAG: destination-oriented DAG
  - DAG with single root
- Rank:
  - partial order in corresponding with the DODAG
- Grounded DODAG
  - DODAG where RPL can find the root
- Floating DODAG
  - A DODAG where there is no path to the root because wrong pointers

RPL: Ideas



- Convergecast (MP2P)
  - DAG with multiple successors if possible
  - DAG defined by specific metrics (e.g. ETX, latency, DAG rank/hop count)
  - Least expensive paths
- Multicast
  - DAG also used for P2MP flows
- MP2P and P2MP for P2P (unicast)
- DAG
  - Depth (aka. rank), i.e. cost towards the sink (root)
  - Rank defines position in the DAG

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RPL: MP2P Forwarding

- Forward to nodes of lesser rank
  - avoids loops
  - loops may occur when the metric has changed or nodes leave due to rank inconsistency
  - use redundancy
- Forward to nodes of equal rank
  - not using DAG links
  - if forwarding to lesser rank (DAG-link) fails
- Do not forward to nodes of higher rank
  - causes loops

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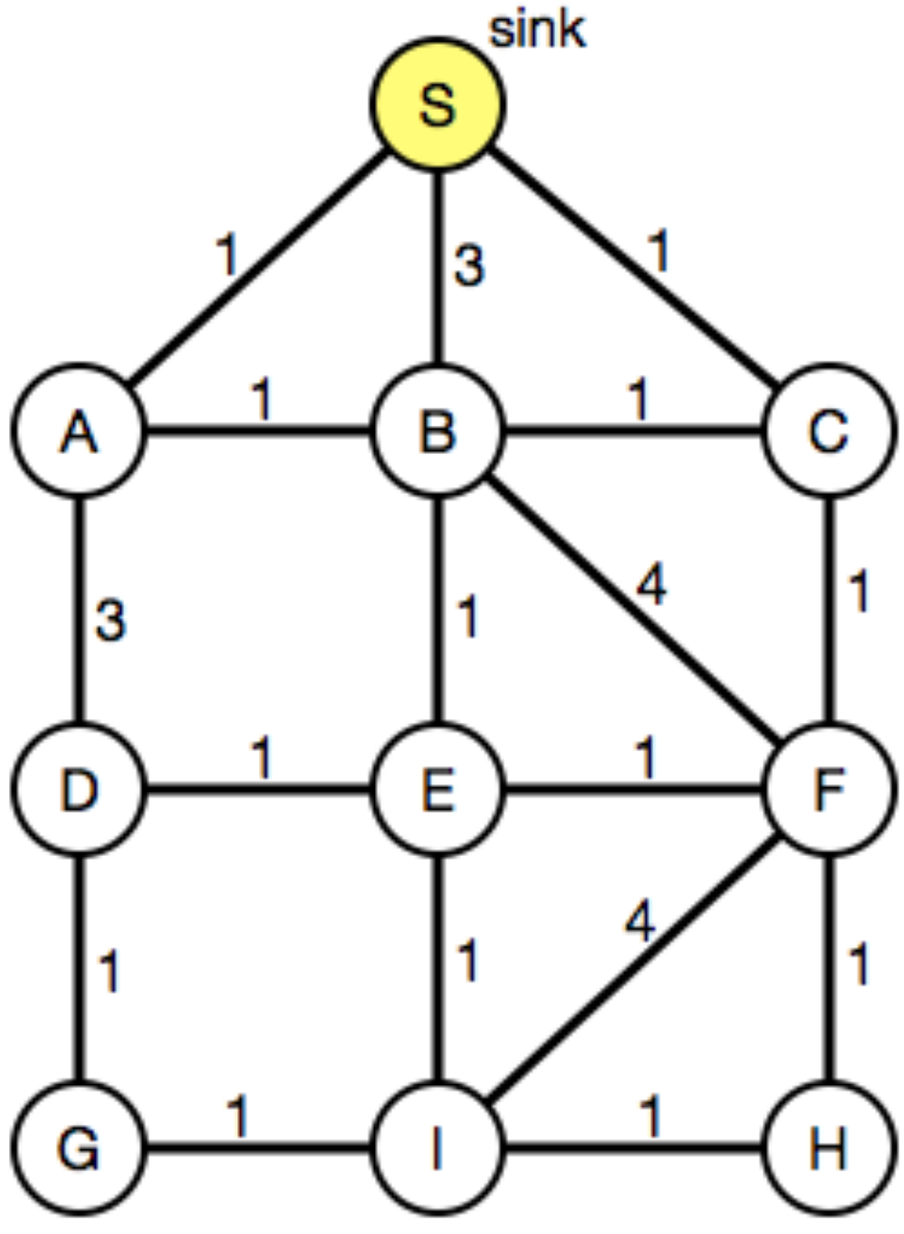
RPL: DAG Construction

- Given LLN with ETX
  - ETX should be stable enough for route computation
  - Nodes are bidirectional and ETX is known at both ends
  - Or use any other comparable metric, e.g. hop distance
- Minimize ETX



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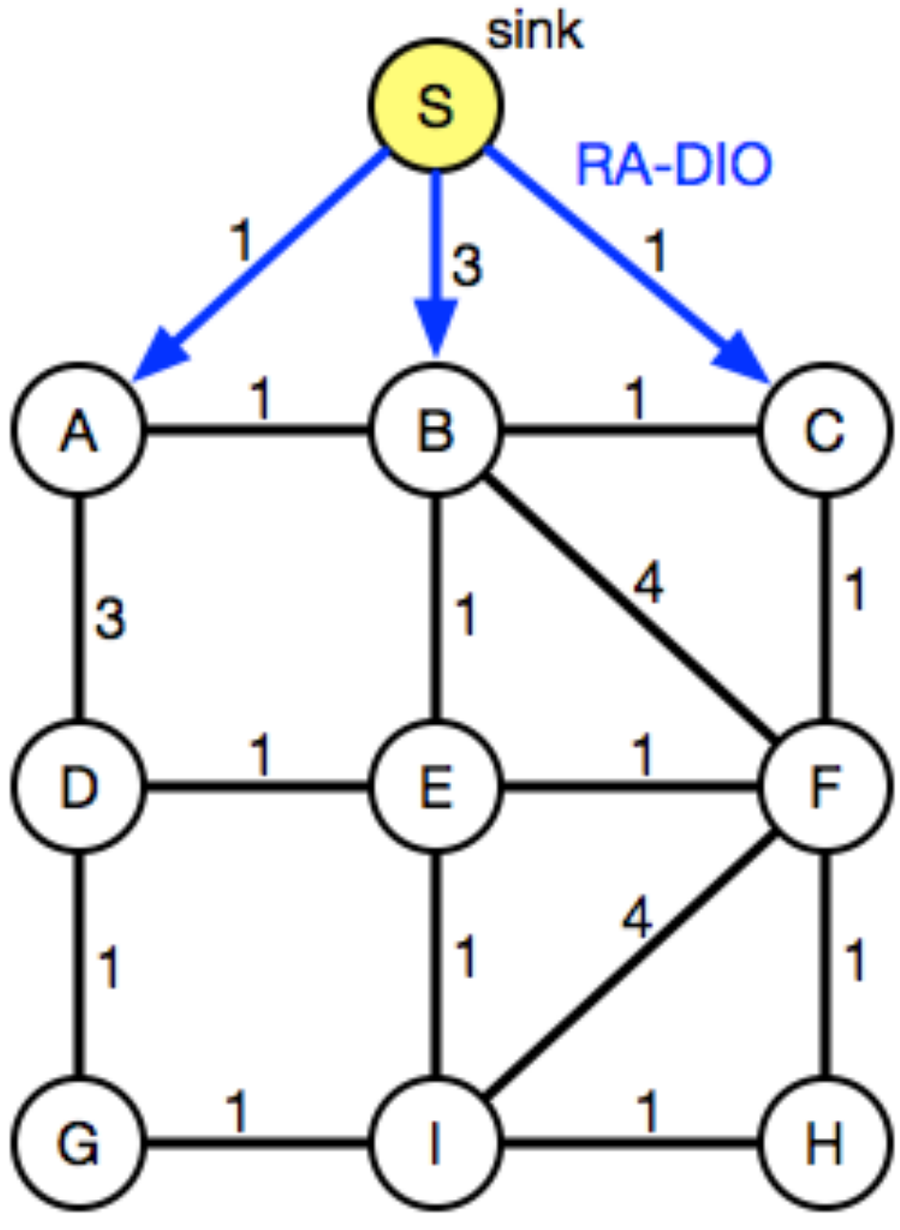
RPL: DAG Construction

- Sink broadasts RA-DIO
  - Router Advertisement (RA)
  - DODAG Information Object (DIO)
- Nodes A, B, C
  - receive RA-DIO
  - join DAG rooted to sink (LBR)



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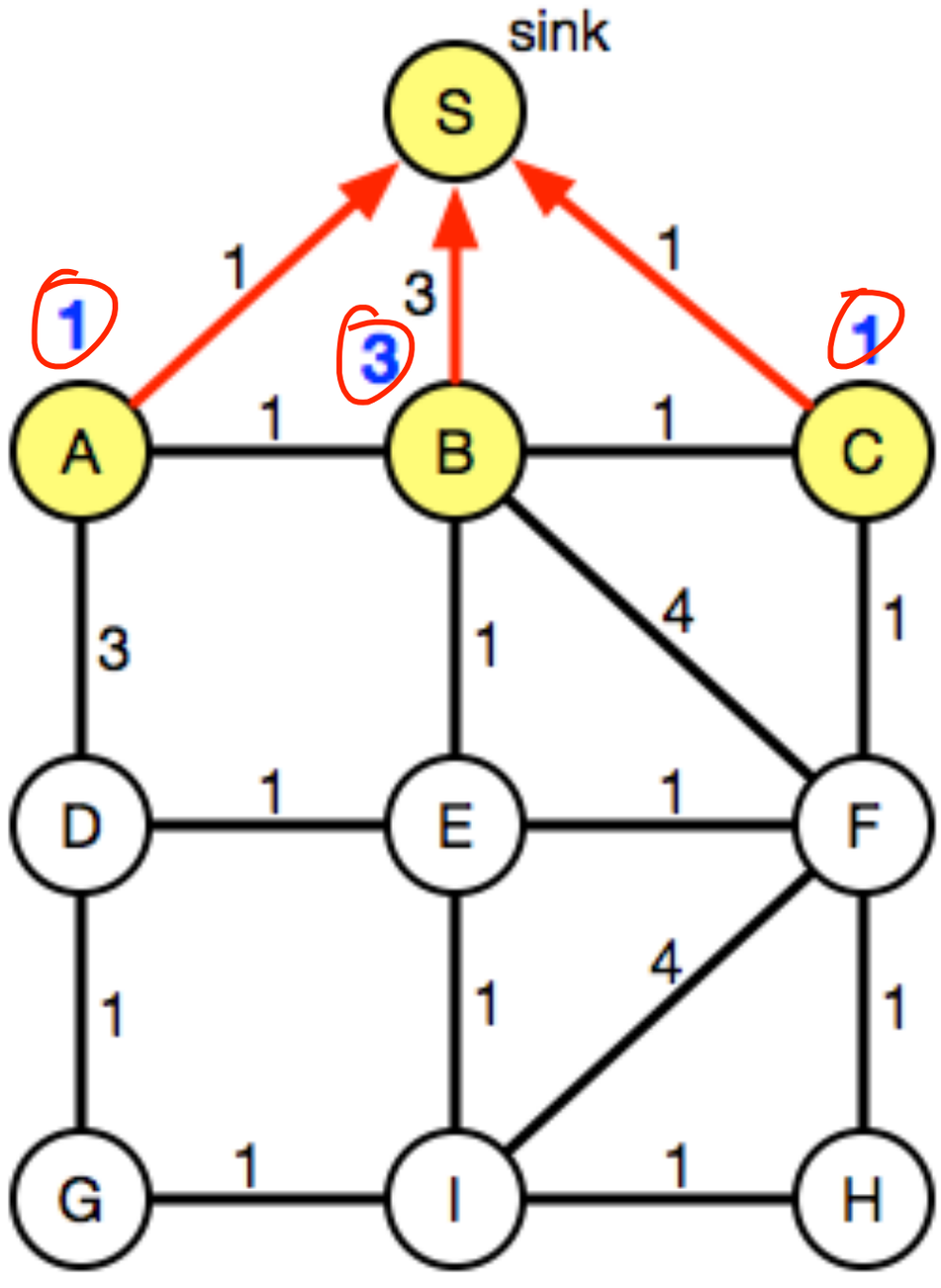
RPL: DAG Construction

- Nodes A, B, C
  - receive RA-DIO
  - join DAG rooted to sink (LBR)
  - compute rank



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RPL: DAG Construction

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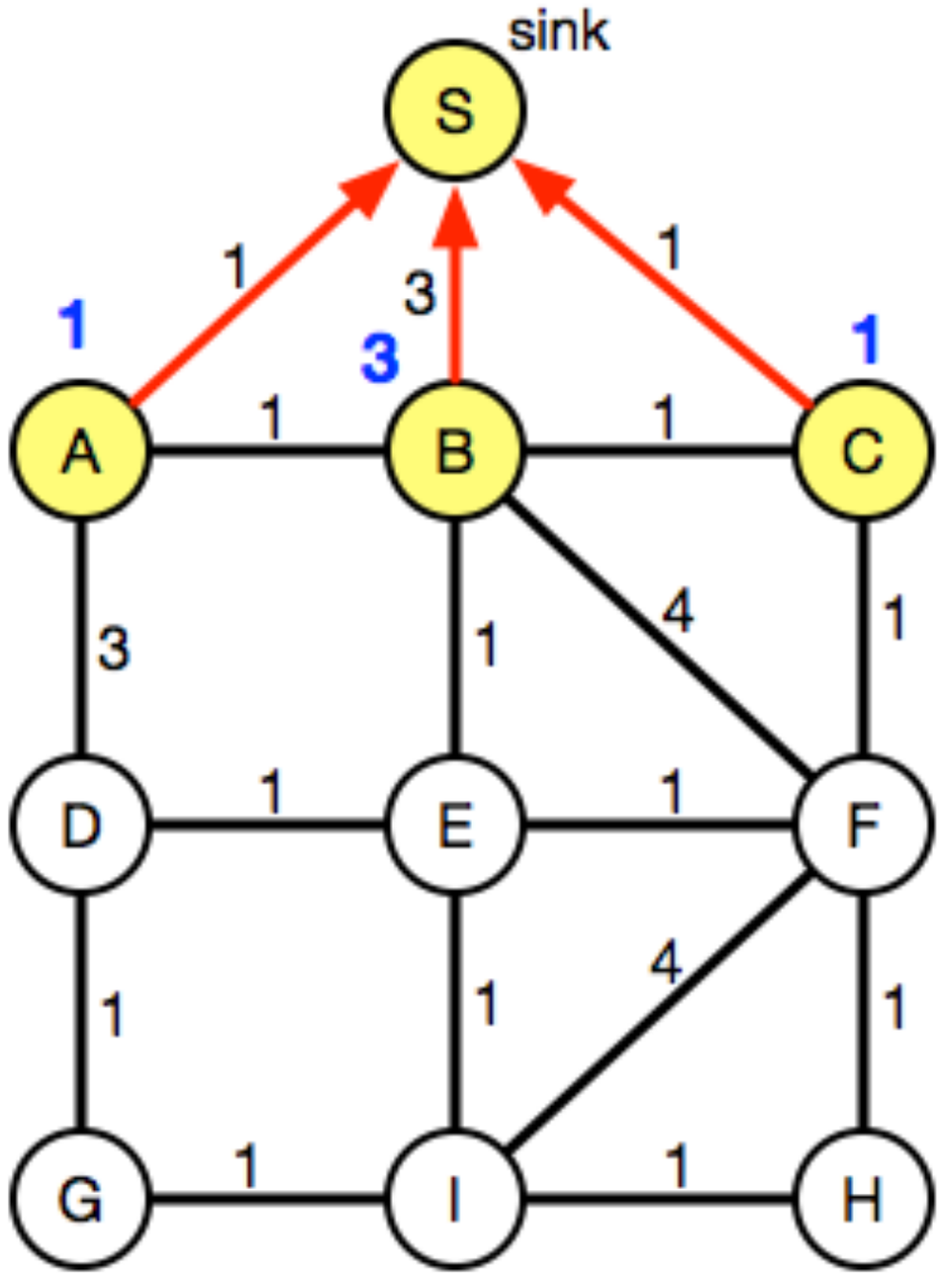

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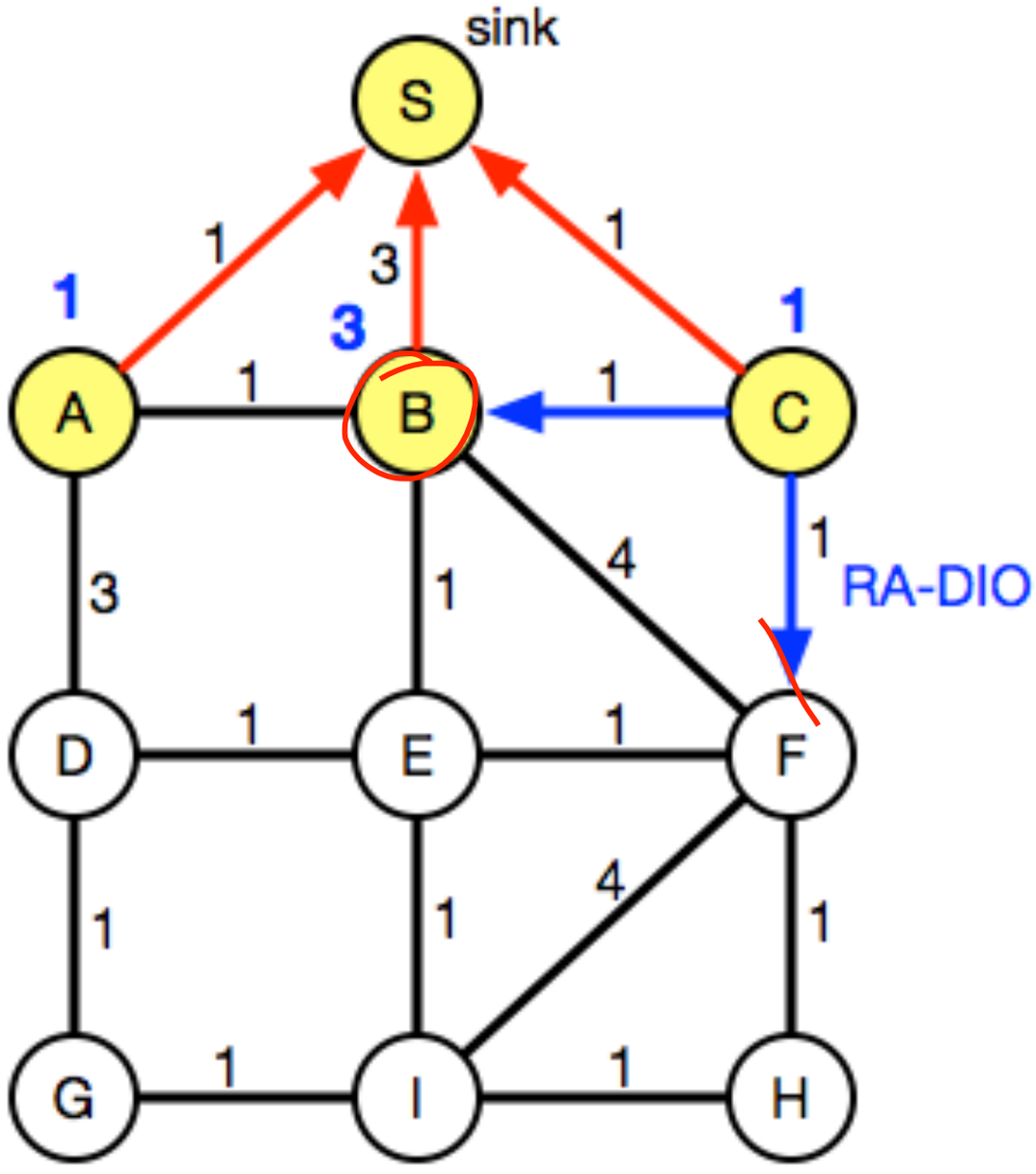
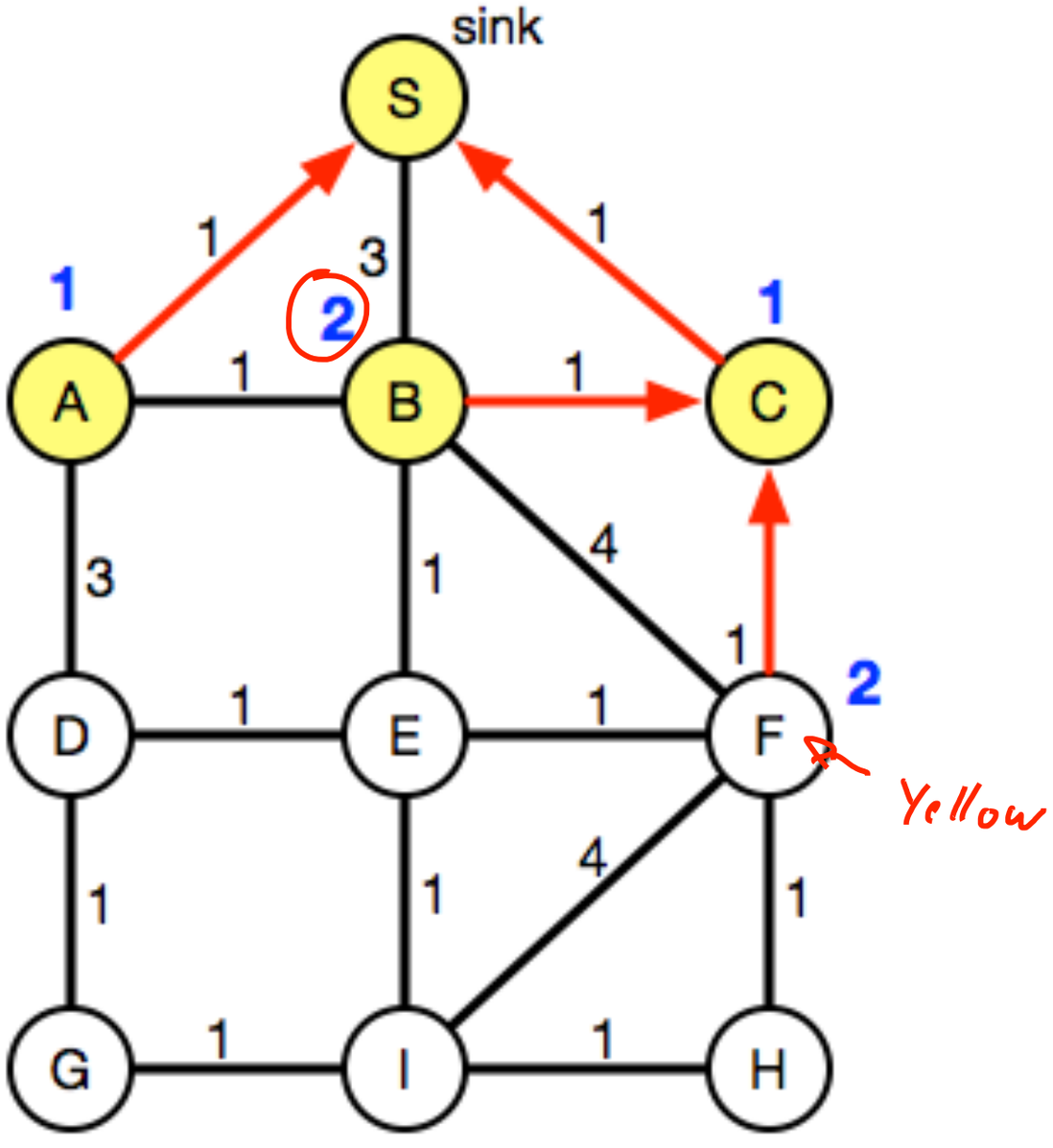
RPL: DAG Construction

- Node C
  - send RA-DIO
- Nodes B,F receive it
  - recompute rank

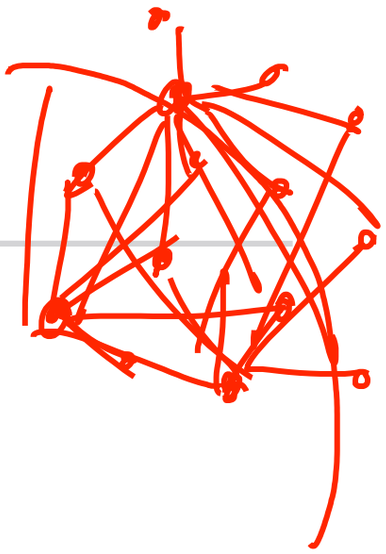


RPL: DAG Construction

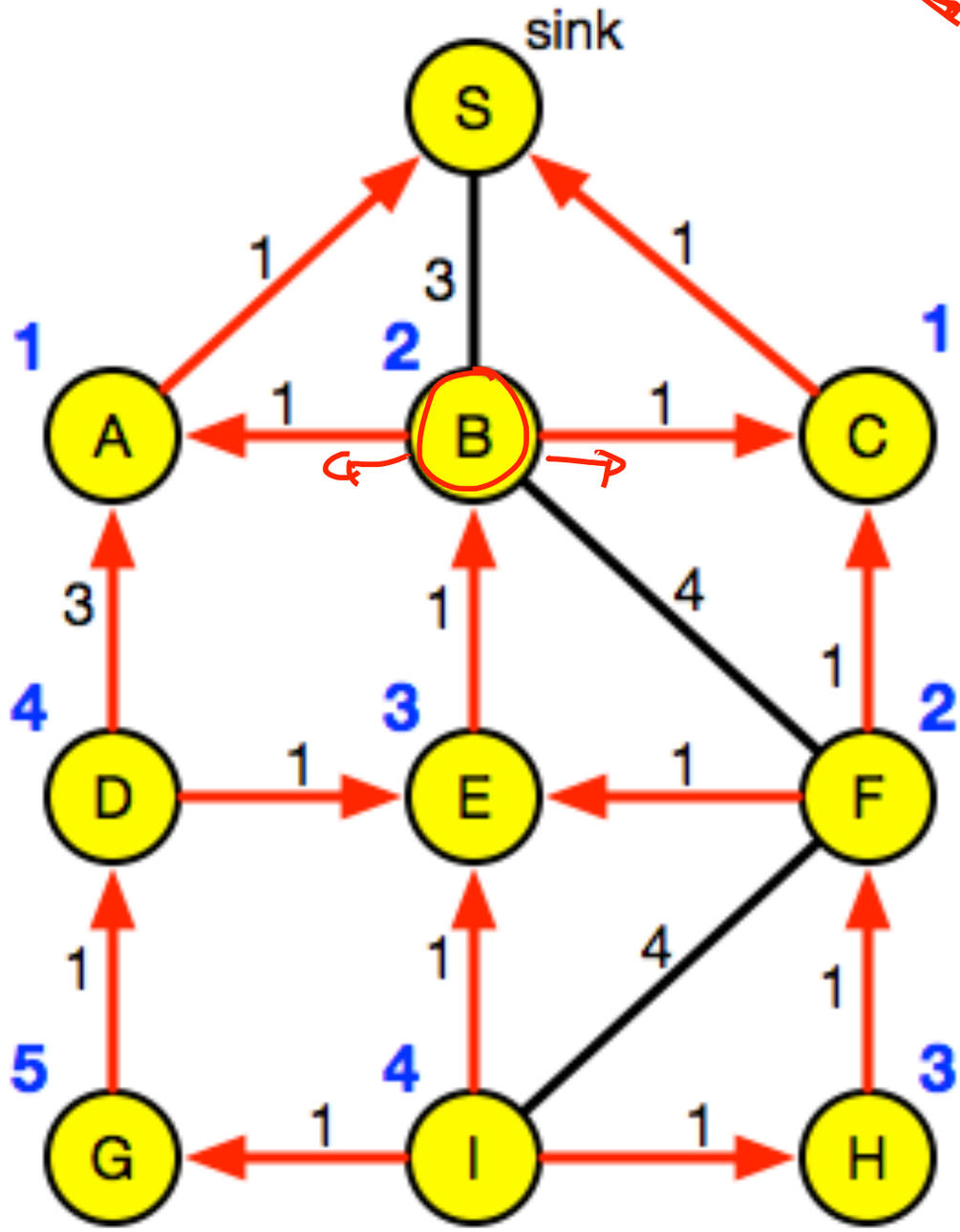
- Nodes B and F
  - recompute rank
- Node B
  - redirects to C
- Node F
  - joins the DAG



RPL: DAG Construction



- Final network
- Rank is rounded
  - such that multiple paths exist
- Maintenance is continued
  - RA (router announcements) use Trickle algorithm



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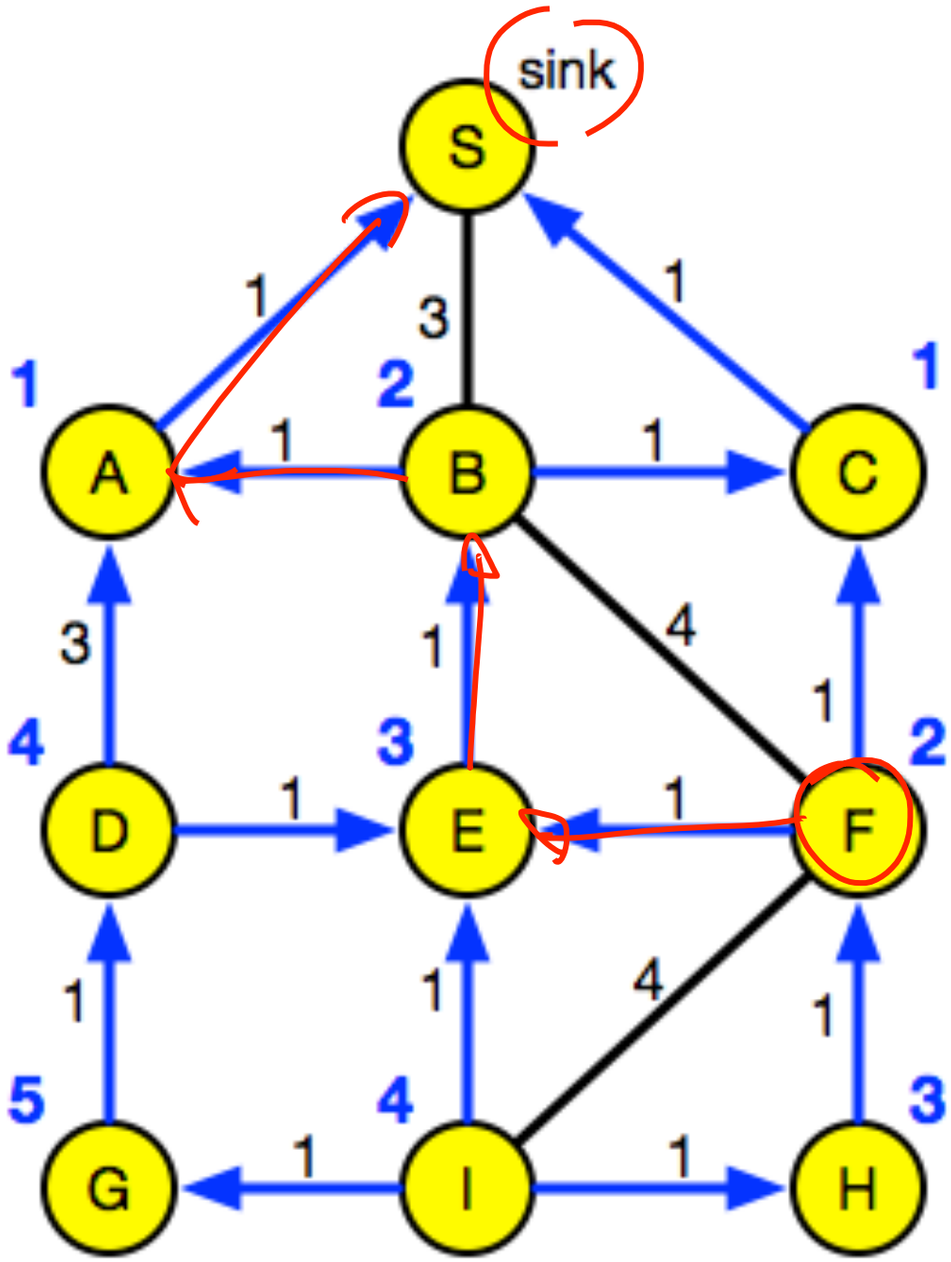
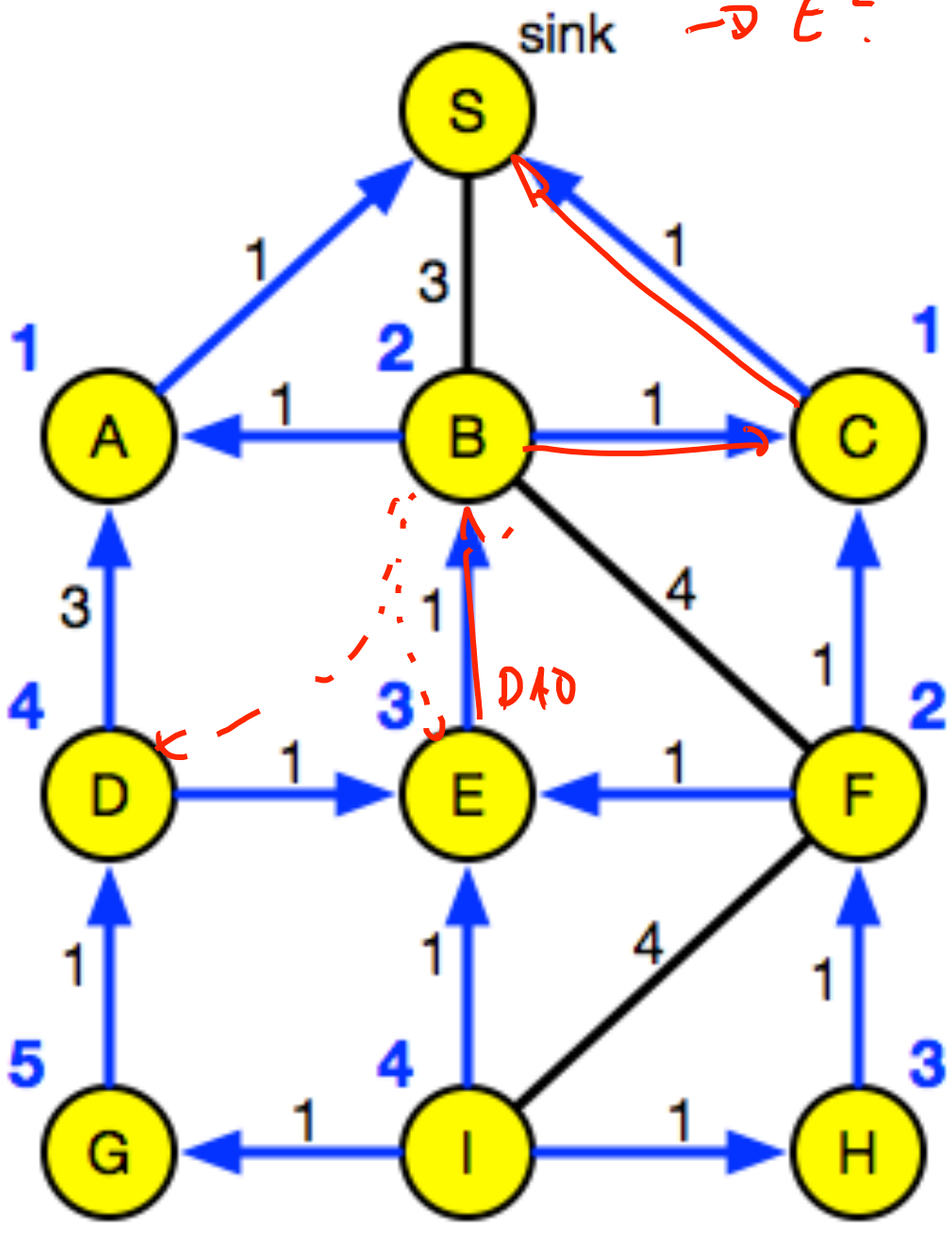
RPL: Convergecast (MP2P)

- MP2P traffic flows along DAG links
  - toward sink/DAG root/LBR



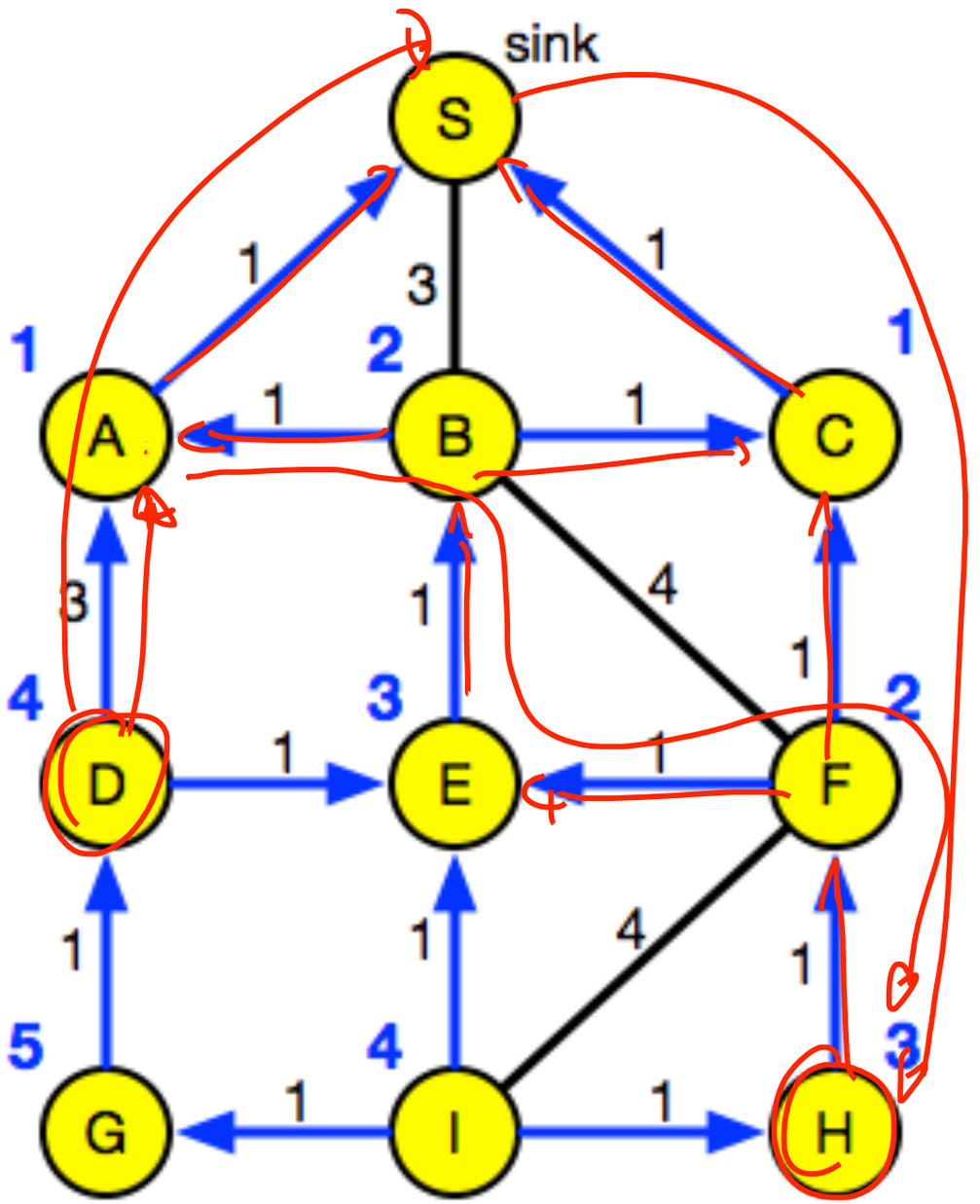
RPL: Multicast (P2MP)

- Destination advertisements object (DAO) message
  - build up routing state outwards from sink
  - toward sink/DAG root/LBR
- Two modes supported
  - Source routing (non storing case)
    - sink gathers information
  - Routing table (storing case)



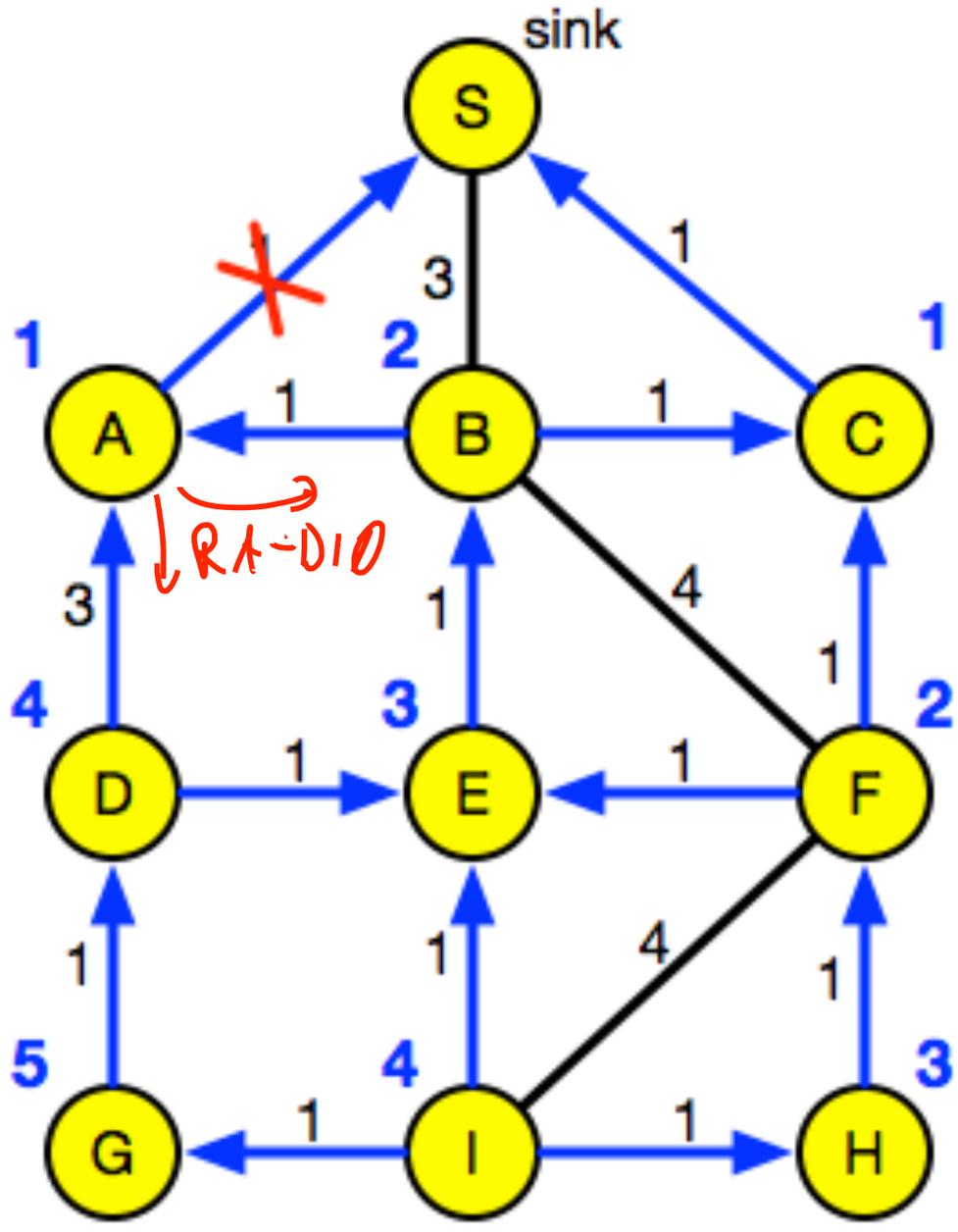
RPL: Unicast (P2P)

- Unicast message
  - travel towards the sink (up)
  - and then towards the target node (down)
- Non-storing case
  - message travels to sink and is sent via source routing
- Storing case
  - message travels up until a node knows the target



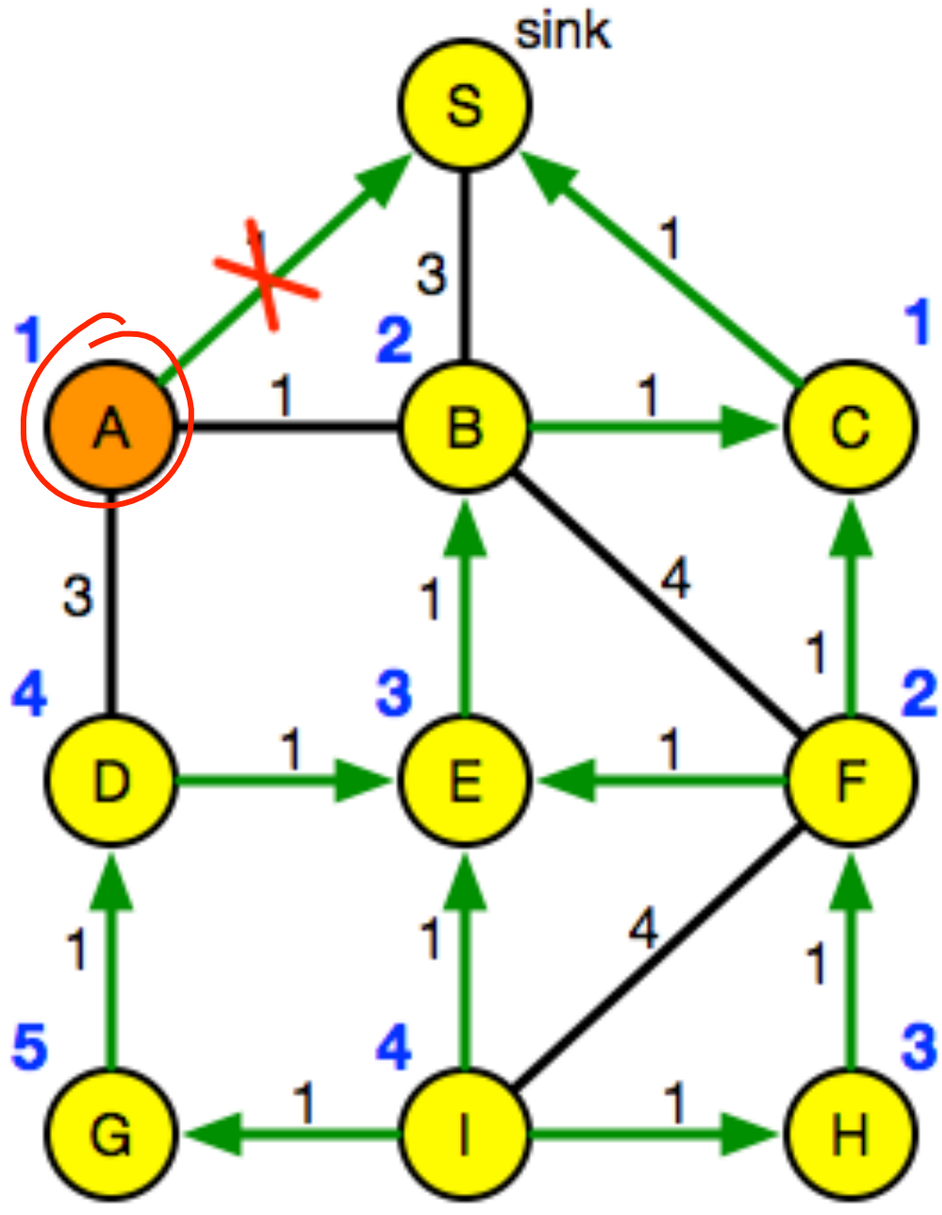
RPL: Loop Avoidance

- Node A looses connection towards sink
  - with no alternatives
- A sends out RA-DIO
  - and becomes root of a **floating DAG**
- Successors of A flood RA-DIO to inform all dependent nodes



RPL: Floating DAG

- Floating DAG
  - does not need to satisfy the DAG constraint
- Nodes A becomes floating DAG
- Node B and D have alternate parents and remove links towards A



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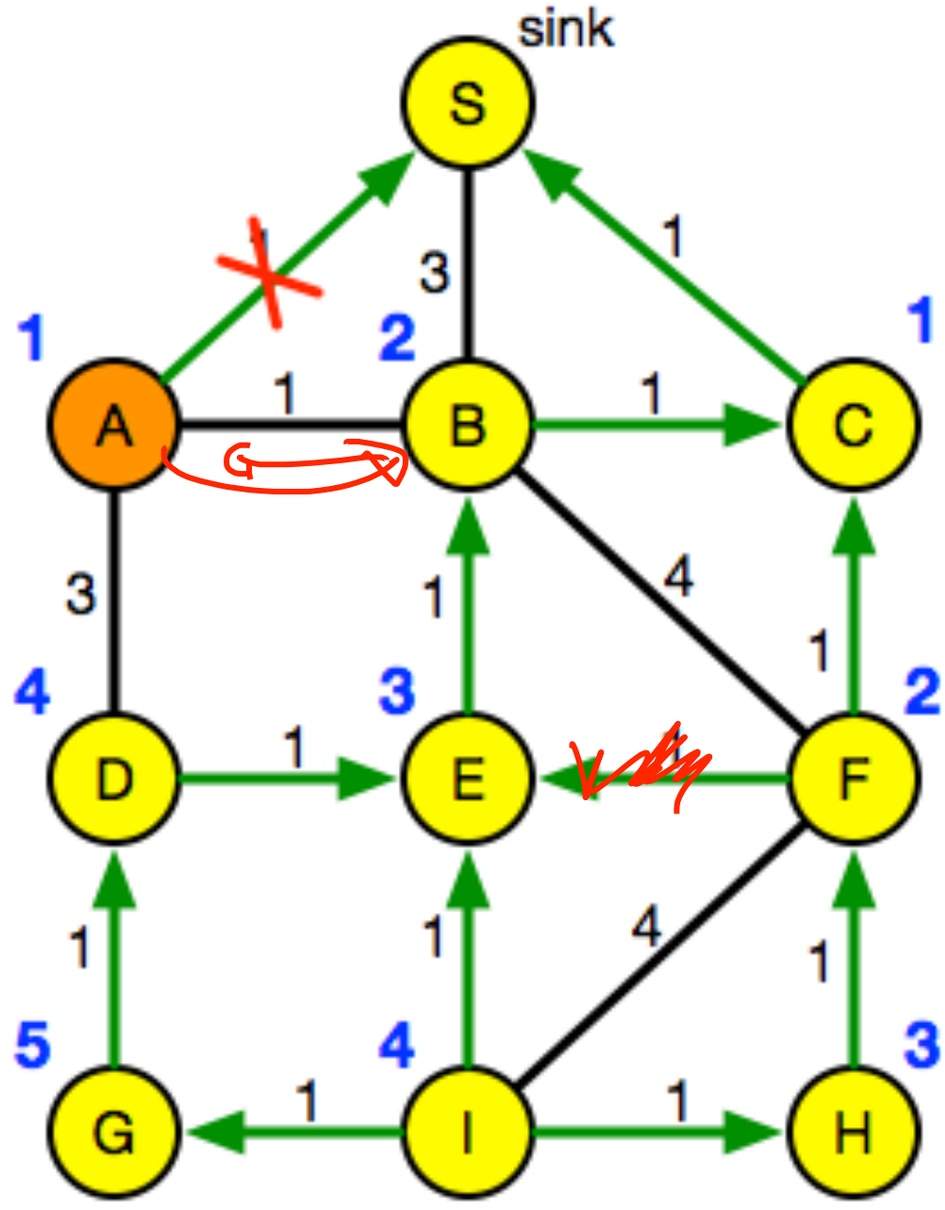
RPL: Floating DAG

- Node B will advertise with RA-DIO
- A joins DAG again



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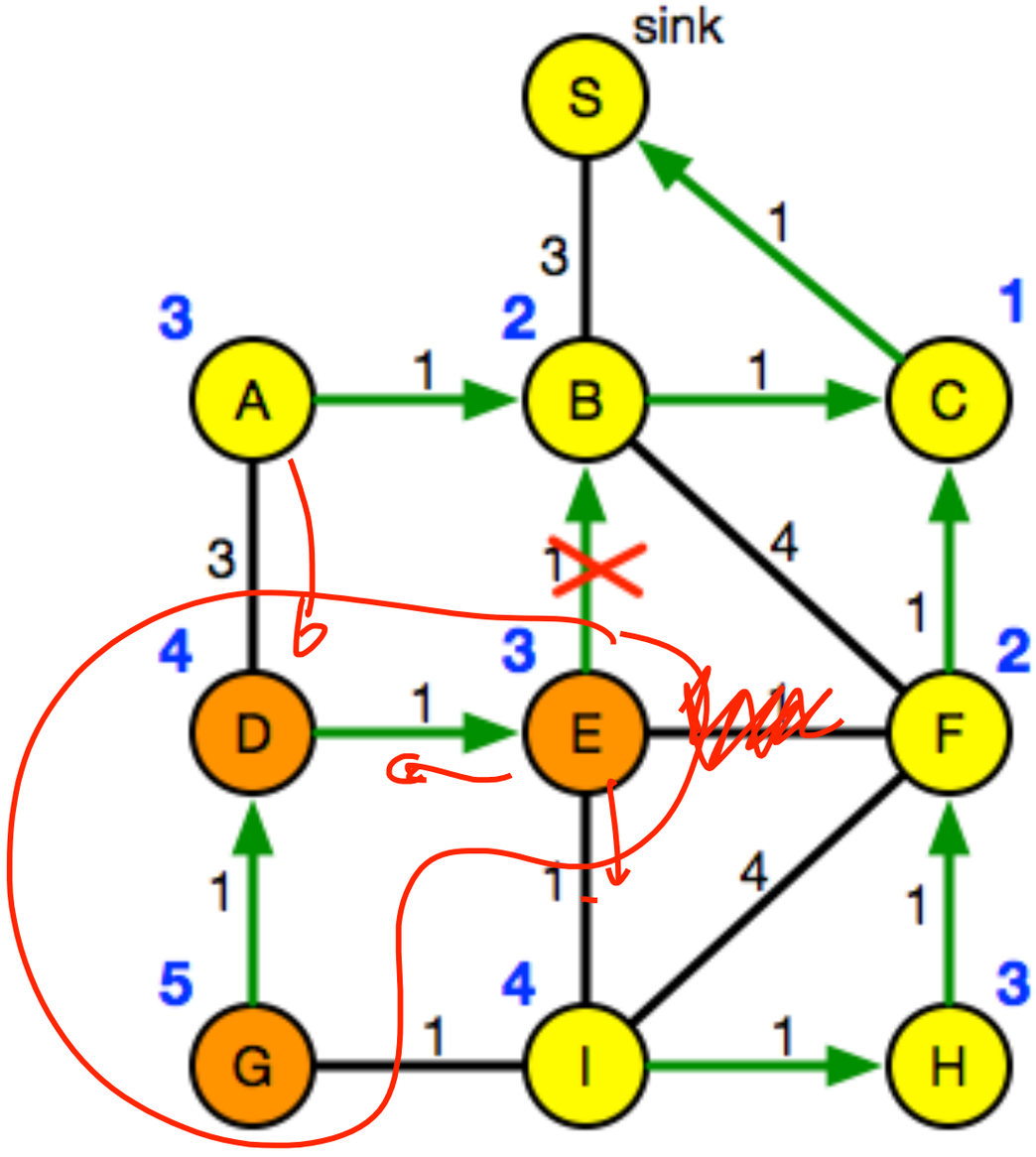
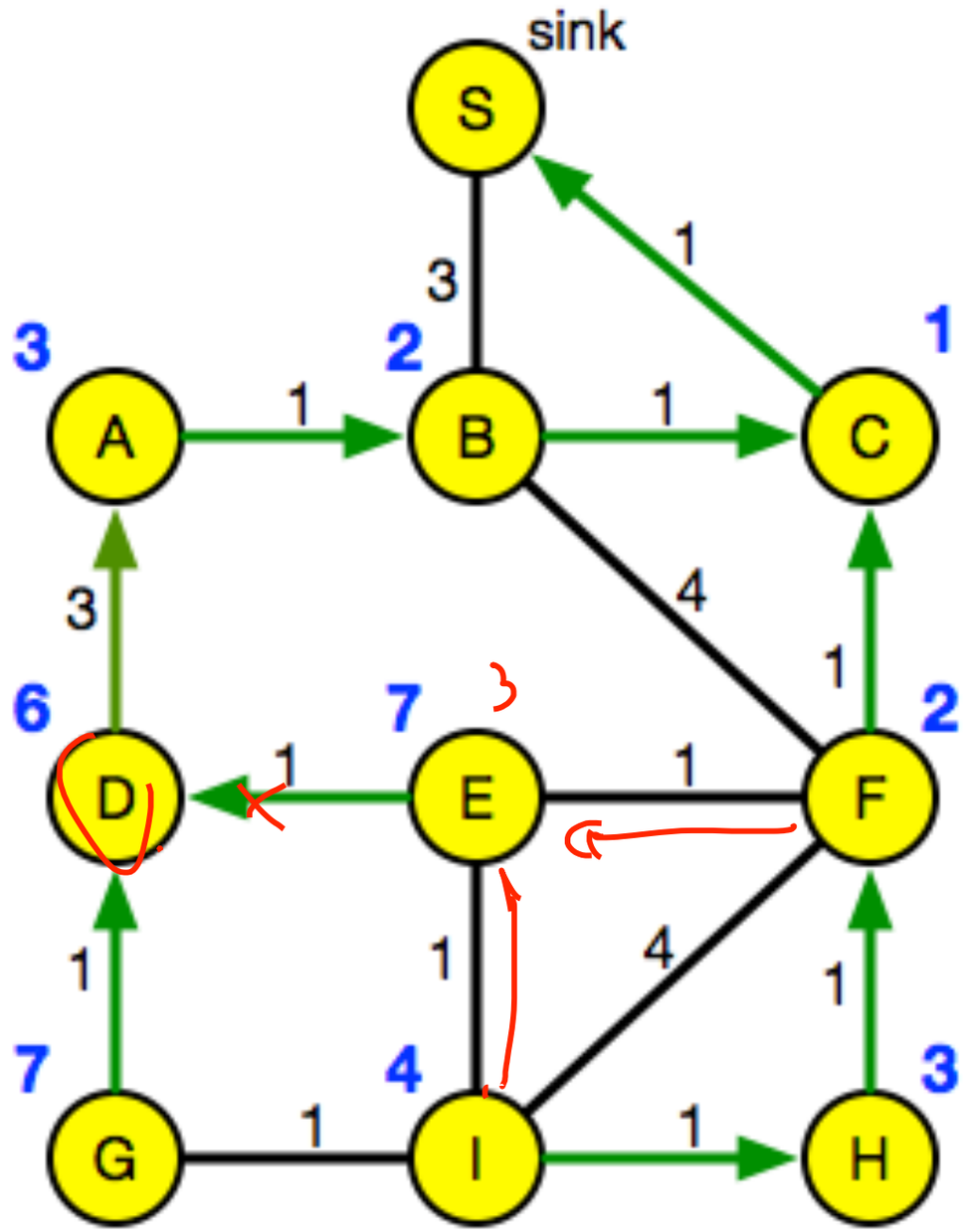
RPL: Floating DAG

- Now link from E to B fails
- Nodes E,D,G become floating DAG
  - informed by E
- Nodes I,F
  - have alternative routes



RPL: Floating DAG

- Assume A advertises link
- D links to A
  - and forwards info to E and G
- Nodes E, G now repair links
- Eventually, again the optimal network will be found



RPL - Conclusion

- specified only for IPv6
- based on Distance Vector
- produces a stable DAG
  - well suited for traffic directions up and down
- problematic for other traffic directions
- Critical evaluation:
  - Clausen, T.; Herberg, U.; Philipp, M.; "A critical evaluation of the IPv6 Routing Protocol for Low Power and Lossy Networks (RPL)", Wireless and Mobile Computing, Networking and Communications (WiMob), 2011 IEEE 7th International Conference on , vol., no., pp. 365-372, 10-12 Oct. 2011
    - assumes bi-directional connections
    - not completely specified
    - Loops are in real experiments a big unresolved problem

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