IETF 100 ROLL

Routing over Low-Power And Lossy Networks

Chairs:
Peter van der Stok
Ines Robles

Secretary:
Michael Richardson

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Source: https://www.ietf.org/about/note-well.html

Meeting Materials

- 13:30-15:00 Wednesday Afternoon session I
- Remote Participation
  - Jabber Room: roll@jabber.ietf.org
  - Meetecho: http://www.meetecho.com/ietf100/roll
- Etherpad:
  - http://tools.ietf.org/wg/roll/minutes
- Audio Streaming:
- Minutes taker:
- Jabber Scribe:
- **Please sign blue sheets :-)**

Agenda

13:30-15:00 Wednesday (15th Nov) Afternoon session I

Item	Time	Presenter
State of the WG	13:30-13:35	Peter/Ines
Use of RPL Info	13:35-13:45	Ines
draft-ietf-roll-efficient-npdao-01	13:45-13:55	Rahul
draft-ietf-roll-dao-projection	13:55-14:00	Pascal
Discussion on work and relations	14:00-14:15	Chairs + WG
draft-qasem-roll-rpl-load-balancing	14:15-14:30	Mamoun
Fast reroute	14:30-14:40	Pascal
draft-pkm-roll-nsa-extension	14:45-14:55	Georgios
Q&A	14:55-15:00	All

Milestones

Sep 2018	Recharter WG or close
Jul 2018	Initial submission of a solution to the problems due to the use of No-Path DAO Messages to the IESG
Nov 2017	Initial submission of a proposal to augment DIS flags and options to the IESG
Nov 2017	Initial submission of a reactive P2P route discovery mechanism based on AODV-RPL protocol to the IESG
Jul 2017	Initial submission of a Forwarder Selection Protocol for MPL to the IESG
Jul 2017	Initial submission of a proposal for Source-Route Multicast for RPL to the IESG
Mar 2017	Initial submission of a root initiated routing state in RPL to the IESG
Mar 2017	Initial submission of a YANG model for MPL to the IESG
Jan 2017	Initial Submission of a proposal with uses cases for RPI, RH3 and IPv6-in-IPv6 encapsulation to the IESG

State of Active Internet-Drafts

Draft	Status
draft-ietf-roll-aodv-rpl-01	Ready for wglc
draft-ietf-roll-dao-projection-01	this meeting
draft-ietf-roll-forw-select-00	expired
draft-ietf-roll-useofrplinfo-16	wglc; this meeting
draft-ietf-roll-dis-modifications-00	expired
draft-ietf-roll-mpl-yang-00	expired
draft-ietf-roll-bier-ccast-00	active
draft-ietf-roll-efficient-npdao-00	this meeting

Open Tickets

Ticket	Status
178: Editorial comments for dao projection draft	New Defect, Created
179: Security considerations for dao projection	New Defect, Created
180: 13 issues to address in dao projection draft (lifetime, MOP, transmissions, route cleanup)	New Defect, Created
182: useofrplinfo review -	New Defect, Created
183: useofrplinfo - editorial review -	New Defect, Created

Related Internet-Drafts

Load Balancing Objective Function in RPL draft-qasem-roll-rpl-load-balancing-02	Presented today
RPL DAG Metric Container (MC) Node State and Attribute (NSA) object type extension draft-pkm-roll-nsa-extension-00	Presented today
RPL-BIER draft-thubert-roll-bier-00	Discussed today

IPRs

Draft-ietf-roll-efficient-npdao-00: 2 IPRs

Draft-ietf-roll-dao-projection-02: 1 IPR

When to use RFC 6553, 6554 and IPv6-in-IPv6

draft-ietf-roll-useofrplinfo-19

Michael Richardson
Pascal Thubert
Ines Robles

IETF 100

New version (16):

- Updates 6553 (**Million thanks to Mike Heard for his comments**)
- Updates 6550 (**Million thanks to Mike Heard for his comments**)
- Text clarification

Why we update the RFC 6553?

Background:

IPv6 Extension Headers - Options

[draft-ietf-6man-rfc2460bis-13#section-4.2]

```
00 - skip over this option and continue processing the header.

01 - discard the packet.

10 - discard the packet and, regardless of whether or not the
     packet's Destination Address was a multicast address, send an
     ICMP Parameter Problem, Code 2, message to the packet's
     Source Address, pointing to the unrecognized Option Type.

11 - discard the packet and, only if the packet's Destination
     Address was not a multicast address, send an ICMP Parameter
     Problem, Code 2, message to the packet's Source Address,
     pointing to the unrecognized Option Type.
```

Why we update the RFC 6553?

Processing of the Hop-by-Hop Options header is now optional,

If the nodes are configured to process the header, and if such nodes encounter an option with the first two bits set to **01 (0x63)** they will **drop** the packet (RPL Option type in RFC 6553).

Hex Value	Binary Value				
	act	chg	rest	Description	Reference
0x63	01	1	00011	RPL Option	[RFC6553]

Figure 1: Option Type in RPL Option.

But, we need that,

If an IPv6 (intermediate) node (RPL-not-capable) receives a packet with an RPL Option, it should **ignore** the HBH RPL option

Ignore = skip over this option and continue processing the header.

Thus, we propose,

Hex Value	Binary Value				
	act	chg	rest	Description	Reference
0x23	00	1	00011	RPL Option	[RFCXXXX]

Figure 2: Proposed change to the Option Type in RPL Option.

The first two bits **(0x23)** indicate that the IPv6 node **MUST skip** over this option and continue processing the header

This ensures that a packet that leaves the RPL domain of an LLN (or that leaves the LLN entirely) **will not be discarded** when it contains the [RFC6553] RPL Hop-by-Hop option known as RPI.

But,

This change creates a **flag day** for existing networks which are currently using 0x63 as the RPI value. A move to 0x23 will not be understood by those networks.

Flag day: A "flag day" is a procedure in which the network, or a part of it, is changed during a planned outage, or suddenly, causing an outage while the network recovers [RFC4192]

So,

In order to avoid a flag day caused by lack of interoperation between new RPI **(0x23)** and old RPI **(0x63)** nodes, the new nodes need to be told that there are old RPI nodes present

This can be done via a **new RPI in the DODAG Configuration Option Flag** which will propagate through the network => We update RFC 6550

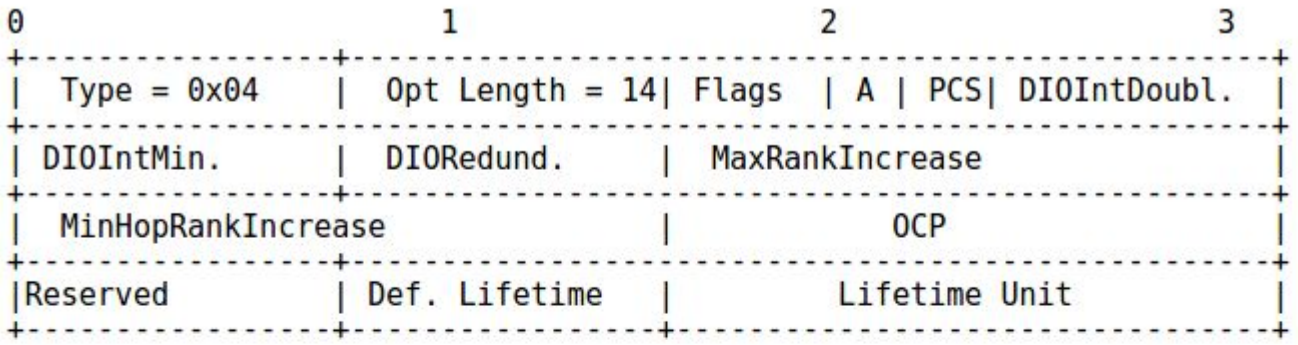


Figure 3: DODAG Configuration Option.

Bit number three of flag field in the DODAG Configuration option is to be used as follows:

Bit number	Description	Reference
3	RPI 0x23 enable	This document

Figure 4: DODAG Configuration Option Flag to indicate the RPI-flag-day.

Is it a problem that we should solve in this document?

3.2. Updates to RFC 8138

RPI-6LoRH header provides a compressed form for the RPL RPI [RFC8138]. It should be considered when the Option Type in RPL Option is decompressed, should take the value of 0x23 instead of 0x63.

IP-in-IP encapsulation in **Storing mode**
(based on the updates)

Interaction between	Use Case	IP-in-IP	IP-in-IP dst
Leaf - Root	Raf to root	No	--
	root to Raf	No	--
	root to ~Raf	No	--
	~Raf to root	Yes	root
Leaf - Internet	Raf to Int	No	--
	Int to Raf	Yes	Raf
	~Raf to Int	Yes	root
	Int to ~Raf	Yes	hop
Leaf - Leaf	Raf to Raf	No	--
	Raf to ~Raf	No	--
	~Raf to Raf	Yes	dst
	~Raf to ~Raf	Yes	hop

Headers needed in **Non-Storing mode**: RPI, RH3,
IP-in-IP encapsulation. (based on the updates)

Interaction between	Use Case	RPI	RH3	IP-in-IP	IP-in-IP dst
Leaf - Root	Raf to root	Yes	No	No	--
	root to Raf	Opt	Yes	No	--
	root to ~Raf	No	Yes	Yes	6LR
	~Raf to root	Yes	No	Yes	root
Leaf - Internet	Raf to Int	Yes	No	Yes	root
	Int to Raf	Opt	Yes	Yes	dst
	~Raf to Int	Yes	No	Yes	root
	Int to ~Raf	Opt	Yes	Yes	6LR
Leaf - Leaf	Raf to Raf	Yes	Yes	Yes	root/dst
	Raf to ~Raf	Yes	Yes	Yes	root/6LR
	~Raf to Raf	Yes	Yes	Yes	root/6LN
	~Raf to ~Raf	Yes	Yes	Yes	root/6LR

Thanks!

Q&A

Efficient route invalidation for RPL

https://tools.ietf.org/html/draft-ietf-roll-efficient-npdao-01

Rahul, Rabi, Zhen@ Huawei

IETF100, Singapore

History:

IETF95 - Presented the problem statement

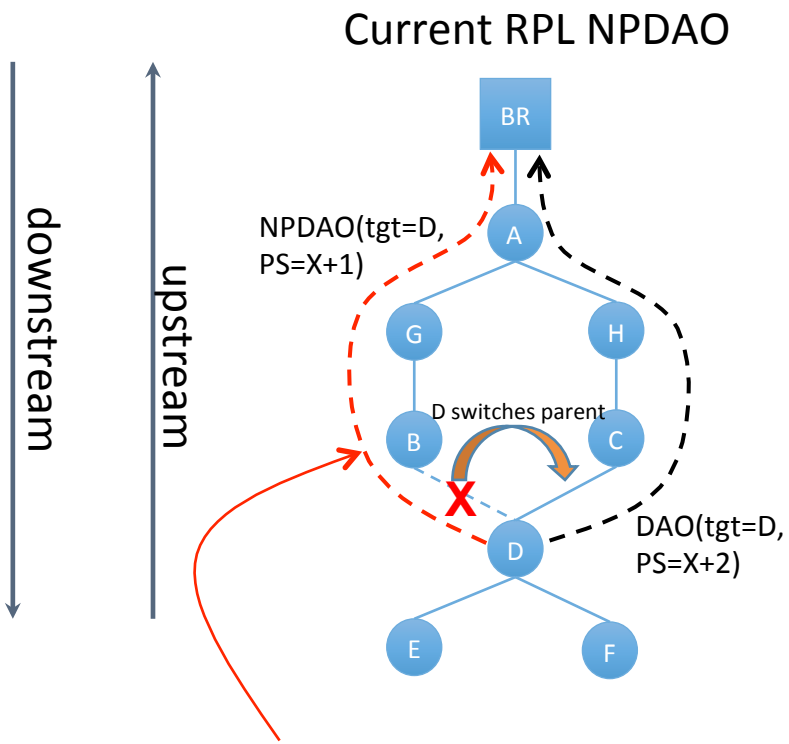
IETF96 - Presented existing solutions based on comments rcvd and why those fall short

IETF98 – Presented new solution for improving route invalidation

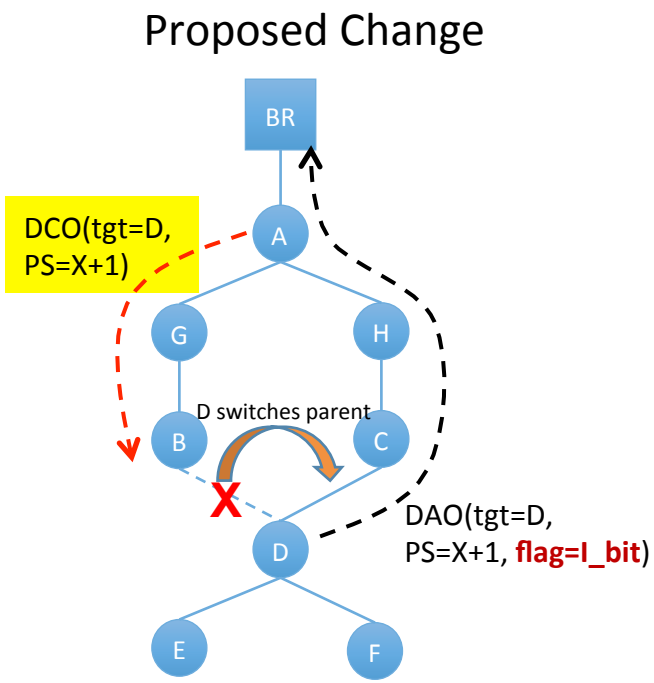
IETF99 – adopted as WG document , thank you for the review

IETF100 – Changes to message codes

Recap: the problem and the solution



NP-DAO via broken links will cause many problems such as reachability and efficiency



- Send the DAO via the new parent;
- Common parent to trigger the DCO to invalidate the previous path

PS = PathSequence
Tgt = Target

Primary update: new RPL message code

Per RFC 6550, DAO (including NPDAO) traverses upstream only.

Previous version,

NPDAO had a flag which said, invalidate and “send downstream”.

New version,

A new message DCO (Dest Cleanup Object) is added for proactive route cleanup.

Primary update: new RPL message code

Reasons for using new code:

- Existing implementations do not need to change, thus incremental code update possible
- RPL message codes are available in plentiful as compared to DAO flags.

Side-Effects – Along comes the ACK

DAO optionally has a DAO-ACK.

DCO would also need one, thus DCO-ACK.

Code	Description	Reference
0x85	Destination Cleanup Object	This document
0x86	Destination Cleanup Object Acknowledgement	This document

Next Step

- Change the implementation (trivial)

- Welcome any feedback from the Open-source community (while we believe the technique description is stable enough)

Thank you

DAO Projection

Pascal Thubert

IETF 100

Singapore, November 2017

Changes Highlights

- Minor updates to 02
- Added 2 IANA request for projected MOPs
- Also a new RPL control code for the Via option
- Work on Fast Reroute, possible additions to this draft
  - Presented separately

ROLL
topics and relations

Peter van der Stok, Ines Robles

IETF 100 - ROLL Working Group

ROLL charter

[A] Guidance in using RFC6553, RFC6554, and IPv6-in-IPv6 encapsulation.
[B] Additional protocol elements to reduce packet size and the amount of required routing states
[C] Automatic selection of MPL forwarders to reduce message replication.
[D] Data models for RPL and MPL management.
[E] Multicast enhancements algorithms.

ROLL topics

YANG models [D]

- draft-ietf-roll-mpl-yang-00 expired
- rpl yang required non existent

Independent topics

- draft-ietf-roll-forw-select-00 expired [C]
- draft-ietf-roll-dis-modifications-00 expired [B]
- draft-ietf-roll-useofrplinfo-16 wglc [A]
- draft-ietf-roll-aodv-rpl-01 wglc [B]

DAG manipulations [B]

- draft-ietf-roll-dao-projection-01 alive
- draft-ietf-roll-efficient-npdao-00 alive
- draft-qasem-roll-rpl-load-balancing-02 alive
- fast reroute non existent
- draft-pkm-roll-nsa-extension-00 alive from 6tisch

BITMAPS and BLOOM Filters

- draft-ietf-roll-ccast-01 alive [E]
- draft-thubert-roll-bier-00 alive [B]
- draft-thubert-6lo-bier-dispatch-03 for reference

YANG models

YANG models [D]

- draft-ietf-roll-mpl-yang-00 — expired
- rpl yang required — non existent

YANG models are requested by routing area

- MPL YANG has been started
- RPL YANG is non existent
- And others…..?

Don’t we want to manage RPL, MPL networks?
Volunteers?

Independent topics

Independent topics

- draft-ietf-roll-forw-select-00 expired [C]
- draft-ietf-roll-dis-modifications-00 expired [B]
- draft-ietf-roll-useofrplinfo-16 wglc [A]
- draft-ietf-roll-aodv-rpl-01 wglc [B]

- Useofrplinfo discusses RPL option headers for network traversal
- Aodv-rpl discusses AODV based route discovery for P2P

Both in WGLC, last stretch

Forw-select discusses creation of 2-layer hierarchical network
Needs co-author.

Dis-modifications discusses management of DIO solicitations
No action needed, wait for authors

DAG manipulations(1)

DAG manipulations [B]

- draft-ietf-roll-dao-projection-01 alive
- draft-ietf-roll-efficient-npdao-00 alive
- draft-qasem-roll-rpl-load-balancing-02 alive
- fast reroute non existent
- draft-pkm-roll-nsa-extension-00 alive from 6tisch

All these drafts discuss the restructuring of the DAG,
based on different criteria, and with different motivations

Questions:

- Can (will) they co-exist
- Do they overlap, compete (technical level)
- Guidance needed?

I really should like someone to look into it with report at IETF101

DAG manipulations(2)

DAG manipulations [B]

- draft-ietf-roll-dao-projection-01 alive
- draft-ietf-roll-efficient-npdao-00 alive
- draft-qasem-roll-rpl-load-balancing-02 alive
- fast reroute non existent
- draft-pkm-roll-nsa-extension-00 alive from 6tisch

Additional topics suggested by Rahul, Pascal

- Route invalidation as stand-alone topic
- Non-RPL (ND) device connected to DAG (6tisch need)
- Guidance to select storing mode or non-storing mode
- Several subtopics
- DAG selection versus parent selection
- Mesh structure distribution

Is there a volunteer(s) to look at the issues of this and former slides

BITMAPS and BLOOM filters (BBF)

BITMAPS and BLOOM Filters

- draft-ietf-roll-ccast-01 alive [E]
- draft-thubert-roll-bier-00 alive [B]
- draft-thubert-6lo-bier-dispatch-03 for reference

Initiated by Carsten with ccast draft
Alternative suggested by Pascal (storing vs non-storing)

Could this be used for unicast?
(IMO) reduces routing tables or packet headers
an absolute MUST for networks > 1000 nodes (6tisch)

Questions:
When is BBF necessary, and which approach is best?

Load Balancing Objective Function in RPL

draft-qasem-roll-rpl-load-balancing-02

Mamoun Qasem

IETF 100

Singapore

Nov 2017

Quick Hint

- In this draft we combined the two drafts in one:

- draft-qasem-roll-rpl-load-balancing-01
- draft-hou-roll-rpl-parent-selection-00

Overview

- Up to now, two objective functions (OFs) and number of metrics have been specified in RPL to optimize the path selections towards the DODAG root.

- However, RPL still suffers from unbalanced and unfair distribution in number of children among the candidate parents.

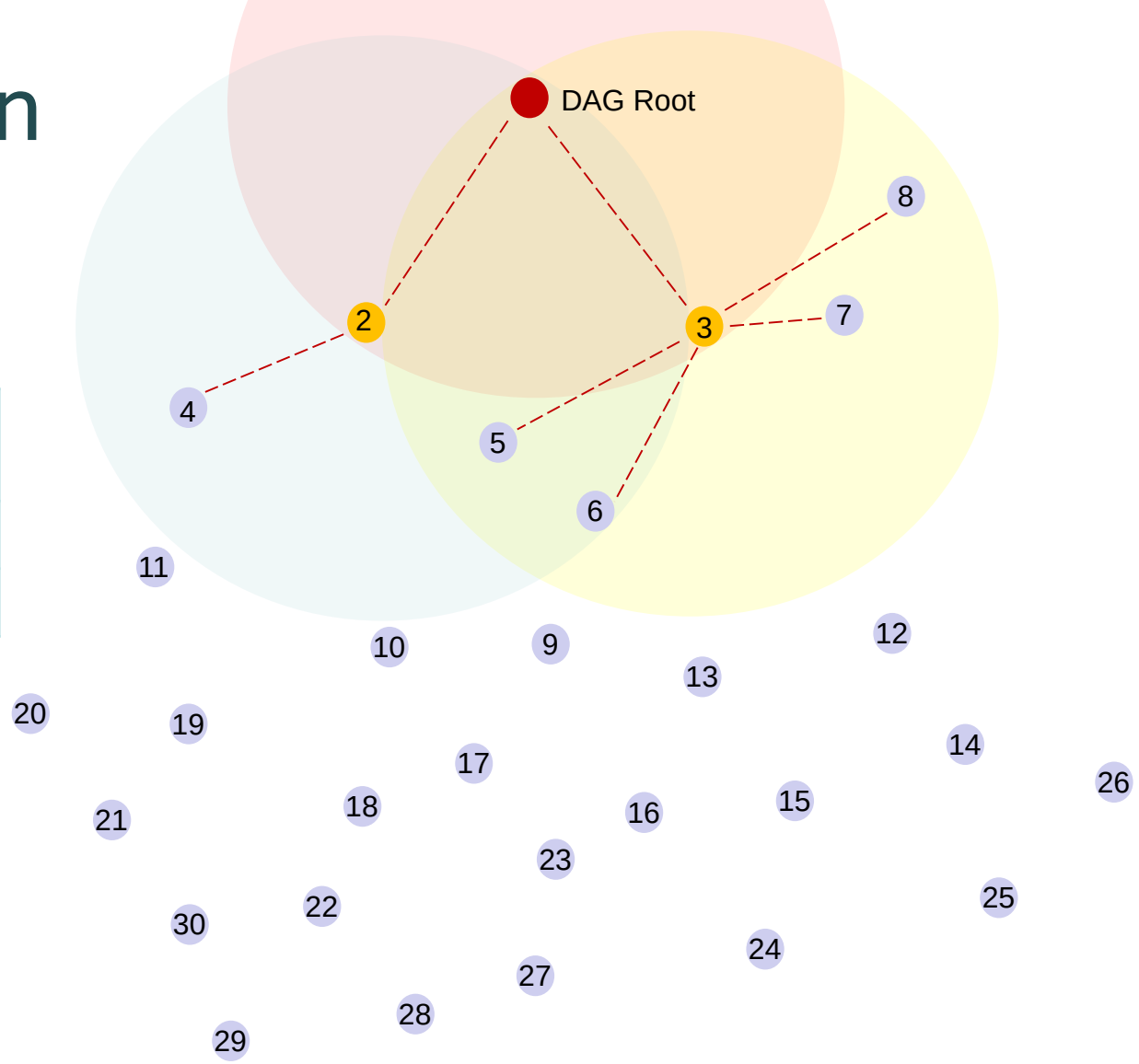
- Consequently, the overloaded parent node would drain its energy much faster than the other candidate parent nodes, which might result in early disconnection the part of the network that is covered by that overloaded parent.

Shared Area


DAG Root
7
2
3
8
4
5
6
11
10
9
12
13
16
15
14
21
22
17
18
19
20
55
55
55
55
55
55
Shared area between nodes 2 & 3

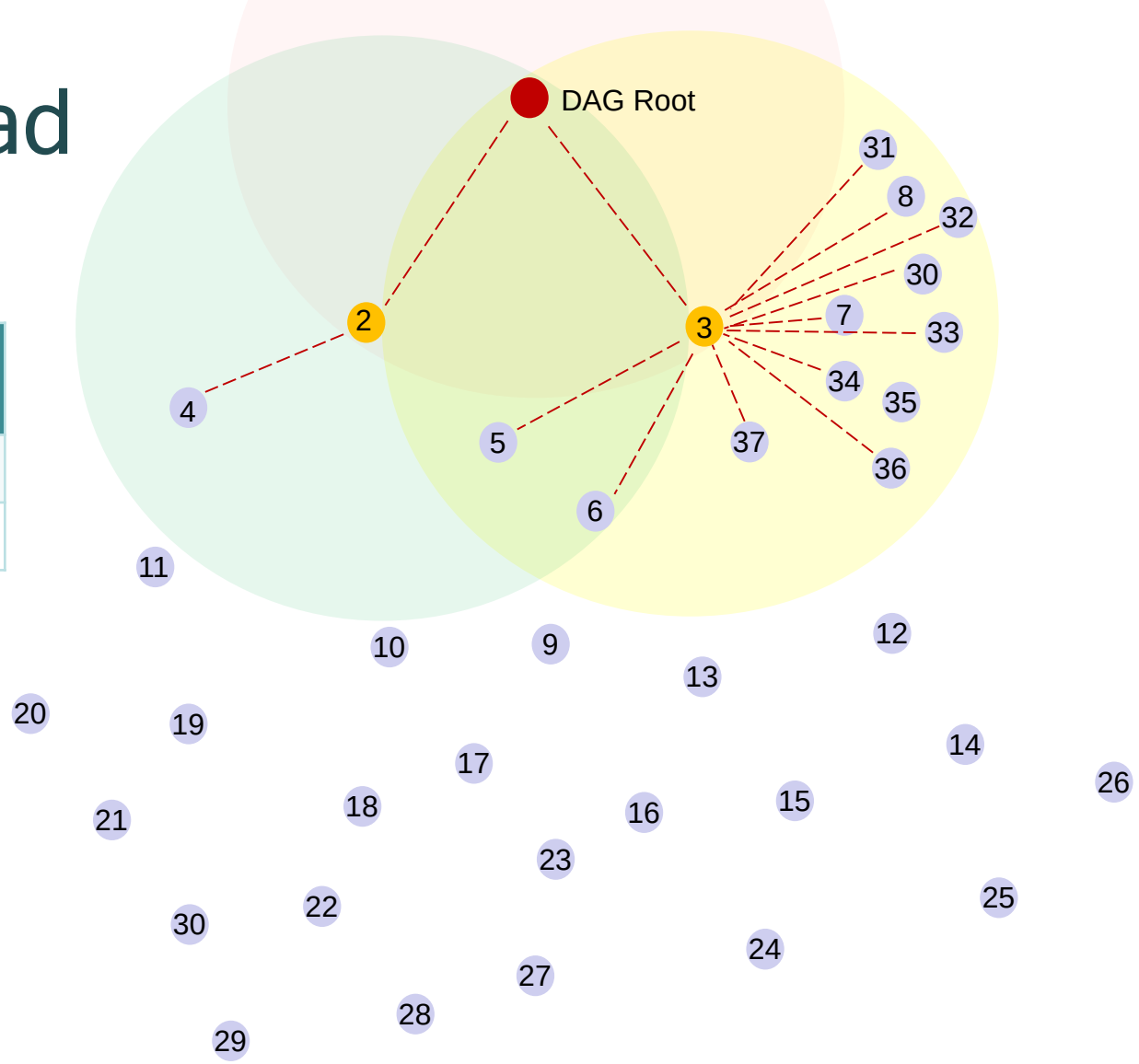
Parent Selection

Parent Node	Number of Children	Children from shared area
2	1	0
3	4	2



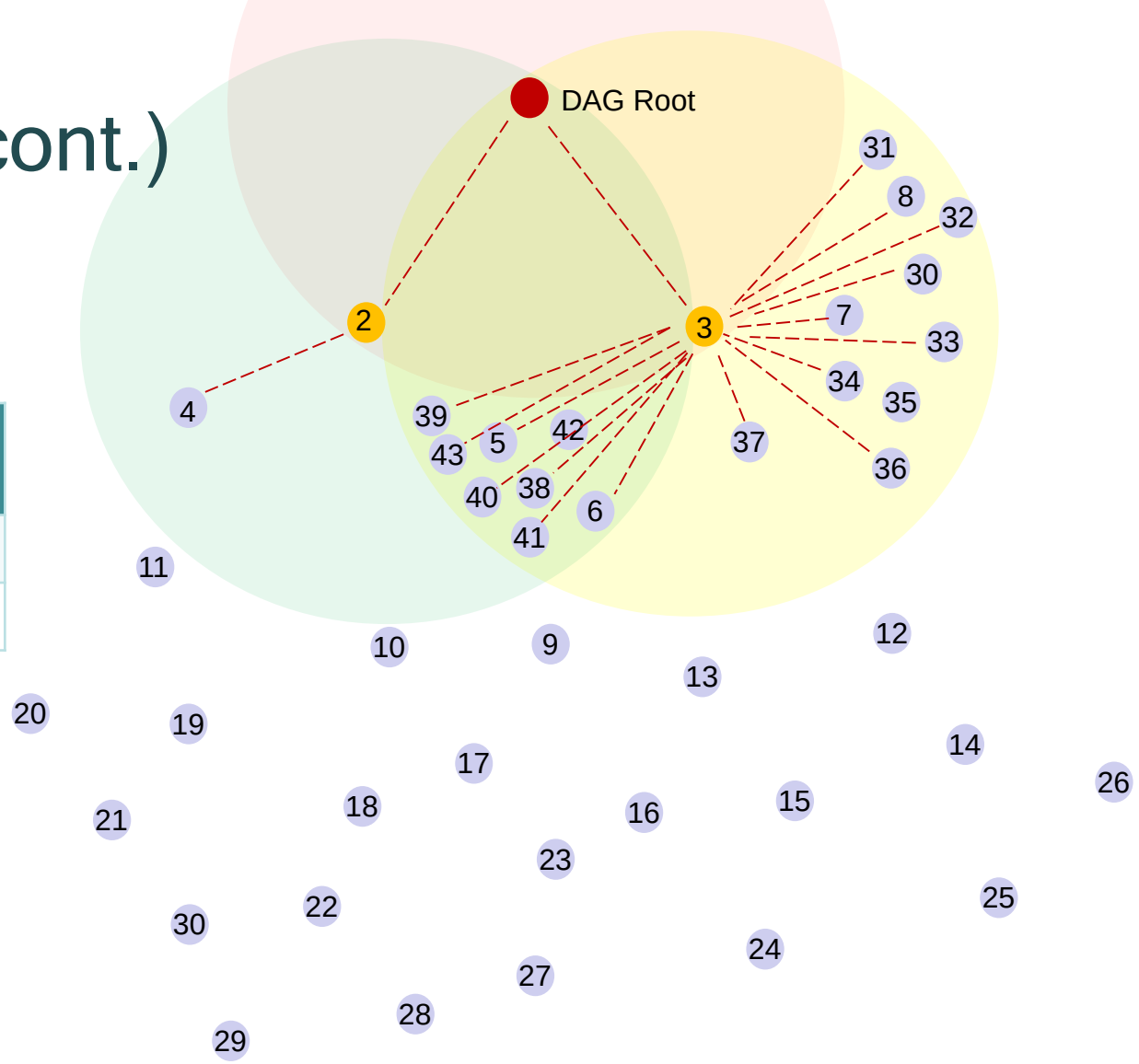
Unbalanced load

Parent Node	Number of Children	Children from shared area
2	1	0
3	10	2



Unbalanced load (cont.)

Parent Node	Number of Children	Children from shared area
2	1	0
3	~~10~~ 18	~~2~~ 8



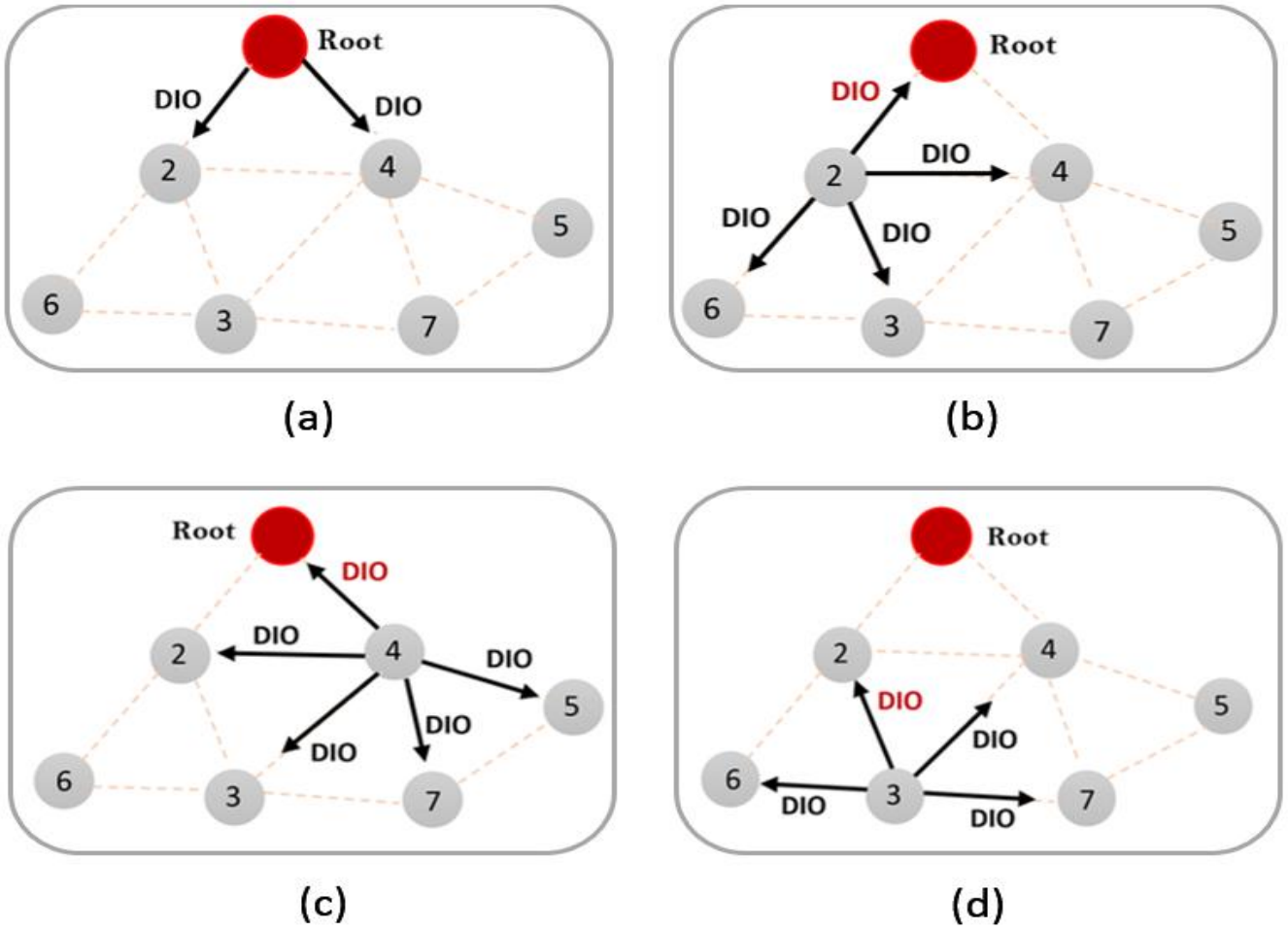
How to tackle this?

The number of children (NOC) can be considered to choose the preferred parent.

Allow the parent node to count its own children.

How??

Using the existing DIO msg without introducing any new msg as they cause more overhead.



DODAG Construction

How to tackle this?

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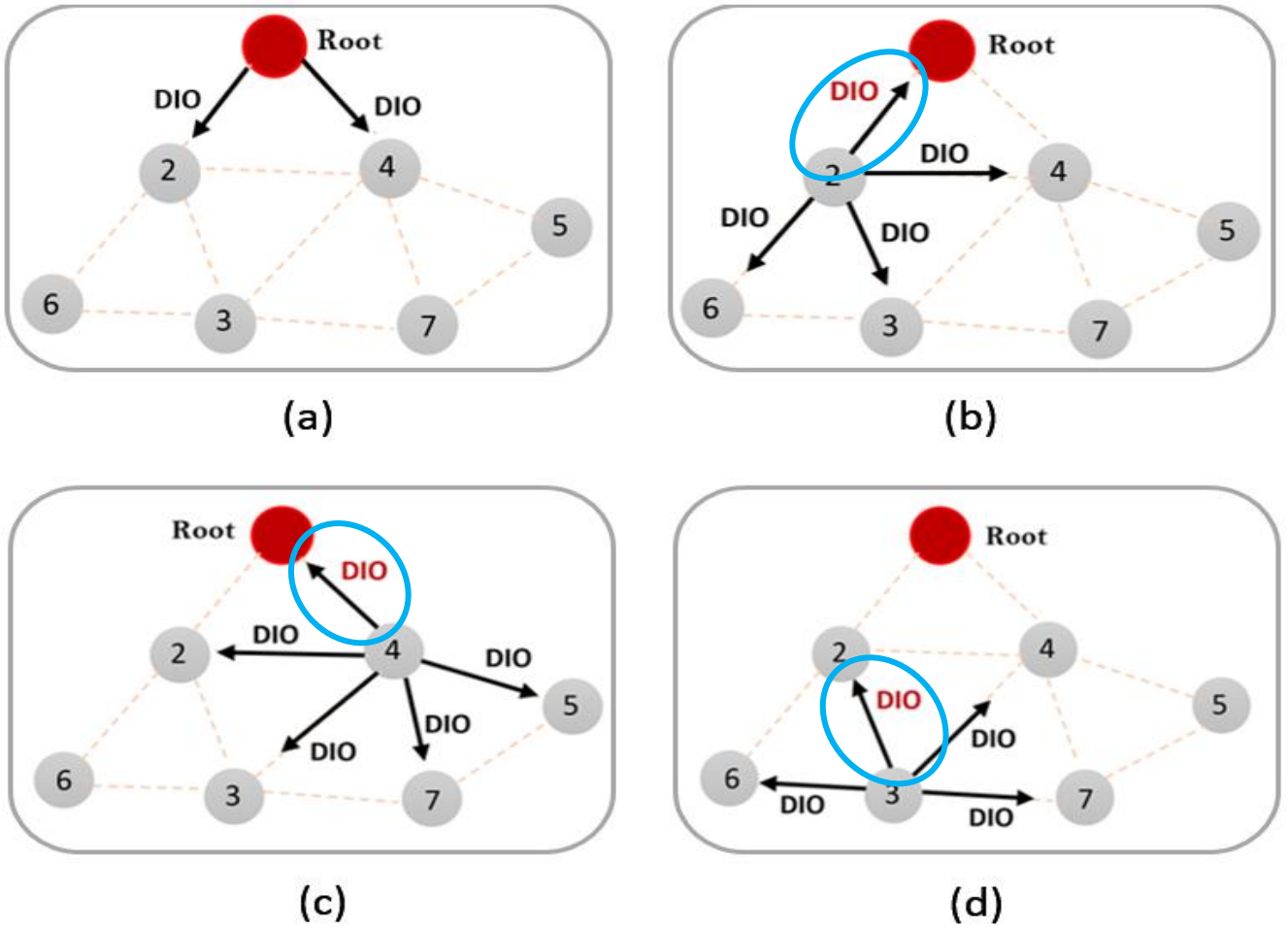
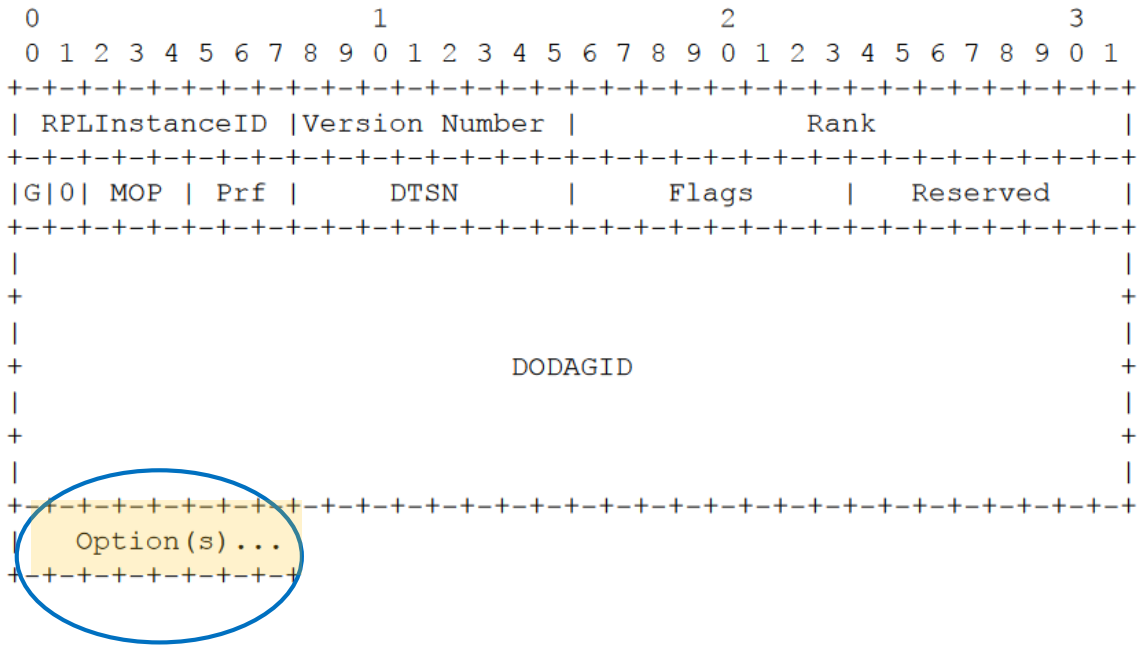
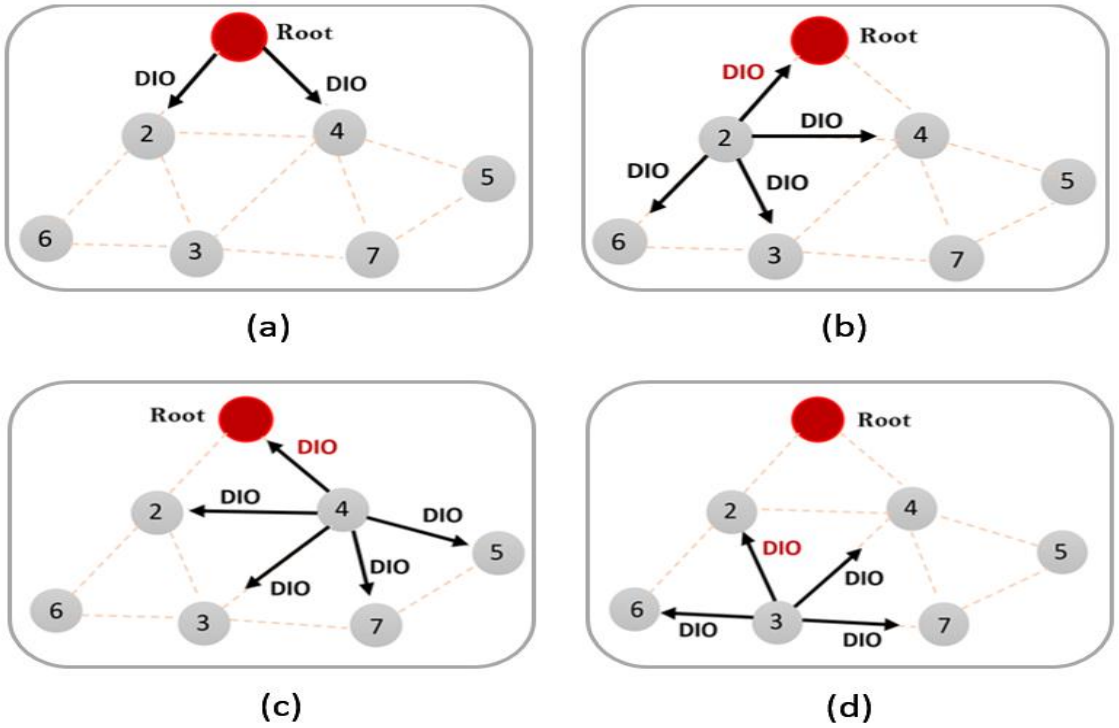


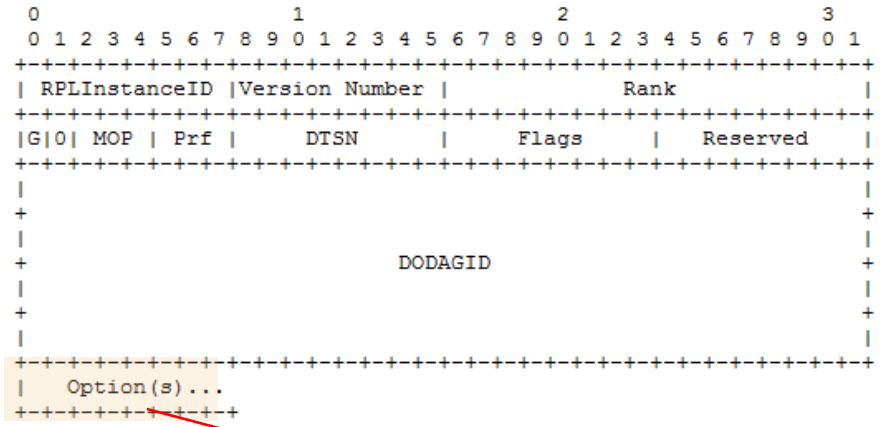
DODAG Construction

The proposed Solution

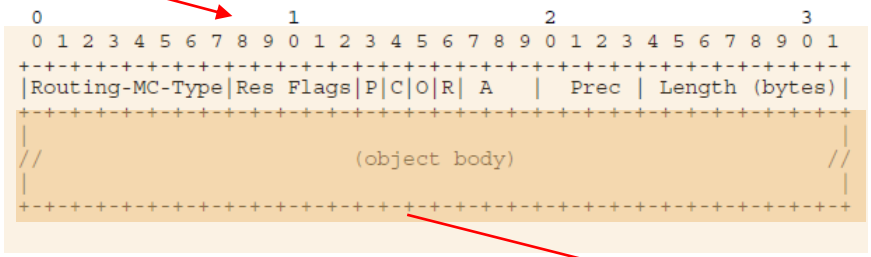




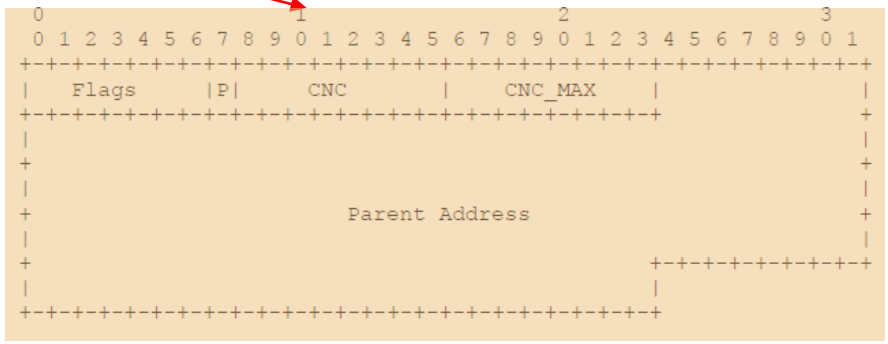
Location in DIO



DIO

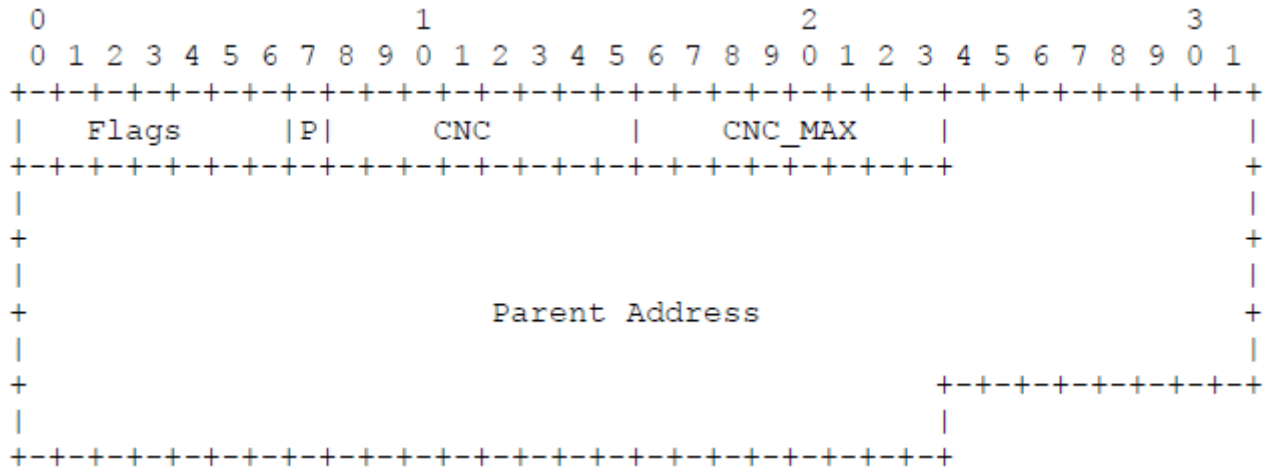


DODAG Metric Container



CNC Object

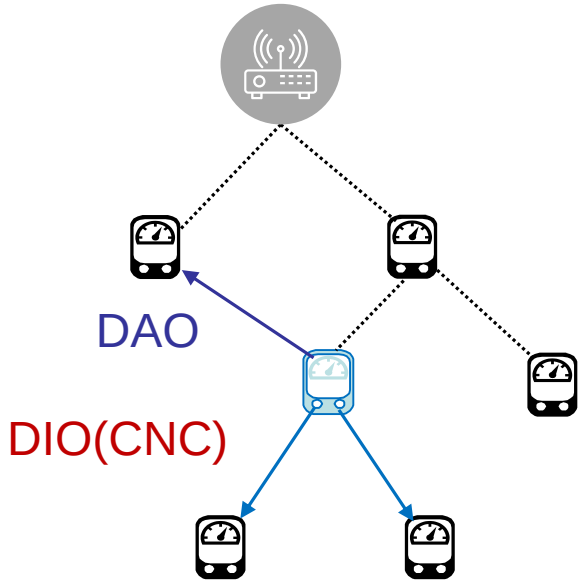
Child Node Count Metric

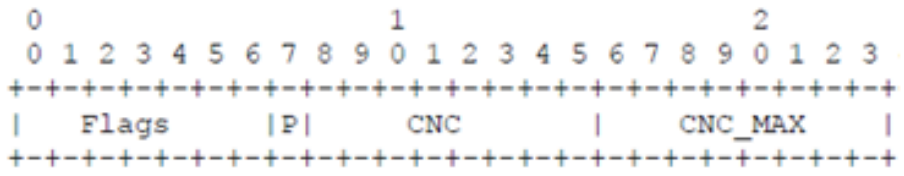


- Child Node Count (CNC) Metric – Object Body Format
  - Flag field
  - ‘P’ Flag: Parent Address State
    - P = 0, no parent address
    - P = 1, “parent address” exists after “CNC_MAC”
  - CNC
    - Number of direct children (at the moment)
  - CNC_MAX
  - Parent Address (optional?)

Storing & Non-storing Modes

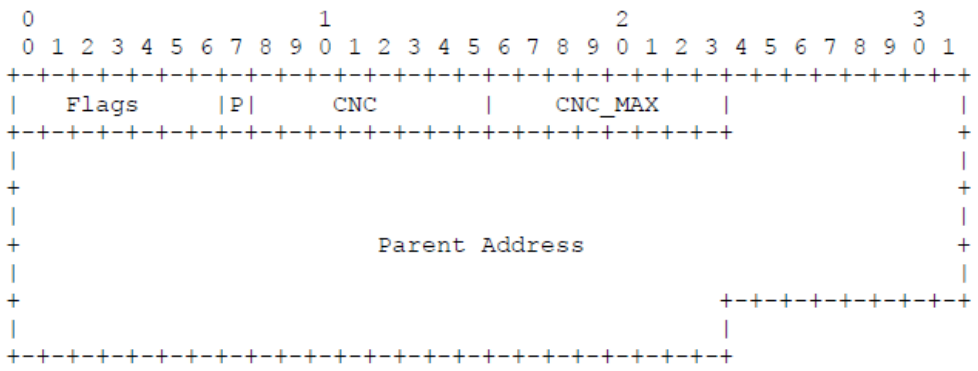
- Storing Mode
  - DAO
    - Count number of children
  - DIO(CNC)
    - ‘P’ Flag set to 0 (no parent address)
    - Inform number to downstream

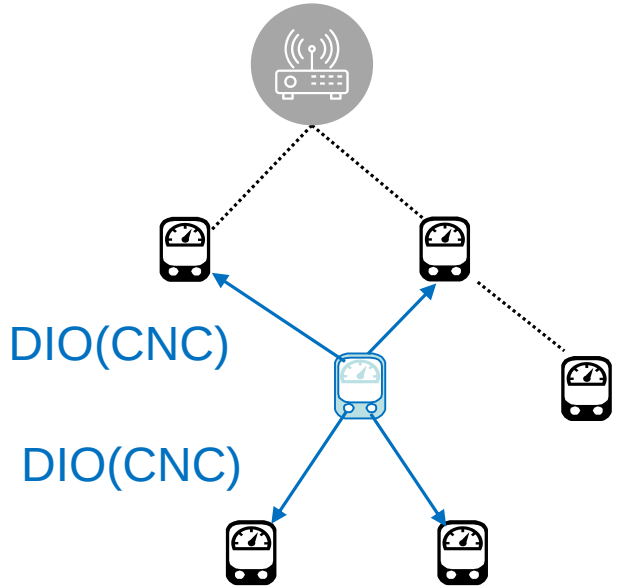




Storing & Non-storing Modes

- Non-storing Mode
  - DIO(CNC)
    - ‘P’ flag set to 1 (parent address exists)
    - UP: Count number of children
      - If ‘P’ flag is 0, NS/NA can be used for counting
    - DOWN: Inform number of downstream





RANK Computing based on CNC

- RANK reflects the ability to hold more child nodes.
- RANK = CNC / CNC_MAX * 255.
  - A node with smaller RANK has high priority to accept new child nodes
  - A node with RANK = 255 should not hold new child nodes any more

Stability Issue

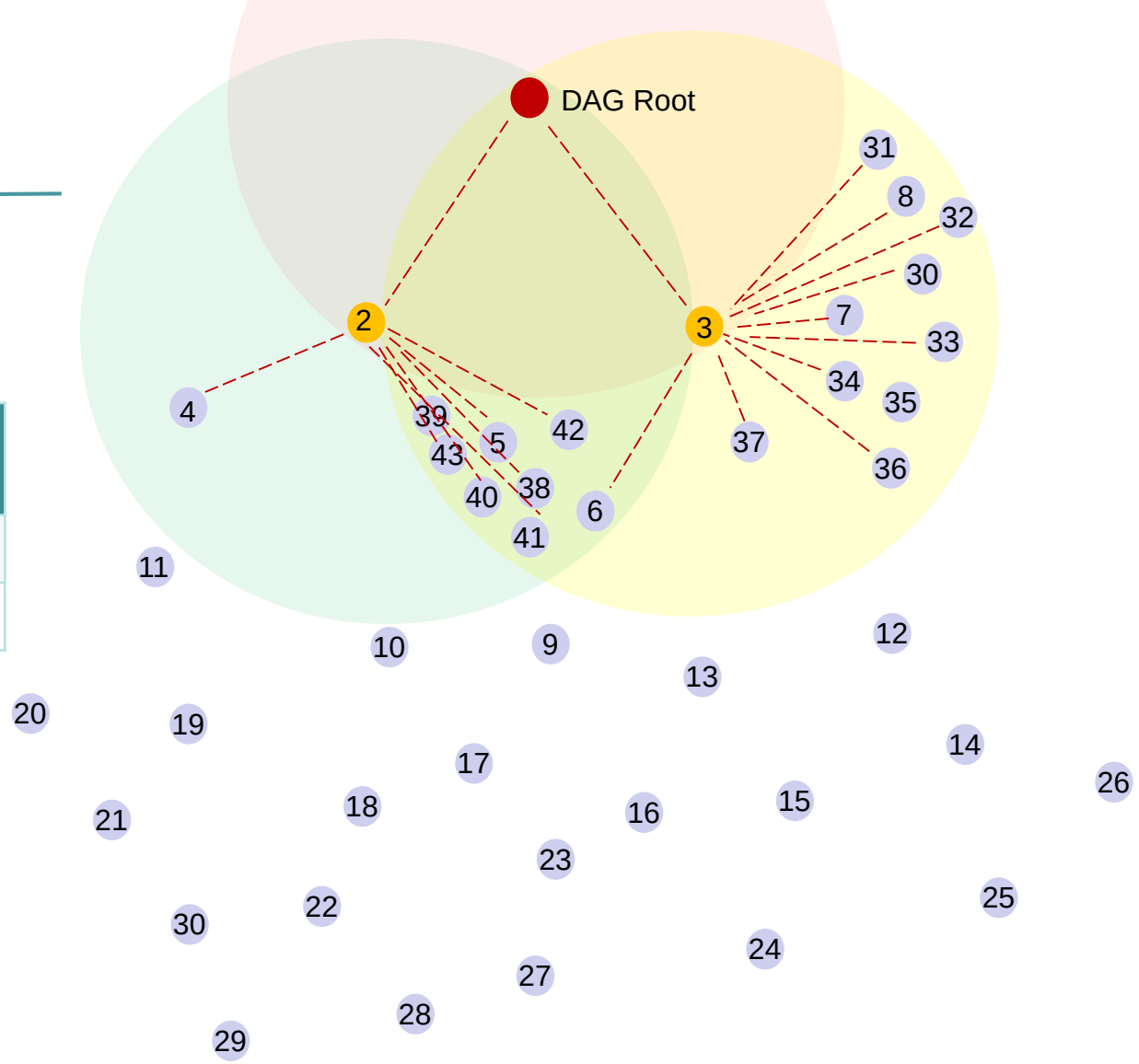
To minimize that:

a) using the number of children along with another metric(s)(e.g. ETX, number of hops, energy, etc., according to the application requirements).

b) Using the hysteresis threshold for the number of children to switch parent, the selected threshold depends on the application requirements.

Expected Balancing

Parent Node	Number of Children	Children from shared area
2	~~1~~ 8	~~0~~ 7
3	~~18~~ 11	~~8~~ 1



Thank you

RPL DAG Metric Container (MC) Node State and Attribute (NSA) object type extension

draft-pkm-roll-nsa-extension-00

Remous-Aris Koutsiamanis
Georgios Z. Papadopoulos: georgios.papadopoulos@imt-atlantique.fr
Nicolas Montavont
Pascal Thubert

ROLL@IETF100

Toward Determinism

- Reliable communication;

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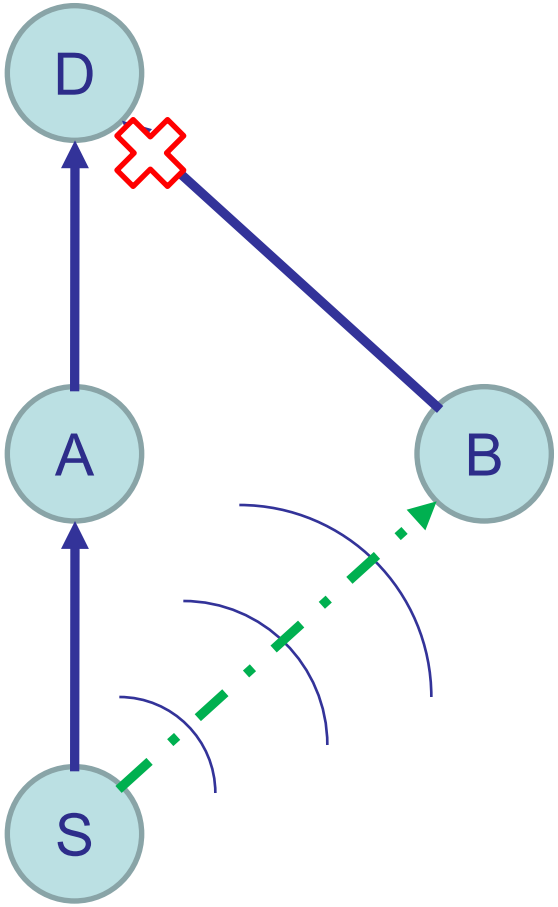
- Packet Replication Elimination.



Requirements [1]

- Alternative Parent Selection;
  - RPL DODAG Information Object (DIO) message format SHOULD be extended
  - routing protocol should be extended to allow for 6TiSCH nodes to select AP(s)
- Promiscuous Overhearing;
  - 6top Protocol should be extended to allow a cell reservation with two receivers
  - 6P ADD Request Format should be transmitted either twice or once in multicast
- Cells without ACKs;
  - only one parent MUST acknowledge the data packet
  - Or an efficient way for double ACKS
- Packet Elimination.
  - Tagging Packets for Flow Identification

[1] G. Z. Papadopoulos, N. Montavont, and P. Thubert, “Exploiting Packet Replication and Elimination in Complex Tracks in 6tisch LLNs,” Working Draft, IETF Secretariat, Internet-Draft draft-papadopoulos-6tisch-pre-reqs-00, July 2017.

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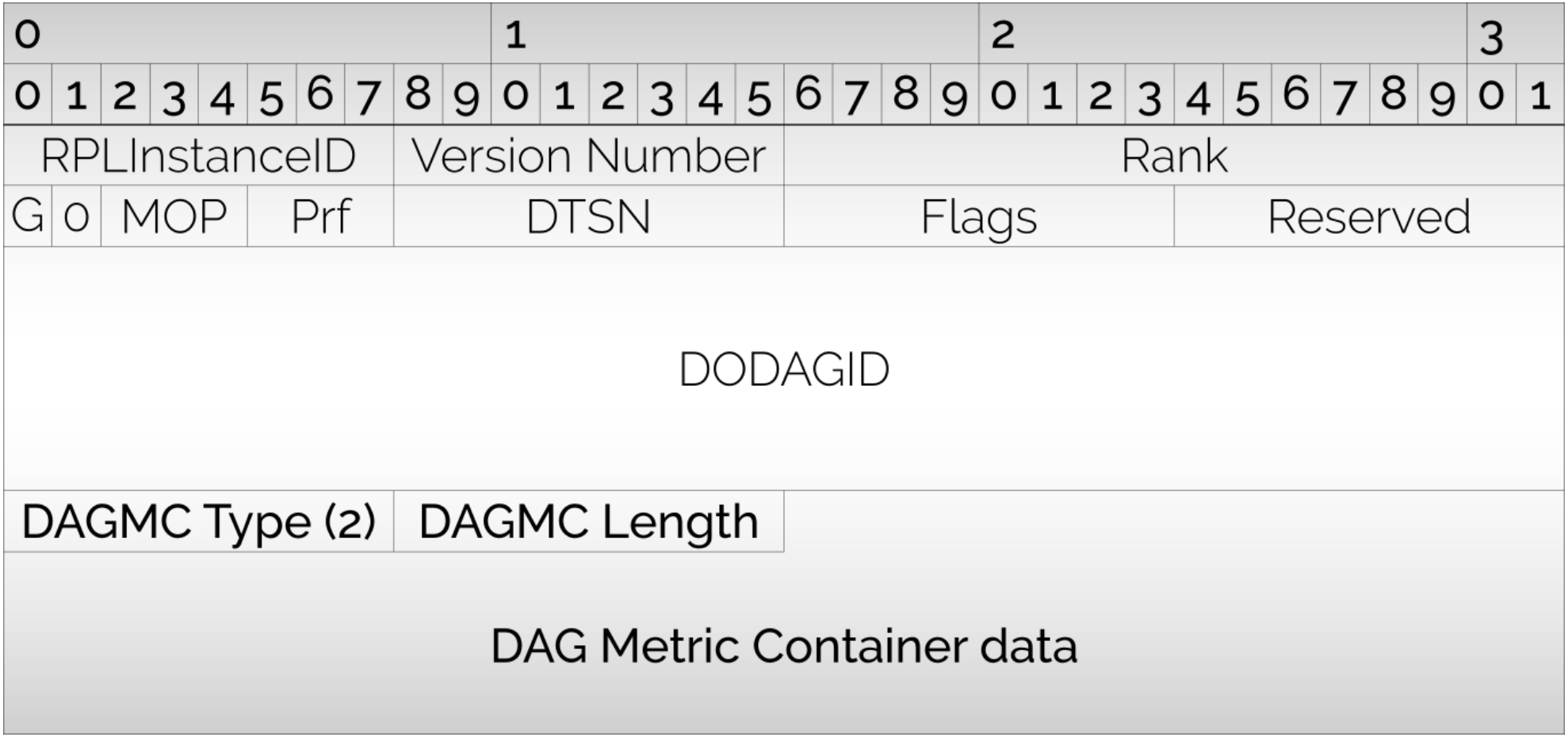
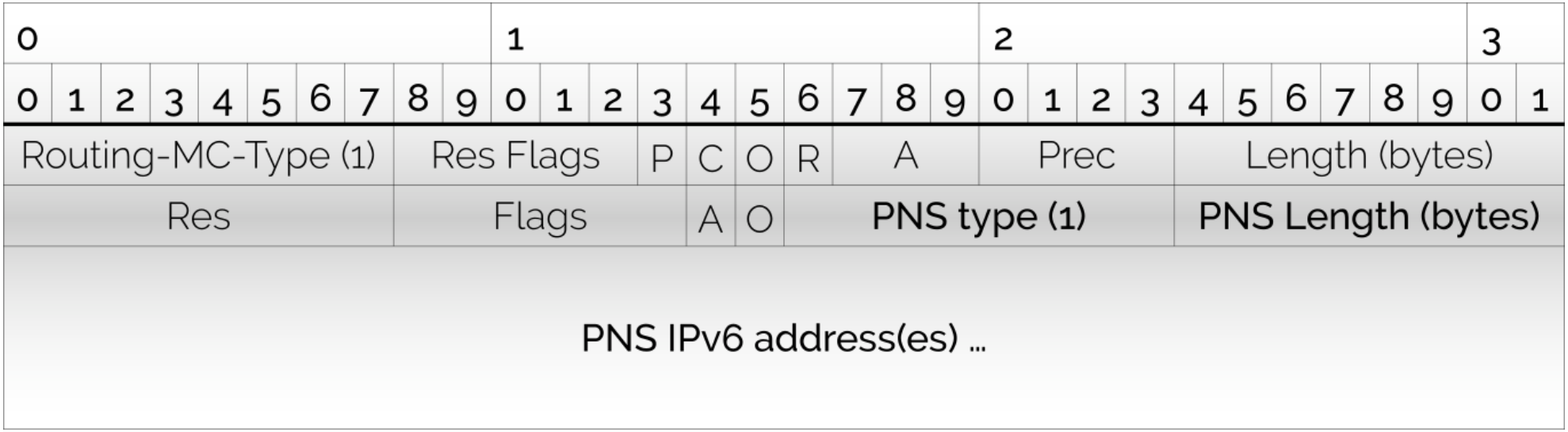
Alternative Parent Selection

One possible option is to select the Alternative Parent as the one having common *ancestor*

DIO Format Example



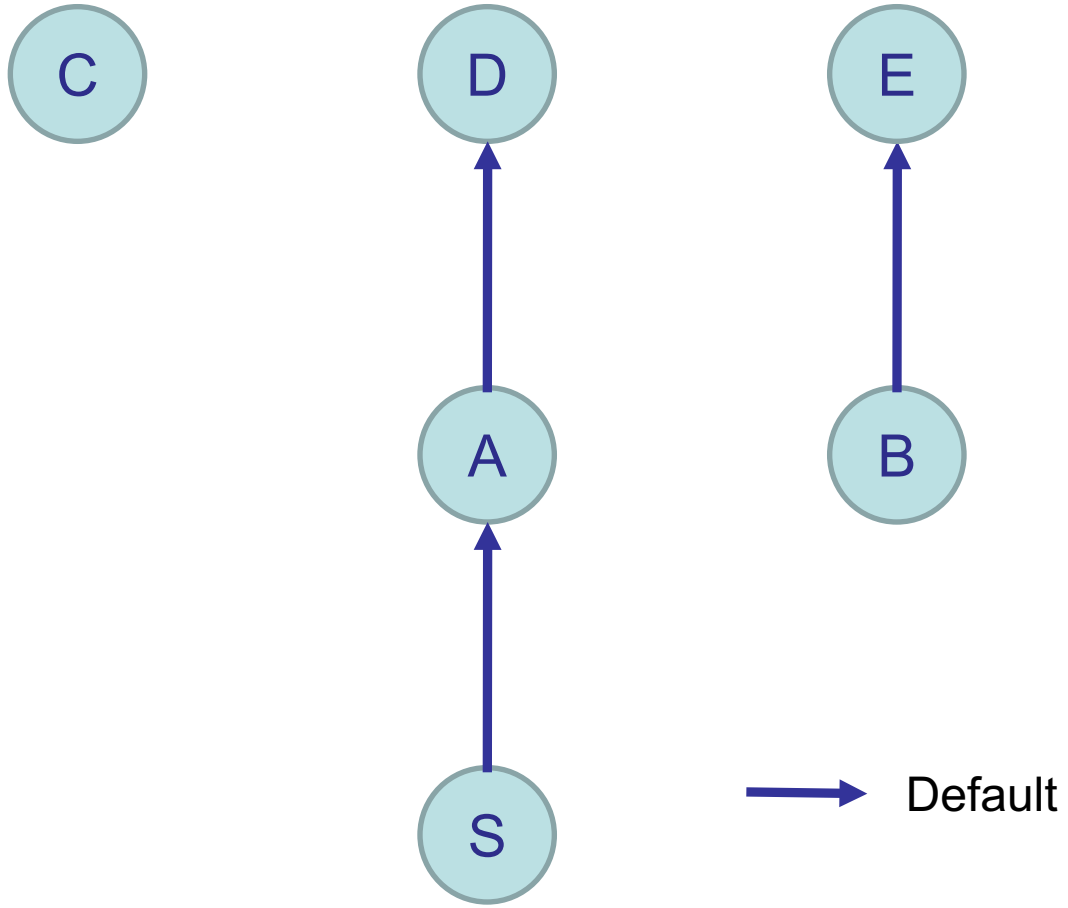
MC/NSA Format Example



- Parent Node Set (PNS)
  - NSA Option
  - PNS type = 1 (8 bits)
  - PNS Length = # of PNS addresses x IPv6 address size (8 bits)
  - PNS IPv6 addresses = 1 or more IPv6 addresses

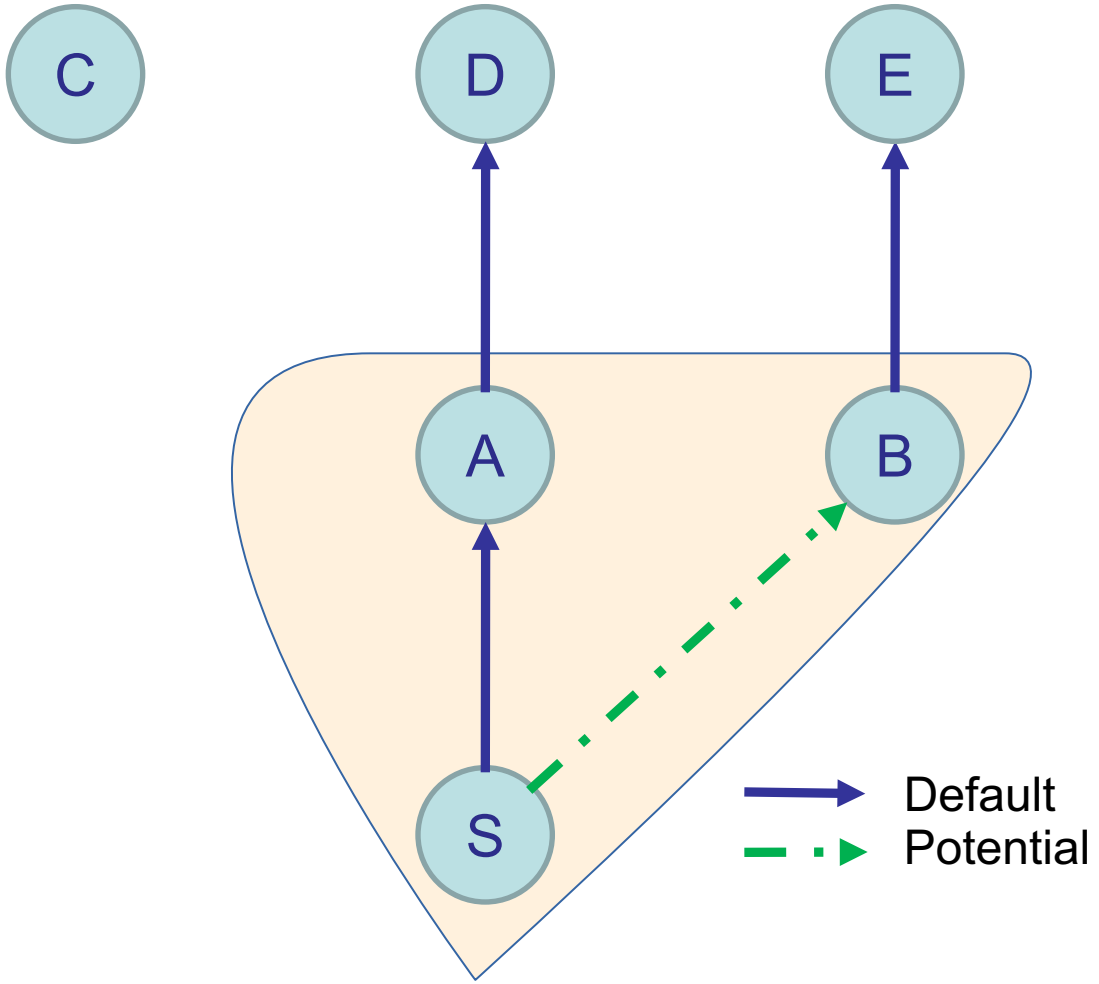
Example

- RPL DAG
  - S→A→D
  - B→E



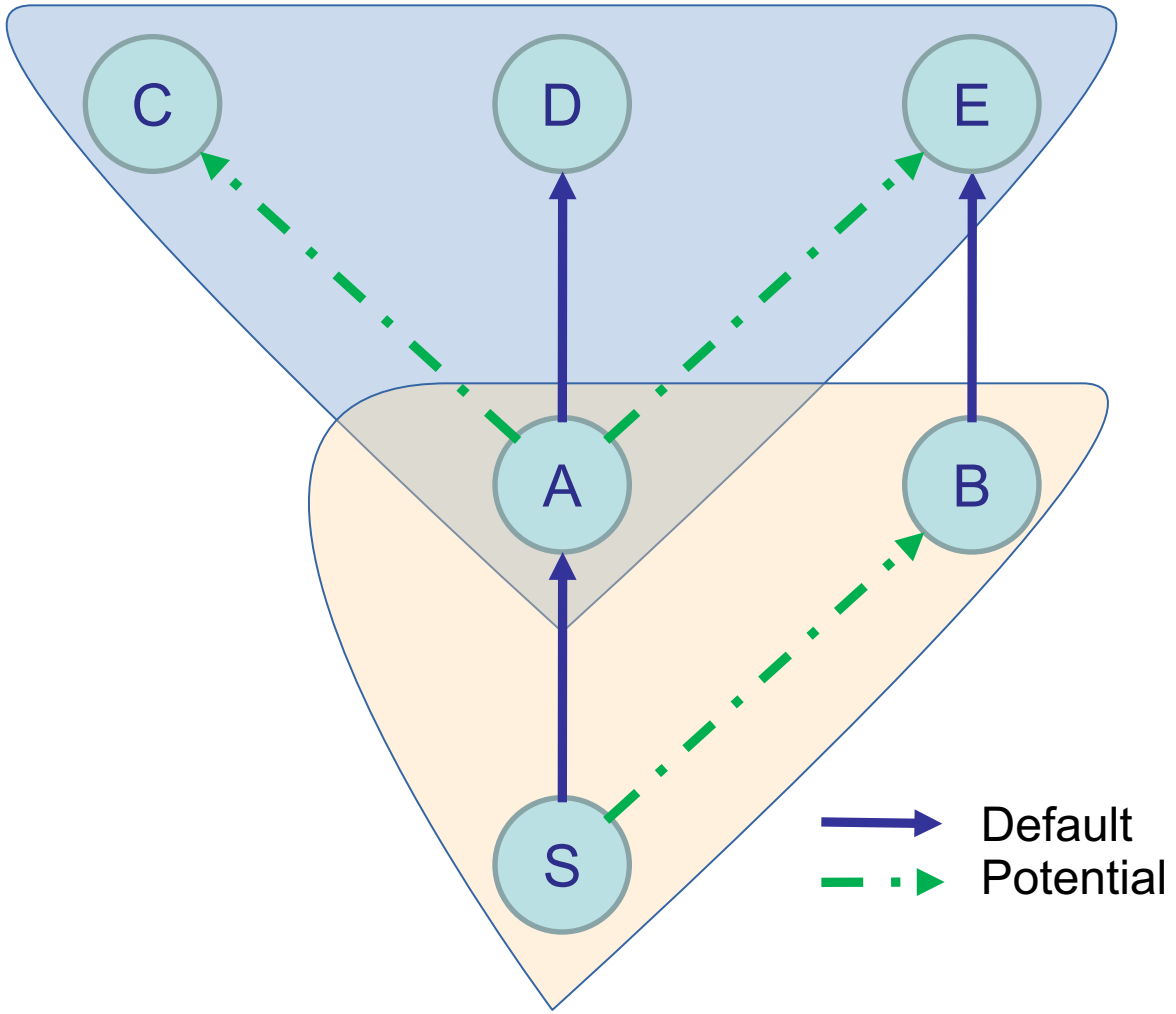
Example

- Parent set S:
  - {A, B}



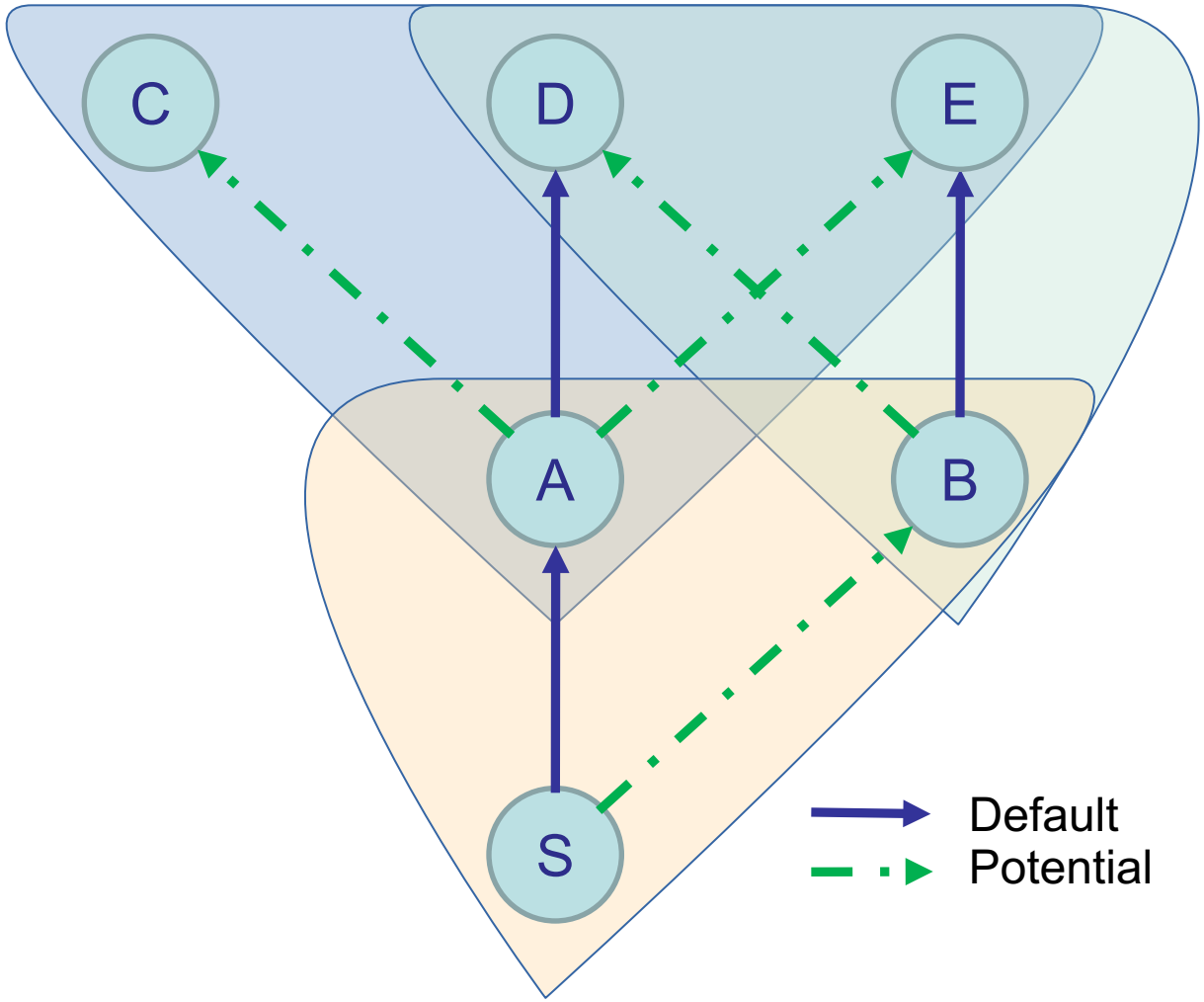
Example

- Parent set S:
  - {A, B}
- Parent Set A:
  - {D, C, E}



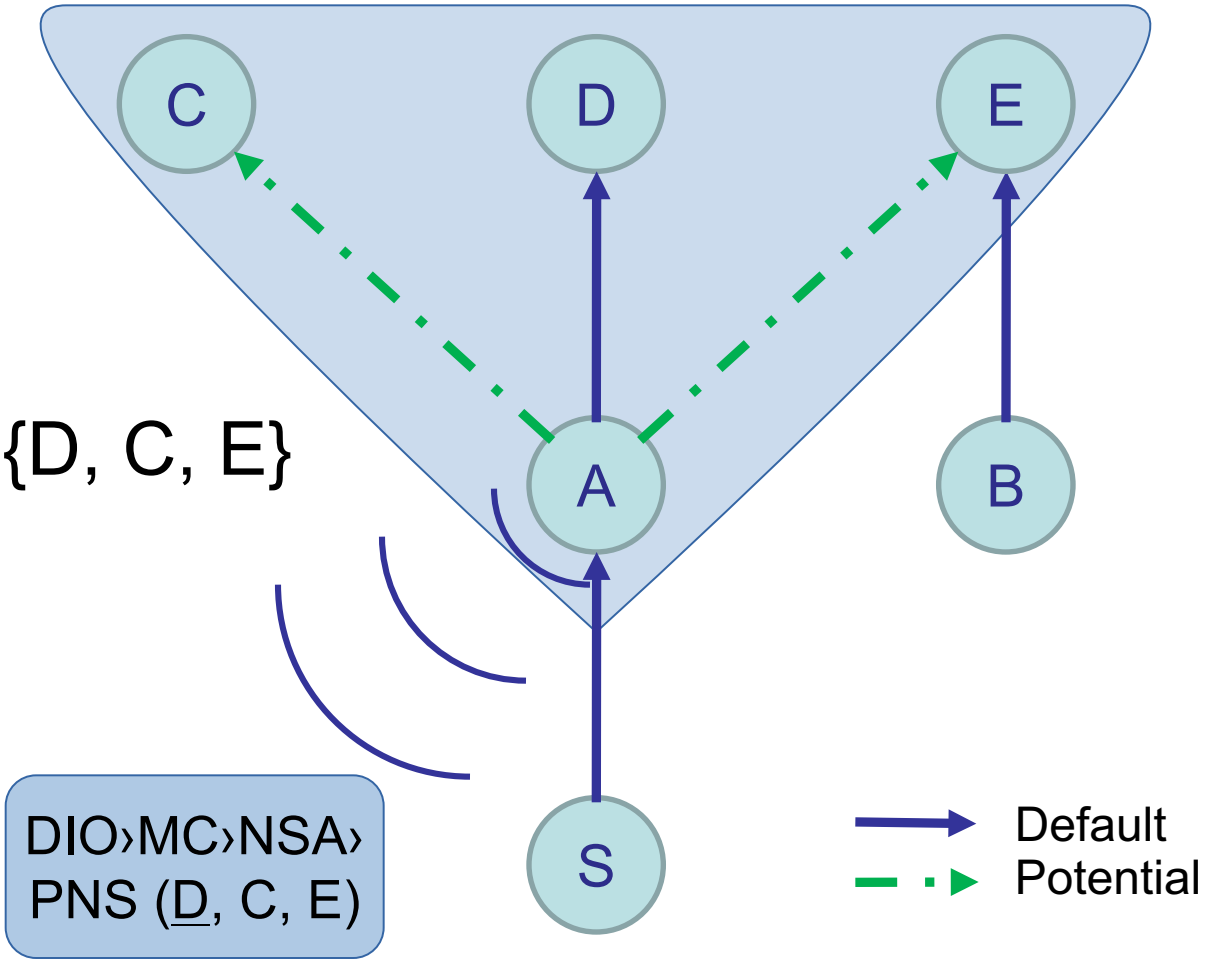
Example

- Parent set S:
  - {A, B}
- Parent Set A:
  - {D, C, E}
- Parent set B:
  - {E, D}



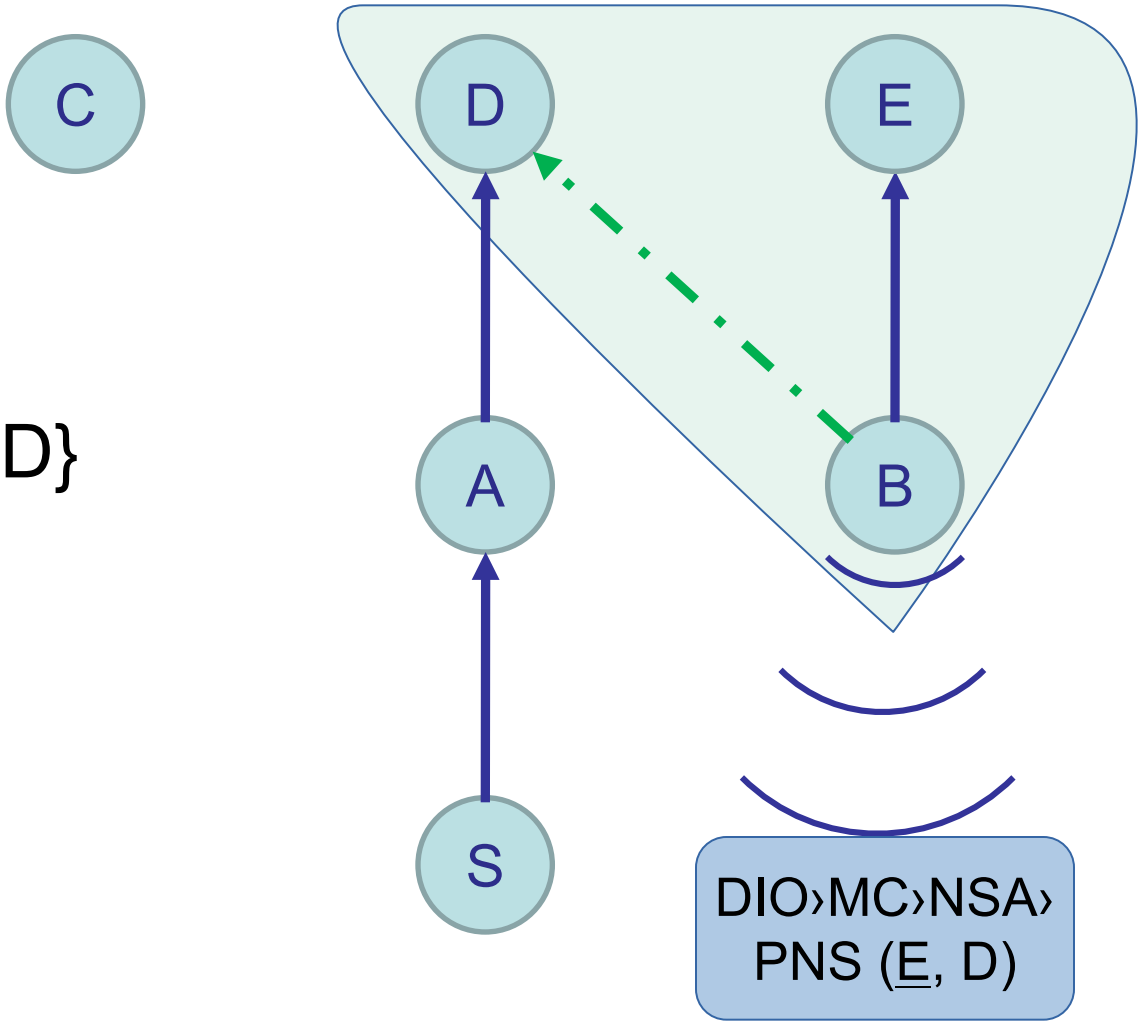
Example

- A's DIO
  - Parent Set A: {D, C, E}



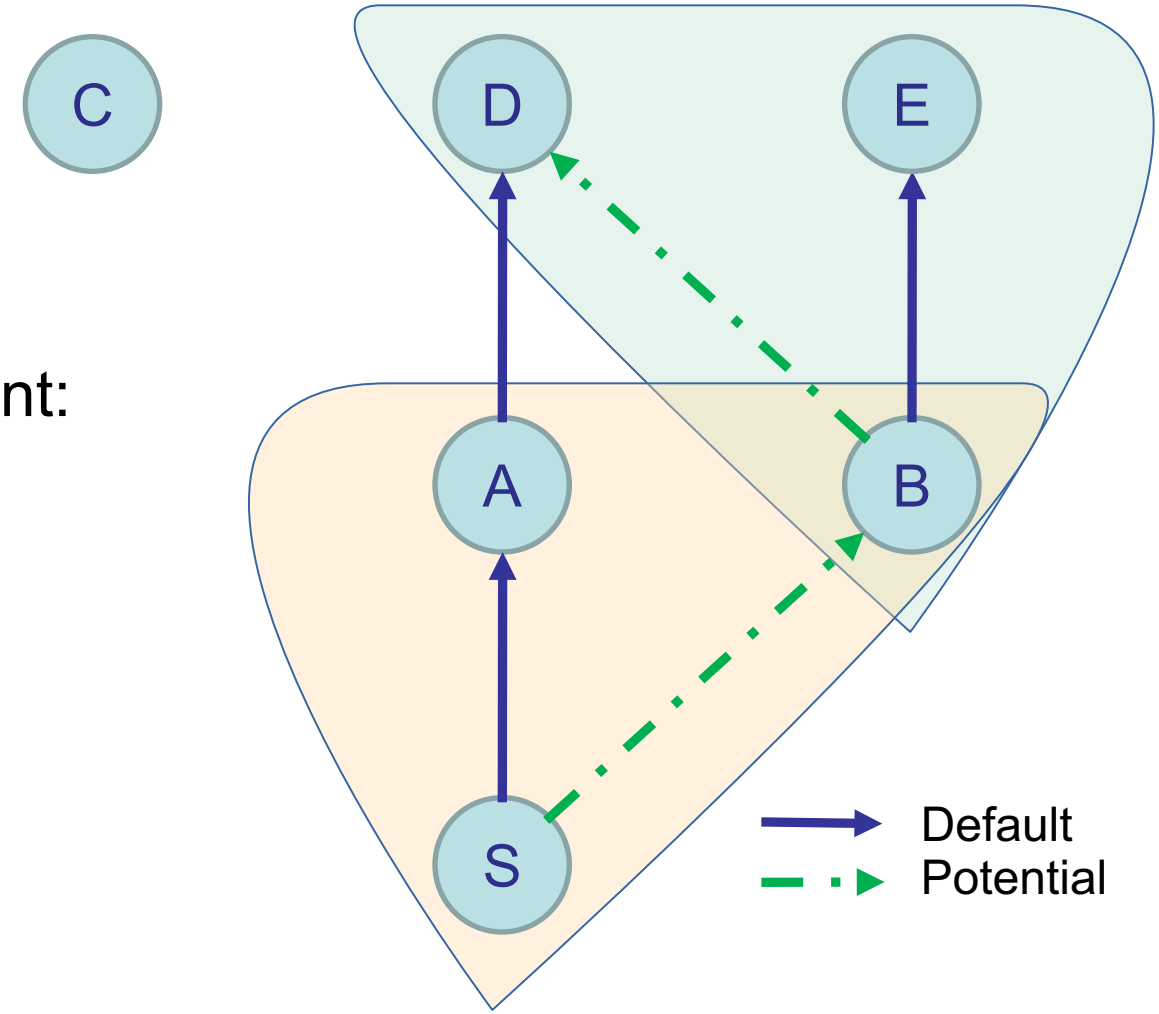
Example

- B's DIO
  - Parent set B: {E, D}



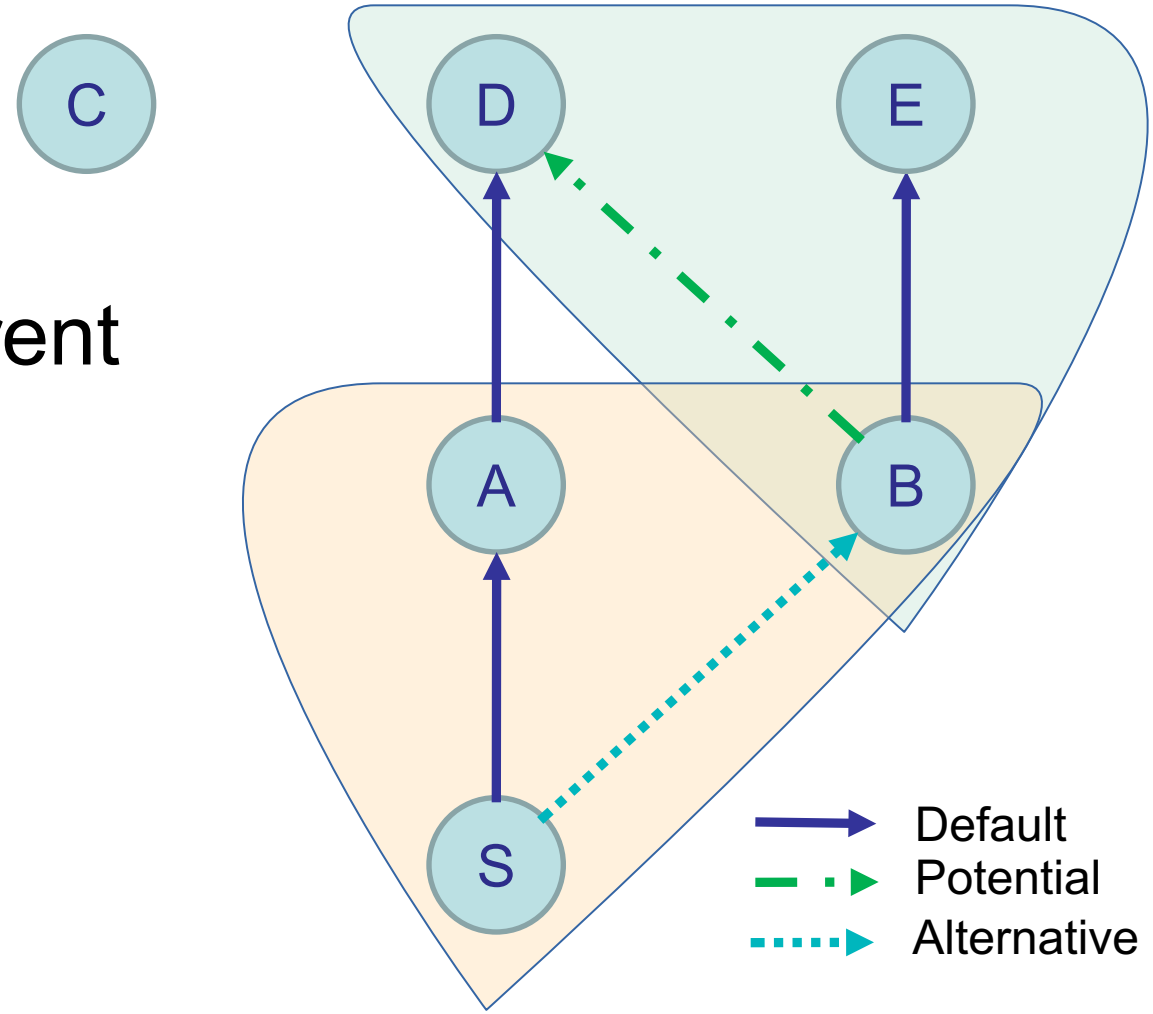
Example

- S via A:
  - Default Grand Parent:
    - D
- S via B:
  - Grand Parent Set:
    - {E, D}
- D is in {E, D}



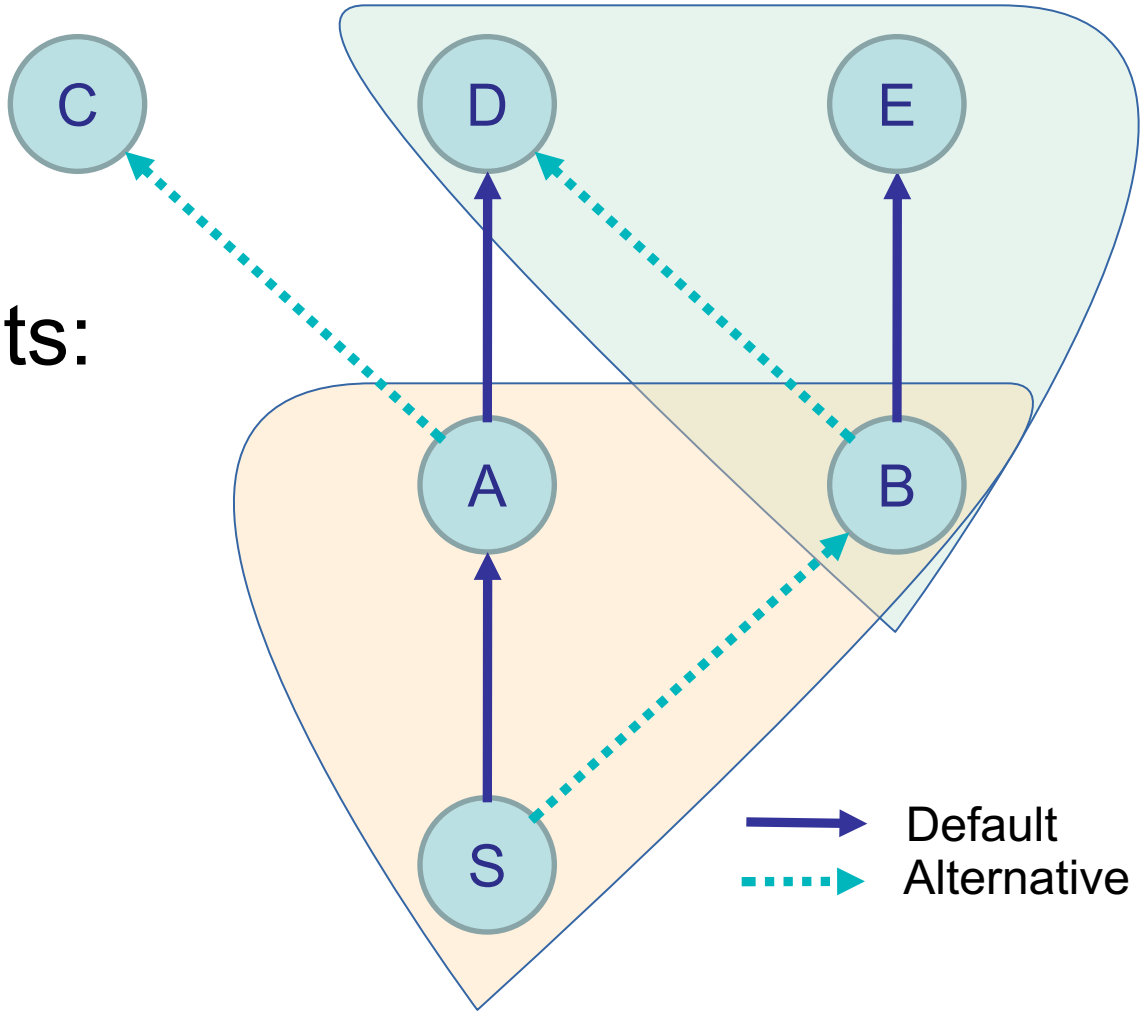
Example

- S → B
  - Alternative Parent



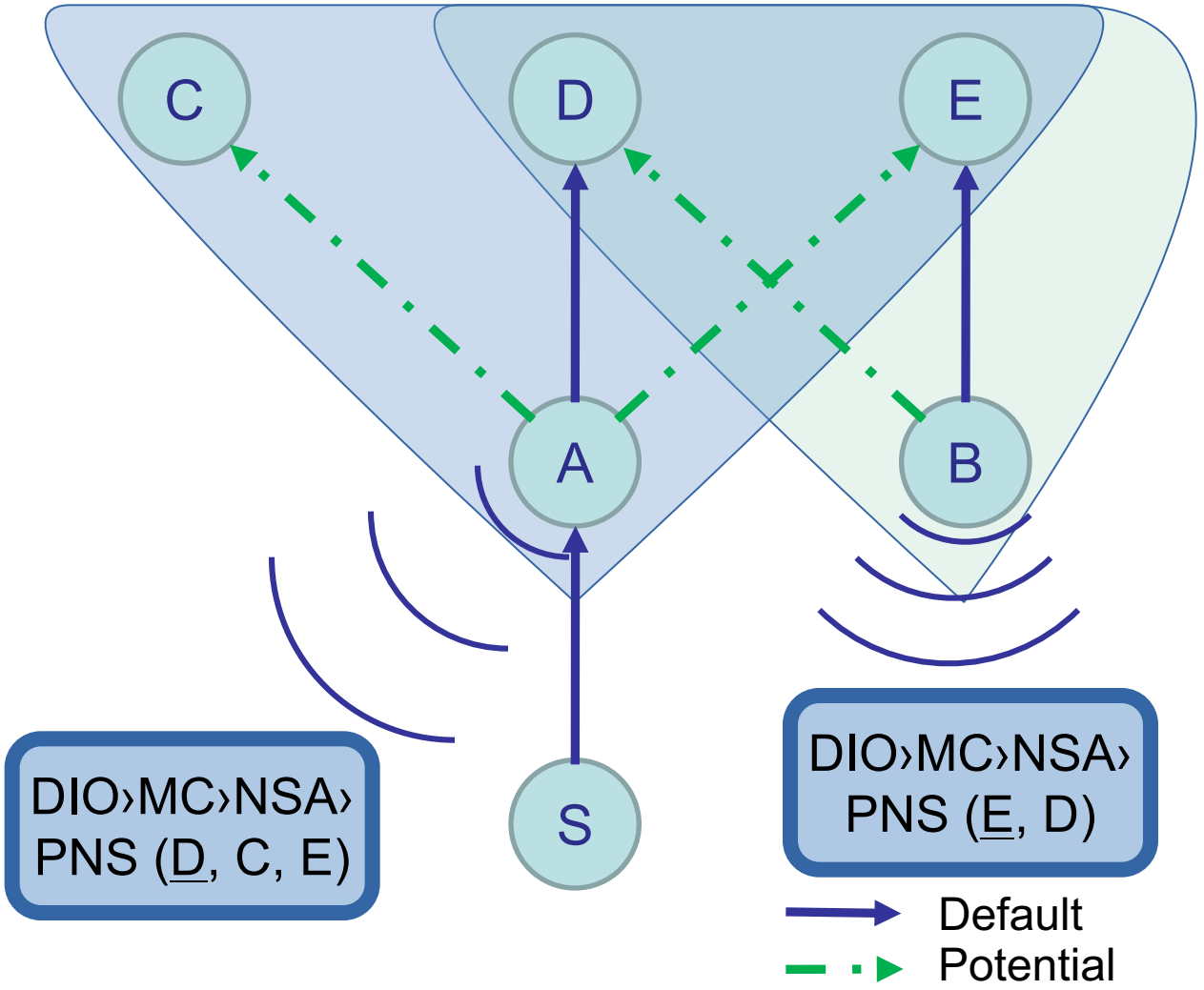
Example

- Similarly:
- Alternative Parents:
  - A → C
  - B → D



Parent Selection - DIO Messages

- Parent Set A:
  - {D, C, E}
- Parent set B:
  - {E, D}



Feedback

- This draft is implemented over Contiki OS

- Volunteers to REVIEW the draft;
- Is it relevant in ROLL WG?

RPL DAG Metric Container (MC) Node State and Attribute (NSA) object type extension

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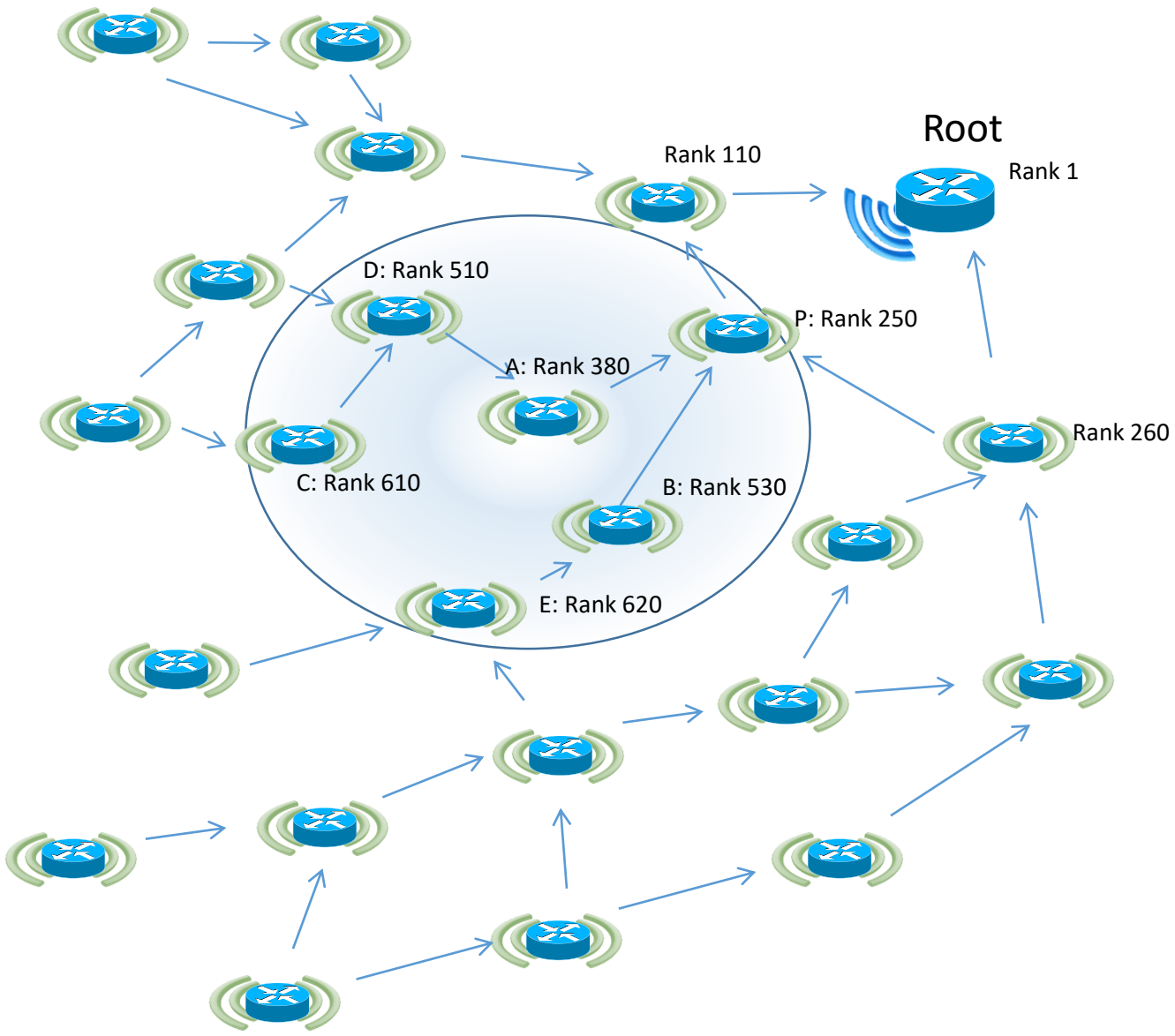
Fast Reroute for RPL

Pascal Thubert

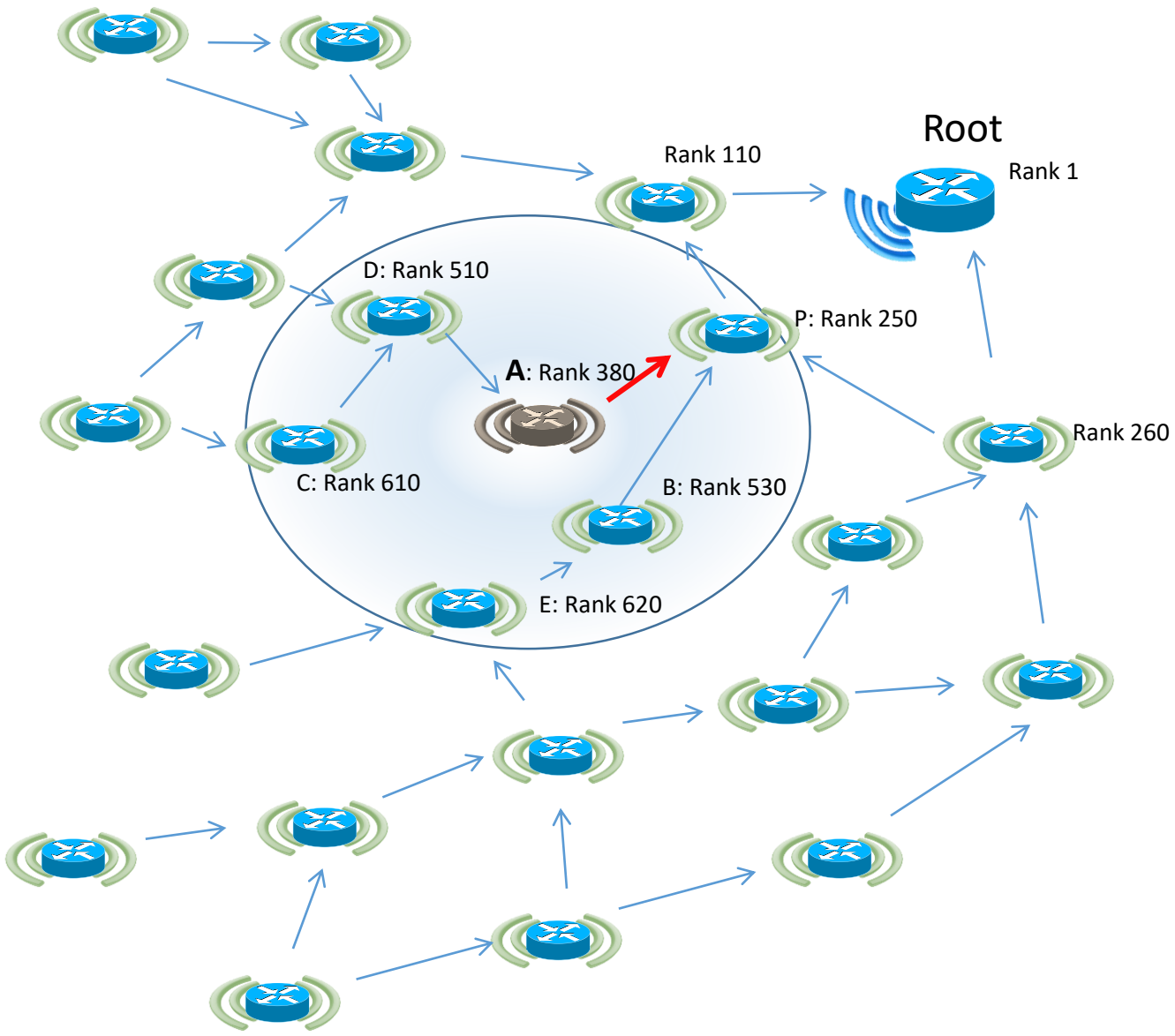
IETF 100

Singapore, November 2017



Initial situation;

- Rank is computed on some metric e.g. LQI.
- Node A has a single parent, node P
- A can hear D and C which are in its subdag
- A can hear B and E which are not

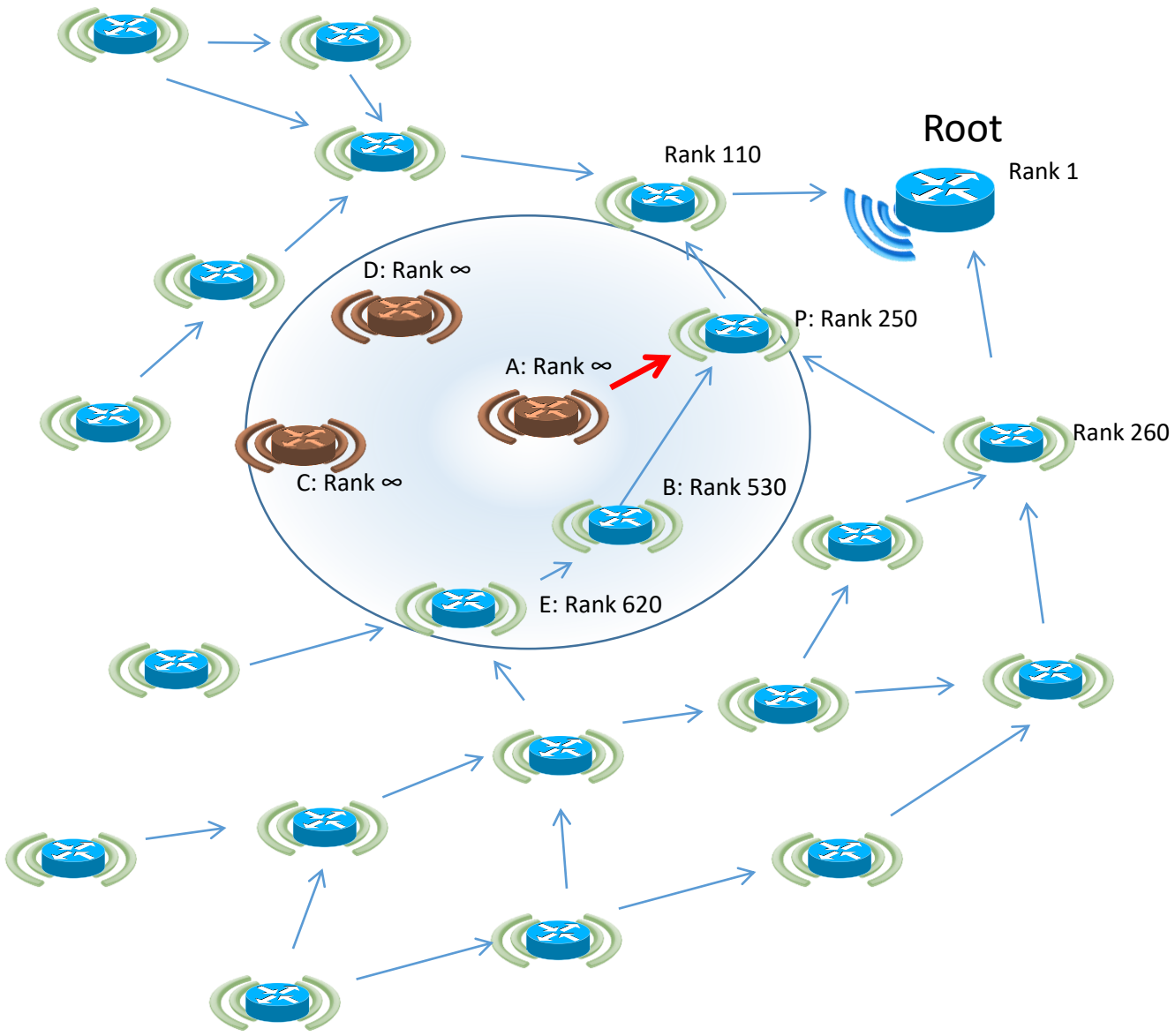


Say that the radio connectivity between A and P dies. A looses it only feasible parent.

Its neighbors are all deeper (higher Rank) so it cannot reattach without risking a loop.

Attaching to D and C would create a loop.
Attaching to E or B would not create a loop.

Trouble is A does not know.



RRFC 6550 says that node A must detach, freeze, and wait for the resulting of the freezing.

Freezing may be done by poisoning, IOW sending infinite rank. A (preferable IMHO) alternative is to form a floating DAG, which spreads the freezing differently with the advantage to maintain the shape of the DODAG in place

After some time, the devices that depended on A are (mostly) frozen or re-parented elsewhere.

From that point, RPL says that the frozen nodes can all reparent, that's A, D and C here, and then the network is fixed

The problem is the "After some time" above. That is disruptive to traffic, which can be unacceptable

Fast Reroute for RPL

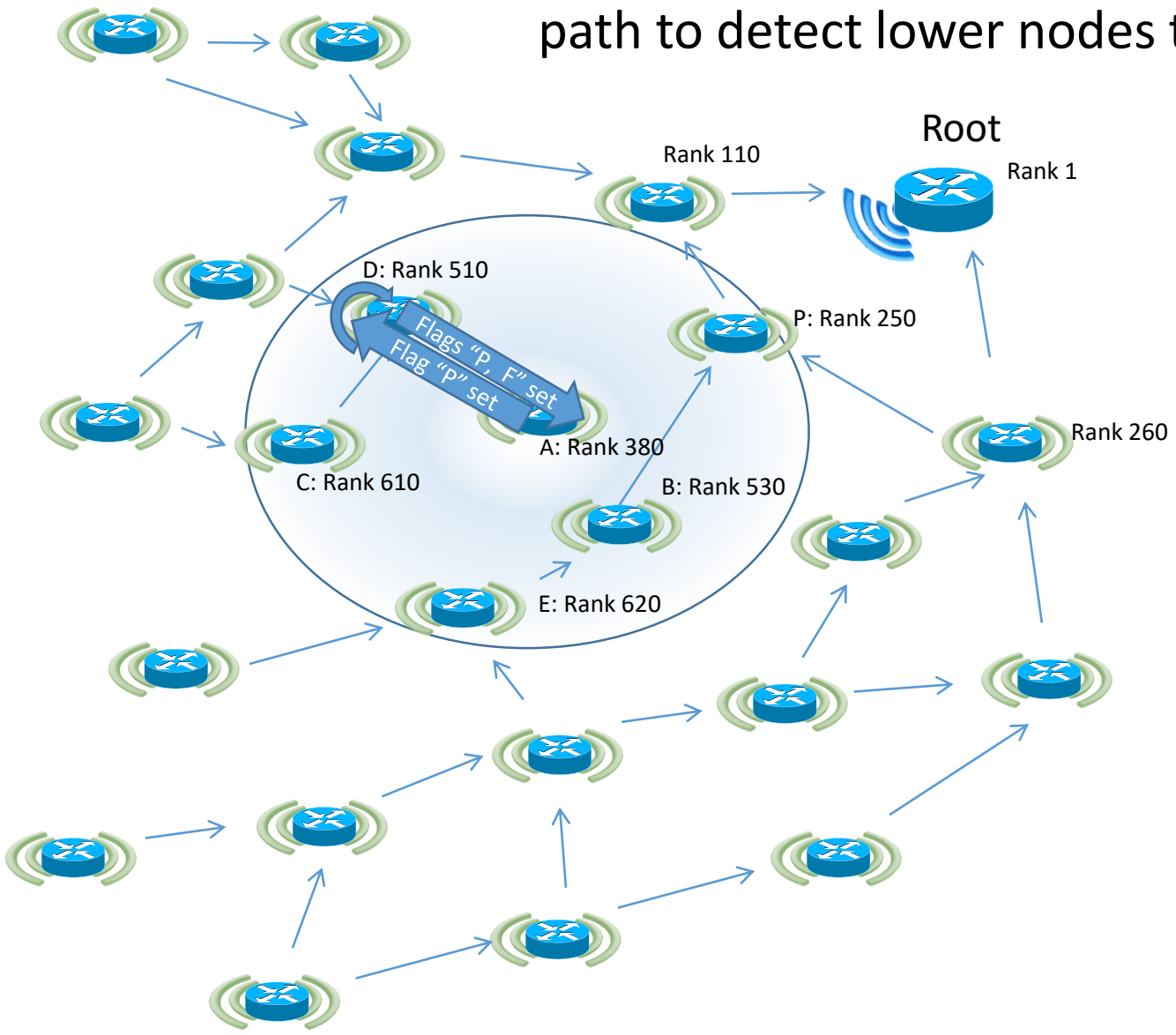
Using datapath exploration

Pascal Thubert

IETF 100

Singapore, November 2017

Proposal use to keep forwarding and to use the data path to detect lower nodes that are feasible successors:



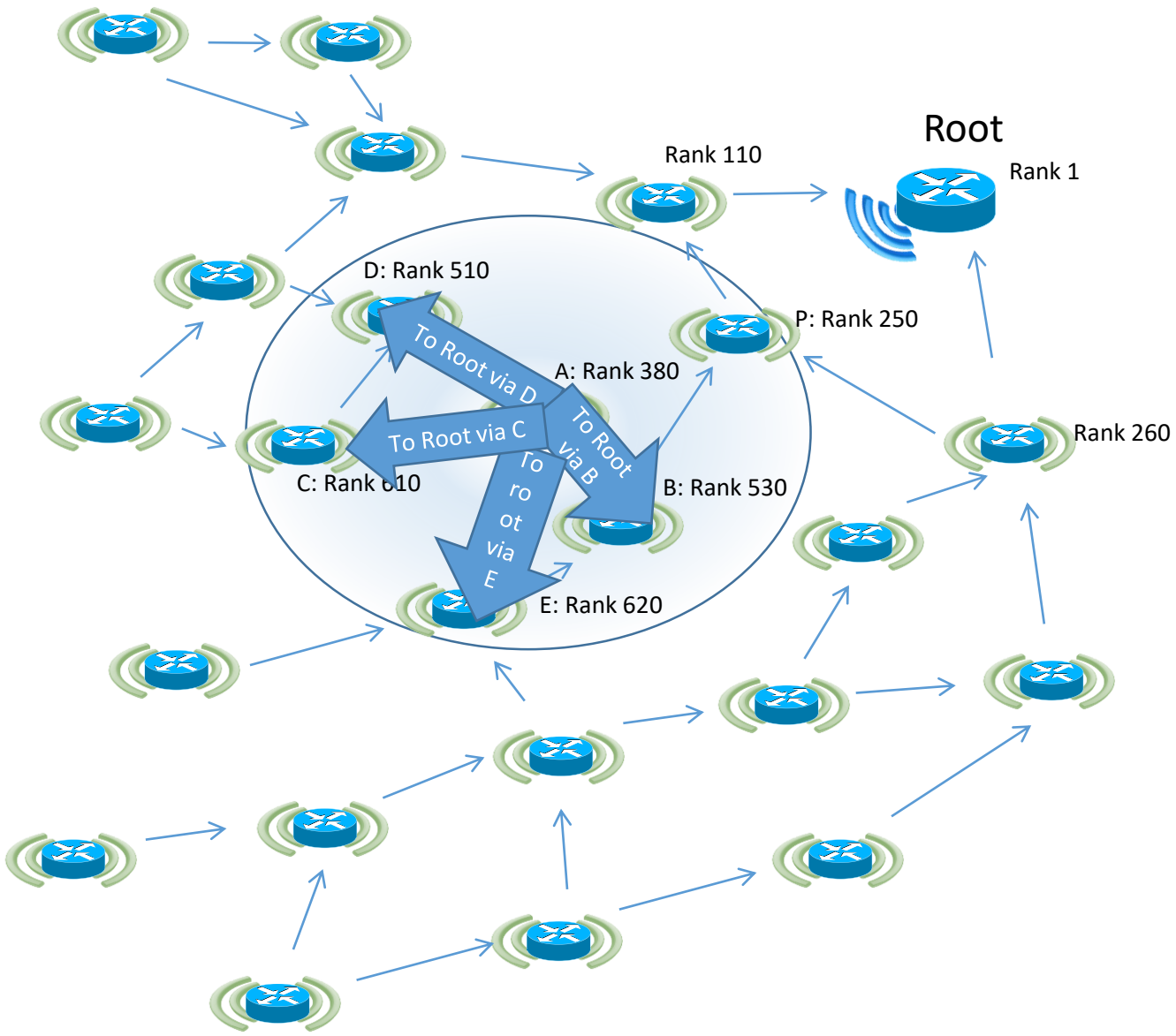
A selects a number if neighbors as prospective parents.

(Optional) We create a new RPI flag for loop detection.

A sends packets using them randomly setting its Rank in RPI to OxFFFF, and sets a new RPI "P" flag. (Alt is set rank to 0xFFFE)

A node that receives a packet with RPI "P" flag from a parent returns it with the RPI "F" flag set, indicating forwarding error and A removes it from the prospective parents. Alt, it may forward via another parent.

During that period, A destroys any packet coming back with the RPI "P" flag on.



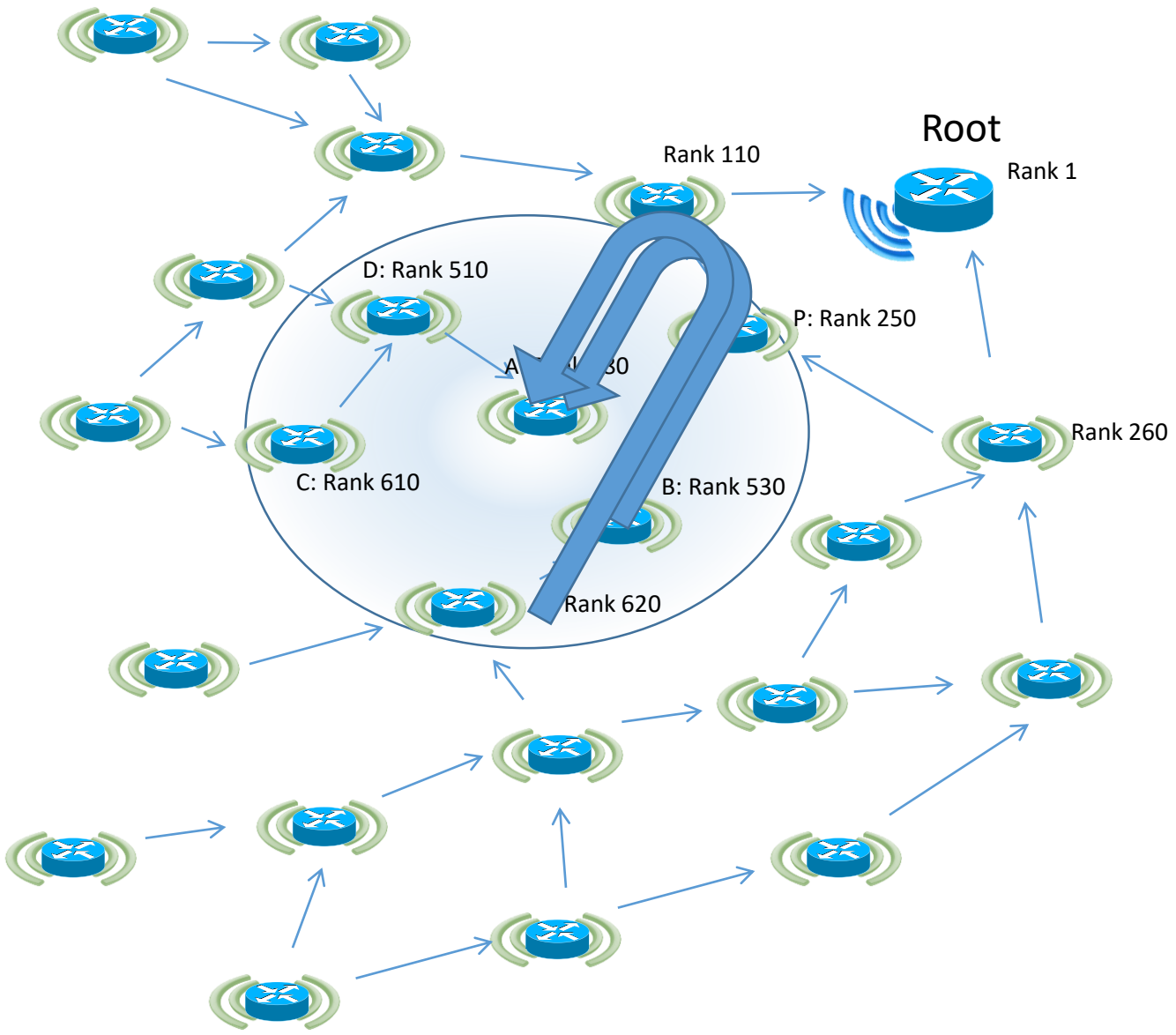
Proposal use the datapath to select a parent faster:

A selects a number if neighbors as prospective parents.

We create a new OAM which allows A to “ping” the Poot. The packet indicates the selected parent.

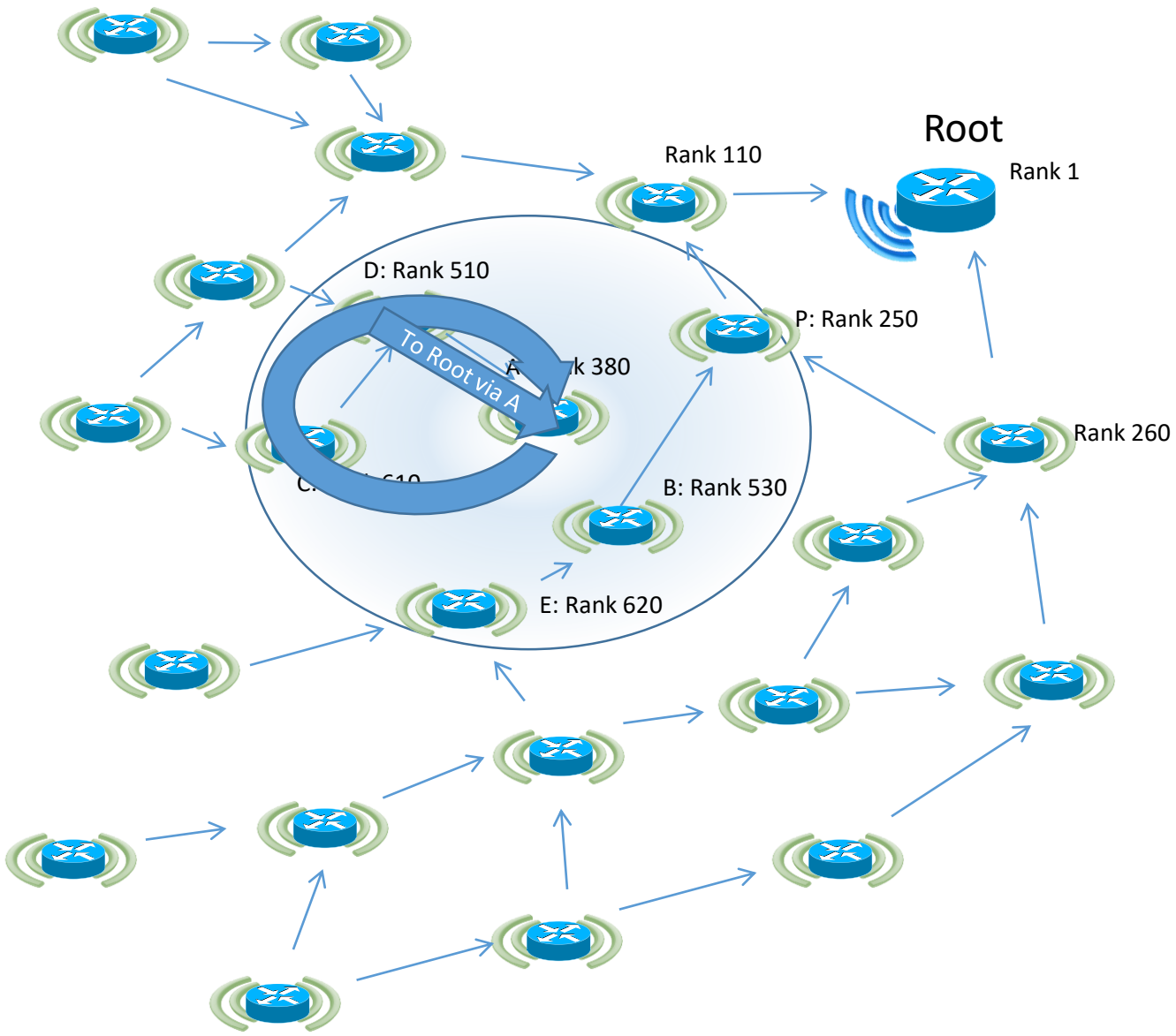
(Optional) The nodes that forward the packet add their IP address as a trace root

A sends a version of that packet unicast to all the selected neighbors



The messages that are responded by the root contain feasible successors. Getting that back may be slow.

A picks them as they come, keeping the best so far as preferred parent



Loops will cause the packet to come back to A.

A recognizes them (e.g. source address is A, a new flag in RPI), and eliminates the neighbor indicated in the packet from the potential parents

Fast Reroute for RPL

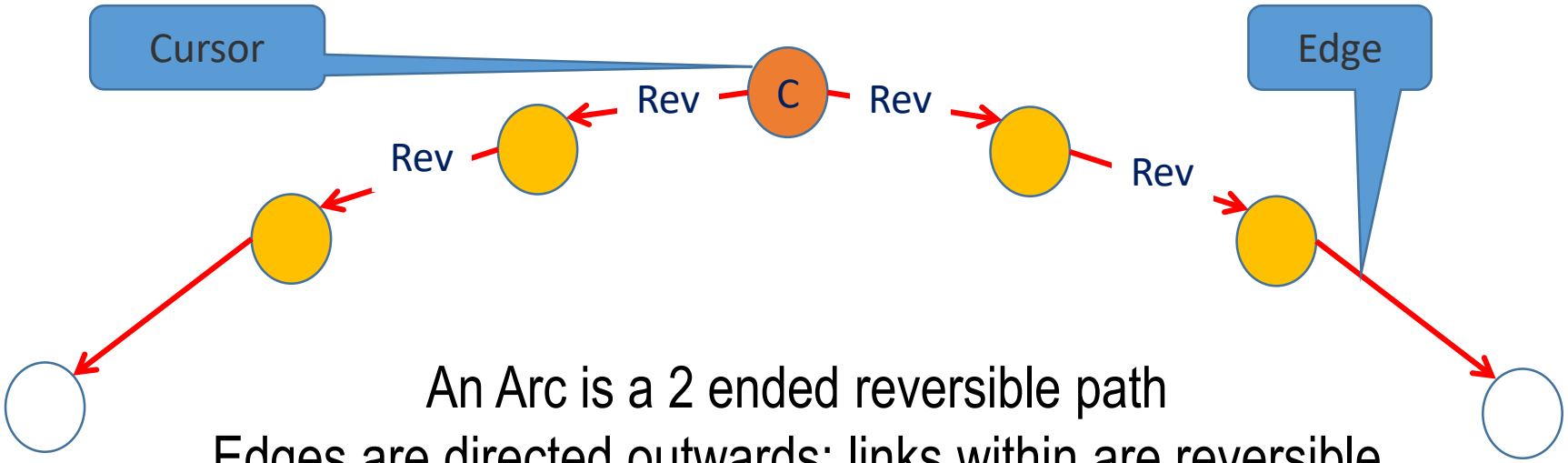
Using central computation for non-congruent routes to root

Pascal Thubert

IETF 100

Singapore, November 2017

Arc concept



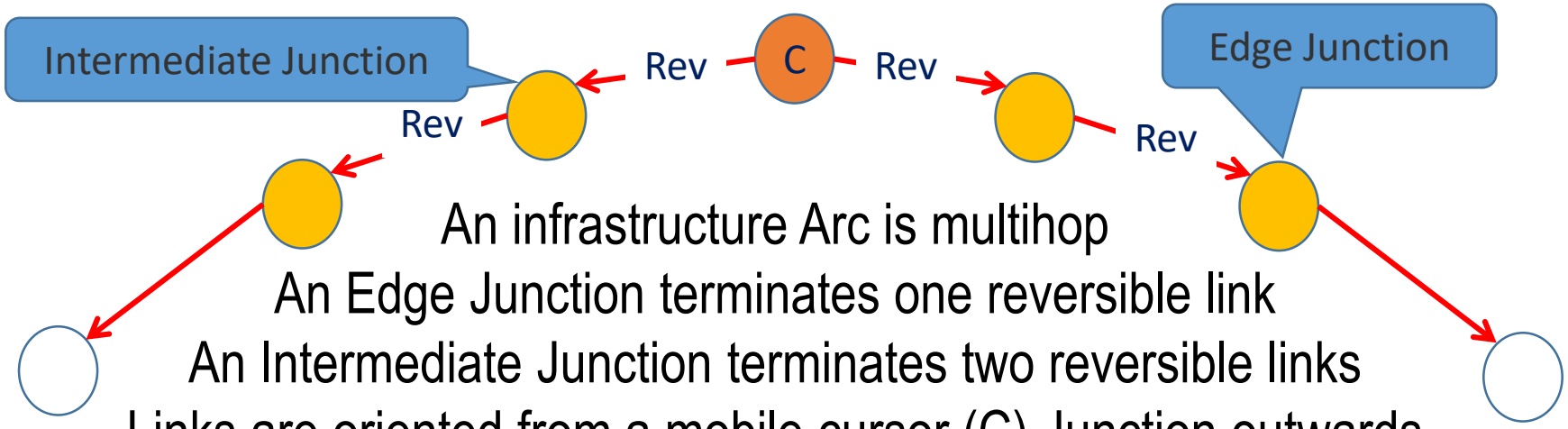
An Arc is a 2 ended reversible path

Edges are directed outwards; links within are reversible

An arc is resilient to any link or Junction break by returning links

Links are oriented from cursor to edges and returned by moving the cursor.

Arc concept (cont'd)

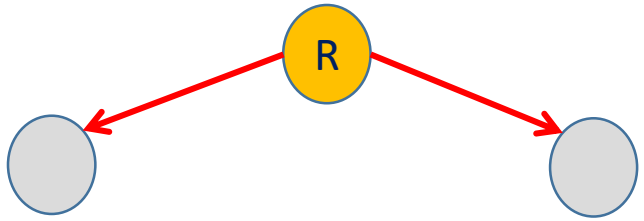


An infrastructure Arc is multihop

An Edge Junction terminates one reversible link

An Intermediate Junction terminates two reversible links

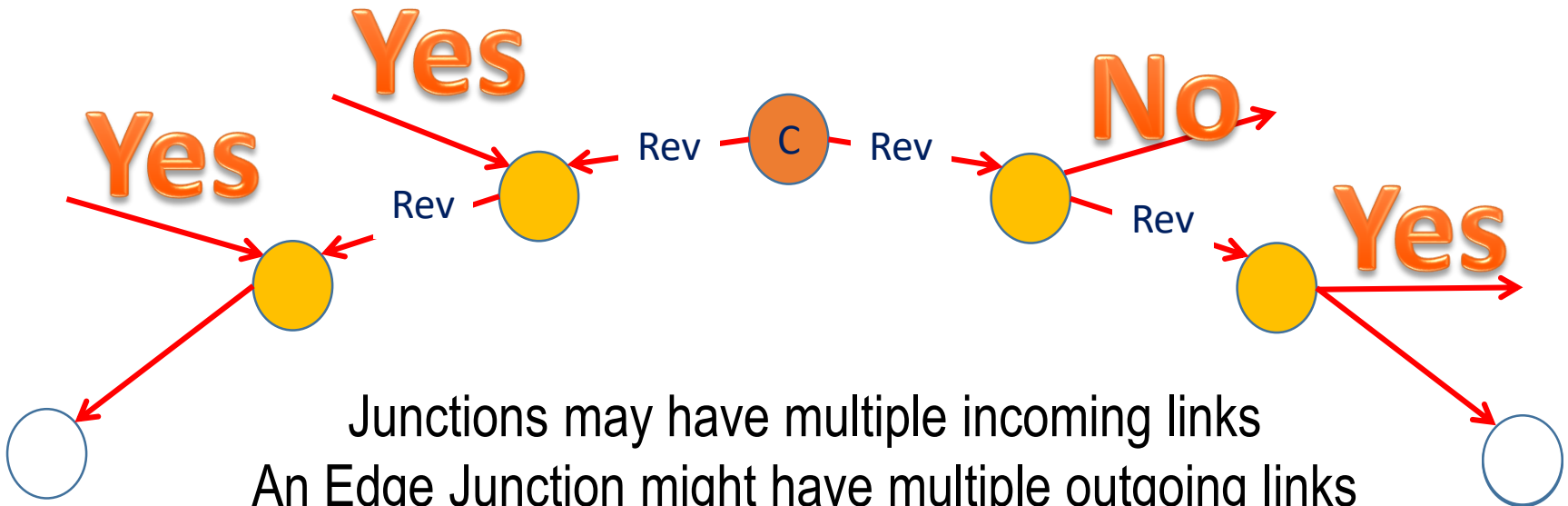
Links are oriented from a mobile cursor (C) Junction outwards



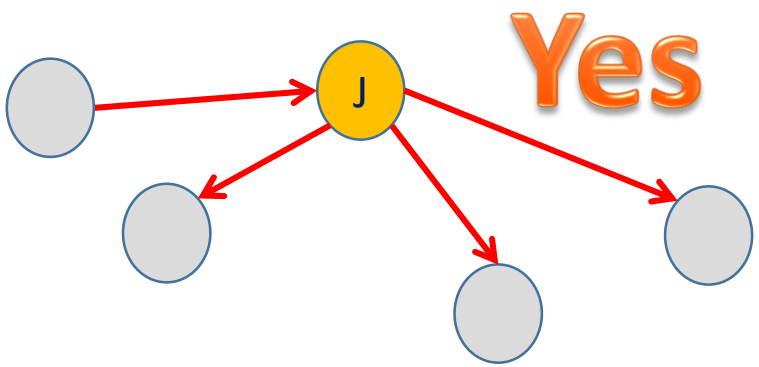
A collapsed Arc does not have an Intermediate Junction

An Edge Junction may belong to multiple collapsed Arcs

Arc concept (cont'd)



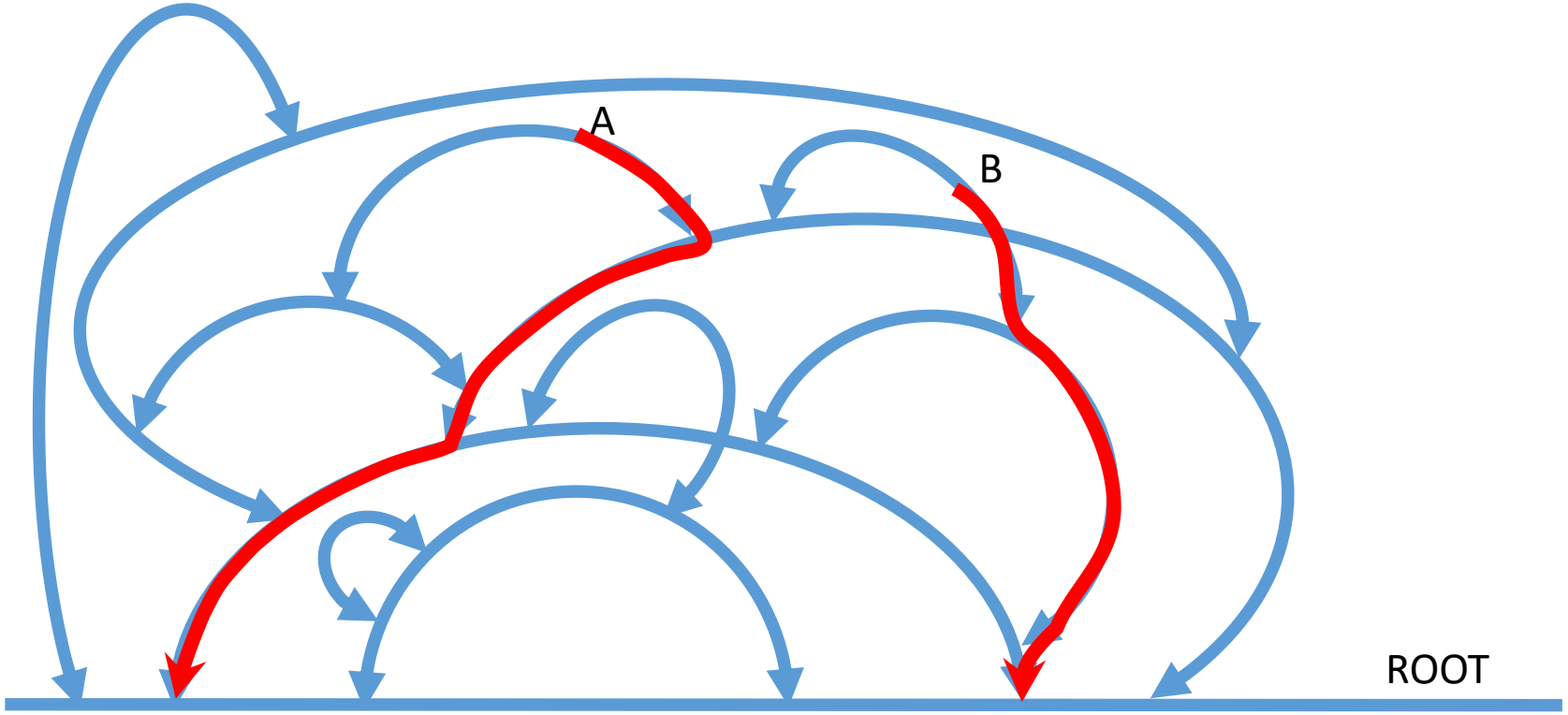
Junctions may have multiple incoming links
An Edge Junction might have multiple outgoing links
An intermediate Junction has no outgoing link but along the Arc



Software-defined Projected ARROW

Arcs for RPL Routing Over Wireless

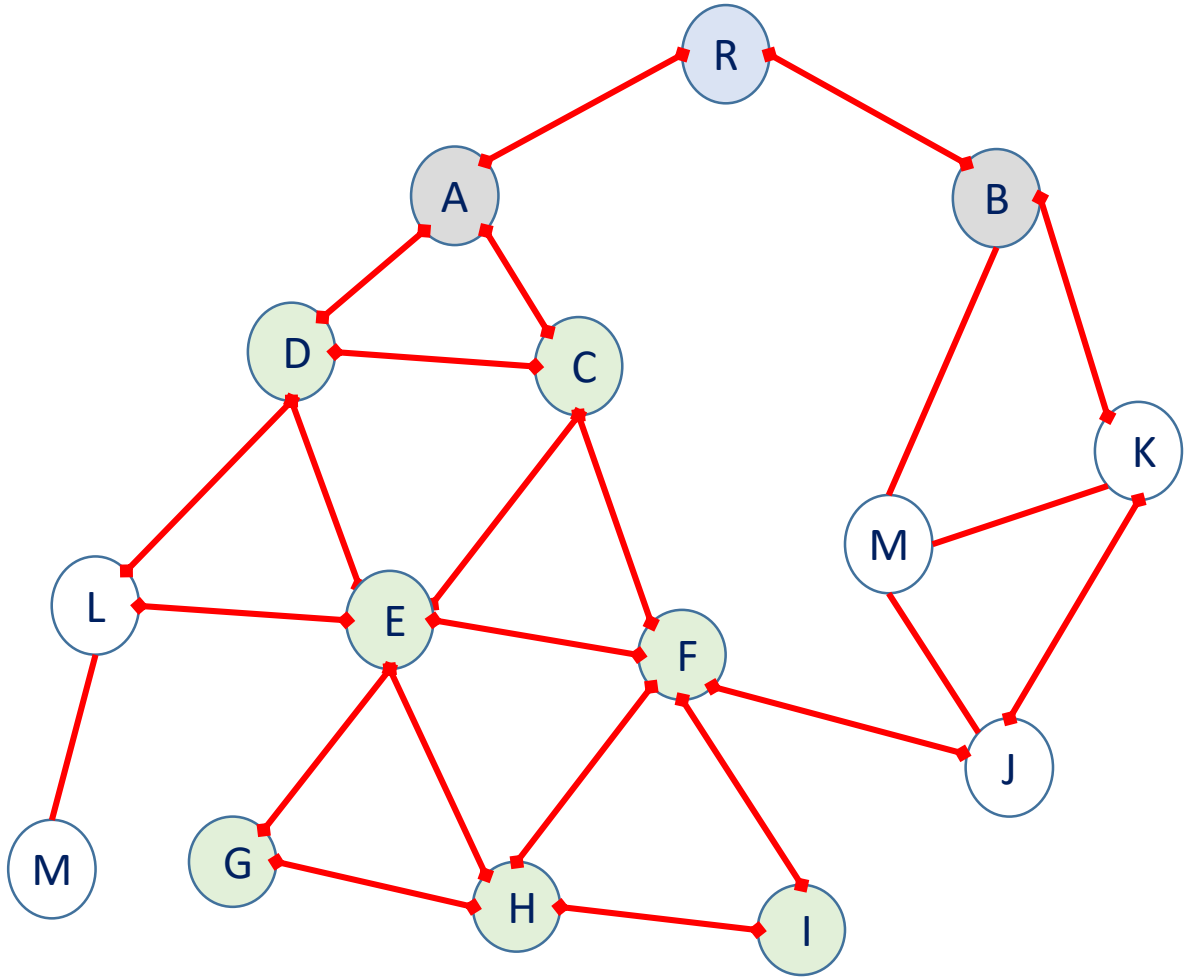
- Metrics are accumulated as usual in RPL (separated from Rank)
- Siblings are allowed (all ARC members have the same Rank)
- Rank of ARC members defines ARC height



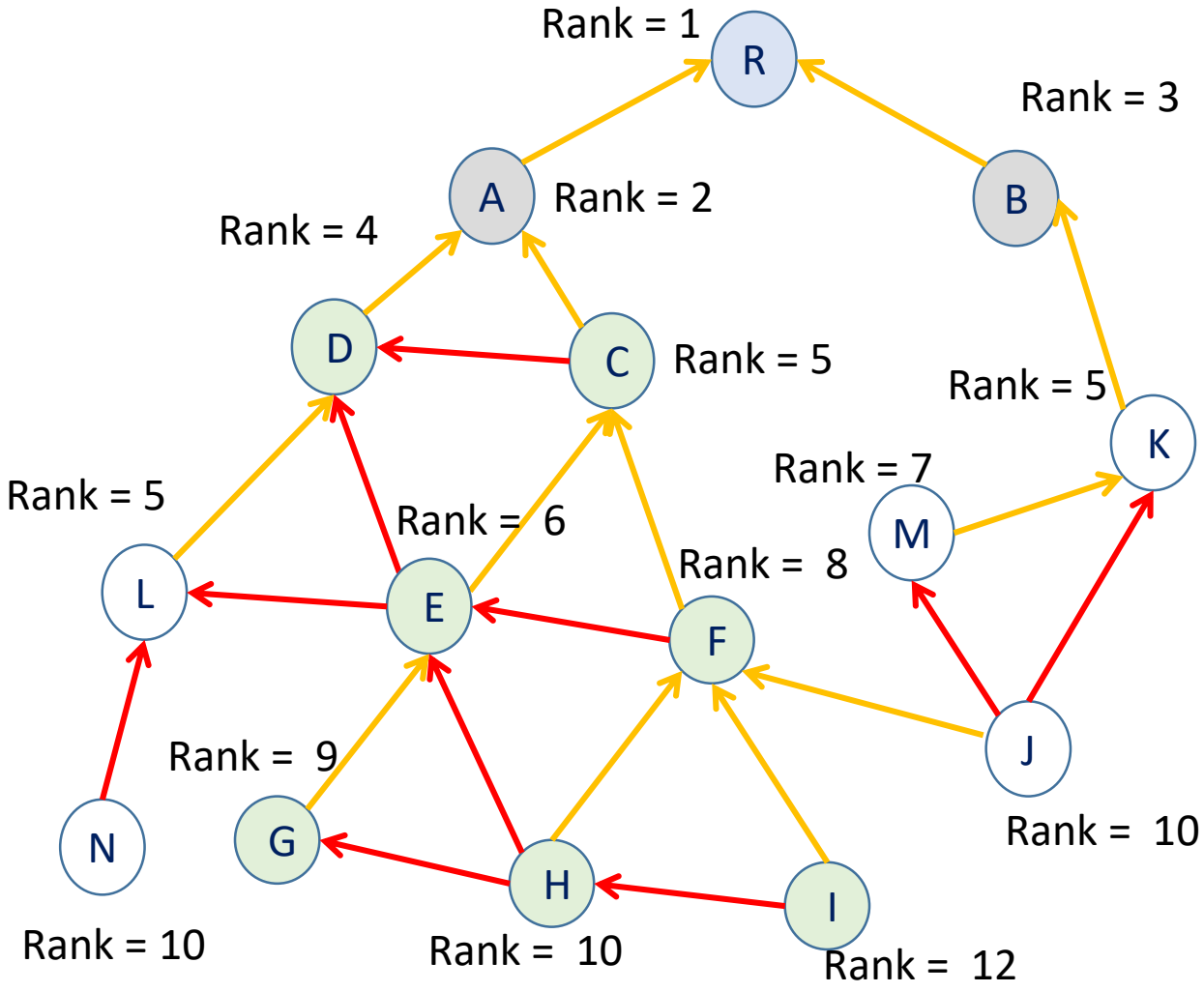
Conditions on RPL operation

- Sparrow requires non-storing mode (NS-mode).
- Nodes must advertise at least 2 parents and report metrics
- Root computes ARC Set based on NS-mode DAO
- Need to update DAO projection to enable inverting parent->child links

ARROW Example: Initial topology



Say standard RPL gives:



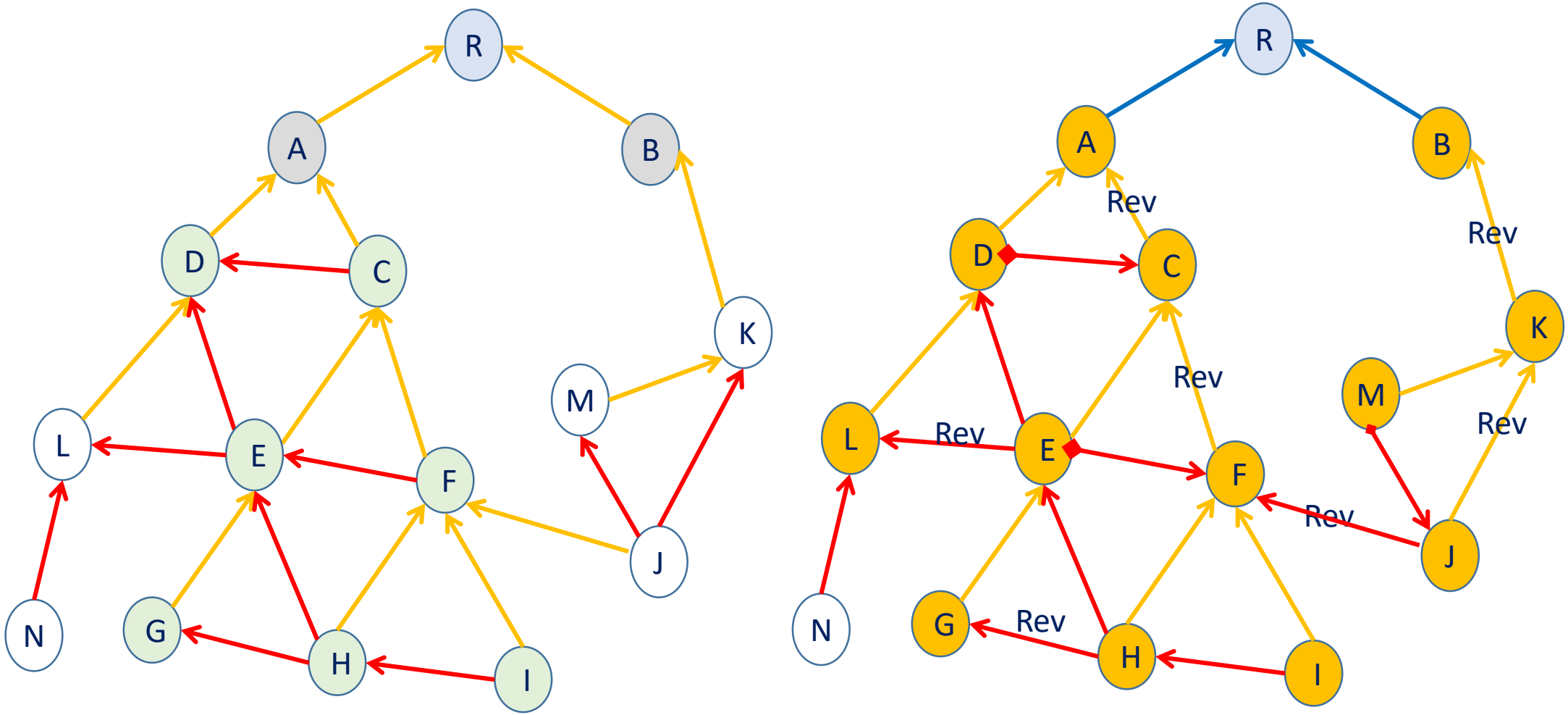
In blue the preferred parent path

In red the alt path as RPL computes them based on Rank relationship.

These « arrows » are advertised to the root using NS-Mode

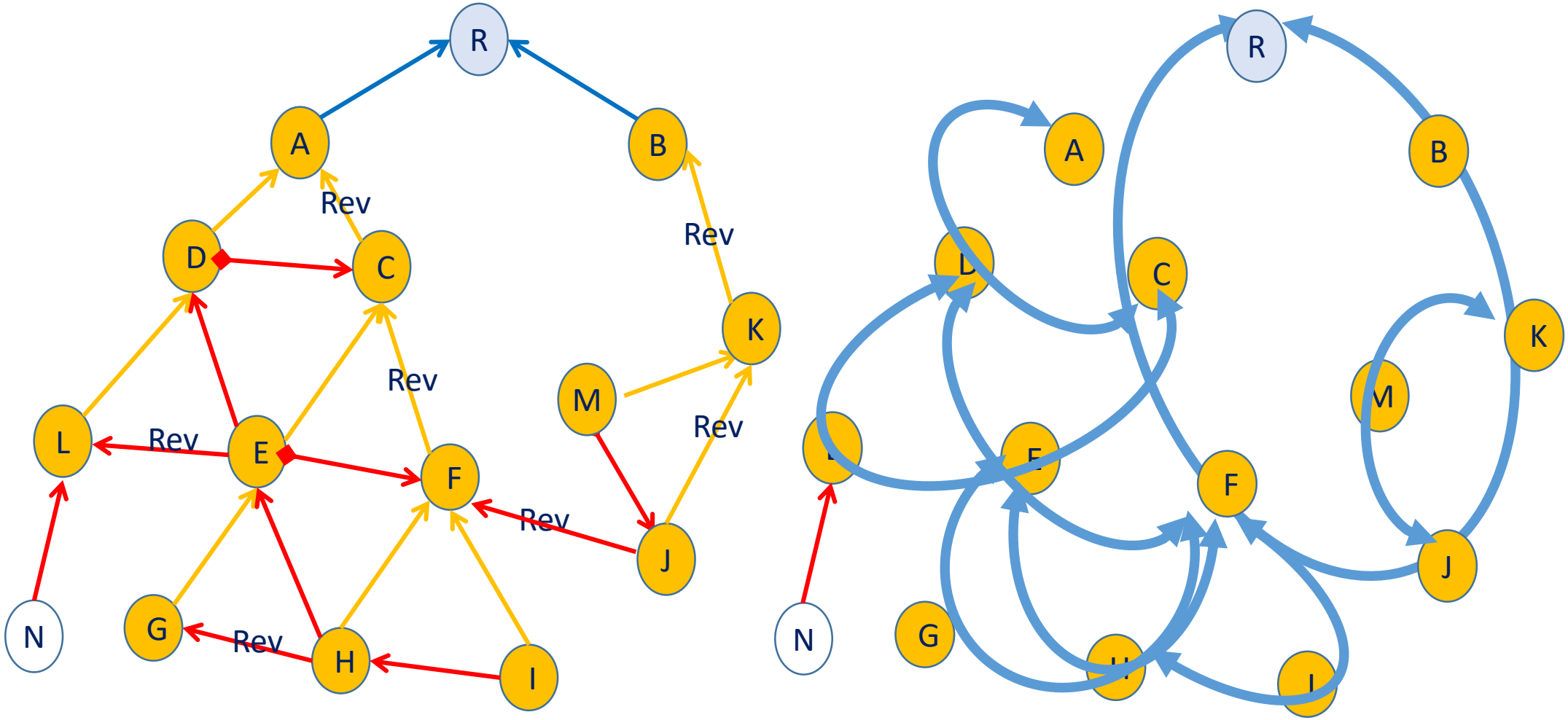
We see that most nodes do not have 2 non-congruent solutions
(in fact, only J does!)

Result of the ARC algorithm:



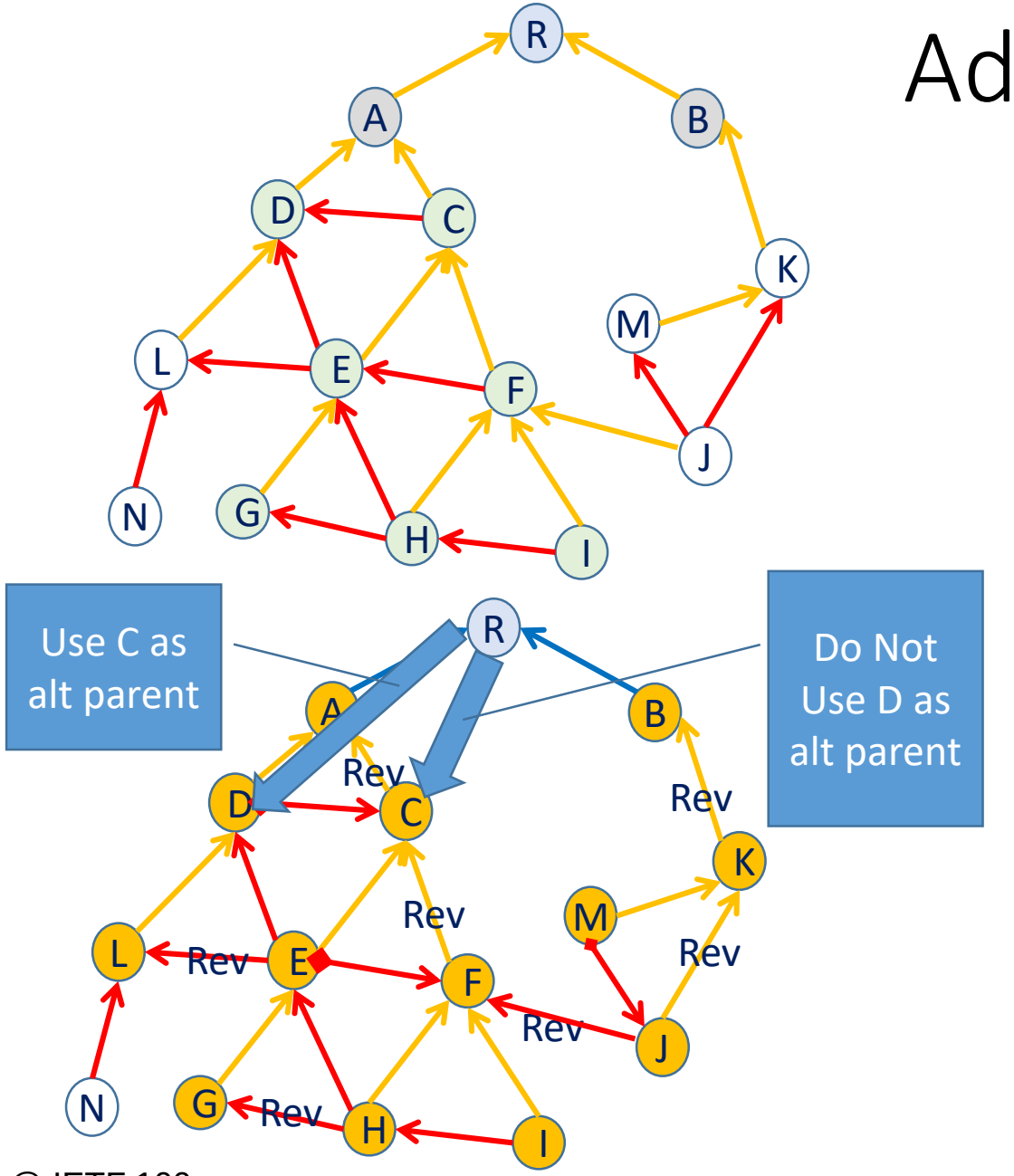
Original RPL DAG ➔ ARC Re-organized DAG

Result of the algorithm:



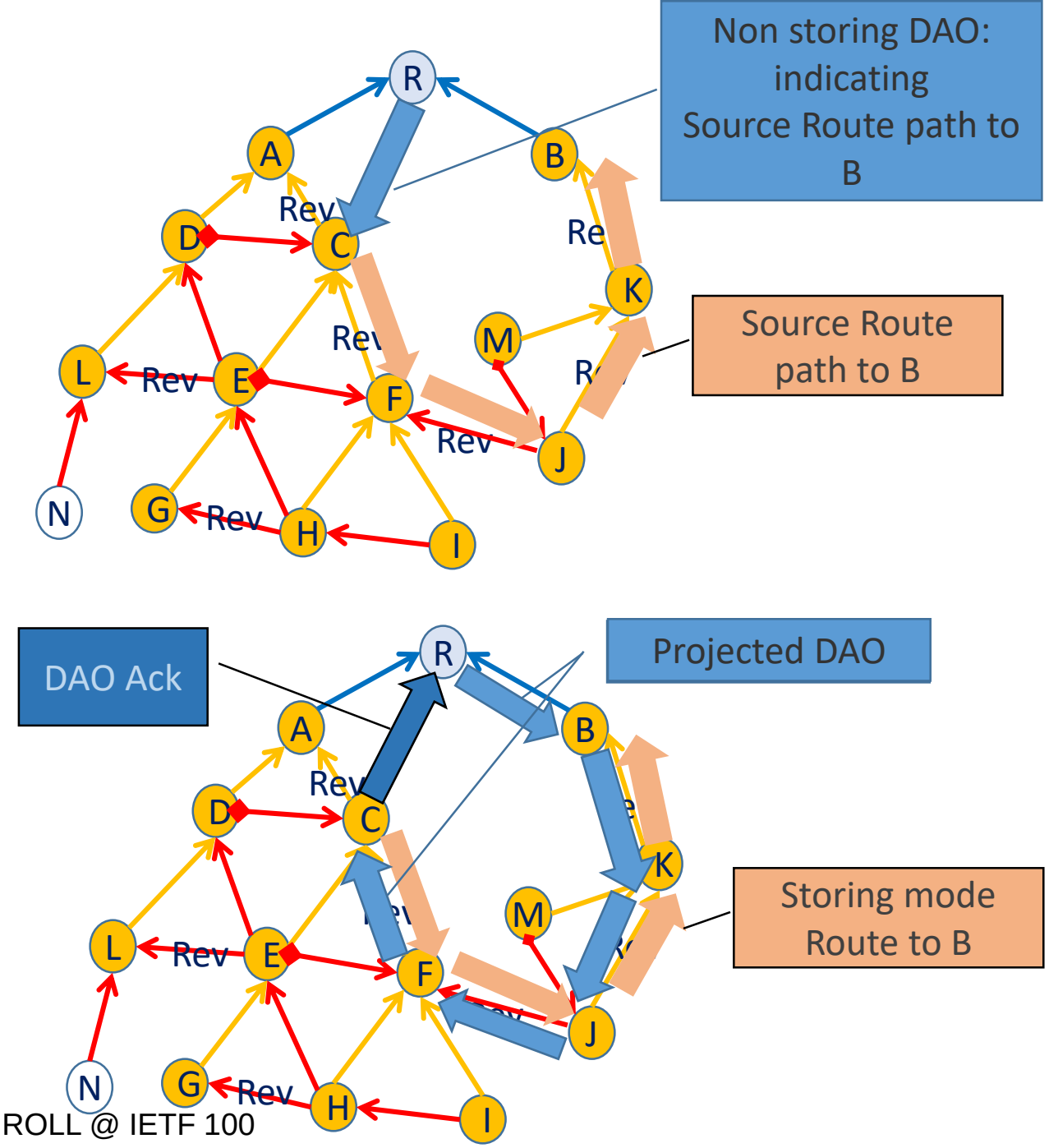
DAG visualization == ARC visualization

Adapting to RPL



1) Root considers changes made on DODAG and notifies nodes, e.g. it tells C that D is not more a feasible successor and it tells D that C is a feasible successor. Same goes between E and F. This can be done with a novel variation of the DAO projection
2) For collapsed ARCs, e.g. D, we are all set
3) For other nodes that are not on collased ARCs, the root computes a path along the ARC towards the other exit of the ARC. For Node C that is Node B.

Cont…



1) The path to B is installed as either storing or non storing projected DAO
2) In NS Mode the source route path from the node to the other ARC edge is indicated to each node
3) In Storing Mode, a route is created from both ends of the ARC allowing each edge (a,d all nodes in between) to route to the other edge
4) If C loses connectivity to A, it uses a tunnel to B till RPL completes local repair. Tunnel has a routing header in NS mode.
5) When the Edge decaps, it must forward outside the ARC; it cannot reinject in the ARC.

AOB?

THANKS!