G3-PLC Alliance

Enabling the smartest grid...together

Welcome to today's technical webinar!

Enhancements for dense G3-PLC networks

G3-PLC Alliance
October 13th 2021

Today's presenters

Cédric Lavenu
EDF R&D and leading G3-PLC Technical Working Group
cedric-2.lavenu@edf.fr

Matteo Varesio
STMicroelectronics
matteo.varesio@st.com

Kevin Jones
Renesas
kevin.jones@renesas.com

Greg Tseng
Vertexcom
greg.tseng@vertexcom.com

Leon Vergeer
General Secretary of the G3-PLC Alliance
leon.vergeer@g3-plc.com

Agenda

1. **Introduction and challenges in dense network routing**
2. Enhanced routing with RREQ jittering
3. Enhanced data broadcast mechanism using the trickle algorithm
4. Enhanced RREQ broadcast mechanism using the trickle algorithm
5. Questions & Answers

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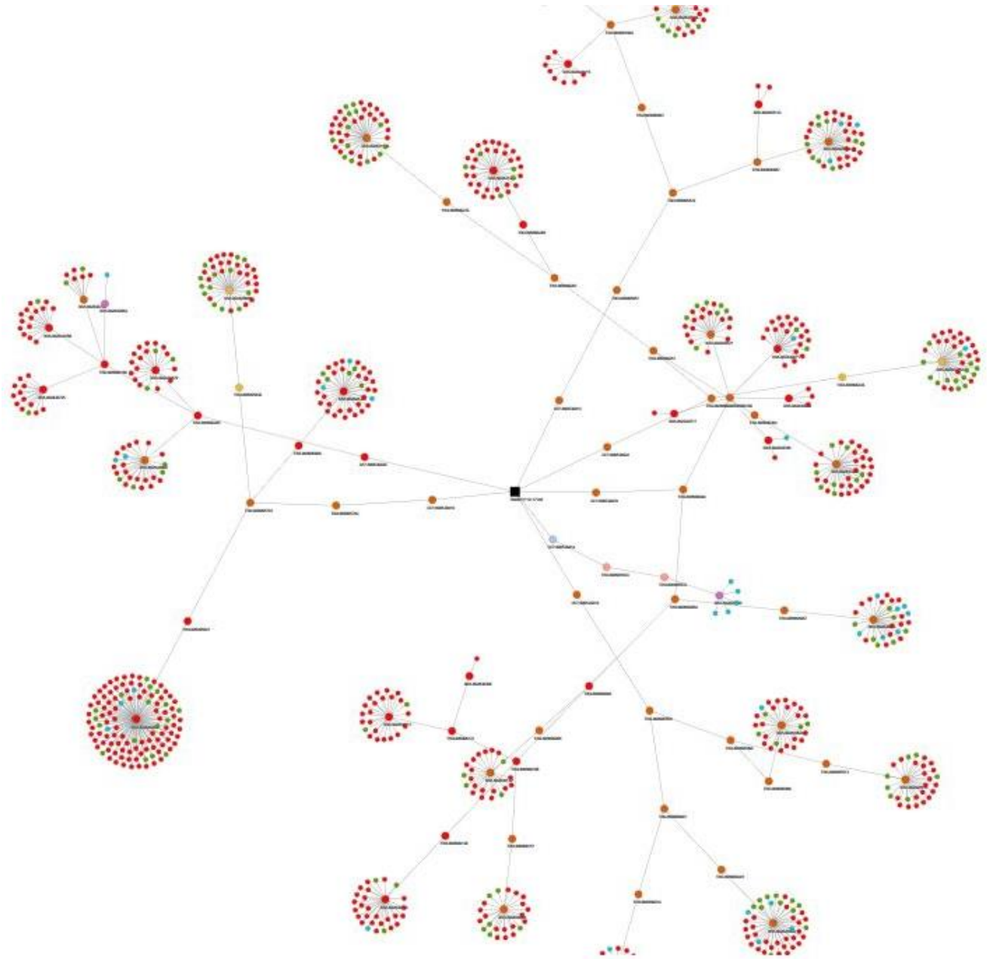
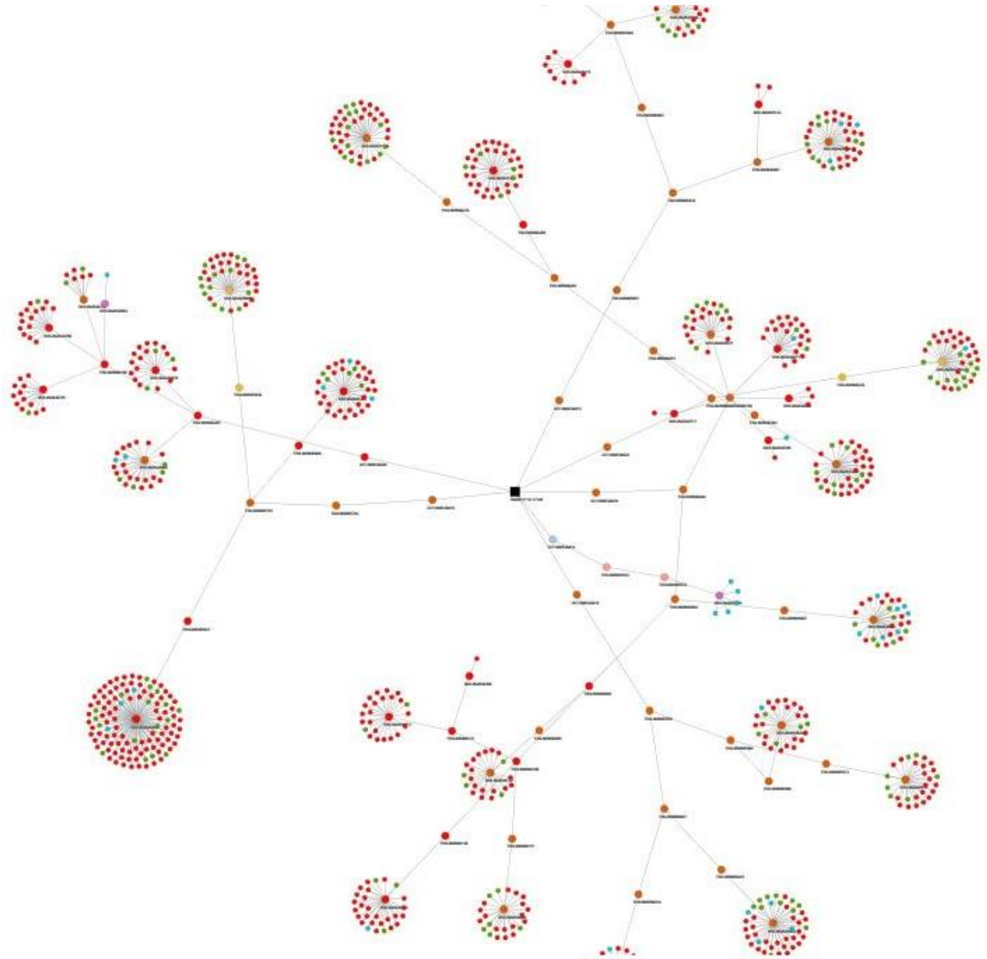
What is a dense network ?

- Experience shows that when G3-PLC is operated in networks with **more than 300 or 400 nodes**, specific behaviours can be observed



What is a dense network ?

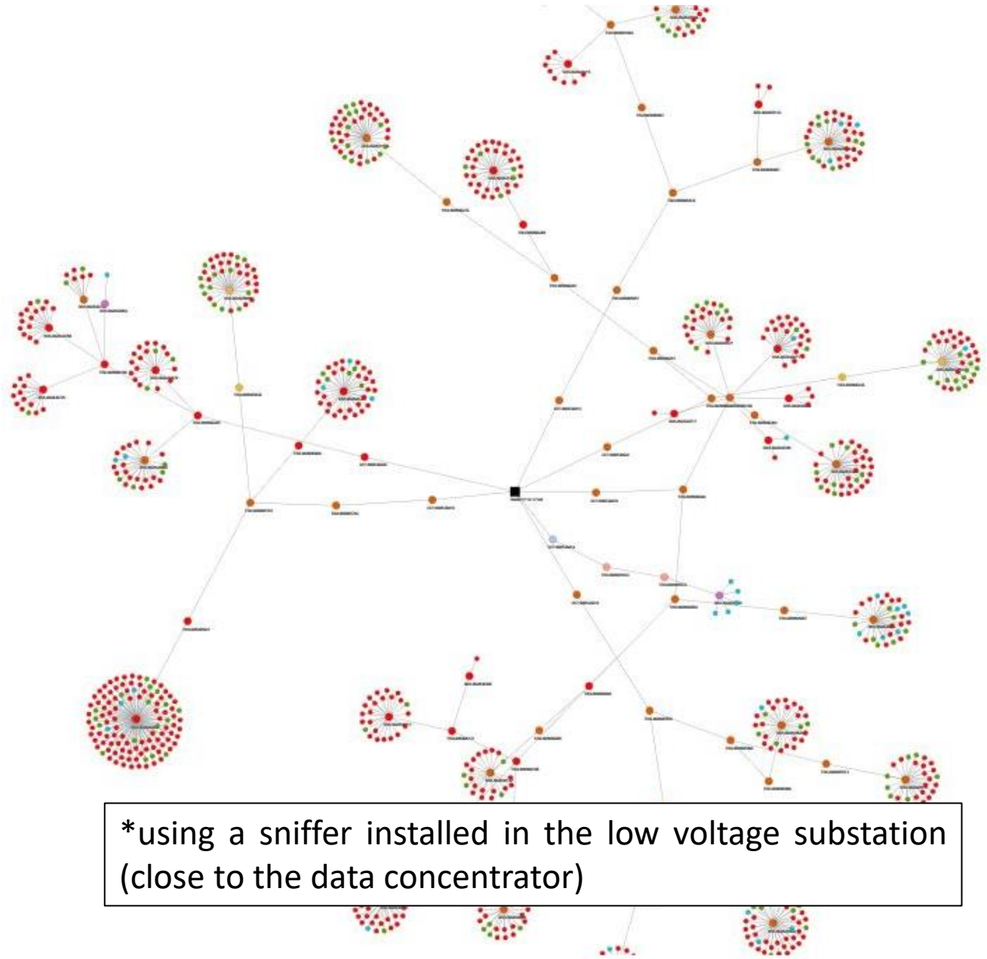
- Experience shows that when G3-PLC is operated in networks with **more than 300 or 400 nodes**, specific behaviours can be observed
- **In dense networks, it is easier to reach the capacity limit when the application traffic increases**



What is a dense network ?

- Experience shows that when G3-PLC is operated in networks with **more than 300 or 400 nodes**, specific behaviours can be observed
- **In dense networks, it is easier to reach the capacity limit when the application traffic increases**
- **Observations in a real 800-node* network show that more than 50% of the packets captured are LOADng broadcast messages**

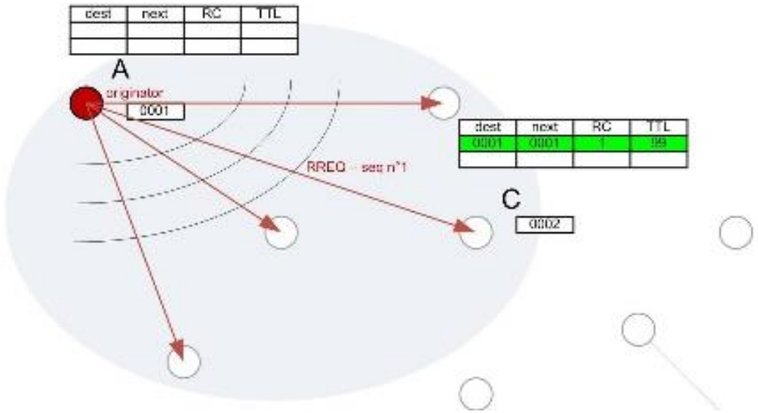
Type of Traffic	Percentage of Packets Received
(MAC) Beacon	<1%
(MAC) Tone Map Response	8%
(6LoWPAN) LOADng RREQ	53%
(6LoWPAN) LOADng RREP and RERR	32%
(6LoWPAN) LOADng PREQ and PREP	1%
(6LoWPAN) Boostrapping	2%
(Application layer) DLMS/COSEM	3%

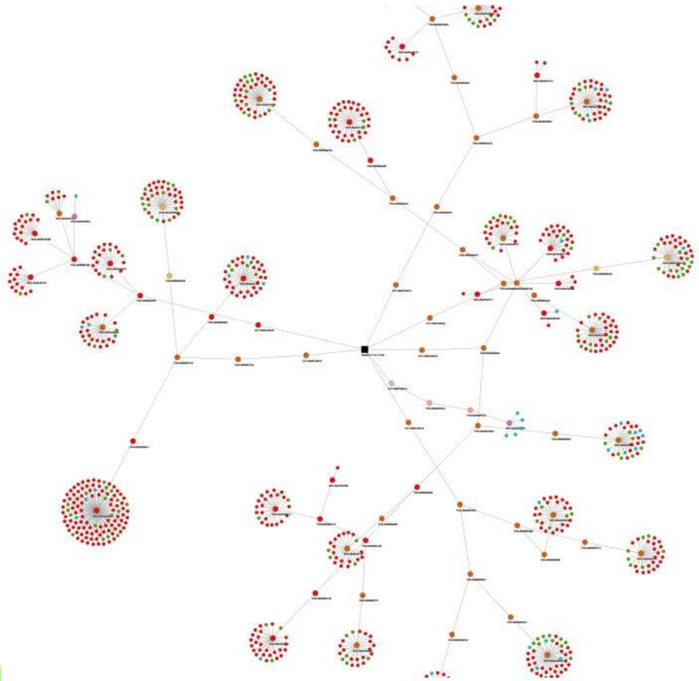


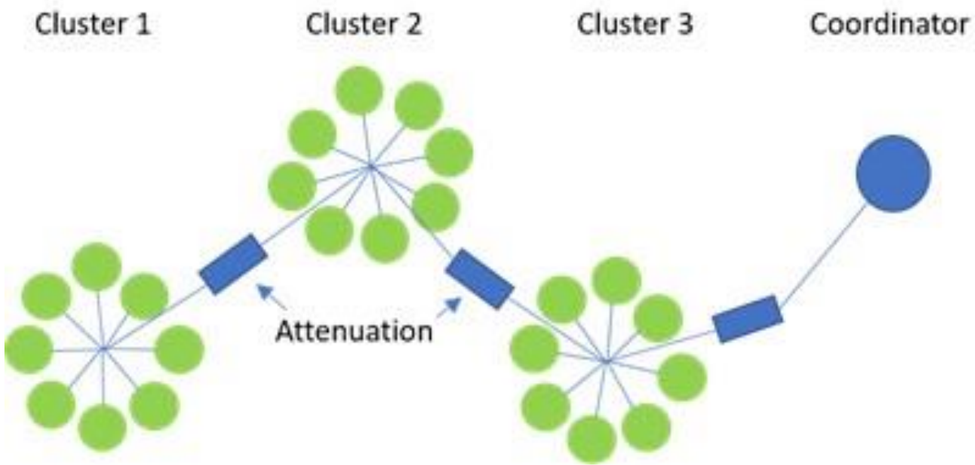
*using a sniffer installed in the low voltage substation (close to the data concentrator)

There is room for improvement !

- **Compared to the « basic » flooding operation, RREQ forwarding can be optimized:**
  - Only the packets maximizing the chances to build routes over stable links shall be forwarded
  - All nodes within the same neighbourhood (cluster) do not need to repeat the same RREQ packet







There is room for improvement !

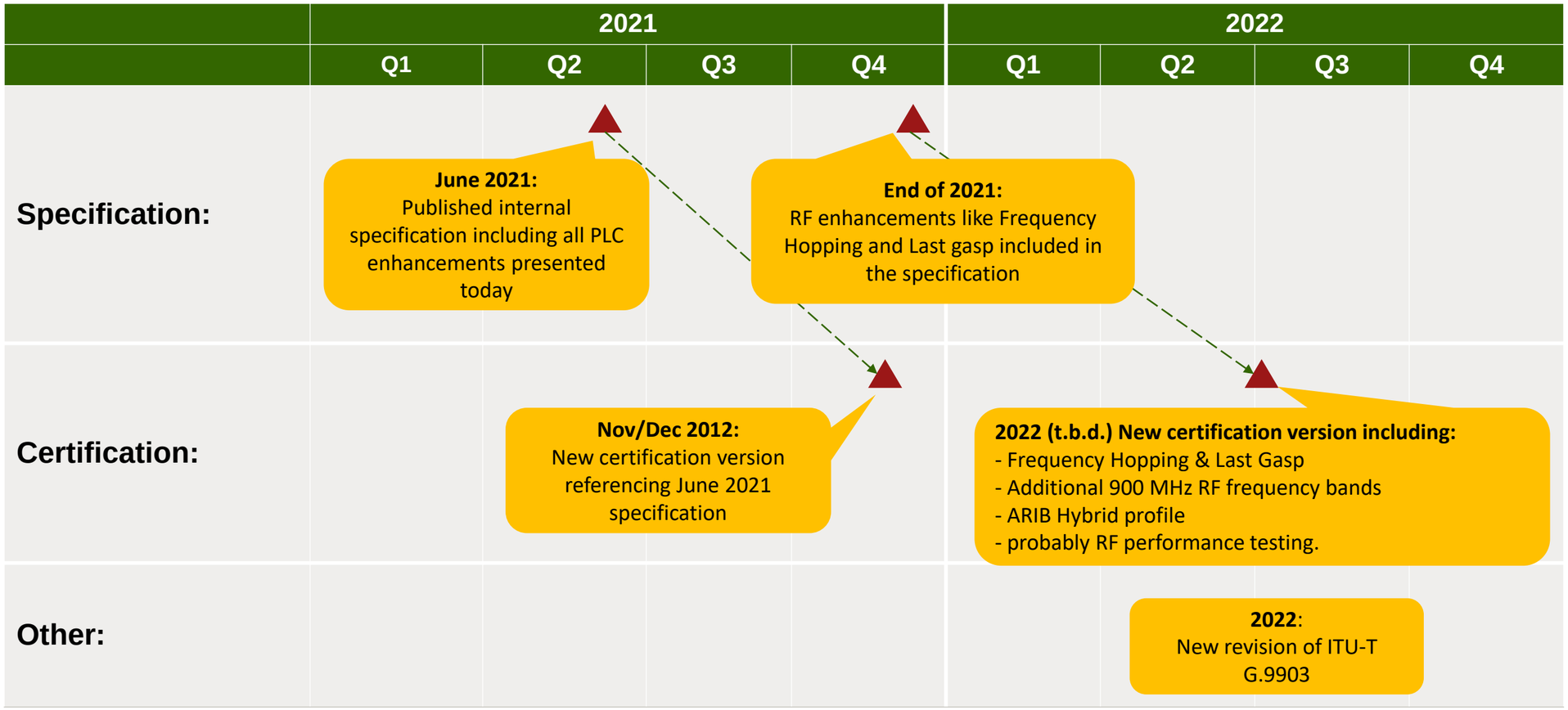
- **Compared to the « basic » flooding operation, RREQ forwarding can be optimized:**
  - Only the packets maximizing the chances to build routes over stable links shall be forwarded
  - All nodes within the same neighbourhood (cluster) do not need to repeat the same RREQ packet
- **Some similar principles can be applied to the G3-PLC data broadcast mechanism as well**
  - According to 2017 G3-PLC specifications each node in the network receiving a broadcast frame shall forward it once

Table 9-32 – Broadcast log table entry

Field	Length	Description
Source Address	16 bits	The 16-bit source address of a broadcast packet. This is the address of the broadcast initiator.
Sequence Number	8 bits	The sequence number contained in the BC0 header.
Valid Time	16 bits	Remaining time in minutes until when this entry in the broadcast log table is considered valid.

G3-PLC Specification and certification roadmap

Indicative release planning 2021 - 2022



Next to that, the technical working group is working on several other topics:

- possible improvements in FCC band for PLC
- Working with DLMS to update COSEM Interface Classes reflecting the ITU-T publications
- Address how to optimally use the existing technology and give guidelines

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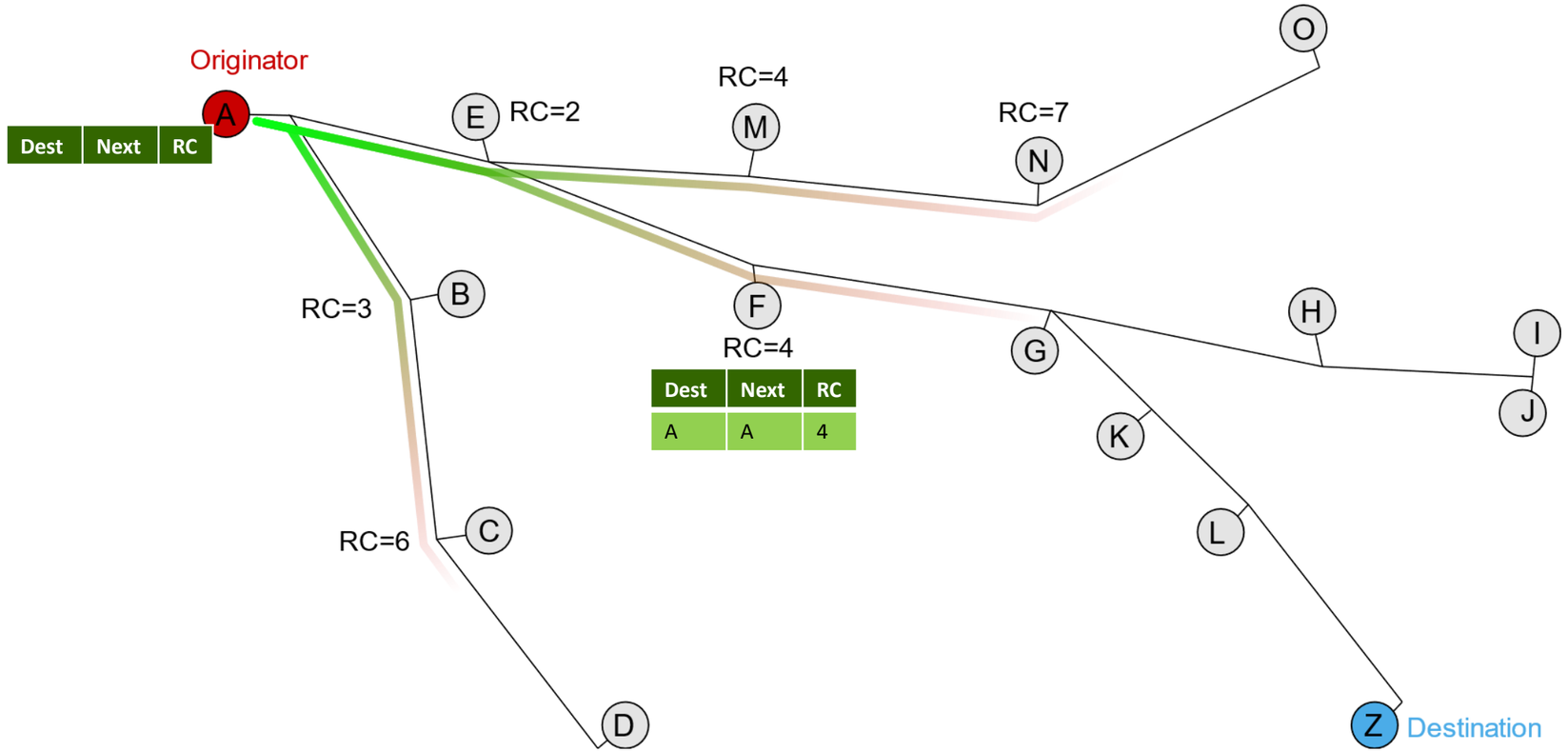
LOADng Routing Algorithm

- **The Lightweight on-demand Ad hoc distance-vector routing protocol – next generation (LOADng)**
  - Annex D of G3-PLC Specifications
- **Reactive protocol**
  - Routes are established only if data has to be sent
- **Control messages : Route Request (RREQ), Route Reply (RREP), Route Error (RERR)**
  - Only the destination can respond to RREQs, even if intermediate nodes have already an active route towards this destination
- **Local repair mechanism**
  - If a link breaks, intermediate nodes intent to repair it locally instead of establishing a whole new route
- **Unidirectional link detection and handling**

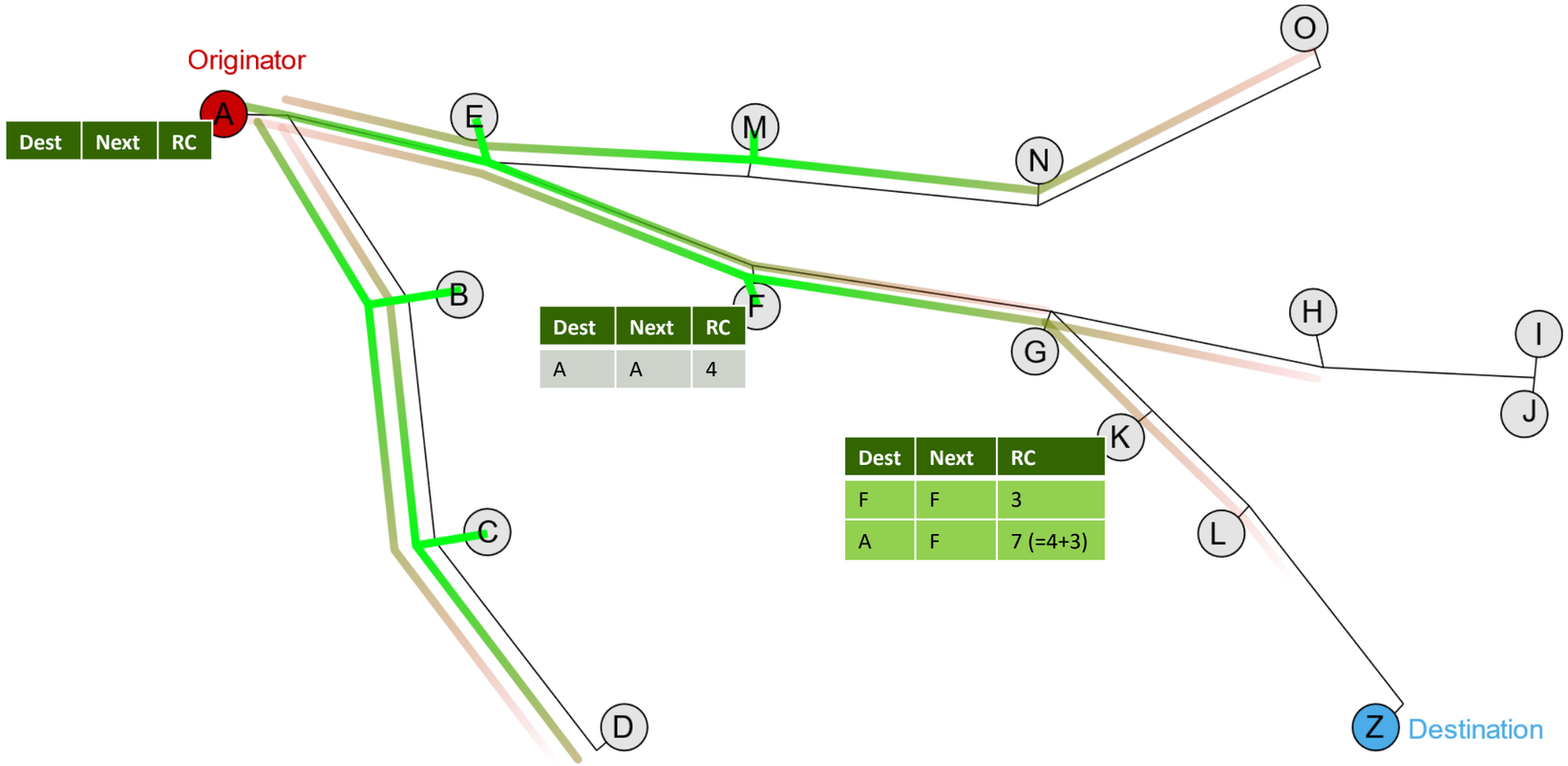
How does LOADng work in G3-PLC?

- Originator **Node A** **broadcast** a **RREQ** towards destination **node Z**
- Nodes receiving the **RREQ** compute the **route-cost** (RC) and stores the reverse route (route toward **node A**)



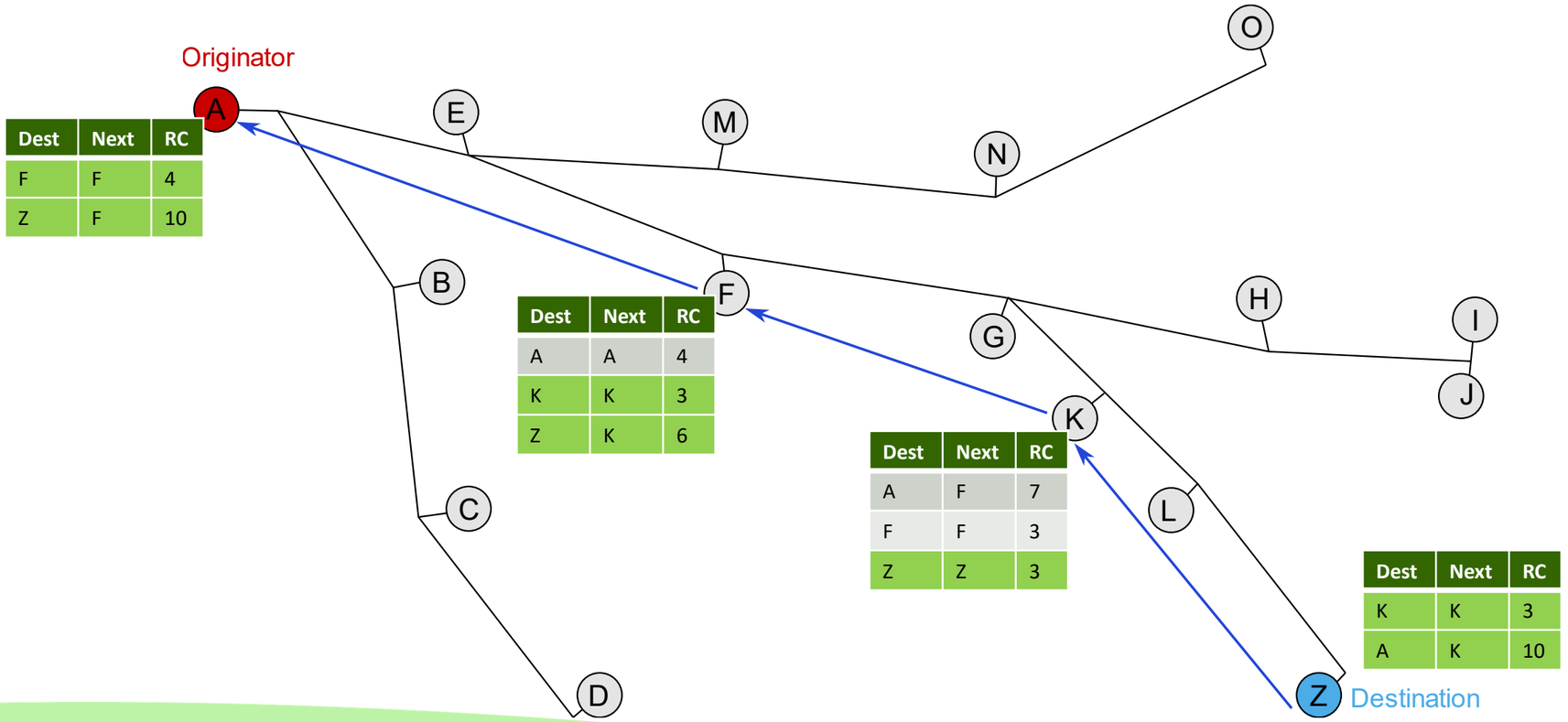
How does LOADng work in G3-PLC?

- Each node propagates the **RREQ**, adding their **route-cost** in the propagated message
- If a **RREQ** is received with a higher **route-cost** than a previous one, it is discarded



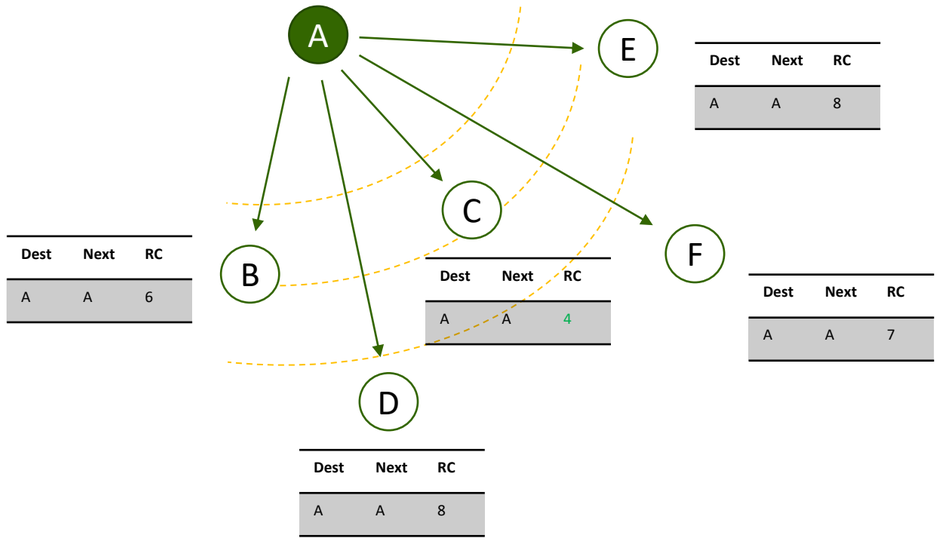
How does LOADng work in G3-PLC?

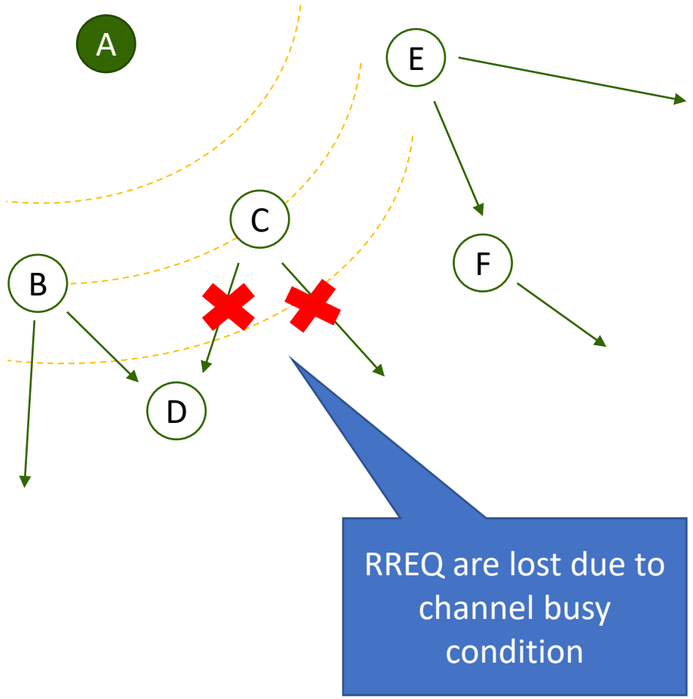
- After receiving several **RREQs** (propagated along different paths), **Node Z** choose the best route towards **node A** according to the routing metric
- **Node Z** sends a **RREP** in **unicast** toward **node A**, along the selected path
- Each node in the path propagate the **RREP** and populate its **routing table** accordingly



LOADng weakness in dense networks

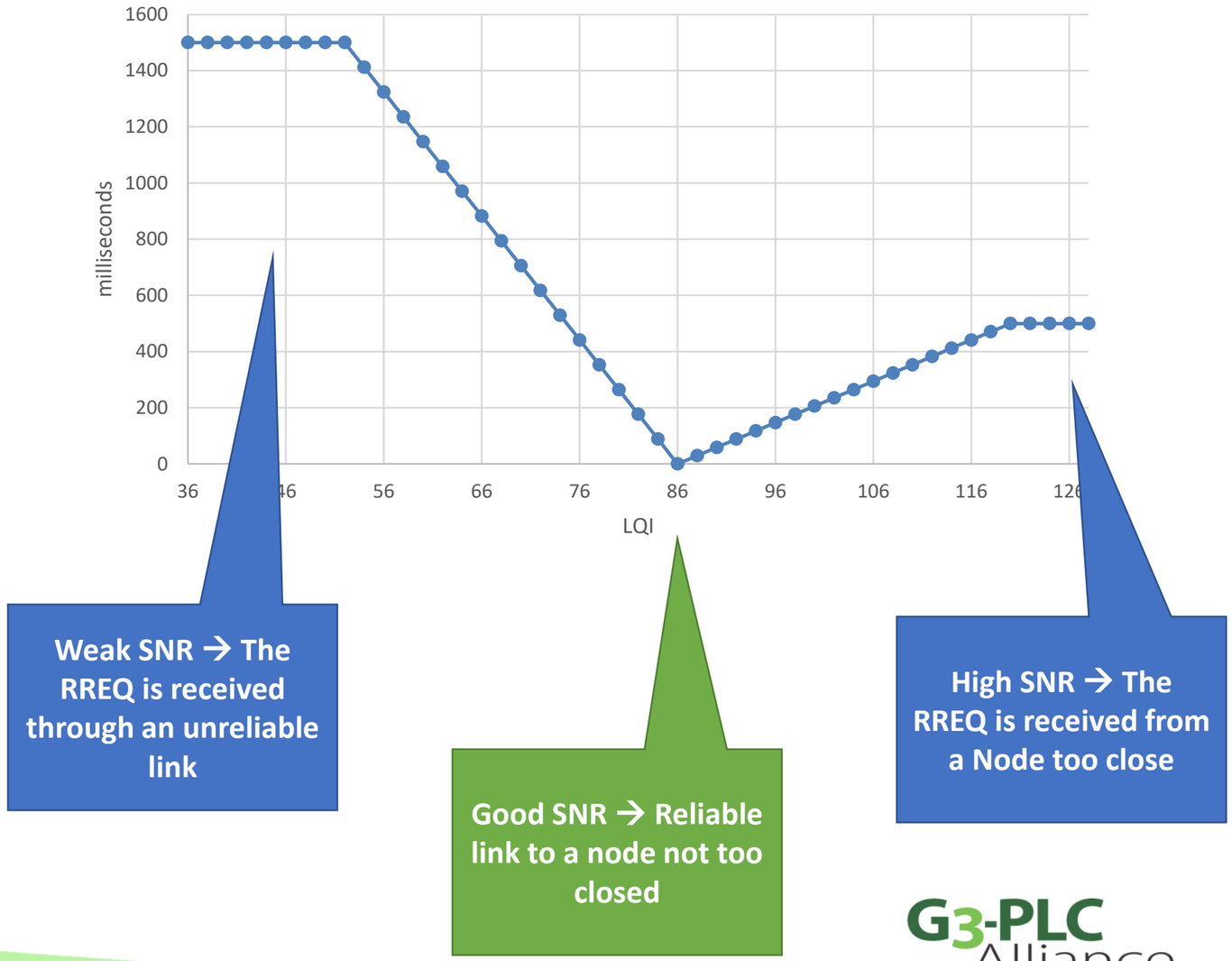
- When RREQ messages are flooded over the network they rely only CSMA/CA access method to be spread over time
- Some RREQs could be afflicted by collisions or could not be transmitted as the channel is busy. **Therefore, some good routes may be lost unexpectedly**





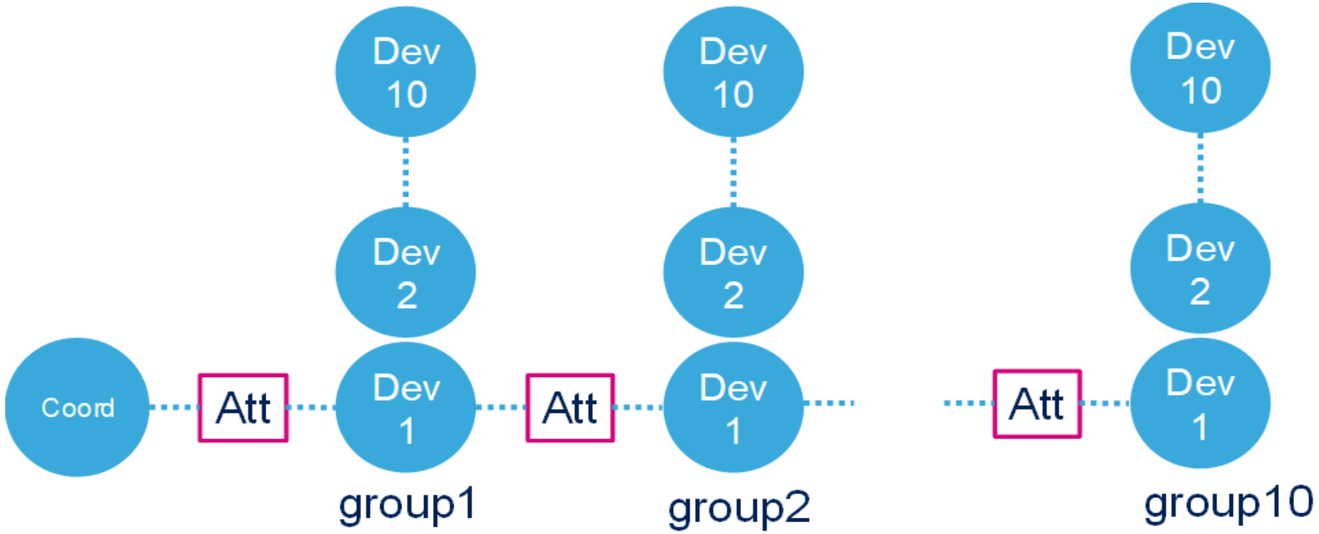
Add controlled jittering in RREQ forwarding

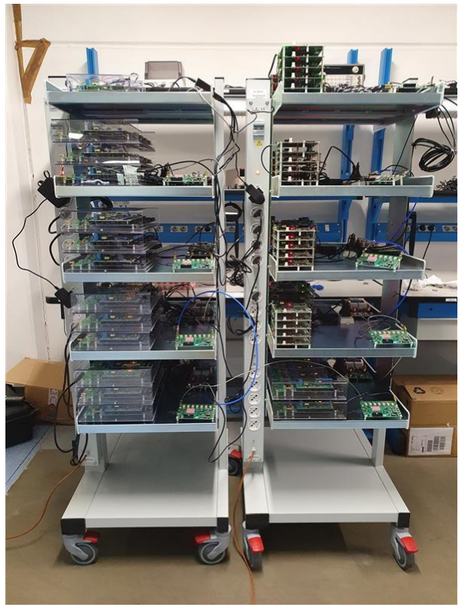
- Apply **controlled jittering** mechanism when forwarding RREQ messages
  - Based on the LQI (SNR) of the received RREQ message
- The intermediate node puts the RREQ message in a queue. **If a new RREQ message with lower RC is received, the original RREQ in the queue is overwritten**
- The goal is to lower the flooding and increase the probability of forwarding only RREQs that may be select-ed by the RREQ destination node



Laboratory test setup

- **Route discovery** from the PAN Coord to all the nodes in the network
- **10 groups** formed of approximately **10 nodes** (total number of 101 nodes)
- Considering three topologies with **0, 10 and 20 dB** attenuations between each group of nodes



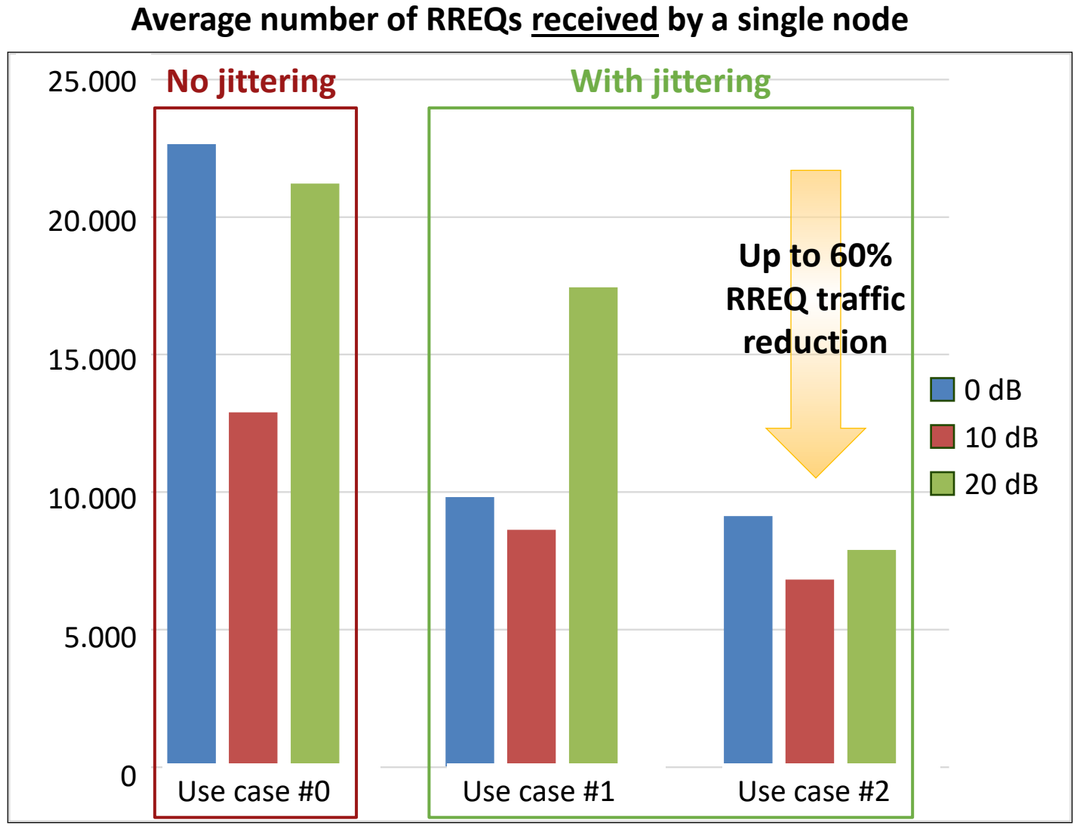


Laboratory test results

Three main use cases have been tested:

- **Use case #0**: no RREQ jittering
- **Use case #1**: jittering with adpLowLQI = 0 and adpHighLQI = 255
- **Use case #2**: jittering with adpLowLQI = 40 and adpHighLQI = 108

Up to 60% reduction of RREQ traffic reduction



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3. **Enhanced data broadcast mechanism using the trickle algorithm**
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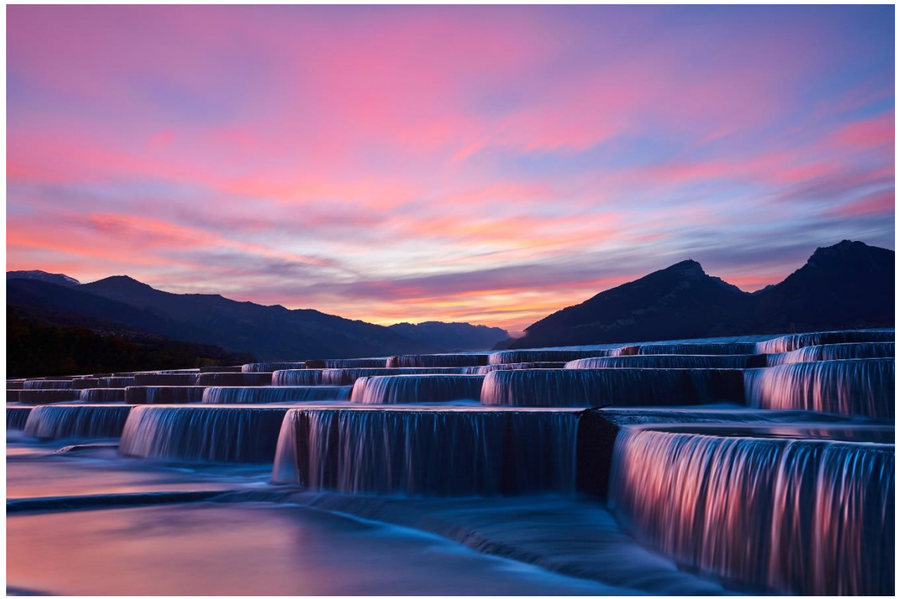
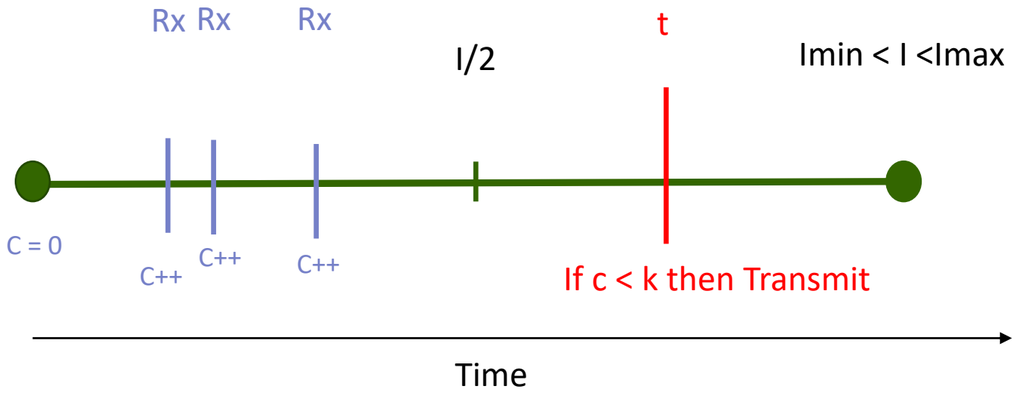
Enhanced data broadcast mechanism using the trickle algorithm. What is Trickle?

- The trickle algorithm is a well know IETF RFC
- https://datatracker.ietf.org/doc/html/rfc6206
- The Trickle algorithm establishes a density-aware local communication.
- A simple suppression mechanism and transmission point selection allow Trickle's communication rate to scale logarithmically with density.
- Is robust to network transience, loss, and disconnection; is simple to implement and requires little in terms of RAM and code space.



Enhanced data broadcast mechanism using the trickle algorithm. How Does Trickle Work?

- A Trickle timer runs for a defined interval and has three configuration parameters:
  - Imin: the minimum interval size.
  - Imax: the maximum interval size Imax,
  - K: a redundancy constant k:



- In addition it maintains three variables
  - I, the current interval size,
  - t, a time within the current interval, and
  - c, a count

- The Trickle algorithm has six rules, RFC section 4.

- The terms "consistent", "inconsistent", and "events" depends on how a protocol uses Trickle

Enhanced data broadcast mechanism using the trickle algorithm. How Does G3-PLC Use Trickle?

- Broadcast data frame transmissions:

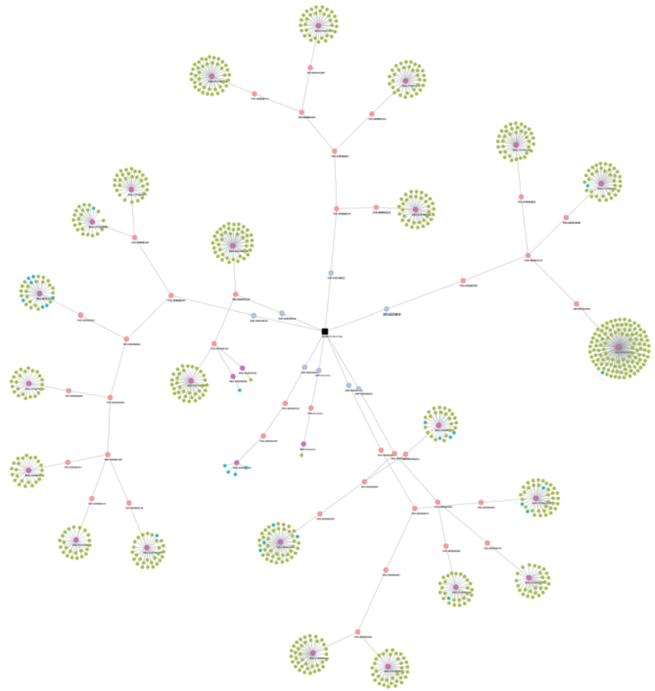
- A node only considers one single time interval for a same broadcast frame. The Trickle timer starts upon reception of this broadcast frame, after which it unavoidably is reset.

- A “consistent” transmission consists in a copy of the same broadcast frame (i.e. a broadcast frames with same BC0 header and source address)

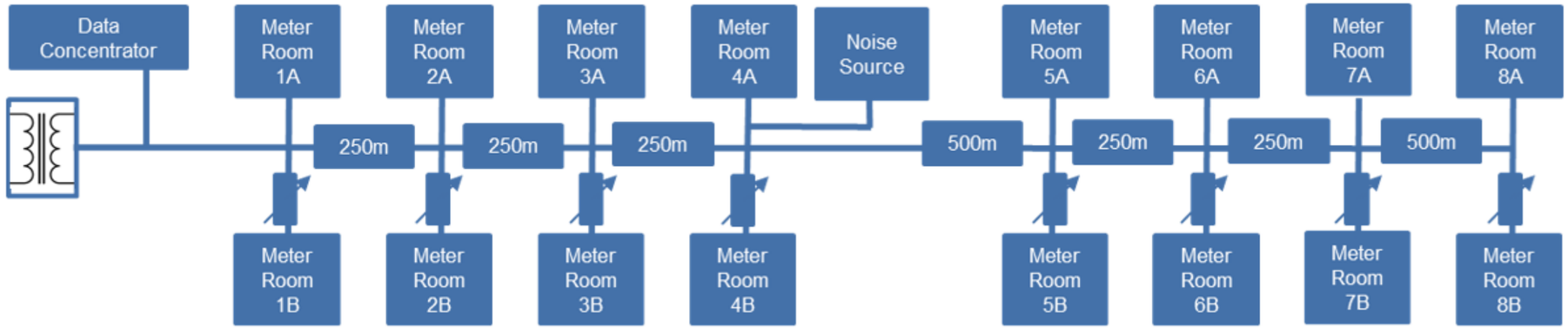
- Considering the same instance of the Trickle algorithm, at time t, Trickle triggers the forwarding of the broadcast frame, if c < Ki.

Enhanced data broadcast mechanism using the trickle algorithm. How Does G3-PLC Use Trickle?

- Section 5 of RFC Using trickle.
- $K_i = min\left[ceil\left(\frac{macPOSRecentEntries}{adpTrickleStep}\right)\ ;\ adpTrickleMaxKi\right]$
- macPOSRecentEntries corresponds to the number of POS table entries having been refreshed recently and which LQI is above adpTrickleMinLQIValue.
- adpTrickleStep corresponds to an indication of the desired redundancy
- adpTrickleMaxKi corresponds to the maximum redundancy constant allowed in the PAN.
- Imin definition: Time duration of broadcasted packet *adpTrickleMaxKi * 3



Enhanced data broadcast mechanism using the trickle algorithm. How has it been tested?



- Using a LAB based setup which is designed to reflect real world conditions and a typical installation.
- ~330 node dense network
- Different configurations of the Trickle algorithm can be tested

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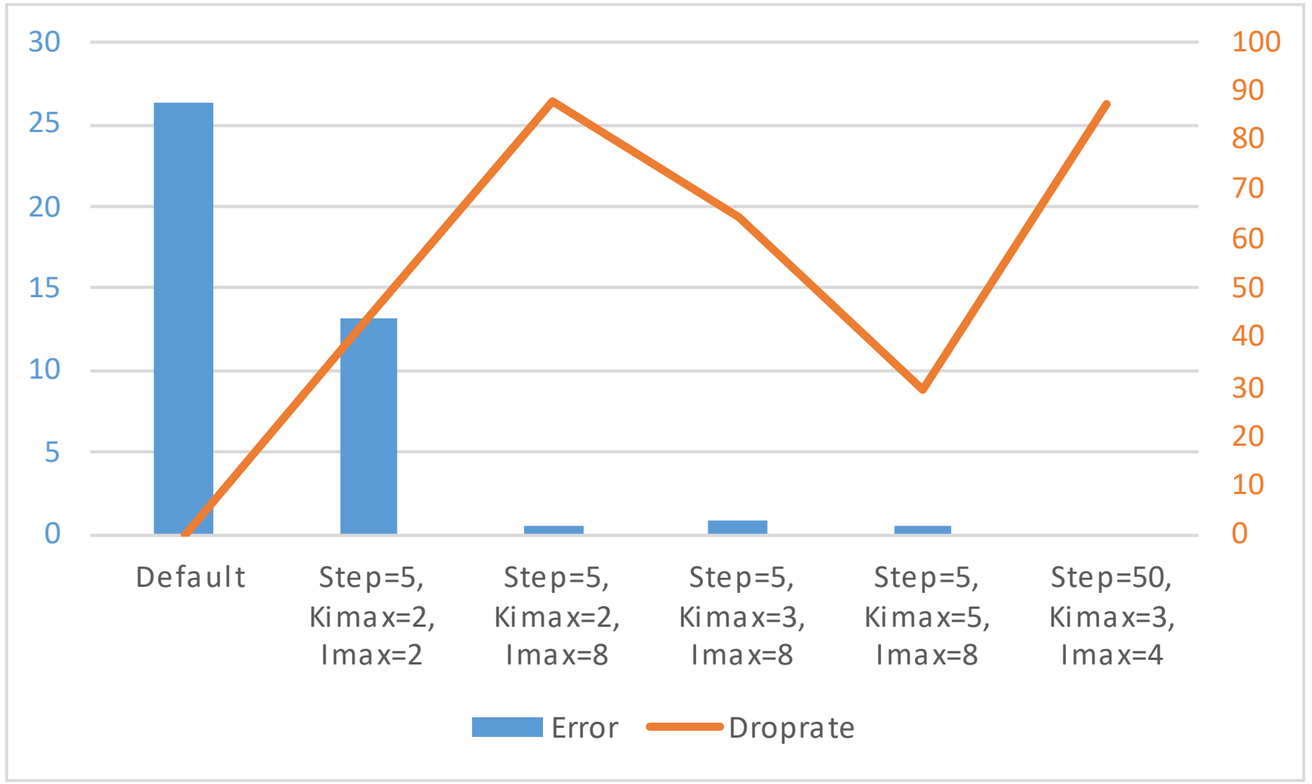
Enhanced data broadcast mechanism using the trickle algorithm. What the results…

- First results are very promising.
- As long as the Trickle timer is sufficiently long enough then the error rate is reduced considerably
- With appropriate settings then drop rate can be as high as >80%. A considerable reduction in Broadcast traffic
- With appropriate settings the error rate is less than 1%.
- Further optimisation can be done in the field using the latest version of the specification.

>80% suppression of Broadcast forwarding

Significant reduction in Error rate ~25% to less than 1%



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Enhanced data broadcast mechanism using the trickle algorithm. The New Specification G.9903 - 2021

- The changes to the specification can be found in sections:
  - Table 9-28 – Adaptation sublayer IB attributes
  - 9.4.2.3 Broadcast optimization using the Trickle algorithm
  - 9.4.2.3.1 Selections from IETF RFC 6206
  - 9.4.2.3.2 Extensions to IETF RFC 6206
  - Table 9-15 Additional attributes to clause

- **Search for the word “trickle” or “trickle algorithm” in the latest version of the G3-PLC specification.**

9.4.2.3 Broadcast optimization using the Trickle algorithm

9.4.2.3.1 Selections from IETF RFC 6206

The Trickle algorithm specified in [IETF RFC 6206] is considered for the optimization of broadcast traffic with the selections specified in Table 9-35-2 and related extensions

Clause	Title and remarks/modifications	Statement
6.4	Mismatched Definitions	I
6.5	Specifying the Constant k	I
6.6	Relationship between k and Imin	I
6.7	Tweaks and Improvements to Trickle	I
6.8	Uses of Trickle	I
7	Acknowledgements	N/R
8	Security Considerations	I
9	References	N/R
9.1	Normative References	N
9.2	Informative References	I

9.4.2.3.2 Extensions to IETF RFC 6206

For each instance of the Trickle algorithm, parameter Ki, aiming at the adaptation of the number of retransmissions within a neighborhood according to its density, is defined as a dynamic version of redundancy constant k.

$$K_i = min\left[ceil\left(\frac{macPOSRecentEntries}{adpTrickleStep}\right) ; adpTrickleMaxKi\right]$$

Where:

– macPOSRecentEntries corresponds to the number of POS table entries having been refreshed recently and which LQI is above adpTrickleMinLQIValue. Recently refreshed entries are characterized such as the (macPOSTableEntryTTL - POSValidTime) difference is less than a configurable threshold macPOSRecentEntryThreshold. If the number of entries satisfying this criterion is zero, than macPOSRecentEntries is set to 1.

– adpTrickleStep corresponds to an indication of the desired redundancy related to the reception of broadcast frames per tier of recent POS table entries.

– adpTrickleMaxKi corresponds to the maximum redundancy constant allowed in the PAN.

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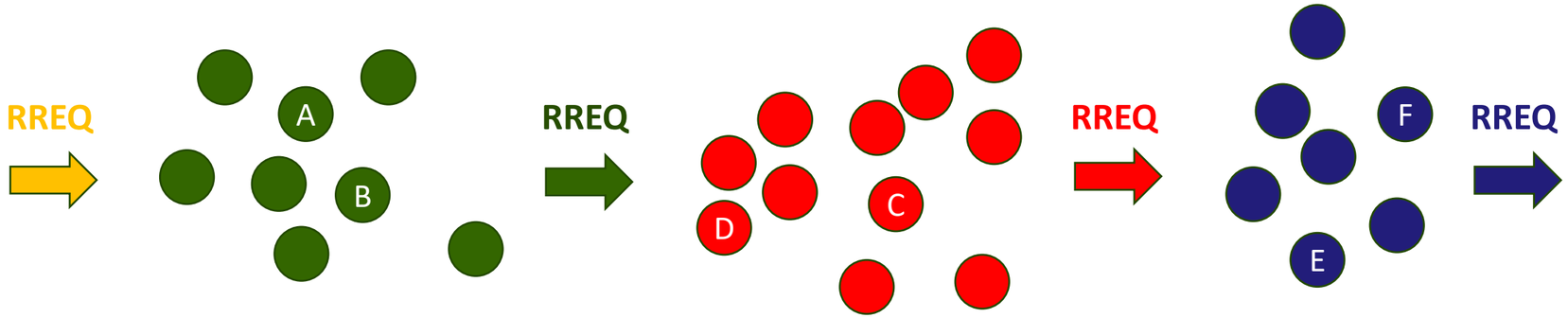
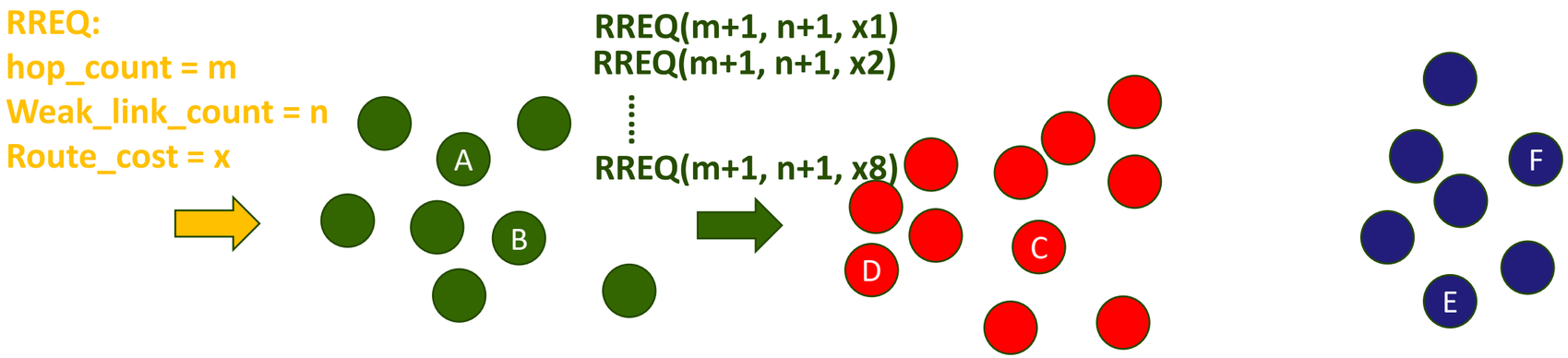
Concepts

- Jittering
  - Ideally this technique can suppress the number of RREQ forwarding down to only one for individual nodes
  - All nodes need to forward RREQ message at least once.
  - For large-scale and dense networks, the number of RREQ forwarding still can be very large
- Trickle
  - For dense networks, which usually consist of clusters of nodes, it would be sufficient if one of few nodes of each cluster forward the RREQ message.
  - Consistent event is defined to determine whether the RREQ message should be forwarded or not for individual nodes.

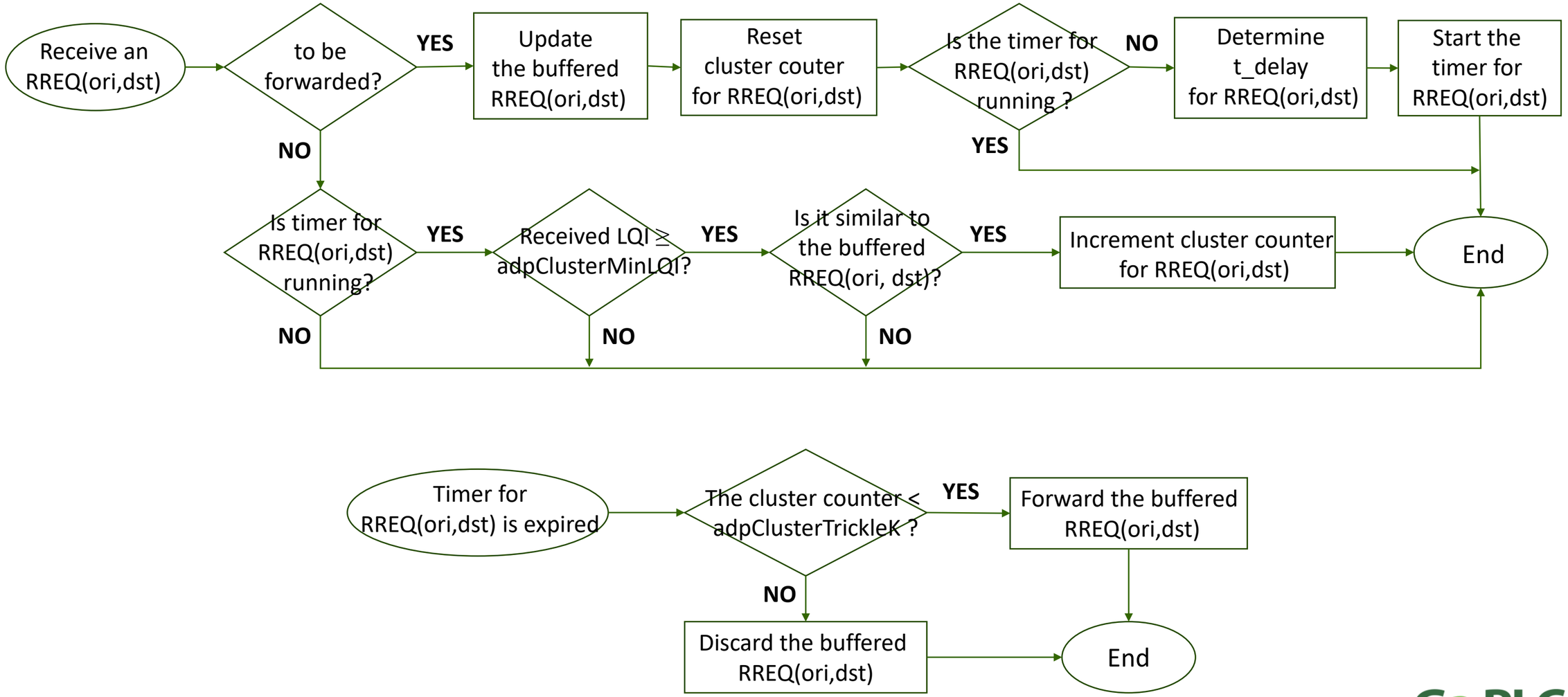


Cluster

- Definition of **consistent event** of the trickle algorithm
  - Same cluster
    - Received LQI ≥ CLUSTER_MIN_LQI
  - Similar RREQ message (compare the received RREQ and to-be-forwarded RREQ)
    - Same hop count
    - Same weak link count
    - Route cost in a range of +/-CLUSTER_RRQ_ROUTE_COST_DEVIATION

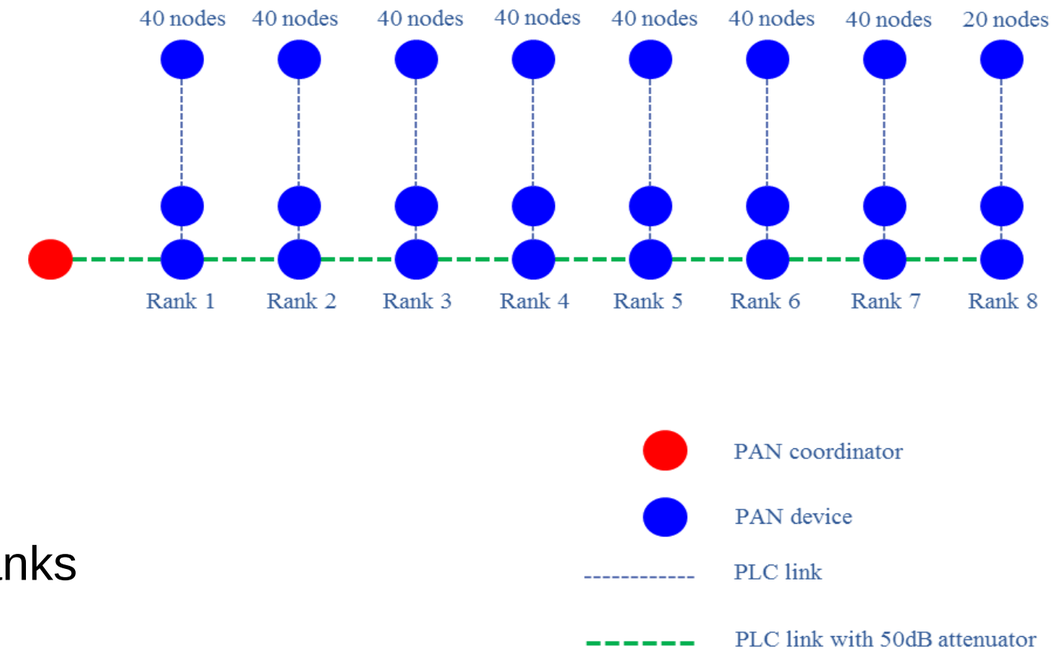


Algorithm


Receive an RREQ(ori,dst)
to be forwarded?
YES
Update the buffered RREQ(ori,dst)
Reset cluster couter for RREQ(ori,dst)
Is the timer for RREQ(ori,dst) running ?
NO
Determine t_delay for RREQ(ori,dst)
Start the timer for RREQ(ori,dst)
YES
NO
Is timer for RREQ(ori,dst) running?
YES
Received LQI ≥ adpClusterMinLQI?
YES
Is it similar to the buffered RREQ(ori, dst)?
YES
Increment cluster counter for RREQ(ori,dst)
End
NO
NO
NO
Timer for RREQ(ori,dst) is expired
The cluster counter < adpClusterTrickleK ?
YES
Forward the buffered RREQ(ori,dst)
NO
Discard the buffered RREQ(ori,dst)
End

Test Configuration

- Laboratory test environment
  - 301 nodes
    - One coordinator
    - 300 regular devices
  - 8 ranks
    - 40 nodes in each of first 7 ranks
    - 20 nodes in the last rank
    - 50 dB attenuators are connected between ranks



- Parameter configurations

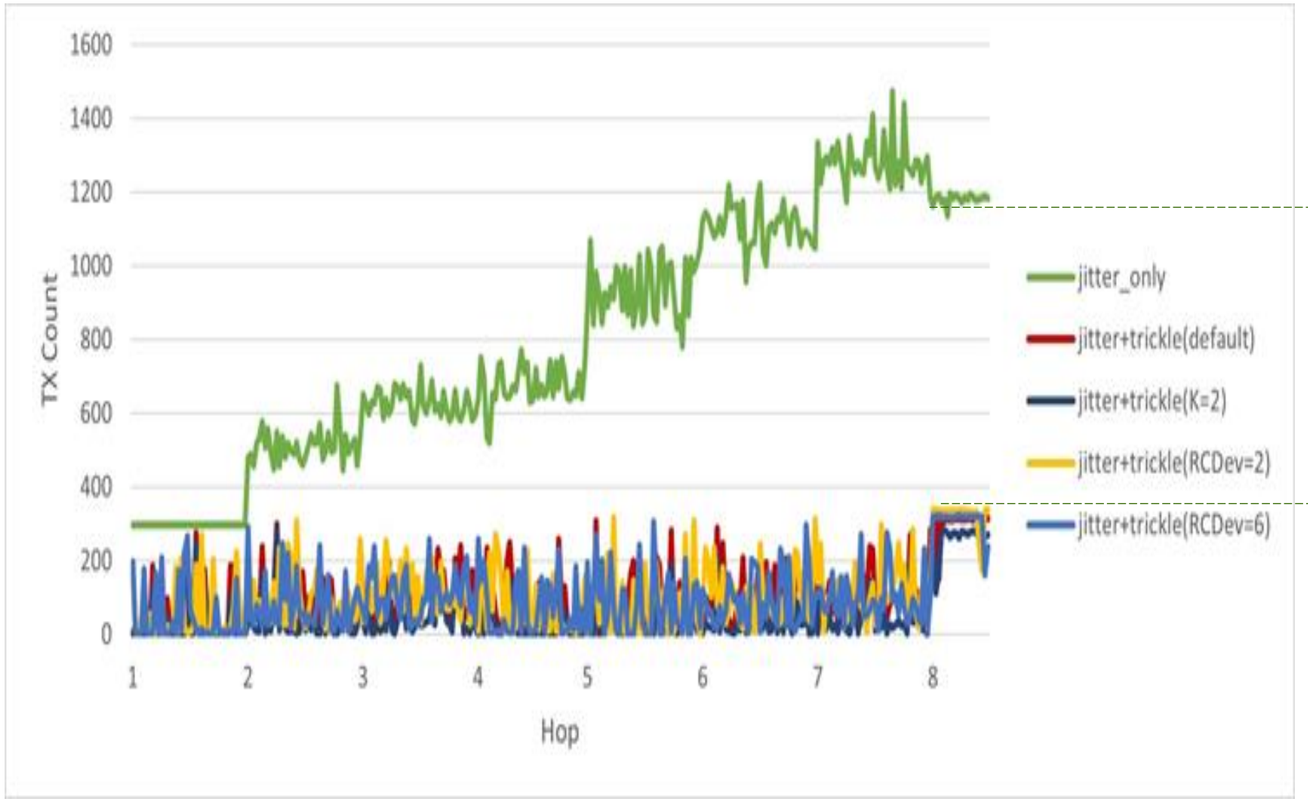
Setting	Jitter	Trickle	CLUSTER_TRICKLE_K	ROUTE_COST_DEVIATION
Jittering	YES	NO	-	-
Trickle 1	YES	YES	3	4
Trickle 2	YES	YES	2	4
Trickle 3	YES	YES	3	2
Trickle 4	YES	YES	3	6

Test Procedure

- The coordinator pings each node in the network (300 pings)
- In order to trigger the route establishment procedure, the coordinator clears the routing table before starting to issue the ping requests to each node
- The information for analysis
  - The total number of RREQs forwarded by each node
  - The route cost from each node to the coordinator
  - The success rate of ping operation

Test Results and Analysis (1)

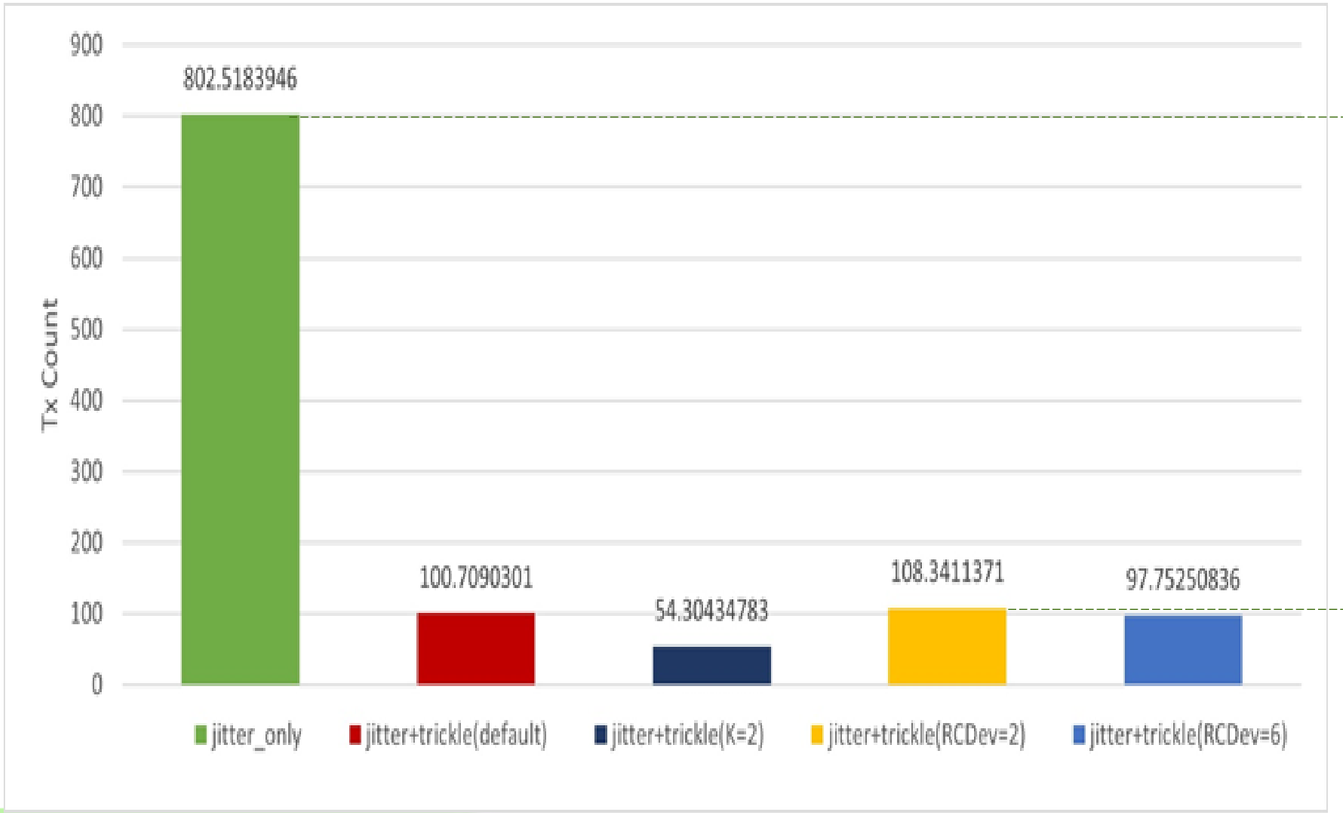
- The total number of RREQ messages forwarded by each node
  - Enabling trickle algorithm leads to significant suppressions of forwarded RREQs
  - The suppression is getting larger for the nodes in higher ranks



Significant additional RREQ traffic reduction

Test Results and Analysis (2)

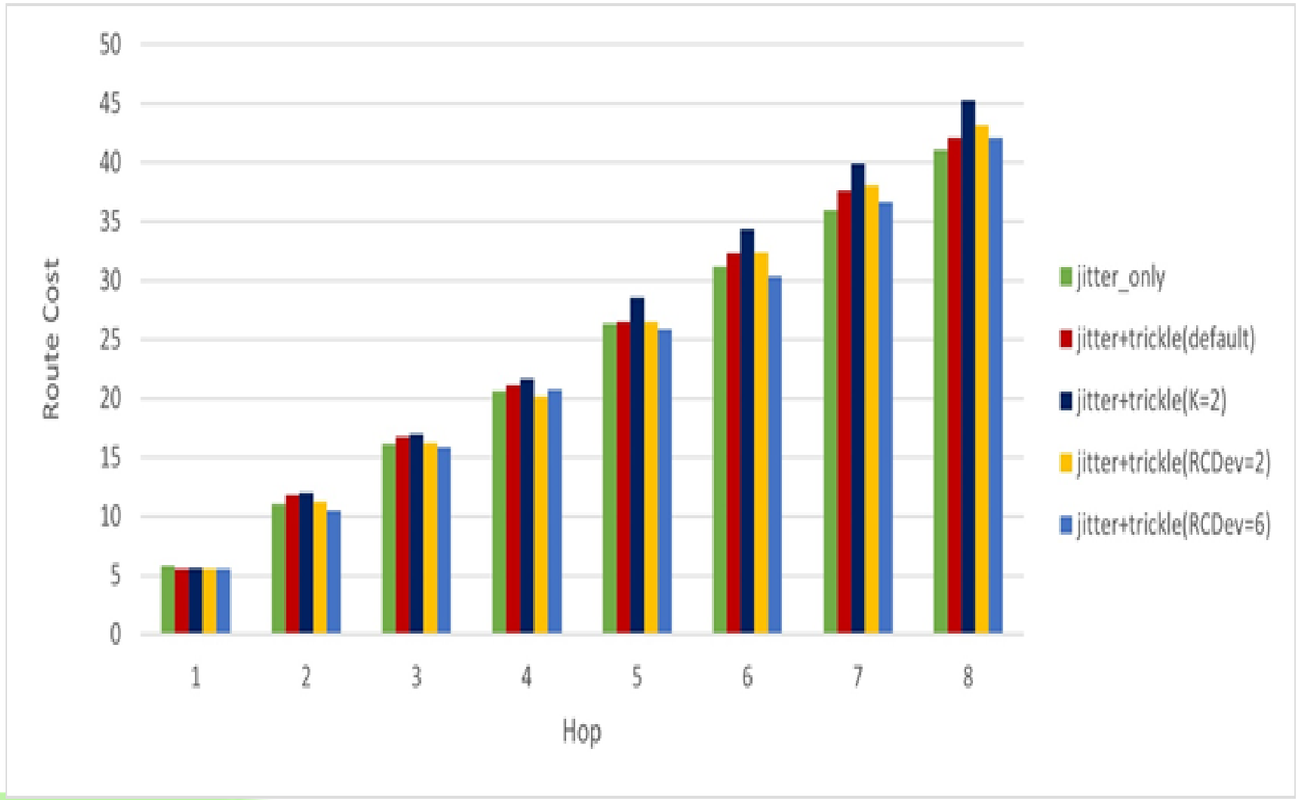
- The average number of RREQ messages forwarded by each node
  - Configurations with trickle algorithm lead to at least 86% suppression of RREQs forwarding compared to the configuration of only enabling RREQ jittering in this test topology



>86% suppression of RREQs forwarding

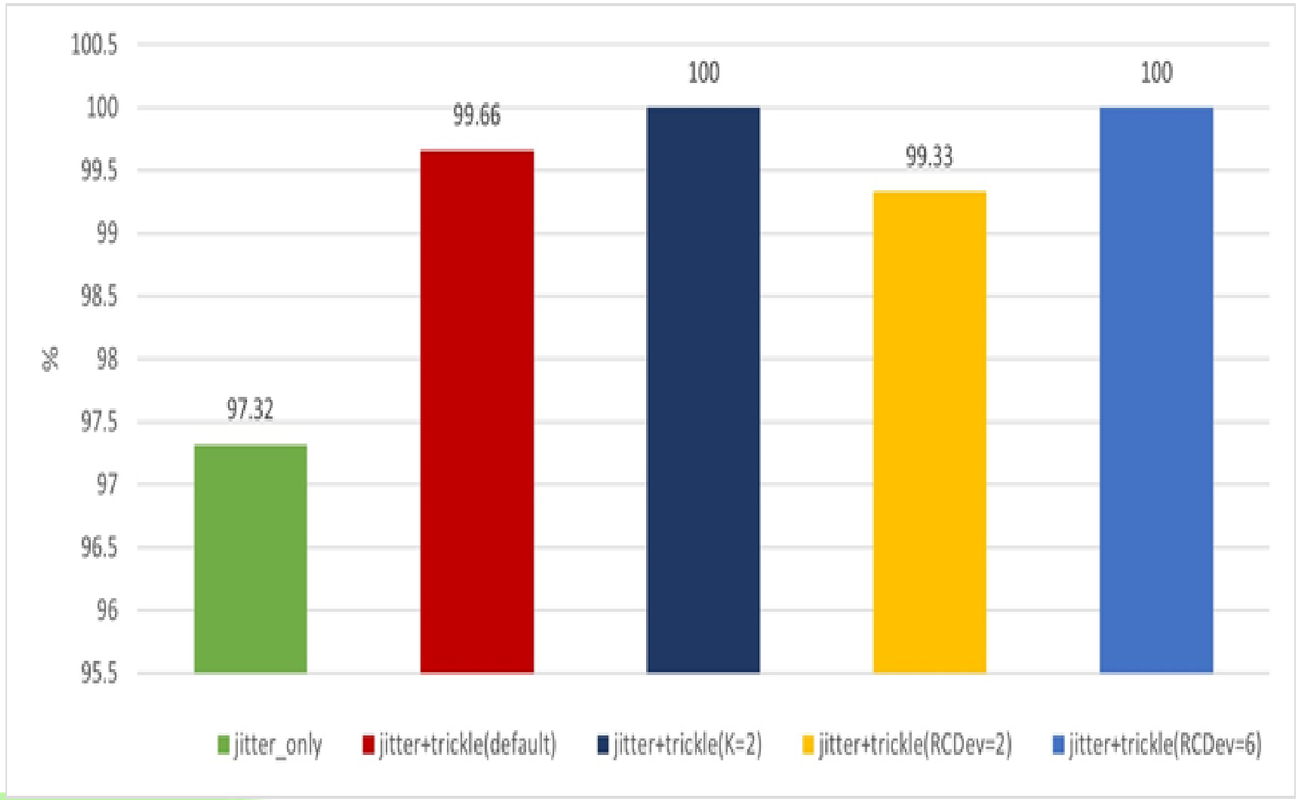
Test Results and Analysis (3)

- The average route cost from each node to the coordinator in different ranks
  - Enabling trickle algorithm does not compromise routes quality while less RREQ messages are forwarded



Test Results and Analysis(4)

- Success rate of PING operation
  - All configurations can provide sufficiently high success rate of PING operations



Conclusion

- Clusterhead forwarding scheme
  - Jittering: lower the flooding
  - Trickle: extra benefits extended from jittering
- The communication quality can be maintained when clusterhead forwarding scheme is enabled
  - Huge reduction of RREQ traffic
  - Suboptimal route establishment
  - High success rate of communication

Agenda

1. Introduction and challenges in dense network routing
2. Enhanced routing with RREQ jittering
3. Enhanced data broadcast mechanism using the trickle algorithm
4. Enhanced RREQ broadcast mechanism using the trickle algorithm
5. **Questions & Answers**

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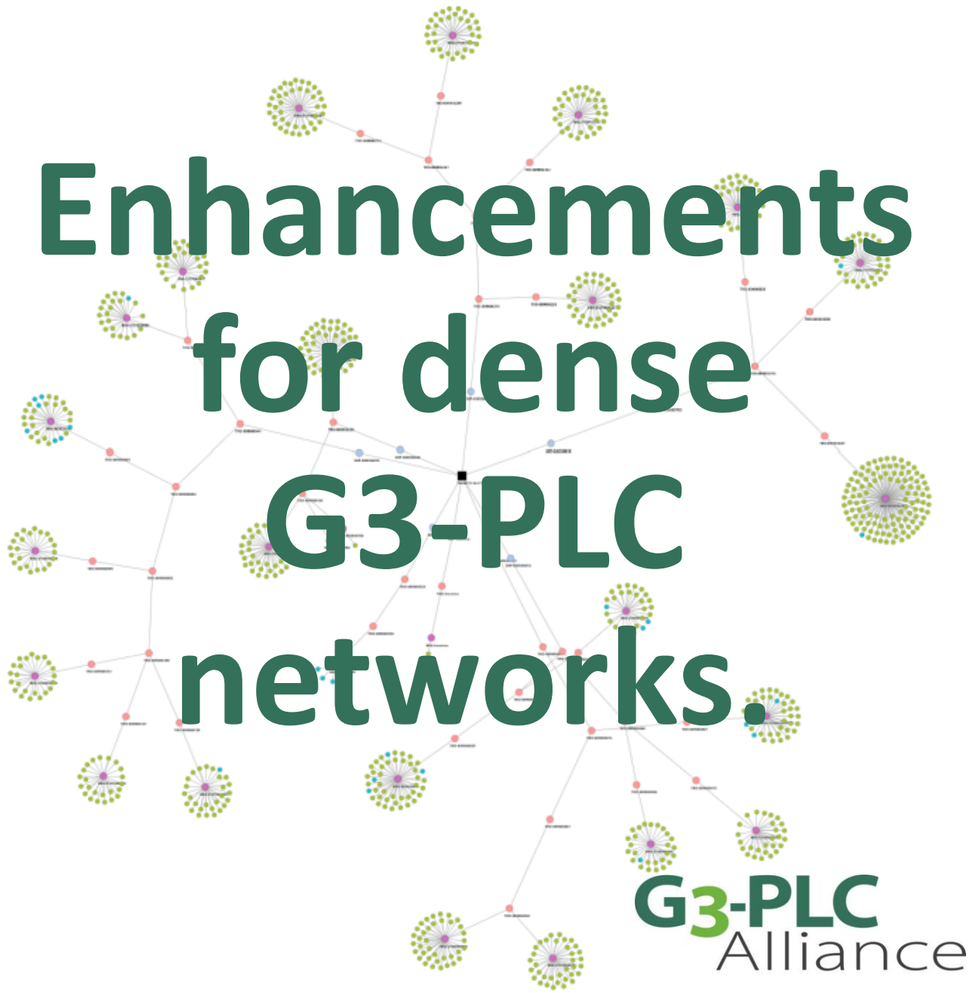
Questions?



Enhancements for dense G3-PLC networks.

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Thank you for attending this webinar today! Do not hesitate to get in touch!

Cédric Lavenu
EDF R&D and leading G3-PLC Technical Working Group
cedric-2.lavenu@edf.fr

Matteo Varesio
STMicroelectronics
matteo.varesio@st.com

For further information you can also visit
https://www.g3-plc.com

Kevin Jones
Renesas
kevin.jones@renesas.com

Greg Tseng
Vertexcom
greg.tseng@vertexcom.com

Leon Vergeer
General Secretary of the G3-PLC Alliance
leon.vergeer@g3-plc.com

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