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RPL Observations
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Abstract

This document describes RPL protocol design issues, various observations and possible consequences of the design and implementation choices. Also mentioned are implementation notes for the developers to be used in specific contexts.

Status of This Memo

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1. Introduction

RPL [RFC6550] specifies a proactive distance-vector routing scheme designed for LLNs (Low Power and Lossy Networks). RPL enables the network to be formed as a DODAG and supports storing mode and non-storing mode of operations. Non-storing mode allows reduced memory resource usage on the nodes by allowing non-BR nodes to operate without managing a routing table and involves use of source routing by the 6LBR to direct the traffic along a specific path. In storing mode of operation intermediate routers maintain routing tables.

This work aims to highlight various issues with RPL which makes it difficult to handle certain scenarios. This work will highlight such issues in context to RPL's mode of operations (storing versus non-storing). There are cases where RPL does not provide clear rules and implementations have to make their choices hindering interoperability and performance.

[I-D.clausen-lln-rpl-experiences] provides some interesting points. Some sections in this draft may overlap with some observations in

[clausen], but this is been done to further extend some scenarios or observations. It is highly encouraged that readers should also visit [I-D.clausen-lln-rpl-experiences] for other insights. Regardless, this draft is self-sufficient in a way that it does not expect to have read [clausen-draft].

1.1. Requirements Language and Terminology

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119 [RFC2119].

NS-MOP = RPL Non-storing Mode of Operation

S-MOP = RPL Storing Mode of Operation

This document uses terminology described in [RFC6550] and [RFC6775].

2. Managing persistent variables across node reboots

2.1. Persistent storage and RPL state information

Devices are required to be functional for several years without manual maintanence. Usually battery power consumption is considered key for operating the devices for several (tens of) years. But apart from battery, flash memory endurance may prove to be a lifetime bottleneck in constrained networks. Endurance is defined as maximum number of erase-write cycles that a NAND/NOR cell can undergo before losing its 'gauranteed' write operation. In some cases (cheaper NAND-MLC/TLC), the endurance can be as less as 2K cycles. Thus for e.g. if a given cell is written 5 times a day, that NAND-flash cell assuming an endurance of 10K cycles may last for less than 6 years.

In a star topology, the amount of persistent data write done by network protocols is very limited. But ad-hoc networks employing routing protocols such as RPL assume certain state information to be retained across node reboots. In case of IoT devices this storage is mostly floating gate based NAND/NOR based flash memory. The impact of loss of this state information differs depending upon the type (6LN/6LR/6LBR) of the node.

2.2. Lollipop Counters

[RFC6550] Section 7.2. explains sequence counter operation defining lollipop [Perlman83] style counters. Lollipop counters specify mechanism in which even if the counter value wraps, the algorithm would be able to tell whether the received value is the latest or

not. This mechanism also helps in "some cases" to recover from node reboot, but is not foolproof.

Consider an e.g. where Node A boots up and initialises the seqcnt to 240 as recommended in [RFC6550]. Node A communicates to Node B using this seqcnt and node B uses this seqcnt to determine whether the information node A sent in the packet is latest. Now lets assume, the counter value reaches 250 after some operations on Node A, and node B keeps receiving updated seqcnt from node A. Now consider that node A reboots, and since it reinitializes the seqcnt value to 240 and sends the information to node B (who has seqcnt of 250 stored on behalf of node A). As per section 7.2. of [RFC6550], when node B receives this packet it will consider the information to be old (since 240 < 250).

A	B	Output
240	240	A<B, old
240	241	A<B, old
240	::	A<B, old
240	256	A<B, old
240	0	A<B, new
240	1	A>B, new
240	::	A>B, new
240	127	A>B, new

Default values for lollipop counters considered from [RFC6550] Section 7.2.

Table 1: Example lollipop counter operation

Based on this figure, there is dead zone (240 to 0) in which if A operates after reboot then the seqcnt will always be considered smaller. Thus node A needs to maintain the seqcnt in persistent storage and reuse this on reboot.

2.3. RPL State variables

The impact of loss of RPL state information differs depending upon the node type (6LN/6LR/6LBR). Following sections explain different state variables and the impact in case this information is lost on reboot.

2.3.1. DODAG Version

The tuple (RPLInstanceID, DODAGID, DODAGVersionNumber) uniquely identifies a DODAG Version. DODAGVersionNumber is incremented everytime a global repair is initiated for the instance (global or local). A node receiving an older DODAGVersionNumber will ignore the DIO message assuming it to be from old DODAG version. Thus a 6LBR node (and 6LR node in case of local DODAG) needs to maintain the DODAGVersionNumber in the persistent storage, so as to be available on reboot. In case the 6LBR could not use the latest DODAGVersionNumber the implication are that it won't be able to recover/re-establish the routing table.

2.3.2. DTSN field in DIO

DTSN (Destination advertisement Trigger Sequence Number) is a DIO message field used as part of procedure to maintain Downward routes. A 6LBR/6LR node may increment a DTSN in case it requires the downstream nodes to send DAO and thus update downward routes on the 6LBR/6LR node. In case of RPL NS-MOP, only the 6LBR maintains the downward routes and thus controls this field update. In case of S-MOP, 6LRs additionally keep downward routes and thus control this field update.

In S-MOP, when a 6LR node switches parent it may have to issue a DIO with incremented DTSN to trigger downstream child nodes to send DAO so that the downward routes are established in all parent/ancestor set. Thus in S-MOP, the frequency of DTSN update might be relatively high (given the node density and hysteresis set by objective function to switch parent).

2.3.3. PathSequence

PathSequence is part of RPL Transit Option, and associated with RPL Target option. A node whichs owns a target address can associate a PathSequence in the DAO message to denote freshness of the target information. This is especially useful when a node uses multiple paths or multiple parents to advertise its reachability.

Loss of PathSequence information maintained on the target node can result in routing adjacencies been lost on 6LRs/6LBR/6BBR.

2.4. State variables update frequency

State variable	Update frequency	Impacts node type
DODAGVersionNumber	Low	6LBR, 6LR(local DODAG)
DTSN	High(SM),Low(NSM)	6LBR, 6LR
PathSequence	High(SM),Low(NSM)	6LR, 6LN

Low=<5 per day, High=>5 per day; SM=Storing MOP, NSM=Non-Storing MOP

Table 2: RPL State variables

2.5. Recommendations

It is necessary that RPL avoids using persistent storage as far as possible. Ideally, extensions to RPL should consider this as a design requirement especially for 6LR and 6LN nodes. DTSN and PathSequence are the primary state variables which have major impact.

2.6. Implementation Notes

An implementation should use a random DAOSequence number on reboot so as to avoid a risk of reusing the same DAOSequence on reboot. A parent node will not respond with a DAO-ACK in case it sees a DAO with the same previous DAOSequence.

Write-Before-Use: The state information should be written to the flash before using it in the messaging. If it is done the other way, then the chances are that the node power downs before writing to the persistent storage.

3. DTSN increment in storing MOP

DTSN increment has major impact on the overall RPL control traffic and on the efficiency of downstream route update. DTSN is sent as part of DIO message and signals the downstream nodes to trigger the target advertisement. The 6LR needs to decide when to update the DTSN and usually it should do it in a conservative way. The DTSN update mechanism determines how soon the downward routes are established along the new path. RPL specifications does not provide any clear mechansim on how the DTSN update should happen in case of storing mode.

```
                                   (6LBR)
                                      |
                                      |
                                      |
                                     (A)
                                     / \
                                    /   \
                                   /     \
                                 (B)    -(C)
                                  |    /  |
                                  |   /   |
                                  |  /    |
                                 (D)-    (E)
                                   \      ;
                                    \    ;
                                     \  ;
                                      (F)
                                      / \
                                     /   \
                                    /     \
                                  (G)     (H)
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Figure 1: Sample topology

Consider example topology shown in figure Figure 1, assume that node D switches the parent from node B to C. Ideally the downstream nodes D and its sub-childs should send their target advertisement to the new path via node C. To achieve this result in a efficient way is a challenge. Incrementing DTSN is the only way to trigger the DAO on downstream nodes. But this trigger should be sent not only on the first hop but to all the grand-child nodes. Thus DTSN has to be incremented in the complete sub-DODAG rooted at node D thus resulting in DIO/DAO storm along the sub-DODAG. This is specifically a big issue in high density networks where the metric deteoration might happen transiently even though the signal strength is good.

The primary implementation issue is whether a child node increment its own DTSN when it receives DTSN update from its parent node? This would result in DAO-updates in the sub-DODAG, thus the cost could be very high. If not incremented it may result in serious loss of connectivity for nodes in the sub-DODAG.

4. DAO retransmission and use of DAO-ACK

[RFC6550] has an optional DAO-ACK mechanism using which an upstream parent confirms the reception of a DAO from the downstream child. In case of storing mode, the DAO is addressed to the immediate hop

upstream parent resulting in DAO-ACK from the parent. There are two implementations possible:

(1) A parent responds with a DAO-ACK immedetialy after receiving the DAO.

(2) A node waits for the upstream parent to send DAO-ACK to respond with a DAO-ACK downstream. This may not be feasible to use on constrained devices because it requires additional state information and timers to be handled on behalf of multiple downstream nodes whose DAO is in transit.

Following scenarios do not have clear handling in the specs:

(1) What happens if the DAO-ACK for the target is lost at the ancestor node link?

(2) What happens if the DAO-ACK with Status!=0 is responded by ancestor node?

(3) Is there any way for the target node to know that the DAO it sent has reached the 6LBR successfully?

Note that any of these inefficiencies are not present in case of NSMOP in which the DAO is addressed directly to the 6LBR.

5. Handling resource unavailability

The nodes in the constrained networks have to maintain various records such as neighbor cache entries and routing entries on behalf of other targets to facilitate packet forwarding. Because of the constrained nature of the devices the memory available may be very limited and thus the path selection algorithm may have to take into consideration such resource constraints as well.

RPL currently does not have any mechanism to advertise such resource indicator metrics. The primary tables associated with RPL are routing table and the neighbor cache. Even though neighbor cache is not directly linked with RPL protocol, the maintenance of routing adjacencies results in updates to neigbor cache.

Following needs to be handled by the specs:

Is it possible to know that an upstream parent/ancestor cannot hold enough routing entries and thus this path should not be used?

Is it possible to know that an upstream parent cannot hold any more neighbor cache entry and thus this upstream parent should not be used?

6. Traffic Types observations

RPL is more suited towards MP2P (multi-point to point) traffic, the central point here usually is a grounded root/6LBR node. [RFC6997] allows establishing P2P paths within the DODAG. There are situations where a MP2P network needs to be established within the DODAG. For e.g. there could be multiple switches connecting the same light bulb. Currently to achieve this, every switch needs to establish a P2P path to the bulb. In cases where the cardinality of nodes connecting to the same node is high the cost of establishing P2P paths could be very high. RPL allows 'floating' DODAG to be created but the specification defines it to be used under other circumstances. To quote [RFC6550],

"A grounded DODAG offers connectivity to hosts that are required for satisfying the application-defined goal. ___A floating DODAG is not expected to satisfy the goal; in most cases, it only provides routes to nodes within the DODAG. Floating DODAGs may be used, for example, to preserve interconnectivity during repair.___"

Thus it is not clear whether floating DODAGs can be put to use for establishing MP2P paths within the DODAG.

7. RPL under-specification

(a) PathSequence: Is it mandatory to use PathSequence in DAO Transit container? RPL mentions that a 6LR/6LBR hosting the routing entry on behalf of target node should refresh the lifetime on reception of a new Path Sequence. But RPL does not necessarily mandate use of Path Sequence. Most of the open source implementation [RIOT] [CONTIKI] currently do not issue Path Sequence in the DAO message.

(b) Target Container aggregation in DAO: RPL allows multiple targets to be aggregated in a single DAO message and has introduced a notion of DelayDAO using which a 6LR node could delay its DAO to enable such aggregation. But RPL does not have clear text on handling of aggregated DAOs and thus it hinders interoperability.

(c) DTSN Update: RPL does not clearly define in which cases DTSN should be updated in case of storing mode of operation. More details for this are presented in Section 3.

8. Acknowledgements

9. IANA Considerations

This memo includes no request to IANA.

10. Security Considerations

This is an information draft and does add any changes to the existing specifications.

11. References

11.1. Normative References

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Appendix A. Additional Stuff

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