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RPL DAG Metric Container Node State and Attribute object type extension
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Abstract

Implementing 6TiSCH Packet Replication and Elimination from / to the RPL root requires the ability to forward copies of packets over different paths via different RPL parents. Selecting the appropriate parents to achieve ultra-low latency and jitter requires information about a node's parents. This document details what information needs to be transmitted and how it is encoded within a packet to enable this functionality.

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Table of Contents

1. Introduction	2
2. Terminology	3
3. Alternative Parent Selection	4
3.1. Common Ancestor Strict	4
3.2. Common Ancestor Medium	5
3.3. Common Ancestor Relaxed	5
4. Node State and Attribute (NSA) object type extension	6
4.1. Usage	8
4.1.1. DAG Metric Container fields	8
4.1.2. Node State and Attribute fields	9
4.2. Compression	9
5. Controlling PRE	9
6. Security Considerations	9
7. IANA Considerations	9
8. References	9
8.1. Informative references	10
8.2. Other Informative References	10
Appendix A. Implementation Status	11
Authors' Addresses	13

1. Introduction

Industrial network applications have stringent requirements on reliability and predictability, and typically leverage 1+1 redundancy, aka Packet Replication and Elimination (PRE) [I-D.papadopoulos-6tisch-pre-reqs] to achieve their goal. In order for wireless networks to be able to be used in such applications, the principles of Deterministic Networking [I-D.ietf-detnet-architecture] lead to designs that aim at maximizing packet delivery rate and minimizing latency and jitter. Additionally, given that the network nodes often do not have an unlimited power supply, energy consumption needs to be minimized as well.

To meet this goal, IEEE Std. 802.15.4 [IEEE802154-2015] provides Time-Slotted Channel Hopping (TSCH), a mode of operation which uses a fixed communication schedule to allow deterministic medium access as well as channel hopping to work around radio interference. However, since TSCH uses retransmissions in the event of a failed transmission, end-to-end delay and jitter performance can deteriorate.

The 6TiSCH working group, focusing on IPv6 over IEEE Std. 802.15.4-TSCH, has worked on the issues previously highlighted and produced the "6TiSCH Architecture" [I-D.ietf-6tisch-architecture] to address that case. Building on this architecture, "Exploiting Packet Replication and Elimination in Complex Tracks in 6TiSCH LLNs" [I-D.papadopoulos-6tisch-pre-reqs] leverages PRE to improve the Packet Delivery Ratio (PDR), provide a hard bound to the end-to-end latency, and limit jitter.

PRE achieves a controlled redundancy by laying multiple forwarding paths through the network and using them in parallel for different copies of a same packet. PRE can follow the Destination-Oriented Directed Acyclic Graph (DODAG) formed by RPL from a node to the root. Building a multi-path DODAG can be achieved based on the RPL capability of having multiple parents for each node in a network, a subset of which is used to forward packets. In order for this subset to be defined, a RPL parent subset selection mechanism, which falls within the remit of the RPL Objective Function (OF), needs to have specific path information. The specification of the transmission of this information is the focus of this document.

More concretely, this specification focuses on the extensions to the DAG Metric Container [RFC6551] required for providing the PRE mechanism a part of the information it needs to operate. This information is the RPL [RFC6550] parent address set of a node and it must be sent to potential children nodes of the node. The RPL DIO Control Message is the canonical way of broadcasting this kind of information and therefore its DAG Metric Container [RFC6551] field is used to append a Node State and Attribute (NSA) object. The node's parent address set is stored as an optional TLV within the NSA object. This specification defines the type value and structure for this TLV.

2. 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 [RFC2119].

The draft uses the following Terminology:

Track A sequence of 6TiSCH schedule resources to support a single-path multi-hop transmission of a packet. See "6TiSCH Architecture" [I-D.ietf-6tisch-architecture] for more.

Complex Track A Track which supports a multi-path multi-hop transmission of a packet. See "6TiSCH Architecture" [I-D.ietf-6tisch-architecture] for more.

Packet Replication and Elimination (PRE) The sending of multiple copies of a packet using multi-path forwarding over a multi-hop network and the consolidation of multiple received packet copies to control flooding. See "Exploiting Packet Replication and Elimination in Complex Tracks in 6TiSCH LLNs" [I-D.papadopoulos-6tisch-pre-reqs] for more.

Alternative Parent (AP) Selection The problem of how to select the next hop target node for a packet copy to be forwarded to when performing packet replication.

3. Alternative Parent Selection

In the RPL protocol, each node maintains a list of potential parents. For PRE, the PP node is defined to be the same as the RPL DODAG Preferred Parent (PP) node. Furthermore, to construct an alternative path toward the root, in addition to the PP node, each 6TiSCH node in the network registers an AP node as well from its Parent Set (PS). There are multiple alternative methods of selecting the AP node, functionality which is included in operation of the RPL Objective Function (OF). A scheme which allows the two paths to remain correlated is detailed here. More specifically, in this scheme a 6TiSCH node will select an alternative parent node close to its PP node to allow the operation of overhearing between parents. If multiple potential APs match this condition, the AP with the lowest rank will be registered.

There are at least three methods of performing the alternative parent selection based on common ancestors (CA), named Common Ancestor Strict, Common Ancestor Medium, and Common Ancestor Relaxed, depending on how restrictive the selection process is. A more restrictive method will limit flooding but might fail to select an appropriate alternative parent, while a less restrictive one will more often find an appropriate alternative parent but might increase flooding.

3.1. Common Ancestor Strict

In CA Strict, the node will check if its Preferred Grand Parent (PGP), the PP of its PP, is the same as the PP of the potential AP.

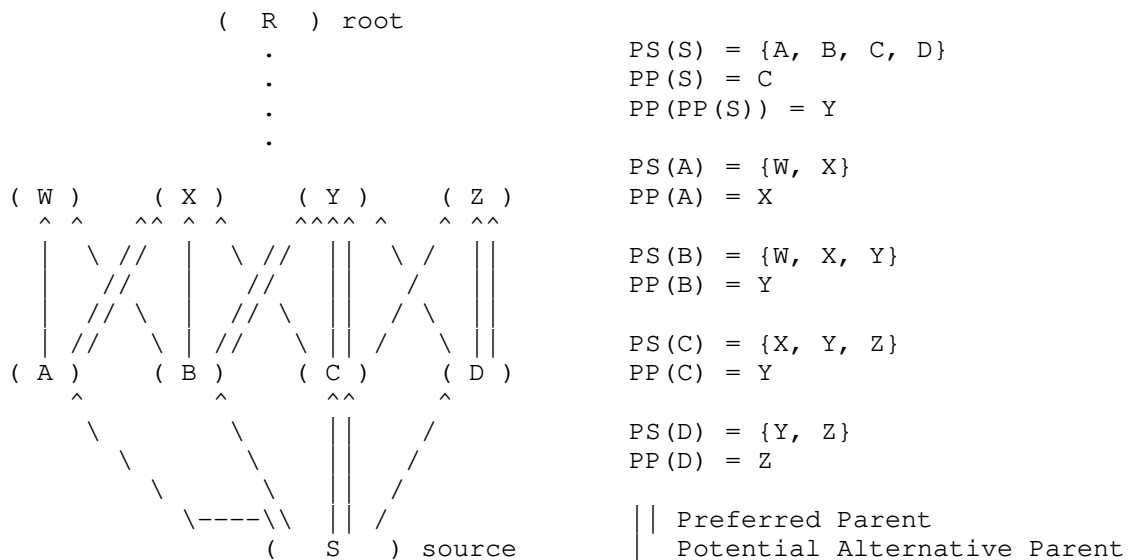


Figure 1: Example Common Ancestor Strict Alternative Parent Selection method

For example, in Figure 1, the source 6TiSCH node S must know its grandparent sets both through nodes A, B, C, and D. The Parent Sets (PS) and the Preferred Parents (PP) of nodes A, B, C, and D are shown on the side of the figure. The CA Strict parent selection method will select an AP for node S for which $PP(PP(S)) = PP(AP)$. Therefore, node S can decide to use node B as its AP node, since $PP(PP(S)) = Y = PP(B)$.

3.2. Common Ancestor Medium

In CA Medium, the node will check if its Preferred Grand Parent (PGP), the PP of its PP, is contained in the PS of the potential AP.

Using the same example, in Figure 1, the CA Medium parent selection method will select an AP for node S for which $PP(PP(S))$ in $PS(AP)$. Therefore, node S can decide to use node B or D as its AP node, since given that $PP(PP(S)) = Y$, for node B $PS(B) = \{W, X, Y\}$ and for node D $PD(D) = \{Y, Z\}$.

3.3. Common Ancestor Relaxed

In CA Relaxed, the node will check if its the Parent Set (PS) of its Preferred Parent (PP), has a common node with the PS of the potential AP.

Using the same example, in Figure 1, the CA Relaxed parent selection method will select an AP for node S for which $PS(PP(S))$ has a non-empty intersection with $PS(AP)$. Therefore, node S can decide to use node A, B or D as its AP node. Given that $PS(PP(S)) = \{X, Y, Z\}$ the alternative parent selection process evaluates the nodes:

- o Node A: $PS(A) = \{W, X\}$ and the common nodes are $\{X\}$
- o Node B: $PS(B) = \{W, X, Y\}$ and the common nodes are $\{X, Y\}$
- o Node D: $PS(D) = \{Y, Z\}$ and the common nodes are $\{Y, Z\}$

4. Node State and Attribute (NSA) object type extension

In order to select their AP node, 6TiSCH nodes need to be aware of their grandparent node sets. Within RPL [RFC6550], the nodes use the DODAG Information Object (DIO) Control Message to broadcast information about themselves to potential children. However, RPL [RFC6550], does not define how to propagate parent set related information, which is what this document addresses.

DIO messages can carry multiple options, out of which the DAG Metric Container option [RFC6551] is the most suitable structurally and semantically for the purpose of carrying the parent set. The DAG Metric Container option itself can carry different nested objects, out of which the Node State and Attribute (NSA) [RFC6551] is appropriate for transferring generic node state data. Within the Node State and Attribute it is possible to store optional TLVs representing various node characteristics. As per the Node State and Attribute (NSA) [RFC6551] description, no TLV has been defined for use. This document defines one TLV for the purpose of transmitting a node's parent set.

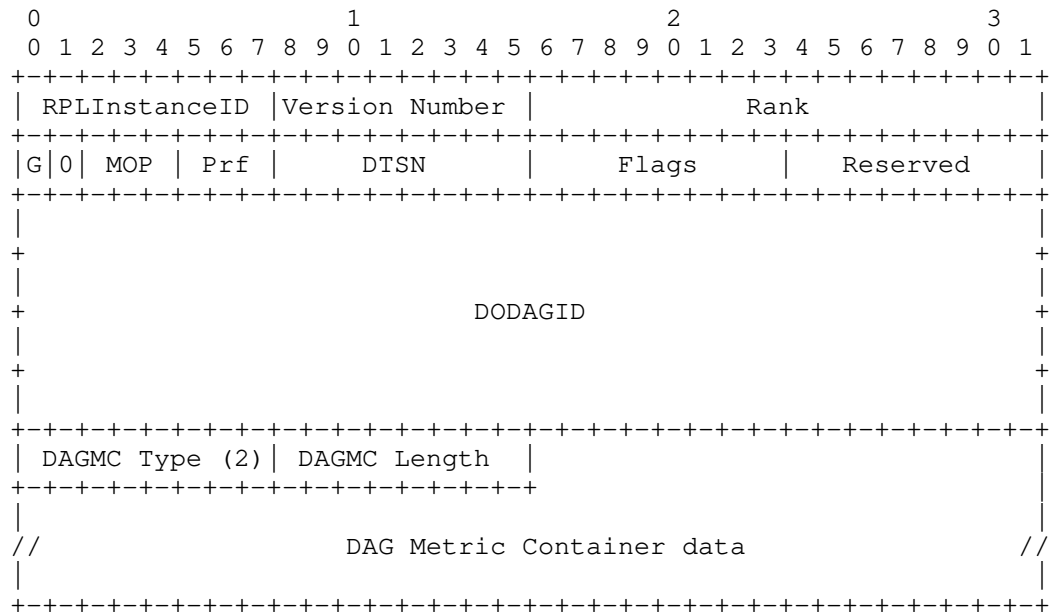


Figure 2: Example DIO Message with a DAG Metric Container option

Figure 2 shows the structure of the DIO Control Message when a DAG Metric Container option is included. The DAG Metric Container option type (DAGMC Type in Figure 2) has the value 0x02 as per the IANA registry for the RPL Control Message Options, and is defined in [RFC6550]. The DAG Metric Container option length (DAGMC Length in Figure 2) expresses the DAG Metric Container length in bytes. DAG Metric Container data holds the actual data and is shown expanded in Figure 3.

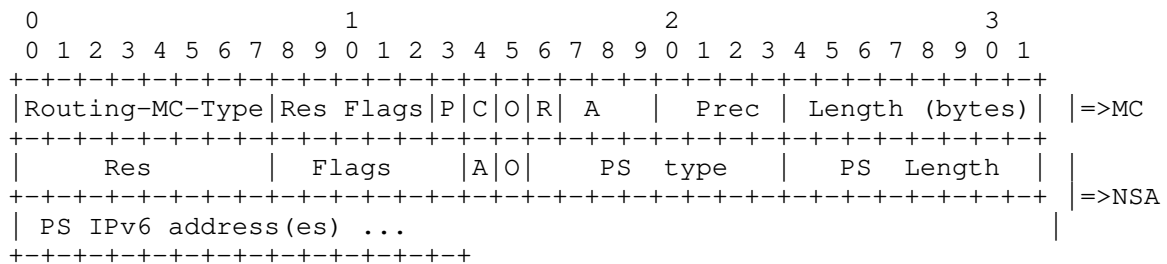


Figure 3: DAG Metric Container (MC) data with Node State and Attribute (NSA) object body and a TLV

The structure of the DAG Metric Container data in the form of a Node State and Attribute (NSA) object with a TLV in the NSA Optional TLVs field is shown in Figure 3. The first 32 bits comprise the DAG Metric Container header and all the following bits are part of the Node State and Attribute object body, as defined in [RFC6551]. This document defines a new TLV, which CAN be carried in the Node State and Attribute (NSA) object Optional TLVs field. The TLV is named Parent Set and is abbreviated as PS in Figure 3.

PS type: The type of the Parent Set TLV. The value is TBD1.

PS Length: The total length of the TLV value field (PS IPv6 address(es)) in bytes.

PS IPv6 address(es): A sequence of zero or more IPv6 addresses belonging to a node's parent set. Each address requires 16 bytes. The order of the parents in the parent set is in decreasing preference based on the Objective Function [RFC6550] used by the node.

4.1. Usage

The PS SHOULD be used in the process of parent selection, and especially in alternative parent selection, since it can help the alternative path from significantly deviating from the preferred path. The Parent Set is information local to the node that broadcasts it.

4.1.1. DAG Metric Container fields

Given the intended usage, when using the PS, the NSA object it is contained in MUST be used as a constraint in the DAG Metric Container. More specifically, using the PS places the following requirements on the DAG Metric Container header fields:

- o 'P' flag: MUST be cleared, since PS is used only with constraints.
- o 'C' flag: MUST be set, since PS is used only with constraints.
- o 'O' flag: Used as per [RFC6550], to indicated optionality.
- o 'R' flag: MUST be cleared, since PS is used only with constraints.
- o 'A' Field: MUST be set to 0 and ignored, since PS is used only with constraints.
- o 'Prec' Field: Used as per [RFC6550].

4.1.2. Node State and Attribute fields

For clarity reasons, the usage of the PS places no additional restrictions on the NSA flags ('A' and 'O'), which can be used as normally defined in [RFC6550].

4.2. Compression

The PS IPv6 address(es) field in the Parent Set TLV add overhead due to their size. Therefore, compression is highly desirable in order for this extension to be usable. To meet this goal, a good compression method candidate is [RFC8138] 6LoWPAN Routing Header (6LoRH). Furthermore, the PS IPv6 address(es) belong by definition to nodes in the same RPL DODAG and are stored in the form of a list of addresses. This makes this field a good candidate for the use of the same compression as in Source Routing Header 6LoRH (SRH-6LoRH), achieving efficiency and implementation reuse. Therefore, the PS IPv6 address(es) field SHOULD be compressed using the compression method for Source Routing Header 6LoRH (SRH-6LoRH) [RFC8138].

5. Controlling PRE

PRE is very helpful when the aim is to increase reliability for a certain track, however it's use creates additional traffic as part of the replication process. It is conceivable that not all tracks have stringent reliability requirements. Therefore, a way to control whether PRE is applied to a track's packets SHOULD be implemented. For example, a traffic class label can be used to determine this behaviour per flow type as described in Deterministic Networking Architecture [I-D.ietf-detnet-architecture].

6. Security Considerations

The structure of the DIO control message is extended, within the pre-defined DIO options. Therefore, the security mechanisms defined in RPL [RFC6550] apply to this proposed extension.

7. IANA Considerations

This proposal requests the allocation of a new value TBD1 for the "Parent Set" TLV in the Routing Metric/Constraint TLVs sub-registry from IANA.

8. References

8.1. Informative references

- [I-D.ietf-6tisch-architecture]
Thubert, P., "An Architecture for IPv6 over the TSCH mode of IEEE 802.15.4", draft-ietf-6tisch-architecture-17 (work in progress), November 2018.
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Finn, N., Thubert, P., Varga, B., and J. Farkas, "Deterministic Networking Architecture", draft-ietf-detnet-architecture-09 (work in progress), October 2018.
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Papadopoulos, G., Montavont, N., and P. Thubert, "Exploiting Packet Replication and Elimination in Complex Tracks in 6TiSCH LLNs", draft-papadopoulos-6tisch-pre-reqs-02 (work in progress), July 2018.
- [RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, DOI 10.17487/RFC2119, March 1997, <<https://www.rfc-editor.org/info/rfc2119>>.
- [RFC6550] Winter, T., Ed., Thubert, P., Ed., Brandt, A., Hui, J., Kelsey, R., Levis, P., Pister, K., Struik, R., Vasseur, JP., and R. Alexander, "RPL: IPv6 Routing Protocol for Low-Power and Lossy Networks", RFC 6550, DOI 10.17487/RFC6550, March 2012, <<https://www.rfc-editor.org/info/rfc6550>>.
- [RFC6551] Vasseur, JP., Ed., Kim, M., Ed., Pister, K., Dejean, N., and D. Barthel, "Routing Metrics Used for Path Calculation in Low-Power and Lossy Networks", RFC 6551, DOI 10.17487/RFC6551, March 2012, <<https://www.rfc-editor.org/info/rfc6551>>.
- [RFC8138] Thubert, P., Ed., Bormann, C., Toutain, L., and R. Cragie, "IPv6 over Low-Power Wireless Personal Area Network (6LoWPAN) Routing Header", RFC 8138, DOI 10.17487/RFC8138, April 2017, <<https://www.rfc-editor.org/info/rfc8138>>.

8.2. Other Informative References

- [IEEE802154-2015]
IEEE standard for Information Technology, "IEEE Std 802.15.4-2015 Standard for Low-Rate Wireless Personal Area Networks (WPANs)", December 2015.

8.3. URIs

- [1] <https://github.com/ariskou/contiki/tree/draft-koutsiamanis-roll-nsa-extension>
- [2] <https://code.wireshark.org/review/gitweb?p=wireshark.git;a=commit;h=e2f6ba229f45d8ccae2a6405e0ef41f1e61da138>

Appendix A. Implementation Status

A research-stage implementation of the PRE mechanism using the proposed extension as part of a 6TiSCH IOT use case was developed at IMT Atlantique, France by Tomas Lagos Jenschke and Remous-Aris Koutsiamanis. It was implemented on the open-source Contiki OS and tested with the Cooja simulator. The DIO DAGMC NSA extension is implemented with a configurable number of parents from the parent set of a node to be reported.

(R)

(11)	(12)	(13)	(14)	(15)	(16)
(21)	(22)	(23)	(24)	(25)	(26)
(31)	(32)	(33)	(34)	(35)	(36)
(41)	(42)	(43)	(44)	(45)	(46)
(51)	(52)	(53)	(54)	(55)	(56)

(S)

Figure 4: Simulation Topology

The simulation setup is:

Topology: 32 nodes structured in regular grid as show in Figure 4. Node S (source) is the only data packet sender, and send data to node R (root). The parent set of each node (except R) is all the nodes in the immediatelly higher row, the immediatelly above 6 nodes. For example, each node in {51, 52, 53, 54, 55, 56} is

connected to all of {41, 42, 43, 44, 45, 46}. Node 11, 12, 13, 14, 15, 16 have a single upwards link to R.

MAC: TSCH with 1 retransmission

Platform: Cooja

Schedule: Static, 2 timeslots per link from each node to each parent in its parent set, 1 broadcast EB slot, 1 sender-based shared timeslot (for DIO and DIS) per node (total of 32).

Simulation lifecycle: Allow link formation for 100 seconds before starting to send data packets. Afterwards, S sends data packets to R. The simulation terminates when 1000 packets have been sent by S.

Radio Links: Links are reset uniformly randomly between 70% and 100% every 60 seconds.

Traffic Pattern: CBR, S sends one non-fragmented UDP packet every 5 seconds to R.

PS extension size: 3 parents.

Routing Methods:

- * RPL: The default RPL non-PRE implementation in Contiki OS.
- * 2nd ETX: PRE with a parent selection method which picks as AP the 2nd best parent in the parent set based on ETX.
- * CA Strict: As described in Section 3.1.
- * CA Medium: As described in Section 3.2.

Simulation results:

Routing Method	Average Packet Delivery Rate (%)	Average Traversed Nodes/packet (#)	Average Duplications/packet (#)
RPL	82.70	5.56	7.02
2nd ETX	99.38	14.43	31.29
CA	97.32	9.86	18.23
Strict CA	99.66	13.75	28.86
Medium			

Links:

- o Contiki OS DIO DAGMC NSA extension (draft-koutsiamanis-roll-nsa-extension branch) [1]
- o Wireshark dissectors (for the optional TLV, i.e., PS) - currently merged / in master [2]

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