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M. Goyal, Ed.
University of Wisconsin
Milwaukee
E. Baccelli
INRIA
A. Brandt
Sigma Designs
J. Martocci
Johnson Controls

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A Mechanism to Measure the Quality of a Point-to-point Route in a Low Power and Lossy Network
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Abstract

This document specifies a mechanism that enables an RPL router to measure the quality of an existing route towards another RPL router in a low power and lossy network, thereby allowing the router to decide if it wants to initiate the discovery of a better route.

Status of this Memo

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1. Introduction

Point to point (P2P) communication between arbitrary routers in a Low power and Lossy Network (LLN) is a key requirement for many applications [RFC5826][RFC5867]. RPL [I-D.ietf-roll-rpl], the IPv6 Routing Protocol for LLNs, constrains the LLN topology to a Directed Acyclic Graph (DAG) built to optimize routing costs to reach the DAG's root and requires the P2P routes to use the DAG links only. Such P2P routes may potentially be suboptimal and may lead to traffic congestion near the DAG root. Additionally, RPL is a proactive routing protocol and hence all P2P routes must be established ahead of the time they are used.

To ameliorate situations, where RPL's P2P routing functionality does not meet the requirements, [I-D.ietf-roll-p2p-rpl] describes a reactive mechanism to discover P2P routes that meet the specified performance criteria. This mechanism, henceforth referred to as the reactive P2P route discovery, allows the specification of routing constraints [I-D.ietf-roll-routing-metrics], that the discovered routes must satisfy. In some cases, the application requirements or the LLN's topological features allow a router to infer the routing constraints intrinsically. For example, the application may require the end-to-end loss rate and/or latency on the route to be below certain thresholds or the LLN topology may be such that a router can safely assume its destination to be less than a certain number of hops away from itself.

When the existing routes are deemed unsatisfactory but the router does not intrinsically know the routing constraints to be used in P2P route discovery, it may be necessary for the router to determine the aggregated values of the routing metrics along the existing route. This knowledge will allow the router to frame reasonable routing constraints for use in P2P route discovery to determine a better route. For example, if the router determines the aggregate ETX [I-D.ietf-roll-routing-metrics] along an existing route to be "x", it can use "ETX < x*y", where y is a certain fraction, as the routing constraint for use in P2P route discovery. Note that it is important that the routing constraints are not overly strict; otherwise the P2P route discovery may fail even though a route, much better than the one currently being used, exists.

This document specifies a mechanism that enables an RPL router to measure the aggregated values of the routing metrics along an existing route to another RPL router in an LLN, thereby allowing the router to decide if it wants to initiate the reactive discovery of a more optimal route and determine the routing constraints to be used for this purpose.

1.1. Terminology

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

Additionally, this document uses terminology from [I-D.ietf-roll-terminology], [I-D.ietf-roll-rpl] and [I-D.ietf-roll-p2p-rpl]. The following terms, originally defined in [I-D.ietf-roll-p2p-rpl], are redefined in the following manner.

Origin: The origin refers to the router that initiates the measurement process defined in this document and is the start point of the P2P route being measured.

Target: The target refers to the router at the end point of the P2P route being measured.

Intermediate Router: A router, other than the origin and the target, on the P2P route being measured.

2. Overview

The mechanism described in this document can be used by an origin in an RPL domain to measure the aggregated values of the routing metrics along a P2P route to a target within the same RPL domain. Such a route could be a source route or a hop-by-hop route established using RPL [I-D.ietf-roll-rpl] or the reactive P2P route discovery [I-D.ietf-roll-p2p-rpl]. The origin sends a Measurement Request message along the route. The Measurement Request accumulates the values of the routing metrics as it travels towards the target. Upon receiving the Measurement Request, the target unicasts a Measurement Reply message, carrying the accumulated values of the routing metrics, back to the origin. Optionally, the origin may allow an intermediate route to generate the Measurement Reply if it already knows the relevant routing metric values along rest of the route.

3. The Measurement Object (MO)

This document defines two new RPL Control Message types, the Measurement Object (MO), with code 0x06 (to be confirmed by IANA), and the Secure MO, with code 0x86 (to be confirmed by IANA). An MO serves as both Measurement Request and Measurement Reply.

3.1. Format of the base MO

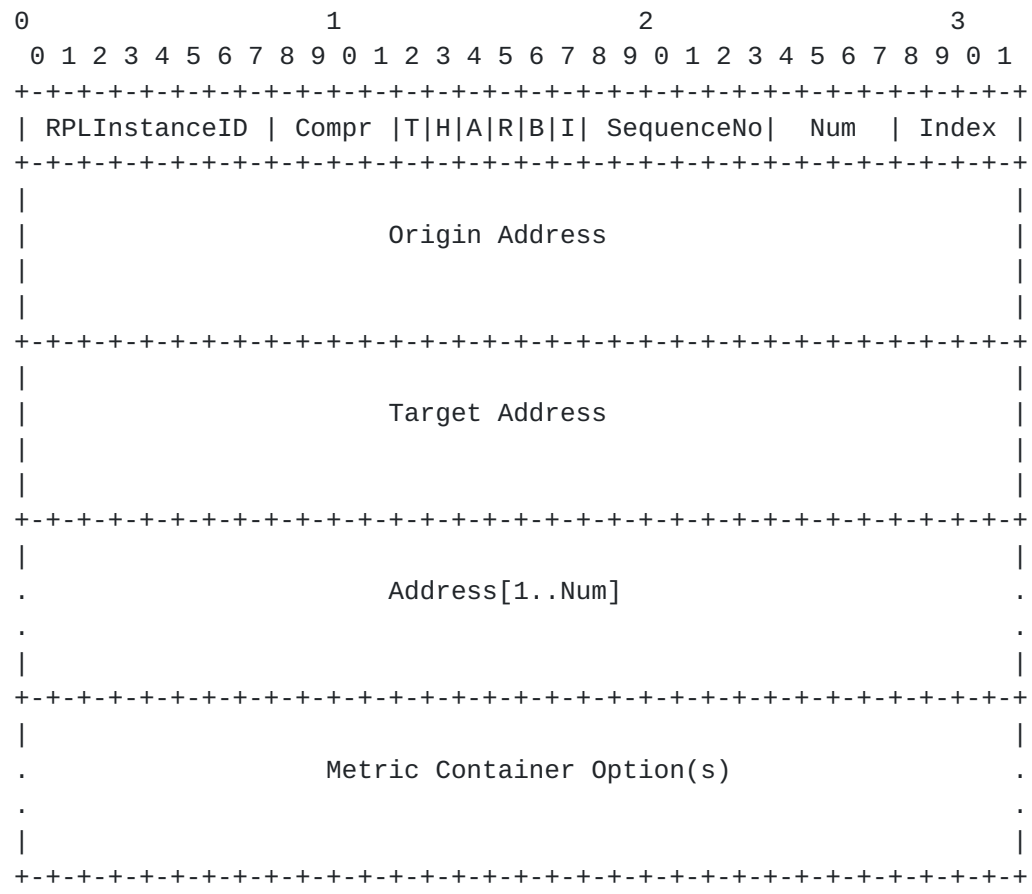

Figure 1: Format of the base Measurement Object (MO)

The format of a base MO is shown in Figure 1. A base MO consists of the following fields:

- RPLInstanceID: Relevant only if the MO travels along a hop-by-hop route. This field identifies the RPLInstanceID of the hop-by-hop route being measured. If the route being measured is a source route, this field MUST be set to 10000000 on transmission and ignored on reception.

- Compr: In many LLN deployments, IPv6 addresses share a well known, common prefix. In such cases, the common prefix can be elided when specifying IPv6 addresses in Origin/Target Address fields and the Address vector. The "Compr" field is a 4-bit unsigned integer that indicates the number of prefix octets that are elided from the IPv6 addresses in Origin/Target Address fields and the Address vector. The Compr value will be 0 if full IPv6 addresses are carried in the Origin/Target Address fields and the Address

vector.

- Type (T): This flag is set if the MO represents a Measurement Request. The flag is cleared if the MO is a Measurement Reply.

- Hop-by-hop (H): This flag is set if the MO travels along a hop-by-hop route. In that case, the hop-by-hop route is identified by the RPLInstanceID and, if the RPLInstanceID is a local value, the Origin Address serving as the DODAGID. This flag is cleared if the MO travels along a source route specified in the Address vector. Note that, in case the P2P route being measured lies along a non-storing DAG, an MO message may travel along a hop-by-hop route till it reaches the DAG's root, which then sends it along a source route to its destination. In that case, the DAG root will reset the H flag and also insert the source route to the destination inside the Address vector.

- Accumulate Route (A): This flag is relevant only if the MO represents a Measurement Request that travels along a hop-by-hop route represented by a local RPLInstanceID. In other words, this flag MAY be set only if T = 1, H = 1 and the RPLInstanceID field has a local value. Otherwise, this flag MUST be cleared. A value 1 in this flag indicates that the Measurement Request MUST accumulate a source route for use by the target to send the Measurement Reply back to the origin. In this case, the intermediate routers MUST add their IPv6 addresses (after eliding Compr number of prefix octets) to the Address vector in the manner specified later.

- Reverse (R): This flag is relevant only if the MO represents a Measurement Request that travels along a source route, specified in the Address vector, to the target. In other words, this flag MAY be set only if T = 1 and H = 0. Otherwise, this flag MUST be cleared. A value 1 in the flag indicates that the Address vector contains a complete source route from the origin to the target, which can be used, after reversal, by the target to source route the Measurement Reply message back to the origin.

- Back Request (B): This flag serves as a request to the target to send a Measurement Request towards the origin. The origin MAY set this flag if it wants to make such a request to the target. On receiving this request, the target MAY generate a Measurement Request to measure the cost of its current (or the most preferred) route to the origin. Receipt of this Measurement Request would allow the origin to know the cost of the back route from the target to itself and thus determine the round-trip cost of reaching the target.

- Intermediate Reply (I): Relevant only if a hop-by-hop route is being measured, this flag serves as a permission to an intermediate router to generate a Measurement Reply if it knows the cost of the rest of the route being measured. The origin MAY set this flag if a hop-by-hop route is being measured (i.e., H = 1) and the origin wants to allow the intermediate routers to generate the Measurement Reply in response to this Measurement Request. Setting this flag may be useful in scenarios where Hop Count [I-D.ietf-roll-routing-metrics] is the routing metric of interest and the origin expects an intermediate router (e.g. the root of a non-storing DAG or a common ancestor of the origin and the target in a storing DAG) to know the Hop Count of the remainder of the route to the target. This flag MUST be cleared if the route being measured is a source route (i.e., H = 0).

- SequenceNo: A 6-bit sequence number, assigned by the origin, that allows the origin to uniquely identify a Measurement Request and the corresponding Measurement Reply.

- Num: This field indicates the number of fields in the Address vector. If the value of this field is zero, the Address vector is not present in the MO.

- Index: If the Measurement Request is traveling along a source route contained in the Address vector (T=1,H=0), this field indicates the index in the Address vector of the next hop on the route. If the Measurement Request is traveling along a hop-by-hop route with a local RPLInstanceID and the A flag is set (T=1,H=1,A=1 and RPLInstanceID field has a local value), this field indicates the index in the Address vector where an intermediate router receiving the MO message must store its IPv6 address. Otherwise, this field MUST be set to zero on transmission and ignored on reception.

- Origin Address: An IPv6 address of the origin after eliding Compr number of prefix octets. If the MO is traveling along a hop-by-hop route and the RPLInstanceID field indicates a local value, the Origin Address field MUST contain the DODAGID value that, along with the RPLInstanceID, uniquely identifies within the RPL domain the hop-by-hop route being measured.

- Target Address: An IPv6 address of the target after eliding Compr number of prefix octets.

- Address[1..Num]: A vector of IPv6 addresses (with Compr number of prefix octets elided) representing a source route to the target:

* Each element in the vector has size (16 - Compr) octets.

* The total number of elements inside the Address vector is given by the Num field.

* When the Measurement Request is traveling along a hop-by-hop route with local RPLInstanceID and has the A flag set, the Address vector is used to accumulate a source route to be used by the target to send the Measurement Reply back to the origin. In this case, the route MUST be accumulated in the forward direction, i.e., from the origin to the target. The target router would reverse this route to obtain a source route from itself to the origin. The IPv6 addresses in the accumulated route MUST be accessible in the backward direction. An intermediate router adding its address to the Address vector MUST ensure that its address does not already exist in the vector.

* When the Measurement Request is traveling along a source route, the Address vector MUST contain a complete route to the target and the IPv6 addresses in the Address vector MUST be accessible in the forward direction, i.e., from the origin to the target. A router (origin or an intermediate router) inserting an Address vector inside an MO MUST ensure that no address appears more than once inside the vector. Each router on the way MUST ensure that the loops do not exist within the source route. The origin may set the R flag in the MO if the route in the Address vector represents a complete route from the origin to the target and this route can be used after reversal by the target to send the Measurement Reply message back to the origin.

* The origin and target addresses MUST NOT be included in the Address vector.

* The Address vector MUST NOT contain any multicast addresses.

o Metric Container Options: An MO MUST contain one or more Metric Container options to accumulate routing metric values for the route being measured.

3.2. Secure MO

A Secure MO message follows the format in Figure 7 of [I-D.ietf-roll-rpl], where the base format is the base MO shown in Figure 1.

4. Originating a Measurement Request

If an origin needs to measure the routing metric values along a P2P route towards a target, it generates an MO message and sets its fields in the manner described below. Additionally, the origin MUST set the T flag to 1 to indicate that the MO represents a Measurement Request. The origin MUST also include one or more Metric Container options inside the MO that carry the routing metric objects of interest. If required, the origin must also initiate these routing metric objects by including the values of the routing metrics for the first hop on the P2P route being measured.

After setting the MO fields as described below, the origin MUST unicast the MO message to the next hop on the P2P route.

4.1. To Measure A Hop-by-hop Route with a Global RPLInstanceID

If a hop-by-hop route with a global RPLInstanceID is being measured, the MO message MUST NOT contain the Address vector and the following MO fields MUST be set in the manner specified below:

- Hop-by-hop (H): This flag MUST be set;
- Accumulate Route (A): This flag MUST be cleared;
- Reverse (R): This flag MUST be cleared;
- Back Request (B): This flag MAY be set if the origin wants to request the target to generate a Measurement Request back to itself;
- Intermediate Reply (I): This flag MAY be set if the origin wants to permit the intermediate routers to generate the Measurement Reply on the target's behalf;
- Num: This field MUST be set to zero;
- Index: This field MUST be set to zero.

4.2. To Measure A Hop-by-hop Route with a Local RPLInstanceID

If a hop-by-hop route with a local RPLInstanceID is being measured and the MO is not accumulating a source route for the target's use, the MO message MUST NOT contain the Address vector and the following MO fields MUST be set in the manner specified below:

- Hop-by-hop (H): This flag MUST be set;

- Accumulate Route (A): This flag MUST be cleared;
- Reverse (R): This flag MUST be cleared;
- Back Request (B): This flag MAY be set if the origin wants to request the target to generate a Measurement Request back to itself;
- Intermediate Reply (I): This flag MAY be set if the origin wants to permit the intermediate routers to generate the Measurement Reply on the target's behalf;
- Num: This field MUST be set to zero;
- Index: This field MUST be set to zero;
- Origin Address: This field MUST contain the DODAGID value (after eliding Compr number of prefix octets) associated with the route being measured.

If a hop-by-hop route with a local RPLInstanceID is being measured and the origin desires the MO to accumulate a source route for the target to send the Measurement Reply message back, it MUST set the following MO fields in the manner specified below:

- Hop-by-hop (H): This flag MUST be set;
- Accumulate Route (A): This flag MUST be set;
- Reverse (R): This flag MUST be cleared;
- Back Request (B): This flag MAY be set if the origin wants to request the target to generate a Measurement Request back to itself;
- Intermediate Reply (I): This flag MAY be set if the origin wants to permit the intermediate routers to generate the Measurement Reply on the target's behalf;
- Address vector: The Address vector must be large enough to accomodate a complete source route from the origin to the target. All the bits in the Address vector field MUST be set to zero;
- Num: This field MUST specify the number of address elements that can fit inside the Address vector;
- Index: This field MUST be set to 1;

- Origin Address: This field MUST contain the DODAGID value (after eliding Compr number of prefix octets) associated with the route being measured.

4.3. To Measure A Source Route

If a source route is being measured, the origin MUST set the following MO fields in the manner specified below:

- RPLInstanceID: This field MUST be set to 10000000;
- Hop-by-hop (H): This flag MUST be cleared;
- Accumulate Route (A): This flag MUST be cleared;
- Reverse (R): This flag MUST be set if the source route in the Address vector can be reversed and used by the target to source route the Measurement Reply message back to the origin. Otherwise, this flag MUST be cleared;
- Back Request (B): This flag MAY be set if the origin wants to request the target to generate a Measurement Request back to itself;
- Intermediate Reply (I): This flag MUST be cleared.
- Address vector:
  - The Address vector MUST contain a complete route from the origin to the target (excluding the origin and the target);
  - The IPv6 addresses (with Compr prefix octets elided) in the Address vector MUST be accessible in the forward direction, i.e., from the origin to the target;
  - To prevent loops in the source route, the origin MUST ensure that
    - Any IPv6 address MUST NOT appear more than once in the Address vector;
    - If the Address vector includes multiple IPv6 addresses assigned to the origin's interfaces, such addresses MUST appear back to back inside the Address vector.
  - Each address appearing in the Address vector MUST be a unicast address.

- Num: This field MUST be set to indicate the number of elements in the Address vector;

- Index: This field MUST be set to 1.

The origin MUST NOT send the packet further if the next hop address on the source route is not on-link.

5. Processing a Measurement Request at an Intermediate Router

A router MAY discard a received MO with no further processing to meet any policy-related goal. Such policy goals may include the need to reduce the router's CPU load or to enhance its battery life.

On receiving an MO, if a router chooses to process the packet further, it MUST check if one of its IPv6 addresses is listed as either the Origin or the Target Address. If not, the router considers itself an Intermediate Router and MUST process the received MO in the following manner.

An intermediate router MUST discard the packet with no further processing if the received MO is not a Measurement Request.

If the I flag is set in the received MO and the intermediate router knows the values of the routing metrics, specified in the Metric Container, for the remainder of the route, it MAY generate a Measurement Reply on the target's behalf in the manner specified in Section 6 (after including in the Measurement Reply the relevant routing metric values for the complete route being measured). Otherwise, the intermediate router MUST process the received MO in the following manner.

The router MUST determine the next hop on the P2P route being measured in the manner described below. The router MUST drop the MO with no further processing and MAY send an ICMPv6 Destination Unreachable (with Code 0 - No Route To Destination) error message to the source of the message if it can not determine the next hop for the message.

After determining the next hop, the router MUST update the routing metric objects, contained in the Metric Container options inside the MO, either by updating the aggregated value for the routing metric or by attaching the local values for the metric inside the object. After updating the routing metrics, the router MUST unicast the MO to the next hop.

5.1. Determining Next Hop For An MO Measuring A Source Route

In case the received MO is measuring a source route (H=0), the router MUST increment the Index field and use the Address[Index] element as the next hop. If Index is greater than Num, the router MUST use the Target Address as the next hop.

An intermediate router MUST discard the MO packet with no further processing if the next hop address is not on-link or is not a unicast address. To prevent loops, an intermediate router MUST check if the Address vector includes multiple IPv6 addresses assigned to the router's interfaces and if such addresses do not appear back to back inside the Address vector. In this case, the router MUST discard the MO packet with no further processing. An MO message MUST NOT leave the RPL domain where it originated. Hence, an intermediate router MUST discard an MO message traveling along a source route if the next hop on the way does not lie within the RPL domain.

5.2. Determining Next Hop For An MO Measuring A Hop-by-hop Route

If the received MO is measuring a hop-by-hop route (H=1), the router MUST use the RPLInstanceID, the Target Address and, if RPLInstanceID is a local value, the DODAGID (same as the Origin Address) to determine the next hop for the MO. Moreover,

- If the RPLInstanceID of the hop-by-hop route is a local value and the A flag is set, the router MUST check if the Address vector already contains one of its IPv6 addresses. If yes, the router MUST discard the packet with no further processing. Otherwise, the router MUST store one of its IPv6 addresses (after eliding Compr prefix octets) at location Address[Index] and then increment the Index field.

- If the router is the root of the non-storing DAG along which the received MO message has been traveling, the router MUST do the following:

  * Reset the H, A and R flags.

  * Insert a source route to the target inside the Address vector as per the following rules:

    + The Address vector MUST contain a complete route from the router to the target (excluding the router and the target);

    + The IPv6 addresses (with Compr prefix octets elided) in the Address vector MUST be accessible in the forward direction, i.e., towards the target;

+ To prevent loops in the source route, the router MUST ensure that

  - Any IPv6 address MUST NOT appear more than once in the Address vector;

  - If the Address vector includes multiple IPv6 addresses assigned to the router's interfaces, such addresses MUST appear back to back inside the Address vector.

+ Each address appearing in the Address vector MUST be a unicast address.

* Specify in the Num field the number of address elements in the Address vector.

* Set the Index field to 1.

6. Processing a Measurement Request at the Target

On receiving an MO, if a router chooses to process the packet further and finds one of its IPv6 addresses listed as the Target Address, it MUST process the received MO in the following manner.

The target MUST discard the packet with no further processing if the received MO is not a Measurement Request.

The target MUST update the routing metric objects in the Metric Container options if required and MAY note the measured values for the complete route if desired.

The target MUST generate a Measurement Reply message. The received Measurement Request message can be trivially converted into the Measurement Reply by reseting the T flag to zero. The target MAY remove the Address vector from the Measurement Reply if desired. The target MUST then unicast the Measurement Reply back to the origin:

o If the Measurement Request traveled along a DAG with a global RPLInstanceID, the Measurement Reply MAY be unicast back to the origin along the same DAG.

o If the Measurement Request traveled along a hop-by-hop route with a local RPLInstanceID and the A flag inside the received message is set, the target MAY reverse the source route contained in the Address vector and use it to send the Measurement Reply back to the origin.

- If the Measurement Request traveled along a source route and the R flag inside the received message is set, the target MAY reverse the source route contained in the Address vector and use it to send the Measurement Reply back to the origin.

If the B flag is set in the received Measurement Request, the target MAY generate a new Measurement Request to measure the cost of its current (or the most preferred) route to the origin. The routing metrics used in the new Measurement Request MUST include the routing metrics specified in the received Measurement Request.

7. Processing a Measurement Reply at the Origin

When a router receives an MO, it examines if one of its IPv6 addresses is listed as the Origin Address. If yes, the router MUST process the received message in the following manner.

The origin MUST discard the packet with no further processing if the received MO is not a Measurement Reply or if the origin has no recollection of sending a Measurement Request with the sequence number listed in the received MO.

The origin SHOULD examine the routing metric objects inside the Metric Container options to evaluate the quality of the measured P2P route. If a routing metric object contains local metric values recorded by routers on the route, the origin MAY aggregate these local values into an end-to-end value as per the aggregation rules for the metric.

8. Security Considerations

The mechanism defined in this document can potentially be used by a compromised router to generate bogus measurement requests to arbitrary target routers. Such bogus measurement requests may cause processing overload in the routers in the network, drain their batteries and cause traffic congestion in the network. Note that some of these problems would occur even if the compromised router were to generate bogus data traffic to arbitrary destinations.

Since a Measurement Request can travel along a source route specified in the Address vector, some of the security concerns that led to the deprecation of Type 0 routing header [RFC5095] may be valid here. To address such concerns, the mechanism described in this document includes several remedies:

- This document requires that a route inserted inside the Address vector must be a strict source route and must not include any multicast addresses.

- This document requires that an MO message must not cross the boundaries of the RPL domain where it is originated. Hence, any security problems associated with the mechanism would be limited to the RPL domain where the MO message is generated.

- A router must drop a received MO message if the next hop address is not on-link or if it is not a unicast address.

- A router must check the source route inside the Address vector of each received MO message to ensure that it does not contain a loop involving the router. The router must drop the received packet if the source route does contain such a loop. This and the previous rule protect the network against some of the security concerns even if a compromised node inserts the Address vector inside the MO message.

9. IANA Considerations

IANA is requested to allocate a new code point in the "RPL Control Codes" registry for the "Measurement Object" described in this document.

Code	Description	Reference
0x06	Measurement Object	This document
0x86	Secure Measurement Object	This document

RPL Control Codes

10. Acknowledgements

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Authors' Addresses

Mukul Goyal (editor)
University of Wisconsin Milwaukee
3200 N Cramer St
Milwaukee, WI 53211
USA

Phone: +1 414 2295001
Email: mukul@uwm.edu

Emmanuel Baccelli
INRIA

Phone: +33-169-335-511
Email: Emmanuel.Baccelli@inria.fr
URI: http://www.emmanuelbaccelli.org/

Anders Brandt
Sigma Designs
Emdrupvej 26A, 1.
Copenhagen, Dk-2100
Denmark

Phone: +45 29609501
Email: abr@sdesigns.dk

Jerald Martocci
Johnson Controls
507 E Michigan Street
Milwaukee 53202
USA

Phone: +1 414 524 4010
Email: jerald.p.martocci@jci.com