CoRE Working Group
Internet-Draft
Intended status: Informational
Expires: January 14, 2021

M. Koster
SmartThings
B. Silverajan, Ed.
Tampere University

July 13, 2020

Dynamic Resource Linking for Constrained RESTful Environments
draft-ietf-core-dynlink-11

Abstract

This specification defines Link Bindings, which provide dynamic linking of state updates between resources, either on an endpoint or between endpoints, for systems using CoAP (RFC7252). This specification also defines Conditional Notification Attributes that work with Link Bindings or with CoAP Observe (RFC7641).

Editor note

The git repository for the draft is found at https://github.com/core-wg/dynlink

Status of This Memo

This Internet-Draft is submitted in full conformance with the provisions of BCP 78 and BCP 79.

Internet-Drafts are working documents of the Internet Engineering Task Force (IETF). Note that other groups may also distribute working documents as Internet-Drafts. The list of current Internet-Drafts is at https://datatracker.ietf.org/drafts/current/.

Internet-Drafts are draft documents valid for a maximum of six months and may be updated, replaced, or obsoleted by other documents at any time. It is inappropriate to use Internet-Drafts as reference material or to cite them other than as "work in progress."

This Internet-Draft will expire on January 14, 2021.

Table of Contents

1. Introduction

IETF Standards for machine to machine communication in constrained environments describe a REST protocol [RFC7252] and a set of related information standards that may be used to represent machine data and machine metadata in REST interfaces. CoRE Link-format [RFC6690] is a standard for doing Web Linking [RFC8288] in constrained environments.

This specification introduces the concept of a Link Binding, which defines a new link relation type to create a dynamic link between resources over which state updates are conveyed. Specifically, a Link Binding is a unidirectional link for binding the states of source and destination resources together such that updates to one are sent over the link to the other. CoRE Link Format representations are used to configure, inspect, and maintain Link Bindings. This specification additionally defines Conditional Notification Attributes for use with Link Bindings and with CoRE Observe [RFC7641].

2. 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 BCP 14 [RFC2119] [RFC8174] when, and only when, they appear in all capitals, as shown here.

This specification requires readers to be familiar with all the terms and concepts that are discussed in [RFC8288] and [RFC6690]. This specification makes use of the following additional terminology:

Link Binding: A unidirectional logical link between a source resource and a destination resource, over which state information is synchronized.

State Synchronization: Depending on the binding method (Polling, Observe, Push) different REST methods may be used to synchronize the resource values between a source and a destination. The process of using a REST method to achieve this is defined as "State Synchronization". The endpoint triggering the state synchronization is the synchronization initiator.

Notification Band: A resource value range that results in state sychronization. The value range may be bounded by a minimum and maximum value or may be unbounded having either a minimum or maximum value.

3. Conditional Notification Attributes

3.1. Attribute Definitions

This specification defines Conditional Notification Attributes, which provide for fine-grained control of notification and state synchronization when using CoRE Observe [RFC7641] or Link Bindings (see Section 4). Conditional Notification Attributes define the conditions that trigger a notification.

When resource interfaces following this specification are made available over CoAP, the CoAP Observation mechanism [RFC7641] MAY also be used to observe any changes in a resource, and receive asynchronous notifications as a result. A resource marked as Observable in its link description SHOULD support these Conditional Notification Attributes.

The set of parameters defined here allow a client to control how often a client is interested in receiving notifications and how much a resource value should change for the new representation to be interesting.

One or more Notification Attributes MAY be included as query parameters in an Observe request.

These attributes are defined below:

Attribute	Parameter	Value
Minimum Period (s)	pmin	xs:decimal (>0)
Maximum Period (s)	pmax	xs:decimal (>0)
Change Step	st	xs:decimal (>0)
Greater Than	gt	xs:decimal
Less Than	lt	xs:decimal
Notification Band	band	xs:boolean

Table 1: Conditional Notification Attributes

Conditional Notification Attributes SHOULD be evaluated on all potential notifications from a resource, whether resulting from an

internal server-driven sampling process or from external update requests to the server.

Note: In this draft, we assume that there are finite quantization effects in the internal or external updates to the value of a resource; specifically, that a resource may be updated at any time with any valid value. We therefore avoid any continuous-time assumptions in the description of the Conditional Notification Attributes and instead use the phrase "sampled value" to refer to a member of a sequence of values that may be internally observed from the resource state over time.

3.1.1. Minimum Period (pmin)

When present, the minimum period indicates the minimum time, in seconds, between two consecutive notifications (whether or not the resource value has changed). In the absence of this parameter, the minimum period is up to the server. The minimum period MUST be greater than zero otherwise the receiver MUST return a CoAP error code 4.00 "Bad Request" (or equivalent).

A server MAY report the last sampled value that occured during the pmin interval, after the pmin interval expires.

Note: Due to finite quantization effects, the time between notifications may be greater than pmin even when the sampled value changes within the pmin interval. Pmin may or may not be used to drive the internal sampling process.

3.1.2. Maximum Period (pmax)

When present, the maximum period indicates the maximum time, in seconds, between two consecutive notifications (whether or not the resource value has changed). In the absence of this parameter, the maximum period is up to the server. The maximum period MUST be greater than zero and MUST be greater than the minimum period parameter (if present) otherwise the receiver MUST return a CoAP error code 4.00 "Bad Request" (or equivalent).

3.1.3. Change Step (st)

When present, the change step indicates how much the value of a resource SHOULD change before triggering a notification, compared to the value of the previous notification. Upon reception of a query including the st attribute, the most recently sampled value of the resource is reported, and then set as the last reported value (last_rep_v). When a subsequent sample or update of the resource value differs from the last reported value by an amount, positive or

negative, greater than or equal to st, and the time for pmin has elapsed since the last notification, a notification is sent and the last reported value is updated to the value sent in the notification. The change step MUST be greater than zero otherwise the receiver MUST return a CoAP error code 4.00 "Bad Request" (or equivalent).

The Change Step parameter can only be supported on resources with a scalar numeric value.

Note: Due to sampling and other constraints, e.g. pmin, the resource value received in two sequential notifications may differ by more than st.

3.1.4. Greater Than (gt)

When present, Greater Than indicates the upper limit value the sampled value SHOULD cross before triggering a notification. A notification is sent whenever the sampled value crosses the specified upper limit value, relative to the last reported value, and the time fpr pmin has elapsed since the last notification. The sampled value is sent in the notification. If the value continues to rise, no notifications are generated as a result of gt. If the value drops below the upper limit value then a notification is sent, subject again to the pmin time.

The Greater Than parameter can only be supported on resources with a scalar numeric value.

3.1.5. Less Than (lt)

When present, Less Than indicates the lower limit value the resource value SHOULD cross before triggering a notification. A notification is sent when the samples value crosses the specified lower limit value, relative to the last reported value, and the time fpr pmin has elapsed since the last notification. The sampled value is sent in the notification. If the value continues to fall no notifications are generated as a result of lt. If the value rises above the lower limit value then a new notification is sent, subject to the pmin time..

The Less Than parameter can only be supported on resources with a scalar numeric value.

3.1.6. Notification Band (band)

The notification band attribute allows a bounded or unbounded (based on a minimum or maximum) value range that may trigger multiple notifications. This enables use cases where different ranges results

in differing behaviour. For example: monitoring the temperature of machinery. Whilst the temperature is in the normal operating range only periodic observations are needed. However as the temperature moves to more abnormal ranges more frequent synchronization/reporting may be needed.

Without a notification band, a transition across a less than (lt), or greater than (gt) limit only generates one notification. This means that it is not possible to describe a case where multiple notifications are sent so long as the limit is exceeded.

The band attribute works as a modifier to the behaviour of gt and lt. Therefore, if band is present in a query, gt, lt or both, MUST be included.

When band is present with the lt attribute, it defines the lower bound for the notification band (notification band minimum). Notifications occur when the resource value is equal to or above the notification band minimum. If lt is not present there is no minimum value for the band.

When band is present with the gt attribute, it defines the upper bound for the notification band (notification band maximum). Notifications occur when the resource value is equal to or below the notification band maximum. If gt is not present there is no maximum value for the band.

If band is present with both the gt and lt attributes, notification occurs when the resource value is greater than or equal to gt or when the resource value is less than or equal to lt.

If a band is specified in which the value of gt is less than that of lt, in-band notification occurs. That is, notification occurs whenever the resource value is between the gt and lt values, including equal to gt or lt.

If the band is specified in which the value of gt is greater than that of lt, out-of-band notification occurs. That is, notification occurs when the resource value not between the gt and lt values, excluding equal to gt and lt.

The Notification Band parameter can only be supported on resources with a scalar numeric value.

3.2. Server processing of Conditional Notification Attributes

Pmin, pmax, st, gt, lt and band may be present in the same query. Howver, they are not defined at multiple prioritization levels. The server sends a notification whenever any of the parameter conditions are met, upon which it updates its last notification value and time to prepare for the next notification. Only one notification occurs when there are multiple conditions being met at the same time. The reference code below illustrates the logic to determine when a notification is to be sent.

```
bool notifiable( Resource * r ) {

#define BAND r->band
#define SCALAR_TYPE ( num_type == r->type )
#define STRING_TYPE ( str_type == r->type )
#define BOOLEAN_TYPE ( bool_type == r->type )
#define PMIN_EX ( r->last_sample_time - r->last_rep_time >= r->pmin )
#define PMAX_EX ( r->last_sample_time - r->last_rep_time > r->pmax )
#define LT_EX ( r->v < r->lt ^ r->last_rep_v < r->lt )
#define GT_EX ( r->v > r->gt ^ r->last_rep_v > r->gt )
#define ST_EX ( abs( r->v - r->last_rep_v ) >= r->st )
#define IN_BAND ( ( r->gt <= r->v && r->v <= r->lt ) || ( r->lt <= r->gt && r->gt
 <= r->v ) || ( r->v <= r->lt && r->lt <= r->gt ) )
#define VB_CHANGE ( r->vb != r->last_rep_vb )
#define VS_CHANGE ( r->vs != r->last_rep_vs )

  return (
    PMIN_EX &&
    ( SCALAR_TYPE ?
      ( ( !BAND && ( GT_EX || LT_EX || ST_EX || PMAX_EX ) ) ||
        ( BAND && IN_BAND && ( ST_EX || PMAX_EX) ) )
    : STRING_TYPE ?
      ( VS_CHANGE || PMAX_EX )
    : BOOLEAN_TYPE ?
      ( VB_CHANGE || PMAX_EX )
    : false )
  );
}
```

Figure 1: Code logic for conditional notification attribute interactions

4. Link Bindings

In a M2M RESTful environment, endpoints may directly exchange the content of their resources to operate the distributed system. For example, a light switch may supply on-off control information that may be sent directly to a light resource for on-off control.

Beforehand, a configuration phase is necessary to determine how the resources of the different endpoints are related to each other. This can be done either automatically using discovery mechanisms or by means of human intervention and a so-called commissioning tool.

In this specification such an abstract relationship between two resources is defined, called a Link Binding. The configuration phase necessitates the exchange of binding information, so a format recognized by all CoRE endpoints is essential. This specification defines a format based on the CoRE Link-Format to represent binding information along with the rules to define a binding method which is a specialized relationship between two resources.

The purpose of such a binding is to synchronize content updates between a source resource and a destination resource. The destination resource MAY be a group resource if the authority component of the destination URI contains a group address (either a multicast address or a name that resolves to a multicast address). Since a binding is unidirectional, the binding entry defining a relationship is present only on one endpoint. The binding entry may be located either on the source or the destination endpoint depending on the binding method.

Conditional Notification Attributes defined in Section 3 can be used with Link Bindings in order to customize the notification behavior and timing.

4.1. The "bind" attribute and Binding Methods

A binding method defines the rules to generate the network-transfer exchanges that synchronize state between source and destination resources. By using REST methods content is sent from the source resource to the destination resource.

This specification defines a new CoRE link attribute "bind". This is the identifier for a binding method which defines the rules to synchronize the destination resource. This attribute is mandatory.

Attribute	Parameter	Value
Binding method	bind	xs:string

Table 2: The bind attribute

The following table gives a summary of the binding methods defined in this specification.

Name	Identifier	Location	Method
Polling	poll	Destination	GET
Observe	obs	Destination	GET + Observe
Push	push	Source	PUT
Execute	exec	Source	POST

Table 3: Binding Method Summary

The description of a binding method defines the following aspects:

Identifier: This is the value of the "bind" attribute used to identify the method.

Location: This information indicates whether the binding entry is stored on the source or on the destination endpoint.

REST Method: This is the REST method used in the Request/Response exchanges.

Conditional Notification: How Conditional Notification Attributes are used in the binding.

The binding methods are described in more detail below.

4.1.1. Polling

The Polling method consists of sending periodic GET requests from the destination endpoint to the source resource and copying the content to the destination resource. The binding entry for this method MUST be stored on the destination endpoint. The destination endpoint MUST ensure that the polling frequency does not exceed the limits defined by the pmin and pmax attributes of the binding entry. The copying process MAY filter out content from the GET requests using value-based conditions (e.g based on the Change Step, Less Than, Greater Than attributes).

4.1.2. Observe

The Observe method creates an observation relationship between the destination endpoint and the source resource. On each notification the content from the source resource is copied to the destination resource. The creation of the observation relationship requires the

CoAP Observation mechanism [RFC7641] hence this method is only permitted when the resources are made available over CoAP. The binding entry for this method MUST be stored on the destination endpoint. The binding conditions are mapped as query parameters in the Observe request (see Section 3).

4.1.3. Push

The Push method can be used to allow a source endpoint to replace an outdated resource state at the destination with a newer representation. When the Push method is assigned to a binding, the source endpoint sends PUT requests to the destination resource when the Conditional Notification Attributes are satisfied for the source resource. The source endpoint SHOULD only send a notification request if any included Conditional Notification Attributes are met. The binding entry for this method MUST be stored on the source endpoint.

4.1.4. Execute

An alternative means for a source endpoint to deliver change-of-state notifications to a destination resource is to use the Execute Method. While the Push method simply updates the state of the destination resource with the representation of the source resource, Execute can be used when the destination endpoint wishes to receive all state changes from a source. This allows, for example, the existence of a resource collection consisting of all the state changes at the destination endpoint. When the Execute method is assigned to a binding, the source endpoint sends POST requests to the destination resource when the Conditional Notification Attributes are satisfied for the source resource. The source endpoint SHOULD only send a notification request if any included Conditional Notification Attributes are met. The binding entry for this method MUST be stored on the source endpoint.

Note: Both the Push and the Execute methods are examples of Server Push mechanisms that are being researched in the Thing-to-Thing Research Group (T2TRG) [I-D.irtf-t2trg-rest-iot].

4.2. Link Relation

Since Binding involves the creation of a link between two resources, Web Linking and the CoRE Link-Format used to represent binding information. This involves the creation of a new relation type, "boundto". In a Web link with this relation type, the target URI contains the location of the source resource and the context URI points to the destination resource.

5. Binding Table

The Binding Table is a special resource that describes the bindings on an endpoint. An endpoint offering a representation of the Binding Table resource SHOULD indicate its presence and enable its discovery by advertising a link at "/.well-known/core" [RFC6690]. If so, the Binding Table resource MUST be discoverable by using the Resource Type (rt) 'core.bnd'.

The Methods column defines the REST methods supported by the Binding Table, which are described in more detail below.

Resource	rt=	Methods	Content-Format
Binding Table	core.bnd	GET, PUT	link-format

Table 4: Binding Table Description

The REST methods GET and PUT are used to manipulate a Binding Table. A GET request simply returns the current state of a Binding Table. A request with a PUT method and a content format of application/link-format is used to clear the bindings to the table or replaces its entire contents. All links in the payload of a PUT rquest MUST have a relation type "boundto".

The following example shows requests for discovering, retrieving and replacing bindings in a binding table.

```
Req: GET /.well-known/core?rt=core.bnd (application/link-format)
Res: 2.05 Content (application/link-format)
</bnd/>;rt=core.bnd;ct=40

Req: GET /bnd/
Res: 2.05 Content (application/link-format)
<coap://sensor.example.com/a/switch1/>;
        rel=boundto;anchor=/a/fan,;bind="obs",
<coap://sensor.example.com/a/switch2/>;
        rel=boundto;anchor=/a/light;bind="obs"

Req: PUT /bnd/ (Content-Format: application/link-format)
<coap://sensor.example.com/s/light>;
  rel="boundto";anchor="/a/light";bind="obs";pmin=10;pmax=60
Res: 2.04 Changed

Req: GET /bnd/
Res: 2.05 Content (application/link-format)
<coap://sensor.example.com/s/light>;
  rel="boundto";anchor="/a/light";bind="obs";pmin=10;pmax=60
```

Figure 2: Binding Table Example

Additional operations on the Binding Table can be specified in future documents. Such operations can include, for example, the usage of the iPATCH or PATCH methods [RFC8132] for fine-grained addition and removal of individual bindings or binding subsets.

6. Implementation Considerations

When using multiple resource bindings (e.g. multiple Observations of resource) with different bands, consideration should be given to the resolution of the resource value when setting sequential bands. For example: Given BandA (Abmn=10, Bbmx=20) and BandB (Bbmn=21, Bbmx=30). If the resource value returns an integer then notifications for values between and inclusive of 10 and 30 will be triggered. Whereas if the resolution is to one decimal point (0.1) then notifications for values 20.1 to 20.9 will not be triggered.

The use of the notification band minimum and maximum allow for a synchronization whenever a change in the resource value occurs. Theoretically this could occur in-line with the server internal sample period for the determining the resource value. Implementors SHOULD consider the resolution needed before updating the resource, e.g. updating the resource when a temperature sensor value changes by 0.001 degree versus 1 degree.

The initiation of a Link Binding can be delegated from a client to a link state machine implementation, which can be an embedded client or a configuration tool. Implementation considerations have to be given to how to monitor transactions made by the configuration tool with regards to Link Bindings, as well as any errors that may arise with establishing Link Bindings in addition to established Link Bindings.

7. Security Considerations

Consideration has to be given to what kinds of security credentials the state machine of a configuration tool or an embedded client needs to be configured with, and what kinds of access control lists client implementations should possess, so that transactions on creating Link Bindings and handling error conditions can be processed by the state machine.

8. IANA Considerations

8.1. Resource Type value 'core.bnd'

This specification registers a new Resource Type Link Target Attribute 'core.bnd' in the Resource Type (rt=) registry established as per [RFC6690].

Attribute Value: core.bnd

Description: See Section 5. This attribute value is used to discover the resource representing a binding table, which describes the link bindings between source and destination resources for the purposes of synchronizing their content.

Reference: This specification. Note to RFC editor: please insert the RFC of this specification.

Notes: None

8.2. Link Relation Type

This specification registers the new "boundto" link relation type as per [RFC8288].

Relation Name: boundto

Description: The purpose of a boundto relation type is to indicate that there is a binding between a source resource and a destination resource for the purposes of synchronizing their content.

Reference: This specification. Note to RFC editor: please insert the RFC of this specification.

Notes: None

Application Data: None

9. Acknowledgements

Acknowledgement is given to colleagues from the SENSEI project who were critical in the initial development of the well-known REST interface concept, to members of the IPSO Alliance where further requirements for interface types have been discussed, and to Szymon Sasin, Cedric Chauvenet, Daniel Gavelle and Carsten Bormann who have provided useful discussion and input to the concepts in this specification. Christian Amsuss supplied a comprehensive review of draft -06. Hannes Tschofenig and Mert Ocak highlighted syntactical corrections in the usage of pmax and pmin in a query. Discussions with Ari Keraenen led to the addition of an extra binding method supporting POST operations.

10. Contributors

Christian Groves
Australia
email: cngroves.std@gmail.com

Zach Shelby
ARM
Vuokatti
FINLAND
phone: +358 40 7796297
email: zach.shelby@arm.com

Matthieu Vial
Schneider-Electric
Grenoble
France
phone: +33 (0)47657 6522
eMail: matthieu.vial@schneider-electric.com

Jintao Zhu
Huawei
Xi'an, Shaanxi Province
China
email: jintao.zhu@huawei.com

11. Changelog

draft-ietf-core-dynlink-11

- Updates to author list

draft-ietf-core-dynlink-10

- Binding methods now support both POST and PUT operations for server push.

draft-ietf-core-dynlink-09

- Corrections in Table 1, Table 2, Figure 2.
- Clarifications for additional operations to binding table added in section 5
- Additional examples in Appendix A

draft-ietf-core-dynlink-08

- Reorganize the draft to introduce Conditional Notification Attributes at the beginning
- Made pmin and pmax type xs:decimal to accommodate fractional second timing
- updated the attribute descriptions. lt and gt notify on all crossings, both directions
- updated Binding Table description, removed interface description but introduced core.bnd rt attribute value

draft-ietf-core-dynlink-07

- Added reference code to illustrate attribute interactions for observations

draft-ietf-core-dynlink-06

- Document restructure and refactoring into three main sections
- Clarifications on band usage
- Implementation considerations introduced
- Additional text on security considerations

draft-ietf-core-dynlink-05

- Addition of a band modifier for gt and lt, adapted from draft-groves-core-obsattr
- Removed statement prescribing gt MUST be greater than lt

draft-ietf-core-dynlink-03

- General: Reverted to using "gt" and "lt" from "gth" and "lth" for this draft owing to concerns raised that the attributes are already used in LwM2M with the original names "gt" and "lt".
- New author and editor added.

draft-ietf-core-dynlink-02

- General: Changed the name of the greater than attribute "gt" to "gth" and the name of the less than attribute "lt" to "lth" due to conlict with the core resource directory draft lifetime "lt" attribute.
- Clause 6.1: Addressed the editor's note by changing the link target attribute to "core.binding".
- Added Appendix A for examples.

draft-ietf-core-dynlink-01

- General: The term state synchronization has been introduced to describe the process of synchronization between destination and source resources.
- General: The document has been restructured the make the information flow better.
- Clause 3.1: The descriptions of the binding attributes have been updated to clarify their usage.
- Clause 3.1: A new clause has been added to discuss the interactions between the resources.
- Clause 3.4: Has been simplified to refer to the descriptions in 3.1. As the text was largely duplicated.
- Clause 4.1: Added a clarification that individual resources may be removed from the binding table.

- Clause 6: Formailised the IANA considerations.

draft-ietf-core-dynlink Initial Version 00:

- This is a copy of draft-groves-core-dynlink-00

draft-groves-core-dynlink Draft Initial Version 00:

- This initial version is based on the text regarding the dynamic linking functionality in I.D.ietf-core-interfaces-05.
- The WADL description has been dropped in favour of a thorough textual description of the REST API.

12. References

12.1. Normative References

[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>.

[RFC6690] Shelby, Z., "Constrained RESTful Environments (CoRE) Link Format", RFC 6690, DOI 10.17487/RFC6690, August 2012, <https://www.rfc-editor.org/info/rfc6690>.

[RFC8174] Leiba, B., "Ambiguity of Uppercase vs Lowercase in RFC 2119 Key Words", BCP 14, RFC 8174, DOI 10.17487/RFC8174, May 2017, <https://www.rfc-editor.org/info/rfc8174>.

[RFC8288] Nottingham, M., "Web Linking", RFC 8288, DOI 10.17487/RFC8288, October 2017, <https://www.rfc-editor.org/info/rfc8288>.

12.2. Informative References

[I-D.irtf-t2trg-rest-iot] Keranen, A., Kovatsch, M., and K. Hartke, "RESTful Design for Internet of Things Systems", draft-irtf-t2trg-rest-iot-06 (work in progress), May 2020.

[RFC7252] Shelby, Z., Hartke, K., and C. Bormann, "The Constrained Application Protocol (CoAP)", RFC 7252, DOI 10.17487/RFC7252, June 2014, <https://www.rfc-editor.org/info/rfc7252>.

[RFC7641] Hartke, K., "Observing Resources in the Constrained Application Protocol (CoAP)", RFC 7641, DOI 10.17487/RFC7641, September 2015, <https://www.rfc-editor.org/info/rfc7641>.

[RFC8132] van der Stok, P., Bormann, C., and A. Sehgal, "PATCH and FETCH Methods for the Constrained Application Protocol (CoAP)", RFC 8132, DOI 10.17487/RFC8132, April 2017, <https://www.rfc-editor.org/info/rfc8132>.

Appendix A. Examples

This appendix provides some examples of the use of binding attribute / observe attributes.

Note: For brevity the only the method or response code is shown in the header field.

A.1. Minimum Period (pmin) example

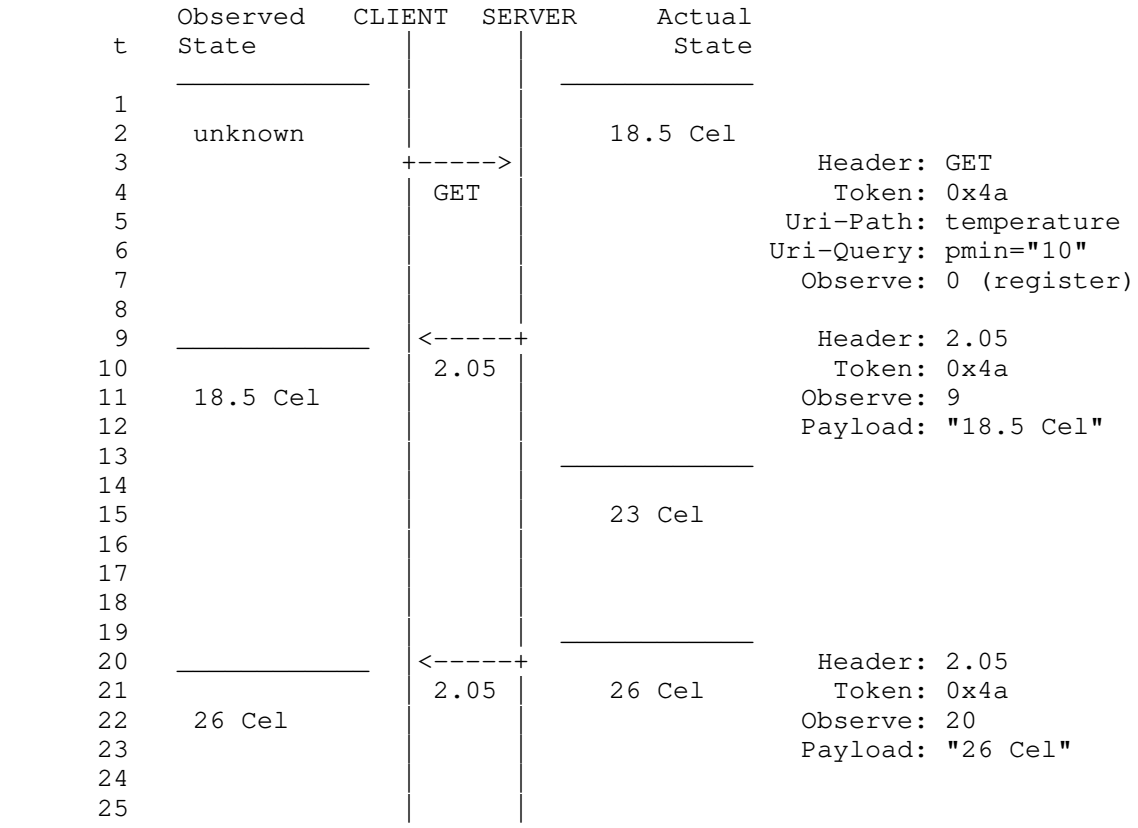
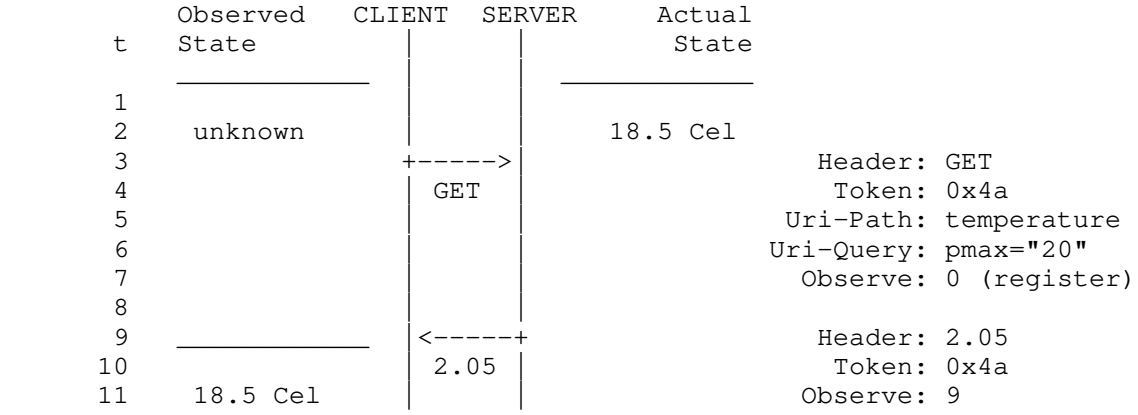


Figure 3: Client registers and receives one notification of the current state and one of a new state state when pmin time expires.

A.2. Maximum Period (pmax) example



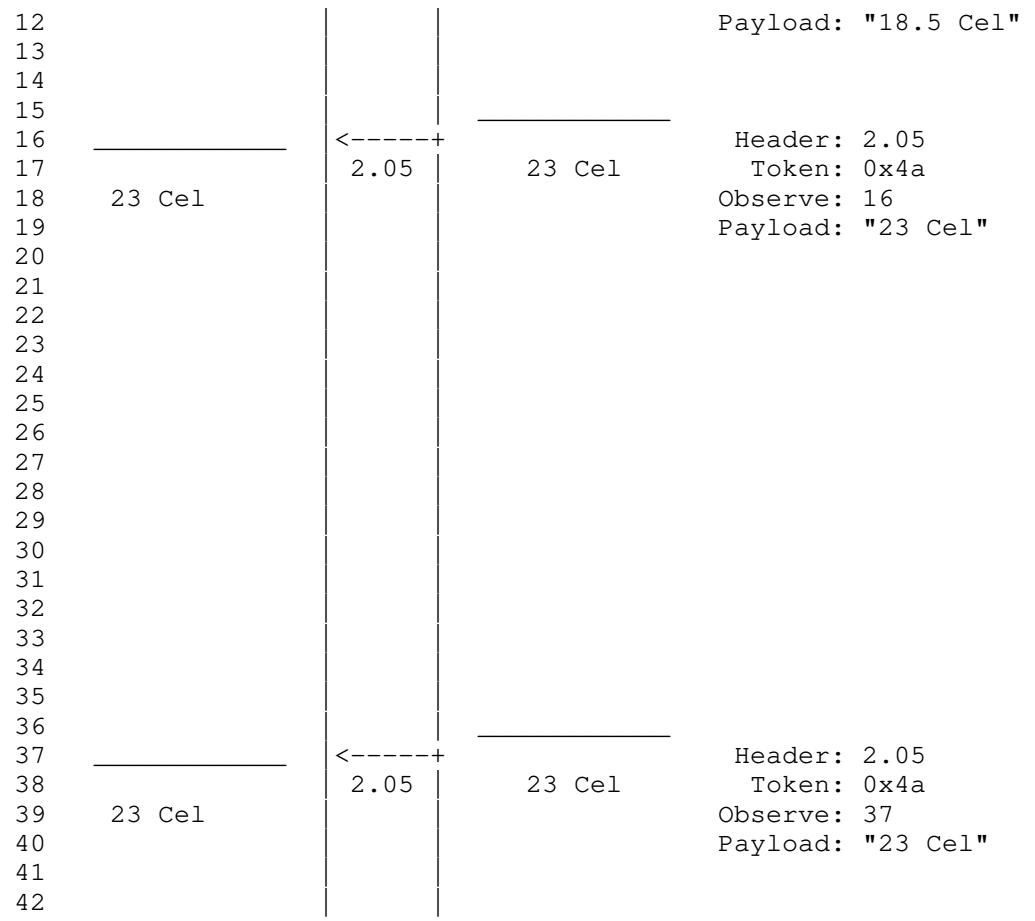


Figure 4: Client registers and receives one notification of the current state, one of a new state and one of an unchanged state when pmax time expires.

A.3. Greater Than (gt) example

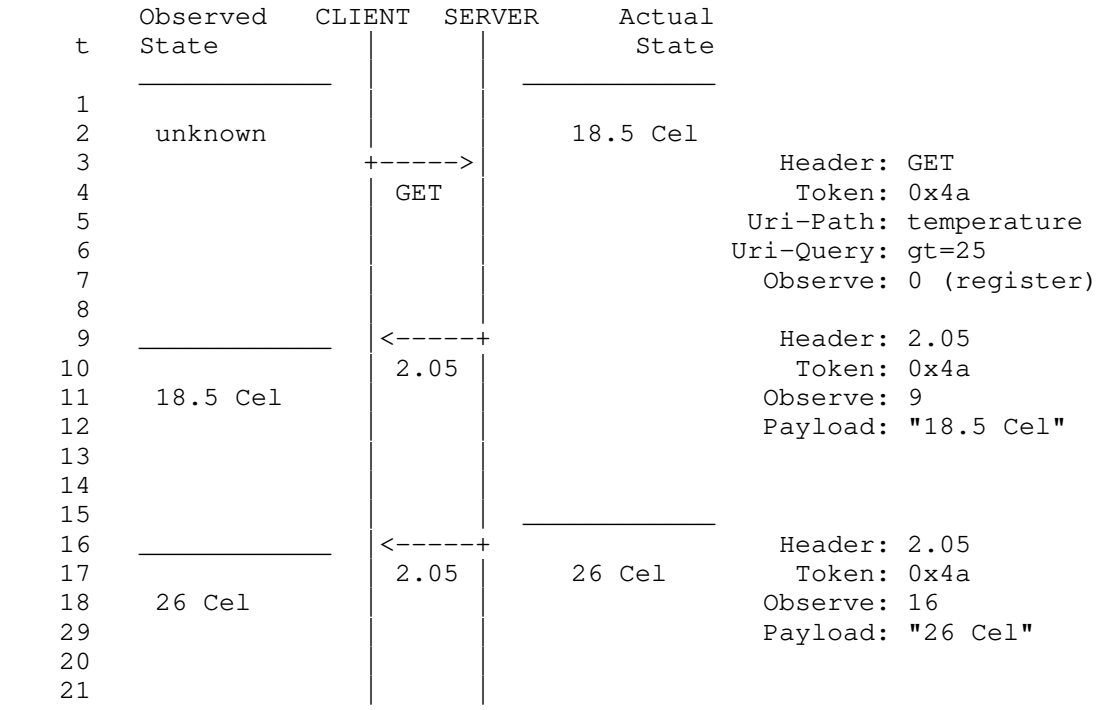
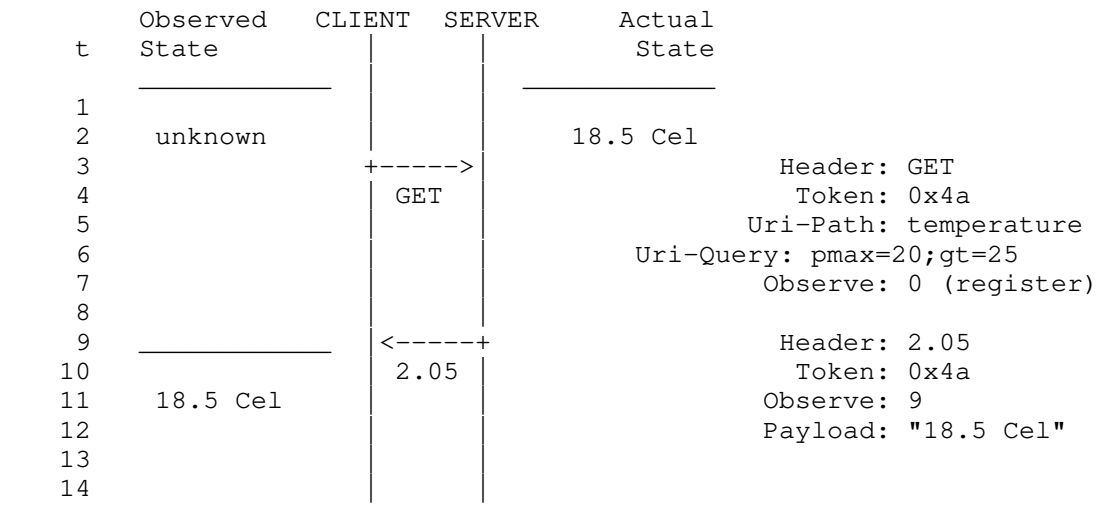


Figure 5: Client registers and receives one notification of the current state and one of a new state when it passes through the greater than threshold of 25.

A.4. Greater Than (gt) and Period Max (pmax) example



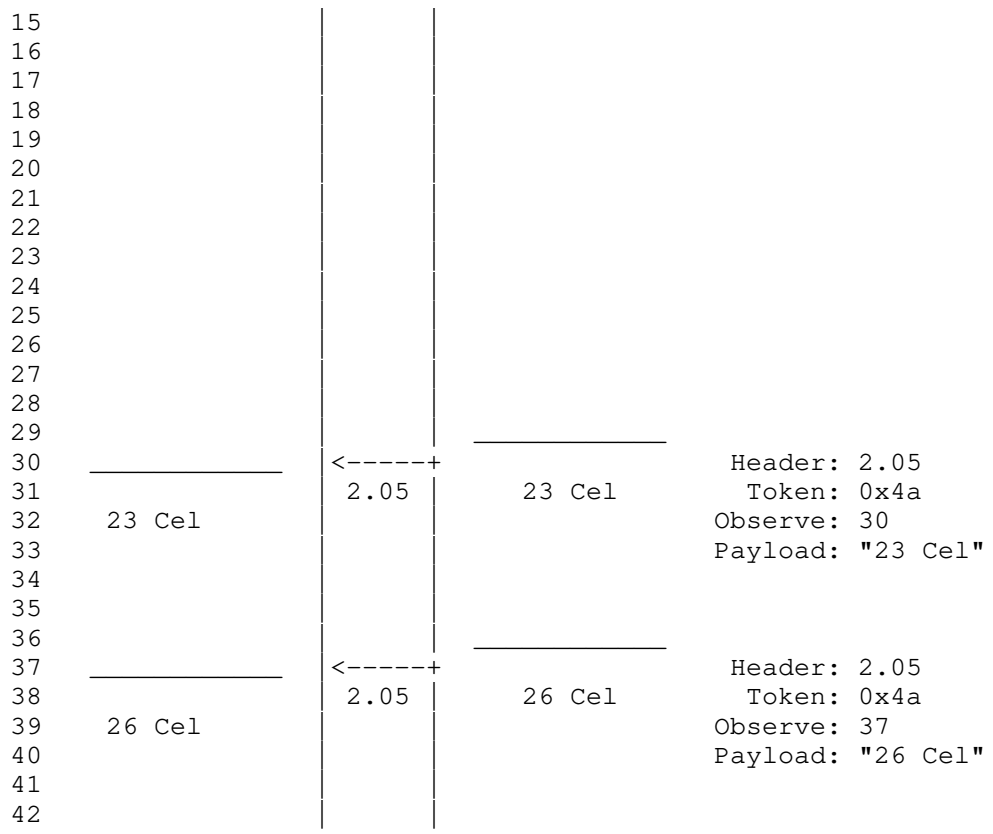


Figure 6: Client registers and receives one notification of the current state, one when pmax time expires and one of a new state when it passes through the greater than threshold of 25.

Authors' Addresses

Michael Koster
SmartThings
665 Clyde Avenue
Mountain View 94043
USA

Email: michael.koster@smartthings.com

Bilhanan Silverajan (editor)
Tampere University
Kalevantie 4
Tampere FI-33100
Finland

Email: bilhanan.silverajan@tuni.fi

CoRE
Internet-Draft
Intended status: Standards Track
Expires: 14 January 2021

Z. Shelby
ARM
M. Koster
SmartThings
C. Bormann
Universitaet Bremen TZI
P. van der Stok
consultant
C. Amsüss, Ed.
13 July 2020

CoRE Resource Directory
draft-ietf-core-resource-directory-25

Abstract

In many IoT applications, direct discovery of resources is not practical due to sleeping nodes, disperse networks, or networks where multicast traffic is inefficient. These problems can be solved by employing an entity called a Resource Directory (RD), which contains information about resources held on other servers, allowing lookups to be performed for those resources. The input to an RD is composed of links and the output is composed of links constructed from the information stored in the RD. This document specifies the web interfaces that an RD supports for web servers to discover the RD and to register, maintain, lookup and remove information on resources. Furthermore, new target attributes useful in conjunction with an RD are defined.

Note to Readers

Discussion of this document takes place on the CORE Working Group mailing list (core@ietf.org), which is archived at https://mailarchive.ietf.org/arch/browse/core/ (https://mailarchive.ietf.org/arch/browse/core/).

Source for this draft and an issue tracker can be found at https://github.com/core-wg/resource-directory (https://github.com/core-wg/resource-directory).

Status of This Memo

This Internet-Draft is submitted in full conformance with the provisions of BCP 78 and BCP 79.

This Internet-Draft will expire on 14 January 2021.

Table of Contents

1. Introduction

In the work on Constrained RESTful Environments (CoRE), a REST architecture suitable for constrained nodes (e.g. with limited RAM and ROM [RFC7228]) and networks (e.g. 6LoWPAN [RFC4944]) has been established and is used in Internet-of-Things (IoT) or machine-to-machine (M2M) applications such as smart energy and building automation.

The discovery of resources offered by a constrained server is very important in machine-to-machine applications where there are no humans in the loop and static interfaces result in fragility. The discovery of resources provided by an HTTP Web Server is typically called Web Linking [RFC8288]. The use of Web Linking for the description and discovery of resources hosted by constrained web servers is specified by the CoRE Link Format [RFC6690]. However, [RFC6690] only describes how to discover resources from the web server that hosts them by querying "/.well-known/core". In many constrained scenarios, direct discovery of resources is not practical due to sleeping nodes, disperse networks, or networks where multicast traffic is inefficient. These problems can be solved by employing an entity called a Resource Directory (RD), which contains information about resources held on other servers, allowing lookups to be performed for those resources.

This document specifies the web interfaces that an RD supports for web servers to discover the RD and to register, maintain, lookup and remove information on resources. Furthermore, new target attributes useful in conjunction with an RD are defined. Although the examples in this document show the use of these interfaces with CoAP [RFC7252], they can be applied in an equivalent manner to HTTP [RFC7230].

2. 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 BCP 14 [RFC2119] [RFC8174] when, and only when, they appear in all capitals, as shown here.

The term "byte" is used in its now customary sense as a synonym for "octet".

This specification requires readers to be familiar with all the terms and concepts that are discussed in [RFC3986], [RFC8288] and [RFC6690]. Readers should also be familiar with the terms and concepts discussed in [RFC7252]. To describe the REST interfaces defined in this specification, the URI Template format is used [RFC6570].

This specification makes use of the following additional terminology:

resolve against
: The expression "a URI-reference is _resolved against_ a base URI" is used to describe the process of [RFC3986] Section 5.2. Noteworthy corner cases are that if the URI-reference is a (full) URI and resolved against any base URI, that gives the original full URI, and that resolving an empty URI reference gives the base URI without any fragment identifier.

Resource Directory (RD)
: A web entity that stores information about web resources and implements the REST interfaces defined in this specification for discovery, for the creation, the maintenance and the removal of registrations, and for lookup of the registered resources.

Sector
: In the context of an RD, a sector is a logical grouping of endpoints.

  The abbreviation "d=" is used for the sector in query parameters for compatibility with deployed implementations.

Endpoint
: Endpoint (EP) is a term used to describe a web server or client in [RFC7252]. In the context of this specification an endpoint is used to describe a web server that registers resources to the RD. An endpoint is identified by its endpoint name, which is included during registration, and has a unique name within the associated sector of the registration.

Registration Base URI
: The Base URI of a Registration is a URI that typically gives scheme and authority information about an Endpoint. The Registration Base URI is provided at registration time, and is used by the RD to resolve relative references of the registration into URIs.

Target
: The target of a link is the destination address (URI) of the link. It is sometimes identified with "href=", or displayed as "<target>". Relative targets need resolving with respect to the Base URI (section 5.2 of [RFC3986]).

  This use of the term Target is consistent with [RFC8288]'s use of the term.

Context
: The context of a link is the source address (URI) of the link, and describes which resource is linked to the target. A link's context is made explicit in serialized links as the "anchor=" attribute.

  This use of the term Context is consistent with [RFC8288]'s use of the term.

Directory Resource
: A resource in the RD containing registration resources.

Registration Resource
: A resource in the RD that contains information about an Endpoint and its links.

Commissioning Tool
: Commissioning Tool (CT) is a device that assists during the installation of the network by assigning values to parameters, naming endpoints and groups, or adapting the installation to the needs of the applications.

Registrant-ep
: Registrant-ep is the endpoint that is registered into the RD. The registrant-ep can register itself, or a CT registers the registrant-ep.

RDAO
: Resource Directory Address Option. A new IPv6 Neighbor Discovery option defined for announcing an RD's address.

3. Architecture and Use Cases

3.1. Principles

The RD is primarily a tool to make discovery operations more efficient than querying /.well-known/core on all connected devices, or across boundaries that would be limiting those operations.

It provides information about resources hosted by other devices that could otherwise only be obtained by directly querying the /.well-known/core resource on these other devices, either by a unicast request or a multicast request.

Information SHOULD only be stored in the RD if it can be obtained by querying the described device's /.well-known/core resource directly.

Data in the RD can only be provided by the device which hosts those data or a dedicated Commissioning Tool (CT). These CTs are thought to act on behalf of endpoints too constrained, or generally unable, to present that information themselves. No other client can modify data in the RD. Changes to the information in the RD do not propagate automatically back to the web servers from where the information originated.

3.2. Architecture

The RD architecture is illustrated in Figure 1. An RD is used as a repository of registrations describing resources hosted on other web servers, also called endpoints (EP). An endpoint is a web server associated with a scheme, IP address and port. A physical node may host one or more endpoints. The RD implements a set of REST interfaces for endpoints to register and maintain RD registrations, and for endpoints to lookup resources from the RD. An RD can be logically segmented by the use of Sectors.

A mechanism to discover an RD using CoRE Link Format [RFC6690] is defined.

Registrations in the RD are soft state and need to be periodically refreshed.

An endpoint uses specific interfaces to register, update and remove a registration. It is also possible for an RD to fetch Web Links from endpoints and add their contents to its registrations.

At the first registration of an endpoint, a "registration resource" is created, the location of which is returned to the registering endpoint. The registering endpoint uses this registration resource to manage the contents of registrations.

A lookup interface for discovering any of the Web Links stored in the RD is provided using the CoRE Link Format.

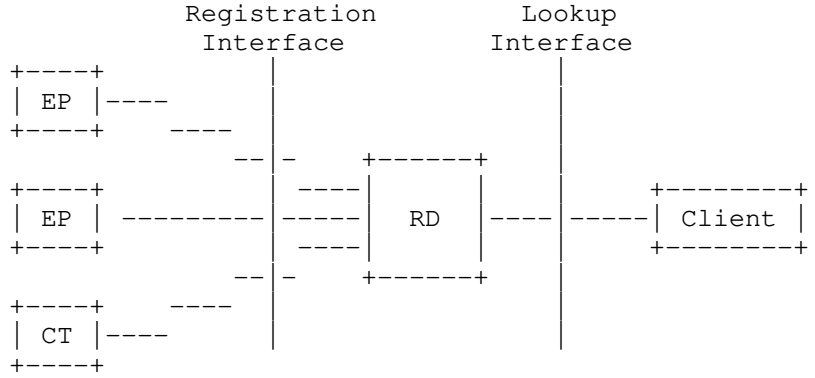


Figure 1: The RD architecture.

A Registrant-EP MAY keep concurrent registrations to more than one RD at the same time if explicitly configured to do so, but that is not expected to be supported by typical EP implementations. Any such registrations are independent of each other. The usual expectation when multiple discovery mechanisms or addresses are configured is that they constitute a fall-back path for a single registration.

3.3. RD Content Model

The Entity-Relationship (ER) models shown in Figure 2 and Figure 3 model the contents of /.well-known/core and the RD respectively, with entity-relationship diagrams [ER]. Entities (rectangles) are used for concepts that exist independently. Attributes (ovals) are used for concepts that exist only in connection with a related entity. Relations (diamonds) give a semantic meaning to the relation between entities. Numbers specify the cardinality of the relations.

Some of the attribute values are URIs. Those values are always full URIs and never relative references in the information model. They can, however, be expressed as relative references in serializations, and often are.

These models provide an abstract view of the information expressed in link-format documents and an RD. They cover the concepts, but not necessarily all details of an RD's operation; they are meant to give an overview, and not be a template for implementations.

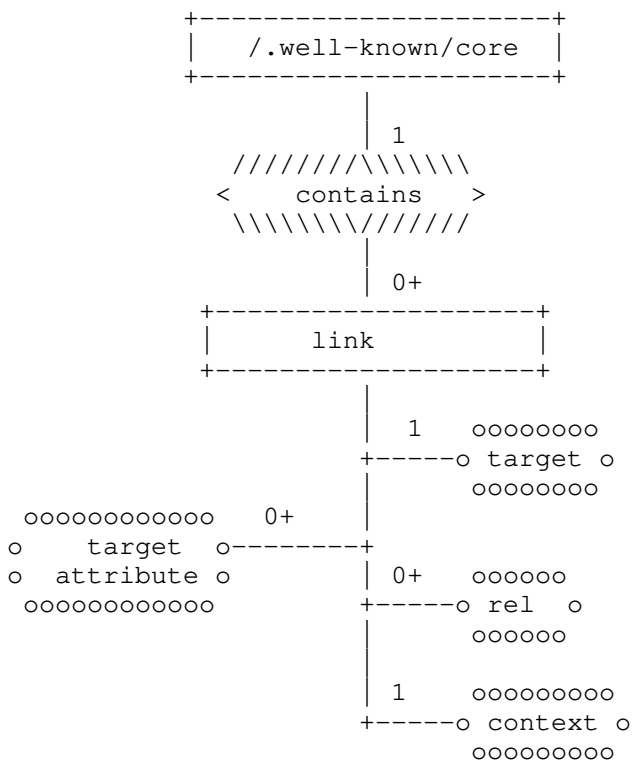


Figure 2: ER Model of the content of /.well-known/core

The model shown in Figure 2 models the contents of /.well-known/core which contains:

* a set of links belonging to the hosting web server

The web server is free to choose links it deems appropriate to be exposed in its ".well-known/core". Typically, the links describe resources that are served by the host, but the set can also contain links to resources on other servers (see examples in [RFC6690] page 14). The set does not necessarily contain links to all resources served by the host.

A link has the following attributes (see [RFC8288]):

* Zero or more link relations: They describe relations between the link context and the link target.

  In link-format serialization, they are expressed as space-separated values in the "rel" attribute, and default to "hosts".

* A link context URI: It defines the source of the relation, e.g. _who_ "hosts" something.

  In link-format serialization, it is expressed in the "anchor" attribute. It defaults to that document's URI.

* A link target URI: It defines the destination of the relation (e.g. _what_ is hosted), and is the topic of all target attributes.

  In link-format serialization, it is expressed between angular brackets, and sometimes called the "href".

* Other target attributes (e.g. resource type (rt), interface (if), or content format (ct)). These provide additional information about the target URI.

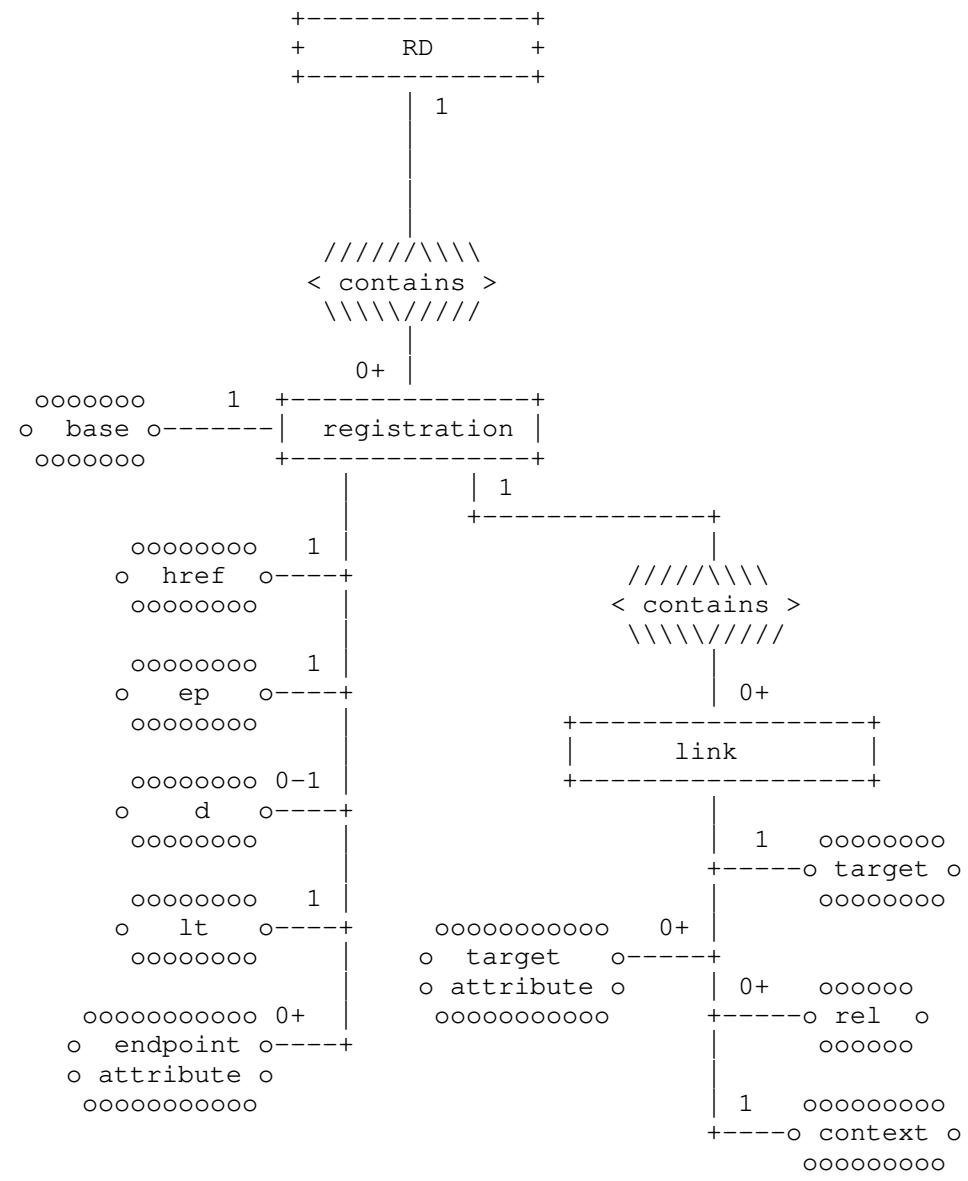


Figure 3: ER Model of the content of the RD

The model shown in Figure 3 models the contents of the RD which contains in addition to /.well-known/core:

* 0 to n Registrations of endpoints,

A registration is associated with one endpoint. A registration defines a set of links as defined for /.well-known/core. A Registration has six types of attributes:

* an endpoint name ("ep", a Unicode string) unique within a sector

* a Registration Base URI ("base", a URI typically describing the scheme://authority part)

* a lifetime ("lt"),

* a registration resource location inside the RD ("href"),

* optionally a sector ("d", a Unicode string)

* optional additional endpoint attributes (from Section 9.3)

The cardinality of "base" is currently 1; future documents are invited to extend the RD specification to support multiple values (e.g. [I-D.silverajan-core-coap-protocol-negotiation]). Its value is used as a Base URI when resolving URIs in the links contained in the endpoint.

Links are modelled as they are in Figure 2.

3.4. Link-local addresses and zone identifiers

Registration Base URIs can contain link-local IP addresses. To be usable across hosts, those can not be serialized to contain zone identifiers (see [RFC6874] Section 1).

Link-local addresses can only be used on a single link (therefore RD servers can not announce them when queried on a different link), and lookup clients using them need to keep track of which interface they got them from.

Therefore, it is advisable in many scenarios to use addresses with larger scope if available.

3.5. Use Case: Cellular M2M

Over the last few years, mobile operators around the world have focused on development of M2M solutions in order to expand the business to the new type of users: machines. The machines are connected directly to a mobile network using an appropriate embedded wireless interface (GSM/GPRS, WCDMA, LTE) or via a gateway providing short and wide range wireless interfaces. From the system design point of view, the ambition is to design horizontal solutions that

can enable utilization of machines in different applications depending on their current availability and capabilities as well as application requirements, thus avoiding silo like solutions. One of the crucial enablers of such design is the ability to discover resources (and thus the endpoints they are hosted on) capable of providing required information at a given time or acting on instructions from the end users.

Imagine a scenario where endpoints installed on vehicles enable tracking of the position of these vehicles for fleet management purposes and allow monitoring of environment parameters. During the boot-up process endpoints register with an RD, which is hosted by the mobile operator or somewhere in the cloud. Periodically, these endpoints update their registration and may modify resources they offer.

When endpoints are not always connected, for example because they enter a sleep mode, a remote server is usually used to provide proxy access to the endpoints. Mobile apps or web applications for environment monitoring contact the RD, look up the endpoints capable of providing information about the environment using an appropriate set of link parameters, obtain information on how to contact them (URLs of the proxy server), and then initiate interaction to obtain information that is finally processed, displayed on the screen and usually stored in a database. Similarly, fleet management systems provide the appropriate link parameters to the RD to look up for EPs deployed on the vehicles the application is responsible for.

3.6. Use Case: Home and Building Automation

Home and commercial building automation systems can benefit from the use of M2M web services. The discovery requirements of these applications are demanding. Home automation usually relies on run-time discovery to commission the system, whereas in building automation a combination of professional commissioning and run-time discovery is used. Both home and building automation involve peer-to-peer interactions between endpoints, and involve battery-powered sleeping devices.

Two phases can be discerned for a network servicing the system: (1) installation and (2) operation. During the operational phase, the network is connected to the Internet with a Border router (6LBR) and the nodes connected to the network can use the Internet services that are provided by the Internet Provider or the network administrator. During the installation phase, the network is completely stand-alone, no 6LBR is connected, and the network only supports the IP communication between the connected nodes. The installation phase is usually followed by the operational phase.

3.7. Use Case: Link Catalogues

Resources may be shared through data brokers that have no knowledge beforehand of who is going to consume the data. An RD can be used to hold links about resources and services hosted anywhere to make them discoverable by a general class of applications.

For example, environmental and weather sensors that generate data for public consumption may provide data to an intermediary server, or broker. Sensor data are published to the intermediary upon changes or at regular intervals. Descriptions of the sensors that resolve to links to sensor data may be published to an RD. Applications wishing to consume the data can use RD Lookup to discover and resolve links to the desired resources and endpoints. The RD service need not be coupled with the data intermediary service. Mapping of RDs to data intermediaries may be many-to-many.

Metadata in web link formats like [RFC6690] which may be internally stored as triples, or relation/attribute pairs providing metadata about resource links, need to be supported by RDs. External catalogues that are represented in other formats may be converted to common web linking formats for storage and access by RDs. Since it is common practice for these to be encoded in URNs [RFC8141], simple and lossless structural transforms should generally be sufficient to store external metadata in RDs.

The additional features of an RD allow sectors to be defined to enable access to a particular set of resources from particular applications. This provides isolation and protection of sensitive data when needed. Application groups with multicast addresses may be defined to support efficient data transport.

4. RD discovery and other interface-independent components

This and the following sections define the required set of REST interfaces between an RD, endpoints and lookup clients. Although the examples throughout these sections assume the use of CoAP [RFC7252], these REST interfaces can also be realized using HTTP [RFC7230]. Only multicast discovery operations are not possible on HTTP, and Simple Registration can not be executed as base attribute (which is mandatory for HTTP) can not be used there. In all definitions in these sections, both CoAP response codes (with dot notation) and HTTP response codes (without dot notation) are shown. An RD implementing this specification MUST support the discovery, registration, update, lookup, and removal interfaces.

All operations on the contents of the RD MUST be atomic and idempotent.

For several operations, interface templates are given in list form; those describe the operation participants, request codes, URIs, content formats and outcomes. Sections of those templates contain normative content about Interaction, Method, URI Template and URI Template Variables as well as the details of the Success condition. The additional sections on options like Content-Format and on Failure codes give typical cases that an implementation of the RD should deal with. Those serve to illustrate the typical responses to readers who are not yet familiar with all the details of CoAP based interfaces; they do not limit what a server may respond under atypical circumstances.

REST clients (registrant-EPs and CTs during registration and maintenance, lookup clients, RD servers during simple registrations) MUST be prepared to receive any unsuccessful code and act upon it according to its definition, options and/or payload to the best of their capabilities, falling back to failing the operation if recovery is not possible. In particular, they should retry the request upon 5.03 (Service Unavailable; 503 in HTTP) according to the Max-Age (Retry-After in HTTP) option, and fall back to link-format when receiving 4.15 (Unsupported Content-Format; 415 in HTTP).

An RD MAY make the information submitted to it available to further directories, if it can ensure that a loop does not form. The protocol used between directories to ensure loop-free operation is outside the scope of this document.

4.1. Finding a Resource Directory

A (re-)starting device may want to find one or more RDs for discovery purposes. Dependent on the operational conditions, one or more of the techniques below apply.

The device may be pre-configured to exercise specific mechanisms for finding the RD:

1. It may be configured with a specific IP address for the RD. That IP address may also be an anycast address, allowing the network to forward RD requests to an RD that is topologically close; each target network environment in which some of these preconfigured nodes are to be brought up is then configured with a route for this anycast address that leads to an appropriate RD. (Instead of using an anycast address, a multicast address can also be preconfigured. The RD servers then need to configure one of their interfaces with this multicast address.)

2. It may be configured with a DNS name for the RD and use DNS to return the IP address of the RD; it can find a DNS server to perform the lookup using the usual mechanisms for finding DNS servers.

3. It may be configured to use a service discovery mechanism such as DNS-SD, as outlined in Section 4.1.2.

For cases where the device is not specifically configured with a way to find an RD, the network may want to provide a suitable default.

1. If the address configuration of the network is performed via SLAAC, this is provided by the RDAO option Section 4.1.1.

2. If the address configuration of the network is performed via DHCP, this could be provided via a DHCP option (no such option is defined at the time of writing).

Finally, if neither the device nor the network offers any specific configuration, the device may want to employ heuristics to find a suitable RD.

The present specification does not fully define these heuristics, but suggests a number of candidates:

1. In a 6LoWPAN, just assume the Border Router (6LBR) can act as an RD (using the ABRO option to find that [RFC6775]). Confirmation can be obtained by sending a Unicast to "coap://[6LBR]/.well-known/core?rt=core.rd*".

2. In a network that supports multicast well, discovering the RD using a multicast query for /.well-known/core as specified in CoRE Link Format [RFC6690]: Sending a Multicast GET to "coap://[MCD1]/.well-known/core?rt=core.rd*". RDs within the multicast scope will answer the query.

When answering a multicast request directed at a link-local address, the RD may want to respond from a routable address; this makes it easier for registrants to use one of their own routable addresses for registration.

As some of the RD addresses obtained by the methods listed here are just (more or less educated) guesses, endpoints MUST make use of any error messages to very strictly rate-limit requests to candidate IP addresses that don't work out. For example, an ICMP Destination Unreachable message (and, in particular, the port unreachable code for this message) may indicate the lack of a CoAP server on the candidate host, or a CoAP error response code such as 4.05 "Method Not Allowed" may indicate unwillingness of a CoAP server to act as a directory server.

The following RD discovery mechanisms are recommended:

* In managed networks with border routers that need stand-alone operation, the RDAO option is recommended (e.g. operational phase described in Section 3.6).

* In managed networks without border router (no Internet services available), the use of a preconfigured anycast address is recommended (e.g. installation phase described in Section 3.6).

* In networks managed using DNS-SD, the use of DNS-SD for discovery as described in Section 4.1.2 is recommended.

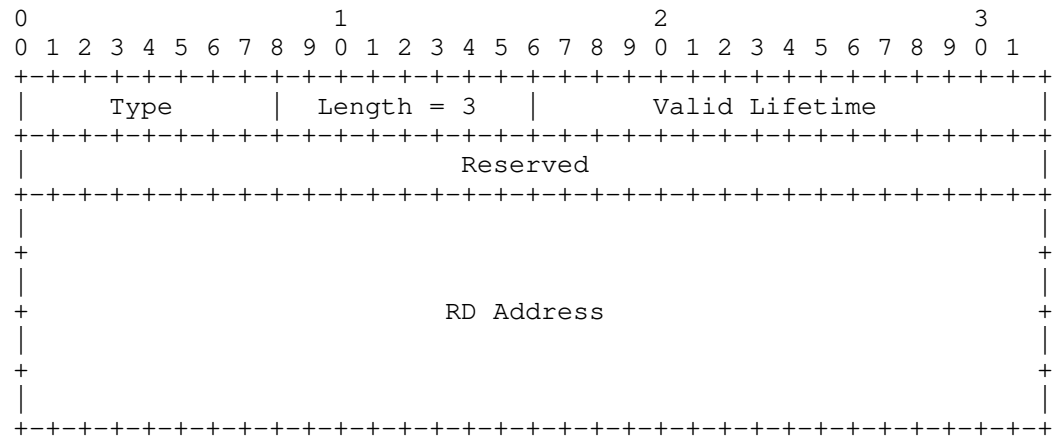
The use of multicast discovery in mesh networks is NOT recommended.

4.1.1. Resource Directory Address Option (RDAO)

The Resource Directory Address Option (RDAO) using IPv6 Neighbor Discovery (ND) carries information about the address of the RD. This information is needed when endpoints cannot discover the RD with a link-local or realm-local scope multicast address, for instance because the endpoint and the RD are separated by a Border Router (6LBR). In many circumstances the availability of DHCP cannot be guaranteed either during commissioning of the network. The presence and the use of the RD is essential during commissioning.

It is possible to send multiple RDAO options in one message, indicating as many RD addresses.

The RDAO format is:



Fields:

Type: TBD38

Length: 8-bit unsigned integer. The length of the option in units of 8 bytes. Always 3.

Valid Lifetime: 16-bit unsigned integer. The length of time in units of 60 seconds (relative to the time the packet is received) that this RD address is valid. A value of all zero bits (0x0) indicates that this RD address is not valid anymore.

Reserved: This field is unused. It MUST be initialized to zero by the sender and MUST be ignored by the receiver.

RD Address: IPv6 address of the RD.

Figure 4: Resource Directory Address Option

4.1.2. Using DNS-SD to discover a Resource Directory

An RD can advertise its presence in DNS-SD [RFC6763] using the service name "_core-rd._udp" (for CoAP), "_core-rd-dtls._udp" (for CoAP over DTLS), "_core-rd._tcp" (for CoAP over TCP) or "_core-rd-tls._tcp" (for CoAP over TLS) defined in this document. (For the WebSocket transports of CoAP, no service is defined as DNS-SD is typically unavailable in environments where CoAP over WebSockets is used).

The selection of the service indicates the protocol used, and the SRV record points the client to a host name and port to use as a starting point for the URI discovery steps of Section 4.3.

This section is a simplified concrete application of the more generic mechanism specified in [I-D.ietf-core-rd-dns-sd].

4.2. Payload Content Formats

RDs implementing this specification MUST support the application/link-format content format (ct=40).

RDs implementing this specification MAY support additional content formats.

Any additional content format supported by an RD implementing this specification SHOULD be able to express all the information expressible in link-format. It MAY be able to express information that is inexpressible in link-format, but those expressions SHOULD be avoided where possible.

4.3. URI Discovery

Before an endpoint can make use of an RD, it must first know the RD's address and port, and the URI path information for its REST APIs. This section defines discovery of the RD and its URIs using the well-known interface of the CoRE Link Format [RFC6690] after having discovered a host as described in Section 4.1.

Discovery of the RD registration URI path is performed by sending either a multicast or unicast GET request to "/.well-known/core" and including a Resource Type (rt) parameter [RFC6690] with the value "core.rd" in the query string. Likewise, a Resource Type parameter value of "core.rd-lookup*" is used to discover the URIs for RD Lookup operations, core.rd* is used to discover all URI paths for RD operations. Upon success, the response will contain a payload with a link format entry for each RD function discovered, indicating the URI of the RD function returned and the corresponding Resource Type.

When performing multicast discovery, the multicast IP address used will depend on the scope required and the multicast capabilities of the network (see Section 9.5).

An RD MAY provide hints about the content-formats it supports in the links it exposes or registers, using the "ct" target attribute, as shown in the example below. Clients MAY use these hints to select alternate content-formats for interaction with the RD.

HTTP does not support multicast and consequently only unicast discovery can be supported at the using the HTTP "/.well-known/core" resource.

RDs implementing this specification MUST support query filtering for the rt parameter as defined in [RFC6690].

While the link targets in this discovery step are often expressed in path-absolute form, this is not a requirement. Clients of the RD SHOULD therefore accept URIs of all schemes they support, both as URIs and relative references, and not limit the set of discovered URIs to those hosted at the address used for URI discovery.

The URI Discovery operation can yield multiple URIs of a given resource type. The client of the RD can use any of the discovered addresses initially.

The discovery request interface is specified as follows (this is exactly the Well-Known Interface of [RFC6690] Section 4, with the additional requirement that the server MUST support query filtering):

Interaction: EP and Client -> RD

Method: GET

URI Template: /.well-known/core{?rt}

URI Template Variables: rt := Resource Type. SHOULD contain one of the values "core.rd", "core.rd-lookup*", "core.rd-lookup-res", "core.rd-lookup-ep", or "core.rd*"

Accept: absent, application/link-format or any other media type representing web links

The following response is expected on this interface:

Success: 2.05 "Content" or 200 "OK" with an application/link-format or other web link payload containing one or more matching entries for the RD resource.

The following example shows an endpoint discovering an RD using this interface, thus learning that the directory resource location, in this example, is /rd, and that the content-format delivered by the server hosting the resource is application/link-format (ct=40). Note that it is up to the RD to choose its RD locations.

```
Req: GET coap://[MCD1]/.well-known/core?rt=core.rd*

Res: 2.05 Content
</rd>;rt="core.rd";ct=40,
</rd-lookup/ep>;rt="core.rd-lookup-ep";ct=40,
</rd-lookup/res>;rt="core.rd-lookup-res";ct=40
```

Figure 5: Example discovery exchange

The following example shows the way of indicating that a client may request alternate content-formats. The Content-Format code attribute "ct" MAY include a space-separated sequence of Content-Format codes as specified in Section 7.2.1 of [RFC7252], indicating that multiple content-formats are available. The example below shows the required Content-Format 40 (application/link-format) indicated as well as a CBOR and JSON representation from [I-D.ietf-core-links-json] (which have no numeric values assigned yet, so they are shown as TBD64 and TBD504 as in that draft). The RD resource locations /rd, and /rd-lookup are example values. The server in this example also indicates that it is capable of providing observation on resource lookups.

```
Req: GET coap://[MCD1]/.well-known/core?rt=core.rd*

Res: 2.05 Content
</rd>;rt="core.rd";ct="40 65225",
</rd-lookup/res>;rt="core.rd-lookup-res";ct="40 TBD64 TBD504";obs,
</rd-lookup/ep>;rt="core.rd-lookup-ep";ct="40 TBD64 TBD504"
```

Figure 6: Example discovery exchange indicating additional content-formats

From a management and maintenance perspective, it is necessary to identify the components that constitute the RD server. The identification refers to information about for example client-server incompatibilities, supported features, required updates and other aspects. The URI discovery address, a described in section 4 of [RFC6690] can be used to find the identification.

It would typically be stored in an implementation information link (as described in [I-D.bormann-t2trg-rel-impl]):

```
Req: GET /.well-known/core?rel=impl-info

Res: 2.05 Content
<http://software.example.com/shiny-resource-directory/1.0beta1>;
    rel="impl-info"
```

Figure 7: Example exchange of obtaining implementation information

Note that depending on the particular server's architecture, such a link could be anchored at the RD server's root, at the discovery site (as in this example) or at individual RD components. The latter is to be expected when different applications are run on the same server.

5. Registration

After discovering the location of an RD, a registrant-ep or CT MAY register the resources of the registrant-ep using the registration interface. This interface accepts a POST from an endpoint containing the list of resources to be added to the directory as the message payload in the CoRE Link Format [RFC6690] or other representations of web links, along with query parameters indicating the name of the endpoint, and optionally the sector, lifetime and base URI of the registration. It is expected that other specifications will define further parameters (see Section 9.3). The RD then creates a new registration resource in the RD and returns its location. The receiving endpoint MUST use that location when refreshing registrations using this interface. Registration resources in the RD are kept active for the period indicated by the lifetime parameter. The creating endpoint is responsible for refreshing the registration resource within this period using either the registration or update interface. The registration interface MUST be implemented to be idempotent, so that registering twice with the same endpoint parameters ep and d (sector) does not create multiple registration resources.

The following rules apply for a registration request targeting a given (ep, d) value pair:

* When the (ep, d) value pair of the registration-request is different from any existing registration, a new registration is generated.

* When the (ep, d) value pair of the registration-request is equal to an existing registration, the content and parameters of the existing registration are replaced with the content of the registration request.

The posted link-format document can (and typically does) contain relative references both in its link targets and in its anchors, or contain empty anchors. The RD server needs to resolve these references in order to faithfully represent them in lookups. They are resolved against the base URI of the registration, which is provided either explicitly in the "base" parameter or constructed implicitly from the requester's URI as constructed from its network address and scheme.

For media types to which Appendix C applies (i.e. documents in application/link-format), the RD only needs to accept representations in Limited Link Format as described there. Its behavior with representations outside that subset is implementation defined.

The registration request interface is specified as follows:

Interaction: EP -> RD

Method: POST

URI Template: {+rd}{?ep,d,lt,base,extra-attrs*}

URI Template Variables: rd := RD registration URI (mandatory). This is the location of the RD, as obtained from discovery.

ep := Endpoint name (mostly mandatory). The endpoint name is an identifier that MUST be unique within a sector. As the endpoint name is a Unicode string, it is encoded in UTF-8 (and possibly pct-encoded) during variable expansion (see [RFC6570] Section 3.2.1). The endpoint name MUST NOT contain any character in the inclusive ranges 0-31 or 127-159. The maximum length of this parameter is 63 UTF-8 encoded bytes. If the RD is configured to recognize the endpoint (e.g. based on its security context), the RD assigns an endpoint name based on a set of configuration parameter values.

d := Sector (optional). The sector to which this endpoint belongs. When this parameter is not present, the RD MAY associate the endpoint with a configured default sector or leave it empty. The sector is encoded like the ep parameter, and is limited to 63 UTF-8 encoded bytes as well. The endpoint name and sector name are not set when one or both are set in an accompanying authorization token.

lt := Lifetime (optional). Lifetime of the

registration in seconds. Range of 1-4294967295. If no lifetime is included in the initial registration, a default value of 90000 (25 hours) SHOULD be assumed.

base := Base URI (optional). This parameter sets the base URI of the registration, under which the relative links in the payload are to be interpreted. The specified URI typically does not have a path component of its own, and MUST be suitable as a base URI to resolve any relative references given in the registration. The parameter is therefore usually of the shape "scheme://authority" for HTTP and CoAP URIs. The URI SHOULD NOT have a query or fragment component as any non-empty relative part in a reference would remove those parts from the resulting URI.

In the absence of this parameter the scheme of the protocol, source address and source port of the registration request are assumed. The Base URI is consecutively constructed by concatenating the used protocol's scheme with the characters "://", the requester's source address as an address literal and ":" followed by its port (if it was not the protocol's default one) in analogy to [RFC7252] Section 6.5.

This parameter is mandatory when the directory is filled by a third party such as an commissioning tool.

If the registrant-ep uses an ephemeral port to register with, it MUST include the base parameter in the registration to provide a valid network path.

A registrant that can not be reached by potential lookup clients at the address it registers from (e.g. because it is behind some form of Network Address Translation (NAT)) MUST provide a reachable base address with its registration.

If the Base URI contains a link-local IP literal, it MUST NOT contain a Zone Identifier, and MUST be local to the link on which the registration request is received.

Endpoints that register with a base that contains a path component can not meaningfully use [RFC6690] Link Format due to its prevalence of the Origin concept in relative reference resolution. Those applications should use different representations of links to which Appendix C is not applicable (e.g. [I-D.hartke-t2trg-coral]).

extra-attrs := Additional registration

attributes (optional). The endpoint can pass any parameter registered at Section 9.3 to the directory. If the RD is aware of the parameter's specified semantics, it processes it accordingly. Otherwise, it MUST store the unknown key and its value(s) as an endpoint attribute for further lookup.

Content-Format: application/link-format or any other indicated media type representing web links

The following response is expected on this interface:

Success: 2.01 "Created" or 201 "Created". The Location-Path option or Location header field MUST be included in the response. This location MUST be a stable identifier generated by the RD as it is used for all subsequent operations on this registration resource. The registration resource location thus returned is for the purpose of updating the lifetime of the registration and for maintaining the content of the registered links, including updating and deleting links.

A registration with an already registered ep and d value pair responds with the same success code and location as the original registration; the set of links registered with the endpoint is replaced with the links from the payload.

The location MUST NOT have a query or fragment component, as that could conflict with query parameters during the Registration Update operation. Therefore, the Location-Query option MUST NOT be present in a successful response.

If the registration fails, including request timeouts, or if delays from Service Unavailable responses with Max-Age or Retry-After accumulate to exceed the registrant's configured timeouts, it SHOULD pick another registration URI from the "URI Discovery" step and if there is only one or the list is exhausted, pick other choices from the "Finding a Resource Directory" step. Care has to be taken to consider the freshness of results obtained earlier, e.g. of the result of a "/.well-known/core" response, the lifetime of an RDAO option and of DNS responses. Any rate limits and persistent errors from the "Finding a Resource Directory" step must be considered for the whole registration time, not only for a single operation.

The following example shows a registrant-ep with the name "node1" registering two resources to an RD using this interface. The location "/rd" is an example RD location discovered in a request similar to Figure 5.

```
Req: POST coap://rd.example.com/rd?ep=node1
Content-Format: 40
Payload:
</sensors/temp>;ct=41;rt="temperature-c";if="sensor",
<http://www.example.com/sensors/temp>;
  anchor="/sensors/temp";rel="describedby"

Res: 2.01 Created
Location-Path: /rd/4521
```

Figure 8: Example registration payload

An RD may optionally support HTTP. Here is an example of almost the same registration operation above, when done using HTTP.

```
Req:
POST /rd?ep=node1&base=http://[2001:db8:1::1] HTTP/1.1
Host: example.com
Content-Type: application/link-format

</sensors/temp>;ct=41;rt="temperature-c";if="sensor",
<http://www.example.com/sensors/temp>;
  anchor="/sensors/temp";rel="describedby"

Res:
HTTP/1.1 201 Created
Location: /rd/4521
```

Figure 9: Example registration payload as expressed using HTTP

5.1. Simple Registration

Not all endpoints hosting resources are expected to know how to upload links to an RD as described in Section 5. Instead, simple endpoints can implement the Simple Registration approach described in this section. An RD implementing this specification MUST implement Simple Registration. However, there may be security reasons why this form of directory discovery would be disabled.

This approach requires that the registrant-ep makes available the hosted resources that it wants to be discovered, as links on its "/.well-known/core" interface as specified in [RFC6690]. The links in that document are subject to the same limitations as the payload of a registration (with respect to Appendix C).

* The registrant-ep finds one or more addresses of the directory server as described in Section 4.1.

* The registrant-ep sends (and regularly refreshes with) a POST request to the "/.well-known/core" URI of the directory server of choice. The body of the POST request is empty, and triggers the resource directory server to perform GET requests at the requesting registrant-ep's /.well-known/core to obtain the link-format payload to register.

  The registrant-ep includes the same registration parameters in the POST request as it would per Section 5. The registration base URI of the registration is taken from the registrant-ep's network address (as is default with regular registrations).

  Example request from registrant-EP to RD (unanswered until the next step):

```
Req: POST /.well-known/core?lt=6000&ep=node1
(No payload)
```

Figure 10: First half example exchange of a simple registration

* The RD queries the registrant-ep's discovery resource to determine the success of the operation. It SHOULD keep a cache of the discovery resource and not query it again as long as it is fresh.

  Example request from the RD to the registrant-EP:

```
Req: GET /.well-known/core
Accept: 40

Res: 2.05 Content
Content-Format: 40
Payload:
</sen/temp>
```

Figure 11: Example exchange of the RD querying the simple endpoint

With this response, the RD would answer the previous step's request:

```
Res: 2.04 Changed
```

Figure 12: Second half example exchange of a simple registration

The sequence of fetching the registration content before sending a successful response was chosen to make responses reliable, and the caching item was chosen to still allow very constrained registrants. Registrants MUST be able to serve a GET request to "/.well-known/core" after having requested registration. Constrained devices MAY regard the initial request as temporarily failed when they need RAM

occupied by their own request to serve the RD's GET, and retry later when the RD already has a cached representation of their discovery resources. Then, the RD can reply immediately and the registrant can receive the response.

The simple registration request interface is specified as follows:

Interaction: EP -> RD

Method: POST

URI Template: /.well-known/core{?ep,d,lt,extra-attrs*}

URI Template Variables are as they are for registration in Section 5. The base attribute is not accepted to keep the registration interface simple; that rules out registration over CoAP-over-TCP or HTTP that would need to specify one.

The following response is expected on this interface:

Success: 2.04 "Changed".

For the second interaction triggered by the above, the registrant-ep takes the role of server and the RD the role of client. (Note that this is exactly the Well-Known Interface of [RFC6690] Section 4):

Interaction: RD -> EP

Method: GET

URI Template: /.well-known/core

The following response is expected on this interface:

Success: 2.05 "Content".

When the RD is in a position to successfully execute this second interaction and other network participants that can reach it are not, it SHOULD verify that the apparent registrant-ep intends to register with the given registration parameters before revealing the obtained discovery information to lookup clients. An easy way to do that is to verify the simple registration request's sender address using the Echo option as described in [I-D.ietf-core-echo-request-tag] Section 2.4.

The RD MUST delete registrations created by simple registration after the expiration of their lifetime. Additional operations on the registration resource cannot be executed because no registration location is returned.

5.2. Third-party registration

For some applications, even Simple Registration may be too taxing for some very constrained devices, in particular if the security requirements become too onerous.

In a controlled environment (e.g. building control), the RD can be filled by a third party device, called a Commissioning Tool (CT). The commissioning tool can fill the RD from a database or other means. For that purpose scheme, IP address and port of the URI of the registered device is the value of the "base" parameter of the registration described in Section 5.

It should be noted that the value of the "base" parameter applies to all the links of the registration and has consequences for the anchor value of the individual links as exemplified in Appendix B. An eventual (currently non-existing) "base" attribute of the link is not affected by the value of "base" parameter in the registration.

5.3. Operations on the Registration Resource

This section describes how the registering endpoint can maintain the registrations that it created. The registering endpoint can be the registrant-ep or the CT. The registrations are resources of the RD.

An endpoint should not use this interface for registrations that it did not create. This is usually enforced by security policies, which in general require equivalent credentials for creation of and operations on a registration.

After the initial registration, the registering endpoint retains the returned location of the Registration Resource for further operations, including refreshing the registration in order to extend the lifetime and "keep-alive" the registration. When the lifetime of the registration has expired, the RD SHOULD NOT respond to discovery queries concerning this endpoint. The RD SHOULD continue to provide access to the Registration Resource after a registration time-out occurs in order to enable the registering endpoint to eventually refresh the registration. The RD MAY eventually remove the registration resource for the purpose of garbage collection. If the Registration Resource is removed, the corresponding endpoint will need to be re-registered.

The Registration Resource may also be used cancel the registration using DELETE, and to perform further operations beyond the scope of this specification.

These operations are described below.

5.3.1. Registration Update

The update interface is used by the registering endpoint to refresh or update its registration with an RD. To use the interface, the registering endpoint sends a POST request to the registration resource returned by the initial registration operation.

An update MAY update the lifetime or the base URI registration parameters "lt", "base" as in Section 5. Parameters that are not being changed SHOULD NOT be included in an update. Adding parameters that have not changed increases the size of the message but does not have any other implications. Parameters MUST be included as query parameters in an update operation as in Section 5.

A registration update resets the timeout of the registration to the (possibly updated) lifetime of the registration, independent of whether a "lt" parameter was given.

If the base URI of the registration is changed in an update, relative references submitted in the original registration or later updates are resolved anew against the new base.

The registration update operation only describes the use of POST with an empty payload. Future standards might describe the semantics of using content formats and payloads with the POST method to update the links of a registration (see Section 5.3.3).

The update registration request interface is specified as follows:

Interaction: EP -> RD

Method: POST

URI Template: {+location}{?lt,base,extra-attrs*}

URI Template Variables: location := This is the Location returned by the RD as a result of a successful earlier registration.

lt := Lifetime (optional). Lifetime of the

registration in seconds. Range of 1-4294967295. If no lifetime is included, the previous last lifetime set on a previous update or the original registration (falling back to 90000) SHOULD be used.

base := Base URI (optional). This parameter updates the Base URI established in the original registration to a new value. If the parameter is set in an update, it is stored by the RD as the new Base URI under which to interpret the relative links present in the payload of the original registration, following the same restrictions as in the registration. If the parameter is not set in the request but was set before, the previous Base URI value is kept unmodified. If the parameter is not set in the request and was not set before either, the source address and source port of the update request are stored as the Base URI.

extra-attrs := Additional registration attributes (optional). As with the registration, the RD processes them if it knows their semantics. Otherwise, unknown attributes are stored as endpoint attributes, overriding any previously stored endpoint attributes of the same key.

Note that this default behavior does not allow removing an endpoint attribute in an update. For attributes whose functionality depends on the endpoints' ability to remove them in an update, it can make sense to define a value whose presence is equivalent to the absence of a value. As an alternative, an extension can define different updating rules for their attributes. That necessitates either discovery of whether the RD is aware of that extension, or tolerating the default behavior.

Content-Format: none (no payload)

The following responses are expected on this interface:

Success: 2.04 "Changed" or 204 "No Content" if the update was successfully processed.

Failure: 4.04 "Not Found" or 404 "Not Found". Registration does not exist (e.g. may have been removed).

If the registration fails in any way, including "Not Found" and request timeouts, or if the time indicated in a Service Unavailable Max-Age/Retry-After exceeds the remaining lifetime, the registering endpoint SHOULD attempt registration again.

The following example shows how the registering endpoint updates its registration resource at an RD using this interface with the example location value: /rd/4521.

```
Req: POST /rd/4521

Res: 2.04 Changed
```

Figure 13: Example update of a registration

The following example shows the registering endpoint updating its registration resource at an RD using this interface with the example location value: /rd/4521. The initial registration by the registering endpoint set the following values:

* endpoint name (ep)=endpoint1

* lifetime (lt)=500

* Base URI (base)=coap://local-proxy-old.example.com:5683

* payload of Figure 8

The initial state of the RD is reflected in the following request:

```
Req: GET /rd-lookup/res?ep=endpoint1

Res: 2.05 Content
Payload:
<coap://local-proxy-old.example.com:5683/sensors/temp>;ct=41;
    rt="temperature-c";if="sensor";
    anchor="coap://local-proxy-old.example.com:5683/",
<http://www.example.com/sensors/temp>;
    anchor="coap://local-proxy-old.example.com:5683/sensors/temp";
    rel="describedby"
```

Figure 14: Example lookup before a change to the base address

The following example shows the registering endpoint changing the Base URI to "coaps://new.example.com:5684":

```
Req: POST /rd/4521?base=coaps://new.example.com:5684

Res: 2.04 Changed
```

Figure 15: Example registration update that changes the base address

The consecutive query returns:

```
Req: GET /rd-lookup/res?ep=endpoint1

Res: 2.05 Content
Payload:
<coap://new.example.com:5684/sensors/temp>;ct=41;
    rt="temperature-c";if="sensor";
    anchor="coap://new.example.com:5684/",
<http://www.example.com/sensors/temp>;
    anchor="coap://new.example.com:5684/sensors/temp";
    rel="describedby"
```

Figure 16: Example lookup after a change to the base address

5.3.2. Registration Removal

Although RD registrations have soft state and will eventually timeout after their lifetime, the registering endpoint SHOULD explicitly remove an entry from the RD if it knows it will no longer be available (for example on shut-down). This is accomplished using a removal interface on the RD by performing a DELETE on the endpoint resource.

The removal request interface is specified as follows:

Interaction: EP -> RD

Method: DELETE

URI Template: {+location}

URI Template Variables: location := This is the Location returned by the RD as a result of a successful earlier registration.

The following responses are expected on this interface:

Success: 2.02 "Deleted" or 204 "No Content" upon successful deletion

Failure: 4.04 "Not Found" or 404 "Not Found". Registration does not exist (e.g. may already have been removed).

The following examples shows successful removal of the endpoint from the RD with example location value /rd/4521.

```
Req: DELETE /rd/4521

Res: 2.02 Deleted
```

Figure 17: Example of a registration removal

5.3.3. Further operations

Additional operations on the registration can be specified in future documents, for example:

* Send iPATCH (or PATCH) updates ([RFC8132]) to add, remove or change the links of a registration.

* Use GET to read the currently stored set of links in a registration resource.

Those operations are out of scope of this document, and will require media types suitable for modifying sets of links.

6. RD Lookup

To discover the resources registered with the RD, a lookup interface must be provided. This lookup interface is defined as a default, and it is assumed that RDs may also support lookups to return resource descriptions in alternative formats (e.g. JSON or CBOR link format [I-D.ietf-core-links-json]) or using more advanced interfaces (e.g. supporting context or semantic based lookup) on different resources that are discovered independently.

RD Lookup allows lookups for endpoints and resources using attributes defined in this document and for use with the CoRE Link Format. The result of a lookup request is the list of links (if any) corresponding to the type of lookup. Thus, an endpoint lookup MUST return a list of endpoints and a resource lookup MUST return a list of links to resources.

The lookup type is selected by a URI endpoint, which is indicated by a Resource Type as per Table 1 below:

Lookup Type	Resource Type	Mandatory
Resource	core.rd-lookup-res	Mandatory
Endpoint	core.rd-lookup-ep	Mandatory

Table 1: Lookup Types

6.1. Resource lookup

Resource lookup results in links that are semantically equivalent to the links submitted to the RD. The links and link parameters returned by the lookup are equal to the submitted ones, except that the target and anchor references are fully resolved.

Links that did not have an anchor attribute are therefore returned with the base URI of the registration as the anchor. Links of which href or anchor was submitted as a (full) URI are returned with these attributes unmodified.

Above rules allow the client to interpret the response as links without any further knowledge of the storage conventions of the RD. The RD MAY replace the registration base URIs with a configured intermediate proxy, e.g. in the case of an HTTP lookup interface for CoAP endpoints.

If the base URI of a registration contains a link-local address, the RD MUST NOT show its links unless the lookup was made from the same link. The RD MUST NOT include zone identifiers in the resolved URIs.

6.2. Lookup filtering

Using the Accept Option, the requester can control whether the returned list is returned in CoRE Link Format ("application/link-format", default) or in alternate content-formats (e.g. from [I-D.ietf-core-links-json]).

The page and count parameters are used to obtain lookup results in specified increments using pagination, where count specifies how many links to return and page specifies which subset of links organized in sequential pages, each containing 'count' links, starting with link zero and page zero. Thus, specifying count of 10 and page of 0 will return the first 10 links in the result set (links 0-9). Count = 10 and page = 1 will return the next 'page' containing links 10-19, and so on.

Multiple search criteria MAY be included in a lookup. All included criteria MUST match for a link to be returned. The RD MUST support matching with multiple search criteria.

A link matches a search criterion if it has an attribute of the same name and the same value, allowing for a trailing "*" wildcard operator as in Section 4.1 of [RFC6690]. Attributes that are defined as "link-type" match if the search value matches any of their values (see Section 4.1 of [RFC6690]; e.g. "?if=core.s" matches ";if="abc core.s";"). A resource link also matches a search criterion if its endpoint would match the criterion, and vice versa, an endpoint link matches a search criterion if any of its resource links matches it.

Note that "href" is a valid search criterion and matches target references. Like all search criteria, on a resource lookup it can match the target reference of the resource link itself, but also the registration resource of the endpoint that registered it. Queries for resource link targets MUST be in URI form (i.e. not relative references) and are matched against a resolved link target. Queries for endpoints SHOULD be expressed in path-absolute form if possible and MUST be expressed in URI form otherwise; the RD SHOULD recognize either. The "anchor" attribute is usable for resource lookups, and, if queried, MUST be for in URI form as well.

Endpoints that are interested in a lookup result repeatedly or continuously can use mechanisms like ETag caching, resource observation ([RFC7641]), or any future mechanism that might allow more efficient observations of collections. These are advertised, detected and used according to their own specifications and can be used with the lookup interface as with any other resource.

When resource observation is used, every time the set of matching links changes, or the content of a matching link changes, the RD sends a notification with the matching link set. The notification contains the successful current response to the given request, especially with respect to representing zero matching links (see "Success" item below).

The lookup interface is specified as follows:

Interaction: Client -> RD

Method: GET

URI Template: {+type-lookup-location}{?page,count,search*}

URI Template Variables: type-lookup-location := RD Lookup URI for a given lookup type (mandatory). The address is discovered as described in Section 4.3.

search := Search criteria for limiting the number of results (optional).

The search criteria are an associative array, expressed in a form-style query as per the URI template (see [RFC6570] Sections 2.4.2 and 3.2.8)

page := Page (optional). Parameter cannot be used without the count parameter. Results are returned from result set in pages that contain 'count' links starting from index (page * count). Page numbering starts with zero.

count := Count (optional). Number of results is limited to this parameter value. If the page parameter is also present, the response MUST only include 'count' links starting with the (page * count) link in the result set from the query. If the count parameter is not present, then the response MUST return all matching links in the result set. Link numbering starts with zero.

Accept: absent, application/link-format or any other indicated media type representing web links

The following responses codes are defined for this interface:

Success: 2.05 "Content" or 200 "OK" with an "application/link-format" or other web link payload containing matching entries for the lookup. The payload can contain zero links (which is an empty payload in [RFC6690] link format, but could also be "[]" in JSON based formats), indicating that no entities matched the request.

6.3. Resource lookup examples

The examples in this section assume the existence of CoAP hosts with a default CoAP port 61616. HTTP hosts are possible and do not change the nature of the examples.

The following example shows a client performing a resource lookup with the example resource look-up locations discovered in Figure 5:

```
Req: GET /rd-lookup/res?rt=temperature

Res: 2.05 Content
<coap://[2001:db8:3::123]:61616/temp>;rt="temperature";
           anchor="coap://[2001:db8:3::123]:61616"
```

Figure 18: Example a resource lookup

A client that wants to be notified of new resources as they show up can use observation:

```
Req: GET /rd-lookup/res?rt=light
Observe: 0

Res: 2.05 Content
Observe: 23
Payload: empty

(at a later point in time)

Res: 2.05 Content
Observe: 24
Payload:
<coap://[2001:db8:3::124]/west>;rt="light";
    anchor="coap://[2001:db8:3::124]",
<coap://[2001:db8:3::124]/south>;rt="light";
    anchor="coap://[2001:db8:3::124]",
<coap://[2001:db8:3::124]/east>;rt="light";
    anchor="coap://[2001:db8:3::124]"
```

Figure 19: Example an observing resource lookup

The following example shows a client performing a paginated resource lookup

```
Req: GET /rd-lookup/res?page=0&count=5

Res: 2.05 Content
<coap://[2001:db8:3::123]:61616/res/0>;rt=sensor;ct=60;
    anchor="coap://[2001:db8:3::123]:61616",
<coap://[2001:db8:3::123]:61616/res/1>;rt=sensor;ct=60;
    anchor="coap://[2001:db8:3::123]:61616",
<coap://[2001:db8:3::123]:61616/res/2>;rt=sensor;ct=60;
    anchor="coap://[2001:db8:3::123]:61616",
<coap://[2001:db8:3::123]:61616/res/3>;rt=sensor;ct=60;
    anchor="coap://[2001:db8:3::123]:61616",
<coap://[2001:db8:3::123]:61616/res/4>;rt=sensor;ct=60;
    anchor="coap://[2001:db8:3::123]:61616"

Req: GET /rd-lookup/res?page=1&count=5

Res: 2.05 Content
<coap://[2001:db8:3::123]:61616/res/5>;rt=sensor;ct=60;
    anchor="coap://[2001:db8:3::123]:61616",
<coap://[2001:db8:3::123]:61616/res/6>;rt=sensor;ct=60;
    anchor="coap://[2001:db8:3::123]:61616",
<coap://[2001:db8:3::123]:61616/res/7>;rt=sensor;ct=60;
    anchor="coap://[2001:db8:3::123]:61616",
<coap://[2001:db8:3::123]:61616/res/8>;rt=sensor;ct=60;
    anchor="coap://[2001:db8:3::123]:61616",
<coap://[2001:db8:3::123]:61616/res/9>;rt=sensor;ct=60;
    anchor="coap://[2001:db8:3::123]:61616"
```

Figure 20: Examples of paginated resource lookup

The following example shows a client performing a lookup of all resources of all endpoints of a given endpoint type. It assumes that two endpoints (with endpoint names "sensor1" and "sensor2") have previously registered with their respective addresses "coap://sensor1.example.com" and "coap://sensor2.example.com", and posted the very payload of the 6th request of section 5 of [RFC6690].

It demonstrates how absolute link targets stay unmodified, while relative ones are resolved:

```
Req: GET /rd-lookup/res?et=oic.d.sensor

<coap://sensor1.example.com/sensors>;ct=40;title="Sensor Index";
    anchor="coap://sensor1.example.com",
<coap://sensor1.example.com/sensors/temp>;rt="temperature-c";
    if="sensor"; anchor="coap://sensor1.example.com",
<coap://sensor1.example.com/sensors/light>;rt="light-lux";
    if="sensor"; anchor="coap://sensor1.example.com",
<http://www.example.com/sensors/t123>;rel="describedby";
    anchor="coap://sensor1.example.com/sensors/temp",
<coap://sensor1.example.com/t>;rel="alternate";
    anchor="coap://sensor1.example.com/sensors/temp",
<coap://sensor2.example.com/sensors>;ct=40;title="Sensor Index";
    anchor="coap://sensor2.example.com",
<coap://sensor2.example.com/sensors/temp>;rt="temperature-c";
    if="sensor"; anchor="coap://sensor2.example.com",
<coap://sensor2.example.com/sensors/light>;rt="light-lux";
    if="sensor"; anchor="coap://sensor2.example.com",
<http://www.example.com/sensors/t123>;rel="describedby";
    anchor="coap://sensor2.example.com/sensors/temp",
<coap://sensor2.example.com/t>;rel="alternate";
    anchor="coap://sensor2.example.com/sensors/temp"
```

Figure 21: Example of resource lookup from multiple endpoints

6.4. Endpoint lookup

The endpoint lookup returns registration resources which can only be manipulated by the registering endpoint.

Endpoint registration resources are annotated with their endpoint names (ep), sectors (d, if present) and registration base URI (base; reports the registrant-ep's address if no explicit base was given) as well as a constant resource type (rt="core.rd-ep"); the lifetime (lt) is not reported. Additional endpoint attributes are added as target attributes to their endpoint link unless their specification says otherwise.

Links to endpoints SHOULD be presented in path-absolute form or, if required, as (full) URIs. (This avoids the RFC6690 ambiguities.)

Base addresses that contain link-local addresses MUST NOT include zone identifiers, and such registrations MUST NOT be shown unless the lookup was made from the same link from which the registration was made.

While Endpoint Lookup does expose the registration resources, the RD does not need to make them accessible to clients. Clients SHOULD NOT attempt to dereference or manipulate them.

An RD can report endpoints in lookup that are not hosted at the same address. Lookup clients MUST be prepared to see arbitrary URIs as registration resources in the results and treat them as opaque identifiers; the precise semantics of such links are left to future specifications.

The following example shows a client performing an endpoint type (et) lookup with the value oic.d.sensor (which is currently a registered rt value):

```
Req: GET /rd-lookup/ep?et=oic.d.sensor

Res: 2.05 Content
</rd/1234>;base="coap://[2001:db8:3::127]:61616";ep="node5";
et="oic.d.sensor";ct="40";rt="core.rd-ep",
</rd/4521>;base="coap://[2001:db8:3::129]:61616";ep="node7";
et="oic.d.sensor";ct="40";d="floor-3";rt="core.rd-ep"
```

Figure 22: Examples of endpoint lookup

7. Security policies

The security policies that are applicable to an RD strongly depend on the application, and are not set out normatively here.

This section provides a list of aspects that applications should consider when describing their use of the RD, without claiming to cover all cases. It is using terminology of [I-D.ietf-ace-oauth-authz], in which the RD acts as the Resource Server (RS), and both registrant-eps and lookup clients act as Clients (C) with support from an Authorization Server (AS), without the intention of ruling out other (e.g. certificate / public-key infrastructure (PKI) based) schemes.

Any, all or none of the below can apply to an application. Which are relevant depends on its protection objectives.

7.1. Endpoint name

Whenever an RD needs to provide trustworthy results to clients doing endpoint lookup, or resource lookup with filtering on the endpoint name, the RD must ensure that the registrant is authorized to use the given endpoint name. This applies both to registration and later to operations on the registration resource. It is immaterial there whether the client is the registrant-ep itself or a CT is doing the registration: The RD can not tell the difference, and CTs may use authorization credentials authorizing only operations on that particular endpoint name, or a wider range of endpoint names.

When certificates are used as authorization credentials, the sector(s) and endpoint name(s) can be transported in the subject. In an ACE context, those are typically transported in a scope claim.

7.1.1. Random endpoint names

Conversely, in applications where the RD does not check the endpoint name, the authorized registering endpoint can generate a random number (or string) that identifies the endpoint. The RD should then remember unique properties of the registrant, associate them with the registration for as long as its registration resource is active (which may be longer than the registration's lifetime), and require the same properties for operations on the registration resource.

Registrants that are prepared to pick a different identifier when their initial attempt at registration is unauthorized should pick an identifier at least twice as long as the expected number of registrants; registrants without such a recovery options should pick significantly longer endpoint names (e.g. using UUID URNs [RFC4122]).

7.2. Entered resources

When lookup clients expect that certain types of links can only originate from certain endpoints, then the RD needs to apply filtering to the links an endpoint may register.

For example, if clients use an RD to find a server that provides firmware updates, then any registrant that wants to register (or update) links to firmware sources will need to provide suitable credentials to do so, independently of its endpoint name.

Note that the impact of having undesirable links in the RD depends on the application: if the client requires the firmware server to present credentials as a firmware server, a fraudulent link's impact is limited to the client revealing its intention to obtain updates and slowing down the client until it finds a legitimate firmware server; if the client accepts any credentials from the server as long as they fit the provided URI, the impact is larger.

An RD may also require that only links are registered on whose anchor (or even target) the RD recognizes as authoritative of. One way to do this is to demand that the registrant present the same credentials as a client that they'd need to present if contacted as a server at the resources' URI, which may include using the address and port that are part of the URI. Such a restriction places severe practical limitations on the links that can be registered.

As above, the impact of undesirable links depends on the extent to which the lookup client relies on the RD. To avoid the limitations, RD applications should consider prescribe that lookup clients only use the discovered information as hints, and describe which pieces of information need to be verified with the server because they impact the application's security.

7.3. Link confidentiality

When registrants publish information in the RD that is not available to any client that would query the registrant's .well-known/core interface, or when lookups to that interface are subject so stricter firewalling than lookups to the RD, the RD may need to limit which lookup clients may access the information.

In those situations, the registrant needs to be careful to authenticate the RD as well. The registrant needs to know in advance which AS, audience and scope values indicate an RD it may trust for this purpose, and can not rely on the RD to provide AS address and token details. (In contrast, in the other scenarios it may try to register, and follow the pointers the RD gives it as to which credentials it needs to provide in order to perform its registration).

7.4. Segmentation

Within a single RD, different security policies can apply.

One example of this are multi-tenant deployments separated by the sector (d) parameter. Some sectors might apply limitations on the endpoint names available, while others use a random identifier approach to endpoint names and place limits on the entered links based on their attributes instead.

Care must be taken in such setups to determine the applicable access control measures to each operation. One easy way to do that is to mandate the use of the sector parameter on all operations, as no credentials are suitable for operations across sector borders anyway.

8. Security Considerations

The security considerations as described in Section 5 of [RFC8288] and Section 6 of [RFC6690] apply. The "/.well-known/core" resource may be protected e.g. using DTLS when hosted on a CoAP server as described in [RFC7252]. DTLS or TLS based security SHOULD be used on all resource directory interfaces defined in this document.

8.1. Endpoint Identification and Authentication

An Endpoint (name, sector) pair is unique within the set of endpoints registered by the RD. An Endpoint MUST NOT be identified by its protocol, port or IP address as these may change over the lifetime of an Endpoint.

Every operation performed by an Endpoint on an RD SHOULD be mutually authenticated using Pre-Shared Key, Raw Public Key or Certificate based security.

Consider the following threat: two devices A and B are registered at a single server. Both devices have unique, per-device credentials for use with DTLS to make sure that only parties with authorization to access A or B can do so.

Now, imagine that a malicious device A wants to sabotage the device B. It uses its credentials during the DTLS exchange. Then, it specifies the endpoint name of device B as the name of its own endpoint in device A. If the server does not check whether the identifier provided in the DTLS handshake matches the identifier used at the CoAP layer then it may be inclined to use the endpoint name for looking up what information to provision to the malicious device.

Endpoint authentication needs to be checked independently of whether there are configured requirements on the credentials for a given endpoint name (Section 7.1) or whether arbitrary names are accepted (Section 7.1.1).

Simple registration could be used to circumvent address based access control: An attacker would send a simple registration request with the victim's address as source address, and later look up the victim's .well-known/core content in the RD. Mitigation for this is recommended in Section 5.1.

8.2. Access Control

Access control SHOULD be performed separately for the RD registration and Lookup API paths, as different endpoints may be authorized to register with an RD from those authorized to lookup endpoints from the RD. Such access control SHOULD be performed in as fine-grained a level as possible. For example access control for lookups could be performed either at the sector, endpoint or resource level.

8.3. Denial of Service Attacks

Services that run over UDP unprotected are vulnerable to unknowingly become part of a DDoS attack as UDP does not require return routability check. Therefore, an attacker can easily spoof the source IP of the target entity and send requests to such a service which would then respond to the target entity. This can be used for large-scale DDoS attacks on the target. Especially, if the service returns a response that is order of magnitudes larger than the request, the situation becomes even worse as now the attack can be amplified. DNS servers have been widely used for DDoS amplification attacks. There is also a danger that NTP Servers could become implicated in denial-of-service (DoS) attacks since they run on unprotected UDP, there is no return routability check, and they can have a large amplification factor. The responses from the NTP server were found to be 19 times larger than the request. An RD which responds to wild-card lookups is potentially vulnerable if run with CoAP over UDP. Since there is no return routability check and the responses can be significantly larger than requests, RDs can unknowingly become part of a DDoS amplification attack.

[RFC7252] describes this at length in its Section 11.3, including some mitigation by using small block sizes in responses. The upcoming [I-D.ietf-core-echo-request-tag] updates that by describing a source address verification mechanism using the Echo option.

[If this document is published together with or after I-D.ietf-core-echo-request-tag, the above paragraph is replaced with the following:

[RFC7252] describes this at length in its Section 11.3, and [I-D.ietf-core-echo-request-tag] (which updates the former) recommends using the Echo option to verify the request's source address.

]

9. IANA Considerations

9.1. Resource Types

IANA is asked to enter the following values into the Resource Type (rt=) Link Target Attribute Values sub-registry of the Constrained Restful Environments (CoRE) Parameters registry defined in [RFC6690]:

Value	Description	Reference
core.rd	Directory resource of an RD	RFCTHIS Section 4.3
core.rd-lookup-res	Resource lookup of an RD	RFCTHIS Section 4.3
core.rd-lookup-ep	Endpoint lookup of an RD	RFCTHIS Section 4.3
core.rd-ep	Endpoint resource of an RD	RFCTHIS Section 6

Table 2

9.2. IPv6 ND Resource Directory Address Option

This document registers one new ND option type under the sub-registry "IPv6 Neighbor Discovery Option Formats":

* Resource Directory Address Option (TBD38)

[The RFC editor is asked to replace TBD38 with the assigned number in the document; the value 38 is suggested.]

9.3. RD Parameter Registry

This specification defines a new sub-registry for registration and lookup parameters called "RD Parameters" under "CoRE Parameters". Although this specification defines a basic set of parameters, it is expected that other standards that make use of this interface will define new ones.

Each entry in the registry must include

* the human readable name of the parameter,

* the short name as used in query parameters or target attributes,

* indication of whether it can be passed as a query parameter at registration of endpoints, as a query parameter in lookups, or be expressed as a target attribute,

* syntax and validity requirements if any,

* a description,

* and a link to reference documentation.

The query parameter MUST be both a valid URI query key [RFC3986] and a token as used in [RFC8288].

The description must give details on whether the parameter can be updated, and how it is to be processed in lookups.

The mechanisms around new RD parameters should be designed in such a way that they tolerate RD implementations that are unaware of the parameter and expose any parameter passed at registration or updates on in endpoint lookups. (For example, if a parameter used at registration were to be confidential, the registering endpoint should be instructed to only set that parameter if the RD advertises support for keeping it confidential at the discovery step.)

Initial entries in this sub-registry are as follows:

Full name	Short	Validity	Use	Description
Endpoint Name	ep	Unicode*	RLA	Name of the endpoint
Lifetime	lt	1-4294967295	R	Lifetime of the registration in seconds
Sector	d	Unicode*	RLA	Sector to which this endpoint belongs
Registration Base URI	base	URI	RLA	The scheme, address and port and path at which this server is available
Page	page	Integer	L	Used for pagination
Count	count	Integer	L	Used for pagination
Endpoint Type	et	Section 9.3.1	RLA	Semantic type of the endpoint (see Section 9.4)

Table 3: RD Parameters

(Short: Short name used in query parameters or target attributes. Validity: Unicode* = 63 Bytes of UTF-8 encoded Unicode, with no control characters as per Section 5. Use: R = used at registration, L = used at lookup, A = expressed in target attribute

The descriptions for the options defined in this document are only summarized here. To which registrations they apply and when they are to be shown is described in the respective sections of this document. All their reference documentation entries point to this document.

The IANA policy for future additions to the sub-registry is "Expert Review" as described in [RFC8126]. The evaluation should consider formal criteria, duplication of functionality (Is the new entry redundant with an existing one?), topical suitability (E.g. is the described property actually a property of the endpoint and not a property of a particular resource, in which case it should go into the payload of the registration and need not be registered?), and the potential for conflict with commonly used target attributes (For

example, "if" could be used as a parameter for conditional registration if it were not to be used in lookup or attributes, but would make a bad parameter for lookup, because a resource lookup with an "if" query parameter could ambiguously filter by the registered endpoint property or the [RFC6690] target attribute).

9.3.1. Full description of the "Endpoint Type" Registration Parameter

An endpoint registering at an RD can describe itself with endpoint types, similar to how resources are described with Resource Types in [RFC6690]. An endpoint type is expressed as a string, which can be either a URI or one of the values defined in the Endpoint Type sub-registry. Endpoint types can be passed in the "et" query parameter as part of extra-attrs at the Registration step, are shown on endpoint lookups using the "et" target attribute, and can be filtered for using "et" as a search criterion in resource and endpoint lookup. Multiple endpoint types are given as separate query parameters or link attributes.

Note that Endpoint Type differs from Resource Type in that it uses multiple attributes rather than space separated values. As a result, RDs implementing this specification automatically support correct filtering in the lookup interfaces from the rules for unknown endpoint attributes.

9.4. "Endpoint Type" (et=) RD Parameter values

This specification establishes a new sub-registry under "CoRE Parameters" called '"Endpoint Type" (et=) RD Parameter values'. The registry properties (required policy, requirements, template) are identical to those of the Resource Type parameters in [RFC6690], in short:

The review policy is IETF Review for values starting with "core", and Specification Required for others.

The requirements to be enforced are:

* The values MUST be related to the purpose described in Section 9.3.1.

* The registered values MUST conform to the ABNF reg-rel-type definition of [RFC6690] and MUST NOT be a URI.

* It is recommended to use the period "." character for segmentation.

The registry initially contains one value:

* "core.rd-group": An application group as described in Appendix A.

9.5. Multicast Address Registration

IANA is asked to assign the following multicast addresses for use by CoAP nodes:

IPv4 - "all CoRE Resource Directories" address MCD2 (suggestion: 224.0.1.189), from the "IPv4 Multicast Address Space Registry". As the address is used for discovery that may span beyond a single network, it has come from the Internetwork Control Block (224.0.1.x) [RFC5771].

IPv6 - "all CoRE Resource Directories" address MCD1 (suggestions FF0X::FE), from the "IPv6 Multicast Address Space Registry", in the "Variable Scope Multicast Addresses" space (RFC 3307). Note that there is a distinct multicast address for each scope that interested CoAP nodes should listen to; CoAP needs the Link-Local and Site-Local scopes only.

[The RFC editor is asked to replace MCD1 and MCD2 with the assigned addresses throughout the document.]

9.6. Well-Known URIs

IANA is asked to extend the reference for the "core" URI suffix in the "Well-Known URIs" registry to reference this document next to [RFC6690], as this defines the resource's behavior for POST requests.

9.7. Service Names and Transport Protocol Port Number Registry

IANA is asked to enter four new items into the Service Names and Transport Protocol Port Number Registry:

* Service name: "core-rd", Protocol: "udp", Description: "Resource Directory accessed using CoAP"

* Service name "core-rd-dtls", Protocol: "udp", Description: "Resource Directory accessed using CoAP over DTLS"

* Service name: "core-rd", Protocol: "tcp", Description: "Resource Directory accessed using CoAP over TCP"

* Service name "core-rd-tls", Protocol: "tcp", Description: "Resource Directory accessed using CoAP over TLS"

All in common have this document as their reference.

10. Examples

Two examples are presented: a Lighting Installation example in Section 10.1 and a LWM2M example in Section 10.2.

10.1. Lighting Installation

This example shows a simplified lighting installation which makes use of the RD with a CoAP interface to facilitate the installation and start-up of the application code in the lights and sensors. In particular, the example leads to the definition of a group and the enabling of the corresponding multicast address as described in Appendix A. No conclusions must be drawn on the realization of actual installation or naming procedures, because the example only "emphasizes" some of the issues that may influence the use of the RD and does not pretend to be normative.

10.1.1. Installation Characteristics

The example assumes that the installation is managed. That means that a Commissioning Tool (CT) is used to authorize the addition of nodes, name them, and name their services. The CT can be connected to the installation in many ways: the CT can be part of the installation network, connected by WiFi to the installation network, or connected via GPRS link, or other method.

It is assumed that there are two naming authorities for the installation: (1) the network manager that is responsible for the correct operation of the network and the connected interfaces, and (2) the lighting manager that is responsible for the correct functioning of networked lights and sensors. The result is the existence of two naming schemes coming from the two managing entities.

The example installation consists of one presence sensor, and two luminaries, luminary1 and luminary2, each with their own wireless interface. Each luminary contains three lamps: left, right and middle. Each luminary is accessible through one endpoint. For each lamp a resource exists to modify the settings of a lamp in a luminary. The purpose of the installation is that the presence sensor notifies the presence of persons to a group of lamps. The group of lamps consists of: middle and left lamps of luminary1 and right lamp of luminary2.

Before commissioning by the lighting manager, the network is installed and access to the interfaces is proven to work by the network manager.

At the moment of installation, the network under installation is not necessarily connected to the DNS infra structure. Therefore, SLAAC IPv6 addresses are assigned to CT, RD, luminaries and sensor shown in Table 4 below:

Name	IPv6 address
luminary1	2001:db8:4::1
luminary2	2001:db8:4::2
Presence sensor	2001:db8:4::3
RD	2001:db8:4::ff

Table 4: interface SLAAC addresses

In Section 10.1.2 the use of RD during installation is presented.

10.1.2. RD entries

It is assumed that access to the DNS infrastructure is not always possible during installation. Therefore, the SLAAC addresses are used in this section.

For discovery, the resource types (rt) of the devices are important. The lamps in the luminaries have rt: light, and the presence sensor has rt: p-sensor. The endpoints have names which are relevant to the light installation manager. In this case luminary1, luminary2, and the presence sensor are located in room 2-4-015, where luminary1 is located at the window and luminary2 and the presence sensor are located at the door. The endpoint names reflect this physical location. The middle, left and right lamps are accessed via path /light/middle, /light/left, and /light/right respectively. The identifiers relevant to the RD are shown in Table 5 below:

Name	endpoint	resource path	resource type
luminary1	lm_R2-4-015_wndw	/light/left	light
luminary1	lm_R2-4-015_wndw	/light/middle	light
luminary1	lm_R2-4-015_wndw	/light/right	light
luminary2	lm_R2-4-015_door	/light/left	light
luminary2	lm_R2-4-015_door	/light/middle	light
luminary2	lm_R2-4-015_door	/light/right	light
Presence sensor	ps_R2-4-015_door	/ps	p-sensor

Table 5: RD identifiers

It is assumed that the CT knows the RD's address, and has performed URI discovery on it that returned a response like the one in the Section 4.3 example.

The CT inserts the endpoints of the luminaries and the sensor in the RD using the registration base URI parameter (base) to specify the interface address:

```
Req: POST coap://[2001:db8:4::ff]/rd
  ?ep=lm_R2-4-015_wndw&base=coap://[2001:db8:4::1]&d=R2-4-015
Payload:
</light/left>;rt="light",
</light/middle>;rt="light",
</light/right>;rt="light"

Res: 2.01 Created
Location-Path: /rd/4521

Req: POST coap://[2001:db8:4::ff]/rd
  ?ep=lm_R2-4-015_door&base=coap://[2001:db8:4::2]&d=R2-4-015
Payload:
</light/left>;rt="light",
</light/middle>;rt="light",
</light/right>;rt="light"

Res: 2.01 Created
Location-Path: /rd/4522

Req: POST coap://[2001:db8:4::ff]/rd
  ?ep=ps_R2-4-015_door&base=coap://[2001:db8:4::3]d&d=R2-4-015
Payload:
</ps>;rt="p-sensor"

Res: 2.01 Created
Location-Path: /rd/4523
```

Figure 23: Example of registrations a CT enters into an RD

The sector name d=R2-4-015 has been added for an efficient lookup because filtering on "ep" name is more awkward. The same sector name is communicated to the two luminaries and the presence sensor by the CT.

The group is specified in the RD. The base parameter is set to the site-local multicast address allocated to the group. In the POST in the example below, the resources supported by all group members are published.

```
Req: POST coap://[2001:db8:4::ff]/rd
?ep=grp_R2-4-015&et=core.rd-group&base=coap://[ff05::1]
Payload:
</light/left>;rt="light",
</light/middle>;rt="light",
</light/right>;rt="light"

Res: 2.01 Created
Location-Path: /rd/501
```

Figure 24: Example of a multicast group a CT enters into an RD

After the filling of the RD by the CT, the application in the luminaries can learn to which groups they belong, and enable their interface for the multicast address.

The luminary, knowing its sector and being configured to join any group containing lights, searches for candidate groups and joins them:

```
Req: GET coap://[2001:db8:4::ff]/rd-lookup/ep
  ?d=R2-4-015&et=core.rd-group&rt=light

Res: 2.05 Content
</rd/501>;ep="grp_R2-4-015";et="core.rd-group";
          base="coap://[ff05::1]";rt="core.rd-ep"
```

Figure 25: Example of a lookup exchange to find suitable multicast addresses

From the returned base parameter value, the luminary learns the multicast address of the multicast group.

Alternatively, the CT can communicate the multicast address directly to the luminaries by using the "coap-group" resource specified in [RFC7390].

```
Req: POST coap://[2001:db8:4::1]/coap-group
Content-Format: application/coap-group+json
Payload:
{ "a": "[ff05::1]", "n": "grp_R2-4-015"}

Res: 2.01 Created
Location-Path: /coap-group/1
```

Figure 26: Example use of direct multicast address configuration

Dependent on the situation, only the address, "a", or the name, "n", is specified in the coap-group resource.

The presence sensor can learn the presence of groups that support resources with rt=light in its own sector by sending the same request, as used by the luminary. The presence sensor learns the multicast address to use for sending messages to the luminaries.

10.2. OMA Lightweight M2M (LWM2M) Example

This example shows how the OMA LWM2M specification makes use of RDs.

OMA LWM2M is a profile for device services based on CoAP(OMA Name Authority). LWM2M defines a simple object model and a number of abstract interfaces and operations for device management and device service enablement.

An LWM2M server is an instance of an LWM2M middleware service layer, containing an RD along with other LWM2M interfaces defined by the LWM2M specification.

The registration interface of this specification is used to provide the LWM2M Registration interface.

LWM2M does not provide for registration sectors and does not currently use the rd-lookup interface.

The LWM2M specification describes a set of interfaces and a resource model used between a LWM2M device and an LWM2M server. Other interfaces, proxies, and applications are currently out of scope for LWM2M.

The location of the LWM2M Server and RD URI path is provided by the LWM2M Bootstrap process, so no dynamic discovery of the RD is used. LWM2M Servers and endpoints are not required to implement the /.well-known/core resource.

10.2.1. The LWM2M Object Model

The OMA LWM2M object model is based on a simple 2 level class hierarchy consisting of Objects and Resources.

An LWM2M Resource is a REST endpoint, allowed to be a single value or an array of values of the same data type.

An LWM2M Object is a resource template and container type that encapsulates a set of related resources. An LWM2M Object represents a specific type of information source; for example, there is a LWM2M

Device Management object that represents a network connection, containing resources that represent individual properties like radio signal strength.

Since there may potentially be more than one of a given type object, for example more than one network connection, LWM2M defines instances of objects that contain the resources that represent a specific physical thing.

The URI template for LWM2M consists of a base URI followed by Object, Instance, and Resource IDs:

{/base-uri}{/object-id}{/object-instance}{/resource-id}{/resource-instance}

The five variables given here are strings. base-uri can also have the special value "undefined" (sometimes called "null" in RFC 6570). Each of the variables object-instance, resource-id, and resource-instance can be the special value "undefined" only if the values behind it in this sequence also are "undefined". As a special case, object-instance can be "empty" (which is different from "undefined") if resource-id is not "undefined".

base-uri := Base URI for LWM2M resources or "undefined" for default (empty) base URI

object-id := OMNA (OMA Name Authority) registered object ID (0-65535)

object-instance := Object instance identifier (0-65535) or "undefined"/"empty" (see above)) to refer to all instances of an object ID

resource-id := OMNA (OMA Name Authority) registered resource ID (0-65535) or "undefined" to refer to all resources within an instance

resource-instance := Resource instance identifier or "undefined" to refer to single instance of a resource

LWM2M IDs are 16 bit unsigned integers represented in decimal (no leading zeroes except for the value 0) by URI format strings. For example, a LWM2M URI might be:

/1/0/1

The base URI is empty, the Object ID is 1, the instance ID is 0, the resource ID is 1, and the resource instance is "undefined". This example URI points to internal resource 1, which represents the registration lifetime configured, in instance 0 of a type 1 object (LWM2M Server Object).

10.2.2. LWM2M Register Endpoint

LWM2M defines a registration interface based on the REST API, described in Section 5. The RD registration URI path of the LWM2M RD is specified to be "/rd".

LWM2M endpoints register object IDs, for example </1>, to indicate that a particular object type is supported, and register object instances, for example </1/0>, to indicate that a particular instance of that object type exists.

Resources within the LWM2M object instance are not registered with the RD, but may be discovered by reading the resource links from the object instance using GET with a CoAP Content-Format of application/link-format. Resources may also be read as a structured object by performing a GET to the object instance with a Content-Format of senml+json.

When an LWM2M object or instance is registered, this indicates to the LWM2M server that the object and its resources are available for management and service enablement (REST API) operations.

LWM2M endpoints may use the following RD registration parameters as defined in Table 3 :

ep - Endpoint Name
lt - registration lifetime

Endpoint Name, Lifetime, and LWM2M Version are mandatory parameters for the register operation, all other registration parameters are optional.

Additional optional LWM2M registration parameters are defined:

Name	Query	Validity	Description
Binding Mode	b	{"U",UQ","S","SQ","US","UQS"}	Available Protocols
LWM2M Version	ver	1.0	Spec Version
SMS Number	sms		MSISDN

Table 6: LWM2M Additional Registration Parameters

The following RD registration parameters are not currently specified for use in LWM2M:

et - Endpoint Type
base - Registration Base URI

The endpoint registration must include a payload containing links to all supported objects and existing object instances, optionally including the appropriate link-format relations.

Here is an example LWM2M registration payload:

</1>,</1/0>,</3/0>,</5>

This link format payload indicates that object ID 1 (LWM2M Server Object) is supported, with a single instance 0 existing, object ID 3 (LWM2M Device object) is supported, with a single instance 0 existing, and object 5 (LWM2M Firmware Object) is supported, with no existing instances.

10.2.3. LWM2M Update Endpoint Registration

The LwM2M update is really very similar to the registration update as described in Section 5.3.1, with the only difference that there are more parameters defined and available. All the parameters listed in that section are also available with the initial registration but are all optional:

lt - Registration Lifetime
b - Protocol Binding
sms - MSISDN
link payload - new or modified links

A Registration update is also specified to be used to update the LWM2M server whenever the endpoint's UDP port or IP address are changed.

10.2.4. LWM2M De-Register Endpoint

LWM2M allows for de-registration using the delete method on the returned location from the initial registration operation. LWM2M de-registration proceeds as described in Section 5.3.2.

11. Acknowledgments

Oscar Novo, Srdjan Krco, Szymon Sasin, Kerry Lynn, Esko Dijk, Anders Brandt, Matthieu Vial, Jim Schaad, Mohit Sethi, Hauke Petersen, Hannes Tschofenig, Sampo Ukkola, Linyi Tian, Jan Newmarch, Matthias Kovatsch, Jaime Jimenez and Ted Lemon have provided helpful comments, discussions and ideas to improve and shape this document. Zach would also like to thank his colleagues from the EU FP7 SENSEI project, where many of the RD concepts were originally developed.

12. Changelog

changes from -24 to -25

* Large rework of section 7 (Security policies)

  Rather than prescribing which data in the RD _is_ authenticated (and how), it now describes what applications built on an RD _can_ choose to authenticate, show possibilities on how to do it and outline what it means for clients.

  This addresses Russ' Genart review points on details in the text in a rather broad fashion. That is because the discussion on the topic inside the WG showed that that text on security has been driven more review-by-review than by an architectural plan of the authors and WG.

* Add concrete suggestions (twice as long as registrant number with retries, or UUIDs without) for random endpoint names

* Point out that simple registration can have faked origins, RECOMMEND mitigation when applicable and suggest the Echo mechanism to implement it.

* Reference existing and upcoming specifications for DDOS mitigation in CoAP.
* Explain the provenance of the example's multicast address.
* Make "SHOULD" of not manipulating foreign registrations a "should" and explain how it is enforced
* Clarify application of RFC6570 to search parameters
* Syntactic fixes in examples
* IANA:
  - Don't announce expected number of registrations (goes to write-up)
  - Include syntax as part of a field's validity in entry requirements
* Editorial changes
  - Align wording between abstract and introduction
  - Abbreviation normalization: "ER model", "RD"
  - RFC8174 boilerplate update
  - Minor clarity fixes
  - Markup and layouting

changes from -23 to -24

* Discovery using DNS-SD added again
* Minimum lifetime (lt) reduced from 60 to 1
* References added
* IANA considerations
  - added about .well-known/core resource
  - added DNS-SD service names
  - made RDAO option number a suggestion

- added "reference" field to endpoint type registry

* Lookup: mention that anchor is a legitimate lookup attribute

* Terminology and example fixes

* Layout fixes, esp. the use of non-ASCII characters in figures

changes from -22 to -23

* Explain that updates can not remove attributes

* Typo fixes

changes from -21 to -22

* Request a dedicated IPv4 address from IANA (rather than sharing with All CoAP nodes)

* Fix erroneous examples

* Editorial changes

  - Add figure numbers to examples

  - Update RD parameters table to reflect changes of earlier versions in the text

  - Typos and minor wording

changes from -20 to -21

(Processing comments during WGLC)

* Defer outdated description of using DNS-SD to find an RD to the defining document

* Describe operational conditions in automation example

* Recommend particular discovery mechanisms for some managed network scenarios

changes from -19 to -20

(Processing comments from the WG chair review)

* Define the permissible characters in endpoint and sector names

* Express requirements on NAT situations in more abstract terms

* Shifted heading levels to have the interfaces on the same level

* Group instructions for error handling into general section

* Simple Registration: process reflowed into items list

* Updated introduction to reflect state of CoRE in general, reference RFC7228 (defining "constrained") and use "IoT" term in addition to "M2M"

* Update acknowledgements

* Assorted editorial changes

  - Unify examples style

  - Terminology: RDAO defined and not only expanded

  - Add CT to Figure 1

  - Consistency in the use of the term "Content Format"

changes from -18 to -19

* link-local addresses: allow but prescribe split-horizon fashion when used, disallow zone identifiers

* Remove informative references to documents not mentioned any more

changes from -17 to -18

* Rather than re-specifying link format (Modernized Link Format), describe a Limited Link Format that’s the uncontested subset of Link Format

* Acknowledging the -17 version as part of the draft

* Move "Read endpoint links" operation to future specification like PATCH

* Demote links-json to an informative reference, and removed them from exchange examples

* Add note on unusability of link-local IP addresses, and describe mitigation.

* Reshuffling of sections: Move additional operations and endpoint lookup back from appendix, and groups into one

* Lookup interface tightened to not imply applicability for non link-format lookups (as those can have vastly different views on link cardinality)

* Simple registration: Change sequence of GET and POST-response, ensuring unsuccessful registrations are reported as such, and suggest how devices that would have required the inverse behavior can still cope with it.

* Abstract and introduction reworded to avoid the impression that resources are stored in full in the RD

* Simplify the rules governing when a registration resource can or must be changed.

* Drop a figure that has become useless due to the changes of and -13 and -17

* Wording consistency fixes: Use "Registrations" and "target attributes"

* Fix incorrect use of content negotiation in discovery interface description (Content-Format -> Accept)

* State that the base attribute value is part of endpoint lookup even when implicit in the registration

* Update references from RFC5988 to its update RFC8288

* Remove appendix on protocol-negotiation (which had a note to be removed before publication)

changes from -16 to -17

(Note that -17 is published as a direct follow-up to -16, containing a single change to be discussed at IETF103)

* Removed groups that are enumerations of registrations and have dedicated mechanism

* Add groups that are enumerations of shared resources and are a special case of endpoint registrations

changes from -15 to -16

* Recommend a common set of resources for members of a group

* Clarified use of multicast group in lighting example

* Add note on concurrent registrations from one EP being possible but not expected

* Refresh web examples appendix to reflect current use of Modernized Link Format

* Add examples of URIs where Modernized Link Format matters

* Editorial changes

changes from -14 to -15

* Rewrite of section "Security policies"

* Clarify that the "base" parameter text applies both to relative references both in anchor and href

* Renamed "Registree-EP" to Registrant-EP"

* Talk of "relative references" and "URIs" rather than "relative" and "absolute" URIs. (The concept of "absolute URIs" of [RFC3986] is not needed in RD).

* Fixed examples

* Editorial changes

changes from -13 to -14

* Rename "registration context" to "registration base URI" (and "con" to "base") and "domain" to "sector" (where the abbreviation "d" stays for compatibility reasons)

* Introduced resource types core.rd-ep and core.rd-gp

* Registration management moved to appendix A, including endpoint and group lookup

* Minor editorial changes

  - PATCH/iPATCH is clearly deferred to another document

  - Recommend against query / fragment identifier in con=

- Interface description lists are described as illustrative
- Rewording of Simple Registration

* Simple registration carries no error information and succeeds immediately (previously, sequence was unspecified)
* Lookup: href are matched against resolved values (previously, this was unspecified)
* Lookup: lt are not exposed any more
* con/base: Paths are allowed
* Registration resource locations can not have query or fragment parts
* Default life time extended to 25 hours
* clarified registration update rules
* lt-value semantics for lookup clarified.
* added template for simple registration

changes from -12 to -13

* Added "all resource directory" nodes MC address
* Clarified observation behavior
* version identification
* example rt= and et= values
* domain from figure 2
* more explanatory text
* endpoints of a groups hosted by different RD
* resolve RFC6690-vs-8288 resolution ambiguities:
  - require registered links not to be relative when using anchor
  - return absolute URIs in resource lookup

changes from -11 to -12

* added Content Model section, including ER diagram

* removed domain lookup interface; domains are now plain attributes of groups and endpoints

* updated chapter "Finding a Resource Directory"; now distinguishes configuration-provided, network-provided and heuristic sources

* improved text on: atomicity, idempotency, lookup with multiple parameters, endpoint removal, simple registration

* updated LWM2M description

* clarified where relative references are resolved, and how context and anchor interact

* new appendix on the interaction with RFCs 6690, 5988 and 3986

* lookup interface: group and endpoint lookup return group and registration resources as link targets

* lookup interface: search parameters work the same across all entities

* removed all methods that modify links in an existing registration (POST with payload, PATCH and iPATCH)

* removed plurality definition (was only needed for link modification)

* enhanced IANA registry text

* state that lookup resources can be observable

* More examples and improved text

changes from -09 to -10

* removed "ins" and "exp" link-format extensions.

* removed all text concerning DNS-SD.

* removed inconsistency in RDAO text.

* suggestions taken over from various sources

* replaced "Function Set" with "REST API", "base URI", "base path"

* moved simple registration to registration section

changes from -08 to -09

* clarified the "example use" of the base RD resource values /rd, /rd-lookup, and /rd-group.

* changed "ins" ABNF notation.

* various editorial improvements, including in examples

* clarifications for RDAO

changes from -07 to -08

* removed link target value returned from domain and group lookup types

* Maximum length of domain parameter 63 bytes for consistency with group

* removed option for simple POST of link data, don't require a .well-known/core resource to accept POST data and handle it in a special way; we already have /rd for that

* add IPv6 ND Option for discovery of an RD

* clarify group configuration section 6.1 that endpoints must be registered before including them in a group

* removed all superfluous client-server diagrams

* simplified lighting example

* introduced Commissioning Tool

* RD-Look-up text is extended.

changes from -06 to -07

* added text in the discovery section to allow content format hints to be exposed in the discovery link attributes

* editorial updates to section 9

* update author information

* minor text corrections

Changes from -05 to -06

* added note that the PATCH section is contingent on the progress of the PATCH method

changes from -04 to -05

* added Update Endpoint Links using PATCH

* http access made explicit in interface specification

* Added http examples

Changes from -03 to -04:

* Added http response codes

* Clarified endpoint name usage

* Add application/link-format+cbor content-format

Changes from -02 to -03:

* Added an example for lighting and DNS integration

* Added an example for RD use in OMA LWM2M

* Added Read Links operation for link inspection by endpoints

* Expanded DNS-SD section

* Added draft authors Peter van der Stok and Michael Koster

Changes from -01 to -02:

* Added a catalogue use case.

* Changed the registration update to a POST with optional link format payload. Removed the endpoint type update from the update.

* Additional examples section added for more complex use cases.

* New DNS-SD mapping section.

* Added text on endpoint identification and authentication.

* Error code 4.04 added to Registration Update and Delete requests.

* Made 63 bytes a SHOULD rather than a MUST for endpoint name and resource type parameters.

Changes from -00 to -01:

* Removed the ETag validation feature.

* Place holder for the DNS-SD mapping section.

* Explicitly disabled GET or POST on returned Location.

* New registry for RD parameters.

* Added support for the JSON Link Format.

* Added reference to the Groupcomm WG draft.

Changes from -05 to WG Document -00:

* Updated the version and date.

Changes from -04 to -05:

* Restricted Update to parameter updates.

* Added pagination support for the Lookup interface.

* Minor editing, bug fixes and reference updates.

* Added group support.

* Changed rt to et for the registration and update interface.

Changes from -03 to -04:

* Added the ins= parameter back for the DNS-SD mapping.

* Integrated the Simple Directory Discovery from Carsten.

* Editorial improvements.

* Fixed the use of ETags.

* Fixed tickets 383 and 372

Changes from -02 to -03:

* Changed the endpoint name back to a single registration parameter ep= and removed the h= and ins= parameters.

* Updated REST interface descriptions to use RFC6570 URI Template format.

* Introduced an improved RD Lookup design as its own function set.

* Improved the security considerations section.

* Made the POST registration interface idempotent by requiring the ep= parameter to be present.

Changes from -01 to -02:

* Added a terminology section.

* Changed the inclusion of an ETag in registration or update to a MAY.

* Added the concept of an RD Domain and a registration parameter for it.

* Recommended the Location returned from a registration to be stable, allowing for endpoint and Domain information to be changed during updates.

* Changed the lookup interface to accept endpoint and Domain as query string parameters to control the scope of a lookup.

13. References

13.1. Normative References

[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>.

[RFC3986] Berners-Lee, T., Fielding, R., and L. Masinter, "Uniform Resource Identifier (URI): Generic Syntax", STD 66, RFC 3986, DOI 10.17487/RFC3986, January 2005, <https://www.rfc-editor.org/info/rfc3986>.

[RFC6570] Gregorio, J., Fielding, R., Hadley, M., Nottingham, M., and D. Orchard, "URI Template", RFC 6570, DOI 10.17487/RFC6570, March 2012, <https://www.rfc-editor.org/info/rfc6570>.

[RFC6690] Shelby, Z., "Constrained RESTful Environments (CoRE) Link Format", RFC 6690, DOI 10.17487/RFC6690, August 2012, <https://www.rfc-editor.org/info/rfc6690>.

[RFC6763] Cheshire, S. and M. Krochmal, "DNS-Based Service Discovery", RFC 6763, DOI 10.17487/RFC6763, February 2013, <https://www.rfc-editor.org/info/rfc6763>.

[RFC8126] Cotton, M., Leiba, B., and T. Narten, "Guidelines for Writing an IANA Considerations Section in RFCs", BCP 26, RFC 8126, DOI 10.17487/RFC8126, June 2017, <https://www.rfc-editor.org/info/rfc8126>.

[RFC8174] Leiba, B., "Ambiguity of Uppercase vs Lowercase in RFC 2119 Key Words", BCP 14, RFC 8174, DOI 10.17487/RFC8174, May 2017, <https://www.rfc-editor.org/info/rfc8174>.

13.2. Informative References

[ER] Chen, P., "The entity-relationship model--toward a unified view of data", DOI 10.1145/320434.320440, ACM Transactions on Database Systems Vol. 1, pp. 9-36, March 1976, <https://doi.org/10.1145/320434.320440>.

[I-D.bormann-t2trg-rel-impl] Bormann, C., "impl-info: A link relation type for disclosing implementation information", Work in Progress, Internet-Draft, draft-bormann-t2trg-rel-impl-01, 27 March 2020, <http://www.ietf.org/internet-drafts/draft-bormann-t2trg-rel-impl-01.txt>.

[I-D.hartke-t2trg-coral] Hartke, K., "The Constrained RESTful Application Language (CoRAL)", Work in Progress, Internet-Draft, draft-hartke-t2trg-coral-09, 8 July 2019, <http://www.ietf.org/internet-drafts/draft-hartke-t2trg-coral-09.txt>.

[I-D.ietf-ace-oauth-authz] Seitz, L., Selander, G., Wahlstroem, E., Erdtman, S., and H. Tschofenig, "Authentication and Authorization for Constrained Environments (ACE) using the OAuth 2.0 Framework (ACE-OAuth)", Work in Progress, Internet-Draft, draft-ietf-ace-oauth-authz-35, 24 June 2020, <http://www.ietf.org/internet-drafts/draft-ietf-ace-oauth-authz-35.txt>.

[I-D.ietf-core-echo-request-tag]
Amsuess, C., Mattsson, J., and G. Selander, "CoAP: Echo, Request-Tag, and Token Processing", Work in Progress, Internet-Draft, draft-ietf-core-echo-request-tag-09, 9 March 2020, <http://www.ietf.org/internet-drafts/draft-ietf-core-echo-request-tag-09.txt>.

[I-D.ietf-core-links-json]
Li, K., Rahman, A., and C. Bormann, "Representing Constrained RESTful Environments (CoRE) Link Format in JSON and CBOR", Work in Progress, Internet-Draft, draft-ietf-core-links-json-10, 26 February 2018, <http://www.ietf.org/internet-drafts/draft-ietf-core-links-json-10.txt>.

[I-D.ietf-core-rd-dns-sd]
Stok, P., Koster, M., and C. Amsuess, "CoRE Resource Directory: DNS-SD mapping", Work in Progress, Internet-Draft, draft-ietf-core-rd-dns-sd-05, 7 July 2019, <http://www.ietf.org/internet-drafts/draft-ietf-core-rd-dns-sd-05.txt>.

[I-D.silverajan-core-coap-protocol-negotiation]
Silverajan, B. and M. Ocak, "CoAP Protocol Negotiation", Work in Progress, Internet-Draft, draft-silverajan-core-coap-protocol-negotiation-09, 2 July 2018, <http://www.ietf.org/internet-drafts/draft-silverajan-core-coap-protocol-negotiation-09.txt>.

[RFC3306] Haberman, B. and D. Thaler, "Unicast-Prefix-based IPv6 Multicast Addresses", RFC 3306, DOI 10.17487/RFC3306, August 2002, <https://www.rfc-editor.org/info/rfc3306>.

[RFC3849] Huston, G., Lord, A., and P. Smith, "IPv6 Address Prefix Reserved for Documentation", RFC 3849, DOI 10.17487/RFC3849, July 2004, <https://www.rfc-editor.org/info/rfc3849>.

[RFC4122] Leach, P., Mealling, M., and R. Salz, "A Universally Unique IDentifier (UUID) URN Namespace", RFC 4122, DOI 10.17487/RFC4122, July 2005, <https://www.rfc-editor.org/info/rfc4122>.

[RFC4944] Montenegro, G., Kushalnagar, N., Hui, J., and D. Culler, "Transmission of IPv6 Packets over IEEE 802.15.4 Networks", RFC 4944, DOI 10.17487/RFC4944, September 2007, <https://www.rfc-editor.org/info/rfc4944>.

[RFC5771] Cotton, M., Vegoda, L., and D. Meyer, "IANA Guidelines for IPv4 Multicast Address Assignments", BCP 51, RFC 5771, DOI 10.17487/RFC5771, March 2010, <https://www.rfc-editor.org/info/rfc5771>.

[RFC6775] Shelby, Z., Ed., Chakrabarti, S., Nordmark, E., and C. Bormann, "Neighbor Discovery Optimization for IPv6 over Low-Power Wireless Personal Area Networks (6LoWPANs)", RFC 6775, DOI 10.17487/RFC6775, November 2012, <https://www.rfc-editor.org/info/rfc6775>.

[RFC6874] Carpenter, B., Cheshire, S., and R. Hinden, "Representing IPv6 Zone Identifiers in Address Literals and Uniform Resource Identifiers", RFC 6874, DOI 10.17487/RFC6874, February 2013, <https://www.rfc-editor.org/info/rfc6874>.

[RFC7228] Bormann, C., Ersue, M., and A. Keranen, "Terminology for Constrained-Node Networks", RFC 7228, DOI 10.17487/RFC7228, May 2014, <https://www.rfc-editor.org/info/rfc7228>.

[RFC7230] Fielding, R., Ed. and J. Reschke, Ed., "Hypertext Transfer Protocol (HTTP/1.1): Message Syntax and Routing", RFC 7230, DOI 10.17487/RFC7230, June 2014, <https://www.rfc-editor.org/info/rfc7230>.

[RFC7252] Shelby, Z., Hartke, K., and C. Bormann, "The Constrained Application Protocol (CoAP)", RFC 7252, DOI 10.17487/RFC7252, June 2014, <https://www.rfc-editor.org/info/rfc7252>.

[RFC7390] Rahman, A., Ed. and E. Dijk, Ed., "Group Communication for the Constrained Application Protocol (CoAP)", RFC 7390, DOI 10.17487/RFC7390, October 2014, <https://www.rfc-editor.org/info/rfc7390>.

[RFC7641] Hartke, K., "Observing Resources in the Constrained Application Protocol (CoAP)", RFC 7641, DOI 10.17487/RFC7641, September 2015, <https://www.rfc-editor.org/info/rfc7641>.

[RFC8132] van der Stok, P., Bormann, C., and A. Sehgal, "PATCH and FETCH Methods for the Constrained Application Protocol (CoAP)", RFC 8132, DOI 10.17487/RFC8132, April 2017, <https://www.rfc-editor.org/info/rfc8132>.

[RFC8141] Saint-Andre, P. and J. Klensin, "Uniform Resource Names (URNs)", RFC 8141, DOI 10.17487/RFC8141, April 2017, <https://www.rfc-editor.org/info/rfc8141>.

[RFC8288] Nottingham, M., "Web Linking", RFC 8288, DOI 10.17487/RFC8288, October 2017, <https://www.rfc-editor.org/info/rfc8288>.

Appendix A. Groups Registration and Lookup

The RD-Groups usage pattern allows announcing application groups inside an RD.

Groups are represented by endpoint registrations. Their base address is a multicast address, and they SHOULD be entered with the endpoint type "core.rd-group". The endpoint name can also be referred to as a group name in this context.

The registration is inserted into the RD by a Commissioning Tool, which might also be known as a group manager here. It performs third party registration and registration updates.

The links it registers SHOULD be available on all members that join the group. Depending on the application, members that lack some resource MAY be permissible if requests to them fail gracefully.

The following example shows a CT registering a group with the name "lights" which provides two resources. The directory resource path /rd is an example RD location discovered in a request similar to Figure 5. The group address in the example is constructed from [RFC3849]'s reserved 2001:db8:: prefix as a unicast-prefix based site-local address (see [RFC3306].

```
Req: POST coap://rd.example.com/rd?ep=lights&et=core.rd-group
                                  &base=coap://[ff35:30:2001:db8::1]
Content-Format: 40
Payload:
</light>;rt="light";if="core.a",
</color-temperature>;if="core.p";u="K"

Res: 2.01 Created
Location-Path: /rd/12
```

Figure 27: Example registration of a group

In this example, the group manager can easily permit devices that have no writable color-temperature to join, as they would still respond to brightness changing commands. Had the group instead

contained a single resource that sets brightness and color temperature atomically, endpoints would need to support both properties.

The resources of a group can be looked up like any other resource, and the group registrations (along with any additional registration parameters) can be looked up using the endpoint lookup interface.

The following example shows a client performing and endpoint lookup for all groups.

```
Req: GET /rd-lookup/ep?et=core.rd-group

Res: 2.05 Content
Payload:
</rd/501>;ep="GRP_R2-4-015";et="core.rd-group";
                                    base="coap://[ff05::1]",
</rd/12>;ep=lights&et=core.rd-group;
         base="coap://[ff35:30:2001:db8::1]";rt="core.rd-ep"
```

Figure 28: Example lookup of groups

The following example shows a client performing a lookup of all resources of all endpoints (groups) with et=core.rd-group.

```
Req: GET /rd-lookup/res?et=core.rd-group

<coap://[ff35:30:2001:db8::1]/light>;rt="light";if="core.a";
     et="core.rd-group";anchor="coap://[ff35:30:2001:db8::1]",
<coap://[ff35:30:2001:db8::1]/color-temperature>;if="core.p";u="K";
     et="core.rd-group";
     anchor="coap://[ff35:30:2001:db8::1]"
```

Figure 29: Example lookup of resources inside groups

Appendix B. Web links and the Resource Directory

Understanding the semantics of a link-format document and its URI references is a journey through different documents ([RFC3986] defining URIs, [RFC6690] defining link-format documents based on [RFC8288] which defines Link header fields, and [RFC7252] providing the transport). This appendix summarizes the mechanisms and semantics at play from an entry in ".well-known/core" to a resource lookup.

This text is primarily aimed at people entering the field of Constrained Restful Environments from applications that previously did not use web mechanisms.

The explanation of the steps makes some shortcuts in the more confusing details of [RFC6690], which are justified as all examples being in Limited Link Format.

B.1. A simple example

Let's start this example with a very simple host, "2001:db8:f0::1". A client that follows classical CoAP Discovery ([RFC7252] Section 7), sends the following multicast request to learn about neighbours supporting resources with resource-type "temperature".

The client sends a link-local multicast:

```
GET coap://[ff02::fd]:5683/.well-known/core?rt=temperature

RES 2.05 Content
</temp>;rt=temperature;ct=0
```

Figure 30: Example of direct resource discovery

where the response is sent by the server, "[2001:db8:f0::1]:5683".

While the client - on the practical or implementation side - can just go ahead and create a new request to "[2001:db8:f0::1]:5683" with Uri-Path: "temp", the full resolution steps for insertion into and retrieval from the RD without any shortcuts are:

B.1.1. Resolving the URIs

The client parses the single returned record. The link's target (sometimes called "href") is ""/temp"", which is a relative URI that needs resolving. The base URI <coap://[ff02::fd]:5683/.well-known/core> is used to resolve the reference /temp against.

The Base URI of the requested resource can be composed from the options of the CoAP GET request by following the steps of [RFC7252] section 6.5 (with an addition at the end of 8.2) into ""coap://[2001:db8:f0::1]/.well-known/core"".

Because ""/temp"" starts with a single slash, the record's target is resolved by replacing the path ""/.well-known/core"" from the Base URI (section 5.2 [RFC3986]) with the relative target URI ""/temp"" into ""coap://[2001:db8:f0::1]/temp"".

B.1.2. Interpreting attributes and relations

Some more information but the record's target can be obtained from the payload: the resource type of the target is "temperature", and its content format is text/plain (ct=0).

A relation in a web link is a three-part statement that specifies a named relation between the so-called "context resource" and the target resource, like "_This page_ has _its table of contents_ at _/toc.html_". In link format documents, there is an implicit "host relation" specified with default parameter: rel="hosts".

In our example, the context resource of the link is the URI specified in the GET request "coap::///[2001:db8:f0::1]/.well-known/core". A full English expression of the "host relation" is:

'"coap://[2001:db8:f0::1]/.well-known/core" is hosting the resource "coap://[2001:db8:f0::1]/temp", which is of the resource type "temperature" and can be accessed using the text/plain content format.'

B.2. A slightly more complex example

Omitting the "rt=temperature" filter, the discovery query would have given some more records in the payload:

```
GET coap://[ff02::fd]:5683/.well-known/core

RES 2.05 Content
</temp>;rt=temperature;ct=0,
</light>;rt=light-lux;ct=0,
</t>;anchor="/sensors/temp";rel=alternate,
<http://www.example.com/sensors/t123>;anchor="/temp";
    rel="describedby"
```

Figure 31: Extended example of direct resource discovery

Parsing the third record, the client encounters the "anchor" parameter. It is a URI relative to the Base URI of the request and is thus resolved to ""coap://[2001:db8:f0::1]/sensors/temp"". That is the context resource of the link, so the "rel" statement is not about the target and the Base URI any more, but about the target and the resolved URI. Thus, the third record could be read as ""coap://[2001:db8:f0::1]/sensors/temp" has an alternate representation at "coap://[2001:db8:f0::1]/t"".

Following the same resolution steps, the fourth record can be read as ""coap://[2001:db8:f0::1]/sensors/temp" is described by "http://www.example.com/sensors/t123"".

B.3. Enter the Resource Directory

The RD tries to carry the semantics obtainable by classical CoAP discovery over to the resource lookup interface as faithfully as possible.

For the following queries, we will assume that the simple host has used Simple Registration to register at the RD that was announced to it, sending this request from its UDP port "[2001:db8:f0::1]:6553":

```
POST coap://[2001:db8:f01::ff]/.well-known/core?ep=simple-host1
```

Figure 32: Example request starting a simple registration

The RD would have accepted the registration, and queried the simple host's ".well-known/core" by itself. As a result, the host is registered as an endpoint in the RD with the name "simple-host1". The registration is active for 90000 seconds, and the endpoint registration Base URI is ""coap://[2001:db8:f0::1]"" following the resolution steps described in Appendix B.1.1. It should be remarked that the Base URI constructed that way always yields a URI of the form: scheme://authority without path suffix.

If the client now queries the RD as it would previously have issued a multicast request, it would go through the RD discovery steps by fetching "coap://[2001:db8:f0::ff]/.well-known/core?rt=core.rd-lookup-res", obtain "coap://[2001:db8:f0::ff]/rd-lookup/res" as the resource lookup endpoint, and issue a request to "coap://[2001:db8:f0::ff]/rd-lookup/res?rt=temperature" to receive the following data:

```
<coap://[2001:db8:f0::1]/temp>;rt=temperature;ct=0;
    anchor="coap://[2001:db8:f0::1]"
```

Figure 33: Example payload of a response to a resource lookup

This is not _literally_ the same response that it would have received from a multicast request, but it contains the equivalent statement:

'"coap://[2001:db8:f0::1]" is hosting the resource "coap://[2001:db8:f0::1]/temp", which is of the resource type "temperature" and can be accessed using the text/plain content format.'

(The difference is whether "/" or "/.well-known/core" hosts the resources, which does not matter in this application; if it did, the endpoint would have been more explicit. Actually, /.well-known/core does NOT host the resource but stores a URI reference to the resource.)

To complete the examples, the client could also query all resources hosted at the endpoint with the known endpoint name "simple-host1". A request to "coap://[2001:db8:f0::ff]/rd-lookup/res?ep=simple-host1" would return

```
<coap://[2001:db8:f0::1]/temp>;rt=temperature;ct=0;
    anchor="coap://[2001:db8:f0::1]",
<coap://[2001:db8:f0::1]/light>;rt=light-lux;ct=0;
    anchor="coap://[2001:db8:f0::1]",
<coap://[2001:db8:f0::1]/t>;
    anchor="coap://[2001:db8:f0::1]/sensors/temp";rel=alternate,
<http://www.example.com/sensors/t123>;
    anchor="coap://[2001:db8:f0::1]/sensors/temp";rel="describedby"
```

Figure 34: Extended example payload of a response to a resource lookup

All the target and anchor references are already in absolute form there, which don’t need to be resolved any further.

Had the simple host done an equivalent full registration with a base= parameter (e.g. "?ep=simple-host1&base=coap+tcp://simple-host1.example.com"), that context would have been used to resolve the relative anchor values instead, giving

```
<coap+tcp://simple-host1.example.com/temp>;rt=temperature;ct=0;
    anchor="coap+tcp://simple-host1.example.com"
```

Figure 35: Example payload of a response to a resource lookup with a dedicated base URI

and analogous records.

B.4. A note on differences between link-format and Link header fields

While link-format and Link header fields look very similar and are based on the same model of typed links, there are some differences between [RFC6690] and [RFC8288], which are dealt with differently:

* "Resolving the target against the anchor": [RFC6690] Section 2.1 states that the anchor of a link is used as the Base URI against which the term inside the angle brackets (the target) is resolved,

falling back to the resource's URI with paths stripped off (its "Origin"). In contrast to that, [RFC8288] Section B.2 describes that the anchor is immaterial to the resolution of the target reference.

RFC6690, in the same section, also states that absent anchors set the context of the link to the target's URI with its path stripped off, while according to [RFC8288] Section 3.2, the context is the resource's base URI.

The rules introduced in Appendix C ensure that an RD does not need to deal with those differences when processing input data. Lookup results are required to be absolute references for the same reason.

* There is no percent encoding in link-format documents.

  A link-format document is a UTF-8 encoded string of Unicode characters and does not have percent encoding, while Link header fields are practically ASCII strings that use percent encoding for non-ASCII characters, stating the encoding explicitly when required.

  For example, while a Link header field in a page about a Swedish city might read

  Link: </temperature/Malm%C3%B6>;rel="live-environment-data"

  a link-format document from the same source might describe the link as

  </temperature/Malmö>;rel="live-environment-data"

  Parsers and producers of link-format and header fields need to be aware of this difference.

Appendix C. Limited Link Format

The CoRE Link Format as described in [RFC6690] has been interpreted differently by implementers, and a strict implementation rules out some use cases of an RD (e.g. base values with path components).

This appendix describes a subset of link format documents called Limited Link Format. The rules herein are not very limiting in practice - all examples in RFC6690, and all deployments the authors are aware of already stick to them - but ease the implementation of RD servers.

It is applicable to representations in the application/link-format media type, and any other media types that inherit [RFC6690] Section 2.1.

A link format representation is in Limited Link format if, for each link in it, the following applies:

* All URI references either follow the URI or the path-absolute ABNF rule of RFC3986 (i.e. target and anchor each either start with a scheme or with a single slash),

* if the anchor reference starts with a scheme, the target reference starts with a scheme as well (i.e. relative references in target cannot be used when the anchor is a full URI), and

* the application does not care whether links without an explicitly given anchor have the origin's "/" or "/.well-known/core" resource as their link context.

Authors' Addresses

Zach Shelby
ARM
150 Rose Orchard
San Jose, 95134
United States of America

Phone: +1-408-203-9434
Email: zach.shelby@arm.com

Michael Koster
SmartThings
665 Clyde Avenue
Mountain View, 94043
United States of America

Phone: +1-707-502-5136
Email: Michael.Koster@smartthings.com

Carsten Bormann
Universitaet Bremen TZI
Postfach 330440
D-28359 Bremen
Germany

Phone: +49-421-218-63921

Email: cabo@tzi.org

Peter van der Stok
consultant

Phone: +31-492474673 (Netherlands), +33-966015248 (France)
Email: consultancy@vanderstok.org
URI: www.vanderstok.org

Christian Amsüss (editor)
Hollandstr. 12/4
1020
Austria

Phone: +43-664-9790639
Email: christian@amsuess.com