The Cost of Installing a New Communication Schedule in a 6TiSCH Low-Power Wireless Network using CoAP (Extended Version)

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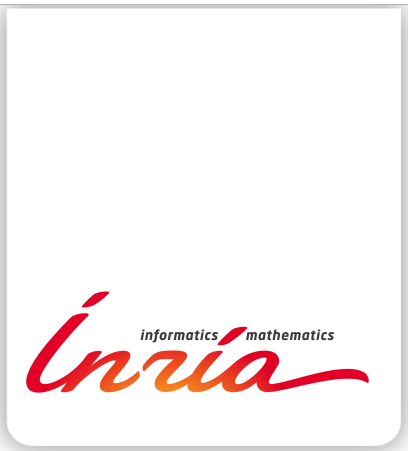
RESEARCH REPORT
N° 8817
November 2015
Project-Team EVA

ISSN 0249-6399 ISRN INRIA/RR--8817--FR+ENG



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Research Report n° 8817 — November 2015 — 56 pages

Abstract: Scheduling in a IEEE802.15.4e TSCH (6TiSCH) low-power wireless network can be done in a centralized or distributed way. When using centralized scheduling, a scheduler installs a communication schedule into the network. This can be done in a standards-based way using CoAP. In this report, we compute the number of packets and the latency this takes, on real-world examples. The result is that the cost is very high using today's standards, much higher than when using an ad-hoc solution such as OCARI. We conclude by making recommendations to drastically reduce the number of messages and improve the efficiency of the standardized approach.

Key-words: Low-Power Wireless Mesh Networks, IEEE802.15.4e TSCH, 6TiSCH, CoAP, OCARI.

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Installer un Ordonnancement dans un Réseau 6TiSCH Contraint Multi-Saut en utilisant CoAP *(Version Longue)*

Résumé : Dans ce rapport de recherche, nous montrons comment installer un ordonnancement d'activités des noeuds dans un réseau contraint radio multi-sauts IEEE802.15.4e TSCH en utilisant le standard CoAP. A travers un exemple illustratif simple, nous calculons le nombre de messages véhiculés dans l'ensemble du réseau pour différentes méthodes compatibles avec ces standards existants. Nous notons que l'utilisation des standards existants se traduit par un coût tres important en terme de nombre de messages et en latence. Ce coût est bien superieur à celui d'une solution ad-hoc comme OCARI. Nous concluons en faisant différentes recommandations pour réduire ce nombre de messages et donc améliorer l'efficacité des protocoles standardisés.

Mots-clés : Réseaux Contraints Radio Multi-Sauts, IEEE802.15.4e TSCH, 6TiSCH, CoAP, OCARI.

Contents

1 Context

Low-Power Wireless Mesh Networks support applications with strong requirements in terms of latency, energy efficiency and reliability. To cope with these requirements, the IEEE802.15.4e amendment [1] introduces the Time Slotted Channel Hopping (TSCH) mode. This mode uses time slotted medium access control, coupled with channel hopping. A Slotframe, depicted in Fig. 1, is a sequence of time slots. These timeslots can be scheduled to enable collision-free wireless communication between the nodes in the network. This schedule is periodically computed and installed into the network. In this report, we focus on the cost of installing this schedule.

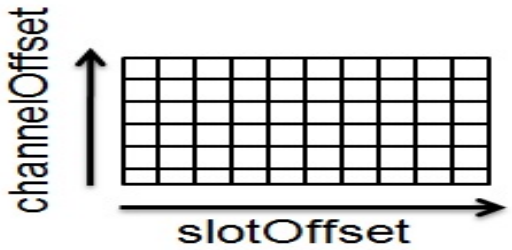


Figure 1: A Slotframe in an IEEE802.15.4e TSCH network.

Examples use cases include, but are not limited to:

- instrumentation of a temporary industrial worksite,
- fire detection,
- intrusion detection in an industrial storage site,
- monitoring of air quality in a city,
- pollutant detection in a smart city,
- monitoring the snow height in a ski resort,
- structure health monitoring in an aircraft.

These applications are in charge of data gathering: data measured by wireless sensor nodes are transferred to a sink, possibly over multiple hops. To improve the quality of data gathered, the network must meet the requirements listed above.

In this document, we consider an IEEE802.15.4e TSCH network. This network operates according to a schedule, which indicate for each time slot and each channel the nodes that communicate. To ensure determinism of the medium access, the schedule must be built collision-free. We assume that this schedule is computed in a centralized way, usually by the sink node. In this report, we want to evaluate the number of messages it takes to install this schedule on all sensor nodes, using the CoAP standard [2]. We compare these results with an ad hoc solution based on OCARI [3].

The remaining of this research report is organized as follows. Section 2 defines the problem, including the assumptions and models adopted. Section 3 compares different solutions based on IETF standards, and an ad-hoc solution called OCARI. Section 4 makes recommendations to reduce the number of messages in these standardized solutions. Section 5 concludes this paper.

2 Problem Statement

We first define the problem considered in this research report.

2.1 Models and assumptions

A 6TiSCH network is based on the IEEE802.15.4e TSCH [1] standard. On top of it, there is 6loWPAN [4] that allows the use of IPv6. The transport protocol used is UDP. The RPL [5] routing protocol builds the destination-oriented directed acyclic graph (DODAG) rooted at the sink. This DODAG enables each node that is not the sink to know its parent in the routing tree. Finally, CoAP [2] is used at the application layer. The resulting protocol stack is depicted in Fig. 2.

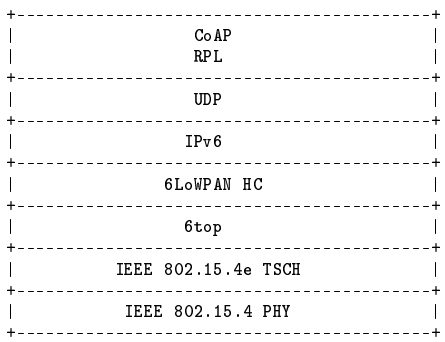


Figure 2: The 6TiSCH Protocol Stack.

The schedule orchestrating all communication consists of a list of assignations. We assume that any schedule has a sequence number $ScheduleNumber$ given by the scheduler and kept on each wireless sensor node. Each *assignation* of the schedule describes a transmission in the network. An assignation is a tuple $(SlotOffset, ChannelOffset, Tx, Rx)$, where Tx is the address of the transmitter and Rx is the address of the receiver.

2.2 Notations

In this paper, we adopt the following notations.

Let $Nassign$ be the number of assignations in the new schedule.

Let $Gen(u)$ denote the number of messages locally generated by node u.

Let $Trans(u)$ be the number of transmissions of node u in the new schedule. This number includes the messages locally generated by u, and the messages received from its children and forwarded to its parent.

Let $Depth(u)$ denote the depth of node u in the DODAG.

Let $Child(u)$ be the set of children of node u in the DODAG.

Let $B(u)$ be the number of blocks of size $BlockSize$ needed to transfer the information related to cells involving node u.

Let $Bsched$ be the number of blocks of size $BlockSize$ needed to transfer the information related to the whole schedule.

Let $BlockSize$ be the maximum size of blocks allowed in the useful payload. The value of $BlockSize$ depends on the method chosen to transfer the schedule, as described in Section 3.

Let P be the number of nodes that are parents in the DODAG. This number includes the sink node.

Let $CoAPcon$ denote a CoAP message that should be confirmed.

Let $CoAPack$ be the acknowledgment of a CoAP message.

Let $Nfield$ denote the number of fields that are updated per cell.

The different fields of a cell [6] that should be updated are:

- $SlotOffset$ defines, with the ChannelOffset, the cell considered in the schedule,
- $ChannelOffset$ defines, with the SlotOffset, the cell considered in the schedule,
- $LinkOption$ specifies the role of the node: Transmitter (Tx) or Receiver (Rx);
- $NodeAddress$ denotes the node address of the remote node in the assignation received.

2.3 Properties

Since any node u has to transmit its own messages $Gen(u)$ as well as all messages it receives from its children, we get the following property:

Property 1 *Assuming that any node $u \neq$ sink generates locally $Gen(u)$ messages per slotframe, it needs to transmit $Trans(u)$ messages per slotframe, with*

$$Trans(u) = \sum_{v \in subtree(u)} Gen(v), \tag{1}$$

where $subtree(u)$ denotes all nodes belonging to the subtree rooted at u, including node u itself.

Taking into account the different communication protocols used by the wireless sensor nodes, and given in Section 2.1, we compute the available payload in a CoAP message, using the formats depicted in Fig. 3 for the MAC frame and Fig. 4 for a CoAP option.

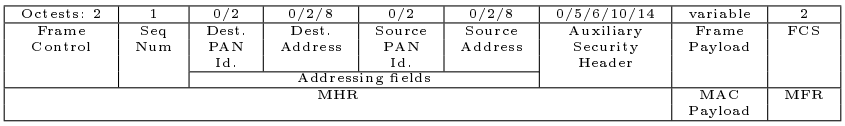


Figure 3: Format of a MAC frame.

More precisely, when the *Block* option [7] is used to fragment a long CoAP datagram into blocks, the size of the *Option Delta extended* field is taken equal to one octet, whereas the size of the *Option value* field depends on the block numbering used, as illustrated in Fig. 5. The smallest size is 2 octets, meaning that blocks are numbered on 4 bits, leading to a maximum number of blocks of 16. If the number of blocks exceeds 16, then a numbering on 12 bits is used, leading to a maximum number of blocks of 4096. In our computation, we take into account the two possibilities.

Table 1 gives the size of the successive payloads available at each layer in the protocol stack.

The PHY layer MTU IEEE802.15.4 [8] is 127 bytes.

MAC header and footer require a total of 29 bytes in the context of the IEEE802.15.4e TSCH mode Indeed, authors of [9] determine that data messages must provide in their MAC header fields 64-bit addresses for the destination and the source. Moreover, the Auxiliary Security

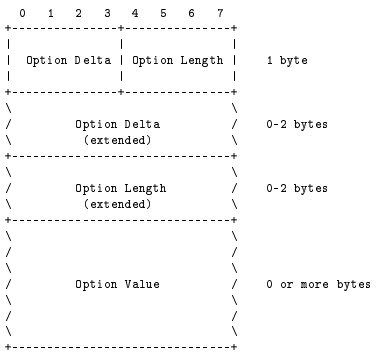


Figure 4: Format of a CoAP option.

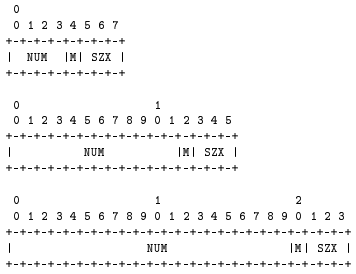


Figure 5: *Option Value* for the *Block* Option in CoAP.

Table 1: Payloads.

	Frame Control	Seq Num	Dest PAN	Dest @	Src @	Aux Sec Header	MIC	**Payload**	FCS
IEEE802.15.4e TSCH	2	1	2	8	8	2	4	**98**	2

	LOWPAN_IPHC	Hop limit	Src @	Dest @	**Payload**
6loWPAN - IP	2	1	8	8	**79**

	LOWPAN_NHC	Port src + dest	**Payload**
6loWPAN - UDP	1	1	**77**

	Header	URI	Payload marker	**Payload without block**
COAP without frag	4	11	1	**61**

	Header	URI	Option delta + Length	Option Delta extended	Option value	Payload marker	**Payload with block**
COAP with $\leq$ 16 frag	4	11	1	1	1	1	**32**
COAP with $\leq$ 4096 frag	4	11	1	1	2	1	**32**

header (AS) is coded with 2 bytes and the Message Integrity Code (MIC) is coded with 4 bytes. Finally, the MAC payload contains 98 bytes.

At the Network layer, the protocol requires 19 bytes for the IP compressed header (2 bytes), the Hop limit (1 byte) and the Source and Destination addresses coded on 8 bytes each.

At the Transport layer, the payload is reduced by 2 bytes corresponding to the UDP compressed header and the destination and source port coded together in 1 byte.

At the Application layer, the size of the applicative payload, depends on the CoAP option used. Fisrt, 4 bytes of header and 1 byte of payload marker are required. Moreover, the URI targeting the resource is defines as follows: `/mg/6t/hash` where `/mg/6t/` is the main path to the 6top management resources and `hash` is a hash of 30 bits (4 bytes) defining the rest of the path towards the targeted resource.

The three different possibilities studied are: without fragmentation, with less than 16 fragments and with less than 4096 fragments. In any case, we get a useful payload whose size is less than 61 bytes. For the *Block* option, it is specified in CoAP that the block size should be a power of two. As a consequence, the only possibility with this payload size is a block size of 32 bytes.

2.4 Problem definition

With the assumptions given in Section 2.1, the problem consists in computing the number of messages it takes to install a new schedule, as a function of various parameters such as the number of wireless sensor nodes, or the number of cells in the schedule. More precisely, the scheduler computes the new schedule and uses CoAP messages to send the fields values of the cells to each node. Each wireless node in the network should know all the information related to, on the one hand the cells in which it transmits, on the other hand the cells in which it receives.

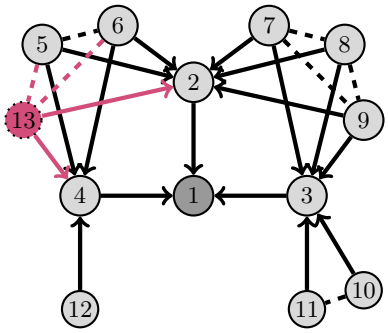
We distinguish different solutions, depending on the entity updated each time (e.g. a cell or a list of cells), what is updated (e.g. the whole schedule or only the differences with regard to the current one), the type of communication used (e.g. broadcast, unicast).

3 Standards-based and Ad-hoc Solutions

3.1 Illustrative example

As an illustrative example, we consider the topology depicted in Fig. 6a, in which solid lines represent links in the DODAG rooted at node 1, and the dashed lines represent additional links (i.e. links that are not used to forward data to the sink). In this configuration, three channels are available for the network, and the sink is assumed to be equipped with 3 radio interfaces. All nodes generate one message per SlotFrame, except nodes 2, 5 and 10 that generate 2 messages. We first assume that the network consists of 12 wireless nodes (i.e. node 13 is not present). We evaluate the total number of control messages needed to install the first schedule, considering the five solutions described in the following sections. In a second step, we assume that node 13 joins the network, we then evaluate the total number of control messages it takes to update and install the schedule.

Figs. 6b and 6c depict the schedules computed by MODESA [10], with and without node 13. Without node 13, the schedule consists of 24 assignations distributed in 9 slots, whereas it contains 26 assignations distributed in 9 slots when node 13 is present. When node 13 joins the network, a new schedule is computed in which 12 cells differ from the previous schedule. These cells are represented in black in Fig. 6c.



(a) Network topology of the illustrative example.

CO \ SO	0	1	2	3	4	5	6	7	8
0	4→1	2→1	4→1	2→1	4→1	2→1	4→1	2→1	3→1
1	3→1	10→3	3→1	11→3	3→1	10→3	3→1	7→3	
2	5→2	6→4	2→1	12→4	9→2	5→4	8→2		

(b) First schedule computed by MODESA without the node 13.

CO \ SO	0	1	2	3	4	5	6	7	8
0	4→1	2→1	4→1	2→1	4→1	2→1	4→1	2→1	4→1
1	3→1	10→3	3→1	11→3	3→1	12→4	3→1	5→4	3→1
2	2→1	5→4	9→2	6→4	8→2	10→3	13→2	7→3	

(c) Second schedule computed by MODESA with the node 13.

Figure 6: The illustrative example.

Property 2 *In both cases, the schedules computed by MODESA are optimal in term of number of slots. The minimum number of slots is equal to* $max(S_n, S_t)$ *with* $S_n = \lceil \sum_{u \neq sink} Gen(u)/g \rceil$ *and* $S_t = Gen(Child1) + 2 \sum_{v \in Subtree(Child1), v \neq Child1} Gen(v) + \delta$ *with* $g = min(n_{interf}, n_{channel}, n_{child})$

and $\delta = 1$ if the $(g+1)^{th}$ child requires the same number of transmissions as Child1, the most transmitting child of the sink, and $\delta = 0$ otherwise. This property was proved in [11].

3.2 Ad-hoc Solution

The ad-hoc solution presented in Fig. 7 is based on the OCARI [12] protocol. OCARI schedules activities in the network in a cycle organized in four periods.

First, OCARI synchronizes the network in a multihop way by cascading beacons during the [T0,T1] period. With this synchronized network, the "rendez-vous" T1 and T2 are known by every node of the network.

The period [T1,T2] is dedicated to control traffic used to collect network characteristics in order to compute a schedule for user data.

Period [T2,T3] allows user data gathering.

Finally, the period [T3,T0'] is a sleep period, all nodes sleep to save energy.

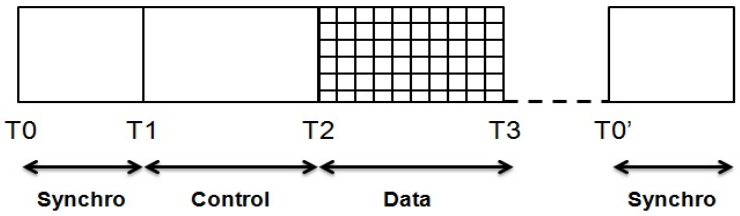


Figure 7: Cycle provided by the ad hoc solution

In this context, the beacons synchronizing the network are used to broadcast the schedule to all nodes. The OCARI protocol benefits of an association mechanism allowing the allocation of 16-bit short addresses to nodes. An assignation is then described by a tuple (SlotOffset, ChannelOffset, Tx, Rx) coded in 7 bytes: 2 bytes for SlotOffset, 1 byte for ChannelOffset, 2 bytes for Tx, 2 bytes for Rx.

In our previous illustrative example, the first schedule to install is made of 24 assignations and the second one is composed of 26 assignations. Therefore, we need to transmit 24 * 7 = 168 bytes for the first schedule and 26 * 7 = 182 bytes for the second. Since in our ad-hoc solution the maximum payload available in a beacon is 80 bytes, we need 3 messages sent by each parent node, leading to a total of 3 * 4 = 12 messages, since in our example P = 4 parent nodes.

3.3 Updating Fields One-by-One

In the naive solution, the scheduler transfers each cell field, one by one, for any assignation present in its new schedule, both on the transmitter and on the receiver if it is not the scheduler node itself. The update is made by a `POST` in CoAP that is acknowledged.

To update a field cell on a node, the scheduler sends one *CoAPcon* message and receives one *CoAPack* acknowledgment. Since each assignation requires the update of $Nfield$ cell fields on each node involved (transmitter or receiver), the scheduler will send $Nfield$ *CoAPcon* messages and receive $Nfield$ *CoAPack* acknowledgments for each assignation where the receiver is not the scheduler node itself. To evaluate the total number of messages transiting in the network, we have to take into account the distance in number of hops of each node u to the scheduler node, that is $Depth(u)$. Any node $u \neq sink$ should be notified for the $Trans(u)$ assignations for which it is transmitter. This generates a total of $Nfield \cdot (1CoAPcon + 1CoAPack) \sum_{u \neq sink} Trans(u) \cdot Depth(u)$ control messages in the network. Similarly, node u

should be notified for the $\sum_{v \in Child(u)} Trans(v)$ assignations for which it is receiver. This generates a total of $Nfield \cdot (1CoAPcon + 1CoAPack) \sum_{u \neq sink} Depth(u) \sum_{v \in Child(u)} Trans(v)$ control messages in the network.

This results in the total number of messages denoted $Nmsg(Naive)$, see (2).

$$Nmsg(Naive) = Nfield \cdot (1CoAPcon + 1CoAPack) \cdot \sum_{u \neq sink} Depth(u) \left(Trans(u) + \sum_{v \in Child(u)} Trans(v) \right) \tag{2}$$

Fig. 8 describes a transcription of a POST request in CoAP to set the value 3 for the nodeAddress field of the cell defined by slotOffset = 3 and channelOffset = 1.

```
REQ:
  POST
  coap://<ip>:5683/mg/6t/cellList/nodeAddress/?slotOffset=3&channelOffset=1 3
```

Figure 8: A POST request in CoAP addressing the nodeAddress value of a cell.

Table 2 presents the number of messages required for first installing the schedule computed for a network of 12 nodes (see Fig. 6a), then updating this schedule taking into account the new node 13. We can notice that it could be clearly prohibitive to use this method due to the strong overhead induced in a small network.

Table 2: Total number of messages required for installing and updating the schedules with the Naive method.

	without node 13			with node 13	
Node	Assignations	$Nfield$	Messages	Assignations * $Nfield$	Messages
2	8	4	64	2*2 + 2*1	8 + 4
3	9	4	72	3*1	6
4	7	4	56	3*1 + 2*4	6 + 16
5	2	4	32	2*2	16
6	1	4	16	1*1	4
7	1	4	16	1*1	4
8	1	4	16	1*1	4
9	1	4	16	1*1	4
10	2	4	32	1*1	4
11	1	4	16	0	0
12	1	4	16	1*2	8
13	-	-	-	1*4	16
Total	-	-	**352**	-	**100**

3.4 Send a PATCH to Each Node

In this second solution, the scheduler transfers at once a list of cells that must be updated. More precisely, it sends only the differences between the current schedule and the new one using the PATCH option. The scheduler sends to each node u, $B(u)$ blocks containing the patches involving u either as transmitter or as receiver and receives an acknowledgment per block, as recommended by [6]. The total number of messages transiting in the network is formalized in (3).

$$Nmsg(Patch) = (1CoAPcon + 1CoAPack) \cdot \sum_{u \neq sink} B(u) \cdot Depth(u) \tag{3}$$

An example of such a PATCH is described in Fig. 9. In this PATCH request written as recommended in [13], the two communications involving node 5 in the first schedule are presented as one transmission towards node 2 and another towards node 4.

```
REQ:
PATCH
coap://<ip>:5683/mg/6t/cellList
[
  {
    "op":    "replace",
    "path":  "/nodeAddress?slotOffset=0&channelOffset=2",
    "value": 2
  },
  {
    "op":    "replace",
    "path":  "/linkType?slotOffset=0&channelOffset=2",
    "value": 1
  },
  {
    "op":    "replace",
    "path":  "/nodeAddress?slotOffset=5&channelOffset=2",
    "value": 4
  },
  {
    "op":    "replace",
    "path":  "/LinkType?slotOffset=5&channelOffset=2",
    "value": 1
  }
]
```

Figure 9: Example of a PATCH request that installs the schedule on node 5.

Table 3 presents the number of messages required for installing and updating the schedule computed for our illustrative network (see Fig. 6a).

We notice that the PATCH method introduces a large overhead even for a small network.

Table 3: Total number of messages required for installing and updating the schedules with the PATCH method.

	without node 13			with node 13		
Node	CBOR bytes	Blocks	Messages	CBOR bytes	Blocks	Messages
2	1049	33	66	397	13	26
3	918	29	58	208	7	14
4	918	29	58	533	17	34
5	263	9	36	269	9	36
6	132	5	20	67	3	12
7	132	5	20	70	3	12
8	132	5	20	67	3	12
9	132	5	20	67	3	12
10	263	9	36	70	3	12
11	132	5	20	0	0	0
12	132	5	20	136	5	20
13	-	-	-	132	5	20
Total	-	-	**374**	-	-	**210**

3.5 Broadcast the Complete Schedule to all Nodes

In this solution, the scheduler broadcasts the complete schedule using a specific JSON document syntax. Each node u filters only the cells it is involved in. To be sure that each node receives the new schedule, the scheduler initially makes an *Observe* of the Schedule Number on each node. Hence, each time, this number is increased, the scheduler is notified. This $Notify$ is

interpreted by the scheduler as an acknowledgment of the successful receipt of the schedule with the Sequence Number given.

To disseminate an *Observe* on all nodes except the sink requires P messages. This broadcast is done at network initialization and each time a new node joins the network.

To disseminate $Bsched$ blocks of 32 bytes on on all nodes except the sink requires $P \cdot Bsched$ messages.

To notify the scheduler of a change of the schedule number on all nodes except the sink requires $\sum_{u \neq sink} Depth(u)$ messages.

At each new schedule, a total number of control messages transiting in the network is at (4). δ_P is 1 if at least a new node has joined the network since the last transmission of the *Observe*, 0 otherwise.

$$Nmsg(Broadcast) = P \cdot Bsched + \sum_{u \neq sink} Depth(u) + \delta_P \cdot P \tag{4}$$

Fig. 10 depicts the `POST` request with a JSON document describing the first schedule of our example. This request is broadcast to all nodes of the network. The length of the CBOR transcription of the JSON document describing our schedule is 149 bytes. This CBOR transcription is divided into 5 fragments of 32 bytes, hence $Bsched = 5$. In our example topology, the number of parents broadcasting the schedule is $P = 4$ (node 1, 2, 3, 4) and the sum of depths of nodes is $\sum_{u \neq sink} Depth(u) = 19$. For this first schedule, as all nodes just joined the network $\delta_P = 1$. Finally, $msg(Broadcast) = 4 \cdot 5 + 19 + 1 \cdot 4 = 43$.

```
REQ:
POST
coap://<ip>:5683/mg/6t/schedule
{
  "ScheduleNumber": "1",
  "Schedule":
  [
    [0, 0, 4, 1],
    [0, 1, 3, 1],
    [0, 2, 5, 2],
    [1, 0, 2, 1],
    [1, 1, 10, 3],
    [1, 2, 6, 4],
    [2, 0, 4, 1],
    [2, 1, 3, 1],
    [2, 2, 2, 1],
    [3, 0, 2, 1],
    [3, 1, 11, 3],
    [3, 2, 12, 4],
    [4, 0, 4, 1],
    [4, 1, 3, 1],
    [4, 2, 9, 2],
    [5, 0, 2, 1],
    [5, 1, 10, 3],
    [5, 2, 5, 4],
    [6, 0, 4, 1],
    [6, 1, 3, 1],
    [6, 2, 8, 2],
    [7, 0, 2, 1],
    [7, 1, 7, 3],
    [8, 0, 3, 1]
  ]
}
```

Figure 10: A POST request broadcasting the first schedule to all nodes in the network.

Fig. 11 depicts the same `POST` request for the second schedule of our illustrative example. This request is also broadcast to all nodes of the network including the joining node 13. The length of the CBOR transcription of the JSON document describing our schedule is 159 bytes.

This CBOR transcription is divided into 5 fragments of 32 bytes, hence $Bsched = 5$. As in the previous case, the number of parents broadcasting the schedule is $P = 4$ but now the sum of depths of nodes is $\sum_{u \neq sink} Depth(u) = 21$. For this second schedule, node 13 just joined the network, hence $\delta_P = 1$. Finally, $msg(Broadcast) = 4 \cdot 5 + 21 + 1 \cdot 4 = 45$.

```
REQ:
POST
coap://<ip>:5683/mg/6t/schedule
{
  "ScheduleNumber": "2",
  "Schedule":
  [
    [0, 0, 4, 1],
    [0, 1, 3, 1],
    [0, 2, 2, 1],
    [1, 0, 2, 1],
    [1, 1, 10, 3],
    [1, 2, 5, 4],
    [2, 0, 4, 1],
    [2, 1, 3, 1],
    [2, 2, 9, 2],
    [3, 0, 2, 1],
    [3, 1, 11, 3],
    [3, 2, 6, 4],
    [4, 0, 4, 1],
    [4, 1, 3, 1],
    [4, 2, 8, 2],
    [5, 0, 2, 1],
    [5, 1, 12, 4],
    [5, 2, 10, 3],
    [6, 0, 4, 1],
    [6, 1, 3, 1],
    [6, 2, 13, 2],
    [7, 0, 2, 1],
    [7, 1, 5, 4],
    [7, 2, 7, 3],
    [8, 0, 4, 1],
    [8, 1, 3, 1]
  ]
}
```

Figure 11: A POST request broadcasting the updated schedule to all nodes in the network.

The overhead associated with this method for installing or updating a schedule is smaller compared to the naive and patch methods. However, the overhead increases with the amount of traffic in the network. It can be prohibitive to broadcast a huge schedule particularly for a small update. One option is to only sends a DIFF of the schedule.

3.6 Broadcast a DIFF of the Schedule to all Nodes

In this solution, the scheduler broadcasts only the differences between the current schedule and the new one, using a specific JSON document syntax. Each node u filters only the cells involving it as transmitter or receiver.

To ensure that each node receives the new schedule, the scheduler initially makes an *Observe* of the Schedule Number on each node. Hence, each time, this number is increased, the scheduler is notified. This $Notify$ is interpreted by the scheduler as an acknowledgment of the successful receipt of the schedule with the Sequence Number given.

Fig. 12 depicts the `POST` request with a JSON document describing the first schedule of our illustrative example. This request is broadcast to all nodes of the network. The length of the CBOR transcription of the JSON document describing our schedule is 144 bytes. This CBOR transcription is divided into 5 fragments of 32 bytes, hence $Bsched = 5$. In our example topology, the number of parents broadcasting the schedule is $P = 4$ (node 1, 2, 3, 4) and the sum of depths

of nodes is $\sum_{u \neq sink} Depth(u) = 19$. For this first schedule, as all node just joined the network $\delta_P = 1$. Finally, $msg(Broadcast) = 4 \cdot 5 + 19 + 1 \cdot 4 = 43$.

```
REQ:
POST
coap://<ip>:5683/mg/6t/schedule
{
  "ScheduleNumber": "1",
  "Add":
  [
    [0, 0, 4, 1],
    [0, 1, 3, 1],
    [0, 2, 5, 2],
    [1, 0, 2, 1],
    [1, 1, 10, 3],
    [1, 2, 6, 4],
    [2, 0, 4, 1],
    [2, 1, 3, 1],
    [2, 2, 2, 1],
    [3, 0, 2, 1],
    [3, 1, 11, 3],
    [3, 2, 12, 4],
    [4, 0, 4, 1],
    [4, 1, 3, 1],
    [4, 2, 9, 2],
    [5, 0, 2, 1],
    [5, 1, 10, 3],
    [5, 2, 5, 4],
    [6, 0, 4, 1],
    [6, 1, 3, 1],
    [6, 2, 8, 2],
    [7, 0, 2, 1],
    [7, 1, 7, 3],
    [8, 0, 3, 1]
  ]
}
```

Figure 12: A POST request broadcasting the first schedule as a DIFF to all nodes in the network.

Fig. 13 depicts the same `POST` request for the second schedule of our illustrative example. This request is also broadcast to all nodes of the network including the joining node 13. The length of the CBOR transcription of the JSON document describing our schedule is 141 bytes. This CBOR transcription is divided into 5 fragments of 32 bytes, hence $Bsched = 5$. As in the previous case, the number of parents broadcasting the schedule is $P = 4$ but now the sum of depths of nodes is $\sum_{u \neq sink} Depth(u) = 21$. For this second schedule, node 13 just joined the network so $\delta_P = 1$. Finally, $msg(Broadcast) = 4 \cdot 5 + 21 + 1 \cdot 4 = 45$.

We can notice that the DIFF method requires the same overhead as the simple broadcast for the our illustrative network. However, when few transmissions have to be updated in a large scale network with a long schedule description, this DIFF method is more efficient.

```
REQ:
POST
coap://<ip>:5683/mg/6t/schedule
{
  "ScheduleNumber": "2",
  "Remove":
  [
    [0, 2, 5, 2],
    [1, 2, 6, 4],
    [2, 2, 2, 1],
    [3, 2, 12, 4],
    [4, 2, 9, 2],
    [5, 1, 10, 3],
    [5, 2, 5, 4],
    [6, 2, 8, 2],
    [7, 1, 7, 3],
    [8, 0, 3, 1]
  ],
  "Add":
  [
    [0, 2, 2, 1],
    [1, 2, 5, 4],
    [2, 2, 9, 2],
    [3, 2, 6, 4],
    [4, 2, 8, 2],
    [5, 1, 12, 4],
    [5, 2, 10, 3],
    [6, 2, 13, 2],
    [7, 1, 5, 4],
    [7, 2, 7, 3],
    [8, 0, 4, 1],
    [8, 1, 3, 1]
  ]
}
```

Figure 13: A POST request broadcasting the updated schedule as a DIFF to all nodes in the network.

3.7 Comparative Evaluation

Table 4 shows a synthetic view of the number of messages needed to install and update a schedule, for the small illustrative network of Section 3.1. Available standardized mechanisms must be improved in order to be deployed in real implementation. In the next section, we propose three recommendations allowing a substantial performance saving.

Table 4: Number of messages needed to install or update schedules.

	install first schedule	udapte
Nmsg(Adhoc)	12	12
Nmsg(Naive)	352	100
Nmsg(Patch)	374	206
Nmsg(Broadcast)	43	45

4 Recommendations

We propose some recommendations to decrease the number of messages needed to install a schedule using CoAP.

4.1 Short Addresses at MAC layer

If an association mechanism could be implemented in a multi-hop fashion in order to ensure that the LBR can do the mapping between Long and Short Addresses, 12 bytes could be saved at the MAC layer using the short addresses. The payload at MAC layer can then be extended to 110 bytes and the maximum applicative payload could be higher than 64 bytes (73 bytes exactly). So the block size relevant in this context should be 64 bytes, enhancing dramatically the performance of the PATCH method as it is shown in Table 5. Indeed, we need only 206 messages to install the first schedule with 64-byte blocks instead of 374 messages with 32-byte blocks and 104 messages to update the schedule instead of 210 with 32-byte blocks.

Table 5 presents the number of messages required for installing and updating the schedule computed for our illustrative network (see Fig. 6a). We see a dramatic saving for this PATCH method compared to the previous results in Section 3.4.

Table 5: Total number of messages required for installing and updating the schedules with the PATCH method.

	without node 13			with node 13		
Node	CBOR bytes	Blocks	Messages	CBOR bytes	Blocks	Messages
2	1049	17	34	397	7	14
3	918	15	30	208	4	8
4	918	15	30	533	9	18
5	263	5	20	269	5	20
6	132	3	12	67	1	4
7	132	3	12	70	1	4
8	132	3	12	67	1	4
9	132	3	12	67	1	4
10	263	5	20	70	1	4
11	132	3	12	0	0	0
12	132	3	12	136	3	12
13	-	-	-	132	3	12
Total	-	-	**206**	-	-	**104**

With the method of broadcasting a schedule to all nodes in the network, the savings in term of the number of messages is also significant. In our example topology, for the two solutions proposed (broadcast the whole schedule or broadcast a DIFF schedule), we obtain $msg(Broadcast) = 4 \cdot Bsched + 19 + 1 \cdot 4 = 35$ messages with $Bsched = 3$ for the fisrt schedule. For updating the schedule with the presence of node 13, we obtain $msg(Broadcast) = 4 \cdot Bsched + 21 + 1 \cdot 4 = 37$ messages with $Bsched = 3$.

Table 6 shows that using short addresses can save around 45% of messages required to install the schedule with the PATCH method and approximatively 50% of messages needed to update it. In the case of the broadcast method, the saving is lower but still significant with a gain of 14% for installing the schedule and 17% for updating it.

4.2 A cellId Coding the slotOffset and channelOffset

In order to compress the path descriptions used for the PATCH method, a coding of the tuple {slotOffset, channelOffset} could be used. Each cell must be uniquely identified by its *CellId*, where cells are numbered from slot 0, channel 0 up to channel 15 and then from slot 1, channel

Table 6: Number of messages needed to install or update schedules using short addresses at MAC layer.

	install first schedule	udapte
Nmsg(Adhoc)	12	12
Nmsg(Naive)	352	100
Nmsg(Patch)	206	104
Nmsg(Broadcast)	35	37

0 up to channel 15. This is equivalent to identifying each cell by a sequence number equal to $SlotOffset * 16 + ChannelOffset$. This sequence number is coded on two bytes, where the 4 least significant bits are used to code the $ChannelOffset$ and the remaining 12 bits code the $SlotOffset$, enabling a maximum of 4096 slots in the SlotFrame.

Table 7 presents the number of messages required for installing and updating the schedule computed for our illustrative network (see Fig. 6a). We notice that this simple coding mechanism brings a greater gain compared to the previous results in Section 3.4.

Table 7: Total number of messages required for installing and updating the schedules with the PATCH method using a cellId.

	without node 13			with node 13		
Node	CBOR bytes	Blocks	Messages	CBOR bytes	Blocks	Messages
2	729	12	24	275	5	10
3	636	10	20	132	3	6
4	636	10	20	371	6	12
5	181	3	12	132	3	12
6	92	2	8	44	1	4
7	92	2	8	45	1	4
8	92	2	8	44	1	4
9	92	2	8	44	1	4
10	183	3	12	44	1	4
11	92	2	8	0	0	0
12	92	2	8	44	1	4
13	-	-	-	92	2	8
Total	-	-	**136**	-	-	**72**

Fig. 14 depicts the schedule description using the cellId coding in the context of the broadcasting method. In our example, no saving can be noticed and more generally the cell coding impact seems negligible in this method.

Table 8 demonstrates that using a cellId coding, in addition with the short addresses, can save around 64% of messages required to install the schedule with the Patch method and more than 65% of messages needed to update it.

Table 8: Number of messages needed to install or update schedules.

	install first schedule	udapte
Nmsg(Adhoc)	12	12
Nmsg(Naive)	352	100
Nmsg(Patch)	136	72
Nmsg(Broadcast)	35	37

4.3 Shorter Syntax for the PATCH Method

In order to transmit smaller payloads, a more concise syntax for PATCH requests could be used. An example shorter syntax is presented in Fig. 15. The CBOR transcription of this

```
REQ:
POST
coap://<ip>:5683/mg/6t/schedule
{
  "ScheduleNumber": "1",
  "Schedule":
  [
    [0, 4, 1],
    [1, 3, 1],
    [2, 5, 2],
    [16, 2, 1],
    [17, 10, 3],
    [18, 6, 4],
    [32, 4, 1],
    [33, 3, 1],
    [34, 2, 1],
    [48, 2, 1],
    [49, 11, 3],
    [50, 12, 4],
    [64, 4, 1],
    [65, 3, 1],
    [66, 9, 2],
    [80, 2, 1],
    [81, 10, 3],
    [82, 5, 4],
    [96, 4, 1],
    [97, 3, 1],
    [98, 8, 2],
    [112, 2, 1],
    [113, 7, 3],
    [128, 3, 1]
  ]
}
```

Figure 14: A POST request broadcasting the first schedule to all nodes in the network using a CellId.

JSON document transmitted in the PATCH request ot node 5 is 26% shorter than the CBOR transcription using the syntax described in [13].

```
  PATCH
  coap://<ip>:5683/mg/6t/cellList
  [
    {
      "o": "rpl",
      "p": "/nodeAddress?cellId=2",
      "v": 2
    },
    {
      "o": "rpl",
      "p": "/linkType?cellId=2",
      "v": 1
    },
    {
      "o": "rpl",
      "p": "/nodeAddress?cellId=82",
      "v": 4
    },
    {
      "o": "rpl",
      "p": "/LinkType?cellId=82",
      "v": 1
    }
  ]
```

Figure 15: Example of a PATCH request that installs the schedule on node 5 with a short syntax.

Table 9 presents the number of messages required for installing and updating the schedule computed for our illustrative network (see Fig. 6a) with the recommended syntax. This shorter

syntax brings a greater gain compared to the previous results in Section 3.4.

Table 9: Total number of messages required for installing and updating the schedules with the PATCH method.

	without node 13			with node 13		
Node	CBOR bytes	Blocks	Messages	CBOR bytes	Blocks	Messages
2	537	9	18	203	4	8
3	468	8	16	96	2	4
4	468	8	16	275	5	10
5	133	3	12	96	2	8
6	68	1	4	32	1	4
7	70	1	4	33	1	4
8	68	1	4	32	1	4
9	68	1	4	32	1	4
10	135	3	12	32	1	4
11	68	1	4	0	0	0
12	68	1	4	32	1	4
13	-	-	-	68	1	4
Total	-	-	**98**	-	-	**58**

Table 10 shows that using a short syntax in PATCH requests, in addition with the two previous recommendations, saves 74% of messages required to install the schedule with the PATCH method, and around 72% of messages needed to update it.

Table 10: Number of messages needed to install or update schedules.

	install first schedule	udapte
Nmsg(Adhoc)	12	12
Nmsg(Naive)	352	100
Nmsg(Patch)	98	58
Nmsg(Broadcast)	35	37

5 Conclusion

In this research report, we describe three methods for the setting up of a schedule in a IEEE802.15.4e TSCH (6TiSCH) network, using a fully standards-based approach: 6LoWPAN [4], CoAP [2], Block [7], CoMI [6] and Patch [13]. We compare these methods with OCARI, an ad-hoc protocol. With the current standards, installing a new schedule using IETF standards is very costly in terms of number of packets and latency.

That therefore make three recommendations for reducing the cost. Following these simple recommendations results in 70% less packets for the PATCH method, 15% less packets for the Broadcast method. The recommendation with the highest reduction in number of packets is havaing an association step for the nodes to acquire unique 2-byte addresses.

References

[1] IEEE, "IEEE Standard for Local and metropolitan area networks–Part 15.4: Low-Rate Wireless Personal Area Networks (LR-WPANs) Amendment 1: MAC Sublayer," April 2012.

[2] Z. Shelby, K. Hartke, and C. Bormann, "The Constrained Application Protocol (CoAP)," June 2014.

[3] K. Al Agha, G. Chalhoub, A. Guitton, E. Livolant, S. Mahfoudh, P. Minet, M. Misson, J. Rahmé, T. Val, and A. van den Bossche, "Cross-layering in an Industrial Wireless Sensor Network: Case Study of OCARI," *Journal of Networks*, vol. 4, no. 6, pp. 411–420, 2009.

[4] G. Montenegro, N. Kushalnagar, J. Hui, and D. Culler, "Transmission of IPv6 Packets over IEEE 802.15.4 Networks," September 2007.

[5] T. Winter, P. Thubert, A. Brandt, J. Hui, R. Kelsey, P. Levis, K. Pister, R. Struik, J. Vasseur, and R. Alexander, "RPL: IPv6 Routing Protocol for Low-Power and Lossy Networks," March 2012.

[6] P. Van der Stok, B. Andy, J. Schönwälder, and A. Sehgal, "CoAP Management Interface," July 2015.

[7] C. Bormann and Z. Shelby, "Block-wise Transfers in CoAP," September 2015.

[8] IEEE, "IEEE Standard for Local and metropolitan area networks–Part 15.4: Low-Rate Wireless Personal Area Networks (LR-WPANs)," September 2011.

[9] X. Vilajosana and K. Pister, "Minimal 6TiSCH Configuration," September 2015.

[10] R. Soua, P. Minet, and E. Livolant, "MODESA: An Optimized Multichannel Slot Assignment for Raw Data Convergecast in Wireless Sensor Networks," in *International Performance Computing and Communications Conference (IPCCC)*, (Austin, TX, USA), pp. 91–100, IEEE, 2012.

[11] R. Soua, P. Minet, and E. Livolant, "A Distributed Joint Channel and Slot Assignment for Convergecast in Wireless Sensor Networks," in *6th International Conference on New Technologies, Mobility and Security (NTMS)*, (Dubai, United Arab Emirates), pp. 1–5, 30 March - 2 April 2014.

[12] G. Chalhoub, E. Livolant, A. Guitton, A. van den Bossche, M. Misson, and T. Val, "Specifications and Evaluation of a MAC Protocol for a LP-WPAN," *Ad Hoc & Sensor Wireless Networks*, vol. 7, no. 1-2, pp. 69–89, 2009.

[13] P. van der Stok and A. Sehgal, "Patch Method for Constrained Application Protocol (CoAP)," Tech. Rep. draft-vanderstok-core-patch-02 [work-in-progress], IETF, October 2015.

Appendix A Example of a CBOR Transcription of the JSON Document Describing a PATCH

```
84                                  # array(4)
   a3                               # map(3)
      62                            # text(2)
         6f70                       # "op"
      67                            # text(7)
         7265706c616365             # "replace"
      64                            # text(4)
         70617468                   # "path"
      78 29                         # text(41)
         2f6e6f6465416464726573733f736c6f744f66667365743d30266368616e6e656c4f66667365743d32 # "/nodeAddress?slotOffset=0&channelOffset=2"
      65                            # text(5)
         76616c7565                 # "value"
      02                            # unsigned(2)
   a3                               # map(3)
      62                            # text(2)
         6f70                       # "op"
      67                            # text(7)
         7265706c616365             # "replace"
      64                            # text(4)
         70617468                   # "path"
      78 26                         # text(38)
         2f6c696e6b547970653f736c6f744f66667365743d30266368616e6e656c4f66667365743d32 # "/linkType?slotOffset=0&channelOffset=2"
      65                            # text(5)
         76616c7565                 # "value"
      01                            # unsigned(1)
   a3                               # map(3)
      62                            # text(2)
         6f70                       # "op"
      67                            # text(7)
         7265706c616365             # "replace"
      64                            # text(4)
         70617468                   # "path"
      78 29                         # text(41)
         2f6e6f6465416464726573733f736c6f744f66667365743d35266368616e6e656c4f66667365743d32 # "/nodeAddress?slotOffset=5&channelOffset=2"
      65                            # text(5)
         76616c7565                 # "value"
      04                            # unsigned(4)
   a3                               # map(3)
      62                            # text(2)
         6f70                       # "op"
      67                            # text(7)
         7265706c616365             # "replace"
      64                            # text(4)
         70617468                   # "path"
      78 26                         # text(38)
         2f4c696e6b547970653f736c6f744f66667365743d35266368616e6e656c4f66667365743d32 # "/LinkType?slotOffset=5&channelOffset=2"
      65                            # text(5)
         76616c7565                 # "value"
      01                            # unsigned(1)
```

Appendix B Installing a Schedule Node-by-Node with the PATCH Method

B.1 First Schedule (without node 13)

B.1.1 PATCH request for install the schedule on node 2

```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
       {
           "op":    "replace",
           "path":  "/nodeAddress?slotOffset=0&channelOffset=2",
           "value": 5
       },
       {
           "op":    "replace",
           "path":  "/linkType?slotOffset=0&channelOffset=2",
           "value": 2
       },
       {
           "op":    "replace",
           "path":  "/nodeAddress?slotOffset=1&channelOffset=0",
           "value": 1
       },
       {
```

```
        "op":    "replace",
        "path":  "/LinkType?slotOffset=1&channelOffset=0",
        "value": 1
    },
    {
        "op":    "replace",
        "path":  "/nodeAddress?slotOffset=2&channelOffset=2",
        "value": 1
    },
    {
        "op":    "replace",
        "path":  "/linkType?slotOffset=2&channelOffset=2",
        "value": 1
    },
    {
        "op":    "replace",
        "path":  "/nodeAddress?slotOffset=3&channelOffset=0",
        "value": 1
    },
    {
        "op":    "replace",
        "path":  "/linkType?slotOffset=3&channelOffset=0",
        "value": 1
    },
    {
        "op":    "replace",
        "path":  "/nodeAddress?slotOffset=4&channelOffset=2",
        "value": 9
    },
    {
        "op":    "replace",
        "path":  "/linkType?slotOffset=4&channelOffset=2",
        "value": 2
    },
    {
        "op":    "replace",
        "path":  "/nodeAddress?slotOffset=5&channelOffset=0",
        "value": 1
    },
    {
        "op":    "replace",
        "path":  "/LinkType?slotOffset=5&channelOffset=0",
        "value": 1
    },
    {
        "op":    "replace",
        "path":  "/nodeAddress?slotOffset=6&channelOffset=2",
        "value": 8
    },
    {
        "op":    "replace",
        "path":  "/linkType?slotOffset=6&channelOffset=2",
        "value": 2
    },
    {
        "op":    "replace",
        "path":  "/nodeAddress?slotOffset=7&channelOffset=0",
        "value": 1
    },
    {
        "op":    "replace",
        "path":  "/LinkType?slotOffset=7&channelOffset=0",
        "value": 1
    }
]
```


The 1049 bytes of the CBOR transcription of the JSON document describing the patch for install the schedule on node 2

B.1.2 PATCH Request for Installing the schedule on node 3

```
PATCH
```

```
coap://<ip>:5683/mg/6t/cellList
[
       {
           "op":    "replace",
           "path":  "/nodeAddress?slotOffset=0&channelOffset=1",
           "value": 1
       },
       {
           "op":    "replace",
           "path":  "/linkType?slotOffset=0&channelOffset=1",
           "value": 1
       },
       {
           "op":    "replace",
           "path":  "/nodeAddress?slotOffset=1&channelOffset=1",
           "value": 10
       },
       {
           "op":    "replace",
           "path":  "/LinkType?slotOffset=1&channelOffset=1",
           "value": 2
       },
       {
           "op":    "replace",
           "path":  "/nodeAddress?slotOffset=2&channelOffset=1",
           "value": 1
       },
       {
           "op":    "replace",
           "path":  "/linkType?slotOffset=2&channelOffset=1",
           "value": 1
       },
       {
           "op":    "replace",
           "path":  "/nodeAddress?slotOffset=3&channelOffset=1",
           "value": 11
       },
       {
           "op":    "replace",
           "path":  "/linkType?slotOffset=3&channelOffset=1",
           "value": 2
       },
       {
           "op":    "replace",
           "path":  "/nodeAddress?slotOffset=4&channelOffset=1",
           "value": 1
       },
       {
           "op":    "replace",
           "path":  "/linkType?slotOffset=4&channelOffset=1",
           "value": 1
       },
       {
           "op":    "replace",
           "path":  "/nodeAddress?slotOffset=5&channelOffset=1",
           "value": 10
       },
       {
           "op":    "replace",
           "path":  "/LinkType?slotOffset=5&channelOffset=1",
           "value": 2
       },
       {
           "op":    "replace",
           "path":  "/nodeAddress?slotOffset=8&channelOffset=1",
           "value": 1
       },
       {
           "op":    "replace",
           "path":  "/linkType?slotOffset=8&channelOffset=1",
           "value": 1
       }
]
```

The 918 bytes of the CBOR transcription of the JSON document describing the patch for install the schedule on node 3.

B.1.3 PATCH Request for Installing the Schedule on node 4

```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
       {
           "op":    "replace",
           "path":  "/nodeAddress?slotOffset=0&channelOffset=0",
           "value": 1
       },
       {
           "op":    "replace",
           "path":  "/linkType?slotOffset=0&channelOffset=0",
           "value": 1
       },
       {
           "op":    "replace",
           "path":  "/nodeAddress?slotOffset=1&channelOffset=2",
           "value": 6
       },
       {
           "op":    "replace",
           "path":  "/LinkType?slotOffset=1&channelOffset=2",
           "value": 2
       },
       {
           "op":    "replace",
           "path":  "/nodeAddress?slotOffset=2&channelOffset=0",
           "value": 1
       },
       {
           "op":    "replace",
           "path":  "/linkType?slotOffset=2&channelOffset=0",
           "value": 1
       },
       {
           "op":    "replace",
           "path":  "/nodeAddress?slotOffset=3&channelOffset=2",
           "value": 12
       },
       {
           "op":    "replace",
           "path":  "/linkType?slotOffset=3&channelOffset=2",
           "value": 2
       },
       {
           "op":    "replace",
           "path":  "/nodeAddress?slotOffset=4&channelOffset=0",
           "value": 1
       },
       {
           "op":    "replace",
           "path":  "/linkType?slotOffset=4&channelOffset=0",
           "value": 1
       },
       {
           "op":    "replace",
           "path":  "/nodeAddress?slotOffset=5&channelOffset=2",
           "value": 5
       },
       {
           "op":    "replace",
           "path":  "/LinkType?slotOffset=5&channelOffset=2",
           "value": 2
       },
       {
           "op":    "replace",
           "path":  "/nodeAddress?slotOffset=6&channelOffset=0",
           "value": 1
```

```
      },
      {
          "op":    "replace",
          "path":  "/linkType?slotOffset=6&channelOffset=0",
          "value": 1
      }
]
```

The 918 bytes of the CBOR transcription of the JSON document describing the patch for install the schedule on node 4.

B.1.4 PATCH Request for Installing the Schedule on node 5

```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
      {
          "op":    "replace",
          "path":  "/nodeAddress?slotOffset=0&channelOffset=2",
          "value": 2
      },
      {
          "op":    "replace",
          "path":  "/linkType?slotOffset=0&channelOffset=2",
          "value": 1
      },
      {
          "op":    "replace",
          "path":  "/nodeAddress?slotOffset=5&channelOffset=2",
          "value": 4
      },
      {
          "op":    "replace",
          "path":  "/LinkType?slotOffset=5&channelOffset=2",
          "value": 1
      }
]
```

The 263 bytes of the CBOR transcription of the JSON document describing the patch for install the schedule on node 5.

B.1.5 PATCH Request for Installing the Schedule on Node 6

```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
      {
          "op":    "replace",
          "path":  "/nodeAddress?slotOffset=1&channelOffset=2",
          "value": 4
      },
      {
          "op":    "replace",
          "path":  "/linkType?slotOffset=1&channelOffset=2",
          "value": 1
      }
]
```

The 132 bytes of the CBOR transcription of the JSON document describing the patch for install the schedule on node 6.

B.1.6 PATCH Request for Installing the Schedule on Node 7

```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
      {
```

```
            "op":    "replace",
            "path":  "/nodeAddress?slotOffset=7&channelOffset=1",
            "value": 3
        },
        {
            "op":    "replace",
            "path":  "/linkType?slotOffset=7&channelOffset=1",
            "value": 1
        }
]
```

The 132 bytes of the CBOR transcription of the JSON document describing the patch for install the schedule on node 7.

B.1.7 PATCH Request for Installing the Schedule on Node 8

```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
        {
            "op":    "replace",
            "path":  "/nodeAddress?slotOffset=6&channelOffset=2",
            "value": 2
        },
        {
            "op":    "replace",
            "path":  "/linkType?slotOffset=6&channelOffset=2",
            "value": 1
        }
]
```

The 132 bytes of the CBOR transcription of the JSON document describing the patch for install the schedule on node 8.

B.1.8 PATCH Request for Installing the Schedule on Node 9

```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
        {
            "op":    "replace",
            "path":  "/nodeAddress?slotOffset=4&channelOffset=2",
            "value": 2
        },
        {
            "op":    "replace",
            "path":  "/linkType?slotOffset=4&channelOffset=2",
            "value": 1
        }
]
```

The 132 bytes of the CBOR transcription of the JSON document describing the patch for install the schedule on node 9.

B.1.9 PATCH Request for Installing the Schedule on Node 10

```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
        {
            "op":    "replace",
            "path":  "/nodeAddress?slotOffset=1&channelOffset=1",
            "value": 3
        },
        {
            "op":    "replace",
            "path":  "/linkType?slotOffset=1&channelOffset=1",
```

```
            "value": 1
        },
        {
            "op":    "replace",
            "path":  "/nodeAddress?slotOffset=5&channelOffset=1",
            "value": 3
        },
        {
            "op":    "replace",
            "path":  "/LinkType?slotOffset=5&channelOffset=1",
            "value": 1
        }
]
```

The 263 bytes of the CBOR transcription of the JSON document describing the patch for install the schedule on node 10.

B.1.10 PATCH Request for Installing the Schedule on Node 11

```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
        {
            "op":    "replace",
            "path":  "/nodeAddress?slotOffset=3&channelOffset=1",
            "value": 3
        },
        {
            "op":    "replace",
            "path":  "/linkType?slotOffset=3&channelOffset=1",
            "value": 1
        }
]
```

The 132 bytes of the CBOR transcription of the JSON document describing the patch for install the schedule on node 11.

B.1.11 PATCH Request for Installing the Schedule on Node 12

```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
        {
            "op":    "replace",
            "path":  "/nodeAddress?slotOffset=3&channelOffset=2",
            "value": 4
        },
        {
            "op":    "replace",
            "path":  "/linkType?slotOffset=3&channelOffset=2",
            "value": 1
        }
]
```

The 132 bytes of the CBOR transcription of the JSON document describing the patch for install the schedule on node 12

B.2 Second Schedule with Node 13

B.2.1 PATCH Request for Updating the Schedule on Node 2

```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
        {
            "op":    "replace",
```

```
            "path":  "/nodeAddress?slotOffset=0&channelOffset=2",
            "value": 1
        },
        {
            "op":    "replace",
            "path":  "/linkType?slotOffset=0&channelOffset=2",
            "value": 1
        },
        {
            "op":    "replace",
            "path":  "/nodeAddress?slotOffset=2&channelOffset=2",
            "value": 9
        },
        {
            "op":    "replace",
            "path":  "/LinkType?slotOffset=2&channelOffset=2",
            "value": 2
        },
        {
            "op":    "replace",
            "path":  "/nodeAddress?slotOffset=4&channelOffset=2",
            "value": 8
        },
        {
            "op":    "replace",
            "path":  "/nodeAddress?slotOffset=6&channelOffset=2",
            "value": 13
        }
]
```

The 397 bytes of the CBOR transcription of the JSON document describing the patch for update the schedule on node 2.

B.2.2 PATCH Request for Updating the Schedule on Node 3

```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
        {
            "op":    "replace",
            "path":  "/channelOffset?slotOffset=5&channelOffset=1",
            "value": 2
        },
        {
            "op":    "replace",
            "path":  "/channelOffset?slotOffset=7&channelOffset=1",
            "value": 2
        },
        {
            "op":    "replace",
            "path":  "/channelOffset?slotOffset=8&channelOffset=0",
            "value": 1
        }
]
```

The 208 bytes of the CBOR transcription of the JSON document describing the patch for update the schedule on node 3.

B.2.3 PATCH Request for Updating the Schedule on Node 4

```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
        {
            "op":    "replace",
            "path":  "/nodeAddress?slotOffset=1&channelOffset=2",
            "value": 5
        },
        {
```

```
            "op":    "replace",
            "path":  "/nodeAddress?slotOffset=3&channelOffset=2",
            "value": 6
        },
        {
            "op":    "replace",
            "path":  "/channelOffset?slotOffset=5&channelOffset=2",
            "value": 1
        },
        {
            "op":    "replace",
            "path":  "/nodeAddress?slotOffset=5&channelOffset=1",
            "value": 12
        },
        {
            "op":    "replace",
            "path":  "/nodeAddress?slotOffset=7&channelOffset=1",
            "value": 5
        },
        {
            "op":    "replace",
            "path":  "/linkType?slotOffset=7&channelOffset=1",
            "value": 2
        },
        {
            "op":    "replace",
            "path":  "/nodeAddress?slotOffset=8&channelOffset=0",
            "value": 1
        },
        {
            "op":    "replace",
            "path":  "/linkType?slotOffset=8&channelOffset=0",
            "value": 1
        }
]
```

The 533 bytes of the CBOR transcription of the JSON document describing the patch for update the schedule on node 4.

B.2.4 PATCH Request for Updating the Schedule on Node 5

```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
        {
            "op":    "replace",
            "path":  "/slotOffset?slotOffset=0&channelOffset=2",
            "value": 1
        },
        {
            "op":    "replace",
            "path":  "/nodeAddress?slotOffset=1&channelOffset=2",
            "value": 4
        },
        {
            "op":    "replace",
            "path":  "/slotOffset?slotOffset=5&channelOffset=2",
            "value": 7
        },
        {
            "op":    "replace",
            "path":  "/channelOffset?slotOffset=7&channelOffset=2",
            "value": 1
        }
]
```

The 269 bytes of the CBOR transcription of the JSON document describing the patch for update the schedule on node 5.

B.2.5 PATCH Request for Updating the Schedule on Node 6

```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
      {
          "op":    "replace",
          "path":  "/slotOffset?slotOffset=1&channelOffset=2",
          "value": 3
      }
]
```

The 67 bytes of the CBOR transcription of the JSON document describing the patch for update the schedule on node 6.

B.2.6 PATCH Request for Updating the Schedule on Node 7

```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
      {
          "op":    "replace",
          "path":  "/channelOffset?slotOffset=7&channelOffset=1",
          "value": 2
      }
]
```

The 70 bytes of the CBOR transcription of the JSON document describing the patch for update the schedule on node 7.

B.2.7 PATCH Request for Updating the Schedule on Node 8

```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
      {
          "op":    "replace",
          "path":  "/slotOffset?slotOffset=6&channelOffset=2",
          "value": 4
      }
]
```

The 67 bytes of the CBOR transcription of the JSON document describing the patch for update the schedule on node 8.

B.2.8 PATCH Request for Updating the Schedule on Node 9

```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
      {
          "op":    "replace",
          "path":  "/slotOffset?slotOffset=4&channelOffset=2",
          "value": 2
      }
]
```

The 67 bytes of the CBOR transcription of the JSON document describing the patch for update the schedule on node 9.

B.2.9 PATCH Request for Updating the Schedule on Node 10

```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
      {
          "op":    "replace",
          "path":  "/channelOffset?slotOffset=5&channelOffset=1",
          "value": 2
      }
]
```

The 70 bytes of the CBOR transcription of the JSON document describing the patch for update the schedule on node 10.

B.2.10 PATCH Request for Updating the Schedule on Node 11

The 0 bytes of the CBOR transcription of the JSON document describing the patch for update the schedule on node 11.

B.2.11 PATCH Request for Updating the Schedule on Node 12

```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
      {
          "op":    "replace",
          "path":  "/slotOffset?slotOffset=3&channelOffset=2",
          "value": 5
      },
      {
          "op":    "replace",
          "path":  "/channelOffset?slotOffset=5&channelOffset=2",
          "value": 1
      }
]
```

The 136 bytes of the CBOR transcription of the JSON document describing the patch for update the schedule on node 12.

B.2.12 PATCH Request for Updating the Schedule on Node 13

```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
      {
          "op":    "replace",
          "path":  "/nodeAddress?slotOffset=6&channelOffset=2",
          "value": 2
      },
      {
          "op":    "replace",
          "path":  "/linkType?slotOffset=6&channelOffset=2",
          "value": 1
      }
]
```

The 132 bytes of the CBOR transcription of the JSON document describing the patch for update the schedule on node 13.

B.3 PATCH Requests Installing the First Schedule with cellId Coding

B.3.1 PATCH Request for Install the Schedule on Node 2 with cellId Coding

```
PATCH
```

```
coap://<ip>:5683/mg/6t/cellList
[
       {
           "op":    "replace",
           "path":  "/nodeAddress?cellId=2",
           "value": 5
       },
       {
           "op":    "replace",
           "path":  "/linkType?cellId=2",
           "value": 2
       },
       {
           "op":    "replace",
           "path":  "/nodeAddress?cellId=16",
           "value": 1
       },
       {
           "op":    "replace",
           "path":  "/LinkType?cellId=16",
           "value": 1
       },
       {
           "op":    "replace",
           "path":  "/nodeAddress?cellId=34",
           "value": 1
       },
       {
           "op":    "replace",
           "path":  "/linkType?cellId=34",
           "value": 1
       },
       {
           "op":    "replace",
           "path":  "/nodeAddress?cellId=48",
           "value": 1
       },
       {
           "op":    "replace",
           "path":  "/linkType?cellId=48",
           "value": 1
       },
       {
           "op":    "replace",
           "path":  "/nodeAddress?cellId=66",
           "value": 9
       },
       {
           "op":    "replace",
           "path":  "/linkType?cellId=66",
           "value": 2
       },
       {
           "op":    "replace",
           "path":  "/nodeAddress?cellId=80",
           "value": 1
       },
       {
           "op":    "replace",
           "path":  "/LinkType?cellId=80",
           "value": 1
       },
       {
           "op":    "replace",
           "path":  "/nodeAddress?cellId=98",
           "value": 8
       },
       {
           "op":    "replace",
           "path":  "/linkType?cellId=98",
           "value": 2
       },
       {
```

```
            "op":    "replace",
            "path":  "/nodeAddress?cellId=112",
            "value": 1
        },
        {
            "op":    "replace",
            "path":  "/LinkType?cellId=112",
            "value": 1
        }
]
```

The 729 bytes of the CBOR transcription of the JSON document describing the patch for install the schedule on node 2.

B.3.2 PATCH Request for Install the Schedule on Node 3 with cellId Coding

```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
        {
            "op":    "replace",
            "path":  "/nodeAddress?cellId=1",
            "value": 1
        },
        {
            "op":    "replace",
            "path":  "/linkType?cellId=1",
            "value": 1
        },
        {
            "op":    "replace",
            "path":  "/nodeAddress?cellId=17",
            "value": 10
        },
        {
            "op":    "replace",
            "path":  "/LinkType?cellId=17",
            "value": 2
        },
        {
            "op":    "replace",
            "path":  "/nodeAddress?cellId=33",
            "value": 1
        },
        {
            "op":    "replace",
            "path":  "/linkType?cellId=33",
            "value": 1
        },
        {
            "op":    "replace",
            "path":  "/nodeAddress?cellId=49",
            "value": 11
        },
        {
            "op":    "replace",
            "path":  "/linkType?cellId=49",
            "value": 2
        },
        {
            "op":    "replace",
            "path":  "/nodeAddress?cellId=65",
            "value": 1
        },
        {
            "op":    "replace",
            "path":  "/linkType?cellId=65",
            "value": 1
        },
        {
            "op":    "replace",
```

```
            "path":  "/nodeAddress?cellId=81",
            "value": 10
        },
        {
            "op":    "replace",
            "path":  "/LinkType?cellId=81",
            "value": 2
        },
        {
            "op":    "replace",
            "path":  "/nodeAddress?cellId=97",
            "value": 1
        },
        {
            "op":    "replace",
            "path":  "/linkType?cellId=97",
            "value": 1
        }
]
```

The 636 bytes of the CBOR transcription of the JSON document describing the patch for install the schedule on node 3.

B.3.3 PATCH Request for Install the Schedule on Node 4 with cellId Coding

```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
        {
            "op":    "replace",
            "path":  "/nodeAddress?cellId=0",
            "value": 1
        },
        {
            "op":    "replace",
            "path":  "/linkType?cellId=0",
            "value": 1
        },
        {
            "op":    "replace",
            "path":  "/nodeAddress?cellId=18",
            "value": 6
        },
        {
            "op":    "replace",
            "path":  "/LinkType?cellId=18",
            "value": 2
        },
        {
            "op":    "replace",
            "path":  "/nodeAddress?cellId=32",
            "value": 1
        },
        {
            "op":    "replace",
            "path":  "/linkType?cellId=32",
            "value": 1
        },
        {
            "op":    "replace",
            "path":  "/nodeAddress?cellId=50",
            "value": 12
        },
        {
            "op":    "replace",
            "path":  "/linkType?cellId=50",
            "value": 2
        },
        {
            "op":    "replace",
            "path":  "/nodeAddress?cellId=64",
```

```
            "value": 1
        },
        {
            "op":    "replace",
            "path":  "/linkType?cellId=64",
            "value": 1
        },
        {
            "op":    "replace",
            "path":  "/nodeAddress?cellId=82",
            "value": 5
        },
        {
            "op":    "replace",
            "path":  "/LinkType?cellId=82",
            "value": 2
        },
        {
            "op":    "replace",
            "path":  "/nodeAddress?cellId=96",
            "value": 1
        },
        {
            "op":    "replace",
            "path":  "/linkType?cellId=96",
            "value": 1
        }
]
```

The 636 bytes of the CBOR transcription of the JSON document describing the patch for install the schedule on node 4.

B.3.4 PATCH Request for Install the Schedule on Node 5 with cellId Coding

```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
        {
            "op":    "replace",
            "path":  "/nodeAddress?cellId=2",
            "value": 2
        },
        {
            "op":    "replace",
            "path":  "/linkType?cellId=2",
            "value": 1
        },
        {
            "op":    "replace",
            "path":  "/nodeAddress?cellId=82",
            "value": 4
        },
        {
            "op":    "replace",
            "path":  "/LinkType?cellId=82",
            "value": 1
        }
]
```

The 181 bytes of the CBOR transcription of the JSON document describing the patch for install the schedule on node 5.

B.3.5 PATCH Request for Install the Schedule on Node 6 with cellId Coding

```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
        {
            "op":    "replace",
```

```
            "path":  "/nodeAddress?cellId=18",
            "value": 4
        },
        {
            "op":    "replace",
            "path":  "/linkType?cellId=18",
            "value": 1
        }
]
```

The 92 bytes of the CBOR transcription of the JSON document describing the patch for install the schedule on node 6.

B.3.6 PATCH Request for Install the Schedule on Node 7 with cellId Coding

```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
        {
            "op":    "replace",
            "path":  "/nodeAddress?cellId=113",
            "value": 3
        },
        {
            "op":    "replace",
            "path":  "/linkType?cellId=113",
            "value": 1
        }
]
```

The 94 bytes of the CBOR transcription of the JSON document describing the patch for install the schedule on node 7.

B.3.7 PATCH Request for Install the Schedule on Node 8 with cellId Coding

```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
        {
            "op":    "replace",
            "path":  "/nodeAddress?cellId=98",
            "value": 2
        },
        {
            "op":    "replace",
            "path":  "/linkType?cellId=98",
            "value": 1
        }
]
```

The 92 bytes of the CBOR transcription of the JSON document describing the patch for install the schedule on node 8.

B.3.8 PATCH Request for Install the Schedule on Node 9 with cellId Coding

```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
        {
            "op":    "replace",
            "path":  "/nodeAddress?cellId=66",
            "value": 2
        },
        {
            "op":    "replace",
            "path":  "/linkType?cellId=66",
            "value": 1
```

```
      }
]
```

The 92 bytes of the CBOR transcription of the JSON document describing the patch for install the schedule on node 9.

B.3.9 PATCH Request for Install the Schedule on Node 10 with cellId Coding

```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
      {
          "op":    "replace",
          "path":  "/nodeAddress?cellId=17",
          "value": 3
      },
      {
          "op":    "replace",
          "path":  "/linkType?cellId=17",
          "value": 1
      },
      {
          "op":    "replace",
          "path":  "/nodeAddress?cellId=81",
          "value": 3
      },
      {
          "op":    "replace",
          "path":  "/LinkType?cellId=81",
          "value": 1
      }
]
```

The 183 bytes of the CBOR transcription of the JSON document describing the patch for install the schedule on node 10.

B.3.10 PATCH Request for Install the Schedule on Node 11 with cellId Coding

```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
      {
          "op":    "replace",
          "path":  "/nodeAddress?cellId=49",
          "value": 3
      },
      {
          "op":    "replace",
          "path":  "/linkType?cellId=49",
          "value": 1
      }
]
```

The 92 bytes of the CBOR transcription of the JSON document describing the patch for install the schedule on node 11.

B.3.11 PATCH Request for Install the Schedule on Node 12 with cellId Coding

```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
      {
          "op":    "replace",
          "path":  "/nodeAddress?cellId=50",
          "value": 4
      },
      {
```

```
            "op":    "replace",
            "path":  "/linkType?cellId=50",
            "value": 1
        }
]
```

The 92 bytes of the CBOR transcription of the JSON document describing the patch for install the schedule on node 12.

B.4 PATCH Requests Installing the Second Schedule with cellID Coding

B.4.1 PATCH Request for Updating the Schedule on Node 2 with cellId Coding

```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
        {
            "op":    "replace",
            "path":  "/nodeAddress?cellId=2",
            "value": 1
        },
        {
            "op":    "replace",
            "path":  "/linkType?cellId=2",
            "value": 1
        },
        {
            "op":    "replace",
            "path":  "/nodeAddress?cellId=34",
            "value": 9
        },
        {
            "op":    "replace",
            "path":  "/LinkType?cellId=34",
            "value": 2
        },
        {
            "op":    "replace",
            "path":  "/nodeAddress?cellId=66",
            "value": 8
        },
        {
            "op":    "replace",
            "path":  "/nodeAddress?cellId=66",
            "value": 13
        }
]
```

The 275 bytes of the CBOR transcription of the JSON document describing the patch for update the schedule on node 2.

B.4.2 PATCH Request for Updating the Schedule on Node 3 with cellId Coding

```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
        {
            "op":    "replace",
            "path":  "/cellId?cellId=81",
            "value": 82
        },
        {
            "op":    "replace",
            "path":  "/cellId?cellId=112",
            "value": 113
        },
        {
```

```
            "op":    "replace",
            "path":  "/cellId?cellId=128",
            "value": 129
        }
]
```

The 132 bytes of the CBOR transcription of the JSON document describing the patch for update the schedule on node 3.

B.4.3 PATCH Request for Updating the Schedule on Node 4 with cellId Coding

```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
        {
            "op":    "replace",
            "path":  "/nodeAddress?cellId=18",
            "value": 5
        },
        {
            "op":    "replace",
            "path":  "/nodeAddress?cellId=50",
            "value": 6
        },
        {
            "op":    "replace",
            "path":  "/cellId?cellId=82",
            "value": 81
        },
        {
            "op":    "replace",
            "path":  "/nodeAddress?cellId=81",
            "value": 12
        },
        {
            "op":    "replace",
            "path":  "/nodeAddress?cellId=113",
            "value": 5
        },
        {
            "op":    "replace",
            "path":  "/linkType?cellId=113",
            "value": 2
        },
        {
            "op":    "replace",
            "path":  "/nodeAddress?cellId=128",
            "value": 1
        },
        {
            "op":    "replace",
            "path":  "/linkType?cellId=128",
            "value": 1
        }
]
```

The 371 bytes of the CBOR transcription of the JSON document describing the patch for update the schedule on node 4.

B.4.4 PATCH Request for Updating the Schedule on Node 5 with cellId Coding

```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
        {
            "op":    "replace",
            "path":  "/cellId?cellId=2",
            "value": 18
        },
```

```
      {
          "op":    "replace",
          "path":  "/nodeAddress?cellId=18",
          "value": 4
      },
      {
          "op":    "replace",
          "path":  "/cellId?cellId=82",
          "value": 113
      }
]
```

The 132 bytes of the CBOR transcription of the JSON document describing the patch for update the schedule on node 5.

B.4.5 PATCH Request for Updating the Schedule on Node 6 with cellId Coding

```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
      {
          "op":    "replace",
          "path":  "/cellId?cellId=18",
          "value": 50
      }
]
```

The 44 bytes of the CBOR transcription of the JSON document describing the patch for update the schedule on node 6.

B.4.6 PATCH Request for Updating the Schedule on Node 7 with cellId Coding

```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
      {
          "op":    "replace",
          "path":  "/cellId?cellId=113",
          "value": 114
      }
]
```

The 45 bytes of the CBOR transcription of the JSON document describing the patch for update the schedule on node 7.

B.4.7 PATCH Request for Updating the Schedule on Node 8 with cellId Coding

```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
      {
          "op":    "replace",
          "path":  "/cellId?cellId=98",
          "value": 66
      }
]
```

The 44 bytes of the CBOR transcription of the JSON document describing the patch for update the schedule on node 8.

B.4.8 PATCH Request for Updating the Schedule on Node 9 with cellId Coding

```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
      {
          "op":    "replace",
          "path":  "/cellId?cellId=66",
          "value": 34
      }
]
```

The 44 bytes of the CBOR transcription of the JSON document describing the patch for update the schedule on node 9.

B.4.9 PATCH Request for Updating the Schedule on Node 10 with cellId Coding

```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
      {
          "op":    "replace",
          "path":  "/cellId?cellId=81",
          "value": 82
      }
]
```

The 44 bytes of the CBOR transcription of the JSON document describing the patch for update the schedule on node 10.

B.4.10 PATCH Request for Updating the Schedule on Node 11 with cellId Coding

The 0 bytes of the CBOR transcription of the JSON document describing the patch for update the schedule on node 11.

B.4.11 PATCH Request for Updating the Schedule on Node 12 with cellId Coding

```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
      {
          "op":    "replace",
          "path":  "/cellId?cellId=50",
          "value": 81
      }
]
```

The 44 bytes of the CBOR transcription of the JSON document describing the patch for update the schedule on node 12.

B.4.12 PATCH Request for Updating the Schedule on Node 13 with cellId Coding

```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
      {
          "op":    "replace",
          "path":  "/nodeAddress?cellId=98",
          "value": 2
      },
      {
          "op":    "replace",
          "path":  "/linkType?cellId=98",
          "value": 1
      }
]
```

The 92 bytes of the CBOR transcription of the JSON document describing the patch for update the schedule on node 13.

B.5 PATCH Requests for Installing the First Schedule with a Shorter Syntax

B.5.1 PATCH Request for Installing the Schedule on Node 2 with a Shorter Syntax

```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
       {
           "o": "rpl",
           "p": "/nodeAddress?cellId=2",
           "v": 5
       },
       {
           "o": "rpl",
           "p": "/linkType?cellId=2",
           "v": 2
       },
       {
           "o": "rpl",
           "p": "/nodeAddress?cellId=16",
           "v": 1
       },
       {
           "o": "rpl",
           "p": "/LinkType?cellId=16",
           "v": 1
       },
       {
           "o": "rpl",
           "p": "/nodeAddress?cellId=34",
           "v": 1
       },
       {
           "o": "rpl",
           "p": "/linkType?cellId=34",
           "v": 1
       },
       {
           "o": "rpl",
           "p": "/nodeAddress?cellId=48",
           "v": 1
       },
       {
           "o": "rpl",
           "p": "/linkType?cellId=48",
           "v": 1
       },
       {
           "o": "rpl",
           "p": "/nodeAddress?cellId=66",
           "v": 9
       },
       {
           "o": "rpl",
           "p": "/linkType?cellId=66",
           "v": 2
       },
       {
           "o": "rpl",
           "p": "/nodeAddress?cellId=80",
           "v": 1
       },
       {
           "o": "rpl",
           "p": "/LinkType?cellId=80",
           "v": 1
```

```
        },
        {
            "o": "rpl",
            "p": "/nodeAddress?cellId=98",
            "v": 8
        },
        {
            "o": "rpl",
            "p": "/linkType?cellId=98",
            "v": 2
        },
        {
            "o": "rpl",
            "p": "/nodeAddress?cellId=112",
            "v": 1
        },
        {
            "o": "rpl",
            "p": "/LinkType?cellId=112",
            "v": 1
        }
]
```

The 537 bytes of the CBOR transcription of the JSON document describing the patch for install the schedule on node 2.

B.5.2 PATCH Request for Installing the Schedule on Node 3 with a Shorter Syntax

```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
        {
            "o": "rpl",
            "p": "/nodeAddress?cellId=1",
            "v": 1
        },
        {
            "o": "rpl",
            "p": "/linkType?cellId=1",
            "v": 1
        },
        {
            "o": "rpl",
            "p": "/nodeAddress?cellId=17",
            "v": 10
        },
        {
            "o": "rpl",
            "p": "/LinkType?cellId=17",
            "v": 2
        },
        {
            "o": "rpl",
            "p": "/nodeAddress?cellId=33",
            "v": 1
        },
        {
            "o": "rpl",
            "p": "/linkType?cellId=33",
            "v": 1
        },
        {
            "o": "rpl",
            "p": "/nodeAddress?cellId=49",
            "v": 11
        },
        {
            "o": "rpl",
            "p": "/linkType?cellId=49",
            "v": 2
        },
```

```
      {
          "o": "rpl",
          "p": "/nodeAddress?cellId=65",
          "v": 1
      },
      {
          "o": "rpl",
          "p": "/linkType?cellId=65",
          "v": 1
      },
      {
          "o": "rpl",
          "p": "/nodeAddress?cellId=81",
          "v": 10
      },
      {
          "o": "rpl",
          "p": "/LinkType?cellId=81",
          "v": 2
      },
      {
          "o": "rpl",
          "p": "/nodeAddress?cellId=97",
          "v": 1
      },
      {
          "o": "rpl",
          "p": "/linkType?cellId=97",
          "v": 1
      }
]
```

The 468 bytes of the CBOR transcription of the JSON document describing the patch for install the schedule on node 3.

B.5.3 PATCH Request for Installing the Schedule on Node 4 with a Shorter Syntax

```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
      {
          "o": "rpl",
          "p": "/nodeAddress?cellId=0",
          "v": 1
      },
      {
          "o": "rpl",
          "p": "/linkType?cellId=0",
          "v": 1
      },
      {
          "o": "rpl",
          "p": "/nodeAddress?cellId=18",
          "v": 6
      },
      {
          "o": "rpl",
          "p": "/LinkType?cellId=18",
          "v": 2
      },
      {
          "o": "rpl",
          "p": "/nodeAddress?cellId=32",
          "v": 1
      },
      {
          "o": "rpl",
          "p": "/linkType?cellId=32",
          "v": 1
      },
      {
```

```
            "o": "rpl",
            "p": "/nodeAddress?cellId=50",
            "v": 12
        },
        {
            "o": "rpl",
            "p": "/linkType?cellId=50",
            "v": 2
        },
        {
            "o": "rpl",
            "p": "/nodeAddress?cellId=64",
            "v": 1
        },
        {
            "o": "rpl",
            "p": "/linkType?cellId=64",
            "v": 1
        },
        {
            "o": "rpl",
            "p": "/nodeAddress?cellId=82",
            "v": 5
        },
        {
            "o": "rpl",
            "p": "/LinkType?cellId=82",
            "v": 2
        },
        {
            "o": "rpl",
            "p": "/nodeAddress?cellId=96",
            "v": 1
        },
        {
            "o": "rpl",
            "p": "/linkType?cellId=96",
            "v": 1
        }
]
```

The 468 bytes of the CBOR transcription of the JSON document describing the patch for install the schedule on node 4.

B.5.4 PATCH Request for Installing the Schedule on Node 5 with a Shorter Syntax

```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
        {
            "o": "rpl",
            "p": "/nodeAddress?cellId=2",
            "v": 2
        },
        {
            "o": "rpl",
            "p": "/linkType?cellId=2",
            "v": 1
        },
        {
            "o": "rpl",
            "p": "/nodeAddress?cellId=82",
            "v": 4
        },
        {
            "o": "rpl",
            "p": "/LinkType?cellId=82",
            "v": 1
        }
]
```

The 133 bytes of the CBOR transcription of the JSON document describing the patch for install the schedule on node 5.

B.5.5 PATCH Request for Installing the Schedule on Node 6 with a Shorter Syntax

```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
      {
          "o": "rpl",
          "p": "/nodeAddress?cellId=18",
          "v": 4
      },
      {
          "o": "rpl",
          "p": "/linkType?cellId=18",
          "v": 1
      }
]
```

The 68 bytes of the CBOR transcription of the JSON document describing the patch for install the schedule on node 6.

B.5.6 PATCH Request for Installing the Schedule on Node 7 with a Shorter Syntax

```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
      {
          "o": "rpl",
          "p": "/nodeAddress?cellId=113",
          "v": 3
      },
      {
          "o": "rpl",
          "p": "/linkType?cellId=113",
          "v": 1
      }
]
```

The 70 bytes of the CBOR transcription of the JSON document describing the patch for install the schedule on node 7.

B.5.7 PATCH Request for Installing the Schedule on Node 8 with a Shorter Syntax

```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
      {
          "o": "rpl",
          "p": "/nodeAddress?cellId=98",
          "v": 2
      },
      {
          "o": "rpl",
          "p": "/linkType?cellId=98",
          "v": 1
      }
]
```

The 68 bytes of the CBOR transcription of the JSON document describing the patch for install the schedule on node 8.

B.5.8 PATCH Request for Installing the Schedule on Node 9 with a Shorter Syntax

```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
      {
          "o": "rpl",
          "p": "/nodeAddress?cellId=66",
          "v": 2
      },
      {
          "o": "rpl",
          "p": "/linkType?cellId=66",
          "v": 1
      }
]
```

The 68 bytes of the CBOR transcription of the JSON document describing the patch for install the schedule on node 9.

B.5.9 PATCH Request for Installing the Schedule on Node 10 with a Shorter Syntax

```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
      {
          "o": "rpl",
          "p": "/nodeAddress?cellId=17",
          "v": 3
      },
      {
          "o": "rpl",
          "p": "/linkType?cellId=17",
          "v": 1
      },
      {
          "o": "rpl",
          "p": "/nodeAddress?cellId=81",
          "v": 3
      },
      {
          "o": "rpl",
          "p": "/LinkType?cellId=81",
          "v": 1
      }
]
```

The 135 bytes of the CBOR transcription of the JSON document describing the patch for install the schedule on node 10.

B.5.10 PATCH Request for Installing the Schedule on Node 11 with a Shorter Syntax

```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
      {
          "o": "rpl",
          "p": "/nodeAddress?cellId=49",
          "v": 3
      },
      {
          "o": "rpl",
          "p": "/linkType?cellId=49",
          "v": 1
      }
]
```

The 68 bytes of the CBOR transcription of the JSON document describing the patch for install the schedule on node 11.

B.5.11 PATCH Request for Installing the Schedule on Node 12 with a Shorter Syntax

```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
       {
           "o": "rpl",
           "p": "/nodeAddress?cellId=50",
           "v": 4
       },
       {
           "o": "rpl",
           "p": "/linkType?cellId=50",
           "v": 1
       }
]
```

The 68 bytes of the CBOR transcription of the JSON document describing the patch for install the schedule on node 12.

B.6 PATCH Requests for Installing the Second Schedule with a Shorter Syntax

B.6.1 PATCH Request for Updating the Schedule on Node 2 with a Shorter Syntax

```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
       {
           "o": "rpl",
           "p": "/nodeAddress?cellId=2",
           "v": 1
       },
       {
           "o": "rpl",
           "p": "/linkType?cellId=2",
           "v": 1
       },
       {
           "o": "rpl",
           "p": "/nodeAddress?cellId=34",
           "v": 9
       },
       {
           "o": "rpl",
           "p": "/LinkType?cellId=34",
           "v": 2
       },
       {
           "o": "rpl",
           "p": "/nodeAddress?cellId=66",
           "v": 8
       },
       {
           "o": "rpl",
           "p": "/nodeAddress?cellId=66",
           "v": 13
       }
]
```

The 203 bytes of the CBOR transcription of the JSON document describing the patch for update the schedule on node 2.

B.6.2 PATCH Request for Updating the Schedule on Node 3 with a Shorter Syntax

```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
       {
           "o": "rpl",
           "p": "/cellId?cellId=81",
           "v": 82
       },
       {
           "o": "rpl",
           "p": "/cellId?cellId=112",
           "v": 113
       },
       {
           "o": "rpl",
           "p": "/cellId?cellId=128",
           "v": 129
       }
]
```

The 96 bytes of the CBOR transcription of the JSON document describing the patch for update the schedule on node 3.

B.6.3 PATCH Request for Updating the Schedule on Node 4 with a Shorter Syntax

```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
       {
           "o": "rpl",
           "p": "/nodeAddress?cellId=18",
           "v": 5
       },
       {
           "o": "rpl",
           "p": "/nodeAddress?cellId=50",
           "v": 6
       },
       {
           "o": "rpl",
           "p": "/cellId?cellId=82",
           "v": 81
       },
       {
           "o": "rpl",
           "p": "/nodeAddress?cellId=81",
           "v": 12
       },
       {
           "o": "rpl",
           "p": "/nodeAddress?cellId=113",
           "v": 5
       },
       {
           "o": "rpl",
           "p": "/linkType?cellId=113",
           "v": 2
       },
       {
           "o": "rpl",
           "p": "/nodeAddress?cellId=128",
           "v": 1
       },
       {
           "o": "rpl",
           "p": "/linkType?cellId=128",
           "v": 1
       }
]
```

The 275 bytes of the CBOR transcription of the JSON document describing the patch for update the schedule on node 4.

B.6.4 PATCH Request for Updating the Schedule on Node 5 with a Shorter Syntax

```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
      {
          "o": "rpl",
          "p": "/cellId?cellId=2",
          "v": 18
      },
      {
          "o": "rpl",
          "p": "/nodeAddress?cellId=18",
          "v": 4
      },
      {
          "o": "rpl",
          "p": "/cellId?cellId=82",
          "v": 113
      }
]
```

The 96 bytes of the CBOR transcription of the JSON document describing the patch for update the schedule on node 5.

B.6.5 PATCH Request for Updating the Schedule on Node 6 with a Shorter Syntax

```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
      {
          "o": "rpl",
          "p": "/cellId?cellId=18",
          "v": 50
      }
]
```

The 32 bytes of the CBOR transcription of the JSON document describing the patch for update the schedule on node 6.

B.6.6 PATCH Request for Updating the Schedule on Node 7 with a Shorter Syntax

```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
      {
          "o": "rpl",
          "p": "/cellId?cellId=113",
          "v": 114
      }
]
```

The 33 bytes of the CBOR transcription of the JSON document describing the patch for update the schedule on node 7.

B.6.7 PATCH Request for Updating the Schedule on Node 8 with a Shorter Syntax

```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
      {
          "o": "rpl",
```

```
            "p": "/cellId?cellId=98",
            "v": 66
        }
]
```

The 32 bytes of the CBOR transcription of the JSON document describing the patch for update the schedule on node 8.

B.6.8 PATCH Request for Updating the Schedule on Node 9 with a Shorter Syntax

```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
        {
            "o": "rpl",
            "p": "/cellId?cellId=66",
            "v": 34
        }
]
```

The 32 bytes of the CBOR transcription of the JSON document describing the patch for update the schedule on node 9.

B.6.9 PATCH Request for Updating the Schedule on Node 10 with a Shorter Syntax

```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
        {
            "o": "rpl",
            "p": "/cellId?cellId=81",
            "v": 82
        }
]
```

The 32 bytes of the CBOR transcription of the JSON document describing the patch for update the schedule on node 10.

B.6.10 PATCH Request for Updating the Schedule on Node 11 with a Shorter Syntax

The 0 bytes of the CBOR transcription of the JSON document describing the patch for update the schedule on node 11.

B.6.11 PATCH Request for Updating the Schedule on Node 12 with a Shorter Syntax

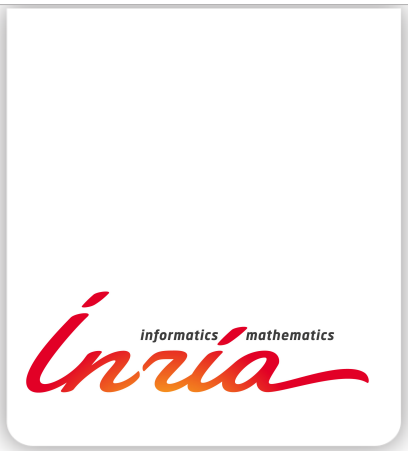
```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
        {
            "o": "rpl",
            "p": "/cellId?cellId=50",
            "v": 81
        }
]
```

The 32 bytes of the CBOR transcription of the JSON document describing the patch for update the schedule on node 12.

B.6.12 PATCH Request for Updating the Schedule on Node 13 with a Shorter Syntax

```
PATCH
coap://<ip>:5683/mg/6t/cellList
[
      {
          "o": "rpl",
          "p": "/nodeAddress?cellId=98",
          "v": 2
      },
      {
          "o": "rpl",
          "p": "/linkType?cellId=98",
          "v": 1
      }
]
```

The 68 bytes of the CBOR transcription of the JSON document describing the patch for update the schedule on node 13.



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Publisher
Inria
Domaine de Voluceau - Rocquencourt
BP 105 - 78153 Le Chesnay Cedex
inria.fr

ISSN 0249-6399