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Publish-Subscribe Deployment Option for NDN in the Constrained Internet of Things

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Abstract

Constrained IoT devices often operate more efficiently in a loosely coupled environment without maintaining end-to-end connectivity between nodes. Information Centric Networking naturally supports this demand by replicated data distribution and hop wise forwarding. This document outlines a deployment option for NDN in low-power and lossy networks (LLNs) that follows a publish-subscribe pattern. The proposed protocol scheme simplifies name-based routing significantly and facilitates even large off-duty cycles for constrained nodes.

Status of This Memo

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1. Introduction

In the emerging Internet of Things (IoT), it is expected that large quantities of very constrained sensors and actuators collect, communicate, and process massive amounts of machine data. Early experiments with constrained nodes show promising results for different deployments of ICN communication [NDN-EXP].

Characteristics of constrained nodes:

- o Battery-powered with sleep cycles
- o Failing nodes
- o Low power lossy networks

Challenges of NDN deployment [RFC7927]

- o Complexity of name-based routing
- o State management at nodes
- o Clear separation between control and data plane
- o Adaptation to constrained wireless transmission

o Mobility management

1.1. Baseline Scenarios

Multiple scenarios have been discussed in [RFC7476] and [IWMT] that evaluate the applicability of ICN in IoT.

We consider two characteristic constrained IoT scenarios with the enumerated challenges:

Stationary IoT nodes within reach of fixed uplinks for home, building, and factory automation, stationary monitoring, ...

* Reliability, resilience of operation
* Radio coordination, coverage
* Energy constraints, device lifetime
* Interference with rivaling appliances

Mobile IoT nodes with sparse coverage or intermittent connectivity for urban or rural mobility and sensing, industrial Internet in widespread environments, disaster recovery and rescue ...

* Exploit connectivity when available
* Large off-duty cycles of nodes
* Partitioned networks
* Limited dependability
* Environmental impact and disturbance

IoT scenarios usually impose routing requirements to support mobile nodes, handle failing links and to be resilient against attacks. A secure and autonomous bootstrapping is essential, especially for large-scale IoT deployments.

1.2. Benefits of Loose Coupling in the IoT

ICN decouples content consumers from data producers (decoupling in space). A more sophisticated decoupling can be provided with the publish-subscribe messaging pattern that further adds a decoupling in time and synchronization. Constrained devices in LLNs can leverage this loose coupling to increase sleep cycles and delegate the authority over as much information as possible to more powerful

devices that act as content proxies. In Figure 1, once content is published to the content proxy (CP) by a producer (P), consumers (C) can retrieve this content from (CP) without interacting with the producer. This indirection when retrieving information allows (P) to align sleep cycles accordingly to the period of generating new sensor readings, instead of handling content requests from any consumers (C).

```
                         (CP)
                        / | \
                       /  |  `-----.
                      /   |   |  |  \
                    (P)  (C) ...... (C)
```

Figure 1: Content Proxy (CP) - Producer (P) - Consumer (C)

TODO: The problem of PUSH

2. Terminology

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119 [RFC2119]. The use of the term, "silently ignore" is not defined in RFC 2119. However, the term is used in this document and can be similarly construed.

This document uses the terminology of [RFC7476], [RFC7927], and [RFC7945] for ICN entities.

The following terms are used in the document and defined as follows:

Content Proxy Stable node for replicating content.

Cloud Gateway A Gateway that enables content transfer to and from a remote cloud storage, possibly by performing some kind of protocol translation.

PAM Prefix Advertisement Message.

NAM Name Advertisement Message.

3. Publish-Subscribe in IoT Edge Networks

The publish-subscribe system is centered around prefix-specific content proxies (CPs) that are deployed in IoT edge networks. Such proxy function can be hosted on the Cloud- or Internet Gateway, or may reside on a stable, less constrained node within the IoT

infrastructure. It is assumed that a CP is present for each prefix covering publishable content.

Implementing a pub-sub NDN involves several steps that are bound to the tight requirements of resource-constrained devices. These steps include:

1. Building the prefix-specific routing topology tailored to constrained networks

2. Mapping _Publish_ to NDN semantics

3. Mapping _Subscribe_ to NDN semantics

3.1. Topology Maintenance and Routing

A (sensor) node that wants to publish a data item needs to rely on path information towards the Content Proxy. Following the approach of PANINI [PANINI], default routes will be established as follows.

Each CP in the local IoT sub-network advertises the prefix(es) it represents to the routing system. It does so by broadcasting Prefix Advertisement Messages (PAMs) on the link layer (see Section 4 for the corresponding protocol details). Nodes that newly receive PAM advertisements will add or refresh a prefix-specific default route in their FIB. Intermediate nodes in a multi-hop environment also re-broadcast PAMs, so that the entire sub-network is flooded and default route entries build a shortest path tree (SPT) towards the CP as shown in Table 1 (alternatively, a DODAG w.r.t. a gateway for redundant CPs).

```
        (CP)
    PAM /  \
       /    \ PAM
     (A)    (B)
     /|\    /|\
    : : :  : : : PAM
```

Figure 2: SPT building by Prefix Advertisement Messages (PAMs)

Information flowing from constrained sensor nodes towards a gateway is the prevalent communication pattern in the IoT (converge cast). The publish-subscribe system hence establishes a default routing (see sample FIB in Table 1) and uses the tree (DODAG) topology with default routes towards the CP as a first step of content aggregation. Content replication towards other CPs, an Internet gateway, or into a cloud can follow subsequently.

Prefix	Face	Lifetime
/	Fx	Ft
...	...	...

Table 1: FIB with a default route

It is noteworthy that the role of the new PAM message remains orthogonal to the existing Interest or Data semantics. A PAM never carries data nor requests, but persists on the control plane of name-based routing. User applications stay unaffected, and continue to rely on the NDN-specific request-response paradigm.

3.2. Mapping Publish to NDN

In classical publish-subscribe systems, a _Publish_ is typically implemented as a push mechanism on the data plane. However, this contradicts the request-response paradigm employed by NDN. To adapt the _Publish_ operation to NDN semantics, it is split into two phases and the required push mechanism is moved into the control plane. The two phases consist of:

1. Announcing names of Named Data Objects (NDO) on the control plane

2. Requesting NDOs on the data plane

The first phase is the actual announcement of names in the upwards direction towards the CP. Because of NDN's name-based routing approach, the announcement of names is subject of the routing protocol and therefore belongs to the control plane. For this purpose, the control message type Name Advertisement Message (NAM) is adapted from PANINI [PANINI]. Similarly to the PAM, a NAM message utilizes a push mechanism in the control plane without interfering with the request-response mechanism on the data plane. NAMs are directed towards the (prefix-specific) parent of a node and traverse hop-by-hop along the gradient towards the CP. Each intermediate hop on the gradient installs forwarding states in the downward direction by using the announced names in the NAM and the incoming face. Typically, states are short-lived for content replication, only. NAMs contain one or multiple names encoded as TLV elements in the payload.

Figure 3 (a) depicts the propagation of the NAM towards the (CP). In this example, the name _/HAW/temp123_ is announced by (C) via (A) to (CP).

```
    +-----------------------------------------------------------------+
    |                                                                 |
    |   +----------------------+  +-------------------------------+   |
    |   |                      |  |                               |   |
    |   |     Mt: /HAW/temp123 |  |   Mt: /HAW/temp123 = 23C      |   |
    |   |     ,->(CP)          |  |          ,---(CP)<--,         |   |
    |   | NAM |  /             |  |          |    /     |         |   |
    |   |     | /              |  |          |   /    ,-'         |   |
    |   |     (A)<-,           |  | Interest | (A)    | Data(23C) |   |
    |   |       \  | NAM       |  |          |   \    `-,         |   |
    |   |        \ |           |  |          |    \     |         |   |
    |   |        (C)           |  |          `--->(C)---'         |   |
    |   |     /HAW/temp123     |  |       /HAW/temp123 = 23C      |   |
    |   |                      |  |                               |   |
    |   +----------------------+  +-------------------------------+   |
    |          (a) Phase 1                  (b) Phase 2               |
    +-----------------------------------------------------------------+
```

Figure 3: Publish

In addition to a FIB, the (CP) maintains another data structure _Mt_ (Meta-Table) to store all announced names annotated with additional context information and a lifetime. Upon receipt of a NAM, the _Mt_ is updated accordingly. Context information consists of generic properties attached to a name (e.g. topic names and content freshness indicators) and are out of scope of this document. The _Mt_ has its own name and can be requested by other devices.

In the second phase, the (CP) requests the content of newly learned names from the first phase. For content requests, the regular NDN Interest-Data exchange on the data plane is used and is depicted in Figure 3 (b). Upon receipt, the content is cached on the (CP).

3.3. Mapping Subscribe to NDN

In the proposed publish-subscribe system, the _Subscribe_ operation is equivalent to an Interest-based request of previously learned content names. A device can learn about new content by (a) Name Advertisements of the CP via dedicated prefix path (TODO) or broadcast. It may as well poll the _Mt_ in order to learn about general updates at the CP. Context information in the _Mt_ may give indications about periodic sensor readings, so that a periodic polling of the _Mt_ can be aligned with the sensor reading period.

```
        +---------------------------------------------------------+
        |                                                         |
        |   +-----------------------+  +-----------------------+  |
        |   |                       |  |                       |  |
        |   |    Data (Mt)          |  |    Data (Nx)          |  |
        |   |       ,-------->(S)   |  |       ,-------->(S)   |  |
        |   |     (CP)<--------'    |  |     (CP)<--------'    |  |
        |   |     /  \  Int. (Mt)   |  |     /  \  Int. (Nx)   |  |
        |   |    /    \             |  |    /    \             |  |
        |   |  (A)    (B)           |  |  (A)    (B)           |  |
        |   |  /|\    /|\           |  |  /|\    /|\           |  |
        |   | : : :  : : :          |  | : : :  : : :          |  |
        |   |                       |  |                       |  |
        |   +-----------------------+  +-----------------------+  |
        |       (a) Request Mt         (b) Request Content        |
        +---------------------------------------------------------+
```

Figure 4: Subscribe

In Figure 4 (a), a subscriber (S) requests the _Mt_ to learn about new names. A new name (Nx) is then requested via the regular Interest/Data request-response paradigm in Figure 4 (b).

The majority of constrained devices at the IoT edge are mostly content producers, but not consumers. Subscribers do not necessarily need to be part of the distribution tree, but may reach the gateway (CP) by other means.

3.4. Content Replication between Proxy Instances

TODO

4. Control Plane Messaging

TODO

5. Security Considerations

TODO

6. References

6.1. Normative References

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