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An Architecture for IPv6 over Time Slotted Channel Hopping

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Abstract

This document presents an architecture for an IPv6 multilink subnet that is composed of a high speed powered backbone and a number of IEEE802.15.4e TSCH wireless networks attached and synchronized by Backbone Routers. Route Computation may be achieved in a centralized fashion by a Path Computation Element, in a distributed fashion using the Routing Protocol for Low Power and Lossy Networks, or in a mixed mode. The Backbone Routers perform proxy Neighbor discovery operations over the backbone on behalf of the wireless device, so they can share a same subnet and appear to be connected to the same backbone as classical devices.

Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119 [RFC2119].

Status of this Memo

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1. Introduction

The emergence of radio technology enabled a large variety of new types of devices to be interconnected, at a very low marginal cost compared to wire, at any range from Near Field to interplanetary distances, and in circumstances where wiring could be less than practical, for instance rotating devices.

At the same time, a new breed of Time Sensitive Networks is being developped to enable traffic that is highly sensitive to jitter and quite sensitive to latency. Such traffic is not limited to voice and video, but also includes command and control operations such as found in industrial automation or in-vehicule sensors and actuators.

At IEEE802.1, the "Audio/Video Task Group", was renamed TSN for Time Sensitive Networking to address Deterministic Ethernet. The IEEE802.15.4 Medium Access Control MAC) has evolved with IEEE802.15.4e that provides in particular the Time Slotted Channel Hopping (TSCH) mode for industrial-type applications.

Though at a different time scale, both standards provide Deterministic capabilities to the point that a packet that pertains to a certain flow will cross the network from node to node following a very precise schedule, like a train leaves intermediate stations at precise times along its path. The time slotted aspect reduces collisions, and saves energy, and enables to more closely engineer the network for deterministic properties. The channel hopping aspect is a simple and efficient technique to get around statistical interference by WIFI emitters.

This document presents an architecture for an IPv6 multilink subnet that is composed of a high speed powered backbone and a number of IEEE802.15.4e TSCH wireless networks attached and synchronized by backbone routers. Route Computation may be achieved in a centralized fashion by a Path Computation Entity (PCE), in a distributed fashion using the Routing Protocol for Low Power and Lossy Networks (RPL), or in a mixed mode. The Backbone Routers perform proxy Ipv6 Neighbor Discovery (ND) operations over the backbone on behalf of the wireless device, so they can share a same IPv6 subnet and appear to be connected to the same backbone as classical devices.

2. Terminology

The draft uses terminology defined in [I-D.palattella-6tsch- terminology], [I-D.chakrabarti-nordmark-6man-efficient-nd], [RFC5191] and [RFC4080].

It conforms to the terms and models described for IPv6 in [RFC5889] and uses the vocabulary and the concepts defined in [RFC4291] for IPv6.

3. Applications and Goals

The architecture derives from existing industrial standards for Process Control by its focus on Deterministic Networking, in particular with the use of the IEEE802.15.4e TSCH MAC and the centralized path computation entity. This approach leverages the TSCH MAC benefits for high reliability against interferences, low-power consumption on deterministic traffic, and its Traffic Engineering capabilities. Deterministic Networking applies in particular to open and close control loops, as well as supervisory control flows, and management.

Additional industrial use cases are addressed with the addition of a more autonomic and distributed routing based on RPL. These use cases include plant setup and decommissioning, as well as monitoring of lots of lesser importance measurements such as corrosion and events. RPL also enables mobile use cases such as mobile workers and cranes.

A Backbone Router is included in order to scale the factory plant subnet to address large deployments, with proxy ND and time synchronization over a high speed backbone.

The architecture also applies to building automation that leverage RPL's storing mode to address multipath over a large number of hops, in-vehicule command and control that can be as demanding as industrial applications, commercial automation and asset tracking with mobile scenarios, home automation and domotics which become more reliable and thus provide a better user experience, and resource management (energy, water, etc...).

4. Overview and Scope

The scope of the present work is a subnet that, in its basic configuration, is made of a IEEE802.15.4e Time Slotted Channel Hopping (TSCH) [I-D.watteyne-6tsch-tsch-lln-context] MAC Route-Over Low Power Lossy Network (LLN).

```
               +-----+
               |     | LLN Border
               |     | router
               +-----+
             o    o   o
      o     o   o     o
         o   o LLN   o    o     o
            o   o   o       o
                    o
```

The LLN devices communicate over IPv6 [RFC2460] using the 6LoWPAN Header Compression (6LoWPAN HC) [RFC6282]. Neighbor Devices are discovered with 6LoWPAN Neighbor Discovery (6LoWPAN ND) [RFC6775] and the Routing Protocol for Low Power and Lossy Networks (RPL) [RFC6550] enables routing within the LLN. RPL forms Destination Oriented Directed Acyclic Graphs (DODAGs) within instances of the protocol, each instance being associated with an Objective Function (OF) to form a routing topology. A particular LLN device, usually powered, acts as RPL root, 6LoWPAN HC terminator, and LLN Border Router (LBR) to the outside.

An extended configuration of the subnet comprises multiple LLNs. The LLNs are interconnected and synchronized over a backbone, that can be wired or wireless. The backbone can be a classical IPv6 network, with Neighbor Discovery operating as defined in [RFC4861] and [RFC4862]. The backbone can also support Efficiency aware IPv6 Neighbor Discovery Optimizations [I-D.chakrabarti-nordmark-6man-efficient-nd] in mixed mode as described in [I-D.thubert-6lowpan-backbone-router].

Security is often handled at layer 2 and Layer 4. Authentication during the join process is handled with the Protocol for Carrying Authentication for Network Access (PANA) [RFC5191].

The LLN devices are time-synchronized at MAC level. The MAC coordinator that serves as time source through Enhanced Beacons (EB) is loosely coupled with the RPL parent; this way, the time synchronization starts at the RPL root and follows the RPL DODAGs with no timing loop.

In the extended configuration, the functionality of the LBR is enhanced to that of Backbone Router (BBR). A BBR is an LBR, but also an Energy Aware Default Router (NEAR) as defined in [I-D.chakrabarti-nordmark-6man-efficient-nd]. The BBR performs ND proxy operations between the registered devices and the classical ND devices that are located over the backbone. 6TSCH BBRs synchronize with one another over the backbone, so as to ensure that the multiple LLNs that form the IPv6 subnet stay tightly synchronized. If the Backbone is Deterministic (such as defined by the Time Sensitive Networking WG at IEEE), then the Backbone Router ensures that the end-to-end deterministic behavior is maintained between the LLN and the backbone.

```
               ---+------------------------
                  |      External Network
                  |
               +-----+                 +-----+
               |     | Router          |     | PCE
               |     |                 |     |
               +-----+                 +-----+
                  |                       |
                  |     Subnet Backbone   |
            +--------------------+------------------+
            |                    |                  |
         +-----+             +-----+             +-----+
         |     | Backbone    |     | Backbone    |     | Backbone
    o    |     | router      |     | router      |     | router
         +-----+             +-----+             +-----+
    o                  o                   o                 o   o
        o    o   o         o   o  o   o         o  o   o    o
   o             o        o  LLN      o      o         o      o
      o   o    o      o      o o     o  o   o    o    o     o
```

The main architectural blocks are arranged as follows:

```
        +-----+-----+-----+-----+-------+-----+
        |PCEP |   CoAP    |PANA |6LoWPAN| RPL |
        | PCC |DTLS |     |     |   ND  |     |
        +-----+-----+-----+-----+-------+-----+-----+
        | TCP |       UDP       |    ICMP     |RSVP |
        +-----+-----+-----+-----+-------+-----+-----+
        |                 IPv6                      |
        +-------------------------------------------+
        |               6LoWPAN HC                  |
        +-------------------------------------------+
        |                   6TUS                    |
        +-------------------------------------------+
        |             802.15.4e   TSCH              |
        +-------------------------------------------+
```

RPL is the routing protocol of choice for LLNs. (TBD RPL) whether there is a need to define a 6TSCH OF.

(tbd NME) COMAN is working on network Management for LLN. They are considering the Open Mobile Alliance (OMA) Lightweight M2M (LWM2M) Objet system. This standard includes DTLS, CoAP (core plus the Block and Observe patterns), SenML and CoAP Resource Directory.

(tbd PCC) need to work with PCE WG to define flows to PCE, and define how to accomodate PCE routes and reservation. Will probably look a lot like GMPLS

(tbd Backbone Router) need to work woth 6MAN to define ND proxy. Also need BBR sync sync between deterministic ethernet and 6TSCH LLNs.

IEEE802.1TSN: external, maintain consistency.
IEEE802.15.4: external, (tbd need updates?).
ISA100.20 Common Network Management: external, maintain consistency.
IoT6 European Project: external, maintain consistency.

5. Centralized vs. Distributed Routing

6. Functional Flows

7. Network Synchronization

The mechanism(s) used for time synchronization is something that we might have to reconcile with RPL discovery and maintenance traffic. Time synchronization in TSCH is based on three mechanisms:

Enhanced Beacons
Enhanced ACKs
Frame based synchronization

If a node communicates intermittently (sleepy, battery operated) it can also proactively ping its time source and receive time stamps. In order to maximize battery life and network throughput, it is advisable that RPL ICMP discovery and maintenance traffic (governed by the trickle timer) be somehow coordinated with the transmission of time synch packets (especially with enhanced beacons). This could be a function of the shim layer or it could be deferred to the device management entity. Any suggestions, ideas on this topic?

8. TSCH and 6TUS

8.1. 6tus

6tus is an adaptation layer which is the next higher layer to TSCH and which offers a set of commands defining a data and management interface. 6tus is defined in [I-D.wang-6tsch-6tus]
The management interface of 6tus enables an upper layer to schedule cells and slotframes in the TSCH schedule.
If the scheduling entity explicitly specifies the slotOffset/ channelOffset of the cells to be added/deleted, those cells are marked as "hard". 6tus can not move hard cells in the TSCH schedule. Hard cells are typically used by an central PCE.

6tus contains a monitoring process which monitors the performance of cells, and can move a cell in the TSCH schedule when it performs bad. This is only applicable to cells which are marked as "soft". To reserve a soft cell, the higher layer does not indicate the slotOffset/channelOffset of the cell to add, but rather the resulting bandwidth and QoS requirements. When the monitoring process triggers an cell reallocation, the two neighbor motes communication over this cells negociate the new position in the TSCH schedule of this cell.

8.2. Slotframes and Priorities

6tus uses priority queues to manage concurrent data flows of different prioroties. When a packet is received from an higher layer for transmission, the I-MUX module of 6tus inserts that packet in the outgoing queue which matches the packet best (DSCP can therefore be used). At each schedule transmit slot, the MUX module looks for the frame in all the outgoing queues that best matches the cells. If a frame is found, it is given to TSCH for transmission.

8.3. Centralized Flow Reservation

In a centralized setting, a PCE computes the TSCH schedule, and communicates with the different nodes in the network to configure their TSCH schedule. Since it has full knowledge of the network's topology, the PCE can compute a collision-free schedule, which result in a high degree of communication determinism.

The protocol for the PCE to communicate with the motes is not yet defined. This protocol typically reserves hard cells on the transmitter side of a dedicated cell, and the negociation protocol of 6tus takes care of reserving the same cell on the receiver node.

8.4. Distributed Flow Reservation

In a distributed setting, no central PCE in present in the network. Nodes use 6tus to reserve soft cells with their neighbors. Since no node has full knowledge of the network's topology and the traffic requirements, scheduling collisions are possible, for example because of a hidden terminal problem.

A schedule collision can be detected if two motes have multiple dedicated cells schedule to one another. The statistics process of 6tus can be configure to continuously compute the packet delivery ratio of those cells, and the monitoring process of 6tus can declare a soft cell to perform bad when that statistics for that cell is significantly worse than for the other cell to the same neighbor. When this happens, the monitoring process of 6tus moves the cell to another location in the 6TSCH schedule, through a re-negociation procedure with the neighbor.

The entity that builds and maintains the schedule in a distributed fashion is not yet defined.

8.5. Packet Marking and Handling

```
                  ---+----------------
          Sender                                                    Receiver
      +------------+     +-----+     +-----+      +-----+      +------------+
      |Application|---->| R1 |---->| R2 |----->|BBR |----->|Application|
      |   +--+     |     |+--+|     |+--+|      |+--+|      |   +--+     |
      |   |NE|====|=====||NE||=====||NE||======||NE||======|===|NE|     |
      |   +--+     |     |+--+|     |+--+|      |+--+|      |   +--+     |
      |    |^      |     | |^ |     | |^ |      | |^ |      |    |^      |
      |    v|      |     | v| |     | v| |      | v| |      |    v|      |
      |   +--+     |     |+--+|     |+--+|      |+--+|      |   +--+     |
      |   |6T|     |     ||6T||     ||6T||      ||6T||      |   |6T|     |
      |   |us|     |     ||us||     ||us||      ||us||      |   |us|     |
      |   +--+     |     |+--+|     |+--+|      |+--+|      |   +--+     |
      +------------+     +-----+     +-----+      +-----+      +------------+

         +--+
         |NE| = NSIS      ==== = Signaling    ---> = Data flow messages
         +--+   Entity           Messages           (unidirectional)

         +--+
         |6T|   6TUS layer
         |us| (and IEEE802.15.4e TSCH MAC below)
         +--+
```

reservation Deterministic flow allocation (hard reservation of time slots) eg centralized RSVP? metrics? Hop-by-hop interaction with 6TUS. Lazy reservation (use shared slots to transport extra burst and then dynamically (de)allocate) Classical QoS (dynamic based on observation)

9. Management

10. IANA Considerations

This specification does not require IANA action.

11. Security Considerations

This specification is not found to introduce new security threat.

12. Acknowledgements

13. References

13.1. Normative References

[RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, March 1997.

[RFC2460] Deering, S.E. and R.M. Hinden, "Internet Protocol, Version 6 (IPv6) Specification", RFC 2460, December 1998.

[RFC4080] Hancock, R., Karagiannis, G., Loughney, J. and S. Van den Bosch, "Next Steps in Signaling (NSIS): Framework", RFC 4080, June 2005.

[RFC4291] Hinden, R. and S. Deering, "IP Version 6 Addressing Architecture", RFC 4291, February 2006.

[RFC4861] Narten, T., Nordmark, E., Simpson, W. and H. Soliman, "Neighbor Discovery for IP version 6 (IPv6)", RFC 4861, September 2007.

[RFC4862] Thomson, S., Narten, T. and T. Jinmei, "IPv6 Stateless Address Autoconfiguration", RFC 4862, September 2007.

[RFC5191] Forsberg, D., Ohba, Y., Patil, B., Tschofenig, H. and A. Yegin, "Protocol for Carrying Authentication for Network Access (PANA)", RFC 5191, May 2008.

[RFC5889] Baccelli, E. and M. Townsley, "IP Addressing Model in Ad Hoc Networks", RFC 5889, September 2010.

[RFC5974] Manner, J., Karagiannis, G. and A. McDonald, "NSIS Signaling Layer Protocol (NSLP) for Quality-of-Service Signaling", RFC 5974, October 2010.

[RFC6282] Hui, J. and P. Thubert, "Compression Format for IPv6 Datagrams over IEEE 802.15.4-Based Networks", RFC 6282, September 2011.

[RFC6550] Winter, T., Thubert, P., Brandt, A., Hui, J., Kelsey, R., Levis, P., Pister, K., Struik, R., Vasseur, JP. and R. Alexander, "RPL: IPv6 Routing Protocol for Low-Power and Lossy Networks", RFC 6550, March 2012.

[RFC6775] Shelby, Z., Chakrabarti, S., Nordmark, E. and C. Bormann, "Neighbor Discovery Optimization for IPv6 over Low-Power Wireless Personal Area Networks (6LoWPANs)", RFC 6775, November 2012.

13.2. Informative References

[I-D.chakrabarti-nordmark-6man-efficient-nd]
Chakrabarti, S., Nordmark, E. and M. Wasserman, "Efficiency aware IPv6 Neighbor Discovery Optimizations", Internet-Draft draft-chakrabarti-nordmark-6man-efficient-nd-01, November 2012.

[I-D.palattella-6tsch-terminology]

Palattella, M., Thubert, P., Watteyne, T. and Q. Wang, "Terminology in IPv6 over Time Slotted Channel Hopping", Internet-Draft draft-palattella-6tsch-terminology-00, March 2013.

[I-D.svshah-tsvwg-lln-diffserv-recommendations]
Shah, S. and P. Thubert, "Differentiated Service Class Recommendations for LLN Traffic", Internet-Draft draft-svshah-tsvwg-lln-diffserv-recommendations-00, February 2013.

[I-D.thubert-6lowpan-backbone-router]
Thubert, P., "6LoWPAN Backbone Router", Internet-Draft draft-thubert-6lowpan-backbone-router-03, February 2013.

[I-D.wang-6tsch-6tus]
Wang, Q., Vilajosana, X. and T. Watteyne, "6tus Adaptation Layer Specification", Internet-Draft draft-wang-6tsch-6tus-00, March 2013.

[I-D.watteyne-6tsch-tsch-lln-context]
Watteyne, T., "Using IEEE802.15.4e TSCH in an LLN context: Overview, Problem Statement and Goals", Internet-Draft draft-watteyne-6tsch-tsch-lln-context-01, February 2013.

[I-D.watteyne-6tsch-tsch-lln-context]
Watteyne, T., "Using IEEE802.15.4e TSCH in an LLN context: Overview, Problem Statement and Goals", Internet-Draft draft-watteyne-6tsch-tsch-lln-context-01, February 2013.

[I-D.watteyne-6tsch-tsch-lln-context]
Watteyne, T., "Using IEEE802.15.4e TSCH in an LLN context: Overview, Problem Statement and Goals", Internet-Draft draft-watteyne-6tsch-tsch-lln-context-01, February 2013.

13.3. External Informative References

[HART] www.hartcomm.org, "Highway Addressable Remote Transducer, a group of specifications for industrial process and control devices administered by the HART Foundation", .

[IEEE802.1TSNTG]
IEEE Standards Association, "IEEE 802.1 Time-Sensitive Networks Task Group", March 2013, <http://www.ieee802.org/1/pages/avbridges.html>.

[ISA100.11a]
ISA, "ISA100, Wireless Systems for Automation", May 2008, <http://www.isa.org/Community/SP100WirelessSystemsforAutomation>.

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