6TSCH
Internet-Draft
Intended status: Standards Track
Expires: September 12, 2013

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March 11, 2013

An Architecture for IPv6 over Time Synchronized Channel Hopping
draft-thubert-6tsch-architecture-00

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].

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1. Introduction

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-vehicle sensors and actuators.

At IEEE802.1, the "Audio/Video Task Group", was rename TSN for Time Sensitive Networking. The IEEE802.15.4 Medium Access Control (MAC) has evolved with IEEE802.15.4e which provides in particular the Time Synchronized Channel Hopping (TSCH) mode for industrial-type applications. Both provide Deterministic capabities 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 reduce collisions, and saves energy. 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 Element (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. 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 Synchronized 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
```

Figure 1: Basic Configuration

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
```

Figure 2: Extended Configuration

The main architactural blocks are arranged as follows:

```
        +-----+-----+-----+-----+-----+--------+
        |PANA | RPL |RSVP | PCE |   IP         |
        |     |     |/NSIS| /CNM|/ FORWARDING  |
        +-----+-----+-----+-----+--------+-----+-------+
        |        6LoWPAN                 | 6LoWPAN ND  |
        |          HC                    +-------------+
        |                                              |
        +----------------------------------------------+
        |            6TUS                              |
        +----------------------------------------------+
        |          802.15.4e   TSCH                    |
        +----------------------------------------------+
```

Figure 3: 6TSCH stack

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

PCE => group needs to work with PCE WG to define flows to PCE, and define how to accomodate PCE routes and reservation.

BBR => group needs to work woth 6MAN to define ND proxy. Also need BBR sync, time sync between deterministic ethernet and 6TSCH net.

IEEE802.1TSN => external, maintain liaison.

IEEE802.15.4 => external, maintain liaison.

ISA100.20 Common Network Management (CNM) => external, maintain liaison.

IoT6 => external, maintain liaison.

4. Centralized vs. Distributed Routing

5. Functional Flows

6. 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?

7. TSCH and 6TUS

7.1. 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 defines in [I-D.draft-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.

7.2. 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.

7.3. 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.

7.4. 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.

7.5. 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)
         +--+
```

Figure 4: NSIS flow

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)

8. Management

9. IANA Considerations

This specification does not require IANA action.

10. Security Considerations

This specification is not found to introduce new security threat.

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