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Intended status: Informational K. Pister
Expires: January 15, 2014 University of California Berkeley
July 14, 2013

Minimal 6TSCH Configuration
draft-vilajosana-6tsch-basic-01

Abstract

This document describes the minimal set of rules to operate a [IEEE802154e] Timeslotted Channel Hopping (TSCH) network. These rules can be used during early interoperability testing and development, when the centralized and distributed solutions developed by the 6TSCH group are not fully implemented yet, or otherwise not available.

Status of This Memo

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1. Introduction

The nodes in a [IEEE802154e] TSCH network follow a communication schedule. The entity (centralized or decentralized) responsible for building and maintaining that schedule has very precise control over the trade-off between the network's latency, bandwidth, reliability and power consumption. During early interoperability testing and development, however, simplicity is often more important than efficiency. The goal of this document is to define the simplest set of rules for building a [IEEE802154e] TSCH-compliant network, at the necessary price of lesser efficiency.

2. Basic Schedule

In order to form a network, a minimum schedule configuration is required so nodes can advertise the presence of the network, and allow other nodes to join.

2.1. Slotframe

The Slotframe, as defined in [I-D.palattella-6tsch-terminology], is an abstraction of the MAC layer that defines a collection of time slots of equal length and priority, and which repeats over time. In order to set up a basic TSCH network, nodes need to be synchronized with the same slotframe configuration so they can exchange Enhanced Beacons (EBs) and data packets. This document recommends the following slotframe configuration.

Basic configuration

Property	Value
Number of time slots per Slotframe	101
Number of available channels	16
Number of EBs cells	1 (slotOffset 0)
Number of scheduled cells	5 (slotOffsets 1,2,3,4,5)
Number of unscheduled cells	95 (from slotOffset 6 to 100)
Number of MAC retransmissions (max)	3
Time Slot duration	15ms

The suggested basic schedule is hard-coded in each node. The slotframe is composed of 101 time slots. The first slot in the slotframe is used to send Enhanced Beacons announcing the presence of the network. These EBs are not acknowledged. Five cells are scheduled for exchanging data packets, as described in Section 2.2. These cells are scheduled at slotOffset 1 to 5, and channeOffset 0. Per the IEEE802.15.4e TSCH standard, data packets sent on these cells to a unicast MAC address are acknowledged by the receiver. The 95 remaining cells are unscheduled, i.e., the radio of the nodes remains off.

Basic schedule overview

```
             +-----+-----+-----+-----+-----+-----+-----+     +-----+
chan.Off. 0  | EB  |TxRxS|TxRxS|TxRxS|TxRxS|TxRxS| OFF | ... | OFF |
             +-----+-----+-----+-----+-----+-----+-----+     +-----+
chan.Off. 1  |     |     |     |     |     |     |     | ... |     |
             +-----+-----+-----+-----+-----+-----+-----+     +-----+
               ...
             +-----+-----+-----+-----+-----+-----+-----+     +-----+
chan.Off. 15 |     |     |     |     |     |     |     | ... |     |
             +-----+-----+-----+-----+-----+-----+-----+     +-----+
                0     1     2     3     4     5     6          100
```

2.2. Cell Options

Per the [IEEE802154e] TSCH standard, each scheduled cell has a bitmap of cell options assigned. All scheduled cells in the basic schedule are configured as Hard cells [I-D.watteyne-6tsch-tsch-lln-context][I-D.draft-wang-6tsch-6top] since reallocation is not considered in that simple approach.

The EB cell is assigned the following bitmap of cell options:

b0 = Transmit = 1 (set)

b1 = Receive = 0 (clear)

b2 = Shared = 0 (clear)

b3 = Timekeeping = 0 (clear)

b4 = Hard = 1 (set)

b5-b7 = Reserved (clear)

The data cells are assigned the bitmap of cell options below that results in "Slotted Aloha" behavior. Because both the "Transmit" and "Receive" bits are set, a node either transmits, if there is a packet in its queue, or listens if it has nothing to transmit. Because the "shared" bit is set,in presence of collisions it uses the backoff mechanism defined in [IEEE802154e].

b0 = Transmit = 1 (set)

b1 = Receive = 1 (set)

b2 = Shared = 1 (set)

b3 = Timekeeping = 0 (clear)

b4 = Hard = 1 (set)

b5-b7 = Reserved (clear)

All remaining cells are unscheduled. Thus the nodes can keep their radio off. In a memory efficient implementation, scheduled cells could be represented by a circular linked list. Unscheduled cells should not occupy any memory.

2.3. Retransmissions

The maximum number of MAC-layer retransmissions is set to 3. For packets which require an acknowledgement, if none is received after a total of 4 attempts, the transmissions is considered failed at the MAC layer, and the upper layer needs to be notified. Packets sent to the broadcast MAC address (including EBs) are not acknowledged and therefore not retransmitted.

2.4. Time Slot timming

The figure below shows an active timeslot in which a packet is sent from the transmitter node (TX) to the receiver node (RX), and a MAC acknowledgement is sent back from the RX to the TX node, indicating successful reception. The TsTxOffset duration defines the instant in the timeslot when the first byte of the transmitted packet leaves the radio of the TX node. The radio of the RX node is turned on TsLongGT /2 before that instant, and listen for at least TsLongGT. This allows for a de-synchronization between the two node of at most TsLongGT. The RX node needs to send the first byte of the MAC acknowledgement exactly TsTxAckDelay after the end of the last byte of the received packet. TX's radio has to be turned on TsShortGT/2 before that time, and keep listening for at least TsShortGT.

Time slot internal timing diagram

```
      /------------------- Time Slot duration --------------------/
      |                                       /tsShortGT/         |
      |            |                             | | |            |
      |------------+-----------------+--------------+------+------|
   TX |            |    TX-Packet    |              |RX Ack|      |
      |------------+-----------------+--------------+------+------|
      |/tsTxOffset/|                 |              |      |      |
      |            |                 |              |      |      |
      |------------+-----------------+--------------+------+------|
   RX |         |  |  | RX-Packet    |              |TX Ack|      |
      |---------+--+--+--------------+--------------+------+------|
      |         |  |  |              |              |      |      |
      |        /tsLongGT/            |/TsTxAckDelay/|      |      |
     Start                                                      End
      of                                                         of
     Slot                                                       Slot
```

[IEEE802154e] does not define the different durations of a time slot. It does allow those durations to be sent in the EBs (through a TimeSlot IE), but for simplicity, this document recommends to hard-code the different durations to the values listed below.

Timeslot durations

IEEE802.15.4e TSCH parmeter	Value
TsTxOffset	4000us
TsLongGT	2600us
TsTxAckDelay	4606us
TsShortGT	1000us
Time Slot duration	15000us

3. Enhanced Beacons Configuration and Content

[IEEE802154e] does not define how often or which EBs are sent. The choice of the duration between two EBs needs to take into account whether EBs are used as the only mechanism to synchronize devices, or whether a Keep-Alive (KA) mechanism is used in parallel. For a simplest TSCH configuration, it is recommended to sent EBs at least once every 10s. For additional reference see

[I-D.watteyne-6tsch-tsch-lln-context] where different synchronization approaches are summarized.

EBs must be sent with the Beacon IEEE802.15.4 frame type and this document recommends that they carry the following Information Elements (IEs):

3.1. Sync IE

Contains synchronization information such as ASN and join priority.

3.1.1. IE Header

Length (b0-b7) = 0x06

Sub-ID (b8-b14) = 0x1a

Type (b15) = 0x00 (short)

3.1.2. IE Content

ASN Byte 1 (b16-b23)

ASN Byte 2 (b24-b31)

ASN Byte 3 (b32-b39)

ASN Byte 4 (b40-b47)

ASN Byte 5 (b48-b55)

Join Priority (b56-b63)

3.2. Frame and Link IE

Although the schedule is hard-coded in each node, this document recommends to indicate the schedule in each EB through a Frame and Link IE. This enables nodes which implement [IEEE802154e] fully to be able to configure their schedule as they join the network, and interact with nodes using a hard-coded schedule.

3.2.1. IE Header

Length (b0-b7) = variable

Sub-ID (b8-b14) = 0x1b

Type (b15) = 0x00 (short)

3.2.2. IE Content

Slotframes (b16-b23) = 0x01

Slotframe ID (b24-b31) = 0x01

Size Slotframe (b32-b47) = 0x65

Links (b48-b55) = 0x06

For each link in the basic schedule:

Channel Offset (2B) = 0x00

Slot Number (2B) = from (0x00 to 0x05)

LinkOption (1B) = as described in Section 2.2

4. Acknowledgement

MAC-layer acknowledgement frames are built according to [IEEE802154e]. Data frames and command frames sent to a unicast MAC destination address request an acknowledgement. The acknowledgement frame is of type ACK (0x10). Each acknowledgement contains the following IE:

4.1. ACK/NACK Time Correction IE

The ACK/NACK time correction IE is used to carry the measured desynchronization between the sender and the receiver.

4.1.1. IE Header

Length (b0-b7) = 0x02

Sub-ID (b8-b14) = 0x1e

Type (b15) = 0x00 (short)

4.1.2. IE Content

Time Synch Info and ACK status (b16-b31)

The possible values for the Time Synch Info and ACK status are described in the following table:

ACK status and Time Synch information.

ACK Status	Value
ACK with positive time correction	0x0000 - 0x07ff
ACK with negative time correction	0x0800 - 0x0fff
NACK with positive time correction	0x8000 - 0x87ff
NACK with negative time correction	0x8800 - 0x8fff

5. Neighbor information

[IEEE802154e] does not define how and when each node in the network keeps information about its neighbors. This document recommends to keep the following information in the neighbor table:

5.1. Neighbor Table

The exact format of the neighbor table is implementation-specific, but it should at least contain the following information, for each neighbor:

Neighbor statistics:

number of transmitted packets to that neighbor

number of transmitted packets that have been acknowledged by that neighbor

number of received packets from that neighbor

number of received packets that have been acknowledged for that neighbor

Neighbor address.

ASN when that neighbor was heard for the last time. This can be used to trigger a keep-alive message.

RPL rank of that neighbor.

A flag which indicates whether this neighbor is a time source neighbor.

Connectivity statistics (RSSI, LQI, etc), which can be used to determine the quality of the link.

In addition of that information, each node has to be able to compute some RPL objective function (OF) taking into account the neighbor and connectivity statistics. An example RPL objective function is the ETX.

5.2. Time Parent Selection

Each node selects a time parent amongst its known neighbors. When a node joins a network, it has no routing information yet. Its (possibly temporary) time parent is the node it can hear "best", for example based on RSSI measurements of the EBs it received. After having acquired a RPL rank, the RPL routing parents should also be IEEE802.15.4e time source neighbors.

Optionally, a node can choose to use an counter to avoid frequent changes in time source neighbor selection. Based on some thresholds (on RSSI for example), if the quality of the link with time parent changes over or below the thresholds for a certain number of times (e.g., 3), the instability counter is incremented and another time parent is selected.

6. Queues and Priorities

[IEEE802154e] does not define the use of queues to handle upper layer data (either application or control data from upper layers). This document recommends to use a single queue with the following rules:

When the node is not synchronized to the network, higher layers are not able to insert packets into the queue.

Lower-layer packets have a higher priority that packets received from a higher layer.

IEEE802.15.4 frames of types Beacon and Command have a higher priority than IEEE802.15.4 frames of types Data and ACK.

One entry in the queue is reserved at all times for a IEEE802.15.4 frames of types Beacon or Command frames.

7. References

7.1. Normative References

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7.3. External Informative References

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