

6TiSCH  
Internet-Draft  
Intended status: Informational  
Expires: January 5, 2015

X. Vilajosana, Ed.  
Universitat Oberta de Catalunya  
K. Pister  
University of California Berkeley  
July 4, 2014

Minimal 6TiSCH Configuration  
draft-ietf-6tisch-minimal-02

## Abstract

This document describes the minimal set of rules to operate a [[IEEE802154e](#)] Timeslotted Channel Hopping (TSCH) network. This minimal mode of operation can be used during network bootstrap, as a fallback mode of operation when no dynamic scheduling solution is available or functioning, or during early interoperability testing and development.

## 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

This Internet-Draft is submitted in full conformance with the provisions of [BCP 78](#) and [BCP 79](#).

Internet-Drafts are working documents of the Internet Engineering Task Force (IETF). Note that other groups may also distribute working documents as Internet-Drafts. The list of current Internet-Drafts is at <http://datatracker.ietf.org/drafts/current/>.

Internet-Drafts are draft documents valid for a maximum of six months and may be updated, replaced, or obsoleted by other documents at any time. It is inappropriate to use Internet-Drafts as reference material or to cite them other than as "work in progress."

This Internet-Draft will expire on January 5, 2015.

## Copyright Notice

Copyright (c) 2014 IETF Trust and the persons identified as the document authors. All rights reserved.

Internet-Draft

6tisch-minimal

July 2014

This document is subject to [BCP 78](http://trustee.ietf.org/license-info) and the IETF Trust's Legal Provisions Relating to IETF Documents (<http://trustee.ietf.org/license-info>) in effect on the date of publication of this document. Please review these documents carefully, as they describe your rights and restrictions with respect to this document. Code Components extracted from this document must include Simplified BSD License text as described in Section 4.e of the Trust Legal Provisions and are provided without warranty as described in the Simplified BSD License.

## Table of Contents

<a href="#">1.</a>	<a href="#">Introduction</a>	<a href="#">3</a>
<a href="#">2.</a>	<a href="#">Minimal Schedule Configuration</a>	<a href="#">3</a>
<a href="#">2.1.</a>	<a href="#">Slotframe</a>	<a href="#">3</a>
<a href="#">2.2.</a>	<a href="#">Cell Options</a>	<a href="#">5</a>
<a href="#">2.3.</a>	<a href="#">Retransmissions</a>	<a href="#">6</a>
<a href="#">2.4.</a>	<a href="#">Time Slot timing</a>	<a href="#">6</a>
<a href="#">3.</a>	<a href="#">Enhanced Beacons Configuration and Content</a>	<a href="#">8</a>
<a href="#">3.1.</a>	<a href="#">Sync IE</a>	<a href="#">8</a>
<a href="#">3.1.1.</a>	<a href="#">IE Header</a>	<a href="#">8</a>
<a href="#">3.1.2.</a>	<a href="#">IE Content</a>	<a href="#">8</a>
<a href="#">3.2.</a>	<a href="#">TSCH Timeslot IE</a>	<a href="#">9</a>
<a href="#">3.2.1.</a>	<a href="#">IE Header</a>	<a href="#">9</a>
<a href="#">3.2.2.</a>	<a href="#">IE Content</a>	<a href="#">9</a>
<a href="#">3.3.</a>	<a href="#">Channel Hopping IE</a>	<a href="#">9</a>
<a href="#">3.3.1.</a>	<a href="#">IE Header</a>	<a href="#">9</a>
<a href="#">3.3.2.</a>	<a href="#">IE Content</a>	<a href="#">9</a>
<a href="#">3.4.</a>	<a href="#">Frame and Link IE</a>	<a href="#">9</a>
<a href="#">3.4.1.</a>	<a href="#">IE Header</a>	<a href="#">9</a>
<a href="#">3.4.2.</a>	<a href="#">IE Content</a>	<a href="#">10</a>
<a href="#">4.</a>	<a href="#">Acknowledgment</a>	<a href="#">10</a>
<a href="#">4.1.</a>	<a href="#">ACK/NACK Time Correction IE</a>	<a href="#">10</a>
<a href="#">4.1.1.</a>	<a href="#">IE Header</a>	<a href="#">10</a>
<a href="#">4.1.2.</a>	<a href="#">IE Content</a>	<a href="#">10</a>
<a href="#">5.</a>	<a href="#">Neighbor information</a>	<a href="#">11</a>
<a href="#">5.1.</a>	<a href="#">Neighbor Table</a>	<a href="#">11</a>
<a href="#">5.2.</a>	<a href="#">Time Source Neighbor Selection</a>	<a href="#">12</a>
<a href="#">6.</a>	<a href="#">Queues and Priorities</a>	<a href="#">12</a>
<a href="#">7.</a>	<a href="#">RPL on TSCH</a>	<a href="#">13</a>
<a href="#">7.1.</a>	<a href="#">RPL Objective Function Zero</a>	<a href="#">13</a>
<a href="#">7.1.1.</a>	<a href="#">Rank computation</a>	<a href="#">13</a>
<a href="#">7.1.2.</a>	<a href="#">Rank computation Example</a>	<a href="#">14</a>

<a href="#">7.2.</a>	RPL Configuration . . . . .	<a href="#">16</a>
<a href="#">7.2.1.</a>	Mode of Operation . . . . .	<a href="#">17</a>
<a href="#">7.2.2.</a>	Trickle Timer . . . . .	<a href="#">17</a>
<a href="#">7.2.3.</a>	Hysteresis . . . . .	<a href="#">17</a>
<a href="#">7.2.4.</a>	Variable Values . . . . .	<a href="#">17</a>

<a href="#">8.</a>	Acknowledgements . . . . .	<a href="#">18</a>
<a href="#">9.</a>	References . . . . .	<a href="#">18</a>
<a href="#">9.1.</a>	Normative References . . . . .	<a href="#">18</a>
<a href="#">9.2.</a>	Informative References . . . . .	<a href="#">19</a>
<a href="#">9.3.</a>	External Informative References . . . . .	<a href="#">20</a>
	Authors' Addresses . . . . .	<a href="#">20</a>

## [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. One 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. Yet, this minimal mode of operation can also be used during network bootstrap before any schedule is installed into the network so nodes can self-organize and the management and configuration information be distributed. In addition, as outlined in [[I-D.phinney-roll-rpl-industrial-applicability](#)], the minimal configuration can be used as a fallback mode of operation, ensuring connectivity of nodes in case that dynamic scheduling mechanisms fail or are not available. [[IEEE802154e](#)] provides a mechanism whereby the details of slotframe length, timeslot timing, and channel hopping pattern are communicated at synchronization to a node, also Enhanced Beacons can be used to periodically update nodes information. This document describes specific settings for these parameters. Nodes MUST broadcast properly formed Enhanced Beacons to announce these values, but during initial implementation and debugging it may be convenient to preconfigure these values.

## [2.](#) Minimal Schedule Configuration

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.ietf-6tisch-terminology](#)], is an abstraction of the link layer that defines a collection of time slots of equal length, and which repeats over time. In order to set up a minimal 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.

### Minimal configuration

Property	Value
Number of time slots per Slotframe	Variable
Number of available frequencies	16
Number of scheduled cells	1 (slotOffset 0) (macLinkType NORMAL)
Number of unscheduled cells	The remainder of the slotframe
Number of MAC retransmissions (max)	3 (4 attempts to tx)

The slotframe is composed of a configurable number of time slots. Choosing the number of time slots per slotframe needs to take into account network requirements such as density, bandwidth per node, etc. In the minimal configuration, there is only a single active slot in slotframe, used to transmit data and EBs, and receive information. The trade-off between bandwidth, latency and energy consumption can be controlled by choosing a different slotframe

length. The active slot MAY be scheduled at the slotoffset 0x00 and channeloffset 0x00 and MUST be announced in the EBs. EBs are sent using this active slot and are not acknowledged. Data packets, as described in [Section 2.2](#) use the same active slot. Per [\[IEEE802154e\]](#), data packets sent unicast on this cell are acknowledged by the receiver. The remaining cells are unscheduled, and MAY be used by dynamic scheduling solutions. Details about such dynamic scheduling solution are out of scope.

The slotframe length (expressed in number of time slots) is configurable. The length used determines the duty cycle of the network. For example, a network with a 0.99% duty cycle is composed of a slotframe of 101 slots, which includes 1 active slot. The present document RECOMMENDS the use of a default slot duration set to 10ms and its corresponding default timeslot timings defined by the [\[IEEE802154e\]](#) macTimeslotTemplate. The use of the default macTimeslotTemplate MUST be announced in the EB by using the Timeslot IE containing only the default macTimeslotTemplateId. Other time slot durations MAY be supported and MUST be announced clearly. If

one uses a timeslot duration different than 10ms, it is RECOMMENDED to use a power-of-two of 10ms (i.e. 20ms, 40ms, 80ms, etc.). In this case, EBs MUST contain the complete TimeSlot IE as described in [Section 2.4](#). This document also recommends to manufacturers to clearly indicate nodes not supporting the default timeslot value.

Example schedule with 0.99% duty cycle

```

Chan.  +-----+-----+
Off.0  | TxRxS/EB |   OFF   |
Chan.  +-----+-----+
Off.1  |           |           |
      +-----+-----+
      ...
Chan.  +-----+-----+
Off.15 |           |           |
      +-----+-----+
           0           1-100

```

EB: Enhanced Beacon  
Tx: Transmit  
Rx: Receive

S: Shared  
OFF: Unscheduled (can be used by a dynamic scheduling mechanism)

## [2.2.](#) Cell Options

Per the [[IEEE802154e](#)] TSCH, each scheduled cell has an associated bitmap of cell options, called LinkOption. The scheduled cell in the minimal schedule is configured as Hard cell [[I-D.ietf-6tisch-tsch](#)] [I-D.ietf-6tisch-6top-interface]. Additional available cells can be scheduled by a dynamic scheduling solution. The dynamic scheduling solution is out of scope, and this specification does not make any restriction on the LinkOption associated with those dynamically scheduled cells (i.e. they can be hard cells or soft cells).

The active cell is assigned the bitmap of cell options below. Because both the "Transmit" and "Receive" bits are set, a node transmits if there is a packet in its queue, and listens otherwise. Because the "shared" bit is set, the back-off mechanism defined in [[IEEE802154e](#)] is used to resolve contention. This results in "Slotted Aloha" behavior. The "Timekeeping" flag is never set, since the time source neighbor is selected using the DODAG structure of the network (detailed below).

b0 = Transmit = 1 (set)

b1 = Receive = 1 (set)

b2 = Shared = 1 (set)

b3 = Timekeeping = 0 (clear)

b4-b7 = Reserved (clear)

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

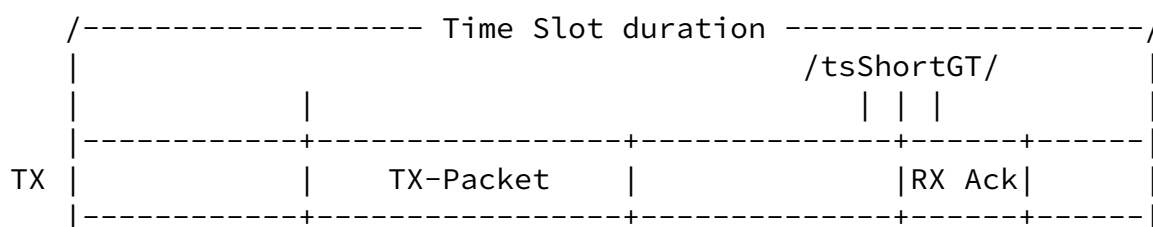
## [2.3.](#) Retransmissions

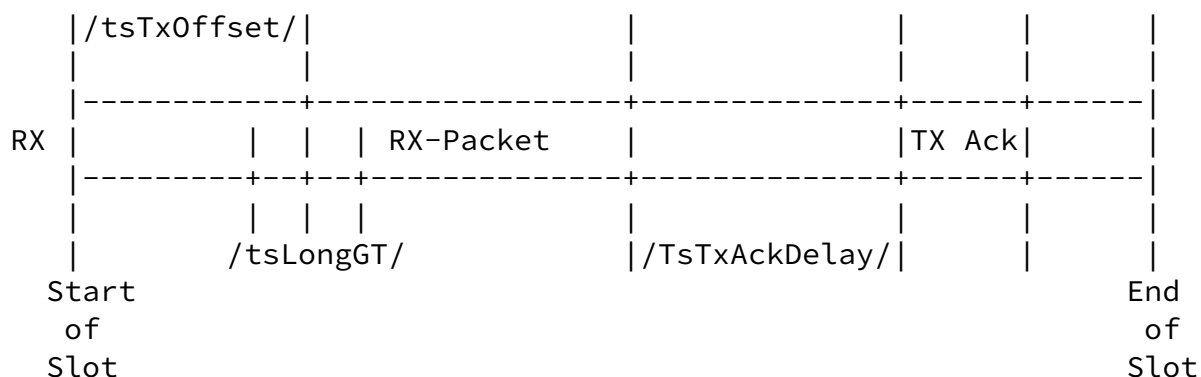
The maximum number of link layer retransmissions is set to 3. For packets which require an acknowledgement, if none is received after a total of 4 attempts, the transmissions is considered failed and the link layer MUST notify the upper layer. Packets sent to the broadcast MAC address (including EBs)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

#### [2.4.](#) Time Slot timing

The figure below shows an active timeslot in which a packet is sent from the transmitter node (TX) to the receiver node (RX). A link-layer acknowledgement is sent by the RX node to the TX node when the packet is to be acknowledged. 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 listens 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





A 10ms time slot length is the default value defined by [\[IEEE802154e\]](#). [Section 6.4.3.3.3](#) of the [\[IEEE802154e\]](#) defines a default macTimeslotTemplate, i.e. the different duration within the slot. These values are summarized in the following table and MUST be used when utilizing the default time slot duration. In this case, the Timeslot IE only transports the macTimeslotTemplateId (0x00) as the timing values are well-known. If a timeslot template other than the default is used, the EB MUST contain a complete TimeSlot IE indicating the timeslot duration and the corresponding timeslot timings, requiring 25 bytes.

Default timeslot durations (per [\[IEEE802154e\]](#), Section 6.4.3.3.3)

IEEE802.15.4e TSCH parameter	Value
TsTxOffset	2120us
TsLongGT	2000us
TsTxAckDelay	1000us
TsShortGT	400us
Time Slot duration	10000us



[IEEE802154e] does not define how often EBs are sent, not their contents. 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 also used. For a minimal TSCH configuration, a mote SHOULD send an EB every EB\_PERIOD. For additional reference see [[I-D.ietf-6tisch-tsch](#)] where different synchronization approaches are summarized.

EBs MUST be sent with the Beacon IEEE802.15.4 frame type and this EBs MUST carry the Information Elements (IEs) listed below.

The content of the IEs is presented here for completeness, however this information is redundant with [[I-D.ietf-6tisch-tsch](#)] and [[IEEE802154e](#)].

### [3.1.](#) Sync IE

Contains synchronization information such as ASN and Join Priority. The value of Join Priority is discussed in [Section 5.2](#).

#### [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.](#) TSCH Timeslot IE

Contains the timeslot template identifier. This specification uses the default timeslot template as defined in [[IEEE802154e](#)], Section 5.2.4.15.

#### [3.2.1.](#) IE Header

Length (b0-b7) = 0x01

Sub-ID (b8-b14) = 0x1c

Type (b15) = 0x00 (short)

#### [3.2.2.](#) IE Content

Timeslot Template ID (b0-b7) = 0x00

### [3.3.](#) Channel Hopping IE

Contains the channel hopping template identifier. This specification uses the default channel hopping template, as defined in [[IEEE802154e](#)], Section 5.2.4.16.

#### [3.3.1.](#) IE Header

Length (b0-b7) = 0x01

Sub-ID (b8-b14) = 0x1d

Type (b15) = 0x00 (short)

#### [3.3.2.](#) IE Content

Channel Hopping Template ID (b0-b7) = 0x00

### [3.4.](#) Frame and Link IE

Each node MUST indicate the schedule in each EB through a Frame and Link IE. This enables nodes which implement [[IEEE802154e](#)] to configure their schedule as they join the network.

#### [3.4.1.](#) IE Header

Length (b0-b7) = variable

Sub-ID (b8-b14) = 0x1b

Internet-Draft

6tisch-minimal

July 2014

Type (b15) = 0x00 (short)

#### [3.4.2.](#) IE Content

# Slotframes (b16-b23) = 0x01

Slotframe ID (b24-b31) = 0x01

Size Slotframe (b32-b47) = variable

# Links (b48-b55) = 0x01

For the active cell in the minimal schedule:

Channel Offset (2B) = 0x00

Slot Number (2B) = 0x00

LinkOption (1B) = as described in [Section 2.2](#)

### [4.](#) Acknowledgment

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

#### [4.1.](#) ACK/NACK Time Correction IE

The ACK/NACK time correction IE carries the measured de-synchronization 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 Synchronization Information and ACK status (b16-b31)

The possible values for the Time Synchronization Information and ACK status are described in [[IEEE802154e](#)] and reproduced in the following table:

ACK status and Time Synchronization 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 contain the following information for each neighbor:

Neighbor statistics:

numTx: number of transmitted packets to that neighbor

numTxAck: number of transmitted packets that have been acknowledged by that neighbor

numRx: number of received packets from that neighbor

The EUI64 of the neighbor.

Timestamp when that neighbor was heard for the last time. This can be based on the ASN counter or any other time base. Can be used to trigger a keep-alive message.

RPL rank of that neighbor.

A flag indicating whether this neighbor is a time source neighbor.

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

In addition to 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 OF Zero as described in [[RFC6552](#)] and [Section 7.1.1](#).

## [5.2](#). Time Source Neighbor Selection

Each node MUST select at least one time source neighbor among the nodes in its RPL routing parent set. When a node joins a network, it has no routing information. To select its time source neighbor, it uses the Join Priority field in the EB, as described in [Section 5.2.4.13](#) and Table 52b of [[IEEE802154e](#)]. The Sync IE contains the ASN and 1 Byte field named Join Priority. The Join Priority of any node is equivalent to the result of the function DAGRank(rank) as defined by [[RFC6550](#)] and [Section 7.1.1](#). The Join Priority of the DAG root is zero, i.e., EBs sent from the DAG root are sent with Join Priority equal to 0. A lower value of the Join Priority indicates that the device is the preferred one to connect to. When a node joins the network, it MUST NOT send EBs before having acquired a RPL rank. This avoids routing loops and matches RPL topology with underlying mesh topology. As soon as a node acquires a RPL rank (see [[RFC6550](#)] and [Section 7.1.1](#)), it SHOULD send Enhanced Beacons including a Sync IE with Join Priority field set to DAGRank(rank), where rank is the node's rank. If a node receives EBs from different nodes with equal Join Priority, the time source

neighbor selection should be assessed by other metrics that can help determine the better connectivity link. Time source neighbor hysteresis SHOULD be used, according to the rules defined in [Section 7.2.3](#). If connectivity to the time source neighbor is lost, a new time source neighbor MUST be chosen among the neighbors in the RPL routing parent set.

The decision for a node to select one Time Source Neighbor when multiple EBs are received is open to implementers. For example a node MAY wait until one EB from NUM\_NEIGHBOURS\_TO\_WAIT neighbors have been received to select the best Time Source Neighbor. This condition MAY apply unless a second EB is not received after MAX\_EB\_DELAY seconds. This avoids initial hysteresis when selecting a first Time Source Neighbor.

Optionally, some form of hysteresis SHOULD be implemented to avoid frequent changes in time source neighbors.

## [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 the use of 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.

Frames generated by the MAC layer (e.g., EBs and ACK) have a higher priority than 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 an IEEE802.15.4 frames of types Beacon or Command frames.

## [7.](#) RPL on TSCH

Nodes in the network MUST use the RPL routing protocol [[RFC6550](#)].

## [7.1.](#) RPL Objective Function Zero

Nodes in the network MUST use the RPL routing protocol [[RFC6550](#)] and implement the RPL Objective Function Zero [[RFC6552](#)].

### [7.1.1.](#) Rank computation

The rank computation is described at [[RFC6552](#)], [Section 4.1](#). Briefly, a node rank is computed by the following equation:

$$R(N) = R(P) + \text{rank\_increase}$$

$$\text{rank\_increase} = (R_f * S_p + S_r) * \text{MinHopRankIncrease}$$

Where:

$R(N)$ : Rank of the node.

$R(P)$ : Rank of the parent obtained as part of the DIO information.

$\text{rank\_increase}$ : The result of a function that determines the rank increment.

$R_f$  ( $\text{rank\_factor}$ ): A configurable factor that is used to multiply the effect of the link properties in the  $\text{rank\_increase}$  computation. If none is configured,  $\text{rank\_factor}$  of 1 is used. In this specification, a  $\text{rank\_factor}$  of 1 MUST be used.

$S_p$  ( $\text{step\_of\_rank}$ ): (strictly positive integer) - an intermediate computation based on the link properties with a certain neighbor. In this specification,  $2 * \text{ETX}$  (Expected Transmissions) as defined by [[decouti03high](#)] and [[RFC6551](#)] MUST be used. The ETX is computed as the inverse of the Packet Delivery Ratio (PDR), and MAY be computed as the number of acknowledged packets, divided by the number of transmitted packets to a certain node. E.g:  
 $S_p = 2 * \text{numTX} / \text{numTXAck}$

$S_r$  ( $\text{stretch\_of\_rank}$ ): (unsigned integer) - the maximum increment to the  $\text{step\_of\_rank}$  of a preferred parent, to allow the selection

of an additional feasible successor. If none is configured to the device, then the `step_of_rank` is not stretched. In this specification, `stretch_of_rank` MUST be set to 0.

**MinHopRankIncrease:** the `MinHopRankIncrease` is set to the fixed constant `DEFAULT_MIN_HOP_RANK_INCREASE` [[RFC6550](#)]. `DEFAULT_MIN_HOP_RANK_INCREASE` has a value of 256.

**DAGRank(rank):** Equivalent to the floor of  $(R_f * S_p + S_r)$  as defined by [[RFC6550](#)]. Specifically, when an Objective Function computes Rank, this is defined as an unsigned integer (i.e., a 16-bit value) Rank quantity. When the Rank is compared, e.g. to determine parent relationships or loop detection, the integer portion of the Rank is used. The integer portion of the Rank is computed by the `DAGRank()` macro as `floor(x)` where `floor(x)` is the function that evaluates to the greatest integer less than or equal to  $x$ .  $\text{DAGRank}(\text{rank}) = \text{floor}(\text{rank} / \text{MinHopRankIncrease})$

Rank computation scenario

```

+-----+
|   P   | R(P)
|       |
+-----+
      |
      |
      |
+-----+
|   N   | R(N)=R(P) + rank_increase
|       | rank_increase = (Rf*Sp + Sr) * MinHopRankIncrease
+-----+ Sp=2*ETX

```

### [7.1.2.](#) Rank computation Example

This section illustrates with an example the use of the Objective Function Zero. Assume the following parameters:

$$R_f = 1$$

$$S_p = 2 * ETX$$



$S_r = 0$

$\text{minHopRankIncrease} = 256$  (default in RPL)

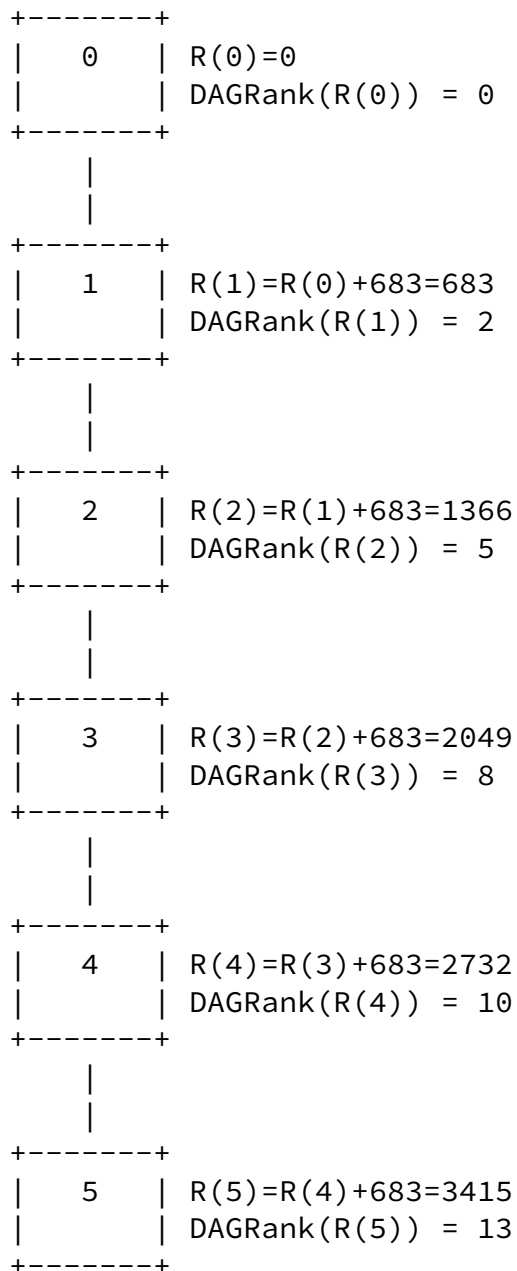
$\text{ETX} = (\text{numTX} / \text{numTXAck})$

$r(n) = r(p) + \text{rank\_increase}$

$\text{rank\_increase} = (R_f * S_p + S_r) * \text{minHopRankIncrease}$

$\text{rank\_increase} = 512 * \text{numTx} / \text{numTxACK}$

Rank computation example for 5 hop network where numTx=100 and numTxAck=75 for all nodes



## 7.2. RPL Configuration

In addition to the Objective Function (OF), a minimal configuration for RPL should indicate the preferred mode of operation and trickle timer operation so different RPL implementations can inter-operate. RPL information SHOULD be transported in the flow label in the LLN as defined in [[I-D.thubert-6man-flow-label-for-rpl](#)]

Internet-Draft

6tisch-minimal

July 2014

### [7.2.1.](#) Mode of Operation

For downstream route maintenance, in a minimal configuration, RPL SHOULD be set to operate in the Non-Storing mode as described by [\[RFC6550\] Section 9.7](#). Storing mode ([\[RFC6550\] Section 9.8](#)) MAY be supported in less constrained devices.

### [7.2.2.](#) Trickle Timer

RPL signaling messages such as DIOs are sent using the Trickle Algorithm [\[RFC6550\]](#) ([Section 8.3.1](#)) and [\[RFC6206\]](#). For this specification, the Trickle Timer MUST be used with the RPL defined default values [\[RFC6550\]](#) ([Section 8.3.1](#)). For a description of the Trickle timer operation see [Section 4.2](#) on [\[RFC6206\]](#).

### [7.2.3.](#) Hysteresis

According to [\[RFC6552\]](#), [\[RFC6719\]](#) recommends the use of a boundary value (PARENT\_SWITCH\_THRESHOLD) to avoid constant changes of parent when ranks are compared. When evaluating a parent that belongs to a smaller path cost than current minimum path, the candidate node is selected as new parent only if the difference between the new path and the current path is greater than the defined PARENT\_SWITCH\_THRESHOLD. Otherwise the node MAY continue to use the current preferred parent. As for [\[RFC6719\]](#) the recommended value for PARENT\_SWITCH\_THRESHOLD is 192 when ETX metric is used, the recommendation for this document is to use PARENT\_SWITCH\_THRESHOLD equal to 394 as the metric being used is 2\*ETX. This mechanism is suited to deal with parent hysteresis in both cases routing parent and time source neighbor selection.

### [7.2.4.](#) Variable Values

The following table presents the RECOMMENDED values for the RPL-related variables defined in the previous section.

Internet-Draft

6tisch-minimal

July 2014

## Recommended variable values

Variable	Value
EB_PERIOD	10s
MAX_EB_DELAY	180
NUM_NEIGHBOURS_TO_WAIT	2
PARENT_SWITCH_THRESHOLD	394

## 8. Acknowledgements

The authors would like to acknowledge the guidance and input provided by the 6TiSCH Chairs Pascal Thubert and Thomas Watteyne.

## 9. References

### 9.1. Normative References

- [RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", [BCP 14](#), [RFC 2119](#), March 1997.
- [RFC6206] Levis, P., Clausen, T., Hui, J., Gnawali, O., and J. Ko, "The Trickle Algorithm", [RFC 6206](#), March 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.

- [RFC6551] Vasseur, JP., Kim, M., Pister, K., Dejean, N., and D. Barthel, "Routing Metrics Used for Path Calculation in Low-Power and Lossy Networks", [RFC 6551](#), March 2012.
- [RFC6552] Thubert, P., "Objective Function Zero for the Routing Protocol for Low-Power and Lossy Networks (RPL)", [RFC 6552](#), March 2012.
- [RFC6719] Gnawali, O. and P. Levis, "The Minimum Rank with Hysteresis Objective Function", [RFC 6719](#), September 2012.

## [9.2](#). Informative References

- [I-D.ietf-6tisch-tsch]  
Watteyne, T., Palattella, M., and L. Grieco, "Using IEEE802.15.4e TSCH in an LLN context: Overview, Problem Statement and Goals", [draft-ietf-6tisch-tsch-00](#) (work in progress), November 2013.
- [I-D.ietf-6tisch-architecture]  
Thubert, P., Watteyne, T., and R. Assimiti, "An Architecture for IPv6 over the TSCH mode of IEEE 802.15.4e", [draft-ietf-6tisch-architecture-02](#) (work in progress), June 2014.
- [I-D.ietf-6tisch-terminology]  
Palattella, M., Thubert, P., Watteyne, T., and Q. Wang, "Terminology in IPv6 over the TSCH mode of IEEE 802.15.4e", [draft-ietf-6tisch-terminology-01](#) (work in progress), February 2014.
- [I-D.ietf-6tisch-6top-interface]  
Wang, Q., Vilajosana, X., and T. Watteyne, "6TiSCH Operation Sublayer (6top) Interface", [draft-ietf-6tisch-6top-interface-00](#) (work in progress), March 2014.
- [I-D.richardson-6tisch-security-architecture]

Richardson, M., "security architecture for 6top: requirements and structure", [draft-richardson-6tisch-security-architecture-02](#) (work in progress), April 2014.

[I-D.ietf-roll-terminology]

Vasseur, J., "Terms used in Routing for Low power And Lossy Networks", [draft-ietf-roll-terminology-13](#) (work in progress), October 2013.

[I-D.phinney-roll-rpl-industrial-applicability]

Phinney, T., Thubert, P., and R. Assimiti, "RPL applicability in industrial networks", [draft-phinney-roll-rpl-industrial-applicability-02](#) (work in progress), February 2013.

[I-D.thubert-6man-flow-label-for-rpl]

Thubert, P., "The IPv6 Flow Label within a RPL domain", [draft-thubert-6man-flow-label-for-rpl-03](#) (work in progress), May 2014.

### [9.3.](#) External Informative References

[IEEE802154e]

IEEE standard for Information Technology, "IEEE std. 802.15.4e, Part. 15.4: Low-Rate Wireless Personal Area Networks (LR-WPANs) Amendment 1: MAC sublayer", April 2012.

[IEEE802154]

IEEE standard for Information Technology, "IEEE std. 802.15.4, Part. 15.4: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks", June 2011.

[decouti03high]

De Couto, D., Aguayo, D., Bicket, J., and R. Morris, "A High-Throughput Path Metric for Multi-Hop Wireless Routing", MobiCom '03, The 9th ACM International Conference on Mobile Computing and Networking, San Diego,

California", June 2003.

[OpenWSN] Watteyne, T., Vilajosana, X., Kerkez, B., Chraim, F., Weekly, K., Wang, Q., Glaser, S., and K. Pister, "OpenWSN: a Standards-Based Low-Power Wireless Development Environment", Transactions on Emerging Telecommunications Technologies , August 2012.

#### Authors' Addresses

Xavier Vilajosana (editor)  
Universitat Oberta de Catalunya  
156 Rambla Poblenou  
Barcelona, Catalonia 08018  
Spain

Phone: +34 (646) 633 681  
Email: xvilajosana@uoc.edu

Kris Pister  
University of California Berkeley  
490 Cory Hall  
Berkeley, California 94720  
USA

Email: pister@eecs.berkeley.edu