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**Packet Sequence Number based directional airtime metric for OLSRv2
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Abstract

This document specifies an directional airtime link metric for usage in OLSRV2.

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1. Introduction

One of the major shortcomings of OLSR [[RFC3626](#)] is the missing of alink cost metric between mesh nodes. Operational experience with mesh networks since the standardization of OLSR has revealed that wireless networks links can have highly variable and heterogeneous properties, which makes a hopcount metric insufficient for effective mesh routing.

Based on this experience, OLSRv2 [[OLSRV2](#)] integrates the concept of link metrics directly into the core specification of the routing protocol. The OLSRv2 routing metric is an external process, it can be any kind of dimensionless additive cost function which reports to the OLSRv2 protocol.

The OLSR.org [[OLSR.org](#)] implementation of OLSR included an Estimated Transmission Count (ETX) metric [[MOBICOM04](#)] since 2004 as a proprietary extension. While this metric is not perfect, it proved to be sufficient for a long time for Community Mesh Networks (Appendix A).

This document describes a Directional Airtime routing metric for OLSRv2, a successor of the OLSR.org routing metric for [[RFC3626](#)]. It takes both the loss rate and the link speed into account to provide a more accurate picture of the mesh network links.

2. Terminology

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 [[RFC2119](#)].

The terminology introduced in [[RFC5444](#)], [[OLSRV2](#)] and [[RFC6130](#)], including the terms "packet", "message" and "TLV" are to be interpreted as described therein.

Additionally, this document uses the following terminology and notational conventions:

QUEUE - a first in, first out queue of integers.

QUEUE[TAIL] - the most recent element in the queue.

add(Queue, value) - adds a new element to the TAIL of the queue.

remove(Queue) - removes the HEAD element of the queue

sum(Queue) - an operation which returns the sum of all elements in a Queue.

diff_seqno(new, old) - an operation which returns the positive distance between two elements of the circular sequence number space defined in [section 5.1 of \[RFC5444\]](#). Its value is either (new - old) if this result is positive, or else its value is (new - old + 65536).

MAX(a,b) - the maximum of a and b.

UNDEFINED - a value not in the normal value range of a variable.
Might be -1 for this protocol.

airtime - the time a transmitted packet blocks a shared medium, e.g., a wireless link.

ETX - Expected Transmission Count, a link metric proportional to the number of transmissions to successfully send an IP packet over a link.

ETT - Estimated Travel Time, a link metric proportional to the amount of airtime needed to transmit an IP packet over a link, not considering layer-2 overhead created by preamble, backoff time and queuing.

DAT - Directional Airtime Metric, the link metric described in this document, which is a directional variant of ETT.

3. Applicability Statement

The Directional Airtime Metric was designed and tested in wireless IEEE 802.11 mesh networks. These networks employ linklayer retransmission to increase the delivery probability and multiple unicast data rates.

The metric must learn about the unicast data rate towards each one-hop neighbor from an external process, either by configuration or by an external measurement process. This measurement could be done by indirect layer-3 measurements like packet-pair or by gathering cross-layer data from the operating system or an external daemon like DLEP [[DLEP](#)].

If [[RFC5444](#)] control traffic is used to determine the link packet loss, the link-layer multicast transmission should not have a higher reception probability than the slowest unicast transmission. It might be necessary to increase the data-rate of the multicast transmissions, e.g. set the multicast data-rate to 6 MBit/s if you use IEEE 802.11g only.

The metric can only handle a certain range of packet loss and unicast data-rate. Maximum packet loss is 15 of 16 packets (without link-layer retransmissions), the unicast data-rate can be between 16 bits/s and 4 GBit/s. The metric has been designed for data-rates of 1 MBit/s and hundreds of MBit/s.

4. Directional Airtime Metric Rational

The Directional Airtime Metric has been inspired by the publications on the ETX [[MOBICOM03](#)] and ETT [[MOBICOM04](#)] metric, but has several key differences.

Instead of measuring the symmetric probability of a bidirectional transmission of a packet over a link and back, the Directional Airtime Metric only measures the unidirectional loss and combines it with the outgoing link speed into the metric cost. There are multiple reasons for this decision:

- o OLSRv2 [[OLSRV2](#)] defines the link metric as directional costs between nodes.
- o Not all linklayer implementations use acknowledgement mechanisms. Most linklayer implementations who do use them use less airtime and a more robust modulation for the acknowledgement than the data transmission, which makes it more likely for the data transmission to be disrupted compared to the acknowledgement.
- o Symmetric link loss would need an additional signaling TLV in the [[RFC6130](#)] HELLO and would delay metric calculating by a HELLO interval.

The Directional Airtime Metric does not integrate the packet size into the link cost. Doing so is not feasible in most link-state routing protocol implementations, multiplying all link costs with the size of a packet would not change the dijkstra result anyways.

The queue based packet loss estimator has been tested for a long time in the OLSR.org ETX implementation, see [Appendix A](#). The output is a time-stable average of the packet loss.

5. Metric Functioning & Overview

The Directional Airtime Metric is calculated for each link set entry, as defined in [\[RFC6130\] section 7.1](#).

The metric processes two kinds of data into the metric value, packet loss rate and link-speed. While the link-speed is taken from an external process, the current packet loss rate is calculated by storing packet reception and packet loss events.

Multiple incoming packet loss/reception events must be averaged into a loss rate to get a smooth metric. Experiments with exponential weighted moving average (EWMA) lead to a highly fluctuating output or a too slow convergence (or both). To get a smoother and more controllable metric result, this metric uses a fixed length double queue to average the incoming events, one queue for received packets and one for the total number of packets sent by the other side of the link.

Because the rate of incoming packets is not uniform over time, the queue is made of a number of counters, each representing a fixed time interval. Incoming packet loss and packet reception event are accumulated in the current queue element until a timer adds a new empty counter to both queues and remove the oldest counter from both.

In addition to the queued packet loss, this metric uses a timer to detect a total link-loss. For every NHDP HELLO interval in which the metric received no packet from a neighbor, scales the number of received packets in the queue based on the total time interval the queue represents compared to the total time of the lost HELLO intervals.

The average packet loss ratio is calculated as the sum of the 'total package count' queue counters divided by the sum of the 'packets received count' queue counters. This value is then divided through the current link-speed and then scaled into the range of metrics allowed for OLSRv2.

The metric value is then used as `L_in_metric` of the Link Set (as defined in section 8.1. of [\[OLSRV2\]](#)).

6. Protocol Parameters

This specification defines the following parameters, which can be changed without making the metric outputs incomparable with each other:

DAT_MEMORY_LENGTH - Queue length for averaging packet loss. All received and lost packets within the queue are used to calculate the cost of the link.

DAT_REFRESH_INTERVAL - interval in seconds between two metric recalculations as described in [Section 11](#). This value SHOULD be smaller than a typical HELLO interval.

DAT_HELLO_TIMEOUT_FACTOR - timeout factor for HELLO interval at which point a HELLO is definitely considered lost. The value must be a floating point number between 1.0 and 2.0, large enough to take the delay for message aggregation into account.

DAT_SEQNO_RESTART_DETECTION - threshold in number of missing packets (based on received packet sequence numbers) at which point the router considers the neighbor has restarted. This parameter is only used for packet sequence number based loss estimation.

[6.1.](#) **Recommened Values**

The proposed values of the protocol parameters are for Community Mesh Networks, which mostly use immobile mesh nodes. Using this metric for mobile networks might require shorter DAT_REFRESH_INTERVAL and/or DAT_MEMORY_LENGTH.

DAT_MEMORY_LENGTH := 64

DAT_REFRESH_INTERVAL := 1

DAT_HELLO_TIMEOUT_FACTOR := 1.2

DAT_SEQNO_RESTART_DETECTION := 8

[7.](#) **Protocol Constants**

This specification defines the following constants, which cannot be changed without making the metric outputs incomparable:

DAT_MAXIMUM_LOSS - Fraction of the loss rate used in this routing metric. Loss rate will be between $0/\text{DAT_MAXIMUM_LOSS}$ and $(\text{DAT_MAXIMUM_LOSS}-1)/\text{DAT_MAXIMUM_LOSS}$: 16.

DAT_MINIMUM_BITRATE - Minimal bit-rate in Bit/s used by this routing metric: 16.

8. Data Structures

This specification extends the Link Set Tuples of the Interface Information Base, as defined in [\[RFC6130\] section 7.1](#), by the following additional elements for each link tuple when being used with this metric:

`L_DAT_received` is a QUEUE with `DAT_MEMORY_LENGTH` integer elements. Each entry contains the number of successfully received packets within an interval of `DAT_REFRESH_INTERVAL`.

`L_DAT_total` is a QUEUE with `DAT_MEMORY_LENGTH` integer elements. Each entry contains the estimated number of packets transmitted by the neighbor, based on the received packet sequence numbers within an interval of `DAT_REFRESH_INTERVAL`.

`L_DAT_hello_time` is the time when the next hello will be expected.

`L_DAT_hello_interval` is the interval between two hello messages of the links neighbor as signaled by the `INTERVAL_TIME` TLV [\[RFC5497\]](#) of NHDP messages [\[RFC6130\]](#).

`L_DAT_lost_hello_messages` is the estimated number of lost hello messages from this neighbor, based on the value of the hello interval.

`L_DAT_rx_bitrate` is the current bitrate of incoming unicast traffic for this neighbor.

Methods to obtain the value of `L_DAT_rx_bitrate` are out of scope for this specification. Such methods may be static configuration via a configuration file, or dynamic measurement through mechanisms described in a separate specification (e.g. [\[DLEP\]](#)). Any Link tuple with `L_status = HEARD` or `L_status = SYMMETRIC` MUST have a specified value of `L_DAT_rx_bitrate` if it is to be used by this routing metric.

When using packet sequence numbers to estimate the loss rate, the Link Set Tuples get another field:

`L_DAT_last_pkt_seqno` is the last received packet sequence number received from this link.

8.1. Initial Values

When generating a new tuple in the Link Set, as defined in [\[RFC6130\] section 12.5](#) bullet 3, the values of the elements specified in [Section 8](#) are set as follows:

- o `L_DAT_received := 0, ..., 0`. The queue always has `DAT_MEMORY_LENGTH` elements.
- o `L_DAT_total := 0, ..., 0`. The queue always has `DAT_MEMORY_LENGTH` elements.
- o `L_DAT_last_pkt_seqno := UNDEFINED` (no earlier packet received).
- o `L_DAT_hello_time := EXPIRED` (no earlier NHDP HELLO received).
- o `L_DAT_hello_interval := UNDEFINED` (no earlier NHDP HELLO received).
- o `L_DAT_lost_hello_messages := 0` (no HELLO interval without packets).

9. Packets and Messages

9.1. Definitions

For the purpose of this section, note the following definitions:

- o "pkt_seqno" is defined as the [[RFC5444](#)] packet sequence number of the received packet.
- o "interval_time" is the time encoded in the `INTERVAL_TIME` message TLV of a received [[RFC6130](#)] HELLO message.

9.2. Requirements

An implementation of OLSRv2, using the metric specified by this document, **MUST** include the following parts into its [[RFC5444](#)] output:

- o an `INTERVAL_TIME` message TLV in each HELLO message, as defined in [[RFC6130](#)] [section 4.3.2](#).

9.3. Link Loss Data Gathering

While this metric was designed for measuring the packet loss based on the [[RFC5444](#)] packet sequence number, some implementations might not be able to add the packet sequence number to their output.

9.3.1. Packet Sequence based link loss

An implementation of OLSRv2, using the metric specified by this document with packet sequence based link loss, **MUST** include the following element into its [[RFC5444](#)] output:

- o an interface specific packet sequence number as defined in [\[RFC5444\] section 5.1](#) which is incremented by 1 for each outgoing [\[RFC5444\]](#) packet on the interface.

For each incoming [\[RFC5444\]](#) packet, additional processing MUST be carried out after the packet messages have been processed as specified in [\[RFC6130\]](#) and [\[OLSRV2\]](#).

[\[RFC5444\]](#) packets without packet sequence number MUST NOT be processed in this way by this metric.

The router MUST update the Link Set Tuple corresponding to the originator of the packet:

1. If L_DAT_last_pkt_seqno = UNDEFINED, then:
 1. L_DAT_received[TAIL] := 1.
 2. L_DAT_total[TAIL] := 1.
2. Otherwise:
 1. L_DAT_received[TAIL] := L_DAT_received[TAIL] + 1.
 2. diff := seq_diff(pkt_seqno, L_DAT_last_pkt_seqno).
 3. If diff > DAT_SEQNO_RESTART_DETECTION, then:
 1. diff := 1.
 4. L_DAT_total[TAIL] := L_DAT_total[TAIL] + diff.
3. L_DAT_last_pkt_seqno := pkt_seqno.
4. If L_DAT_hello_interval != UNDEFINED, then:
 1. L_DAT_hello_time := current time + (L_DAT_hello_interval * DAT_HELLO_TIMEOUT_FACTOR).
5. L_DAT_lost_hello_messages := 0.

[9.3.2.](#) HELLO based link loss

A metric might just use the incoming NHDP HELLO messages of a neighbor to calculate the link loss. Because this method uses fewer events to calculate the metric, the variance of the output will increase. It might be necessary to increase the value of DAT_MEMORY_LENGTH to compensate this.

For each incoming HELLO Message, after it has been processed as defined in [\[RFC6130\] section 12](#), the Link Set Tuple (section XYZ) corresponding to the incoming HELLO message must be updated.

1. `L_DAT_received[TAIL] := L_DAT_received[TAIL] + 1.`
2. `L_DAT_total[TAIL] := L_DAT_total[TAIL] + 1.`
3. `L_DAT_lost_hello_messages := 0.`

9.3.3. Other measurement of link loss

Instead of using incoming [\[RFC5444\]](#) packets or [\[RFC6130\]](#) messages, the routing daemon can also use other sources to measure the linklayer lossrate (e.g. [\[DLEP\]](#)).

To use a source like this with this metric, the routing daemon has to add incoming total traffic (or the sum of received and lost traffic) and lost traffic to the corresponding queue elements in the Link Set Tuple (section XYZ) corresponding to originator of the traffic.

The routing daemon should also set `L_DAT_lost_hello_messages` to zero every times new packages arrive.

9.4. HELLO Message Processing

For each incoming HELLO Message, after it has been processed as defined in [\[RFC6130\] section 12](#), the Link Set Tuple corresponding to the incoming HELLO message must be updated.

Only HELLO Messages with an `INTERVAL_TIME` message TLVs must be processed.

1. `L_DAT_hello_interval := interval_time.`

10. HELLO Timeout Processing

When `L_DAT_hello_time` has timed out, the following step MUST be done:

1. `L_DAT_lost_hello_messages := L_DAT_lost_hello_messages + 1.`
2. `L_DAT_hello_time := L_DAT_hello_time + L_DAT_hello_interval.`

11. Metric Update

Once every DAT_REFRESH_INTERVAL, all L_in_metric values in all Link Set entries MUST be recalculated:

1. `sum_received := sum(L_DAT_total).`
2. `sum_total := sum(L_DAT_received).`
3. If `L_DAT_hello_interval != UNDEFINED` and `L_DAT_lost_hellos > 0`, then:
 1. `lost_time_proportion := L_DAT_hello_interval * L_DAT_lost_hellos / DAT_MEMORY_LENGTH.`
 2. `sum_received := sum_received * MAX (0, 1 - lost_time_proportion);`
4. If `sum_received < 1`, then:
 1. `L_in_metric := MAXIMUM_METRIC`, as defined in [\[OLSRV2\] section 5.6.1](#).
5. Otherwise:
 1. `loss := sum_total / sum_received.`
 2. If `loss > DAT_MAXIMUM_LOSS`, then:
 1. `loss := DAT_MAXIMUM_LOSS.`
 3. `bitrate := L_DAT_rx_bitrate.`
 4. If `bitrate < DAT_MINIMUM_BITRATE`, then:
 1. `bitrate := DAT_MINIMUM_BITRATE.`
 5. `L_in_metric := (2^24 / DAT_MAXIMUM_LOSS) * loss / (bitrate / DAT_MINIMUM_BITRATE).`
6. `remove(L_DAT_total)`
7. `add(L_DAT_total, 0)`
8. `remove(L_DAT_received)`
9. `add(L_DAT_received, 0)`

12. IANA Considerations

This document contains no actions for IANA.

13. Security Considerations

Artificial manipulation of metrics values can drastically alter network performance. In particular, advertising a higher `L_in_metric` value may decrease the amount of incoming traffic, while advertising lower `L_in_metric` may increase the amount of incoming traffic. By artificially increasing or decreasing the `L_in_metric` values it advertises, a rogue router may thus attract or repulse data traffic. A rogue router may then potentially degrade data throughput by not forwarding data as it should or redirecting traffic into routing loops or bad links.

An attacker might also inject packets with incorrect packet level sequence numbers, pretending to be somebody else. This attack could be prevented by the true originator of the [RFC5444](#) packets by adding a [\[RFC6622\]](#) ICV Packet TLV and [TIMESTAMP](#) Packet TLV to each packet. This allows the receiver to drop all incoming packets which have a forged packet source, both packets generated by the attacker or replayed packets.

14. Acknowledgements

The authors would like to acknowledge the network administrators from Freifunk Berlin [[FREIFUNK](#)] and Funkfeuer Vienna [[FUNKFEUER](#)] for endless hours of testing and suggestions to improve the quality of the original ETX metric for the `olsr.org` routing daemon.

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Appendix A. OLSR.org metric history

The Funkfeuer [[FUNKFEUER](#)] and Freifunk networks [[FREIFUNK](#)] are OLSR-based [[RFC3626](#)] or B.A.T.M.A.N. based wireless community networks with hundreds of routers in permanent operation. The Vienna Funkfeuer network in Austria, for instance, consists of 400 routers (around 600 routes) covering the whole city of Vienna and beyond, spanning roughly 40km in diameter. It has been in operation since 2003 and supplies its users with Internet access. A particularity of the Vienna Funkfeuer network is that it manages to provide Internet access through a city wide, large scale Wi-Fi mesh network, with just a single Internet uplink.

Operational experience of the OLSR project [[OLSR.org](#)] with these networks have revealed that the use of hop-count as routing metric leads to unsatisfactory network performance. Experiments with the ETX metric [[MOBICOM03](#)] were therefore undertaken in parallel in the Berlin Freifunk network as well as in the Vienna Funkfeuer network in 2004, and found satisfactory, i.e., sufficiently easy to implement and providing sufficiently good performance. This metric has now been in operational use in these networks for several years.

The ETX metric of a link is the estimated number of transmissions required to successfully send a packet (each packet equal to or smaller than MTU) over that link, until a link-layer acknowledgement is received. The ETX metric is additive, i.e., the ETX metric of a path is the sum of the ETX metrics for each link on this path.

While the ETX metric delivers a reasonable performance, it doesn't handle well networks with heterogeneous links that have different bitrates. Since every wireless link, when using ETX metric, is characterized only by its packet loss ratio, the ETX metric prefers long-ranged links with low bitrate (with low loss ratios) over short-ranged links with high bitrate (with higher but reasonable loss ratios). Such conditions, when they occur, can degrade the

performance of a network considerably by not taking advantage of higher capacity links.

Because of this the OLSR.org project has implemented the Directional Airtime Metric for OLSRv2, which has been inspired by the Estimated Travel Time (ETT) metric [[MOBICOM04](#)]. This metric uses an unidirectional packet loss, but also takes the bitrate into account to create a more accurate description of the relative costs or capabilities of mesh links.

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