                   Rationale for the Use of Link Metrics
          in the Optimized Link State Routing Protocol Version 2 (OLSRv2)

Abstract

   The Optimized Link State Routing Protocol version 2 (OLSRv2) includes
   the ability to assign metrics to links and to use those metrics to
   allow routing by other than minimum hop count routes. This document
   provides a historic record of the rationale for, and design
   considerations behind, how link metrics were included in OLSRv2.

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1. Introduction

The Optimized Link State Routing Protocol version 1 (OLSRv1)
[RFC3626] is a proactive routing protocol for mobile ad hoc networks
(MANETs) [RFC2501]. OLSRv1 finds the shortest, defined as minimum
number of hops, routes from a router to all possible destinations.

Using only minimum hop routes may result in what are, in practice,
inferior routes. Some examples are given in Section 4. Thus, one of
the distinguishing features of the Optimized Link State Routing
Protocol version 2 (OLSRv2) [RFC7181] is the introduction of the
ability to select routes using link metrics other than the number of
hops.

During the development of OLSRv2, the working group and authors
repeatedly discussed how and why some choices were made in the
protocol specification, particularly at the metric integration level.
Some of the issues may be non-intuitive, and this document is
presented as a record of the considerations and decisions to provide
informational discussion about motivation and historic design
choices. This document is intended to be useful as a reference if
those questions arise again.

Use of the extensible message format [RFC5444] by OLSRv2 has allowed
the addition, by OLSRv2, of link metric information to the HELLO
messages defined in the MANET Neighborhood Discovery Protocol (NHDP)
[RFC6130] as well as inclusion in the Topology Control (TC) messages
defined in [RFC7181].

OLSRv2 essentially first determines local link metrics from 1-hop
neighbors, these being defined by a process outside OLSRv2, then
distributes required link metric values in HELLO messages and TC
messages, and then finally forms routes with minimum total link
metric. Using a definition of route metric other than number of hops
is a natural extension that is commonly used in link state protocols.

A metric-based route selection process for OLSRv2 could have been
handled as an extension to OLSRv2. However, were this to have been
done, OLSRv2 routers that did not implement this extension would not
recognize any link metric information and would attempt to use
minimum hop-count routes. This would have meant that, in effect,
routers that did implement and routers that did not implement this
extension would differ over their valuation of links and routes.
This would have led to the fundamental routing problem of "looping".
Thus, if metric-based route selection were to have been considered
only as an extension to OLSRv2, then routers that did implement and
routers that did not implement this extension would not have been

able to interoperate. This would have been a significant limitation
of such an extension. Link metrics were therefore included as
standard in OLSRv2.

This document discusses the motivation and design rationale behind
how link metrics were included in OLSRv2. The principal issues
involved when including link metrics in OLSRv2 were:

o Assigning metrics to links involved considering separate metrics
   for the two directions of a link, with the receiving router
   determining the metric from transmitter to receiver. A metric
   used by OLSRv2 may be either of:

   * A link metric, the metric of a specific link from an OLSRv2
      interface of the transmitting router to an OLSRv2 interface of
      the receiving router.

   * A neighbor metric, the minimum of the link metrics between two
      OLSRv2 routers, in the indicated direction.

   These metrics are necessarily the same when these routers each
   have a single OLSRv2 interface but may differ when either has
   more. HELLO messages may include both link metrics and neighbor
   metrics. TC messages include only neighbor metrics.

o Metrics as used in OLSRv2 are defined to be dimensionless and
   additive. The assignment of metrics, including their relationship
   to real parameters such as data rate, loss rate, and delay, and
   the management of the choice of metric, is outside the scope of
   [RFC7181], which simply uses these metrics in a consistent manner.
   Within a single MANET, including all components of a temporarily
   fragmented MANET, a single choice of link metric is used. By use
   of a registry of metric types (employing extended types of a
   single Address Block TLV type), routers can be configured to use
   only a subset of the available metric types.

o Node metrics were not included in OLSRv2. Node metrics can be
   implemented by the addition of the corresponding value to all
   incoming link metrics by the corresponding router.

o The separation of the two functions performed by multipoint relays
   (MPRs) in OLSRv1, optimized flooding and reduced topology
   advertisement for routing, into separate sets of MPRs in OLSRv2
   [RFC7181], denoted "flooding MPRs" and "routing MPRs". Flooding
   MPRs can be calculated as in [RFC3626], but the use of link
   metrics in OLSRv2 can improve the MPR selection. Routing MPRs
   need a metric-aware selection algorithm. The selection of routing
   MPRs guarantees the use of minimum distance routes using the

chosen metric, while using only symmetric 2-hop neighborhood
information from HELLO messages and routing MPR selector
information from TC messages.

o The protocol Information Bases defined in OLSRv2 include required
   metric values. This has included additions to the protocol
   Information Bases defined in NHDP [RFC6130] when used by OLSRv2.

2. Terminology

All terms introduced in [RFC5444], including "message" and "TLV"
(type-length-value), are to be interpreted as described there.

All terms introduced in [RFC6130], including "MANET interface",
"HELLO message", "heard", "link", "symmetric link", "1-hop neighbor",
"symmetric 1-hop neighbor", "2-hop neighbor", "symmetric 2-hop
neighbor", "symmetric 2-hop neighborhood", and the symbolic constants
SYMMETRIC and HEARD, are to be interpreted as described there.

All terms introduced in [RFC7181], including "router", "OLSRv2
interface", "willingness", "multipoint relay (MPR)", "MPR selector",
"MPR flooding", and the TLV type LINK_METRIC, are to be interpreted
as described there.

3. Applicability

The objective of this document is to retain the design considerations
behind how link metrics were included in [RFC7181]. This document
does not prescribe any behavior but explains some aspects of the
operation of OLSRv2.

4. Motivational Scenarios

The basic situation that suggests the desirability of use of routes
other than minimum hop routes is shown in Figure 1.

```
                A ----- X ----- B
                 \             /
                  \           /
                   Y ------- Z
```
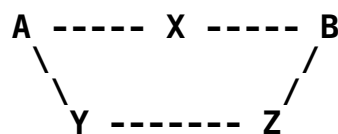
Figure 1

The minimum hop route from A to B is via X. However, if the links A
to X and X to B are poor (e.g., have low data rate or are unreliable)
but the links A to Y, Y to Z, and Z to B are better (e.g., have
reliable high data rate), then the route A to B via Y and Z may be
preferred to that via X.

There are other situations where the use of some links should be
discouraged, even if the avoidance of them does not show immediately
obvious benefits to users. Consider a network with many short-range
links and a few long-range links. Use of minimum hop routes will
immediately lead to heavy use of the long-range links. This will be
particularly undesirable if those links achieve their longer range
through reduced data rate or through being less reliable. However,
even if the long-range links have the same characteristics as the
short-range links, it may be better to reserve usage of the long-
range links for when this usage is particularly valuable -- for
example, when the use of one long-range link saves several short-
range links, rather than the single link saving that is needed for a
minimum hop route.

A related case is that of a privileged relay. An example is an
aerial router in an otherwise ground-based network. The aerial
router may have a link to many, or even all, other routers. That
would lead to all routers attempting to send all their traffic (other
than to symmetric 1-hop neighbors and some symmetric 2-hop neighbors)
via the aerial router. It may, however, be important to reserve that
capacity for cases where the aerial router is actually essential,
such as if the ground-based portion of the network is not connected.

Link metrics provide a possible solution to these scenarios. For
example, in Figure 1, the route A to Y to Z to B could be preferred
to A to X to B by making the metrics on the former path 1 and those
on the latter path 2. The aerial privileged relay could be used only
when necessary by giving its links maximal metric values, with much
smaller other metric values or, if the aerial link is to be preferred
to N ground links, by giving the ground links metric values of 1
while making the sum of the aerial node uplink and downlink metrics
equal to N.

Other cases may involve attempts to avoid areas of congestion,
attempts to route around insecure routers, and attempts by routers to
discourage being used as relays due to, for example, limited battery
power. OLSRv2 does have another mechanism to aid in this: a router's
willingness to act as an MPR. However, there are cases where that
cannot help but where use of non-minimum hop routes could.

Similarly, note that OLSRv2's optional use of link quality (through
its use of [RFC6130]) is not a solution to these problems. Use of
link quality as specified in [RFC6130] allows a router to decline to
use a link, not only on its own, but on all routers' behalf. It does
not, for example, allow the use of a link otherwise determined to be
too low quality to be generally useful as part of a route where no
better links exist. These mechanisms (link quality and link metrics)
solve distinctly different problems.

It should also be noted that the loop-free property of OLSRv2 applies
strictly only in the static state. When the network topology is
changing and when messages can be lost, it is possible for transient
loops to form. However, with update rates appropriate to the rate of
topology change, such loops will be sufficiently rare. Changing link
metrics is a form of network topology change and should be limited to
a rate slower than the message information update rate (defined by
the parameters HELLO_INTERVAL, HELLO_MIN_INTERVAL, REFRESH_INTERVAL,
TC_INTERVAL, and TC_MIN_INTERVAL).

5. Link Metrics

   This section describes the required and selected properties of the
   link metrics used in OLSRv2, followed by implementation details
   achieving those properties.

5.1. Link Metric Properties

   Link metrics in OLSRv2 are:

   o Dimensionless. While they may, directly or indirectly, correspond
      to specific physical information (such as delay, loss rate, or
      data rate), this knowledge is not used by OLSRv2. Instead,
      generating the metric value is the responsibility of a mechanism
      external to OLSRv2.

   o Additive, so that the metric of a route is the sum of the metrics
      of the links forming that route. Note that this requires a metric
      where a low value of a link metric indicates a "good" link and a
      high value of a link metric indicates a "bad" link, and the former
      will be preferred to the latter.

   o Directional, the metric from router A to router B need not be the
      same as the metric from router B to router A, even when using the
      same OLSRv2 interfaces. At router A, a link metric from router B
      to router A is referred to as an incoming link metric, while a
      link metric from router A to router B is referred to as an
      outgoing link metric. (These are, of course, reversed at router
      B.)

   o Specific to a pair of OLSRv2 interfaces, so that if there is more
      than one link from router A to router B, each has its own link
      metric in that direction. There is also an overall metric, a
      "neighbor metric", from router A to router B (its 1-hop neighbor).
      This is the minimum value of the link metrics from router A to
      router B, considering symmetric links only; it is undefined if
      there are no such symmetric links. A neighbor metric from one
      router to another is always equal to a link metric in the same

direction between OLSRv2 interfaces of those routers. When
referring to a specific OLSRv2 interface (for example, in a Link
Tuple or a HELLO message sent on that OLSRv2 interface), a link
metric always refers to a link on that OLSRv2 interface to or from
the indicated 1-hop neighbor OLSRv2 interface, while a neighbor
metric may be equal to a link metric to and/or from another OLSRv2
interface.

5.2. Link Metric Types

There are various physical characteristics that may be used to define
a link metric. Some examples, which also illustrate some
characteristics of metrics that result, are:

o Delay is a straightforward metric; as it is naturally additive,
   the delay of a multi-link route is the sum of the delays of the
   links. This does not directly take into account delays due to
   routers (such as due to router queues or transition of packets
   between router interfaces) rather than links, but these delays can
   be divided among incoming and outgoing links.

o Probability of loss on a link is, as long as probabilities of loss
   are small and independent, approximately additive. (A slightly
   more accurate approach is using a negatively scaled logarithm of
   the probability of not losing a packet.) If losses are not
   independent, then this will be pessimistic.

o Data rates are not additive. They even have the wrong
   characteristic of being good when high and bad when low; thus, a
   mapping that inverts the ordering must be applied. Such a mapping
   can, at best, only produce a metric that is acceptable to treat as
   additive. Consider, for example, a preference for a route that
   maximizes the minimum data rate link on the route and then prefers
   a route with the fewest links of each data rate from the lowest.
   If links may be of three discrete data rates, "high", "medium",
   and "low", then this preference can be achieved, on the assumption
   that no route will have more than 10 links, with metric values of
   1, 10, and 100 for the three data rates.

   If routes can have more than 10 links, the range of metrics must
   be increased; this was one reason for a preference for a wide
   "dynamic range" of link metric values. Depending on the ratios of
   the numerical values of the three data rates, the same effect may
   be achieved by using a scaling of an inverse power of the
   numerical values of the data rates. For example, if the three
   data rates were 2, 5, and 10 Mbit/s, then a possible mapping would
   be the fourth power of 10 Mbit/s divided by the data rate, giving
   metric values of 625, 16, and 1 (good for up to 16 links in a

route). This mapping can be extended to a system with more data
rate values, for example, giving a 4 Mbit/s data rate a metric
value of about 39. This may lose the capability to produce an
absolutely maximal minimum data rate route but will usually
produce either that, or something close (and at times maybe
better, is a route of three 5 Mbit/s links really better than one
of a single 4 Mbit/s link?). Specific metrics will need to define
the mapping.

There are also many other possible metrics, including using physical-
layer information (such as signal-to-noise ratio and error-control
statistics) and information such as packet-queuing statistics.

In a well-designed network, all routers will use the same metric
type. It will not produce good routes if, for example, some link
metrics are based on data rate and some on path loss (except to the
extent that these may be correlated). How to achieve this is an
administrative matter, outside the scope of OLSRv2. In fact, even
the actual physical meanings of the metrics is outside the scope of
OLSRv2. This is because new metrics may be added in the future, for
example, as data rates increase, and may be based on new, possibly
non-physical, considerations, for example, financial cost. Each such
type will have a metric type number. Initially, a single link metric
type zero is defined as indicating a dimensionless metric with no
predefined physical meaning.

An OLSRv2 router is instructed which single link metric type to use
and recognize, without knowing whether it represents delay,
probability of loss, data rate, cost, or any other quantity. This
recognized link metric type number is a router parameter and subject
to change in case of reconfiguration or possibly the use of a
protocol (outside the scope of OLSRv2) permitting a process of link
metric type agreement between routers.

The use of link metric type numbers also suggests the possibility of
use of multiple link metric types and multiple network topologies.
This is a possible future extension to OLSRv2. To allow for that
future possibility, the sending of more than one metric of different
physical types, which should otherwise not be done for reasons of
efficiency, is not prohibited, but types other than that configured
will be ignored.

The following three sections assume a chosen single link metric type,
of unspecified physical nature.

5.3. Directional Link Metrics

   OLSRv2 uses only "symmetric" (bidirectional) links, which may carry
   traffic in either direction. A key decision was whether these links
   should each be assigned a single metric, used in both directions, or
   a metric in each direction, noting that:

   o Links can have different characteristics in each direction. Use
      of directional link metrics recognizes this.

   o In many (possibly most) cases, the two ends of a link will
      naturally form different views as to what the link metric should
      be. To use a single link metric requires a coordination between
      the two that can be avoided if using directional metrics. Note
      that if using a single metric, it would be essential that the two
      ends agree as to its value; otherwise, it is possible for looping
      to occur. This problem does not occur for directional metrics.

   Based on these considerations, directional metrics are used in
   OLSRv2. Each router must thus be responsible for defining the metric
   in one direction only. This could have been in either direction,
   i.e., a router is responsible for either incoming or outgoing link
   metrics, as long as the choice is universal. The former (incoming)
   case is used in OLSRv2 because, in general, receiving routers have
   more information available to determine link metrics (for example,
   received signal strength, interference levels, and error-control
   coding statistics).

   Note that, using directional metrics, if router A defines the metric
   of the link from router B to router A, then router B must use router
   A's definition of that metric on that link in that direction.
   (Router B could, if appropriate, use a bad mismatch between
   directional metrics as a reason to discontinue use of this link,
   using the link quality mechanism defined in [RFC6130]; note that this
   is a distinct mechanism from the use of link metrics.)

5.4. Reporting Link and Neighbor Metrics

   Links, and hence link metrics, are reported in HELLO messages. A
   router must report incoming link metrics in its HELLO messages in
   order for these link metrics to be available at the other end of the
   link. This means that, for a symmetric link, both ends of the link
   will know both of the incoming and outgoing link metrics.

   As well as advertising incoming link metrics, HELLO messages also
   advertise incoming neighbor metrics. These are used for routing MPR
   selection (see Section 6.2), which requires use of the lowest metric

link between two routers when more than one link exists. This
neighbor metric may be using another OLSRv2 interface, and hence, the
link metric alone is insufficient.

Metrics are also reported in TC messages. It can be shown that these
need to be outgoing metrics:

o Router A must be responsible for advertising a metric from router
   A to router B in TC messages. This can be seen by considering a
   route connecting single OLSRv2 interface routers P to Q to R to S.
   Router P receives its only information about the link from R to S
   in the TC messages transmitted by router R, which is an MPR of
   router S (assuming that only MPR selectors are reported in TC
   messages). Router S may not even transmit TC messages (if no
   routers have selected it as an MPR and it has no attached networks
   to report). So any information about the metric of the link from
   R to S must also be included in the TC messages sent by router R;
   hence, router R is responsible for reporting the metric for the
   link from R to S.

o In a more general case, where there may be more than one link from
   R to S, the TC message must, so that minimum metric routes can be
   constructed (e.g., by router P), report the minimum of these
   outgoing link metrics, i.e., the outgoing neighbor metric from R
   to S.

In this example, router P also receives information about the
existence of a link between Q and R in the HELLO messages sent by
router Q. Without the use of metrics, this link could be used by
OLSRv2 for 2-hop routing to router R, using just HELLO messages sent
by router Q. For this property (which accelerates local route
formation) to be retained (from OLSRv1), router P must receive the
metric from Q to R in HELLO messages sent by router Q. This
indicates that router Q must be responsible for reporting the metric
for the outgoing link from Q to R. This is in addition to the
incoming link metric information that a HELLO message must report.
Again, in general, this must be the outgoing neighbor metric, rather
than the outgoing link metric.

In addition, Section 6.1 offers an additional reason for reporting
outgoing neighbor metrics in HELLO messages, without which metrics
can properly affect only routing, not flooding.

Note that there is no need to report an outgoing link metric in a
HELLO message. The corresponding 1-hop neighbor knows that value; it
specified it. Furthermore, for 2-hop neighborhood use, neighbor
metrics are required (as these will, in general, not use the same
OLSRv2 interface).

5.5. Defining Incoming Link Metrics

   When a router reports a 1-hop neighbor in a HELLO message, it may do
   so for the first time with link status HEARD. As the router is
   responsible for defining and reporting incoming link metrics, it must
   evaluate that metric and attach that link metric to the appropriate
   address (which will have link status HEARD) in the next HELLO message
   reporting that address on that OLSRv2 interface. There will, at this
   time, be no outgoing link metric available to report, but a router
   must be able to immediately decide on an incoming link metric once it
   has heard a 1-hop neighbor on an OLSRv2 interface for the first time.

   This is because, when receiving a HELLO message from this router, the
   1-hop neighbor seeing its own address listed with link status HEARD
   will (unless the separate link quality mechanism indicates otherwise)
   immediately consider that link to be SYMMETRIC, advertise it with
   that link status in future HELLO messages, and use it (for MPR
   selection and data traffic forwarding).

   It may, depending on the physical nature of the link metric, be too
   early for an ideal decision as to that metric; however, a choice must
   be made. The metric value may later be refined based on further
   observation of HELLO messages, other message transmissions between
   the routers, or other observations of the environment. It will
   probably be best to over-estimate the metric if initially uncertain
   as to its value, to discourage, rather than over-encourage, its use.
   If no information other than the receipt of the HELLO message is
   available, then a conservative maximum link metric value, denoted
   MAXIMUM_METRIC in [RFC7181], should be used.

5.6. Link Metric Values

   Link metric values are recorded in LINK_METRIC TLVs, defined in
   [RFC7181], using a compressed (lossy) representation that occupies 12
   bits. The use of 12 bits is convenient because, when combined with 4
   flag bits of additional information, described below, this results in
   a 2-octet value field. However, the use of 12 bits, and thus the
   availability of 4 flag bits, was a consequence of a design to use a
   modified exponent/mantissa form with the following characteristics:

   o The values represented are to be positive integers starting 1, 2,
      ...

   o The maximum value represented should be close to, but less than
      2^{24} (^ denotes exponentiation in this section). This is so that
      with a route limited to no more than 255 hops, the maximum route
      metric is less than 2^{32}, i.e., can be stored in 32 bits. (The
      link metric value can be stored in 24 bits.)

A representation that is modified from an exponent/mantissa form with
e bits of exponent and m bits of mantissa and that has the first of
these properties is one that starts at 1, then is incremented by 1 up
to 2^m, then has a further 2^m increments by 2, then a further 2^m
increments by 4, and so on for 2^e sets of increments. This means
that the represented value is never in error by more than a half (if
rounding) or one (if truncating) part in 2^m, usually less.

The position in the increment sequence, from 0 to 2^m-1, is
considered as a form of mantissa and denoted a. The increment
sequence number, from 0 to 2^e-1, is considered as a form of exponent
and denoted b.

The value represented by (b,a) can then be shown to be equal to
(2^m+a+1)2^b-2^m. To verify this, note that:

o With fixed b, the difference between two values with consecutive
   values of a is 2^b, as expected.

o The value represented by (b,2^m-1) is (2^m+2^m)2^b-2^m. The value
   represented by (b+1,0) is (2^m+1)(2^(b+1))-2^m. The difference
   between these two values is 2^(b+1), as expected.

The maximum represented value has b = 2^e-1 and a = 2^m-1 and is
(2^m+2^m)(2^(2^e-1))-2^m = 2^(2^e+m)-2^m. This is slightly less than
2^(2^e+m). The required 24-bit limit can be achieved if 2^e+m = 24.
Of the possible (e,m) pairs that satisfy this equation, the pair e =
4, m = 8 was selected as most appropriate and is that used by OLSRv2.
It uses the previously indicated e+m = 12 bits. An algorithm for
converting from a 24-bit value v to a 12-bit pair (b,a) is given in
Section 6.2 of [RFC7181].

As noted above, the 12-bit representation then shares two octets with
4 flag bits. Putting the flag bits first, it is then natural to put
the exponent bits in the last four bits of the first octet and to put
the mantissa bits in the second octet. The 12 consecutive bits,
using network byte order (most significant octet first), then
represent 256b+a. Note that the ordering of these 12-bit
representation values is the same as the ordering of the 24-bit
metric values. In other words, two 12-bit metrics fields can be
compared for equality/ordering as if they were unsigned integers.

The four flag bits each represent one kind of metric, defined by its
direction (incoming or outgoing) and whether the metric is a link
metric or a neighbor metric. As indicated by the flag bits set, a
metric value may be of any combination of these four kinds of metric.

6. MPRs with Link Metrics

   MPRs are used for two purposes in OLSRv2. In both cases, it is MPR
   selectors that are actually used, MPR selectors being determined from
   MPRs advertised in HELLO messages.

   o Optimized Flooding. This uses the MPR selector status of
      symmetric 1-hop neighbor routers from which messages are received
      in order to determine if these messages are to be forwarded. MPR
      selector status is recorded in the Neighbor Set (defined in
      [RFC6130] and extended in [RFC7181]) and determined from received
      HELLO messages.

   o Routing. Non-local link information is based on information
      recorded in this router's Topology Information Base. That
      information is based on received TC messages. The neighbor
      information in these TC messages consists of addresses of the
      originating router's advertised (1-hop) neighbors, as recorded in
      that router's Neighbor Set (defined in [RFC6130] and extended in
      [RFC7181]). These advertised neighbors include all of the MPR
      selectors of the originating router.

   Metrics interact with these two uses of MPRs differently, as
   described in the following two sections. This leads to the
   requirement for two separate sets of MPRs for these two uses when
   using metrics. The relationship between these two sets of MPRs is
   considered in Section 6.3.

6.1. Flooding MPRs

   The essential detail of the "flooding MPR" selection specification is
   that a router must select a set of MPRs such that a message
   transmitted by a router and retransmitted by all its flooding MPRs
   will reach all of the selecting router's symmetric 2-hop neighbors.

   Flooding MPR selection can ignore metrics and produce a solution that
   meets the required specification. However, that does not mean that
   metrics cannot be usefully considered in selecting flooding MPRs.
   Consider the network in Figure 2, where numbers are metrics of links
   in the direction away from router A, towards router D.

```
              3
          A ----- B
          |       |
       1  |       |  1
          |       |
          C ----- D
              4
```
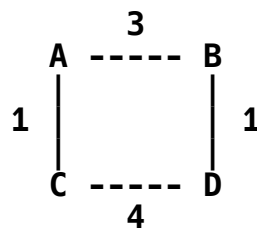
                            Figure 2

Which is the better flooding MPR selection by router A: B or C? If
the metric represents probability of message loss, then clearly
choosing B maximizes the probability of a message sent by A reaching
D. This is despite C having a lower metric in its connection to A
than B does. (Similar arguments about a preference for B can be made
if, for example, the metric represents data rate or delay rather than
probability of loss.)

However, neither should only the second hop be considered. If this
example is modified to that in Figure 3, where the numbers still are
metrics of links in the direction away from router A, towards router
D, then it is possible that, when A is selecting flooding MPRs,
selecting C is preferable to selecting B.

```
              3
          A ----- B
          |       |
       1  |       |  3
          |       |
          C ----- D
              4
```
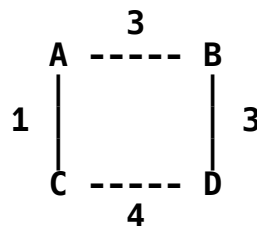
                            Figure 3

If the metrics represent scaled values of delay or the probability of
loss, then selecting C is clearly better. This indicates that the
sum of metrics is an appropriate measure to use to choose between B
and C.

However, this is a particularly simple example. Usually, it is not a
simple choice between two routers as a flooding MPR, each only adding
one router coverage. When considering which router to next add as a
flooding MPR, a more general process should incorporate the metric to
that router and the metric from that router to each symmetric 2-hop
neighbor as well as the number of newly covered symmetric 2-hop
neighbors. Other factors may also be included.

The required specification for flooding MPR selection is in
Section 18.4 (also using Section 18.3) of [RFC7181], which may use
the example MPR selection algorithm in Appendix B of [RFC7181].
However, note that (as in [RFC3626]) each router can make its own
independent choice of flooding MPRs, and flooding MPR selection
algorithm, and still interoperate.

Also note that the references above to the direction of the metrics
is correct: for flooding, directional metrics outward from a router
are appropriate, i.e., metrics in the direction of the flooding.
This is an additional reason for including outward metrics in HELLO
messages, as otherwise a metric-aware MPR selection for flooding is
not possible. The second-hop metrics are outgoing neighbor metrics
because the OLSRv2 interface used for a second-hop transmission may
not be the same as that used for the first-hop reception.

6.2. Routing MPRs

The essential detail of the "routing MPR" selection specification is
that a router must, per OLSRv2 interface, select a set of MPRs such
that there is a 2-hop route from each symmetric 2-hop neighbor of the
selecting router to the selecting router, with the intermediate
router on each such route being a routing MPR of the selecting
router.

It is sufficient, when using an additive link metric rather than a
hop count, to require that these routing MPRs provide not just a
2-hop route but a minimum distance 2-hop route. In addition, a
router is a symmetric 2-hop neighbor even if it is a symmetric 1-hop
neighbor, as long as there is a 2-hop route from it that is shorter
than the 1-hop link from it. (The property that no routes go through
routers with willingness WILL_NEVER is retained. Examples below
assume that all routers are equally willing, with none having
willingness WILL_NEVER.)

For example, consider the network in Figure 4. Numbers are metrics
of links in the direction towards router A, away from router D.
Router A must pick router B as a routing MPR, whereas for minimum hop
count routing, it could alternatively pick router C. Note that the
use of incoming neighbor metrics in this case follows the same
reasoning as for the directionality of metrics in TC messages, as
described in Section 5.4.

```
              2
           A ----- B
           |       |
        1  |       |  1
           |       |
           C ----- D
              3
```
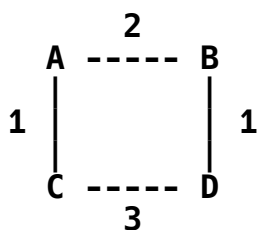
                          Figure 4

In Figure 5, where numbers are metrics of links in the direction
towards router A and away from router C, router A must pick router B
as a routing MPR, but for minimum hop count routing, it would not
need to pick any MPRs.

```
               1
           A - B
            \  |
          4  \ |  2
              \|
               C
```
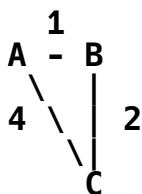
                          Figure 5

In Figure 6, where numbers are metrics of links in the direction
towards router A and away from routers D and E, router A must pick
both routers B and C as routing MPRs, but for minimum hop count
routing, it could pick either.

```
           D           E
           |\         /|
           | \   3   / |
           |  \     /  |
        1  |   \   /   |  1
           |    \ /    |
           |     X     |
           |    / \    |
           |   / 2 \   |
           |  /     \  |
           B           C
            \         /|
          3  \     /   |
              \   / 2
               \ /
                A
```
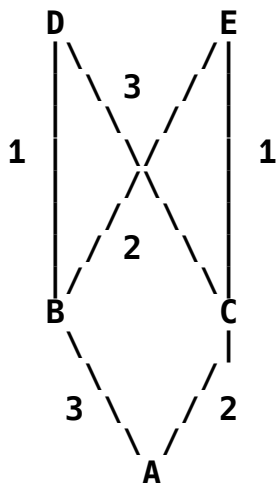
                          Figure 6

It is shown in Appendix A that selecting routing MPRs according to
this definition and advertising only such links (plus knowledge of
local links from HELLO messages) will result in selection of lowest
total metric routes, even if all links (advertised or not) are
considered in the definition of a shortest route.

However, the definition noted above as sufficient for routing MPR
selection is not necessary. For example, consider the network in
Figure 7, where numbers are metrics of links in the direction towards
router A, away from other routers; the metrics from B to C and C to B
are both assumed to be 2.

```
              1
          A ----- B
           \     /
         4  \   / 2
             \ /
              C ----- D ----- E
              3         5
```
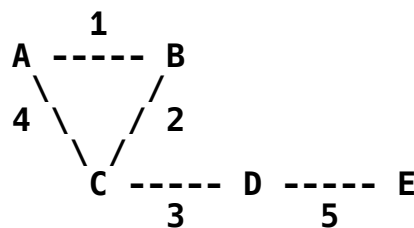
                      Figure 7

Using the above definition, A must pick both B and C as routing MPRs,
in order to cover the symmetric 2-hop neighbors C and D,
respectively. (C is a symmetric 2-hop neighbor because the route
length via B is shorter than the 1-hop link.)

However, A only needs to pick B as a routing MPR, because the only
reason to pick C as a routing MPR would be so that C can advertise
the link to A for routing -- to be used by, for example, E. However,
A knows that no other router should use the link C to A in a shortest
route because routing via B is shorter. So, if there is no need to
advertise the link from C to A, then there is no reason for A to
select C as a routing MPR.

This process of "thinning out" the routing MPR selection uses only
local information from HELLO messages. Using any minimum distance
algorithm, the router identifies shortest routes, whether one, two,
or more hops, from all routers in its symmetric 2-hop neighborhood.
It then selects as MPRs all symmetric 1-hop neighbors that are the
last router (before the selecting router itself) on any such route.
Where there is more than one shortest distance route from a router,
only one such route is required. Alternative routes may be selected
so as to minimize the number of last routers -- this is the
equivalent to the selection of a minimal set of MPRs in the non-
metric case.

Note that this only removes routing MPRs whose selection can be
directly seen to be unnecessary. Consequently, if (as is shown in
Appendix A) the first approach creates minimum distance routes, then
so does this process.

The examples in Figures 5 and 6 show that use of link metrics may
require a router to select more routing MPRs than when not using
metrics and even require a router to select routing MPRs when,
without metrics, it would not need any routing MPRs. This may result
in more, and larger, messages being generated and forwarded more
often. Thus, the use of link metrics is not without cost, even
excluding the cost of link metric signaling.

These examples consider only single OLSRv2 interface routers.
However, if routers have more than one OLSRv2 interface, then the
process is unchanged; other than that, if there is more than one
known metric between two routers (on different OLSRv2 interfaces),
then, considering symmetric links only (as only these are used for
routing) the smallest link metric, i.e., the neighbor metric, is
used. There is no need to calculate routing MPRs per OLSRv2
interface. That requirement results from the consideration of
flooding and the need to avoid certain "race" conditions, which are
not relevant to routing, only to flooding.

The required specification for routing MPR selection is in
Section 18.5 (also using Section 18.3) of [RFC7181], which may use
the example MPR selection algorithm in Appendix B of [RFC7181].
However, note that (as in [RFC3626]) each router can make its own
independent choice of routing MPRs, and routing MPR selection
algorithm, and still interoperate.

6.3. Relationship between MPR Sets

It would be convenient if the two sets of flooding and routing MPRs
were the same. This can be the case if all metrics are equal, but in
general, for "good" sets of MPRs, they are not. (A reasonable
definition of this is that there is no common minimal set of MPRs.)
If metrics are asymmetrically valued (the two sets of MPRs use
opposite direction metrics) or routers have multiple OLSRv2
interfaces (where routing MPRs can ignore this but flooding MPRs
cannot), this is particularly unlikely. However, even using a
symmetrically valued metric with a single OLSRv2 interface on each
router, the ideal sets need not be equal, nor is one always a subset
of the other. To show this, consider these examples, where all
lettered routers are assumed equally willing to be MPRs, and numbers
are bidirectional metrics for links.

In Figure 8, A does not require any flooding MPRs. However, A must
select B as a routing MPR.

```
              1
          A - B
           \  |
        4 \  | 2
             \|
              C
```
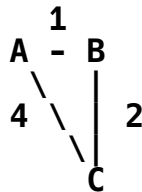
                         Figure 8

In Figure 9, A must select C and D as routing MPRs. However, A's
minimal set of flooding MPRs is just B. In this example, the set of
routing MPRs serves as a set of flooding MPRs, but a non-minimal one
(although one that might be better, depending on the relative
importance of number of MPRs and flooding link metrics).

```
                 2
             C --- E
            /     /
        1 /    / 1
          /  4  /
        A --- B
          \     \
        1 \    \ 1
            \    \
             D --- F
                 2
```
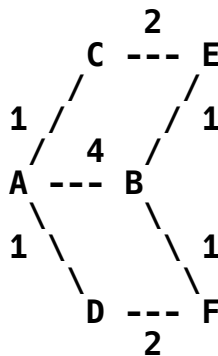
                         Figure 9

However, this is not always the case. In Figure 10, A's set of
routing MPRs must contain B but need not contain C. A's set of
flooding MPRs need not contain B but must contain C. (In this case,
flooding with A selecting B rather than C as a flooding MPR will
reach D but in three hops rather than the minimum two that MPR
flooding guarantees.)

```
          2   1
        B - C - D
        |   /
      1 |  / 4
        | /
        A
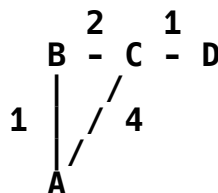```

                        Figure 10

## 7.  Security Considerations

An attacker can have an adverse impact on an OLSRv2 network by creating apparently valid messages that contain incorrect link metrics.  This could take the form of influencing the choice of routes or, in some cases, producing routing loops.  This is a more subtle, and likely to be less effective, attack than other forms of invalid message injection.  These can add and remove other and more basic forms of network information, such as the existence of some routers and links.

As such, no significantly new security issues arose from the inclusion of metrics in OLSRv2.  Defenses to the injection of invalid link metrics are the same as to other forms of invalid message injection, as discussed in the Security Considerations section of [RFC7181].

There are possible uses for link metrics in the creation of security countermeasures to prefer the use of links that have better security properties, including better availability, to those with poorer security properties.  This, however, is beyond the scope of both this document and [RFC7181].

## 8.  Acknowledgements

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## 9.  Informative References

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Appendix A.  MPR Routing Property

   In order for routers to find and use shortest routes in a network
   while using the minimum reduced topology supported by OLSRv2 (that a
   router only advertises its MPR selectors in TC messages), routing MPR
   selection must result in the property that there are shortest routes
   with all intermediate routers being routing MPRs.

   This appendix uses the following terminology and assumptions:

   o  The network is a graph of nodes connected by arcs, where nodes
      correspond to routers with willingness not equal to WILL_NEVER
      (except possibly at the ends of routes).  An arc corresponds to
      the set of symmetric links connecting those routers; the OLSRv2
      interfaces used by those links are not relevant.

   o  Each arc has a metric in each direction, being the minimum of the
      corresponding link metrics in that direction, i.e., the
      corresponding neighbor metric.  This metric must be positive.

   o  A sequence of arcs joining two nodes is referred to as a path.

   o  Node A is an MPR of node B if corresponding router A is a routing
      MPR of router B.

   The required property (of using shortest routes with reduced
   topology) is equivalent to the following property: for any pair of
   distinct nodes X and Z, there is a shortest path from X to Z, X - Y1
   - Y2 - ... - Ym - Z such that Y1 is an MPR of Y2, ..., Ym is an MPR
   of Z.  Call such a path a routable path, and call this property the
   routable path property.

   The required definition for a node X selecting MPRs is that for each
   distinct node Z from which there is a two-arc path, there is a
   shorter, or equally short, path that is either Z - Y - X where Y is
   an MPR of X or is the one-arc path Z - X.  Note that the existence of
   locally known, shorter paths that have more than two arcs, which can
   be used to reduce the numbers of MPRs, is not considered here.  (Such
   reductions are only when the remaining MPRs can be seen to retain all
   necessary shortest paths and therefore retain the required property.)

   Although this appendix is concerned with paths with minimum total
   metric, not number of arcs (hop count), it proceeds by induction on
   the number of arcs in a path.  Although it considers minimum metric
   routes with a bounded number of arcs, it then allows that number of
   arcs to increase so that overall minimum metric paths, regardless of
   the number of arcs, are considered.

Specifically, the routable path property is a corollary of the
property that for all positive integers n and all distinct nodes X
and Z, if there is any path from X to Z of n arcs or fewer, then
there is a shortest path, from among those of n arcs or fewer, that
is a routable path.  This may be called the n-arc routable path
property.

The n-arc routable path property is trivial for n = 1 and directly
follows from the definition of the MPRs of Z for n = 2.

Proceeding by induction, assuming the n-arc routable path property is
true for n = k, consider the case that n = k+1.

Suppose that X - V1 - V2 - ... - Vk - Z is a shortest k+1 arc path
from X to Z.  We construct a path that has no more than k+1 arcs, has
the same or shorter length (hence has the same, shortest, length
considering only paths of up to k+1 arcs, by assumption), and is a
routable path.

First, consider whether Vk is an MPR of Z.  If it is not, then
consider the two-arc path Vk-1 - Vk - Z.  This can be replaced either
by a one-arc path Vk-1 - Z or by a two-arc path Vk-1 - Wk - Z, where
Wk is an MPR of Z, such that the metric from Vk-1 to Z by the
replacement path is no longer.  In the former case (replacement one-
arc path), this now produces a path of length k, and the previous
inductive step may be applied.  In the latter case, we have replaced
Vk by Wk, where Wk is an MPR of Z.  Thus, we need only consider the
case that Vk is an MPR of Z.

We now apply the previous inductive step to the path X - V1 - ... -
Vk-1 - Vk, replacing it by an equal length path X - W1 - ... Wm-1 -
Vk, where m <= k, where this path is a routable path.  Then, because
Vk is an MPR of Z, the path X - W1 - ... - Wm-1 - Vk - Z is a
routable path and demonstrates the n-arc routable path property for n
= k+1.

This thus shows that for any distinct nodes X and Z, there is a
routable path using the MPR-reduced topology from X to Z, i.e., that
OLSRv2 finds minimum length paths (minimum total metric routes).

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