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Link Metrics for the Mobile Ad Hoc Network (MANET) Routing Protocol OLSRv2 - Rationale
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Abstract

This document describes the rationale for and design considerations behind how link metrics are included in OLSRv2, in order to allow routing by other than minimum hop count routes.

Table of Contents

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 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) [OLSRv2] is the introduction of the ability to select routes using link metrics other than the number of hops.

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 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.

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 [OLSRv2].

A metric-based route selection processes for OLSRv2 could have been handled as an extension to OLSRv2. However in this case, legacy OLSRv2 routers, which would not recognize any link metric information, would still attempt to use minimum hop-count routes. This would mean that, in effect, routers differed 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 which did, and routers which did not, implement the 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.

- Metrics as used in OLSRv2 were defined to be dimensionless and additive. The assignment of metrics, including their relationship to real parameters such as bandwidth, loss rate and delay, is outside the scope of OLSRv2, which simply uses these metrics in a consistent manner. However by use of a registry of metric types (employing extended types of a single address block TLV type), routers can use only metrics of the physical type that they are configured to use.

- The separation of the two functions performed by MPRs in OLSRv1, optimized flooding and reduced topology advertisement for routing, into separate sets of MPRs in OLSRv2 [OLSRv2], 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.

- 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", 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", and "symmetric 2-hop neighborhood", are to be interpreted as described there.

All terms introduced in [OLSRv2], including "router", "OLSRv2 interface", "willingness", "MultiPoint Relay (MPR)", "MPR selector", and "MPR flooding" 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 [OLSRv2]. The 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., having low bandwidth or being unreliable) but the links A to Y, Y to Z and Z to B are better (e.g., having reliable high bandwidth) then the route A to B via Y and Z may be preferred to that via X.

There are other situations where, even if the avoidance of some links do not show immediately obvious benefits to users, their use should be discouraged. 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 bandwidth, 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 all 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.

Other cases may involve attempts to avoid areas of congestion, to route around insecure routers (by preference, but prepared to use them if there is no other alternative) and routers attempting to discourage their use 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 with possibly lossy messages, 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:

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

- 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, where the former will be preferred to the latter.

- 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.)

- 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 be 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:

- 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, rather than links, but these can be divided among incoming and outgoing links.) However, given a limited range of link metric value, more than one type of delay metric may be required, representing different ranges of delay value.

- 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. Again, more than one range of values (or more than one scaling of the logarithms) may be needed.

- Bandwidth is not additive, it even has the wrong characteristic of being good when high, bad when low; thus a mapping that inverts its ordering must be applied. Such a mapping can, at best, only produce a metric that it is acceptable to treat as additive. Consider, for example, a preference for a route that maximizes the minimum bandwidth link on the route, and then prefers a route with the fewest links of each bandwidth from the lowest. If links may be of three discrete bandwidths, "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 bandwidths. If routes can have more than 10 links, the range of metrics must be increased; this indicates a preference for a wide "dynamic range" of link metric values. Depending on the ratios of the numerical values of the three bandwidths, the same effect may be achieved by using a scaling of an inverse power of the numerical values of the bandwidths. For example if the three bandwidths were 2, 5 and 10 Mbit/s, then a possible mapping would be the fourth power of 10 Mbit/s divided by the bandwidth, 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 bandwidth values, for example giving a 4 Mbit/s bandwidth a metric value of about 39. This may lose the capability to produce an absolutely maximum minimum bandwidth 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 (e.g., a power and bandwidth scaling).

There are also many other possible metrics, including 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 physical metric type. It will not produce good routes if, for example, some link metrics are based on bandwidth 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 bandwidths 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, bandwidth, 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:

- Links can have different characteristics in each direction, use of directional link metrics recognizes this.

- 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., that 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 in [RFC6130].)

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 that these are each 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:

- 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, in order 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 may be used by OLSRv2 for two 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, and 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. The receiving router will then immediately consider the link to be symmetric and thus will use it.

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.

Thus 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, on receiving a HELLO message from this router, that 1-hop neighbor will (unless link quality indicates otherwise) immediately consider the link to be symmetric and use it. 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, in [OLSRv2] denoted MAXIMUM_METRIC, should be used.

5.6. Link Metric Values

Link metric values are recorded in LINK_METRIC TLVs, defined in [OLSRv2], using a compressed 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 produced a 2 octet value field. However the use of 12 bits was a result from 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, modified from an exponent/mantissa form with e bits of exponent and m bits of mantissa, and which 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.

The position in the increment sequence, from 0 to 2^m-1, is

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

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

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

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

The maximum represented value has a = 2^e-1 and b = 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. An appropriate pair of values to achieve this is e = 4, m = 8.

As noted above, the 12 bit representation 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 normal network octet ordering (high first) then represent 256a+b. 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.

- 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 [OLSRv2]), and determined from received HELLO messages.

- 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 [OLSRv2]). 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, and which 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

MPR selection for flooding can ignore metrics. Selection using any algorithm that ignores metrics, including any allowed by [OLSRv2], will produce a flooding solution that works.

However, that does not mean that metrics cannot be usefully considered in selecting such "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 that C has 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 bandwidth 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:

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

Figure 3

then it is possible that, when A is selecting flooding MPRs, selecting C is preferable to selecting B. 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. A more general process, when considering which router to next add as a flooding MPR, 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 as well as the other factors used in the example algorithm in [OLSRv2].

A candidate algorithm for flooding MPR selection is described in [OLSRv2]. However, note that in [OLSRv2] (as in [RFC3626]), each router can make its own independent choice of flooding MPRs, and flooding MPR selection algorithms, 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 MPR selection specification in [OLSRv2] is that a router must, per OLSRv2 interface, select a set of MPRs such that there is a two 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 an 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 two hop route, but a minimum distance two 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 two hop route from it that is shorter than the one 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, 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, 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
  |   /\   |
  |  /  \  |
  | / 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. But 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 Figure 5 and Figure 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.

A candidate algorithm for routing MPR selection is described in [OLSRv2]. However, note that in [OLSRv2] (as in [RFC3626]), each router can make its own independent choice of routing MPRs, and routing MPR selection algorithms, 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. IANA Considerations

This document has no actions for IANA.

This section may be removed by the RFC Editor.

8. Security Considerations

This document does not specify any security considerations.

This section may be removed by the RFC Editor.

9. Acknowledgements

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Appendix A. MPR Routing Property

In order that routers can 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:

- 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.

- 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.

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

- 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 that 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 which 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, but more than two arc paths, 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 retains 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 which 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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