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OSPF Multipoint Relay (MPR) Extension for Ad Hoc Networks

Status of This Memo

This memo defines an Experimental Protocol for the Internet community. It does not specify an Internet standard of any kind. Discussion and suggestions for improvement are requested. Distribution of this memo is unlimited.

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Abstract

This document specifies an OSPFv3 interface type tailored for mobile ad hoc networks. This interface type is derived from the broadcast interface type, and is denoted the "OSPFv3 MANET interface type".

Table of Contents

1. Introduction

This document specifies an extension of OSPFv3 [RFC5340] that is adapted to mobile ad hoc networks (MANETs) [RFC2501] and based on mechanisms providing:

Flooding-reduction: only a subset of all routers will be involved in (re)transmissions during a flooding operation.

Topology-reduction: only a subset of links are advertised, hence both the number and the size of Link State Advertisements (LSAs) are decreased.

Adjacency-reduction: adjacencies are brought up only with a subset of neighbors for lower database synchronization overhead.

These mechanisms are based on multipoint relays (MPR), a technique developed in the Optimized Link State Routing Protocol (OLSR) [RFC3626].

The extension specified in this document integrates into the OSPF framework by defining the OSPFv3 MANET interface type. While this extension enables OSPFv3 to function efficiently on mobile ad hoc networks, operation of OSPFv3 on other types of interfaces or networks, or in areas without OSPFv3 MANET interfaces, remains unaltered.

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].

This document uses OSPF terminology as defined in [RFC2328] and [RFC5340], and Link-Local Signaling (LLS) terminology as defined in [RFC4813]; it introduces the following terminology to the OSPF nomenclature:

OSPFv3 MANET interface - the OSPFv3 interface type for MANETs, as specified in this document.

Additionally, the following terms are used in this document:

MANET router - a router that has only OSPFv3 MANET interfaces.

Wired router - a router that has only OSPFv3 interface of types other than OSPFv3 MANET interfaces.

Hybrid router - a router that has OSPFv3 interfaces of several types, including at least one of the OSPFv3 MANET interface type.

Neighbor - a router, reachable through an OSPFv3 interface (of any type).

MANET neighbor - a neighbor, reachable through an OSPFv3 MANET interface.

Symmetric 1-hop neighbor - a neighbor, in a state greater than or equal to 2-Way (through an interface of any type).

Symmetric strict 2-hop neighbor - a symmetric 1-hop neighbor of a symmetric 1-hop neighbor, which is not itself a symmetric 1-hop neighbor of the considered router.

Symmetric strict 2-hop neighborhood - the set formed by all the symmetric strict 2-hop neighbors of the considered router.

Synch router - a router that brings up adjacencies with all of its MANET neighbors.

Flooding-MPR - a router that is selected by its symmetric 1-hop neighbor, router X, to retransmit all broadcast protocol packets that it receives from router X, provided that the broadcast protocol packet is not a duplicate and that the Hop Limit field of the protocol packet is greater than one.

Path-MPR - a router that is selected by a symmetric 1-hop neighbor, X, as being on the shortest path from a router in the symmetric strict 2-hop neighborhood of router X to router X.

Multipoint relay (MPR) - a router that is selected by its symmetric 1-hop neighbor as either a Flooding-MPR, a Path-MPR, or both.

Flooding-MPR-selector - a router that has selected its symmetric 1-hop neighbor, router X, as one of its Flooding-MPRs is a Flooding-MPR-selector of router X.

Path-MPR-selector - a router that has selected its symmetric 1-hop neighbor, router X, as one of its Path-MPRs is a Path-MPR selector of router X.

MPR-selector - a router that has selected its symmetric 1-hop neighbor, router X, as either one of its Flooding-MPRs, one of its Path-MPRs, or both is an MPR-selector of router X.

3. Applicability Statement

The OSPFv3 MANET interface type, defined in this specification, allows OSPFv3 to be deployed within an area where parts of that area are a mobile ad hoc network (MANET) with moderate mobility properties.

3.1. MANET Characteristics

MANETs [RFC2501] are networks in which a dynamic network topology is a frequently expected condition, often due to router mobility and/or to varying quality of wireless links -- the latter of which also generally entails bandwidth scarcity and interference issues between neighbors.

Moreover, MANETs often exhibit "semi-broadcast" properties, i.e., a router R that makes a transmission within a MANET can only assume that transmission to be received by a subset of the total number of routers within that MANET. Further, if two routers, R1 and R2, each make a transmission, neither of these transmissions is guaranteed to be received by the same subset of routers within the MANET -- even if R1 and R2 can mutually receive transmissions from each other.

These characteristics are incompatible with several OSPFv3 mechanisms, including, but not limited to, existing mechanisms for control-traffic reduction, such as flooding-reduction, topology-reduction, and adjacency-reduction (e.g., Designated Router).

3.2. OSPFv3 MANET Interface Characteristics

An interface of the OSPFv3 MANET interface type is the point of attachment of an OSPFv3 router to a network that may have MANET characteristics. That is, an interface of the OSPFv3 MANET interface type is able to accommodate the MANET characteristics described in Section 3.1. An OSPFv3 MANET interface type is not prescribing a set of behaviors or expectations that the network is required to satisfy. Rather, it is describing operating conditions under which protocols on an interface towards that network must be able to function (i.e., the protocols are required to be able to operate correctly when faced with the characteristics described in Section 3.1). As such, the

OSPFv3 MANET interface type is a generalization of other OSPFv3 interface types; for example, a protocol operating correctly over an OSPFv3 MANET interface would also operate correctly over an OSPFv3 broadcast interface (whereas the inverse would not necessarily be true).

Efficient OSPFv3 operation over MANETs relies on control-traffic reduction and on using mechanisms appropriate for semi-broadcast. The OSPFv3 MANET interface type, defined in this document, allows networks with MANET characteristics into the OSPFv3 framework by integrating mechanisms (flooding-reduction, topology-reduction, and adjacency-reduction) derived from solutions standardized by the MANET working group.

4. Protocol Overview and Functioning

The OSPFv3 MANET interface type, defined in this specification, makes use of flooding-reduction, topology-reduction, and adjacency-reduction, all based on MPR, a technique derived from [RFC3626], as standardized in the MANET working group. Multicast transmissions of protocol packets are used when possible.

4.1. Efficient Flooding Using MPRs

OSPFv3 MANET interfaces use a flooding-reduction mechanism, denoted MPR flooding [MPR], whereby only a subset of MANET neighbors (those selected as Flooding-MPR) participate in a flooding operation. This reduces the number of (re)transmissions necessary for a flooding operation [MPR-analysis], while retaining resilience against transmission errors (inherent when using wireless links) and against obsolete two-hop neighbor information (e.g., as caused by router mobility) [MPR-robustness].

4.2. MPR Topology-Reduction

OSPFv3 MANET interfaces use a topology-reduction mechanism, denoted MPR topology-reduction, whereby only necessary links to MANET neighbors (those identified by Path-MPR selection as belonging to shortest paths) are included in LSAs. Routers in a MANET periodically generate and flood Router-LSAs describing their selection of such links to their Path-MPRs. Such links are reported as point-to-point links. This reduces the size of LSAs originated by routers on a MANET [MPR-topology], while retaining classic OSPF properties: optimal paths using synchronized adjacencies (if synchronized paths are preferred over non-synchronized paths of equal cost).

4.3. Multicast Transmissions of Protocol Packets

OSPFv3 MANET interfaces employ multicast transmissions when possible, thereby taking advantage of inherent broadcast capabilities of the medium, if present (with wireless interfaces, this can often be the case [RFC2501]). In particular, LSA acknowledgments are sent via multicast over these interfaces, and retransmissions over the same interfaces are considered as implicit acknowledgments. Jitter management, such as delaying packet (re)transmission, can be employed in order to allow several packets to be bundled into a single transmission, which may avoid superfluous retransmissions due to packet collisions [RFC5148].

4.4. MPR Adjacency-Reduction

Adjacencies over OSPFv3 MANET interfaces are required to be formed only with a subset of the neighbors of that OSPFv3 MANET interface. No Designated Router or Backup Designated Router are elected on an OSPFv3 MANET interface. Rather, adjacencies are brought up over an OSPFv3 MANET interface only with MPRs and MPR selectors. Only a small subset of routers in the MANET (called Synch routers) are required to bring up adjacencies with all their MANET neighbors. This reduces the amount of control traffic needed for database synchronization, while ensuring that LSAs still describe only synchronized adjacencies.

5. Protocol Details

This section complements [RFC5340] and specifies the information that must be maintained, processed, and transmitted by routers that operate one or more OSPFv3 MANET interfaces.

5.1. Data Structures

In addition to the values used in [RFC5340], the Type field in the interface data structure can take a new value, "MANET". Furthermore, and in addition to the protocol structures defined by [RFC5340], routers that operate one or more MANET interfaces make use of the data structures described below.

5.1.1. N(i): Symmetric 1-Hop Neighbor Set

The Symmetric 1-hop Neighbor set N(i) records router IDs of the set of symmetric 1-hop neighbors of the router on interface i. More precisely, N(i) records tuples of the form:

(1_HOP_SYM_id, 1_HOP_SYM_time)

where:

1_HOP_SYM_id: is the router ID of the symmetric 1-hop neighbor of this router over interface i.

1_HOP_SYM_time: specifies the time at which the tuple expires and MUST be removed from the set.

For convenience throughout this document, N will denote the union of all N(i) sets for all MANET interfaces on the router.

5.1.2. N2(i): Symmetric Strict 2-Hop Neighbor Set

The Symmetric strict 2-hop Neighbor set N2(i) records links between routers in N(i) and their symmetric 1-hop neighbors, excluding:

(i) the router performing the computation, and

(ii) all routers in N(i).

More precisely, N2(i) records tuples of the form:

(2_HOP_SYM_id, 1_HOP_SYM_id, 2_HOP_SYM_time)

where:

2_HOP_SYM_id: is the router ID of a symmetric strict 2-hop neighbor.

1_HOP_SYM_id: is the router ID of the symmetric 1-hop neighbor of this router through which the symmetric strict 2-hop neighbor can be reached.

2_HOP_SYM_time: specifies the time at which the tuple expires and MUST be removed from the set.

For convenience throughout this document, N2 will denote the union of all N2(i) sets for all MANET interfaces on the router.

5.1.3. Flooding-MPR Set

The Flooding-MPR set on interface i records router IDs of a subset of the routers listed in N(i), selected such that, through this subset, each router listed in N2(i) is reachable in 2 hops by this router. There is one Flooding-MPR set per MANET interface. More precisely, the Flooding-MPR set records tuples of the form:

(Flooding_MPR_id, Flooding_MPR_time)

where:

Flooding_MPR_id: is the router ID of the symmetric 1-hop neighbor of this router that is selected as Flooding-MPR.

Flooding_MPR_time: specifies the time at which the tuple expires and MUST be removed from the set.

Flooding-MPR selection is detailed in Section 5.2.1.

5.1.4. Flooding-MPR-Selector Set

The Flooding-MPR-selector set on interface i records router IDs of the set of symmetric 1-hop neighbors of this router on interface i that have selected this router as their Flooding-MPR. There is one Flooding-MPR-selector set per MANET interface. More precisely, the Flooding-MPR-selector set records tuples of the form:

(Flooding_MPR_SELECTOR_id, Flooding_MPR_SELECTOR_time)

where:

Flooding_MPR_SELECTOR_id: is the router ID of the symmetric 1-hop neighbor of this router, that has selected this router as its Flooding-MPR.

Flooding_MPR_SELECTOR_time: specifies the time at which the tuple expires and MUST be removed from the set.

Flooding-MPR selection is detailed in Section 5.2.1.

5.1.5. Path-MPR Set

The Path-MPR set records router IDs of routers in N that provide shortest paths from routers in N2 to this router. There is one Path-MPR set per router. More precisely, the Path-MPR set records tuples of the form:

(Path_MPR_id, Path_MPR_time)

where:

Path_MPR_id: is the router ID of the symmetric 1-hop neighbor of this router, selected as Path-MPR.

Path_MPR_time: specifies the time at which the tuple expires and MUST be removed from the set.

Path-MPR selection is detailed in Section 5.2.5.

5.1.6. Path-MPR-Selector Set

The Path-MPR-selector set records router IDs of the set of symmetric 1-hop neighbors over any MANET interface that have selected this router as their Path-MPR. There is one Path-MPR-selector set per router. More precisely, the Path-MPR-selector set records tuples of the form:

(Path_MPR_SELECTOR_id, Path_MPR_SELECTOR_time)

where:

Path_MPR_SELECTOR_id: is the router ID of the symmetric 1-hop neighbor of this router that has selected this router as its Path-MPR.

Path_MPR_SELECTOR_time: specifies the time at which the tuple expires and MUST be removed from the set.

Path-MPR selection is detailed in Section 5.2.5.

5.1.7. MPR Set

The MPR set is the union of the Flooding-MPR set(s) and the Path-MPR set. There is one MPR set per router.

5.1.8. MPR-Selector Set

The MPR-selector set is the union of the Flooding-MPR-selector set(s) and the Path-MPR-selector set. There is one MPR-selector set per router.

5.2. Hello Protocol

On OSPFv3 MANET interfaces, packets are sent, received, and processed as defined in [RFC5340] and [RFC2328], and augmented for MPR selection as detailed in this section.

All additional signaling for OSPFv3 MANET interfaces is done through inclusion of TLVs within an LLS block [RFC4813], which is appended to Hello packets. If an LLS block is not already present, an LLS block MUST be created and appended to the Hello packets.

Hello packets sent over an OSPFv3 MANET interface MUST have the L bit of the OSPF Options field set, as per [RFC4813], indicating the presence of an LLS block.

This document defines and employs the following TLVs in Hello packets sent over OSPFv3 MANET interfaces:

FMPR - signaling Flooding-MPR selection;

PMPR - signaling Path-MPR selection;

METRIC-MPR - signaling metrics.

The layout and internal structure of these TLVs is detailed in Section 6.

5.2.1. Flooding-MPR Selection

The objective of Flooding-MPR selection is for a router to select a subset of its neighbors such that a packet, retransmitted by these selected neighbors, will be received by all routers 2 hops away. This property is called the Flooding-MPR "coverage criterion". The Flooding-MPR set of a router is computed such that, for each OSPFv3 MANET interface, it satisfies this criterion. The information required to perform this calculation (i.e., link sensing and neighborhood information) is acquired through periodic exchange of OSPFv3 Hello packets.

Flooding-MPRs are computed by each router that operates at least one OSPFv3 MANET interface. The smaller the Flooding-MPR set is, the lower the overhead will be. However, while it is not essential that the Flooding-MPR set is minimal, the "coverage criterion" MUST be satisfied by the selected Flooding-MPR set.

The willingness of a neighbor router to act as Flooding-MPR MAY be taken into consideration by a heuristic for Flooding-MPR selection. An example heuristic that takes willingness into account is given in Appendix A.

5.2.2. Flooding-MPR Selection Signaling - FMPR TLV

A router MUST signal its Flooding-MPRs set to its neighbors by including an FMPR TLV in generated Hello packets. Inclusion of this FMPR TLV signals the list of symmetric 1-hop neighbors that the sending router has selected as Flooding-MPRs, as well as the willingness of the sending router to be elected Flooding-MPR by other routers. The FMPR TLV structure is detailed in Section 6.1.

5.2.3. Neighbor Ordering

Neighbors listed in the Hello packets sent over OSPFv3 MANET interfaces MUST be included in the order as given below:

1. symmetric 1-hop neighbors that are selected as Flooding-MPRs;

2. other symmetric 1-hop neighbors;

3. other 1-hop neighbors.

This ordering allows correct interpretation of an included FMPR TLV.

5.2.4. Metric Signaling - METRIC-MPR TLV and PMPR TLV

Hello packets sent over OSPFv3 MANET interfaces MUST advertise the costs of links towards ALL the symmetric MANET neighbors of the sending router. If the sending router has more than one OSPFv3 MANET interface, links to ALL the symmetric MANET neighbors over ALL the OSPFv3 MANET interfaces of that router MUST have their costs advertised.

The costs of the links between the router and each of its MANET neighbors on the OSPFv3 MANET interface over which the Hello packet is sent MUST be signaled by including METRIC-MPR TLVs. The METRIC-MPR TLV structure is detailed in Section 6.2.

Moreover, the lowest cost from each MANET neighbor towards the router (regardless of over which interface) MUST be specified in the included PMPR TLV. Note that the lowest cost can be over an interface that is not an OSPFv3 MANET interface.

5.2.5. Path-MPR Selection

A router that has one or more OSPFv3 MANET interfaces MUST select a Path-MPR set from among routers in N. Routers in the Path-MPR set of a router are those that take part in the shortest (with respect to the metrics used) path from routers in N2 to this router. A heuristic for Path-MPR selection is given in Appendix B.

5.2.6. Path-MPR Selection Signaling - PMPR TLV

A router MUST signal its Path-MPR set to its neighbors by including a PMPR TLV in generated Hello packets.

A PMPR TLV MUST contain a list of IDs of all symmetric 1-hop neighbors of all OSPFv3 MANET interfaces of the router. These IDs MUST be included in the PMPR TLV in the order as given below:

1. Neighbors that are both adjacent AND selected as Path-MPR for any OSPFv3 MANET interface of the router generating the Hello packet.

2. Neighbors that are adjacent over any OSPFv3 MANET interface of the router generating the Hello packet.

3. Symmetric 1-hop neighbors on any OSPFv3 MANET interface of the router generating the Hello packet that have not been previously included in this PMPR TLV.

The list of neighbor IDs is followed by a list of costs for the links from these neighbors to the router generating the Hello packet containing this PMPR TLV, as detailed in Section 5.2.4. The PMPR TLV structure is detailed in Section 6.3.

5.2.7. Hello Packet Processing

In addition to the processing specified in [RFC5340], N and N2 MUST be updated when received Hello packets indicate changes to the neighborhood of an OSPFv3 MANET interface i. In particular, if a received Hello packet signals that a tuple in N (or N2) is to be deleted, the deletion is done immediately, without waiting for the tuple to expire. Note that N2 records not only 2-hop neighbors listed in received Hellos but also 2-hop neighbors listed in the appended PMPR TLVs.

The Flooding-MPR set MUST be recomputed when either of N(i) or N2(i) has changed. The Path-MPR set MUST be recomputed when either of N or N2 has changed. Moreover, the Path-MPR set MUST be recomputed if appended LLS information signals change with respect to one or more link costs.

The Flooding-MPR-selector set and the Path-MPR-selector set MUST be updated upon receipt of a Hello packet containing LLS information indicating changes in the list of neighbors that has selected the router as MPR.

If a Hello with the S bit set is received on an OSPFv3 MANET interface of a router, from a non-adjacent neighbor, the router MUST transition this neighbor’s state to ExStart.

5.3. Adjacencies

Adjacencies are brought up between OSPFv3 MANET interfaces as described in [RFC5340] and [RFC2328]. However, in order to reduce the control-traffic overhead over the OSPFv3 MANET interfaces, a router that has one or more such OSPFv3 MANET interfaces MAY bring up adjacencies with only a subset of its MANET neighbors.

Over an OSPFv3 MANET interface, a router MUST bring up adjacencies with all MANET neighbors that are included in its MPR set and its MPR-selector set; this ensures that, beyond the first hop, routes use synchronized links (if synchronized paths are preferred over non-synchronized paths of equal cost). A router MAY bring up adjacencies with other MANET neighbors, at the expense of additional synchronization overhead.

5.3.1. Packets over 2-Way Links

When a router does not form a full adjacency with a MANET neighbor, the state of that neighbor does not progress beyond 2-Way (as defined in [RFC2328]). A router can send protocol packets, such as LSAs, to a MANET neighbor in 2-Way state. Therefore, any packet received from a symmetric MANET neighbor MUST be processed.

As with the OSPF broadcast interface [RFC2328], the next hop in the forwarding table MAY be a neighbor that is not adjacent. However, when a data packet has travelled beyond its first hop, the MPR-selection process guarantees that subsequent hops in the shortest path tree (SPT) will be over adjacencies (if synchronized paths are preferred over non-synchronized paths of equal cost).

5.3.2. Adjacency Conservation

Adjacencies are torn down according to [RFC2328]. When the MPR set or MPR-selector set is updated (due to changes in the neighborhood), and when a neighbor was formerly, but is no longer, in the MPR set or the MPR-selector set, then the adjacency with that neighbor is kept unless the change causes the neighbor to cease being a symmetric 1-hop neighbor.

When a router receives Hello packets from a symmetric 1-hop neighbor that ceases to list this router as being adjacent (see Section 5.2.6), the state of that neighbor MUST be changed to:

1. 2-Way if the neighbor is not in the MPR set or MPR-selector set, or

2. ExStart if either the neighbor is in the MPR set or MPR-selector set, or the neighbor or the router itself is a Synch router.

5.4. Link State Advertisements

Routers generate Router-LSAs periodically, using the format specified in [RFC5340] and [RFC2328].

Routers that have one or more OSPFv3 MANET interfaces MUST include the following links in the Router-LSAs that they generate:

- o links to all neighbors that are in the Path-MPR set, AND

- o links to all neighbors that are in the Path-MPR-selector set.

Routers that have one or more OSPFv3 MANET interfaces MAY list other links they have through those OSPFv3 MANET interfaces, at the expense of larger LSAs.

In addition, routers that have one or more OSPFv3 MANET interfaces MUST generate updated Router-LSAs when either of the following occurs:

- o a new adjacency has been brought up, reflecting a change in the Path-MPR set;

- o a new adjacency has been brought up, reflecting a change in the Path-MPR-selector set;

- o a formerly adjacent and advertised neighbor ceases to be adjacent;

- o the cost of a link to (or from) an advertised neighbor has changed.

5.4.1. LSA Flooding

An originated LSA is flooded, according to [RFC5340], out all interfaces concerned by the scope of this LSA.

Link State Updates received on an interface of a type other than OSPFv3 MANET interface are processed and flooded according to [RFC2328] and [RFC5340], over every interface. If a Link State Update was received on an OSPFv3 MANET interface, it is processed as follows:

1. Consistency checks are performed on the received packet according to [RFC2328] and [RFC5340], and the Link State Update packet is thus associated with a particular neighbor and a particular area.

2. If the Link State Update was received from a router other than a symmetric 1-hop neighbor, the Link State Update MUST be discarded without further processing.

3. Otherwise, for each LSA contained in Link State Updates received over an OSPFv3 MANET interface, the following steps replace steps 1 to 5 of Section 13.3 of [RFC2328].

(1) If an LSA exists in the Link State Database, with the same Link State ID, LS Type, and Advertising Router values as the received LSA, and if the received LSA is not newer (see Section 13.1 of [RFC2328]), then the received LSA MUST NOT be processed, except for acknowledgment as described in Section 5.4.2.

(2) Otherwise, the LSA MUST be attributed a scope according to its type, as specified in Section 3.5 of [RFC5340].

(3) If the scope of the LSA is link local or reserved, the LSA MUST NOT be flooded on any interface.

(4) Otherwise:

+ If the scope of the LSA is the area, the LSA MUST be flooded on all the OSPFv3 interfaces of the router in that area, according to the default flooding algorithm described in Section 5.4.1.1.

+ Otherwise, the LSA MUST be flooded on all the OSPFv3 interfaces of the router according to the default flooding algorithm described in Section 5.4.1.1.

5.4.1.1. Default LSA Flooding Algorithm

The default LSA flooding algorithm is as follows:

1. The LSA MUST be installed in the Link State Database.

2. The Age of the LSA MUST be increased by InfTransDelay.

3. The LSA MUST be retransmitted over all OSPFv3 interfaces of types other than OSPFv3 MANET interface.

4. If the sending OSPFv3 interface is a Flooding-MPR-selector of this router, then the LSA MUST also be retransmitted over all OSPFv3 MANET interfaces concerned by the scope, with the multicast address all_SPF_Routers.

Note that MinLSArrival SHOULD be set to a value that is appropriate to dynamic topologies: LSA updating may need to be more frequent in MANET parts of an OSPF network than in other parts of an OSPF network.

5.4.2. Link State Acknowledgments

When a router receives an LSA over an OSPFv3 MANET interface, the router MUST proceed to acknowledge the LSA as follows:

1. If the LSA was not received from an adjacent neighbor, the router MUST NOT acknowledge it.

2. Otherwise, if the LSA was received from an adjacent neighbor and if the LSA is already in the Link State Database (i.e., the LSA has already been received and processed), then the router MUST send an acknowledgment for this LSA on all OSPFv3 MANET interfaces to the multicast address all_SPF_Routers.

3. Otherwise, if the LSA is not already in the Link State Database:

    1. If the router decides to retransmit the LSA (as part of the flooding procedure), the router MUST NOT acknowledge it, as this retransmission will be considered as an implicit acknowledgment.

    2. Otherwise, if the router decides to not retransmit the LSA (as part of the flooding procedure), the router MUST send an explicit acknowledgment for this LSA on all OSPFv3 MANET interfaces to the multicast address all_SPF_Routers.

If a router sends an LSA on an OSPFv3 MANET interface, it expects acknowledgments (explicit or implicit) from all adjacent neighbors. In the case where the router did not generate, but simply relays, the LSA, then the router MUST expect acknowledgments (explicit or implicit) only from adjacent neighbors that have not previously acknowledged this LSA. If a router detects that some adjacent neighbor has not acknowledged the LSA, then that router MUST retransmit the LSA.

If, due to the MPR flooding-reduction mechanism employed for LSA flooding as described in Section 5.4.1, a router decides to not relay an LSA, the router MUST still expect acknowledgments of this LSA (explicit or implicit) from adjacent neighbors that have not previously acknowledged this LSA. If a router detects that some adjacent neighbor has not acknowledged the LSA, then the router MUST retransmit the LSA.

Note that it may be beneficial to aggregate several acknowledgments in the same transmission, taking advantage of native multicasting (if available). A timer wait MAY thus be used before any acknowledgment transmission.

Additionally, jitter [RFC5148] on packet (re)transmission MAY be used in order to increase the opportunities to bundle several packets together in each transmission.

5.5. Hybrid Routers

In addition to the operations described in Section 5.2, Section 5.3 and Section 5.4, Hybrid routers MUST:

- o select ALL their MANET neighbors as Path-MPRs.

- o list adjacencies over OSPFv3 interfaces of types other than OSPFv3 MANET interface, as specified in [RFC5340] and [RFC2328], in generated Router-LSAs.

5.6. Synch Routers

In a network with no Hybrid routers, at least one Synch router MUST be selected. A Synch router MUST:

- o set the S bit in the PMPR TLV appended to the Hello packets it generates, AND

- o become adjacent with ALL MANET neighbors.

A proposed heuristic for selection of Sync routers is as follows:

- o A router that has a MANET interface and an ID that is higher than the ID of all of its current neighbors, and whose ID is higher than any other ID present in Router-LSAs currently in its Link State Database selects itself as Synch router.

Other heuristics are possible; however, any heuristic for selecting Synch routers MUST ensure the presence of at least one Synch or Hybrid router in the network.

5.7. Routing Table Computation

When routing table (re)computation occurs, in addition to the processing of the Link State Database defined in [RFC5340] and [RFC2328], routers that have one or more MANET interfaces MUST take into account links between themselves and MANET neighbors that are in state 2-Way or higher (as data and protocol packets may be sent, received, and processed over these links too). Thus, the connectivity matrix used to compute routes MUST reflect links between the root and all its neighbors in state 2-Way and higher, as well as links described in the Link State Database.

6. Packet Formats

OSPFv3 packets are as defined by [RFC5340] and [RFC2328]. Additional LLS signaling [RFC4813] is used in Hello packets sent over OSPFv3 MANET interfaces, as detailed in this section.

This specification uses network byte order (most significant octet first) for all fields.

6.1. Flooding-MPR TLV

A TLV of Type FMPR is defined for signaling Flooding-MPR selection, shown in Figure 1.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|            Type=FMPR          |           Length              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  Willingness  | # Sym. Neigh. |  # Flood MPR  |    Reserved   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 1: Flooding-MPR TLV (FMPR)

where:

Willingness - is an 8-bit unsigned integer field that specifies the willingness of the router to flood link-state information on behalf of other routers. It can be set to any integer value from 1 to 6. By default, a router SHOULD advertise a willingness of WILL_DEFAULT = 3.

Sym. Neigh. - is an 8-bit unsigned integer field that specifies the number of symmetric 1-hop neighbors. These symmetric 1-hop neighbors are listed first among the neighbors in a Hello packet.

Flood MPR - is an 8-bit unsigned integer field that specifies the number of neighbors selected as Flooding-MPR. These Flooding-MPRs are listed first among the symmetric 1-hop neighbors.

Reserved - is an 8-bit field that SHOULD be cleared ('0') on transmission and SHOULD be ignored on reception.

6.2. Metric-MPR TLV

A TLV of Type METRIC-MPR is defined for signaling costs of links to neighbors, shown in Figure 2.

```
    0                   1                   2                   3
    0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |        Type=METRIC-MPR        |            Length             |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |         Reserved          |U|R|            Cost 0             |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |           Cost 1              |            Cost 2             |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   :                                                               :
   :                                                               :
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |           Cost n              |             Padding           |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 2: Metric TLV (METRIC-MPR)

where:

Reserved - is a 14-bit field that SHOULD be cleared ('0') on transmission and SHOULD be ignored on reception.

R - is a binary flag, cleared ('0') if the costs advertised in the TLV are direct (i.e., the costs of the links from the router to the neighbors), or set ('1') if the costs advertised are reverse (i.e., the costs of the links from the neighbors to the router). By default, R is cleared ('0').

U - is a binary flag, cleared ('0') if the cost for each link from the sending router and to each advertised neighbor is explicitly included (shown in Figure 3), or set ('1') if a single metric value is included that applies to all links (shown in Figure 4).

Cost n - is an 8-bit unsigned integer field that specifies the cost of the link, in the direction specified by the R flag, between this router and the neighbor listed at the n-th position in the Hello packet when counting from the beginning of the Hello packet and with the first neighbor being at position 0.

Padding - is a 16-bit field that SHOULD be cleared ('0') on transmission and SHOULD be ignored on reception. Padding is included in order that the TLV is 32-bit aligned. Padding MUST be included when the TLV contains an even number of Cost fields and MUST NOT be included otherwise.

```
     0                   1                   2                   3
     0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |        Type=METRIC-MPR        |            Length             |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |          Reserved         |0|R|            Cost 0             |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |            Cost 1             |            Cost 2             |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 3: Metric Advertisement TLV (METRIC-MPR) example with explicit individual link costs (U=0) and an odd number of Costs (and, hence, no padding).

```
     0                   1                   2                   3
     0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |        Type=METRIC-MPR        |            Length             |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |          Reserved         |1|R|            Cost               |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 4: Metric Advertisement TLV (METRIC-MPR) example with a single and uniform link cost (U=1) (and, hence, no padding).

6.3. Path-MPR TLV

A TLV of Type PMPR is defined for signaling Path-MPR selection, shown in Figure 1, as well as the link cost associated with these Path-MPRs.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|           Type=PMPR           |            Length             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  # Sym Neigh  |  # Adj. Neigh |   # Path-MPR  | Reserved  |U|S|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                          Neighbor ID                          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                          Neighbor ID                          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
:                                                               :
:                                                               :
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|            Cost 0             |             Cost 1            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
:                                                               :
:                                                               :
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|            Cost n             |             Padding           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 5: Path-MPR TLV (PMPR)

Sym Neigh. - is an 8-bit unsigned integer field that specifies the number of symmetric 1-hop MANET neighbors of all OSPFv3 MANET interfaces of the router, listed in the PMPR TLV.

Adj. Neigh. - is an 8-bit unsigned integer field that specifies the number of adjacent neighbors. These adjacent neighbors are listed first among the symmetric 1-hop MANET neighbors of all OSPFv3 MANET interfaces of the router in the PMPR TLV.

Path-MPR - is an 8-bit unsigned integer field that specifies the number of MANET neighbors selected as Path-MPR. These Path-MPRs are listed first among the adjacent MANET neighbors in the PMPR TLV.

Reserved - is a 6-bit field that SHOULD be cleared ('0') on transmission and SHOULD be ignored on reception.

U - is a binary flag, cleared ('0') if the cost for each link from each advertised neighbor in the PMPR TLV and to the sending router is explicitly included (as shown in Figure 6), or set ('1') if a single metric value is included that applies to all links (as shown in Figure 7).

S - is a binary flag, cleared ('0') if the router brings up adjacencies only with neighbors in its MPR set and MPR-selector set, as per Section 5.3, or set ('1') if the router brings up adjacencies with all MANET neighbors as a Synch router, as per Section 5.6.

Neighbor ID - is a 32-bit field that specifies the router ID of a symmetric 1-hop neighbor of an OSPFv3 MANET interface of the router.

Cost n - is a 16-bit unsigned integer field that specifies the cost of the link in the direction from the n-th listed advertised neighbor in the PMPR TLV and towards this router. A default value of 0xFFFF (i.e., infinity) MUST be advertised unless information received via Hello packets from the neighbor specifies otherwise, in which case the received information MUST be advertised. If a neighbor is reachable via more than one interface, the cost advertised MUST be the minimum of the costs by which that neighbor can be reached.

Padding - is a 16-bit field that SHOULD be cleared ('0') on transmission and SHOULD be ignored on reception. Padding is included in order that the PMPR TLV is 32-bit aligned. Padding MUST be included when the TLV contains an odd number of Cost fields and MUST NOT be included otherwise.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|             Type=PMPR         |             Length            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  # Sym Neigh  |  # Adj. Neigh |   # Path-MPR  | Reserved  |0|S|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                          Neighbor ID                          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                          Neighbor ID                          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
:                                                               :
:                                                               :
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|              Cost 1           |              Cost 2           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
:                            .......                            :
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|             Cost n-1          |              Cost n           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 6: Path-MPR TLV (PMPR) with explicit individual link costs (U=0) and an even number of Cost fields (hence, no padding).

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|          Type=PMPR            |             Length            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  # Sym Neigh  |  # Adj. Neigh |   # Path-MPR  | Reserved  |1|S|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                          Neighbor ID                          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                          Neighbor ID                          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|              Cost             |              Padding          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 7: Path-MPR TLV (PMPR) with a single and uniform link cost (U=1) (hence, padding included).

7. Security Considerations

[RFC4593] describes generic threats to routing protocols, whose applicability to OSPFv3 [RFC5340] is not altered by the presence of OSPFv3 MANET interfaces. As such, the OSPFv3 MANET interface type does not introduce new security threats to [RFC5340].

However, the use of a wireless medium and the lack of infrastructure, as enabled by the use of the OSPFv3 MANET interface type, may render some of the attacks described in [RFC4593] easier to undertake.

For example, control-traffic sniffing and control-traffic analysis are simpler tasks with wireless than with wires, as it is sufficient to be somewhere within radio range in order to "listen" to wireless traffic. Inconspicuous wiretapping of the right cable(s) is not necessary.

In a similar fashion, physical signal interference is also a simpler task with wireless than with wires, as it is sufficient to emit from somewhere within radio range in order to be able to disrupt the communication medium. No complex wire connection is required.

Other types of interference (including not forwarding packets), spoofing, and different types of falsification or overloading (as described in [RFC4593]) are also threats to which routers using OSPFv3 MANET interfaces may be subject. In these cases, the lack of predetermined infrastructure or authority, enabled by the use of OSPFv3 MANET interfaces, may facilitate such attacks by making it easier to forge legitimacy.

Moreover, the consequence zone of a given threat, and its consequence period (as defined in [RFC4593]), may also be slightly altered over the wireless medium, compared to the same threat over wired networks. Indeed, mobility and the fact that radio range spans "further" than a mere cable may expand the consequence zone in some cases; meanwhile, the more dynamic nature of MANET topologies may decrease the consequence period, as harmful information (or lack of information) will tend to be replaced quicker by legitimate information.

8. IANA Considerations

This document defines three LLS TLVs, for which type values have been allocated from the LLS TLV type registry defined in [RFC4813].

Mnemonic	Type Value	Name
FMPR	3	Flooding-MPR
METRIC-MPR	4	Metric-MPR
PMPR	5	Path-MPR

Table 1: LLS TLV Type Assignments

9. References

9.1. Normative References

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9.2. Informative References

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Appendix A. Flooding-MPR Selection Heuristic

The following specifies a proposed heuristic for selection of Flooding-MPRs on interface i. It constructs a Flooding-MPR set that enables a router to reach routers in the 2-hop neighborhood through relaying by one Flooding-MPR router.

The following terminology will be used in describing the heuristics: D(Y) is the degree of a 1-hop neighbor, router Y (where Y is a member of N(i), defined as the number of neighbors of router Y, EXCLUDING all the members of N(i) and EXCLUDING the router performing the computation. The proposed heuristic can then be described as follows. Begin with an empty Flooding-MPR set. Then:

1. Calculate D(Y), where Y is a member of N(i), for all routers in N(i).

2. Add to the Flooding-MPR set those routers in N(i) that are the only routers to provide reachability to a router in N2(i). For example, if router B in N2(i) can be reached only through a router A in N(i), then add router A to the Flooding-MPR set. Remove the routers from N2(i) that are now covered by a router in the Flooding-MPR set.

3. While there exist routers in N2(i) that are not covered by at least one router in the Flooding-MPR set:

    1. For each router in N(i), calculate the reachability, i.e., the number of routers in N2(i) that are not yet covered by at least one router in the Flooding-MPR set, and that are reachable through this 1-hop neighbor;

    2. Select as a Flooding-MPR the neighbor with the highest willingness among the routers in N(i) with non-zero reachability. In case of a tie among routers with the same willingness, select the router that provides reachability to the maximum number of routers in N2(i). In case of another tie between routers also providing the same amount of reachability, select as Flooding-MPR the router whose D(Y) is greater. Remove the routers from N2(i) that are now covered by a router in the Flooding-MPR set.

4. As an optimization, consider in increasing order of willingness each router Y in the Flooding-MPR set: if all routers in N2(i) are still covered by at least one router in the Flooding-MPR set when excluding router Y, then router Y MAY be removed from the Flooding-MPR set.

Other algorithms, as well as improvements over this algorithm, are possible. Different routers may use different algorithms independently. However, the algorithm used MUST provide the router with a Flooding-MPR set that fulfills the flooding coverage criterion, i.e., it MUST select a Flooding-MPR set such that any 2-hop neighbor is covered by at least one Flooding-MPR router.

Appendix B. Path-MPR Selection Heuristic

The following specifies a proposed heuristic for calculating a Path-MPR set that enables a router to reach routers in the 2-hop neighborhood through shortest paths via routers in its Path-MPR set. The following terminology will be used for describing this heuristic:

A - The router performing the Path-MPR set calculation.

B, C, D, ... - Other routers in the network.

cost(A,B) - The cost of the path through the direct link, from A to B.

dist(C,A) - The cost of the shortest path from C to A.

A cost matrix is populated with the values of the costs of links originating from router A (available locally) and with values listed in Hello packets received from neighbor routers. More precisely, the cost matrix is populated as follows:

1. The coefficients of the cost matrix are set by default to 0xFFFF (maximal value, i.e., infinity).

2. The coefficient cost(A,B) of the cost matrix for a link from router A to a neighbor B (the direct cost for this link) is set to the minimum cost over all interfaces that feature router B as a symmetric 1-hop neighbor. The reverse cost for this link, cost(B,A), is set at the value received in Hello packets from router B. If router B is reachable through several interfaces at the same time, cost(B,A) is set as the minimum cost advertised by router B for its links towards router A.

3. The coefficients of the cost matrix concerning the link between two neighbors of A, routers C and B, are populated at the reception of their Hello packets. The cost(B,C) is set to the value advertised by the Hello packets from B, and, respectively, the cost(C,B) is set to the value advertised in Hello packets from C.

4. The coefficients cost(B,C) of the cost matrix for a link that connects a neighbor B to a 2-hop neighbor C are obtained via the Hello packets received from router B. In this case, cost(B,C) and cost(C,B) are respectively set to the values advertised by router B for the direct cost and reverse cost for node C.

Once the cost matrix is populated, the proposed heuristic can then be described as follows. Begin with an empty Path-MPR set. Then:

1. Using the cost matrix and the Dijkstra algorithm, compute the router distance vector, i.e., the shortest distance for each pair (X,A) where X is in N or N2 minimizing the sum of the cost of the path between X and A.

2. Compute N’ as the subset of N made of the elements X such that cost(X,A)=dist(X,A).

3. Compute N2’ as the subset of N and N2 made of the elements Y that do not belong to N’ and such that there exist X in N’ such cost(Y,X)+cost(X,A)=dist(Y,A).

4. Compute the MPR selection algorithm presented in Appendix A with N’ instead of N(i) and N2’ instead of N2(i). The resulting MPR set is the Path-MPR set.

Other algorithms, as well as improvements over this algorithm, are possible. Different routers may use different algorithms independently. However, the algorithm used MUST provide the router with a Path-MPR set that fulfills the path coverage criterion, i.e., it MUST select a Path-MPR set such that for any element of N or N2 that is not in the Path-MPR set, there exists a shortest path that goes from this element to the router through a neighbor selected as Path-MPR (unless the shortest path is only one hop).

Appendix C. Contributors

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