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# On-Demand Multicast Routing Protocol (ODMRP) for Ad Hoc Networks
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## Abstract

The On-Demand Multicast Routing Protocol (ODMRP) is a multicast routing protocol designed for ad hoc networks with mobile hosts. ODMRP is a mesh-based, rather than a conventional tree-based, multicast scheme and uses a forwarding group concept (only a subset of nodes forwards the multicast packets via scoped flooding). It applies on-demand procedures to dynamically build routes and maintain multicast group membership. ODMRP is well suited for ad hoc wireless networks with mobile hosts where bandwidth is limited, topology changes frequently and rapidly, and power is constrained.

## Status of this Memo

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# 1. Introduction

This document describes the On-Demand Multicast Routing Protocol (ODMRP) [ODMRP-Journal]. ODMRP applies "on-demand" routing techniques to avoid channel overhead and improve scalability. It uses the concept of "forwarding group" [FGMP], a set of nodes responsible for forwarding multicast data, to build a forwarding mesh for each multicast group. By maintaining and using a mesh instead of a tree, the drawbacks of multicast trees in mobile wireless networks (e.g., intermittent connectivity, traffic concentration, frequent tree reconfiguration, non-shortest path in a shared tree, etc.) are avoided. A soft-state approach is taken to maintain multicast group members, meaning that no explicit control message is required to leave the group.

## 1.1. Motivation and Experiments

The main rationale for ODMRP is its potential to reduce control and traffic overhead in certain MANET deployments, typically where multicast traffic is relatively sparse. While this protocol has been extensively studied in simulations, it does not yet benefit from sufficient operational experience in order to be considered for standards track. In addition to general operational experience such as interoperability testing, this specification is intended to collect data on the following points:

- As a multicast routing protocol for MANET, ODMRP can be compared with [RFC6621], but can also be used in conjunction, taking advantage of its Duplicate Packet Detection and optimized flooding mechanisms. The rationale behind ODMRP is that, with sparser traffic, and in particular less sources, ODMRP should reduce the control overhead and number of data packets transmitted by making use of Forwarding Groups. This hypothesis should be validated, and experiments and operational deployments demonstrating the scenarios in which ODMRP performs better, or worse, than [RFC6621] should be performed.

- The potential scope of deployment of ODMRP should be assessed, particularly in comparison to other MANET protocols.

- The effects of the router and interface parameters described in Section 5 should be more clarified, in order to provide guidelines to tune these parameters to specific deployments and a set of defaults backed by operational experience.

- The feasability of implementing ODMRP in common MANET situations should be examined. In particular, it should be determined if a linux user space implementation is possible.

## 2. Terminology and Notation

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 also makes use of the terminology defined in [RFC5444]. Additionally, it uses the notation defined in Section 2.1, and the terminology defined in Section 2.2.

### 2.1. Notation

ODMRP Routers generate and process messages, each of which has a number of distinct fields. For describing the protocol operation, specifically the generation and processing of such messages, the following notation is employed:

MsgType.field

where:

MsgType - is the type of message (e.g., JQ or JR);

field - is the field in the message (e.g., SourceAddress).

Furthermore, the following notational conventions are used:

a := b an assignment operator, whereby the left side (a) is assigned the value of the right side (b)

c = d a comparison operator, returning TRUE if and only if the value of the left side (c) is equal to the value of the right side (d)

The different messages, their fields and their meaning are described in Section 7.

### 2.2. Terminology

ODMRP Router - A router that implements this protocol. An ODMRP Router is equipped with at least one, and possibly more, ODMRP Interfaces.

ODMRP Interface - An ODMRP Router's attachment to a communication medium, over which it receives and generates control messages, according to this specification. An ODMRP Router is assigned one or more addresses.

Neighbor ODMRP Router - An ODMRP Router A is a neighbor of another ODMRP Router B if B can receive control messages from A according to this specification. This relationship is not necessarily symmetrical.

Neighbor Interface - An interface X of an ODMRP Router A is a neighbor relative to interface Y of ODMRP Router B if B can receive control messages sent by A over the link X - Y.

Multicast session - The entity defined by a (multicast group, source) pair, representing the group to which a source sends multicast packets.

Forwarding group - A group of ODMRP Routers participating in multicast packet forwarding for a given Multicast session.

Join Query - The control message sent by multicast sources to establish and update group memberships and routes.

Join Reply - The control message sent by multicast receivers and forwarded by forwarding nodes to build the Multicast overlay according to group membership information.

Upstream - An ODMRP Router (A) is said to be "upstream" compared to another ODMRP Router (B), relatively to a given multicast session, if A is on the path, which is discovered by a Join Query-Join Reply exchange and used by data packets, between B and the multicast source.

Downstream - An ODMRP Router (A) is said to be "downstream" compared to another ODMRP Router (B), relatively to a given multicast session, if B is on the path which is discovered by a Join Query-Join Reply exchange and used by data packets, between A and the multicast source. In other words, A is "downstream" from B if B is "upstream" from A.

## 3. Applicability Statement

This protocol is a multicast routing protocol, intended for use in Mobile Ad Hoc Networks. MANETs generally have constrained resources (processing power, battery, etc.) and very dynamic topologies. With ODMRP, routing state is installed and maintained in an on-demand fashion, which avoids the issue of frequent tree reconfiguration seen with more classic multicast routing protocols.

ODMRP can be used on its own, or in conjunction with any unicast -reactive or proactive- routing protocol, such as [RFC7181] or

[RFC3561]. Additionally, ODMRP can run in conjunction with [RFC6621], and take advantage of any optimized flooding mechanism used in the network, such as those offered by SMF, as described in Section 12.

# 4. Protocol Overview and Functioning

The objective of this protocol is to allow each ODMRP Router to:

- Build a Forwarding Group only when there is data traffic to be sent to a Multicast group.
- Maintain the Forwarding Group for as long as necessary, until there is no more data to be sent to the Multicast group.
- Join any Forwarding Group, in order to receive multicast data packets from the corresponding multicast source. The decision to join a given Forwarding Group is triggered by Multicast membership information relative to the corresponding Multicast session. Such information can be received from other protocols, such as IGMP [RFC3376] and MLD [RFC3810].

## 4.1. Routers and Interfaces

Each ODMRP Router MUST be provisioned with at least one ODMRP Interface, and keep a list of all these interfaces, as described in Section 9. The management of these interfaces (addition, deletion, re-addressing of any interface) is out of scope for this document.

## 4.2. Information Base Overview

Protocol state is recorded in four disctinct information sets: the Multicast Routing Set, the Forwarding Table, the Pending Acknowledgement Set, the Pre-acknowledgement Set and the Blacklist.

The Multicast Routing Set contains tuples, each representing the address of a multicast group, the address of a source sending data to this multicast group, and the next hop towards the multicast source

The Forwarding Table contains tuples, each representing a given Multicast session for which the ODMRP Router forwards packets

The Pending Acknowlegement Set contains tuples, each corresponding to a Join Reply message which has been sent by this Router and is waiting for an acknowledgement from the designated upstream Forwarding Group Router

The Pre-acknowledgement Set contains tuples, representing overheard Join Reply messages, that are not destined to this Router but may pre-acknowledge a future Join Reply from this Router

The Blacklist contains tuples, corresponding to neighbor ODMRP Routers, with which connectivity has been detected to be unidirectional.

## 4.3. Signaling Overview

This protocol generates and processes the following routing messages:

Join Query - Generated by an ODMRP Router while it has data packets to send to a multicast group, and flooded periodically to maintain the Forwarding Group necessary to deliver these data packets. A Join Query message hence advertises a Multicast Session, and contains:

* The multicast group address
* The source address
* A sequence number

Join Reply - Generated by an ODMRP Router belonging to a multicast session in reply to a Join Query message advertising this multicast session, then forwarded by ODMRP Routers belonging to the corresponding Forwarding Group along the reverse path to the multicast source. A Join Reply message contains:

* The multicast group address
* The source address of the corresponding Join Query
* The sequence number carried by the corresponding Join Query
* The address of the next hop on the path towards the multicast session source

## 4.4. Overview

The objectives of this protocol are achieved, for each ODMRP Router, by the following operations:

o When having data to send to a multicast group, for which no Forwarding Group is already established, an ODMRP Router generates a Join Query and transmits it over all of its ODMRP Interfaces.

- Upon receiving a Join Query, an ODMRP Router installs or refreshes a tuple in the Multicast Routing Set indicating the reverse path towards the source of the Join Query, then considers it for forwarding, according to the forwarding mechanism specified for the network.

- If this Router belongs to, i.e., has attached hosts which have subscribed to, the multicast session that the Join Query advertises, it originates a Join Reply and transmits it over all of its ODMRP Interfaces.

- Upon receiving a Join Reply, an ODMRP Router inspects the next hop address carried by this packet:

  * If it corresponds to the address of an interface of this Router, and if the ODMRP Router has a tuple in its Multicast Routing Set, corresponding to the advertised source, the ODMRP Router belongs to the Forwarding Group for the Multicast Session. Consequently, it installs or refreshes the corresponding tuple in its Forwarding Table. It then considers the Join Reply for forwarding, according to the forwarding mechanism specified for the network

  * Otherwise, it silently discards the Join Reply.

- After sending a Join Reply, an ODMRP Router looks in its Pre-acknowledgement Set for a corresponding Overheard tuple.

  * If such a tuple exists, the Overheard tuple is discarded and no further action is taken.

  * Otherwise, i.e., if the Pre-acknowledgement Set does not contain any corresponding Overheard tuple, it creates a Pending Acknowledgement tuple in the Pending Acknowledgement Set.

- While it has data to send to the multicast group, an ODMRP Router periodically originates a Join Query and transmits it to all of its neighbors, in order to maintain the Forwarding Group.

## 5. Parameters and Constants

This specification uses both Router parameters, described in Section 5.1, and per-interface parameters, described in Section 5.2.

### 5.1. Router Parameters

This specification uses the following Router parameters:

ROUTE_REFRESH_INTERVAL - is the interval between two perodic Join Queries sent by a Multicast Source

FG_TIMEOUT - is the minimum time a Forwarding Tuple SHOULD be kept in the Forwarding Table after it was last refreshed

### 5.2. Interface Parameters

This specification uses the following interface parameters:

ROUTE_TIMEOUT - is the minimum time a Routing Tuple SHOULD be kept in the Routing Set after it was last refreshed

JR_RETRIES - is the number of times an ODMRP Router SHOULD attempt to retransmit a given Join Reply before declaring the link with the upstream neighbor interface unidirectional

ACK_TIMEOUT - is the time after which a Pending Tuple expires and MUST be considered invalid, as well as trigger the appropriate action according to Section 11

PRE_ACK_TIMEOUT - is the time after which an Overheard Tuple expires and MUST be considered invalid

## 6. Sequence Numbers

Each ODMRP Router maintains a single sequence number, which must be included in each Join Query message it generates. Each ODMRP Router MUST make sure that no two Join Query messages are generated with the same sequence number, and MUST generate sequence numbers such that these are monotonically increasing. This sequence number is used as freshness information for when comparing routes to the ODMRP Router having generated the message.

However, with a limited number of bits for representing sequence numbers, wrap-around (that the sequence number is incremented from the maximum possible value to zero) will occur. To prevent this from interfering with the operation of the protocol, the following MUST be observed. The term MAX_SEQ_NUM designates in the following the largest possible value for a sequence number. The sequence number S1 is said to be "greater than" (denoted '>') the sequence number S2 if:

S2 < S1 AND S1 - S2 <= MAX_SEQ_NUM/2 OR

S1 < S2 AND S2 - S1 > MAX_SEQ_NUM/2

# 7. Packets and Messages

This section describes the protocol messages generated and processed by ODMRP, according to the notations defined in Section 2. The objective of this section is to specify the content and meaning of each message. The specifics of the encoding of these messages, including the exact type and length of each field, in accordance with [RFC5444], are described in Section 8.

## 7.1. Join Query Format

A Join Query (JQ) message has the following fields:

JQ.AddressLength encodes the length of the addresses carried by this message as follows:

JQ.AddressLength := the length of an address in octets - 1

JQ.MulticastGroupAddress encodes the address of the Multicast Group, to which this Join Query is addressed

JQ.SourceAddress encodes the address of the source of this Join Query

JQ.SequenceNumber encodes the sequence number (see Section 6) of the ODMRP Router, generating the Join Query message

## 7.2. Join Reply Format

A Join Reply (JR) message has the following fields:

JR.AddressLength encodes the length of the addresses carried by this message as follows:

JR.AddressLength := the length of an address in octets - 1

JR.MulticastGroupAddress encodes the address of the Multicast Group, to which this Join Reply is addressed

JR.AckRequired is a boolean flag. When set ('1'), it specifies that the recipient of the Join Reply MUST acknowledge its reception by a sending Join Reply message. If cleared ('0'), the recipient of this message MAY suppress it's Join Reply transmission, according to Section 10

JR.SourceAddress encodes the address of the Source of the Multicast Session

JR.SequenceNumber encodes the sequence number (see Section 6) of the corresponding Join Query message

JR.NextHopAddress encodes the the address of the next hop on the path towards the source of the multicast session

## 8. RFC5444 Encoding

This section describes the encoding of ODMRP messages using [RFC5444].

### 8.1. Join Query Encoding

This protocol defines the Join Query message type. Hence, according to [RFC5444], all Join Query messages are generated, processed and transmitted following this specification. Table 1 shows the mapping between the Join Query elements described in Section 7.1 and their encoding. All elements described in Table 1 MUST be included in every Join Query message.

| JQ Element | RFC5444 Element |
|---|---|
| JQ.AddressLength | <msg-addr-length> |
| JQ.SourceAddress | <msg-orig-addr> |
| JQ.MulticastGroupAddress | Address in address block + TLV |
| JQ.SequenceNumber | <msg-seq-num> |

Table 1: Join Query Message Elements

## 8.2. Join Reply Encoding

This protocol defines the Join Reply message type. Hence, according to [RFC5444], all Join Reply messages are generated, processed and transmitted following this specification. Table 2 shows the mapping between the Join Reply elements described in Section 7.2 and their encoding. With the exception of the ACKREQUIRED TLV, all elements described in Table 2 MUST be included in every Join Reply message.

| JR Element | RFC5444 Element |
|---|---|
| JR.AddressLength | <msg-addr-length> |
| JR.SourceAddress | <msg-orig-addr> |
| | JR.MulticastGroupAddress |
| Address in address block + TLV | JR.SequenceNumber |
| <msg-seq-num | 16 bits, hence MAX_SEQ_NUM is 65535 |
| JR.NextHopAddress | Address in address block + TLV |
| JR.AckRequired | ACKREQUIRED TLV |

Table 2: Join Reply Message Elements

## 9. Information Bases

Each router maintains an Information Base, containing a Local Interface Set, a Multicast Routing Set, a Forwarding Table, a Pending Acknowledgement Set, a Pre-Acknowledgement Set, and a Blacklist, as described in the following sections. These information sets are given so as to facilitate description of message generation, forwarding and processing rules. In particular, an implementation may chose any representation or structure for when maintaining this information.

### 9.1. Local Interface Set

The Local Interface Set records a list of all the interfaces of the ODMRP Router, which participate in the operations of this protocol; that is, over which ODMRP control messages are exchanged, according to this specification. Each tuple of the Interface Set, or Interface Tuple, is as follows:

(I_interface, I_interface_address_list)

Where:

I_interface - The local ODMRP Interface

I_interface_address_list - The list of addresses used by the local interface in the operations of this protocol.

## 9.2. Multicast Routing Set

The Multicast Routing Set contains Routing Tuples, indicating the path towards Multicast Sources, and containing the following fields:

(R_source, R_next_hop, R_local_interface, R_seq_num, R_exp_time)

Where:

R_source - is the address of the Multicast Source.

R_next_hop - is an address of the next hop along the path to the Multicast Source, i.e., an address of one of the interfaces of the neighbor ODMRP Router, from which the last valid Join Query message from this source was received, as recorded by the packet containing this Join Query.

R_local_interface - is the local interface, through which the next hop can be reached.

R_seq_num - corresponds to the JQ.SequenceNumber of the last valid Join Query originated by the Multicast Source and received by this ODMRP Router.

R_exp_time - is the time at which the tuple MUST be considered expired and thus MUST NOT be taken into consideration by the operations of this protocol.

## 9.3. Forwarding Table

The Forwarding Table contains Forwarding Tuples, representing Multicast Sessions for which the ODMRP Router forwards messages, i.e., the ODMRP Router is part of these Multicast Sessions' Forwarding Groups. These tuples are as follows:

(F_multicast_group, F_multicast_source, F_seq_num, F_exp_time)

Where:

F_multicast_group - is the address of the Multicast Group of the Multicast Session, for which the ODMRP Router forwards messages.

F_source - is the address of the Multicast Source of the Multicast Session, for which the ODMRP Router forwards messages.

F_seq_num - is the sequence number, corresponding to the last Join Query sent by the multicast source for the multicast session.

F_exp_time - is the time at which the tuple MUST be considered expired and thus MUST NOT be taken into consideration by the operations of this protocol.

### 9.4. Pending Acknowledgements

The Pending Acknowledgements Set contains Pending Acknowledgement tuples, representing Join Reply messages that are waiting to be acknowledged by the selected upstream Forwarding Group member. These tuples are as follows:

(P_multicast_group, P_multicast_source, P_seq_num, P_local_interface, P_next_hop, P_nth_time, P_exp_time)

Where:

P_multicast_group - is the JR.MulticastGroupAddress carried in the Join Reply awaiting acknowledgement (henceforth corresponding Join Reply).

P_multicast_source - is the JR.SourceAddress field carried in the corresponding Join Reply.

P_seq_num - is the JR.SequenceNumber field of the corresponding Join Reply.

P_next_hop - is the JR.NextHopAddress field of the corresponding Join Reply.

P_local_interface - is the local interface, through which the Join Reply was sent.

P_nth_time - corresponds to the number of times this Join Reply has been previously sent without being acknowledged.

P_exp_time - is the time at which this tuple MUST be considered expired.

P_acknowledged - is a boolean indicating whether the corresponding Join Reply has been acknowledged.

### 9.5. Pre-acknowledgements

The Pre-acknowledgements Set contains Overheard Tuples, corresponding to Join Reply messages, which have been sent by neighbors of this ODMRP Router but do not contain an address of this Router and do not acknowledge any tuple in the Pending Acknowledgement Set. The Overheared Tuples are as follows:

(O_multicast_group, O_multicast_source, O_seq_num, O_originator, O_exp_time)

Where:

O_multicast_group - is the JR.MulticastGroupAddress carried in the overheard Join Reply.

O_multicast_source - is the JR.SourceAddress field carried in the corresponding Join Reply.

O_seq_num - is the JR.SequenceNumber field of the corresponding Join Reply.

O_originator - is the address of the ODMRP Router's interface which has sent the Join Reply.

O_exp_time - is the time at which this tuple expires MUST be considered invalid.

### 9.6. Blacklist

The Blacklist contains Blacklisted Tuples, corresponding to neighbor ODMRP Router interfaces, with which connectivity has been detected to be unidirectional, e.g., which have not acknowledged Join Replies from this Router, as specified in Section 10. In other words, a Blacklisted Tuple corresponds to a link between one local interface and one neighbor interface which has been detected to be unidirectional or broken. The Blacklist Tuples are as follows:

(B_neighbor_interface, B_local_interface, B_exp_time)

Where:

B_neighbor_interface_address_list - is a list of addresses belonging to the blacklisted interface.

B_local_interface - is the interface of this ODMRP router over which packets from the blacklisted interface were received.

B_exp_time - is the time at which this tuple expires and MUST be considered invalid.

## 10. Protocol Details

This protocol generates and processes Join Query and Join Reply messages, according to the operations described in the following sections. This section uses the additional notation and variables:

previous-hop-address - refers to the address of the interface of the neighbor ODMRP Router, from which the message currently processed (Join Query or Join Reply) has been received

this Router - refers to the ODMRP Router generating, processing or forwarding the message (Join Query or Join Reply)

Receiving Interface (receiving-interface) - refers to the local ODMRP Interface, over which the message currently being processed was received

receiving-interface-address - refers to the address of the Receiving Interface

### 10.1. Join Query

A Join Query is generated by an ODMRP Router, which has data to send to a multicast group, for which multicast session has been initialized. Join Queries are then periodically originated by the ODMRP Router while it has data to send to the multicast group.

#### 10.1.1. Invalid Join Queries

A Join Query, received by an ODMRP Router, is invalid and MUST be discarded without processing (and in particular, MUST NOT be considered for forwarding) if any of these conditions applies:

- The address length carried by the Join Query (see Section 7) differs from the length of the addresses of this Router
- The Multicast Routing Set of this Router contains a Multicast Routing tuple, for which:
  - R_multicast_source = JQ.SourceAddress, and

    * R_seqnum > JQ.SequenceNumber or R_seqnum = JQ.SequenceNumber

- JQ.SourceAddress is an address of an interface of this Router
- The Blacklist contains a Blacklisted Tuple, for which
    * previous-hop-address is contained in B_neighbor_interface_address_list
    * B_local_interface = receiving-interface

#### 10.1.2. Join Query Generation

A Join Query is generated according to Section 7 with the following content:

- JQ.AddressLength set to the length of the addresses of this Router minus 1, as specified in Section 7
- JQ.MulticastGroupAddress set to the address of the multicast group, to which this Router is sending data
- JQ.SourceAddress set to an address of this ODMRP Router
- JQ.SequenceNumber set to the current sequence number of this Router, as specified in Section 6

#### 10.1.3. Join Query Processing

Upon receiving a valid Join Query message, an ODMRP Router proceeds as follows:

1. Find the Routing Tuple which satisfies: R_source = JQ.SourceAddress
2. If no such tuple exists, create a Routing Tuple with the following fields:
    * R_source := JQ.SourceAddress
    * R_next_hop := previous-hop
    * R_local_interface := receiving-interface
    * R_seq_num := JQ.SequenceNumber
    * R_exp_time := current_time + ROUTE_TIMEOUT

and insert this tuple in the Routing Set

3. Else, i.e., if such a tuple exist, update it as follows:

   * R_next_hop := previous-hop

   * R_seq_num := JQ.SequenceNumber

   * R_local_interface := receiving-interface

   * R_exp_time := current_time + ROUTE_TIMEOUT

4. Consider the Join Query for forwarding, according to Section 10.1.4

5. If this Router is a member of the Multicast Group, addressed by JQ.MulticastGroupAddress, create a new Join Reply according to Section 10.2 and transmit it to all of this Router's neighbors

### 10.1.4. Join Query Forwarding

A Join Query considered for forwarding MUST be updated as follows:

- JQ.PreviousHop is set to an address of this Router

The Join Query is then forwarded according to the flooding mechanism in place in the network

## 10.2. Join Reply

A Join Reply is generated by an ODMRP Router when it receives a Join Query such that at least one host attached to the ODMRP Router is a member of the Multicast Session advertised by the Join Query. This section makes use of the variable "new-jr", which is a boolean flag set to TRUE if the Join Reply being processed contains more recent data than in the current information base. It has an initial value of FALSE.

### 10.2.1. Invalid Join Replies

A Join Reply, received by an ODMRP Router, is invalid and MUST be discarded without processing (and in particular, MUST NOT be considered for forwarding) if:

- The address length carried by the Join Reply (see Section 7) differs from the length of the address of the ODMRP Router

- There exists a Forwarding Tuple in this Router's Forwarding Group table, such as:
  - F_source = JR.MulticastSourceAddress
  - F_seq_num > JR.SequenceNumber

#### 10.2.2. Join Reply Generation

An ODMRP Router MUST generate a Join Reply in response to a received Join Query (henceforth "corresponding Join Query"), if at least one host attached to this Router is a member of the Multicast Session, advertised by the Join Query. A Join Reply is generated according to Section 7 with the following content:

- JR.AddressLength is set to the length of the address of this router minus 1, as specified in Section 7
- JR.MulticastGroupAddress is set to JQ.MulticastGroupAddress for the corresponding Join Query
- JR.SourceAddress is set to JQ.SourceAddress for the corresponding Join Query
- JR.SequenceNumber is set to JQ.SequenceNumber for the corresponding Join Query
- JR.NextHopAddress is set to the source address of the packet containing the Join Query message

#### 10.2.3. Join Reply Processing

Upon receiving a valid Join Reply, an ODMRP Router proceeds as follows:

1. If JR.NextHopAddress corresponds to an address recorded in the Local Interface Set of this ODMRP Router:
   1. Find the Forwarding Tuple (henceforth Matching Forwarding Tuple) such that:
      + F_multicast_group = JR.MulticastGroupAddress
      + F_multicast_source = JR.MulticastSourceAddress
   2. If no such tuple exists, insert in the Forwarding Table a new Forwarding Tuple such that:

+ F_multicast_group = JR.MulticastGroupAddress

+ F_multicast_source = JR.MulticastSourceAddress

+ F_seq_num = JR.SequenceNumber

+ F_exp_time = current_time + FG_TIMEOUT

And set new-jr to TRUE

3. Otherwise, the variable "new-jr" is set to TRUE if JR.SequenceNumber > F_seq_num, and to FALSE otherwise. Then, the pre-existing Matching Forwarding Tuple is updated as follows:

+ F_seq_num := JR.SequenceNumber

+ F_exp_time := current_time + FG_TIMEOUT

4. If new-jr = TRUE or if JR.AckRequired is set the Join Reply is considered for forwarding. Otherwise, it is not processed further; in particular, it MUST NOT be considered for forwarding.

2. Otherwise, find the Multicast Routing Tuple in the Routing Set (henceforth "Matching Multicast Routing Tuple"), such as:

* R_source = JR.SourceAddress

* R_seq_num <= JR.SequenceNumber

If previous-hop-address = R_next_hop, then:

3. If the Pending Acknowledgement Set contains a Pending Tuple (henceforth "Matching Pending Tuple") such as:

+ P_multicast_group = JR.MulticastAddress

+ P_multicast_source = JR.SourceAddress

+ P_seq_num = JR.SequenceNumber

+ P_next_hop = previous-hop-address

The Matching Pending Tuple MUST be updated as follows:

+ P_acknowledged = TRUE

+ P_exp_time = EXPIRED

The Join Reply is not processed further, and in particular MUST NOT be considered for forwarding

4. Otherwise, if the Pre-Acknowledgement Set does not contain any Overheard Tuple such as:

+ O_multicast_group = JR.MulticastGroupAddress

+ O_multicast_source = JR.SourceAddress

+ O_seq_num = JR.SequenceNumber

+ O_originator = previous-hop-address

Insert a tuple with these fields, and O_exp_time = current_time + PRE_ACK_TIMEOUT in the Pre-Acknowledgement Set. The Join Reply is not processed further, and in particular MUST NOT be considered for forwarding

3. Otherwise, the Join Reply is silently discarded without further processing

### 10.2.4. Join Reply Forwarding

A Join Reply, considered for forwarding, MUST be updated as follows:

- Find the Matching Routing Tuple, such that:
  - R_source = JR.MulticastSourceAddress
  - R_seq_num <= JR.SequenceNumber
- If no such tuple exists, then the Join Reply is not processed further, and in particular MUST NOT be forwarded
- Otherwise, set JR.NextHop to R_next_hop

The Join Reply is then transmitted according to Section 10.2.5

### 10.2.5. Join Reply Transmission

A Join Reply is transmitted to all of an ODMRP Router's neighbors, in order to achieve two objectives:

- Set up or refresh the corresponding Forwarding Tuple for the upstream ODMRP neighbor

- If the Join Reply was not originated by this router, acknowledge its reception to the previous hop

Before transmitting the Join Reply, the Information Base is updated as follows:

1. If the Pre-acknowledgement Set contains a tuple, such that:

    * O_multicast_group = JR.MulticastGroupAddress
    * O_multicast_source = JR.SourceAddress
    * O_seq_num = JR.SequenceNumber
    * O_originator = JR.NextHopAddress

    Then clear the JR.AckRequired flag, and set O_exp_time to EXPIRED

2. Otherwise, if the Pending Acknowledgement Set contains a Pending Tuple such as:

    * P_multicast_group = JR.MulticastGroupAddress
    * P_multicast_source = JR.SourceAddress
    * P_seq_num = JR.SequenceNumber
    * P_next_hop = JR.NextHopAddress

    Then set JR.AckRequired, and increase P_nth_time by 1

3. Finally, if neither the Pre-acknowledgement Set nor the Pending Acknowledgement Set contain a corresponding tuple:

    1. Insert a Pending Tuple in the Pending Acknowledgement Set, such as:

        + P_multicast_group = JR.MulticastGroupAddress
        + P_multicast_source = JR.SourceAddress
        + P_seq_num = JR.SequenceNumber
        + P_next_hop = JR.NextHopAddress
        + P_nth_time = 1

+ P_acknowledged = FALSE

+ P_expiration_time = current_time + ACK_TIMEOUT

2. Clear the JR.AckRequired flag

### 10.3. Forwarding Group Maintenance

While an ODMRP Router has data to send to a Multicast Group (on behalf of the Multicast Source), it MUST maintain the Forwarding Group generated by the initial Join Query. To this end, Join Queries are periodically generated by this Router according to Section 10.1.2. The interval between two Join Queries SHOULD be no less than ROUTE_REFRESH_INTERVAL. Note should be taken that, if the Multicast Session has no member other than the source, the Forwarding Group may contain only the designated ODMRP Router for the Multicast Source. That Router still needs to periodically flood Join Queries in order to rebuild a Forwarding Group if necessary.

### 10.4. Message Transmission

When using physical media subject to collisions and packet loss, both Join Query and Join Reply messages SHOULD be jittered to minimize the effect of collisions, as described in [RFC5148]

## 11. Unidirectional Links Handling

After sending a Join Reply, an ODMRP Router MUST verify that the upstream neighbor has joined the Forwarding Group. To this end, the following three mechanisms are used after transmitting a given Join Reply:

- If the ODMRP Router overhears a corresponding Join Reply from the upstream neighbor (see Section 10.2.3), this verifies that the link is bidirectional and that the upstream neighbor has joined the Forwarding Group (passive acknowledgement)

- If the ODMRP Router has already overheard a corresponding Join Reply from the upstream neighbor prior to transmitting its own Join Reply, this means that the upstream neighbor has already joined the Forwarding Group (see Section 10.2.3) (pre-acknowledgement)

- Otherwise, i.e., if neither the pre-acknowledgement nor the passive acknowledgement have verified that the upstream neighbor joined the Forwarding Group (i.e., if the corresponding Pending Tuple expires with P_acknowledged set to False), then the ODMRP

Router MUST proceed as follows:

1. If the corresponding Pending tuple verifies P_nth_time < JR_RETRIES, then the ODMRP Router MUST retransmit the Join Reply with the JR.AckRequired flag set

2. Otherwise, the link between the local interface and the interface of the upstream ODMRP Router identified by JR.NextHopAddress is considered unidirectional. In that case, the ODMRP Router SHOULD add a tuple in the Blacklist such as:

   + B_neighbor_interface_address_list is set to a list, containing JR.NextHopAddress

   + B_local_interface is set to the interface that received the corresponding Join Query

   + B_exp_time is set to current_time + BLACKLIST_TIMEOUT

   An ODMRP Router MAY attempt to use other mechanisms, such as [I-D.gerla-manet-odmrp-asym], to resume the Forwarding Group building process, instead of or in addition to using the Blacklist

## 12. SMF considerations

This protocol MAY be run in conjunction with SMF [RFC6621], and benefit from some of its features. In particular, if SMF is in use, it is RECOMMENDED that its duplicate packet detection feature described in Section 6 be used for multicast packet forwarding. Additionally, optimized flooding mechanisms, such as E-CDS or S-MPR, as specified in Appendices A through C, MAY be used to flood Join Query messages throughout the network.

## 13. IGMP and MLD considerations

In order to determine whether or not it needs to reply to a Join Query message with a Join Reply message (as specified in Section 10.1.3), an ODMRP Router needs Multicast Group membership information. Such information can be provided by protocols such as IGMP [RFC3376] and/or MLD [RFC3810]. In particular, an ODMRP Router MUST reply with a Join Reply message to a valid Join Query messages advertising a Multicast Session if:

o This Router is subscribed to the corresponding Multicast Group.

- A host attached to this Router has signaled, e.g., using IGMP, that it has subscribed to the corresponding Multicast Group.

## 14. Multicast Packet Forwarding

ODMRP Routers originating and forwarding multicast packets MUST implement a duplicate packet detection (DPD) mechanism. If using IPv4 or IPV6 addresses, the use of SMF [RFC6621] is RECOMMENDED, as described in Section 12.

An ODMRP Router, receiving a non-duplicate multicast data packet, transmits it over all of its interfaces if it is a member of the forwarding group for this data packet, i.e., there exists a tuple in the Forwarding Group Table such as:

F_multicast_group correspond to the multicast address of this packet

F_multicast_source corresponds to the source of this packet

## 15. Security Considerations

This document does currently not have any security considerations. (TBD)

## 16. IANA Considerations

This specification defines two new Message Types, which must be allocated from the "Message Type" repository of [RFC5444].

### 16.1. Join Query Registries

IANA is requested to create a registry for Message-Type-specific Message TLV Types for Join Query messages, with initial assignments according to Table 3.

| Type | Description | Allocation Policy |
|---|---|---|
| 128-223 | Unassigned | Expert Review |

Table 3: Join Query Message-Type-specific Message TLV Types

IANA is requested to create a registry for Message-Type-specific

Address Block TLV Types for Join Query messages, with initial assignments according to Table 4.

| Type | Description | Allocation Policy |
|---|---|---|
| 128 | ADDR-TYPE | |
| 129-223 | Unassigned | Expert Review |

Table 4: Join Query Message-Type-specific Address Block TLV Types

Allocation of the ADDR-TYPE TLV from the Join Query specific Address Block TLV Types will create a new Type Extension Registry with initial assignments as specified in Table 5.

| Name | Type | Type Extension | Description | Allocation Policy |
|---|---|---|---|---|
| ADDR-TYPE | 128 | 0 | MULTICAST-GROUP-ADDRESS | |
| ADDR-TYPE | 128 | 1-255 | Unassigned | Expert Review |

Table 5: Address Block TLV Type assignment for ADDR-TYPE

## 16.2. Join Reply Registries

IANA is requested to create a registry for Message-Type-Specific Message TLV Types for Join Reply messages, with initial assignments according to Table 6.

| Type | Description | Allocation Policy |
|---|---|---|
| 128 | ACKREQUIRED | |
| 129-223 | Unassigned | Expert Review |

Table 6: Join Reply Message-Type-specific Message TLV Types

IANA is requested to create a registry for Message-Type-specific Address Block TLV Types for Join Reply messages, with initial assignments according to Table 7.

| Type | Description | Allocation Policy |
|---|---|---|
| 128 | ADDR-TYPE | |
| 129-223 | Unassigned | Expert Review |

Table 7: Join Reply Message-Type-specific Addres Block TLV Types

Allocation of the ADDR-TYPE TLV from the Join Reply specific Address Block TLV Types will create a new Type Extension Registry with initial assignments as specified in Table 8.

| Name | Type | Type Extension | Description | Allocation Policy |
|---|---|---|---|---|
| ADDR-TYPE | 128 | 0 | MULTICAST-GROUP-ADDRESS | |
| ADDR-TYPE | 128 | 1 | NEXT-HOP-ADDRESS | Expert Review |
| ADDR-TYPE | 128 | 2-255 | Unassigned | Expert Review |

Table 8: Address Block TLV Type assignment for ADDR-TYPE

## 17. Acknowledgements

The authors would like to thank Thomas Clausen and Justin Dean for their insigthful reviews and comments.

## 18. References

### 18.1. Normative References

[RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", RFC 2119, BCP 14, March 1997.

[RFC3376] Cain, B., Deering, S., Kouvelas, I., Fenner, B., and A. Thyagarajan, "Internet Group Management Protocol, Version 3", RFC 3376, October 2002.

[RFC3810] Vida, R. and L. Costa, "Multicast Listener Discovery Version 2 (MLDv2) for IPv6", RFC 3810, June 2004.

[RFC5148] Clausen, T., Dearlove, C., and B. Adamson, "Jitter Considerations in Mobile Ad Hoc Networks (MANETs)", RFC 5148, February 2008.

[RFC5444] Clausen, T., Dearlove, C., Dean, J., and C. Adjih, "Generalized MANET Packet/Message Format", RFC 5444, February 2009.

[RFC6621] Macker, J., "Simplified Multicast Forwarding", RFC 6621, May 2012.

[RFC7181] Clausen, T., Dearlove, C., Jacquet, P., and U. Herberg, "The Optimized Link State Routing Protocol Version 2", RFC 7181, April 2014.

## 18.2. Informative References

[FGMP] Chiang, C., Gerla, M., and L. Zhang, "Forwarding Group Multicast Protocol (FGMP) for Multihop, Mobile Wireless Networks", Avril 1998.

[I-D.gerla-manet-odmrp-asym] Gerla, M., Oh, S., and A. Colin de Verdiere, "ODMRP_ASYM", draft-gerla-manet-odmrp-asym-00 (work in progress).

[I-D.ietf-manet-olsrv2] Clausen, T., Dearlove, C., Jacquet, P., and U. Herberg, "The Optimized Link State Routing Protocol version 2", draft-ietf-manet-olsrv2-19 (work in progress), March 2013.

[ODMRP-Journal] Lee, S., Su, W., and M. Gerla, "On-Demand Multicast Routing Protocol in Multihop Wireless Networks", Journal of Mobile Networks and Applications, Volume 7 Issue 6, Pages 441 - 453, December 2002.

[RFC3561] Perkins, C., Belding-Royer, E., and S. Das, "Ad hoc On-Demand Distance Vector (AODV) Routing", RFC 3561, July 2003.

# Appendix A. Illustrations

This section shows examples of ODMRP control messages encoded using [RFC5444]. [RFC5444] specifies that a packet is formed by a packet header, an optional TLV block and zero or more messages. This specification does not use or require any packet TLV. Additionally, the minimal packet header required by ODMRP is shown in Figure 1.

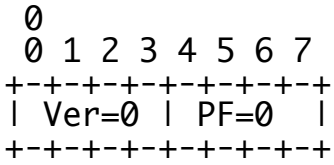


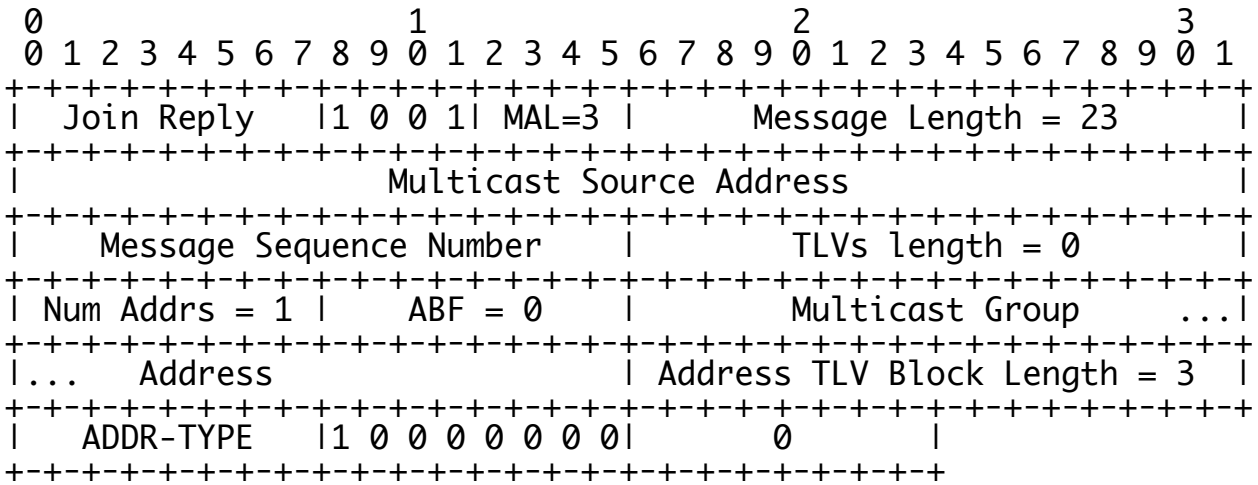

Figure 1: Packet Header

## A.1. Join Query Message

JQ messages are instances of [RFC5444] messages. This section illustrates an example of one such message.

The JQ message's header's flag octet has a value of 9, meaning that the sequence number and source address fields are present, encoding respectively the sequence number and the address of the multicast source that originated the message. Additionally, the address length field (MAL) is set to 3, corresponding to an address length of 4 octets (i.e., the length of an IPv4 address). The overall message size is 23 octets.

An additional Message-Type specific address block is present, with one address and a flag octet (ABF) having value 0, meaning that the address block has no Head or Tail element. The Mid element encodes the Multicast group address. The associated TLV is of type ADDR-TYPE and value 0, i.e. MULTICAST-GROUP-ADDRESS.

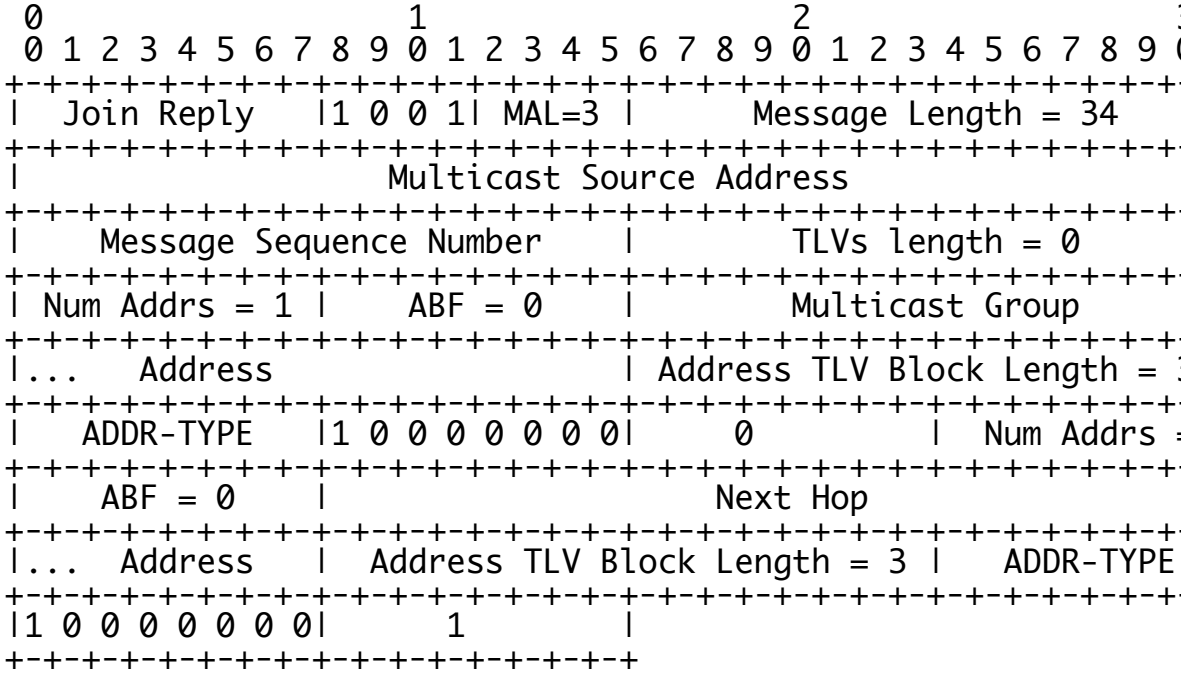



## A.2. Join Reply Message

JR messages are instances of [RFC5444] messages. This section illustrates an example of one such message.

The JR message's header's flag octet has a value of 9, meaning that the sequence number and source address fields are present, encoding respectively the sequence number and the address of the multicast source that originated the message. Additionally, the address length field (MAL) is set to 3, corresponding to an address length of 4 octets (i.e., the length of an IPv4 address). The overall message size is 34 octets.

Two additional Message-Type specific address blocks are present, both with one address and a flag octet (ABF) having value 0, meaning that the address block has no Head or Tail element. For the first address block, the Mid element encodes the Multicast group address; the associated Message-Type-specific TLV is of type ADDR-TYPE and value 0, i.e. MULTICAST-GROUP-ADDRESS. The second address block's Mid element encodes the Next Hop address; its associated Message-Type-specific TLV is of type ADDR-TYPE and value 1, i.e., NEXT-HOP-ADDRESS.

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