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**Dynamic MANET On-demand (DYMO) Routing**  
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Abstract

The Dynamic MANET On-demand (DYMO) routing protocol is intended for use by mobile routers in wireless, multihop networks. DYMO determines unicast routes among DYMO routers within the network in an on-demand fashion, offering improved convergence in dynamic topologies.

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## **1. Overview**

The Dynamic MANET On-demand (DYMO) routing protocol enables reactive, multihop unicast routing among participating DYMO routers. The basic operations of the DYMO protocol are route discovery and route maintenance.

During route discovery, the originator's DYMO router initiates dissemination of a Route Request (RREQ) throughout the network to find a route to the target's DYMO router. During this hop-by-hop dissemination process, each intermediate DYMO router records a route to the originator. When the target's DYMO router receives the RREQ, it responds with a Route Reply (RREP) sent hop-by-hop toward the originator. Each intermediate DYMO router that receives the RREP creates a route to the target, and then the RREP is unicast hop-by-hop toward the originator. When the originator's DYMO router receives the RREP, routes have then been established between the originating DYMO router and the target DYMO router in both directions.

Route maintenance consists of two operations. In order to preserve routes in use, DYMO routers extend route lifetimes upon successfully forwarding a packet. In order to react to changes in the network topology, DYMO routers monitor routes over which traffic is flowing. When a data packet is received for forwarding and a route for the destination is not known or the route is broken, then the DYMO router of the source of the packet is notified. A Route Error (RERR) is sent toward the packet source to indicate the route to that particular destination is invalid or missing. When the source's DYMO router receives the RERR, it deletes the route. If this source's DYMO router later receives a packet for forwarding to the same destination, it will need to perform route discovery again for that destination.

DYMO uses sequence numbers to ensure loop freedom [[Perkins99](#)]. Sequence numbers enable DYMO routers to determine the temporal order of DYMO route discovery messages, thereby avoiding use of stale routing information.

## **2. Applicability Statement**

The DYMO routing protocol is designed for stub or disconnected mobile ad hoc networks (MANETs). DYMO handles a wide variety of mobility patterns by dynamically determining routes on-demand. DYMO also handles a wide variety of traffic patterns. In networks with a large number of routers, DYMO is best suited for sparse traffic scenarios where routers forward packets to only a small portion of the other



DYMO routers, due to the reactive nature of route discovery and route maintenance.

DYMO is applicable to memory constrained devices, since little routing state is maintained in each DYMO router. Only routing information related to active sources and destinations is maintained, in contrast to most proactive routing protocols that require routing information to all routers within the routing region be maintained.

DYMO supports routers with multiple interfaces participating in the MANET. DYMO routers can also perform routing on behalf of other nodes, attached via participating or non-participating interfaces.

DYMO routers perform route discovery to find a route to a particular destination. Therefore, DYMO routers MUST be configured to initiate and respond to route discovery on behalf of certain nodes, identified by address. When DYMO is the only protocol interacting with the forwarding table, DYMO MAY be configured to perform route discovery for all unknown unicast destinations.

At any time within a DYMO routing region only one DYMO router SHOULD be responsible for, i.e. "own", a particular address. Coordination among multiple DYMO routers to distribute routing information correctly for a shared address (i.e. an address that is advertised and can be reached via multiple DYMO routers) is not described in this document. The router behavior for shifting responsibility for an address from one DYMO router to another are described in [Appendix A](#).

DYMO MUST only utilizes bidirectional links. In the case of possible unidirectional links, either blacklists ( see [Section 7.2](#)) or other means (e.g. adjacency establishment with only neighboring routers that have bidirectional communication as indicated by NHDP [[I-D.ietf-manet-nhdp](#)]) of ensuring and monitoring bi-directionality SHOULD be used. Otherwise, persistent packet loss may occur.

The routing algorithm in DYMO may be operated at layers other than the network layer, using layer-appropriate addresses. For operation at other layers DYMO's routing algorithm likely will not need to change. Although, modification of the packet/message format may be required.

### **3. Terminology**

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [[RFC2119](#)].





Additionally, this document uses some terminology from [[RFC5444](#)].

This document defines the following terminology:

#### Adjacency

A relationship between selected bi-directional neighboring routers for the purpose of exchanging routing information. Not every pair of neighboring routers become adjacent. Neighboring routers may form an adjacency based several different pieces of information or protocols; for example, exchange of DYMO routing messages, other protocols (e.g. NDP [[RFC4861](#)] or NHDP [[I-D.ietf-manet-nhdp](#)]), or manual configuration. Similarly, loss of a routing adjacency may also be based upon several pieces of information, and monitoring of adjacencies where packets are being forwarded is required (see [Section 5.5.1](#)).

#### Distance (Dist)

A metric of the distance a message or piece of information has traversed. The minimum value of distance is the number of IP hops traversed. The maximum value is 65,535.

#### DYMO Identifier (DID)

A DID is maintained for each DYMO routing process (ThisNode.DID), and the default value is zero (0). Each routing message is tagged with its associated DID (MsgTLV.DID), unless zero (0). Upon receipt of DYMO protocol message a DYMO routing protocol process SHOULD only attend to messages with a matching DID value.

#### DYMO Sequence Number (SeqNum)

A DYMO Sequence Number is maintained by each DYMO router process. This sequence number is used by other DYMO routers to identify the temporal order of routing information generated and ensure loop-free routes.

#### Forwarding Route

A route that is used to forward data packets. Forwarding routes are generally maintained in a forwarding information base (FIB) or the kernel forwarding/routing table.

#### Multihop-capable Unicast IP Address

A multihop-capable unicast IP address is a unicast IP address that when put into the IP.SourceAddress or IP.DestinationAddress field is scoped sufficiently to be forwarded by a router. For example, site-scoped or globally-scoped unicast IP addresses.



**Originating Node (OrigNode)**

The originating node is the source, its DYMO router creates a DYMO control message on its behalf in an effort to disseminate some routing information. The originating node is also referred to as a particular message's originator.

**Route Error (RERR)**

A RERR message is used to indicate that a DYMO router does not have a forwarding route to one or more particular addresses.

**Route Reply (RREP)**

A RREP message is used to disseminate routing information about the RREP OrigNode to the RREP TargetNode and the DYMO routers between them.

**Route Request (RREQ)**

A RREQ message is issued to discover a valid route to a particular destination address, called the RREQ TargetNode. When a DYMO router processes a RREQ, it learns routing information on how to reach the RREQ OrigNode.

**Target Node (TargetNode)**

The TargetNode is the ultimate destination of a message.

**This Node (ThisNode)**

ThisNode corresponds to the DYMO router process currently performing a calculation or attending to a message.

**Type-Length-Value structure (TLV)**

A generic way to represent information, please see [[RFC5444](#)] for additional information.

**Unreachable Node (UnreachableNode)**

An UnreachableNode is a node for which a forwarding route does not exist.

## **[4.](#) Data Structures**

### **[4.1.](#) Route Table Entry**

The route table entry is a conceptual data structure. Implementations may use any internal representation that conforms to the semantics of a route as specified in this document.

Conceptually, a route table entry has the following fields:



**Route.Address**

The (host or network) destination address of the node(s) associated with the routing table entry.

**Route.Prefix**

Indicates that the associated address is a network address, rather than a host address. The value is the length of the netmask/prefix.

**Route.SeqNum**

The DYMO SeqNum associated with this routing information.

**Route.NextHopAddress**

The IP address of the adjacent DYMO router on the path toward the Route.Address.

**Route.NextHopInterface**

The interface used to send packets toward the Route.Address.

**Route.Forwarding**

A flag indicating whether this Route can be used for forwarding data packets. This flag MAY be provided for management and monitoring.

**Route.Broken**

A flag indicating whether this Route is broken. This flag is set to true if the next-hop becomes unreachable or in response to attending to a RERR (see [Section 5.5.4](#)).

The following field is optional:

**Route.Dist**

A dimensionless metric indicating the distance traversed before reaching the Route.Address node.

Not including optional information may cause performance degradation, but it will not cause the protocol to operate incorrectly.

In addition to a route table data structure, each route table entry may have several timers associated with the information. These timers/timeouts are discussed in [Section 5.2.3](#).

## **[4.2.](#) DYMO Messages**

When describing DYMO protocol messages, it is necessary to refer to fields in several distinct parts of the overall packet. These locations include the IP header, the UDP header, and fields from [\[RFC5444\]](#). This document uses the following notation conventions.



Information found in the table.

Information Location	Notational Prefix
IP header	IP.
UDP header	UDP.
<a href="#">RFC5444</a> message header	MsgHdr.
<a href="#">RFC5444</a> message TLV	MsgTLV.
<a href="#">RFC5444</a> address blocks	AddBlk.
<a href="#">RFC5444</a> address block TLV	AddTLV.

Table 1

#### **4.2.1. Generalized Packet and Message Structure**

DYMO messages conform to the generalized packet and message format as described in [\[RFC5444\]](#). Here is a brief description of the format. A packet is made up of messages. A message is made up of a message header, message TLV block, and zero or more address blocks. Each of the address blocks may also have an associated address TLV block.

For interoperability with other DYMO routers, all DYMO messages specified in this document SHOULD sent using the IP protocol number (138) reserved for manet protocols [\[RFC5498\]](#); or the UDP destination port (269) reserved for manet protocols [\[RFC5498\]](#) and IP protocol number for UDP.

Most DYMO messages are sent with the IP destination address set to the link-local multicast address LL-MANET-Routers [\[RFC5498\]](#) unless otherwise stated. Therefore, all DYMO routers SHOULD subscribe to LL-MANET-Routers [\[RFC5498\]](#) for receiving control packets. Note that multicast packets MAY be sent via unicast. For example, this may occur for certain link-types (non broadcast mediums), improved robustness, or manually configured router adjacencies.

Unicast DYMO messages (e.g. RREP) unless otherwise specified in this document are sent with the IP destination set to the Route.NextHopAddress of the route to the TargetNode.

The IPv4 TTL (IPv6 Hop Limit) field for all packets containing DYMO messages is set to 255. If a packet is received with a value other than 255, it is discarded. This mechanism helps to ensures that packets have not passed through any intermediate routers, and it is known as GTSM [\[RFC5082\]](#).

The length of an address (32 bits for IPv4 and 128 bits for IPv6)





inside a DYMO message depends on the msg-addr-length (MAL) in the msg-header, as specified in [[RFC5444](#)].

The aggregation of multiple messages into a packet is not specified in this document, but if aggregation does occur the IP.SourceAddress and IP.DestinationAddress of all contained messages MUST be the same.

Implementations MAY choose to temporarily delay transmission of messages for the purpose of aggregation (into a single packet) or to improve performance by using jitter [[RFC5148](#)].

DYMO control packets SHOULD be given priority queuing and channel access.

#### **4.2.2. Routing Messages (RM) - RREQ & RREP**

Routing Messages (RMs) are used to disseminate routing information. There are two DYMO message types that are considered to be routing messages (RMs): RREQ and RREP. They contain very similar information and function, but have slightly different handling rules. The main difference between the two messages is that RREQ messages generally solicit a RREP, whereas a RREP is the response to RREQ.

RM creation and handling are described in [Section 5.3](#).

A RM requires the following information:

##### **IP.SourceAddress**

The IP address of the node currently sending this packet. This field is generally filled automatically by the operating system and should not require special handling.

##### **IP.DestinationAddress**

The IP address of the packet destination. For multicast RREQ the IP.DestinationAddress is set to LL-MANET-Routers [[RFC5498](#)]. For unicast RREP the IP.DestinationAddress is set to the NextHopAddress toward the RREP TargetNode.

##### **IP.ProtocolNumber and UDP.DestinationPort**

The IP Protocol Number 138 (manet) has been reserved for MANET protocols [[RFC5498](#)]. In addition to using this IP protocol number, DYMO may use the UDP port 269 (manet) [[RFC5498](#)] in conjunction with the IP Protocol Number 17 (UDP).

##### **MsgHdr.HopLimit**

The remaining number of hops this message is allowed to traverse.



**AddBlk.TargetNode.Address**

The IP address of the message TargetNode. In a RREQ the TargetNode is the destination address for which route discovery is being performed. In a RREP the TargetNode is the RREQ OrigNode address. The TargetNode address is the first address in a routing message.

**AddBlk.OrigNode.Address**

The IP address of the originator and its associated prefix length. In a RREQ the OrigNode is the source's address and prefix. In a RREP the OrigNode is the RREQ TargetNode's address and prefix for which a RREP is being generated. This address is the second address in the message for RREQ.

**OrigNode.AddTLV.SeqNum**

The DYMO sequence number of the originator's DYMO router.

A RM may optionally include the following information:

**TargetNode.AddTLV.SeqNum**

The last known DYMO sequence number of the TargetNode.

**TargetNode.AddTLV.Dist**

The last known Distance to the TargetNode.

**AddBlk.AdditionalNode.Address**

The IP address of an additional node that can be reached via the DYMO router adding this information. Each AdditionalNode.Address MUST include its prefix. Each AdditionalNode.Address MUST also have an associated Node.SeqNum in the address TLV block.

**AdditionalNode.AddTLV.SeqNum**

The DYMO sequence number associated with this routing information.

**OrigNode.AddTLV.Dist**

A metric of the distance to reach the associated OrigNode.Address. This field is incremented by at least one at each intermediate DYMO router.

**AdditionalNode.AddTLV.Dist**

A metric of the distance to reach the associated AdditionalNode.Address. This field is incremented by at least one at each intermediate DYMO router.

Example IPv4 RREQ



```

      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
IP Header
+-+--+--+--+--+--+--+
| IP.Proto = UDP|
+-+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|                               IP.SourceAddress                               |
+-+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|           IP.DestinationAddress = LL-MANET-Routers           |
+-+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|   IP TTL/HopLimit = 255   |
+-+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+

UDP Header
+-+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|   Destination Port = manet   |
+-+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+

Packet Header
+-+--+--+--+--+--+--+--+--+--+
| ver= 0|0|0|0|0|
+-+--+--+--+--+--+--+--+--+--+

Message Header
+-+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|  RREQ-type  |0|1|0|0| MAL=3 |          msg-size=23          |
+-+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
| msg-hoplimit |
+-+--+--+--+--+--+--+--+--+--+

Message TLV Block
+-+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|   msg-tlv-block-size=0   |
+-+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+

Message Body - Address Block
+-+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|Number Adrs=2 |1|0|0|0|0| Rsv |  HeadLength=3 |      Head      :
+-+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
:           Head (cont)           | Target.Tail |  Orig.Tail  |
+-+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+

Message Body - Address Block TLV Block
+-+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|   tlv-block-size=6   |DYMOSeqNum-type|0|1|0|1|0|0|Rsv|
+-+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
| Index-start=1 | tlv-length=2 |          Orig.SeqNum          |
+-+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+

```

Figure 1



#### **4.2.3. Route Error (RERR)**

A RERR message is used to disseminate the information that a route is not available for one or more particular addresses.

RERR creation and handling are described in [Section 5.5](#).

A RERR requires the following information:

##### **IP.SourceAddress**

The IP address of the DYMO router that sent this packet. This field is generally filled automatically by the operating system and should not require special handling.

##### **IP.DestinationAddress**

For multicast RERR messages, The IP address is set to LL-MANET-Routers [[RFC5498](#)]. For unicast RERR messages, the IP address is set to the NextHopAddress.

##### **IP.ProtocolNumber and UDP.DestinationPort**

The IP Protocol Number 138 (manet) has been reserved for MANET protocols [[RFC5498](#)]. In addition to using this IP protocol number, DYMO may use the UDP port 269 (manet) [[RFC5498](#)] in conjunction with the IP Protocol Number 17 (UDP).

##### **MsgHdr.HopLimit**

The remaining number of hops this message is allowed to traverse.

##### **AddBlk.UnreachableNode.Address**

The address of an UnreachableNode and its associated prefix length. Multiple unreachable addresses may be included in a RERR.

A Route Error may optionally include the following information:

##### **UnreachableNode.AddTLV.SeqNum**

The last known DYMO sequence number of the unreachable node. If a SeqNum for an address is zero (0) or not included, it is assumed to be unknown. This case occurs when a node receives a message to forward to a destination for which it does not have any information in its routing table.





## Example IPv4 RERR

```

      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
IP Header
+-+--+--+--+--+--+--+
| IP.Proto = UDP|
+-+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|                               IP.SourceAddress                               |
+-+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|           IP.DestinationAddress = LL-MANET-Routers           |
+-+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|   IP.TTL/HopLimit = 255   |
+-+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
UDP Header
+-+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|   Destination Port = manet   |
+-+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
Packet Header
+-+--+--+--+--+--+--+
| ver= 0|0|0|0|0|
+-+--+--+--+--+--+--+
Message Header
+-+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|  RERR-type   |0|1|0|0| MAL=3 |           msg-size=15           |
+-+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
| msg-hoplimit |
+-+--+--+--+--+--+--+
Message TLV Block
+-+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|   msg-tlv-block-size=0   |
+-+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
Message Body - Address Block
                                     +-+--+--+--+--+--+--+--+--+--+--+
                                     |Number Addrs=1 |0|0|0|0|0| Rsv |
+-+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|                               UnreachableNode.Address                               |
+-+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
Message Body - Address Block TLV Block
+-+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|   TLV-blk-size=0   |
+-+--+--+--+--+--+--+--+--+--+--+--+--+--+--+

```

Figure 2



## **5. Detailed Operation**

### **5.1. DYMO Sequence Numbers**

DYMO sequence numbers allow DYMO routers to judge the freshness of routing information and ensure loop freedom.

#### **5.1.1. Maintaining A Node's Own Sequence Number**

DYMO requires that each DYMO router in the network maintain its own DYMO sequence number (OwnSeqNum) on behalf of the addresses for which it is responsible. OwnSeqNum a 16-bit unsigned integer. The circumstances for ThisNode to increment its OwnSeqNum are described in [Section 5.3](#).

#### **5.1.2. Numerical Operations on OwnSeqNum**

When ThisNode increments its OwnSeqNum it MUST do so by treating the sequence number value as an unsigned number.

#### **5.1.3. OwnSeqNum Rollover**

Incrementing an OwnSeqNum whose value is the largest largest possible number representable as a 16-bit unsigned integer (i.e., 65,535), SHOULD be set to one (1). In other words, the sequence number after 65,535 is 1.

#### **5.1.4. Actions After OwnSeqNum Loss**

A DYMO router SHOULD maintain its sequence number in persistent storage.

If a DYMO router's OwnSeqNum is lost, it MUST take certain actions to avoid creating routing loops. To prevent this possibility after OwnSeqNum loss a DYMO router MUST wait for at least ROUTE\_DELETE\_TIMEOUT before fully participating in the DYMO routing protocol. If a DYMO control message is received during this waiting period, the DYMO router SHOULD handle it normally but MUST NOT transmit or retransmit any DYMO messages. If a data packet is received for forwarding to another destination during this waiting period, the DYMO router MUST generate a RERR message indicating that this route is not available and reset its waiting timeout. At the end of the waiting period the DYMO router sets its OwnSeqNum to one (1) and begins participating.

The longest a node need wait is ROUTE\_SEQNUM\_AGE\_MAX\_TIMEOUT. At the end of the maximum waiting period a node SHOULD set its OwnSeqNum to one (1) and begins participating.



## **5.2. DYMO Routing Table Operations**

### **5.2.1. Judging Routing Information's Usefulness**

Given a route table entry (Route.SeqNum, Route.Dist, and Route.Broken) and new incoming routing information for a particular node in a RM (Node.SeqNum, Node.Dist, and RM message type - RREQ/RREP), the quality of the new routing information is evaluated to determine its usefulness. Incoming routing information is classified as follows:

#### **1. Stale**

If  $\text{Node.SeqNum} - \text{Route.SeqNum} < 0$  (using signed 16-bit arithmetic) the incoming information is stale. Using stale routing information is not allowed, since doing so might result in routing loops.

$(\text{Node.SeqNum} - \text{Route.SeqNum} < 0)$   
using signed 16-bit arithmetic

#### **2. Loop-possible**

If  $\text{Node.SeqNum} == \text{Route.SeqNum}$  the incoming information may cause loops if used; in this case additional information MUST be examined. If Route.Dist or Node.Dist is unknown or zero (0), then the routing information is loop-possible. If  $\text{Node.Dist} > \text{Route.Dist} + 1$ , then the routing information is loop-possible. Using loop-possible routing information is not allowed, otherwise routing loops may be formed.

$(\text{Node.SeqNum} == \text{Route.SeqNum}) \text{ AND}$   
 $((\text{Node.Dist is unknown}) \text{ OR}$   
 $(\text{Route.Dist is unknown}) \text{ OR}$   
 $(\text{Node.Dist} > \text{Route.Dist} + 1))$

#### **3. Inferior or equivalent**

In case of known equal SeqNum, the information is inferior in multiple cases: (case i) if  $\text{Node.Dist} == \text{Route.Dist} + 1$  (it is a greater distance route) AND  $\text{Route.Broken} == \text{false}$ ; (case ii) if  $\text{Node.Dist} == \text{Route.Dist}$  (equal distance route) AND  $\text{Route.Broken} == \text{false}$  AND this RM is a RREQ. This condition reduces the number of RREQ flooded by stopping forwarding of RREQ with equivalent distance.

$((\text{Node.SeqNum} == \text{Route.SeqNum}) \text{ AND}$   
 $((\text{Node.Dist} == \text{Route.Dist} + 1) \text{ AND } (\text{Route.Broken} == \text{false})) \text{ OR}$   
 $((\text{Node.Dist} == \text{Route.Dist}) \text{ AND}$   
 $(\text{RM is RREQ}) \text{ AND } (\text{Route.Broken} == \text{false}))))$



#### 4. Superior

Incoming routing information that does not match any of the above criteria is loop-free and better than the information existing in the routing table. Information is always superior if `Node.SeqNum - Route.SeqNum > 0` (using signed 16-bit arithmetic). In the case of equal sequence numbers, the information is superior in multiple cases: (case i) if `Node.Dist < Route.Dist`; (case ii) if `Node.Dist == Route.Dist + 1` AND `Route.Broken == true` (a broken route is being repaired); (case iii) if `Node.Dist == Route.Dist` AND it is a RREP (RREP with equal distance are forwarded) OR `Route.Broken == true` (a broken route is being repaired). For completeness, we provide the following (optimized) pseudo-code.

```
(Node.SeqNum - Route.SeqNum > 0) OR
    using signed 16-bit arithmetic
((Node.SeqNum == Route.SeqNum) AND
 ((Node.Dist < Route.Dist) OR
  ((Node.Dist == Route.Dist + 1) AND (Route.Broken == true)) OR
  ((Node.Dist == Route.Dist) AND
   ((RM is RREP) OR (Route.Broken == true)))))
```

#### **5.2.2. Creating or Updating a Route Table Entry with Received Superior Routing Information**

The route table entry is populated with the following information:

1. the `Route.Address` is set to `Node.Address`,
2. the `Route.Prefix` is set to the `Node.Prefix`.
3. the `Route.SeqNum` is set to the `Node.SeqNum`,
4. the `Route.NextHopAddress` is set to the node that transmitted this DYMO RM packet (i.e., the `IP.SourceAddress`),
5. the `Route.NextHopInterface` is set to the interface that this DYMO packet was received on,
6. the `Route.Broken` flag is set to false,
7. if known, the `Route.Dist` is set to the `Node.Dist`,

Fields without known values are not populated with any value.

The timer for the minimum delete timeout (`ROUTE_AGE_MIN`) is set to `ROUTE_AGE_MIN_TIMEOUT`. The timer for the maximum delete timeout (`ROUTE_SEQNUM_AGE_MAX`) is set to `Node.AddTLV.VALIDITY_TIME` [[RFC5497](#)] if included; otherwise, `ROUTE_SEQNUM_AGE_MAX` is set to





ROUTE\_SEQNUM\_AGE\_MAX\_TIMEOUT. The usage of these timers and others are described in [Section 5.2.3](#).

At this point, a forwarding route has been created and the Route.Forwarding flag set. Afterward, the route can be used to send any queued data packets and forward any incoming data packets for Route.Address. This route also fulfills any outstanding route discovery attempts for Node.Address.

### **[5.2.3](#). Route Table Entry Timeouts**

#### **[5.2.3.1](#). Minimum Delete Timeout (ROUTE\_AGE\_MIN)**

When a DYMO router transmits a RM, other DYMO routers expect the transmitting DYMO router to have a forwarding route to the RM originator. After updating a route table entry, it SHOULD be maintained for at least ROUTE\_AGE\_MIN. Failure to maintain the information might result in lost messages/packets, or in the worst case scenario several duplicate messages.

After the ROUTE\_AGE\_MIN timeout a route can safely be deleted.

#### **[5.2.3.2](#). Maximum Sequence Number Delete Timeout (ROUTE\_SEQNUM\_AGE\_MAX)**

Sequence number information is time sensitive, and MUST be deleted after a time in order to ensure loop-free routing.

After the ROUTE\_SEQNUM\_AGE\_MAX timeout a route's sequence number information MUST be discarded.

#### **[5.2.3.3](#). Recently Used Timeout (ROUTE\_USED)**

When a route is used to forward data packets, this timer is set to expire after ROUTE\_USED\_TIMEOUT. This operation is also discussed in [Section 5.5.2](#).

If a route has not been used recently, then a timer for ROUTE\_DELETE is set to ROUTE\_DELETE\_TIMEOUT.

#### **[5.2.3.4](#). Delete Information Timeout (ROUTE\_DELETE)**

As time progresses the likelihood that old routing information is useful decreases, especially if the network nodes are mobile. Therefore, old information SHOULD be deleted.

After the ROUTE\_DELETE timeout if a forwarding route exists it SHOULD be removed, and the routing table entry SHOULD also be deleted.



### **5.3. Routing Messages**

#### **5.3.1. RREQ Creation**

Before a DYMO router creates a RREQ it SHOULD increment its OwnSeqNum by one (1) according to the rules specified in [Section 5.1](#). Incrementing OwnSeqNum will ensure that all nodes with existing routing information will consider this new information superior to existing routing table information. If the sequence number is not incremented, certain DYMO routers might not consider this information superior, if they have existing better routing information.

First, ThisNode adds the AddBlk.TargetNode.Address to the RREQ; the unicast IP Destination Address for which a forwarding route does not exist.

If a previous value of the TargetNode.SeqNum is known (from a routing table entry using longest-prefix matching), it SHOULD be placed in TargetNode.AddTLV.SeqNum in all but the last RREQ attempt. If a TargetNode.SeqNum is not included, it is assumed to be unknown by handling nodes. This operation ensures that no intermediate DYMO routers reply, and ensures that the TargetNode's DYMO router increments its sequence number.

Next, the node adds AddBlk.OrigNode.Address, its prefix, and the OrigNode.AddTLV.SeqNum (OwnSeqNum) to the RM.

The OrigNode.Address is the address of the source for which this DYMO router is initiating this route discovery. The OrigNode.Address MUST be a unicast address. This information will be used by nodes to create a route toward the OrigNode, enabling delivery of a RREP, and eventually used for proper forwarding of data packets.

If OrigNode.Dist is included it is set to a number greater than zero (0).

Additional routing information can be added to this RM using the procedure described in [Section 5.3.5](#).

The MsgHdr.HopLimit SHOULD be set to MSG\_HOPLIMIT.

For RREQ, the MsgHdr.HopLimit MAY be set in accordance with an expanding ring search as described in [\[RFC3561\]](#) to limit the RREQ propagation to a subset of the local network and possibly reduce route discovery overhead.

The IP.DestinationAddress for multicast RREQ is set to LL-MANET-Routers. For links that do not support multicast or situations in



which unicast messaging is preferred, the `IP.DestinationAddress` for unicast RREP is set to the `NextHopAddress`.

Each DYMO routing protocol message SHOULD contain `ThisNode.DID`'s value in a message TLV (`MsgTLV.DID`). If `ThisNode.DID` value is zero (0) it MAY be omitted.

### **5.3.2. RREP Creation**

First, the `AddBlk.TargetNode.Address` is added to the RREP. The `TargetNode` is the ultimate destination of this RREP; the RREQ `OrigNode.Address`.

Next, `AddBlk.OrigNode.Address` and prefix are added to the RREP. The `AddBlk.OrigNode.Address` is the RREQ `TargetNode.Address`. The `AddBlk.OrigNode.Address` MUST be a unicast IP address. `ThisNode` SHOULD advertise the largest known prefix containing `AddBlk.OrigNode.Address`.

When the RM `TargetNode`'s DYMO router creates a RREP, if the `TargetNode.SeqNum` was not included in the RREQ, `ThisNode` MUST increment its `OwnSeqNum` by one (1) according to the rules specified in [Section 5.1](#).

If `TargetNode.SeqNum` was included in the RM and `TargetNode.SeqNum - OwnSeqNum < 0` (using signed 16-bit arithmetic), `OwnSeqNum` SHOULD be incremented by one (1) according to the rules specified in [Section 5.1](#).

If `TargetNode.SeqNum` is included in the RM and `TargetNode.SeqNum == OwnSeqNum` (using signed 16-bit arithmetic) and `OrigNode.Dist` will not be included in the RREP being generated, `OwnSeqNum` SHOULD be incremented by one (1) according to the rules specified in [Section 5.1](#).

If `OwnSeqNum` is not incremented the routing information might be considered stale. In this case, the RREP might not reach the RREP Target.

After any of the sequence number operations above, the RREP `OrigNode.AddTLV.SeqNum` (`OwnSeqNum`) MUST also be added to the RREP.

Other `AddTLVs` in the RREP for the `OrigNode` and `TargetNode` SHOULD be included and set accordingly. If `OrigNode.Dist` is included it is set to a number greater than zero (0) and less than or equal to 65,535. The Distance value will influence judgment of the routing information ([Section 5.2.1](#)) against known information at other DYMO routers that handle this RM.



Additional routing information can be added to this RM using the procedure described in [Section 5.3.5](#).

The `MsgHdr.HopLimit` is set to `MSG_HOPLIMIT`.

The `IP.DestinationAddress` for RREP is set to the IP address of the `Route.NextHopAddress` for the route to the RREP `TargetNode`.

Each DYMO routing protocol message SHOULD contain `ThisNode.DID`'s value in a message TLV (`MsgTLV.DID`). If `ThisNode.DID` value is zero (0) it MAY be omitted.

### **[5.3.3](#). Intermediate DYMO Router RREP Creation**

Sometimes a DYMO router other than the `TargetNode`'s DYMO router (call it an "intermediate DYMO router") has routing information that can satisfy an incoming RREQ. An intermediate DYMO router can issue a intermediate DYMO router RREP on behalf of the `TargetNode`'s DYMO router.

Before creating a intermediate DYMO router RREP, `OwnSeqNum` SHOULD be incremented by one (1) according to the rules specified in [Section 5.1](#).

If `OwnSeqNum` is not incremented the routing information about `ThisNode` might be considered stale by a handling DYMO router. In this case, the RREP would not reach the RREP `TargetNode`.

When an intermediate DYMO router originates a RREP in response to a RREQ on behalf of the `TargetNode`'s DYMO router, it sends the RREP to the RREQ `OrigNode` with additional routing information (`Address`, `Prefix`, `SeqNum`, `Dist`, etc.) about the RREQ `TargetNode`. Appending additional routing information is described in [Section 5.3.5](#).

The Intermediate DYMO router SHOULD also issue a RREP to the RREQ `TargetNode`, so that the RREQ `TargetNode` receives routing information on how to reach the RREQ `OrigNode`.

When an intermediate DYMO router creates this RREP, it sends a RREP to the RREQ `TargetNode` with additional routing information (`Address`, `Prefix`, `SeqNum`, `Dist`, etc.) about the RREQ `OrigNode`.

### **[5.3.4](#). RM Handling**

First, `ThisNode` examines the RM to ensure that it contains the required information: `MsgHdr.HopLimit`, `AddBlk.TargetNode.Address`, `AddBlk.OrigNode.Address`, and `OrigNode.AddTLV.SeqNum`. If the required information do not exist, the message is discarded and further





processing stopped.

Next, ThisNode decides whether to attend to this message. If the message contains a MsgTLV.DID it SHOULD match ThisNode.DID's value. If the message does not contain a MsgTLV.DID it is assumed to be zero (0) and SHOULD be discarded if ThisNode.DID's value is not zero (0).

Next, ThisNode MAY selectively attend to messages based upon information in the message. ThisNode SHOULD only handle messages from adjacent DYMO routers. If ThisNode chooses not to handle this message, the message is discarded and further processing stopped.

ThisNode checks if the AddBlk.OrigNode.Address is a valid multihop-capable (e.g. site or global scope) unicast address. If the address is not a valid unicast address, the message is discarded and further processing stopped.

ThisNode also checks whether AddBlk.OrigNode.Address is an address handled by this DYMO router. If this node is the originating DYMO router, the RM is dropped.

ThisNode checks if the AddBlk.TargetNode.Address is a valid multihop-capable unicast address. If the address is not a valid unicast address, the message is discarded and further processing stopped.

Next, ThisNode checks whether its routing table has an entry to the AddBlk.OrigNode.Address using longest-prefix matching [[RFC1812](#)]. If a route with a valid Route.SeqNum does not exist, then the new routing information is considered superior and a new route table entry is created and updated as described in [Section 5.2.2](#). If a route table entry does exist and it has a known Route.SeqNum, the incoming routing information is compared with the route table entry following the procedure described in [Section 5.2.1](#). If the incoming routing information is considered superior, the route table entry is updated as described in [Section 5.2.2](#).

For each address (except the TargetNode) in the RM that includes AddTLV.Dist information, the AddTLV.Dist information MAY be incremented. If the resulting Distance value for the OrigNode is greater than 65,535, the message is discarded. If the resulting Distance value for another node is greater than 65,535, the associated address and its information are removed from the RM. The updated Distance value will influence judgment of the routing information ([Section 5.2.1](#)).

After handling the OrigNode's routing information, then each address that is not the TargetNode MAY be considered for creating and updating routes. Creating and updating routes to other nodes can



eliminate RREQ for those IP destinations, in the event that data needs to be forwarded to the IP destination(s) now or in the near future.

For each of the additional addresses considered, ThisNode first checks that the address is a multihop-capable unicast address. If the address is not a unicast address, the address and all related information MUST be removed.

If the routing table does not have a matching route with a known Route.SeqNum for this additional address using longest-prefix matching, then a route is created and updated as described in [Section 5.2.2](#). If a route table entry exists with a known Route.SeqNum, the incoming routing information is compared with the route table entry following the procedure described in [Section 5.2.1](#). If the incoming routing information is considered superior, the route table entry is updated as described in [Section 5.2.2](#).

If the routing information for an AdditionalNode.Address is not considered superior, then it is removed from the RM. Removing this information ensures that the information is not propagated.

At this point, if the routing information for the OrigNode was not superior then this RM SHOULD be discarded and no further processing of this message SHOULD be performed.

If the ThisNode is the DYMO router responsible for the TargetNode and this RM is a RREQ, then ThisNode responds with a RREP to the RREQ OrigNode (the new RREP's TargetNode). The procedure for issuing a new RREP is described in [Section 5.3.2](#). At this point, ThisNode need not perform any more operations for the RM being processed.

As an alternative to issuing a RREP, ThisNode MAY choose to distribute routing information about ThisNode (the RREQ TargetNode) more widely. That is, ThisNode MAY optionally perform a route discovery; by issuing a RREQ with ThisNode listed as the TargetNode, using the procedure in [Section 5.3.1](#). At this point, ThisNode need not perform any more operations for the RM being processed.

If ThisNode is not the TargetNode, this RM is a RREQ, the RREQ contains the TargetNode.AddTLV.SeqNum, and ThisNode has a forwarding route to the TargetNode with a SeqNum where  $\text{Route.TargetNode.SeqNum} - \text{RREQ.TargetNode.AddTLV.SeqNum} > 0$  (using signed 16-bit arithmetic); then ThisNode MAY respond with an intermediate DYMO router RREP. The procedure for performing intermediate DYMO router RREP is described in [Section 5.3.3](#). If an intermediate DYMO router RREP is sent, ThisNode need not perform any more operations for the RM being processed.



After handling a RM or creating a new RM, ThisNode MAY append additional routing information to the RM prior to redistributing this information, according to the procedure described in [Section 5.3.5](#). The additional routing information can help reduce route discoveries at the expense of increased message size.

For each address (except the TargetNode) in the RM that includes AddTLV.Dist information, the AddTLV.Dist information is incremented by at least one (1). The updated Distance value will influence judgment of the routing information ([Section 5.2.1](#)) against known information at other DYMO routers that handle this RM.

If the resulting Distance value for the OrigNode is greater than 65,535, the message is discarded. If the resulting Distance value for another node is greater than 65,535, the associated address and its information are removed from the RM.

Next, the MsgHdr.HopLimit is decremented by one (1). If this RM's MsgHdr.HopLimit is greater than or equal to one (1), ThisNode is not the TargetNode, AND this RM is a RREQ, then the current RM (altered by the procedure defined above) SHOULD be sent to the IP.DestinationAddress LL-MANET-Routers [[RFC5498](#)]. If the RREQ is unicast, the IP.DestinationAddress is set to the NextHopAddress.

If this RM's MsgHdr.HopLimit is greater than or equal to one (1), ThisNode is not the TargetNode, AND this RM is a RREP, then the current RM is sent to the Route.NextHopAddress for the RREP's TargetNode.Address. If no forwarding route exists to TargetNode.Address, then a RERR SHOULD be issued to the OrigNode of the RREP.

By sending the updated RM ThisNode is advertising that it will provide routing for addresses contained in the outgoing RM based on the information enclosed. ThisNode MAY choose not to send the RM, though not resending this RM could decrease connectivity in the network or result in a non-shortest distance path.

Some examples of why ThisNode might choose to not re-issue a RM are: if ThisNode does not want to advertise routing for the contained addresses because it is already heavily loaded; if ThisNode has already issued nearly identical routing information (e.g. ThisNode had recently issued a RM with nearly the same distance); or if ThisNode is low on energy and does not want to expend energy for control message sending or packet forwarding. These types of advanced behavior are not defined in this specification.



### **5.3.5. Adding Additional Routing Information to a RM**

Appending routing information can alleviate route discovery attempts to the nodes whose information is included, if other DYMO routers use this information to update their routing tables.

DYMO routers can append routing information to a RM. This option (APPEND\_INFORMATION) SHOULD be administratively configurable or intelligently controlled.

Prior to appending an address controlled by this DYMO router to a RM, ThisNode MAY increment its OwnSeqNum as defined in [Section 5.1](#). If OwnSeqNum is not incremented the appended routing information might not be considered superior, when received by nodes with existing routing information. Incrementation of the sequence number when appending information to a RM in transit (APPEND\_INFORMATION\_SEQNUM) SHOULD be administratively configurable or intelligently controlled. Note that, during handling of this RM OwnSeqNum may have already been incremented; and in this case OwnSeqNum need not be incremented again.

If an address controlled by this DYMO router includes ThisNode.Dist, it is set to a number greater than zero (0).

For added addresses (and their prefixes) not controlled by this DYMO router, Route.Dist can be included if known. If Route.Dist is not known, it MUST NOT be included.

The VALIDITY\_TIME of routing information for appended address(es) MUST be included, to inform routers about when to delete this information. The VALIDITY\_TIME TLV is defined in [Section 7.3](#).

Additional information (e.g. SeqNum and Dist) about any appended address(es) SHOULD be included.

Note that the routing information about the TargetNode MUST NOT be added. Also, duplicate address entries SHOULD NOT be added. Instead, only the best routing information ([Section 5.2.1](#)) for a particular address SHOULD be included.

## **5.4. Route Discovery**

When a source's DYMO router needs to forward a data packet on behalf of an attached node and it does not have a forwarding route to the data packet's unicast IP destination address, ThisNode sends a RREQ (described in [Section 5.3.1](#)) to discover a route to the particular destination (TargetNode).





After issuing a RREQ, the OrigNode DYMO router waits for a route to be created to the TargetNode. If a route is not created within RREQ\_WAIT\_TIME, ThisNode may again try to discover a route by issuing another RREQ using the procedure defined in [Section 5.3.1](#) again. Route discovery SHOULD be considered failed after DISCOVERY\_ATTEMPTS\_MAX and the final RREQ's corresponding RREQ\_WAIT\_TIME.

To reduce congestion in a network, repeated attempts at route discovery for a particular TargetNode SHOULD utilize an exponential backoff.

For example, the first time a DYMO router issues a RREQ, it waits RREQ\_WAIT\_TIME for a route to the TargetNode. If a route is not found within that time, the DYMO router MAY send another RREQ. If a route is not found within two (2) times the current waiting time, another RREQ MAY be sent. No more than DISCOVERY\_ATTEMPTS\_MAX route discovery attempts SHOULD be made before considering route discovery for this destination to have failed. For each additional attempt, the waiting time for the previous RREQ is multiplied by two (2) so that the waiting time conforms to a binary exponential backoff.

Data packets awaiting a route SHOULD be buffered by the source's DYMO router. This buffer SHOULD have a fixed limited size (BUFFER\_SIZE\_PACKETS or BUFFER\_SIZE\_BYTES) and older data packets SHOULD be discarded first.

Buffering of data packets can have both positive and negative effects, and therefore buffer settings (BUFFER\_DURING\_DISCOVERY) SHOULD be administratively configurable or intelligently controlled.

If a route discovery attempt has failed (i.e. an attempt or multiple attempts have been made without receiving a RREP) to find a route to the TargetNode, any data packets buffered for the corresponding TargetNode are dropped and a Destination Unreachable ICMP message SHOULD be delivered to the source.

## **5.5. Route Maintenance**

A RERR SHOULD be issued if a data packet is to be forwarded and it cannot be delivered to the next-hop because no forwarding route for the IP.DestinationAddress exists; RERR generation is described in [Section 5.5.3](#).

Upon this condition, an ICMP Destination Unreachable message SHOULD NOT be generated unless this router is responsible for the IP.DestinationAddress and that IP.DestinationAddress is known to be unreachable.



In addition to inability to forward a data packet, a RERR SHOULD be issued immediately after detecting a broken link (see [Section 5.5.1](#)) of a forwarding route to quickly notify DYMO routers that certain routes are no longer available. If a newly unavailable route has not been used recently (indicated by ROUTE\_USED), the RERR SHOULD NOT be generated.

#### **[5.5.1.](#) Active Next-hop Router Adjacency Monitoring**

Nodes MUST monitor connectivity to adjacent next-hop DYMO routers on forwarding routes. This monitoring can be accomplished by one or several mechanisms, including:

- o Neighborhood discovery [[I-D.ietf-manet-nhdp](#)]
- o Route timeout
- o Lower layer feedback that a particular adjacent router is no longer reachable
- o Other monitoring mechanisms or heuristics

Upon determining that a next-hop DYMO router is unreachable, ThisNode MUST remove the affected forwarding routes (those with an unreachable next-hop) and unset the Route.Forwarding flag. ThisNode also flags the associated routes in DYMO's routing table as Broken. For each broken route the timer for ROUTE\_DELETE is set to ROUTE\_DELETE\_TIMEOUT.

#### **[5.5.2.](#) Updating Route Lifetimes During Packet Forwarding**

To avoid removing the forwarding route to reach the IP.SourceAddress, ThisNode SHOULD set a timeout (ROUTE\_USED) to ROUTE\_USED\_TIMEOUT for the route to the IP.SourceAddress upon receiving a data packet. If the timer for ROUTE\_DELETE is set, it is removed.

To avoid removing the forwarding route to the IP.DestinationAddress that is being used, ThisNode SHOULD set a timeout (ROUTE\_USED) to ROUTE\_USED\_TIMEOUT for the route to the IP.DestinationAddress upon sending a data packet. If the timer for ROUTE\_DELETE is set, it is removed.

#### **[5.5.3.](#) RERR Generation**

A RERR informs DYMO routers that a route to certain destinations is not available through ThisNode.

When creating a new RERR, the address of the first UnreachableNode



(IP.DestinationAddress from a data packet or RREP.TargetNode.Address) is inserted into an Address Block AddBlk.UnreachableNode.Address. If a prefix is known for the UnreachableNode.Address, it SHOULD be included. Otherwise, the UnreachableNode.Address is assumed to be a host address with a full length prefix. If a value for the UnreachableNode's SeqNum (UnreachableNode.AddTLV.SeqNum) is known, it SHOULD be placed in the RERR. The MsgHdr.HopLimit is set to MSG\_HOPLIMIT.

Additional UnreachableNodes that require the same unavailable link (routes with the same Route.NextHopAddress and Route.NextHopInterface) SHOULD be added to the RERR, as additional AddBlk.UnreachableNode.Address entries with their associated prefix. The SeqNum if known SHOULD also be included. Appending UnreachableNode information notifies each node that handles this message of additional routes that are no longer available. This option (APPEND\_EXTRA\_UNREACHABLE) SHOULD be administratively configurable or intelligently controlled.

If SeqNum information is not known or not included in the RERR, all nodes handling the RERR will assume their routing information associated with the UnreachableNode is no longer valid and flag those routes as broken.

Each DYMO routing protocol message SHOULD contain ThisNode.DID's value in a message TLV (MsgTLV.DID). If ThisNode.DID value is zero (0) it MAY be omitted.

A multicast RERR is sent to the IP.DestinationAddress LL-MANET-Routers [[RFC5498](#)]. Sending the RERR to the LL-MANET-Routers address notifies all nearby DYMO routers that might depend on the now broken link. If the RERR is unicast, the IP.DestinationAddress is set to the NextHopAddress.

At this point, the packet or message that forced generation of this RERR SHOULD be discarded.

#### **5.5.4. RERR Handling**

First, ThisNode examines the RM to ensure that it contains the required information: MsgHdr.HopLimit and AddBlk.UnreachableNode.Address. If the required information do not exist, the message is discarded and further processing stopped.

Next, ThisNode decides whether to handle this message. If the message contains a MsgTLV.DID it SHOULD match ThisNode.DID's value. If the message does not contain a MsgTLV.DID it is assumed to be zero (0) and SHOULD be discarded if ThisNode.DID's value is not zero (0).



Next, `ThisNode` MAY selectively handle messages based upon information in the message. `ThisNode` MAY choose to only handle messages from adjacent DYMO routers. If `ThisNode` chooses not to handle this message, the message is discarded and further processing stopped.

When a DYMO router handles a RERR, it examines each `UnreachableNode`'s information. The attending DYMO router removes the forwarding route, unsets the `Route.Forwarding` flag, sets the `Route.Broken` flag, and the timer for `ROUTE_DELETE` is set to `ROUTE_DELETE_TIMEOUT` for each `UnreachableNode.Address` found using longest prefix matching that meet all of the following conditions:

1. The `UnreachableNode.Address` is a multihop-capable unicast address.
2. The `Route.NextHopAddress` is the same as the RERR `IP.SourceAddress`.
3. The `Route.NextHopInterface` is the same as the interface on which the RERR was received.
4. The `Route.SeqNum` is zero (0), unknown, OR the `UnreachableNode.SeqNum` is zero (0), unknown, OR `Route.SeqNum - UnreachableNode.SeqNum <= 0` (using signed 16-bit arithmetic).

During handling if `Route.SeqNum` is zero (0) or unknown and `UnreachableNode.SeqNum` exists in the RERR and is not zero (0), then `Route.SeqNum` MAY be set to `UnreachableNode.SeqNum`. Setting `Route.SeqNum` can reduce future RERR handling and forwarding.

Each `UnreachableNode` that did not result in a broken route is removed from the RERR, since propagation of this information will not result in any benefit.

Each `UnreachableNode` that did result in a broken route SHOULD remain in the RERR.

If any `UnreachableNode` was removed, all other information (AddTLVs) associated with the removed address(es) MUST also be removed.

After handling if `Route.SeqNum` is known and an `UnreachableNode.SeqNum` is not included in the RERR, then `Route.SeqNum` (i.e. `UnreachableNode.SeqNum`) MAY be added to the RERR. Including `UnreachableNode.SeqNum` can reduce future RERR handling and forwarding.

If no `UnreachableNode` addresses remain in the RERR, no other handling is required and the RERR is discarded.





If handling continues, the `MsgHdr.HopLimit` is decremented by one (1). Further, if this RERR's new `MsgHdr.HopLimit` is greater than one (1) and at least one unreachable node address remains in the RERR, then the updated RERR SHOULD be sent.

A multicast RERR is sent to the `IP.DestinationAddress` LL-MANET-Routers [[RFC5498](#)]. If the RERR is unicast, the `IP.DestinationAddress` is set to the `NextHopAddress`.

## 5.6. DYMO Identifier (DID)

Each DYMO routing protocol process MUST have an associated DYMO Identifier (DID). The DID allows multiple DYMO routing protocol processes to operate over the same links and on the same device independently. This function may also be used to administratively separate DYMO processes with incompatible options, timers, or extensions.

The DID is similar in function to OSPF Instance ID [[RFC5340](#)] [[I-D.ietf-ospf-multi-instance](#)], OSPF Area ID [[RFC2328](#)] [[RFC5340](#)], and/or the MANET\_ID TLV [[I-D.chakeres-manet-manetid](#)].

All DYMO routers with the same DID that come in contact with each other MUST operate with a compatible set of configuration options, timing parameters (see [Section 6](#)), and protocol extensions. In cases with non-default options, the DID value SHOULD be administratively chosen.

The default DID value is zero (0), and using this value requires that the implementation utilize options and timing parameters compatible with those defined in [Section 6](#).

Each DYMO routing protocol message sent MUST contain its associated DID in a message TLV; unless the DID value is zero (0), in which case it MAY be omitted.

Upon receipt of DYMO protocol message a DYMO routing protocol process SHOULD only process messages with a DID (`MsgTLV.DID`) value matching its own DID (`ThisNode.DID`).

## 5.7. Unknown Message & TLV Types

If a message with an unknown type is received, the message is discarded.

For handling of messages that contain unknown TLV types, the default behavior is to leave the information in control messages unmodified. Although, this behavior (`UNKNOWN_TYPES`) MAY be administratively



controlled.

### **5.8. Advertising Network Addresses**

DYMO routers specify the prefix length for each advertised address. Any nodes (other than the advertising DYMO router) within the advertised prefix **MUST NOT** participate in the DYMO protocol directly. For example, advertising 192.0.2.1 with a prefix length of 24 indicates that all nodes with the matching 192.0.2.X are reachable through this DYMO router.

### **5.9. Simple Internet Attachment**

Simple Internet attachment consists of a stub network of DYMO routers connected to the Internet via a single Internet DYMO router (IDR).

DYMO routers, and hosts behind these routers, wishing to be reachable from hosts on the Internet **MUST** have IP addresses within the IDR's routable and topologically correct prefix (e.g. 192.0.2.0/24).

The IDR is responsible for generating RREQ to find nodes within the DYMO Region on behalf of nodes on the Internet, as well as responding to route requests from the DYMO region on behalf of the nodes on the Internet.



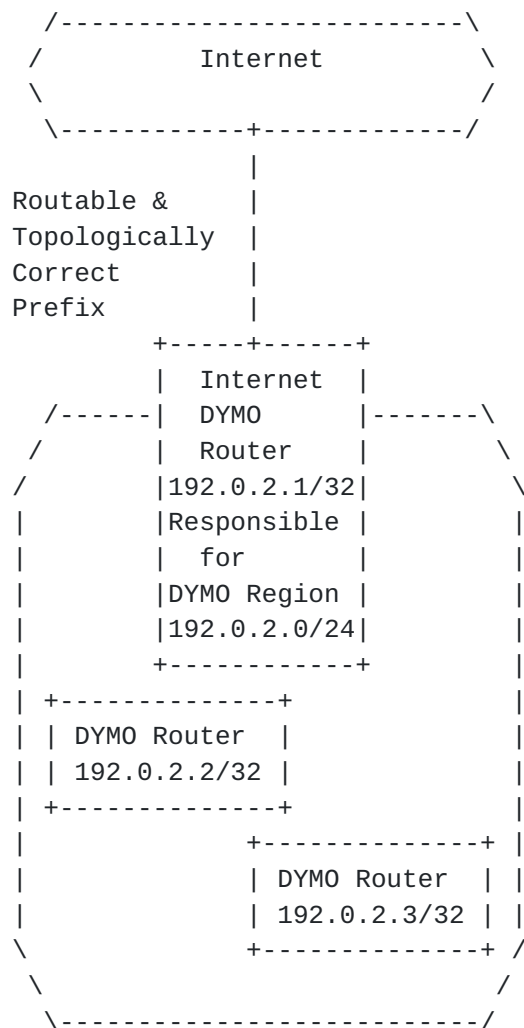


Figure 3: Simple Internet Attachment Example

When a DYMO router within the DYMO Region wants to discover a route to a node on the Internet, it uses the normal DYMO route discovery for that IP Destination Address. The IDR is responsible for properly responding to RREQ on behalf of the Internet destination.

When a packet from a node on the Internet destined for a node in the DYMO region reaches the IDR, if the IDR does not have a route to that destination it will perform normal DYMO route discovery for that destination.

#### [5.10.](#) Multiple Interfaces

DYMO may be used with multiple interfaces; therefore, the particular interface over which packets arrive MUST be known whenever a packet is received. Whenever a new route is created, the interface through which the Route.Address can be reached is also recorded in the route



table entry.

When multiple interfaces are available, a node transmitting a multicast packet with IP.DestinationAddress set to LL-MANET-Routers SHOULD send the packet on all interfaces that have been configured for DYMO operation.

Similarly, DYMO routers should subscribe to LL-MANET-Routers on all their DYMO interfaces.

#### **5.11. DYMO Control Packet/Message Generation Limits**

To ensure predictable control overhead, DYMO router's rate of packet/message generation SHOULD be limited. The rate and algorithm for limiting messages (CONTROL\_TRAFFIC\_LIMITS) is left to the implementor and should be administratively configurable or intelligently controlled. DYMO control messages SHOULD be discarded in the following order of preferences RREQ, RREP, and finally RERR.

### **6. Administratively Configured Parameters and Timer Values**

DYMO contains several parameters which MUST be administratively configured. The list of these follows:

Required Administratively Configured Parameters

Name	Description
DID	All DYMO routers with the same DID that come in contact with each other MUST operate with a compatible set of configuration options, timing parameters, and protocol extensions. If non-default potentially incompatible options, timing parameters or protocol extensions are utilized the DID MUST be set to a non-zero value.
RESPONSIBLE_ADDRESSES	List of addresses, and their associated prefix, for which this DYMO router is responsible.
DYMO_INTERFACES	List of the interfaces participating in DYMO routing protocol.

Table 2





DYMO contains a number of timers. The default timing parameter values follow:

Default Timing Parameter Values

Name	Value
ROUTE_TIMEOUT	5 seconds
ROUTE_AGE_MIN_TIMEOUT	1 second
ROUTE_SEQNUM_AGE_MAX_TIMEOUT	60 seconds
ROUTE_USED_TIMEOUT	ROUTE_TIMEOUT
ROUTE_DELETE_TIMEOUT	2 * ROUTE_TIMEOUT
ROUTE_RREQ_WAIT_TIME	2 seconds
UNICAST_MESSAGE_SENT_TIMEOUT	1 second

Table 3

The above timing parameter values work well for small and medium well-connected networks with moderate topology changes.

The timing parameters SHOULD be administratively configurable for the network where DYMO is used. Ideally, for networks with frequent topology changes the DYMO parameters should be adjusted using either experimentally determined values or dynamic adaptation. For example, in networks with infrequent topology changes ROUTE\_USED\_TIMEOUT may be set to a much larger value.

Default Parameter Values

Name	Value	Description
MSG_HOPLIMIT	10 hops	This value MUST be larger than the DYMO network diameter. Otherwise, routing messages may not reach their intended destinations.
DISCOVERY_ATTEMPTS_MAX	3	The number of route discovery attempts to make before indicating that a particular address is not reachable.

Table 4

In addition to the above parameters and timing values, several



administrative options exist. These options have no influence on correct routing behavior, although they may potentially reduce DYMO routing control messaging in certain situations. The default behavior is to NOT enable any of these options; and although many of these options can be administratively controlled, they may be better served by intelligent control. The following table enumerates several of the options.

Administratively Controlled Options

Name	Description
APPEND_INFORMATION	Whether to append ThisNode's routing information to a RM.
APPEND_INFORMATION_SEQNUM	Whether to increment ThisNode's OwnSeqNum when append ThisNode's routing information to a RM.
BUFFER_DURING_DISCOVERY	Whether and how much data to buffer during route discovery.
APPEND_EXTRA_UNREACHABLE	Whether to append additional Unreachable information to RERR.
UNKNOWN_TYPES	What action to take when an unknown TLV type is received. The default action is to forward this information unmodified. Another action would be to remove this information.
CONTROL_TRAFFIC_LIMITS	DYMO control messaging SHOULD be limited to avoid consuming all the network bandwidth.

Table 5

Note: several fields have limited size (bits or bytes) these sizes and their encoding may place specific limitations on the values that can be set. For example, MsgHdr.HopLimit is a 8-bit field and therefore MSG\_HOPLIMIT cannot be larger than 255.

## 7. IANA Considerations

In its default mode of operation, DYMO uses the UDP port MANET [[RFC5498](#)] to carry protocol packets. DYMO also uses the link-local multicast address LL-MANET-Routers [[RFC5498](#)].

This section specifies several message types, message tlv-types, and address tlv-types.



### 7.1. DYMO Message Types Specification

DYMO Message Types

Name	Type
Route Request (RREQ)	10 - TBD
Route Reply (RREP)	11 - TBD
Route Error (RERR)	12 - TBD

Table 6

### 7.2. Message and Address Block TLV Type Specification

Message TLV Types

Name	Type	Length	Value
Unicast Response Request	10 - TBD	0 octets	Indicates to the processing node that the previous hop (IP.SourceAddress) expects a unicast message within UNICAST_MESSAGE_SENT_TIMEOUT. Any unicast packet will serve this purpose, and it MAY be an ICMP REPLY message. If a message is not sent, then the previous hop can assume that the link is unidirectional and MAY blacklist the link to this node.

Table 7



### 7.3. Address Block TLV Specification

Address Block TLV Types

Name	Type	Length	Value
DYMO Identifier (DID)	9 - TBD	DID length	ThisNode.DID's value. More information can be found in <a href="#">Section 5.6</a>
DYMO Sequence Number (DYMOSeqNum)	10 - TBD	up to 2 octets	The DYMO sequence num associated with this address. The sequence number may be the last known sequence number.
Distance	11 - TBD	up to 2 octets	A metric of the distance traversed by the information associated with this address.
VALIDITY_TIME	1[RFC5497]		The maximum amount of time that information can be maintained before being deleted. The VALIDITY_TIME TLV is defined in [ <a href="#">RFC5497</a> ].

Table 8

## 8. Security Considerations

The objective of the DYMO protocol is for each router to communicate reachability information to addresses for which it is responsible. Positive routing information (i.e. a route exists) is distributed via RMs and negative routing information (i.e. a route does not exist) via RERRs. DYMO routers that handle these messages store the contained information to properly forward data packets, and they generally provide this information to other DYMO routers.

This section does not mandate any specific security measures. Instead, this section describes various security considerations and potential avenues to secure DYMO routing.

The most important security mechanisms for DYMO routing are integrity/authentication and confidentiality.

In situations where routing information or router identity are





suspect, integrity and authentication techniques SHOULD be applied to DYMO messages. In these situations, routing information that is distributed over multiple hops SHOULD also verify the integrity and identity of information based on originator of the routing information.

A digital signature could be used to identify the source of DYMO messages and information, along with its authenticity. A nonce or timestamp SHOULD also be used to protect against replay attacks. S/MIME and OpenPGP are two authentication/integrity protocols that could be adapted for this purpose.

In situations where confidentiality of DYMO messages is important, cryptographic techniques can be applied.

In certain situations, like sending a RREP or RERR, a DYMO router could include proof that it has previously received valid routing information to reach the destination, at one point of time in the past. In situations where routers are suspected of transmitting maliciously erroneous information, the original routing information along with its security credentials SHOULD be included.

Note that if multicast is used, any confidentiality and integrity algorithms used must permit multiple receivers to handle the message.

## **9. Acknowledgments**

DYMO is a descendant of the design of previous MANET reactive protocols, especially AODV [[RFC3561](#)] and DSR [[RFC4728](#)]. Changes to previous MANET reactive protocols stem from research and implementation experiences. Thanks to Elizabeth Belding-Royer for her long time authorship of DYMO. Additional thanks to Luke Klein-Berndt, Pedro Ruiz, Fransisco Ros, Koojana Kuladinithi, Ramon Caceres, Thomas Clausen, Christopher Dearlove, Seung Yi, Romain Thouvenin, Tronje Krop, Henner Jakob, Alexandru Petrescu, Christoph Sommer, Cong Yuan, Lars Kristensen, and Derek Atkins for reviewing of DYMO, as well as several specification suggestions.

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## **[Appendix A](#). Shifting Responsibility for an Address Between DYMO Routers**

Only one DYMO router within a routing region SHOULD be responsible for a particular address at any time. If two DYMO routers dynamically pass responsibility of an address correct DYMO routing behavior must be observed. The DYMO router adding the new address must wait for any exiting routing information about this address to be purged from the network. Therefore, it must wait at least ROUTER\_SEQNUM\_AGE\_MAX\_TIMEOUT after the previous DYMO router for this address stopped participating and advertising routing information on its behalf.

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