Dynamic MANET On-demand for 6LoWPAN (DYMO-low) Routing
draft-montenegro-6lowpan-dymo-low-routing-03

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Abstract

This document specifies how to use the Dynamic MANET On-demand Routing Protocol over IEEE802.15.4 networks.

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1. Introduction

The IEEE 802.15.4 standard [IEEE802.15.4] targets low power personal area networks. The "IPv6 over IEEE 802.15.4" document [I-D.ietf-6lowpan-format] defines basic functionality required to carry IPv6 packets over IEEE 802.15.4 networks (including an adaptation layer, header compression, etc). Likewise, as mesh topologies are expected to be common in LoWPAN networks, the functionality required for packet delivery in IEEE 802.15.4 meshes is defined. However, neither the IEEE 802.15.4 standard nor the "IPv6 over IEEE 802.15.4" specification provide any information as to how such a mesh topology could be obtained and maintained.

This document specifies how to use the Dynamic MANET On-demand Routing Protocol (DYMO) [I-D.ietf-manet-dymo] over IEEE 802.15.4 networks to provide mesh routing. To distinguish this instantiation of the protocol from DYMO over IPv4 and DYMO over IPv6, the label "DYMO-low" is used in this document. Given the very stringent limitations of the target devices, this document specifies simplifications that are recommended to the base DYMO specification.

1.1. Requirements notation

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].

2. Overview

The addresses used in DYMO-low control messages are either 16 bit link layer short address or IEEE 64-bit extended addresses [EUI64]. Additionally, it should be noted that as used in this specification, DYMO-low is not layered on top of IP, but underneath it. It is an underlay. As such, it creates a mesh network topology of IEEE 802.15.4 devices that use single wireless interface each, underneath and unbeknownst to IP. IP sees a PAN as a single link. This is similar to how other technologies regularly create complex structures underneath IP (e.g., ethernet spanning tree bridges, token ring source routing, ATM, etc). One can envision a sub-IP mesh creating the illusion that all the devices on that PAN are on the same IPv6 link (sharing the same IPv6 prefix). At the same time, normal usage of DYMO (above IP) could tie together several such "links" (potentially using different technologies for each) into a larger mesh.

DYMO over IPv4 makes use of broadcast in its route discovery. It does so in order to propagate the Route Request control packets (RREQs). In this specification, such broadcast packets are obtained
by setting the PAN id to the broadcast PAN (0xffff) and by setting the link layer destination address to the broadcast short address (0xffff) DYMO-low control packets use the encapsulation defined in \[I-D.ietf-6lowpan-format\]. All DYMO-low control packets shall use the prot_type value TBD (suggested value of 5). This prot_type is used to send DYMO-low messages in a manner similar to how DYMO uses a properly assigned UDP port.

2.1. Simplifications for DYMO over IEEE 802.15.4

This section specifies simplifications and distinctive features of DYMO-low compared to the base DYMO.

DYMO allows for minimalist implementations by specifying non-essential functionality as optional \[I-D.ietf-manet-dymo\]. In keeping with DYMO, DYMO-low implements the routing message (RM) which provides both the RREQ (route request) and the RREP (route reply). Furthermore, the RERR (route error) message is implemented while UERR (unsupported message error) message is obviated for simplicity. DYMO-low has the following characteristics:

- RREQ messages are transmitted as IEEE 802.15.4 broadcast messages to reach all the next hop neighbors. DYMO packets SHOULD NOT be fragmented.
- Only the final destination SHOULD respond to a RREQ by replying with a RREP.
- Link quality (LQI) of IEEE 802.15.4 \[IEEE802.15.4\] in addition to the route cost is utilized for selecting best route to the destination.
- Hello messages are not used. Instead, the IEEE 802.15.4 acknowledgement mechanism is used to determine if a neighbor is no longer responsive. This information is obtained when transmitting a packet with acknowledgement option turned on.
- Due to space limitations, nodes SHOULD append only one unreachable destination in RERR.
- Sequence numbers are used for loop freedom. The size of the sequence number field is reduced from 32 bits to 16 bits for simplification.
- The transmission method for RREQ and RERR messages in DYMO is link-local multicast. However, considering the energy-constrained nature of 6lowpan, some efficient mechanisms other than broadcast are necessitated in DYMO-low (TBD).
2.2. Terminology

Link Layer Destination Address (LinkLayerDestinationAddress)

The 16 bit short or EUI-64 link layer address of the destination in the MAC layer. It is also called as the next-hop destination during hop-by-hop forwarding of packets.

Link Layer Source Address (LinkLayerSourceAddress)

The 16 bit short or EUI-64 link layer address of the source in the MAC layer. It is also called as the previous-hop source address during hop-by-hop forwarding of packets.

Broadcast

A broadcast in 6lowpan implies link-local multicast in IEEE 802.15.4 MAC layer. This can be done by setting the link layer destination field to 0xffff.

Valid Route

A known route where the Route.ValidTimeout timer is not set to the current time.

3. Data Structures

3.1. 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.

Route Destination Address (Route.DestAddress)

The 16 bit short or EUI-64 link layer address of the final destination of a route.

Route Delete Timeout (Route.DeleteTimeout)

If the current time is after Route.DeleteTimeout the corresponding routing table entry MUST be deleted and the timer associated with this entry are reset.

Route Cost (Route.RouteCost)

Cumulative cost metric used for allowing a node to select an optimum route to the final destination.
Route Next Hop Address (Route.NextHopAddress)

The 16 bit short or EUI-64 link layer address of the next-hop node on the path toward the final destination.

Route.ValidTimeout

The time at which a route table entry is scheduled to be invalidated. The routing table entry is no longer considered valid when the timer is set after Route.ValidTimeout, and Route.DeleteTimeOut is set.

3.2. DYMO-low Messages

DYMO-low messages are categorized either as a Routing Message (RM) or a Route Error (RERR) message.

3.2.1. DYMO-low Routing Messages

A RM can be either a Route Request (RREQ) message or a Route Reply (RREP) message. These messages are very similar in information but vary in the way of their processing.

3.2.1.1. DYMO-low Route Request (RREQ) and Route Reply (RREP) messages

![Figure 1]

Message Type (Type) The following is the list of the currently available message types.

<table>
<thead>
<tr>
<th>Type</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Routing Message (RM)</td>
<td>1</td>
</tr>
<tr>
<td>Route Error (RERR)</td>
<td>2</td>
</tr>
</tbody>
</table>

Time To Live (TTL)
8-bit field that identifies the maximum number of times the message is to be retransmitted.

Target (T-bit)

1 for the 16-bit address of the target.

0 for the EUI-64 address of the target.

Originator (O-bit)

1 for the 16-bit address of the Source.

0 for the EUI-64 address of the Source.

Solicited/Unsolicited (S-bit)

Route discovery is desired (solicited) if S is set. The TargetAddress is only present if S is set. If S is unset (ie, zero), it allows nodes to disseminate unsolicited & undirected routing information.

Coordinator (C-bit)

1 if the node generating DYMO message is a PAN Coordinator (PC). Allows priority routing (TBD) to node if it is a PC 0 if the node generating this message is a not PC (TBD)

A-bit (A)

1-bit selector indicating whether this RM requires a RREP by the TargetAddress. If A=1 the RM is a RREQ and needs a RREP.

Cost Type (CT)

3-bits of CT are currently defined as:

0: Hop count

1-0xf: TBD

RREQ ID

An identifier that uniquely identifies the particular RREQ when taken in conjunction with the originator. It serves two purposes, i) It allows intermediate nodes to process the RREQ message once and ii) It matches a unique RREP message against unique RREQ in the wake of multiple RREQ generation.
Target Address (TargetAddress) - (Optional)

The node that is the ultimate destination of the message. This field is only required if the LinkLayerDestinationAddress is not the BroadcastAddress. TargetAddress is present if the S-bit is set. For RREQ the TargetAddress is the desired destination, the destination for which a valid route does not exist. For RREP the TargetAddress is the RREQ originator. During hop-by-hop transmission of a DYMO-low packet the LinkLayerDestinationAddress is filled with the Route.NextHopAddress of the route table entry associated with the TargetAddress. In case S-bit is unset, the message is neither a RREQ nor a RREP. It can be used an unsolicited routing informational message.

Target Route Cost (TRouteCost) - (Optional)

8-bit field that identifies the routing cost across the number of intermediate nodes through which a packet traversed on the route to this particular TargetAddress.

Originator Address (OriginatorAddress)

The node that is the originator of routing message. In RREQ message, the OriginatorAddress is the node that generates RREQ message. In RREP, the OriginatorAddress is the node that replies to RREQ.

3.2.1.2. Route Error (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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|     Type      |      TTL      |T|O|U|C|A|    TargetAddress    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                         OriginatorAddress                     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                         UnreachableNodeAddress                |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 2

U-bit (T)

1 for the 16-bit address of UnreachableNodeAddress.

0 for the EUI-64 address of UnreachableNodeAddress.

UnreachableNodeAddress
The 16-bit short or EUI-64 link layer address of the node that has become unreachable.

OriginatorAddress

The 16-bit short or EUI-64 link layer address of the node that generates the RERR message.

Target Node Address (TargetAddress)

The 16-bit short or EUI-64 link layer address of the node that is the destination of the RERR message.

4. Detailed operation

4.1. DYMO-low Routing Table Operations

4.1.1. Creating or Updating a Route Table Entry from New Routing Information

While processing a RM, as described in Section 4.2.2, a node checks its routing table for an entry to the OriginatorAddress in the RREQ. If a valid route exists to TargetAddress, the route can be used to send any queued data packets and to fulfill any outstanding route requests.

In the event that no matching entry is found, an entry is created.

If a matching entry is found, the routing information about OriginatorAddress contained in this RM is considered stale if the TRouteCost is greater than Route.RouteCost.

If there exists a route AND the TRouteCost is equal to the Route.RouteCost in this RM, the information is not stale, but the routing information SHOULD be disregarded and no routing update should occur.

If the information in this RM is stale or disregarded this DYMO-low packet MUST be dropped. If the route information for Originator is not stale or disregarded, then the following actions occur to the route table entry for OriginatorAddress:

1. the Route.RouteCost is set to the TRouteCost,

2. the Route.NextHopAddress is set to the node that transmitted this DYMO-low packet (LinkLayerSourceAddress),

3. and the Route.ValidTimeout is set to the current time +
ROUTE_TIMEOUT. If a valid route exists to TargetAddress, the route can be used to send any queued data packets and to fulfill any outstanding route requests.

4.1.2. Route Table Entry Timeouts

If the current time is later than a routing entry’s Route.ValidTimeout, the route is stale and it is not to be used to route packets. The information in invalid entries is still used for generating RREQ messages. If the current time is after Route.DeleteTimeout the corresponding routing table entry MUST be deleted.

4.2. Routing message

4.2.1. Routing message creation

When a node creates a RREQ or RREP, it MUST create the RM. It sets the OriginatorAddress to its own address.

4.2.2. Routing message Processing

After the general DYMO-low message pre-processing (Section 4.5.2), the Routing message is processed to yield the route cost TRouteCost. That is, the route cost TRouteCost is said to be better (or equivalently smaller) than or equal to (Route.RouteCost’) if the following condition holds (Note that the apostrophe refers to Route.RouteCost i.e., an already existing route entry in the routing table)

\[ TRouteCost \leq Route.RouteCost’ \]

If a matching entry to the OriginatorAddress in the routing message is found in the routing table, the routing information about OriginatorAddress contained in this routing message is considered stale if TRouteCost is greater than the Route.RouteCost’. If the information in this routing message is stale or disregarded this DYMO-low packet MUST be dropped.

If there exists a route AND equal the information is not stale, then the routing information SHOULD be disregarded and no routing update should occur. If the route information for OriginatorAddress is not stale or disregarded, then the following actions occur to the route table entry for OriginatorAddress:

1. the Route.RouteCost is set to the TRouteCost,

2. the Route.NextHopAddress is set to the node that transmitted this
DYMO-low packet (LinkLayerSourceAddress),

3. and the Route.ValidTimeout is set to the current time + ROUTE_TIMEOUT.

If this node is the TargetAddress AND the A-bit is set (A=1), this node MUST respond with a RREP. The target node creates a new RM as described in Section 4.2.1. The TargetAddress in the new RM is set to the OriginatorAddress from the RM currently being processed. The A-bit is set to (A=0). The LinkLayerDestinationAddress is set to the Route.NextHopAddress for the TargetAddress. Then the new RM undergoes post-processing, according to Section 4.5.3. If this node is not the TargetAddress, the current RE SHOULD be handled according to Section 4.5.4.

If this node is the TargetAddress, the current packet and any additional elements are processed, but this packet is not retransmitted.

4.3. Energy-aware Route Discovery

A node generates a Route Request (RREQ) to discover a valid route to a particular destination (TargetAddress). A RREQ is a RM with the A-bit is set to one (A=1) to indicate that the TargetAddress must respond with a RREP. The LinkLayerDestinationAddress is set to the BroadcastAddress. The RM is then transmitted according to the procedure defined in Section 4.5.4. After issuing a RREQ, the originating node waits for a route to be created to the TargetAddress. If a RREP is not received within RREQ_WAIT_TIME milliseconds, this node MAY again try to discover a route by issuing another RREQ. An intermediate node that receives RREQ message may agree broadcast it right away only if its energy level permits so. Otherwise, such an energy starved node (shown in Fig. 3) may delay the broadcast of RREQ message by the time factor ‘INDELAY’ (where the notation is intended to represent induced delay) so that other nodes with relatively more energy form the routing path for the TargetAddress. The methods to adjust the value of INDELAY is TBD.

To reduce congestion in a network, repeated attempts at route discovery for a particular TargetAddress SHOULD utilize a binary exponential backoff. The first time a node issues a RREQ, it waits RREQ_WAIT_TIME milliseconds for a route to the TargetAddress. If a route is not found within that time, the node MAY send another RREQ. If a route is not found within two (2) times the current waiting time, another RREQ may be sent, up to a total of RREQ_TRIES. 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 for a route MAY be buffered. If a route discovery has been attempted RREQ_TRIES times
without receiving a route to the TargetAddress, all data packets destined to the corresponding TargetAddress SHOULD be dropped from the buffer.

4.4. Route Maintenance

4.4.1. Monitoring of Active Links

Before a route can be used for forwarding a packet, it MUST be checked to make sure that the route is still valid. If the Route.ValidTimeout is earlier than the current time, the packet cannot be forwarded, and a RERR message MUST be generated (see Section 4.4.3). In this case, the Route.DeleteTimeout is set to Route.ValidTimeout + ROUTE_DELETE_TIMEOUT. If the current time is after Route.DeleteTimeout, then the route SHOULD be deleted, though a route MAY be deleted at any time. Upon detecting a link break the detecting node MUST set the Route.ValidTimeout to the current time for all active routes utilizing the broken link. A RERR MUST be issued if a data packet is received and it cannot be delivered to the next hop. RERR generation is described in Section 4.4.3. A RERR SHOULD be issued after detecting a broken link of an active route to quickly notify nodes that a link break occurred and a route or routes are no longer available.

4.4.2. Updating Route Lifetimes

To avoid route timeouts for active routes, a node SHOULD update the Route.ValidTimeout to the final destination address [I-D.ietf-6lowpan-format] to be the current time + ROUTE_TIMEOUT upon successfully transmitting a packet to the next hop.

4.4.3. Route Error Generation

When a data packet is received for a destination without a valid routing table entry, a Route Error (RERR) MUST be generated by this node. A RERR informs the source that the current route is no longer available. In the RERR, the TargetAddress field is the address of the unreachable node (final destination address) from the data packet. The setting of the LinkLayerDestinationAddress of the RERR and the RERR processing at the receiving node are TBD.

4.5. General DYMO-low Processing

4.5.1. DYMO-low Processing

The Routing Message (RM) MUST be processed completely prior to any transmissions. Unless specific message processing requires dropping the DYMO-low packet, it is retransmitted after processing, according
to the method described in Section 4.5.4.

4.5.1.1. Routing Message Pre-processing

The RM in a DYMO-low packet undergoes pre-processing before the message specific processing occurs. During pre-processing, the TTL is decremented by one (1).

4.5.1.2. Routing Message Post-processing

If the TTL is zero (0) the DYMO-low packet is dropped. If the TTL is greater than zero the DYMO-low packet is re-transmitted after processing of all messages. If the TTL of Routing Message (RM) is zero (0) after processing, it MUST be removed from the DYMO-low packet prior to transmission.

4.5.2. DYMO-low Control Packet Transmission

DYMO-low packet transmission and re-transmission is controlled by the LinkLayerDestinationAddress. If the LinkLayerDestinationAddress is a unicast address, the packet LinkLayerDestinationAddress is replaced by the Route.NextHopAddress from a route table lookup for the TargetAddress. If a route for the TargetAddress is unknown or invalid the packet is dropped and a RERR SHOULD be generated.

4.6. Packet Generation Limits

To avoid congestion, a node SHOULD NOT transmit more than RATE_LIMIT control messages per second. RREQ packets SHOULD be discarded before RREP or RERR packets.

5. Configuration Parameters

Here are some default parameter values for DYMO-low:

<table>
<thead>
<tr>
<th>Parameter Name</th>
<th>Suggested Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>NET_DIAMETER</td>
<td>256</td>
</tr>
<tr>
<td>RATE_LIMIT</td>
<td>2</td>
</tr>
<tr>
<td>ROUTE_TIMEOUT</td>
<td>10 minutes</td>
</tr>
<tr>
<td>ROUTE_DELETE_TIMEOUT</td>
<td>2*ROUTE_TIMEOUT</td>
</tr>
<tr>
<td>RREQ_WAIT_TIME</td>
<td>1000 milliseconds</td>
</tr>
<tr>
<td>RREQ_TRIES</td>
<td>2</td>
</tr>
</tbody>
</table>
6. IANA Considerations

This document needs an additional IANA registry for the prot_type value that indicates the DYMO-low format.

7. Security Considerations

The security considerations of the [RFC3561] are applicable to this document. As described in the charter of the 6lowpan w.g., DYMO-low will also try to reuse existing security considerations related to Ad hoc routing protocols. Further considerations will be studied in the next version.

8. Acknowledgements

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9. References

9.1. Normative References

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