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Quality of Service Extension to Dynamic MANET OnDemand Routing Protocol

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Abstract

This document describes extensions to the Dynamic MANET On-demand (DYMO) routing protocol in order to enable mobile nodes to discover and maintain QoS routes. DYMO is a reactive (on-demand) routing protocol designed for use by mobile nodes in multi-hop wireless ad hoc networks. Extensions of this document include necessary entries to the routing table and DYMO routing messages.

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1. Introduction

The DYMO routing protocol specifies a reactive means to discover and maintain a route to the destination for MANET nodes. A source node disseminates a Route Request (RREQ) message toward the destination node to discover a route to the node. Once the RREQ message arrives at the destination node, it responds a Route Reply (RREP) message back to the source node via the discovered path by unicasting. During such a route discovery process, intermediate nodes (i.e. nodes that relay the RREQ and RREP message) update its routing table based on the routing information that is present in those two messages for each direction. DYMO also offers adaptation to changes in network topology, which can be mainly occurred by the mobility of nodes, by means of the route maintenance mechanisms [1].

In order to provide MANET nodes with QoS routes, extensions to DYMO routing messages are required. These extensions specify the service requirements (e.g. maximum tolerable delay, maximum tolerable jitter, and/or minimum bandwidth limitation) that must be guaranteed by nodes along a route from a source to the destination.

This document describes which extensions are required for support QoS in routing, how service guarantees are achieved by using the defined extensions without high impacts on the existing DYMO operations and how QoS routes are discovered and maintained. The extensions specified in this document conform to the DYMO routing protocol [1] (i.e. the generalized signaling framework specified in [2]).

In the following, the extension to routing table is first described and then two routing message extensions, QoS Route Message (QRM) and QoS Route Error (QRERR), are presented for supporting QoS routing.

2. Terminology

The keywords "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119 [3].

The basic terminology defined in [1] is also used in this document. In addition, the following terminology is used.

Source Identifier (SRC ID)
SRC ID consists of IPSourceAddress and Port number.

QoS Routing Message (QRM)
QRM is an extension to the DYMO Routing Message (RM) to support QoS routing.

QoS Route Request (QRREQ)
A source node, which is intended to discover a QoS enabled route to a corresponding destination, generates and broadcasts a QRREQ message.

QoS Route Respond (QRREP)
The destination generates QRREP to inform the QRREQ generator about a route available for the QoS requirements specified in the QRREQ message.

QoS Route Error (QRERR)
QRERR message is used to allow a node to figure out that one or more routes to destinations are not available.

QoS Parameter (QP)
QoS parameter generally includes bandwidth, end to end delay, jitter loss probability and routing metric. Additional parameters MAY also be defined if required, for example channel assignment. Each of the parameters for a route is considered as follows.

- Bandwidth of a route is the minimum value from all values of intermediate links from source to destination.

- End to end delay is the total summation value of delay introduced by each of intermediate nodes between source and destination pairs.

- End to end jitter is the total summation value of jitter experienced at each of intermediate nodes between source and destination pairs.

- End to end loss probability is the multiplicative value of loss probability expected at each of intermediate nodes between source and destination pairs.

- Routing metric can be any type of metric that nodes can support.

- In a single hop based wireless networking technologies such as WLAN based on IEEE 802.11b, multiple channels have already been used to reduce interference between node and access point. Such a property can also be applied to multi-hop ad-hoc networks, thereby enhancing performance in terms of QoS.

3. Routing Table Entry for QoS Routing

As described in [1], routing table entry is a conceptual data structure so that implementer can use an internal representation. In addition to the entries specified in [1], conceptual entries indicating and managing QoS requirements are required.

In QoS routing, routing table entry can be defined differently according to the type of QoS model; per-flow based model (say IntServ model [4]) or per-class based model (say DiffServ model [5]).

In case of the per-flow based mechanism, the following entries MAY be added to the routing table of each DYMO router on the path. A routing table entry SHOULD be defined for each flow to specify QoS requirements requested by the source (requestor) of the particular flow, where a flow can be identified by the pair of IP address and port number (i.e. SRC ID).

- Minimum Available Bandwidth

- Maximum Tolerable Delay

- Maximum Tolerable Jitter

- Maximum Tolerable Loss Probability

- List of Sources Identifier Requesting Bandwidth Guarantees

- List of Sources Identifier Requesting Delay Guarantees

- List of Sources Identifier Requesting Jitter Guarantees

- List of Sources Identifier Requesting Loss Probability Guarantees

In case of the class-based model, on the other hand, the following fields may be added to the routing table of a DYMO router. Each routing table entry SHOULD be defined for each pre-specified class, where a packet belonging to each class can be distinguished by DSCP (DiffServ Code Point) as specified in [6].

- Minimum Available Bandwidth

- Maximum Tolerable Delay

- Maximum Tolerable Jitter

- Maximum Tolerable Loss Probability

- List of Classes

- List of Sources Identifier belonging to each of the Classes

4. Extensions to DYMO Routing Message (RM)

In DYMO specification, there are two routing messages: RREQ and RREP. This section therefore presents two extensions to the DYMO RM to discover a QoS route: QRREQ and QRREP. The work especially considers the compact representation for use by mobile nodes in using of limited capacity, the future extensions for covering various QoS parameters and the support of the per-flow based mechanism and the per-class based mechanism as well.

4.1 QoS Routing Message (QRM)

QoS Routing Message (QRM) is an extension to the DYMO Routing Message (RM) in order to enable a source to discover a path that is able to guarantee the QoS requirements.

```
 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.DestinationAddress=LL_ALL_MANET_ROUTERS            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+

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

 QoS Route Message Header
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  QoSMsg-type  | Rsv |N|0|0|0|0|           Msg-size            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                      Originator Address                       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|    Hop Limit  | Hop Count     |     Msg Sequence Number       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+

 QoS Route Message Body - Message TLV Block for QoS Request Type
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|     msg-tlv-block-size        |  QoSTC-type    |Resv |0|0|1|0|0|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

```
|     Length    | Traffic class | QosMinBw-type |Resv |0|0|1|0|0|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|    Length     |           QoSParam            | QosMaxDel-type|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|Resv |0|0|1|0|0|    Length     |            QoSParam           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| QosMaxJit-type|Resv |0|0|1|0|0|    Length     |   QoSParam    :
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
:     (cont)    |QosMaxLosP-type|Resv |0|0|1|0|0|    Length     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|           QoSParam            | QosRMet-type  |Resv |0|0|1|0|0|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|    Length     |  MetricValue  | QosRMet-type  |Resv |0|0|1|0|0|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|    Length     |  MetricValue  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
  . . .
```

QoS Route Message Body - Address Block

```
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|Number Addrs=2 |  Resv   |0|1|0| HeadLength=3  |     Head      :
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
:            (cont)             |  Target.Mid   |   Orig.Mid    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

QoS Route Message Body - Address TLV Block for Sequence Number

```
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|       tlv-block-size=6        |DYMOSeqNum-type|Resv |0|1|0|0|0|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Index-start=1 | tlv-length=2  |          Orig.SeqNum          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 . . .
```

QoS Route Message Body - Address Block for QoS parameter

```
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Number Addrs  |  Resv   |0|1|0| HeadLength=3  |     Head      :
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
:            (cont)             |     Mid1      |      ...      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|      MidN     |
+-+-+-+-+-+-+-+-+
```

QoS Route Message Body - Address TLV Block for QoS parameter

```
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|         tlv-block-size        | QoSstate-type |Resv |M|0|1|0|1|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|             Length            |       QoS State Value1        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|             .....             | QoS State ValueN(if presented)|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 1. Exemplified QoS Routing Message (QRM)

The QoS requirements of the source are specified by means of the QoSpar (QoS parameter) tlv.

- QRM conforms to the generalized message format defined in [2].

- msg-type = DYMO-QRREQ or DYMO-QRREP
  The Type field identifies that this element is QRE (i.e. either DYMO-QRREQ or DYMO-QRREP). The field also specifies how the QRE is handled in case where nodes do not implement or understand such QoS extensions. The data structure of the Type is as follows.

```
0                          0
0 1 2 3 4 5 6 7 8          0 1 2 3 4 5 6 7 8
+-+-+-+-+-+-+-+-+-+        +-+-+-+-+-+-+-+-+-+
|      Type       |    =   |M| H |           |
+-+-+-+-+-+-+-+-+-+        +-+-+-+-+-+-+-+-+-+
```

Figure 2. Type

In QRE, M bit MUST be set to one (1) in order to indicate that QRE requires notification via an UERR when QRE is not understood or handled by a node on the path. Therefore QRE MUST convey NotifyAddress field to which UERR is sent. The H bits in the Type field MUST set to (11) in order to force a node which does not support QRE to drop the QRE packet without processing any other QoS DYMO elements.

- msg-semantics
  QRM conforms to the msg-semantics specified in DYMO.

- msg-header-info
  QRM conforms to the msg-header-info specified in DYMO.

- msg-tlv (QoSpar tlv)
  This TLV field can be used differently according to the type of QRM (i.e. whether it is a route request or a route reply element with QoS extensions). In QRREQ message, on one hand, the QoSpar tlv indicates the service requirements that must be met at nodes along a route to the destination. On the other hand, in QRREP message, the destination uses this field to inform the route's resources available for the QoS requestor. The route's resources are gathered or updated by intermediate nodes and contained within the QoSstate-tlv field during the route discovery process.

  Traffic Class Type (QoSTC-type)

  The Traffic Cls field allows mobile nodes to employ the per-class based mechanism (say DiffServ). This field is specified by using 6-bits code, called DSCP (Differentiated Services Code Points) that indicate a particular class [5].

```
 0
 0 1 2 3 4 5 6 7 8
 +-+-+-+-+-+-+-+-+
 |0 0|   DSCP    |
 +-+-+-+-+-+-+-+-+
```
Figure 3. Traffic Class

Minimum Bandwidth Type (QosMinBw-type) This type indicates whether the minimum bandwidth is specified as one of the service requirements within tlv-value.

Maximum Delay Type (QosMaxDel-type) This type indicates whether the maximum delay (end to end delay) is specified as one of the service requirements within tlv-value.

Maximum Jitter (QosMaxJit-type) This type indicates whether the maximum jitter (end to end jitter) is specified as one of the service requirements within tlv-value.

Maximum Loss Probability Type (QosMaxLosP-type) This type indicates whether the maximum loss probability (end to end value) is specified as one of the service requirements within tlv-value.

Routing Metric Type (QosRMet-type) This tlv-type is used to specify the type and value of routing metrics of a node (i.e. ETX, ETT, WCETT) [7]. If an intermediate node along a path to the destination can support the metric in the tlv-type, he can update the MetricValue field and his routing table. If it is not the case, he simply removes the tlv type from msg-tlv. When target node receives the QRREQ containing the QosRMet-type field, then the type of routing metric can be used since entire intermediate nodes of the path can support the routing metric.

QoS parameter value (QoS Param) QoS Param Value fields are defined as follows.

- Minimum Bandwidth Requirement
  16-bit number, measured in kbits/second (kbps). The maximum value is about 131 Mbps (2^17 - 1 kbps). If the required band-width is less than 1kbps, the value is set to one (1). That is, the least bandwidth requirement the source requires is 1 Kbps.

- Maximum End to End Delay Requirement
  16-bit number, measured in milliseconds (ms)

- Maximum End to End Jitter Requirement
  16-bit number, measured in milliseconds (ms)

- Maximum End to End Loss Probability Requirement
  16-bit number, expressed in percentage

- add-block entries
  QRM conforms to the add-block entries specified in DYMO.

- add-tlv
  Most of fields conform to the DYMO routing message specified in [1] except the newly defined QoSpar tlv and QoSstate (QoS State Information) tlv.

- add-block for Qos
  Intermediate nodes along a path to the destination MAY add its address or MAY add dummy address block for QoSstate-tlv. This information may be useful for routing [1].

- add-tlv (QoSstate-tlv)
  QRM conveys QoS State information for each address within QoSstate-tlv. In QoS routing, intermediate nodes along a path to the destination should inform the destination about its current state of resources in order that the destination is able to decide the optimal route among route candidates.

  The number and the type of QoS State Values depend on the QoSpar-tlv. For example, if a source specifies a delay parameter as a QoS requirement (i.e. The QosMDel-type is included in QoSpar-tlv), there MUST exist a QoS state value for presenting a delay value on candidate paths. In this case, all intermediate nodes MUST accumulate its measured delay.

4.2 QoS Route Error (QRERR)

QoS Route Error (QRERR) is an extension to the DYMO RERR message. QRERR message element is generated when an intermediate node realizes a lack of capability to maintain the QoS guarantees for a specific route. The data structure of this element is as follows.

```
    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

     Packet Header

     . . .

    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |0 0 0 0 0 0 0 0| Reserved  |0|0|     Packet Sequence Number    |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+

    QoS Route Message Header
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |    msg-type   | Rsv |N|0|0|0|0|           Msg-size            |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                      Originator Address                       |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |    Hop Limit  |  Hop Count    |      Msg Sequence Number      |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+

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

    QoS Route Message Body - Address Block
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |Number Addrs=2 |  Resv   |0|1|0| HeadLength=3  |     Head      :
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    :            (cont)             |  Target.Mid   |   Orig.Mid    |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     . . .

    QoS Route Message Body - Address TLV Block for unsupported QoS
```

```
parameters
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|          QUN-tlv-Len          |   QUN-type    |Resv |0|1|0|0|0|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  Index Start  |     Length    |         UQParam vaule         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   QUN-type    |Resv |0|1|0|0|0|  Index Start  |     Length    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|         UQParam value         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 . . .
```

Figure 5. QoS Route Error (QRERR)

- QRERR conforms to the generalized message format.

- msg-type = DYMO-QRERR

- msg-semantics QRERR conforms to the msg-semantics of RERR specified in DYMO.

- msg-header-info QRERR conforms to the msg-header-info of RERR specified in DYMO.

- add-block entries QRERR contains 1 or more addresses as QoS Unsupported Node Addresses that is the IP address of the node that cannot guarantee QoS any more.

- add-tlv-block (QUN-tlv) specify unsupported QoS parameters.

Unsupported QoS Parameter tlv type (QUN-type) The main difference between RERR and QRERR is the UQParam (Unsupported QoS Parameter) field which is used to inform the QoS requestor about which QoS parameter is no longer available for the originally specified QoS requirements. Once the QoS requestor receives the QRERR, it rebuilds a QoS route process based on the unavailable QoS parameters if it still has packets to deliver.

QoS Parameter Value The QoS Parameter Value field(s) reports the measured QoS parameter(s) that fails to meet the originally requested QoS. If a particular node is aware of higher delay than the maximum permissible delay, the measured delay is reported to the QoS requestor.

The QRERR message MUST be delivered to all QoS requestors potentially affected by the change in the QoS parameter.

5. QoS DYMO Operations

5.1 QoS Route Discovery

Like DYMO routing procedures, a QoS route is also discovered by means of two way handshaking consisting of a route request and route reply cycle. Instead of DYMO RREQ, the source (QoS requestor) disseminates QRREQ (RREQ with a QoS extension) to the destination. QRREQ message elements therefore should contain required QoS parameters as well as the QoS reporting information on the path that the message has been experienced. Thereafter, the destination node decides a correct route that can meet the QoS requirements and then sends QRREP (RREP with a QoS extension) back to the source.

Ahead of re-broadcasting a QRREQ message by an intermediate node, the node must check its resources whether it is available for the QoS requirements contained within the QRREQ message during the route discovery process. If resources are enough to support service requirements, the intermediate node updates QoS information that is present in the QRREQ message to inform the destination about the current QoS states related to the path.

The QRREQ message should contain two different fields. One is used to specify the QoS requirements of the source (i.e. QoS requestor) that must be met at nodes through the path. The other field is used to inform both the QoS requestor and the destination about the current network conditions such as delay, jitter, and/or bandwidth to discover a proper QoS route.

In case of delay and jitter, intermediate nodes accumulate each of their measured delay and jitter value to the corresponding value of the received QRREQ message. For this reason, the destination can be aware of the end to end delay and jitter along the path.

In case of bandwidth (i.e. capacity to transmit), the node compares its measured value with the value of QoSstate in the received QRREQ message. If the measured value is smaller than the value of the message, the field is updated to the measured one. This field allows the destination to be aware of the actual minimum bandwidth over a route from the source to the destination since the value of QSIB is always bigger than the minimum value that the QoS requestor requires. If it is not the case, a node MUST drop the QRREQ message since there is not enough bandwidth to guarantee the required one. Such a way allows the QoS requestor to be able to increase the minimum bandwidth requirement according to the network condition dynamically.

In QoS enabled DYMO, M-bit MUST be set to one (1) and H-bits MUST be set to (11). Therefore, if the QoS extended element is not supported or handled by the processing node, the node discards the message to prevent that unsupported message is not propagated further.

The MANET-NHDP allows the previous hop to ensure that the link traversed is not unidirectional [8]. It may be useful to detect a unidirectional link(s) along a path in the process of QoS route discovery. The existence of a unidirectional link may not be a problem in some QoS applications such as one-way streaming services. However, others require fully directional link on the path from a source to the destination(s). Examples include multimedia conferencing, IP telephony and most of RTP based QoS applications. Therefore, it is necessary to inform how each of cases is handled at nodes along path.

When a node ensures the link is unidirectional then the QRM receiver is forced to stop the route discovery process.

5.2 QoS Route Maintenance

In order to react to changes in the network resources, nodes monitor their links under the aspect of QoS. When a node is aware of the fact that resources of its link is no longer available for the QoS requestor, a QoS-Route Error (QRERR) is sent to the QoS requestor to inform the current unavailable QoS parameters of the route. Once the requestor receives the QRERR, it re-builds a QoS route process based on the unavailable QoS parameters if it still has packets to deliver.

6. Security Considerations

This document does not discuss any special security concerns in detail. The protocol of this document is built on the assumption that all participating nodes are trusted each other as well as there is no adversary who modifies/injects false route elements to corrupt the QoS routes.

However, support of secure routing protocol is prerequisite for launching a secure communication in the presence of adversaries. In such an environment, most of all MANET routing protocols including DYMO are vulnerable to many kinds of attacks. It is fairly easy to inject fake routing messages or modify legitimate ones so that network operation would be heavily disturbed (e.g., by creating loops or disconnecting the network). Therefore, it is necessary to find a means to authenticate/verify control messages to discover and maintain a proper route. Especially, QRM message MUST be authenticated to enable nodes participating in QoS DYMO routing protocol to assure the origin of the QRM message.

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