Hybrid Hop Count based Multiple Qos Constraints Routing Protocol with Mobility Prediction for Manet

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Abstract

Mobile ad hoc network (MANET) is composed of mobile nodes, which do not have any fixed and wired communication infrastructure. This paper discusses a source based hybrid routing protocol called ‘Hybrid Hop count based Multiple Quality of Service (QoS) constraints Routing Protocol with Mobility Prediction (HMQRPMP) for MANET’. It deals with QoS parameters of wireless links namely delay, delay-jitter, bandwidth, cost, link expiry time and residual battery power of mobile nodes. HMQRPMP selects the best routing path with minimal hop count, maximal link expiry time and high energy level among multiple paths between a source and a destination as to increase packet delivery ratio and reduce control overhead in MANET. It predicts the stability of link expiry time of each link for every path. HMQRPMP changes the behavior of a mobile node from proactive to reactive or vice versa by comparing the nodes energy level against the power thresholds so as to be adoptable to topological changes which increases the lifetime of mobile nodes in MANET.

Keywords: Hybrid Protocol; QoS constraints; Routing, Mobility Prediction; MANET

1. Introduction

Mobile ad hoc networks (MANETs) do not have any fixed wired communication infrastructure. MANET can be deployed in the fields like emergency search, military battlefields and rescue sites where participants share information dynamically using their mobile devices. The issues in MANET are routing, mobility management, security, reliability and power consumption [1]. QoS in MANET is defined as the service guarantee to the user [2]. The QoS constraints are classified as time constraints, space constraints, frequency constraints and reliability constraints [3]. The QoS routing protocols in MANET can be categorized as proactive, reactive and hybrid. Proactive routing protocols are table driven. These are not suitable for MANET when there is high dynamism in mobility. In proactive routing, route discovery is easy but route maintenance is hard.
But reactive routing protocols are on demand routing protocols. These are suitable when there is high dynamism in mobility. In reactive routing, route discovery is hard but route maintenance is easy. Hybrid routing protocols have the advantages of proactive and reactive routing. Some of the QoS routing algorithms for MANET are Core Extraction Distributed Ad hoc Routing (CEDAR), QoS-AODV (QAODV), Ticket-Based Probing (TBP) and Multiple QoS constraints Routing Protocol with Mobile Predicting (MQRPMP).

CEDAR [4] uses clustered network architecture and selects the core dynamically. In CEDAR, there may be chances for the core to fail due to hardware and software problems. In the reactive routing protocol QAODV [5], the source node specifies the QoS parameters in the RREQ packet and every intermediate node checks whether or not it can support that QoS. TBP [6] is a multi-path QoS routing scheme. In TBP, the source sends N number of tickets to find N paths. There is no clear cut heuristic for computing tickets. As well as, resource reservation for one flow denies the availability of that resource for other flows. MQRPMP [7] is a multiple QoS constraints reactive routing protocol with mobility prediction mechanism. It has better PDR than TBP. The cost of communication overhead is also less in MQRPMP than TBP. But all the above mentioned protocols do not address the effective power utilization, hop count constraint and stability of link expiry time in MANET.

This paper discusses a source based hybrid routing protocol called ‘Hybrid Hop count based Multiple Quality of Service (QoS) constraints Routing Protocol with Mobility Prediction (HMQRPMP)’ for MANET. It deals with QoS parameters namely delay (D), delay-jitter (J), bandwidth (B), cost (C), link expiry time (LET), energy level (EL) of nodes and hop count (HC) to select the best routing path among multiple paths between a source and a destination as to increase Packet Delivery Ratio (PDR) and reduce control overhead in mobile communication. HMQRPMP predicts the stability of LET of each link for each path using our new mobility prediction formula. In this protocol, the behavior of a mobile node is changed from proactive to reactive or vice versa based on its EL to extend its lifetime. Since multiple path metrics are considered for route selection in HMQRPMP, HMQRPMP is different and cannot be compared with any other recent hybrid routing protocols for MANET.

The rest of the paper is structured as follows: Section 2 explains the network model of the new protocol. Section 3, describes mobility prediction mechanism. Section 4 analyses the impact of dynamic mobility of mobile nodes. Section 5 introduces a new formula for predicting the stability of wireless link and briefs our new protocol (HMQRPMP) along with its hybrid mechanism using an example. Section 6 shows the simulation set up and the performance comparison of HMQRPMP over MQRPMP and TBP. Finally, Section 7 gives the conclusion and future enhancements of this research work.

2. Network Model
The network model in MANET can be denoted by \( G = \{V, E\} \) where \( V \) is the set of interconnected nodes and \( E \) is the set of full-duplex directed wireless communication links. It considers the existent multiple links between any two nodes and each link considers the QoS parameters D, J, B, C and LET. The links on each path are required to satisfy the QoS constraints. Since the model proposes a hybrid protocol, the EL of each node \( (V_i) \) on each path is compared with power level thresholds Proactive threshold (PRO-TH) and Reactive threshold (REA-TH) to change the behavior of the mobile node. In this model, the Mobility Speed (MS) and the Vicinity Density (VD) of \( V_i \) are checked against the Mobility Speed threshold (MS-TH) and the Vicinity Density threshold (VD-TH) respectively. This model considers the Prediction of stability of LET (PredictedLET) for links.

The path \( P_k \) with less HC, high energy level and high PredictedLET is selected as the optimal path among the existence of multiple paths \( (P_1, P_2, P_3 \ldots \text{ and } P_n) \) between a source and a destination. So the problem of hybrid hop count based multiple QoS constraints routing with dynamic mobility prediction can be defined as follows:
Select $P_k$ with minimal H and PredictLET is largest among $(P_1, P_2, P_3 \ldots \text{ and } P_n)$ where,

\begin{align*}
\sum D_{ij} &\leq D_c \\
\sum J_{ij} &\leq J_c \\
\sum C_{ij} &\geq C_c \\
B_{ij} &\geq B_c \\
EL(V_i) &\geq \text{PRO-TH} \\
EL(V_i) &\leq \text{REA-TH} \\
\text{REA-TH} &\leq EL(V_i) \leq \text{PRO-TH} \\
MS(V_i) &> \text{MS-TH} \\
VD(V_i) &> \text{VD-TH} \\
\text{Avg}(\sum EL(V_i)) &\geq P_c \\
\text{MAX}(\sum \text{predictedLET}) &> \text{MIN(HC)}
\end{align*}

3. Mobility Prediction Mechanism

Due to frequent topological changes in MANET, the reliability of the path is affected. The reliability of a path depends on the stability of each link on that path. The stability of a link is computed using the well known mobility prediction formula [8]. This formula estimates the link expiration time between two adjacent nodes using location information obtained from Global Positioning System (GPS) [9], mobility speed, moving direction and transmission range of mobile nodes. We also assume that all nodes in the network have their clock synchronized [e.g., by using the network time protocol (NTP) or the GPS clock itself]. Assume that the two nodes i and j are within the transmission range r of each other. Let $(x_i, y_i)$ be the coordinate of mobile host i and $(x_j, y_j)$ be that of mobile host j. Also let $v_i$ and $v_j$ be the speeds, and $\theta_i$ and $\theta_j$ be the moving directions of nodes i and j respectively.

Then, the amount of time that they will stay connected - LET, is predicted by the formula given in the following equation (1):

\[
LET = \frac{-(ab+cd)+\sqrt{((a^2+c^2)r^2-(ad-bc)^2)}}{(a^2+c^2)}
\]

where,

\begin{align*}
 a &= v_i \cos \theta_i - v_j \cos \theta_j; \\
 b &= x_i - x_j; \\
 c &= v_i \sin \theta_i - v_j \sin \theta_j \text{ and} \\
 d &= y_i - y_j
\end{align*}

Note that when $v_i = v_j$ and $\theta_i = \theta_j$, LET is set to $\infty$ without applying the above equation.

4. Impact of Dynamic Mobility of Mobile Nodes

The equation (1) can be used for identifying the stability of a link between two adjacent nodes. But during communication, there may be a chance for a mobile node to suddenly increase or decrease its speed or direction when it is moving. This can be known as dynamic mobility. The equation (1) does not address the impact of dynamic mobility. This dynamic mobility is analyzed as follows:

Let us assume that i and j are the two nodes of a link.

**Case 1:** Either i or j is expected to increase or decrease its speed during mobility

**Case 2:** Both mobile nodes i and j are expected to increase or decrease their speed during mobility

In both the cases, due to high dynamism in mobility, the LET between i and j is expected to be changeable, which in turn affects the stability of the link. This affects the stability of the entire path. Apart from this, the nodes on a selected path may have good EL and they may forward many packets.
If any one of the nodes or both the nodes on that path is cut off due to sudden alteration in its speed and/or direction during mobility, the PDR on that path is obviously getting reduced. On the other hand, even though the LET is high, if any one of the nodes or both the nodes of the corresponding link are not having sufficient residual battery power, there may be a chance to lose at least a node in that link which in turn leads to non-existence of the link. This affects the stability of the link and the computed LET for that link is not optimum. So the LET in equation (1) is changeable based on EL of nodes during dynamic mobility.

5. Hybrid Hop Count Based Multiple QoS constraints Routing Protocol with Mobility Prediction

Our protocol introduces a suitable variable called MAF (Mobility Adjustment Factor) to adjust the calculated LET based on EL of nodes during dynamic mobility. The LET value computed using MAF is known as the PredictedLET. The PredictedLET value is computed at each node during route reply and sent to the source for path selection. Therefore, the formula for PredictedLET calculation is shown as follows:

\[ \text{PredictedLET} = \text{CurrentLET} + \text{MAF} \]  

(2)

where, the CurrentLET is computed using the equation (1) and MAF is determined based on the following discussion.

Two assumptions are made to determine the value of MAF. First if the EL of a node is between 90% and 100%, then it is assumed that it can handle heavy traffic for a longer duration and the survival of that node is guaranteed. The availability of such a node in the link could increase PDR. So it is assumed as a good node. Second if the EL of the node is below 91%, then it is assumed to handle normal traffic. The availability of such a node can be assumed as a normal node. It should be noted that these constraint limits are set by the user for checking the EL of a node. The MAF computation for our protocol is shown below.

1) If a normal node is coming to be closer to other node, then it is assumed as gain G. Then MAF = 1
2) If a good node is coming to be closer to other node, then it is assumed as heavy gain GG. Then MAF = 2
3) If both are normal nodes and both are coming to be closer to each other then it is also assumed as very heavy gain GGG. Then MAF = 3
4) If both are coming to be closer to each other but one is normal node and other is good node then it is assumed as positively very heavy gain GGG+. Then MAF = 3.5
5) If both are good nodes and both are coming to be closer to each other then it is assumed as very very heavy gain GGGG. Then MAF = 4
6) If a normal node is going to be disconnected from other node then it is assumed as loss L. Then MAF = -1
7) If a good node is going to be disconnected from other node then it is assumed as heavy loss LL. Then MAF = -2
8) If both are normal nodes and both are going to be disconnected from the each other then it is assumed as very heavy loss LLL. Then MAF = -3
9) If both are going to be disconnected from each other but one is normal node and other is good node then it is assumed as positively very heavy loss LLL-. Then MAF = -3.5
10) If both are good nodes and both are going to be disconnected from each other then it is assumed as very very heavy loss LLLL. Then MAF = -4

The MAF values can be listed as MAFList = {-4,-3.5,-3,-2,-1, 1, 2, 3, 3.5, 4}. So the MAF value of any link at a particular time can be either of the values in the MAFList. When both nodes are not altering their speed and direction, MAF value becomes 0. If MAF = 0 then the PredictedLET is
made equal to the CurrentLET of that link. Our protocol maintains a table called LETtable at each node with the fields namely Source of the link, Destination of the link, LET and PredictedLET. Initially LETtable is empty. Whenever a node receives a route reply, it computes LET using equation (1) and checks whether the corresponding entry is found in the LETtable for that link.

If the entry is not found, then the LET field is set to the newly computed LET and the PredictedLET field is set to zero in LETtable. If the entry is found, then the newly computed LET is treated as CurrentLET and compared with existing LET in LETtable. If the CurrentLET >= LET then the mobile nodes are becoming closer to each other. This shows the increment in the stability of LET which in turn increases PredictedLET. Otherwise, both the nodes are deviating from each other. This shows the decrement in the stability of LET which in turn decreases PredictedLET. The equation (2) can be applied for different types of applications. Since our protocol is a hybrid protocol, it is designed to change the behavior of a mobile node among the following four behavioral modes (BMs).

1. Proactive Mode1 (PM1): The node periodically sends an update packet with Zone Radius $R$ set as the TTL and the update interval is set to a parameter value $i$.
2. Proactive Mode2 (PM2): The node periodically sends an update packet with Zone Radius $R$ set as the TTL and the update interval is set to a parameter value $2 \times i$.
3. Proactive Ready Mode (PRM): The node does not send an update packet but updates its routing table using the received update packets.
4. Reactive Mode (RM): The node does not send and receive an update packet.

Conditions for behavioral changes of mobile nodes are as follows:

1. If a node has more residual battery power than PRO-TH then it is set to PM1.
2. If a node has very low residual backup than REA-TH, then it is switched to RM so as to extend its survival in the communication.
3. If a node has the residual battery power between PRO-TH and REA-TH then it checks its speed against MS-TH. If the mobility speed $>$ MS-TH then the node is switched to RM since there is possibility of more link breakage.
4. If the mobility speed of a node $<$ MS-TH then the vicinity density of the node is compared against VD-TH. If its vicinity density $>$ VD-TH then the node has to deal with more number of control packets. So it is switched to PRM. Otherwise it is switched to PM2.

5.1. Path Discovery

In this protocol, the source starts operating initially in reactive mode. During path discovery, it broadcasts a Route Request (RREQ) with the fields $B_c$, PRO-TH, REA-TH, MS-TH and VD-TH. If an intermediate node (I) receives the RREQ then it forwards the received RREQ on each outgoing link only when $B$ of that link $>$ $B_c$. This reduces the number of RREQs during route discovery. This in turn reduces control overhead. If the destination node receives a duplicate RREQ then it is discarded. Otherwise, the destination node constructs a RREP. The destination node records PRO-TH, REA-TH, MS-TH and VD-TH from the received RREQ and copies them into the RREP. It sets 0 to the fields $D$, $J$, $C$, LET, HC and EL in that RREP. The moving direction and speed of the destination node is also included in the RREP. If an intermediate node receives route reply then it computes and accumulates the values of $D$, $J$, $C$, HC, EL, LET and PredictedLET into its new route reply. It also records PRO-TH, REA-TH, MS-TH and VD-TH from the received RREP and copies them in its new RREP along with its moving direction, speed. Then the new RREP is forwarded to the source. Apart from this, each node changes their behavioral mode according to the pre specified conditions. The source maintains a table called MetricsTable as shown in Table 4 with the fields namely $D_{sum}$, $J_{sum}$, $C_{sum}$, LET$_{sum}$, HC$_{sum}$, EL$_{sum}$ and PredictedLET$_{sum}$ for storing the accumulated values of $D$, $J$, $C$, LET, HC, EL and PredictedLET received from each RREP.

The source sorts the MetricsTable based on PredictedLET. It compares $D_{sum}$, $J_{sum}$, $C_{sum}$ of each route reply against the thresholds $D_c$, $J_c$ and $C_c$. If the comparison is successful then the route mentioned by that corresponding route reply is included in a table called RouteSelectionTable as hwn
in Table 5 at the source. Likewise the source gathers all satisfied RREPs into RouteSelectionTable. The source computes \( \text{Avg}(\sum EL(V_i)) \) for each RREP in the RouteSelectionTable. For each RREP in the RouteSelectionTable, if \( \text{Avg}(\sum EL(V_i)) \geq P_c \), then the corresponding route is recorded in another table called RouteTable as shown in Table 6. Many paths are identified like that.

Among them, the path with minimal \( H \) and highest PredictedLET is selected as an optimal path. The remaining paths can be reserved as backup paths or can be used for multipath routing. During data transmission, except the source, if a node changes its behavioral mode with respect to the recorded thresholds, it starts constructing a new RREP and sends it to the source. It is then up to the source to find whether the path for the received RREP is valid for the next transmission or not. Even though more control overhead is imposed due to the number of new RREPs, the source can select a new optimal path for communication with good PDR. The route discovery procedure for the proposed protocol is given as follows:

**Procedure for the Source:**

If source \( S \) has no paths to destination \( D \)
- Broadcast RREQ
- Execute Route Reply Handling Procedure
End if

**Route Request Handling Procedure:**

If it is an intermediate node \( I \)
- If the received RREQ is not duplicate
  - If \( B_{ij} \geq B_c \) //Minimizing Control Overhead
    - Forward RREQ
  - Else
    - Discard RREQ
End if
Else
- Discard RREQ
End if
If the node is \( D \)
- If the received RREQ is not duplicate
  - Execute Route Reply Handling Procedure
End if
End if

**Route Reply Handling Procedure:**

If it is an intermediate node \( I \) or destination \( D \) // Behavioral Change of Nodes
- If \( EL(V_i) \geq \text{PRO-TH} \) then
  - Set \( V_i \) to PM1
End if
- If \( EL(V_i) \leq \text{REA-TH} \) then
  - Set \( V_i \) to RM
End if
- If \( EL(V_i) \leq \text{PRO-TH} \) and \( \geq \text{REA-TH} \) then
  - If \( MS(V_i) > \text{MS-TH} \) then
    - Set \( V_i \) to RM
  - Else
    - If \( VD(V_i) > \text{VD-TH} \) then
      - Set \( V_i \) to PRM
    - Else
      - Set \( V_i \) to PM2
End if
End if
End if
End if
Record the PRO-TH, REA-TH, MS-TH and VD-TH
Construct and Forward New RREP to Source
End if

If it is an intermediate node I

// Route Reply Construction
D = ReceivedD + CurrentD
J = ReceivedJ + CurrentJ
C = ReceivedC + CurrentC
EL = ReceivedEL + CurrentEL
HC = ReceivedHC + 1
Get the location details from GPS
PredictedLET = CurrentLET + MAF
Construct RREP using D, J, C, HC, EL, LET, PredictedLET, Speed, Direction, PRO-TH, REA-TH, MS-TH, and VD-TH
Forward RREP towards Source
End if

If it is destination node D

// Route Reply Construction
Set 0 to D, J, C, HC, LET, PredictedLET
Set EL = EL (D)
Get the location details from GPS
Construct RREP using D, J, C, HC, EL, LET, PredictedLET, Speed, Direction, PRO-TH, REA-TH, MS-TH, and VD-TH
Forward RREP towards Source
End if

If the node is S
Receive all (RREP) paths with respect to D
Put D, J, C, HC, EL, LET, PredictedLET of each P_i in MetricsTable
If the collection is not NULL
For each path P_i

// Route Selection Table
If \( \sum D_{ij} \leq D_c, \sum J_{ij} \leq J_c, \sum C_{ij} \geq C_c \)
If \( \text{Avg} (\sum EL (V_i)) \geq P_c \)
Put P_i in RouteSelectionTable
Calculate total LET and PredictedLET
If PredictedLET > PredictedLET ( P_j )
Select P_i and Put P_i in RouteTable
Select P_i whose HC is minimum from RouteTable
End if
Delete routing path from MetricsTable
End if
End for
If LET of several paths is equal
Select the least cost route
End if
End if
End if
5.2. Path Maintenance

Due to the frequent changes of network topology and restriction of network resources, the computed optimal route often gets invalid. When the link is cut off, the upstream node issues the routing reconstruction packet (RREC) to the source and the source starts the route discovery again. If the source receives RREP and RREC at the same time, it deals with the RREC.

**Route maintenance procedure by the intermediate node:**
If the link is cut off with its neighbor

  Construct and send RREC to S

End if

If the RREC is received from its neighbor

  Forward the RREC to S

End if

**Route maintenance procedure by the source node:**
If the RREC is received from any I

  Broadcast RREQ packet

End if

5.3. Illustration

Figure 1 depicts a graph with QoS metrics for links in HMQRPMP. Let $D_c = 15$, $J_c = 30$, $B_c = 35$, $C_c = 40$ and $P_c = 70$. Let $PRO-\text{TH} = 90$, $REA-\text{TH} = 40$, $MS-\text{TH} = 21$ and $VD-\text{TH} = 1$ respectively. Let the energy levels of the nodes 1, 2, 3, 4, 5, and 6 are 90, 85, 95, 95, 98 and 85 respectively. The routes from the node 1 to destination 6 are requested. According to multiple QoS constraints, power constraint, LET and PredictedLET the route is calculated. In this example, the path $P_1 (1, 2, 4, 6)$ does not satisfy delay constraint. The paths $P_2 (1,3,5,4,6)$, $P_3 (1,3,2,4,5,6)$, $P_4 (1,2,4,5,6)$ and $P_5 (1,2,3,5,4,6)$ do not satisfy delay constraint, bandwidth and cost constraints respectively. But the paths $P_6 (1,3,5,6)$ and $P_7 (1,3,2,4,6)$ satisfy delay, jitter, bandwidth and cost constraints. All the above-mentioned paths satisfy energy level constraint. Table 1 shows the details of pre calculated LET values for the nodes in the path $P_6$ and $P_7$ based on the equation (1) along with their EL values before mobility of nodes.

![Graph with QoS Metrics for links](image)

**Table 1:** LET and EL values for $P_6$ and $P_7$ based on equation (1)

<table>
<thead>
<tr>
<th>Path</th>
<th>Link</th>
<th>$x_i$</th>
<th>$y_i$</th>
<th>$x_j$</th>
<th>$y_j$</th>
<th>$o_i$</th>
<th>$o_j$</th>
<th>$v_i$</th>
<th>$v_j$</th>
<th>$r$</th>
<th>EL</th>
<th>LET</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_6$</td>
<td>1-3</td>
<td>100</td>
<td>100</td>
<td>150</td>
<td>150</td>
<td>80</td>
<td>70</td>
<td>6</td>
<td>60</td>
<td>145</td>
<td>90</td>
<td>95</td>
</tr>
</tbody>
</table>
Table 2 shows the Current LET for the same paths $P_6$ and $P_7$ based on the equation (2) after mobility of nodes along with their respective changes in EL.

Table 2: Current LET and EL values for $P_6$ and $P_7$ based on equation (2)

<table>
<thead>
<tr>
<th>Path</th>
<th>Link $x_i y_i x_j y_j o_i o_j v_i v_j r$</th>
<th>EL</th>
<th>Current LET</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_6$</td>
<td>$1,3,5,6$</td>
<td>$1-3$</td>
<td>120 90 150 150 80 70 20 60 145 80 92 1.926</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$3-5$</td>
<td>140 180 220 100 45 30 10 15 125 80 95 2.882</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$5-6$</td>
<td>250 150 300 100 55 30 20 15 85 95 80 1.866</td>
</tr>
<tr>
<td>$P_7$</td>
<td>$1,3,2,4,6$</td>
<td>$1-3$</td>
<td>120 90 150 150 80 70 20 60 145 75 92 1.926</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$3-2$</td>
<td>140 150 140 50 60 70 40 15 140 80 80 2.853</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$2-4$</td>
<td>150 80 220 60 70 40 25 40 140 80 93 3.141</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$4-6$</td>
<td>280 70 250 90 120 30 45 35 135 93 75 2.984</td>
</tr>
</tbody>
</table>

Table 3 shows the Predicted LET values using Current LET (shown in table 2) and BM based on the equation (2) for $P_6$ and $P_7$ after mobility of nodes.

Table 3: Predicted LET and BM values for $p6$ and $p7$ based on the equation (2)

<table>
<thead>
<tr>
<th>Path</th>
<th>Link</th>
<th>Node</th>
<th>EL</th>
<th>PRO-TH</th>
<th>REA-TH</th>
<th>MS-TH</th>
<th>VD-TH</th>
<th>BM</th>
<th>Velocity Change</th>
<th>Current LET &gt;= LET</th>
<th>MAF</th>
<th>Predicted LET</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_6$</td>
<td>$1,3,5,6$</td>
<td>$1-3$</td>
<td>1</td>
<td>80</td>
<td>&lt;</td>
<td>&gt;</td>
<td>&lt;</td>
<td>&gt;</td>
<td>PRM</td>
<td>Y</td>
<td>N</td>
<td>2.926</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>92</td>
<td>&gt;</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>PM1</td>
<td>N</td>
<td>N</td>
<td>4.882</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5</td>
<td>95</td>
<td>&gt;</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>PM1</td>
<td>Y</td>
<td>Y</td>
<td>2.984</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6</td>
<td>80</td>
<td>&lt;</td>
<td>&gt;</td>
<td>&lt;</td>
<td>&gt;</td>
<td>PRM</td>
<td>Y</td>
<td>N</td>
<td>3.866</td>
<td></td>
</tr>
</tbody>
</table>

Predicted LETsum 11.664
Table 3: Predicted LET and BM values for p6 and p7 based on the equation (2) - continued

<table>
<thead>
<tr>
<th>Path</th>
<th>Predicted LETsum</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>P6</td>
<td>10.404</td>
</tr>
</tbody>
</table>

From the table 3 for the path P6, the EL of both the nodes 1 and 6 are lying within the range of PRO-TH and REA-TH. Also MS and VD of both the nodes 1 and 6 are < MS-TH and > VD-TH respectively. So the nodes 1 and 6 change their behavior to PRM. Also the nodes 3 and 5 change their behaviors to PM1. Likewise, for the path P7 the node 1 changes to PRM. The node 2 changes to RM when it handles RREP. But it changes to PRM mode when the RREP is handled at node 3 after decrementing its MS where MS < MS-TH. As well as the nodes 3 and 4 change their behavior to PM1. But even though the node 6 in path P7 has the value within the range of PRO-TH and REA-TH, due to MS > MS-TH it is switched to RM mode. The entry NA in Table 3 refers to Not Applicable.

Table 4 is the MetricsTable used at the source. It contains the values of Dsum, Jsum, Csum, LETsum, HCsum, ELsum and PredictedLETsum received from the two route replies for the paths P6 (1,3,5,6) and P7 (1,3,2,4,6) respectively. This MetricsTable is sorted based on the PredictedLETsum. Since the paths P6 and P7 satisfy Avg (∑EL (Vi)) ≥ Pc constraint, they are included in the RouteSelectionTable as mentioned in the Table 5. From the Tables 1, 2 and 3 it is clearly understood that the PredictedLETs of P6 and P7 are higher than their respective LETs after mobility. This shows that these two paths P6 and P7 will be more stable and existing for the long duration till the link is cut off. But among them the PredictedLET of the path P6 is highest than P7. As well as path P6 has minimal number of hops than P7. Therefore the path P6 is selected as the most optimal path than P7 for data transmission and included in the RouteTable as mentioned in Table 6.

Table 4: MetricsTable at source

<table>
<thead>
<tr>
<th>Path</th>
<th>Dsum</th>
<th>Jsum</th>
<th>Csum</th>
<th>LETsum</th>
<th>ELsum</th>
<th>PredictedLETsum (Sorted)</th>
<th>HCsum</th>
</tr>
</thead>
<tbody>
<tr>
<td>P6 (1,3,5,6)</td>
<td>12</td>
<td>18</td>
<td>27</td>
<td>4.29</td>
<td>267</td>
<td>11.664</td>
<td>3</td>
</tr>
<tr>
<td>P7 (1,3,2,4,6)</td>
<td>11</td>
<td>15</td>
<td>39</td>
<td>7.983</td>
<td>340</td>
<td>10.404</td>
<td>4</td>
</tr>
</tbody>
</table>

Table 5: RouteSelectionTable

<table>
<thead>
<tr>
<th>Path</th>
<th>Avg(∑EL (Vi))</th>
<th>Is Avg(∑EL (Vi)) ≥ Pc</th>
<th>HCsum</th>
<th>Optimal Path</th>
</tr>
</thead>
<tbody>
<tr>
<td>P6 (1,3,5,6)</td>
<td>89</td>
<td>Yes</td>
<td>3</td>
<td>Yes</td>
</tr>
<tr>
<td>P7 (1,3,2,4,6)</td>
<td>85</td>
<td>Yes</td>
<td>4</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Table 6: RouteTable

<table>
<thead>
<tr>
<th>Path</th>
<th>HCsum</th>
<th>Selected / Rejected</th>
</tr>
</thead>
<tbody>
<tr>
<td>P6 (1,3,5,6)</td>
<td>3</td>
<td>Yes</td>
</tr>
<tr>
<td>P7 (1,3,2,4,6)</td>
<td>4</td>
<td>No</td>
</tr>
</tbody>
</table>
6. Simulation Scenario and Result Analysis
This section describes the simulation environment and the performance analysis of our protocol HMQRPMP over MQRPMP and TBP.

6.1. Simulation Scenario

<table>
<thead>
<tr>
<th>Simulation Parameters</th>
<th>Values given</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAC Layer</td>
<td>IEEE802.11</td>
</tr>
<tr>
<td>Simulation Area</td>
<td>1KM x 1KM</td>
</tr>
<tr>
<td>Simulation Time</td>
<td>500s</td>
</tr>
<tr>
<td>Mobile Nodes</td>
<td>40</td>
</tr>
<tr>
<td>Node Mobility Speed</td>
<td>0-50 Meters per Second</td>
</tr>
<tr>
<td>Node Moving Pattern</td>
<td>Random Way Point</td>
</tr>
<tr>
<td>Traffic Type</td>
<td>CBR</td>
</tr>
<tr>
<td>traffic load</td>
<td>20 Packets / Second</td>
</tr>
<tr>
<td>Packet Size</td>
<td>512 Bytes</td>
</tr>
<tr>
<td>The average end to end delay</td>
<td>0.2s</td>
</tr>
<tr>
<td>Transmission range for each node</td>
<td>250 Meters</td>
</tr>
</tbody>
</table>

The protocols HMQRPMP, MQRPMP and TBP were simulated using ns2 [10]. The simulation parameters are shown in the Table 7. We carried out two sets of simulations. The first set assumed that initially mobile nodes were having full battery power. The second set assumed different battery powers for mobile nodes. We have set 25% of mobile nodes to have 100% power, 20% of nodes have 90% power, 20% of nodes have 80% power, and 35% of nodes have 50% power. The metrics used for evaluating all these protocols are success rate of data transmission, cost of control overhead. These metrics were compared with the other metrics namely mobility speed and the number of mobile nodes.

6.2. Result Analysis

6.2.1. Mobility Speed vs. Success Rate of Data Transmission
Figure 3(a) shows the success rate of data transmission against node’s mobility speed when the nodes are having full battery power. When the node’s mobility speed is 15 m/s, the success rate of data transmission of MQRPMP and HMQRPMP reaches the value 0.978 and 0.99 which is higher than the TBP value 0.93. Even during the node’s mobility speed of 30 m/s, the success rate of data transmission of MQRPMP and HMQRPMP reaches the value 0.9 and 0.96 which is higher than the TBP value 0.68.

Figure 3(a): Success rate of data transmission vs. node’s mobility speed when full battery powers
Figure 3(b) shows that the success rate of data transmission against node’s mobility speed when the nodes are having different battery powers. When the node’s mobility speed is 15 m/s, the success rate of data transmission of MQRPMP and HMQRPMP reaches the value 0.97 and 0.99 which is higher than the TBP value 0.8. Even during the node’s mobility speed of 30 m/s, the success rate of data transmission of MQRPMP and HMQRPMP reaches the value 0.9 and 0.97 which is higher than the TBP value 0.471. While increasing the node’s mobility speed beyond 30 m/s, the performance of MQRPMP, and TBP is drastically goes down. But among them, due to the implementation of PredictedLET and HC in HMQRPMP, the success rate of data transmission is 0.88 when it is 0.5 in MQRPMP and 0.316 in TPB at the mobility speed of 50 m/s.

![Figure 3(b): Success rate of data transmission vs. node’s mobility speed when different battery powers](image)

6.2.2. Number of Mobile Nodes vs. Control Overhead

Figure 4(a) shows the control overhead incurred against number of nodes when the nodes are having full battery power. When increasing the number of nodes in communication, the cost of transmitting control packets also increases but it is less in HMQRPMP than MQRPMP and TBP. Initially, when the number of nodes is 5 the control overhead is 0.24 for HMQRPMP, MQRPMP and TBP. But while increasing the number of nodes to 25, the control overhead is 0.255, 0.275 and 0.285 for HMQRPMP, MQRPMP and TBP respectively. Since it collects the residual battery backup of each node along the path during route reply as exactly in MQRPMP and handling route failure, the cost of control overhead is still 0.295 in our HMQRPMP which is 0.32 in MQRPMP and 0.35 in TBP when the number of nodes is increased to 40.

![Figure 4(a) Control overhead vs. Number of nodes when full battery powers](image)
Figure 4(b) shows the control overhead incurred against number of nodes when the nodes are having different battery powers. When increasing the number of nodes in communication, the cost of transmitting control packets also increases but it is less in HMQRPMP than MQRPMP and TBP. Initially, when the number of nodes is 5 the control overhead is 0.25 for HMQRPMP, MQRPMP and TBP. But while increasing the number of nodes to 25, the control overhead is 0.274, 0.28 and 0.32 for HMQRPMP, MQRPMP and TBP respectively. Since it collects the residual battery backup of each node along the path during route reply as exactly in MQRPMP and handling route failure, the cost of control overhead is still 0.3 in our HMQRPMP which is 0.34 in MQRPMP and 0.4 in TBP when the number of nodes is increased to 40.

Figure 4(b): Control overhead vs. Number of nodes when different battery powers

7. Summary and Concluding Remarks
This paper discusses the new protocol HMQRPMP with multiple QoS constraints namely delay, jitter, bandwidth, power and cost metrics between a source and a destination. It specifies the network model for HMQRPMP. The main advantage of this protocol is that it is a hybrid protocol that has the advantages of proactive and reactive behavior of mobile nodes. In HMQRPMP, the behavior of the wireless mobile nodes is switched from proactive mode to reactive mode and vice versa based on the residual battery power, which increases the lifetime of the nodes and improves the PDR in MANET. It also predicts the stability of LET by altering the well known mobility prediction formula using mobility adjustment factor which in turns reduces the number of failures in data transmission and produces significant improvement in data transmission rate. It provides a quick response to topological changes in the network with minimal control overhead. Since our network model considers almost many of the user specific QoS constraints, it can be considered as a common framework suitable for all MANET applications.

In future, there can be a possibility to enhance the reliability and security of this routing protocol by adding new constraints. As MANET applications lend themselves well to multicast operations, the protocol can also be further extended as a multicast communication protocol. Since multiple routes are selected it can be extended as a multipath routing too. Moreover, the number of route request packets in route discovery can be minimized as to increase effectiveness of the throughput of the communication.
References


Available at: http://www.navtechgps.com/Downloads/1024.PDF.