Energy Aware Multiple Constraints Multipath QoS Routing Protocol with Mobility Prediction for MANET

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Abstract: - This paper presents a source based reactive protocol called "Energy aware Multipath QoS Routing Protocol with Mobility Prediction (EMQRPMP)" for MANET. It is the enhanced version of the existing protocol called "Power aware Multiple QoS constraints Routing Protocol with Mobility Prediction (PMQRPMP)". It considers quality of service constraints namely delay, delay-jitter, bandwidth, and cost for each link on 'n' available paths and selects 'k' routing paths between a source and a destination during path discovery. EMQRPMP checks bandwidth constraint during route request to minimize control overhead. It also checks power constraint for each node for selecting paths with good battery backup. EMQRPMP uses our new mobility prediction mechanism to find the link expiry time and determines the stability of link expiry time for each link between two adjacent nodes of each path during route reply. It executes path maintenance procedure when the link between two nodes is cut off. EMQRPMP considers the reservation of a backup path during link failure thus reducing control overhead. After finding multiple paths, the source distributes routing load on all the selected paths using an intelligent load distribution algorithm as to increase throughput in MANET.

Key-Words: - Energy level, Multipath Routing, QoS, Protocol, Mobility Prediction, MANET

1 Introduction

Mobile ad hoc networks (MANETs) can be defined as the self organized, self coordinated, infrastructure less, wireless communication networks with mobile nodes. They are suddenly created for the applications such as military battlefields, emergency search, rescue sites, classrooms and conventions, where participants share information dynamically using their mobile devices [1]. Some of the issues identified in MANET are routing, mobility management, security, reliability and power consumption. Quality of Service (QoS) in MANET is defined as the collective effect of service performance, which determines the degree of satisfaction of a user of the service [2]. The QoS constraints can be classified as time constraints, space constraints, and frequency constraints [3].

The QoS models applicable for MANET are Integrated services (IntServ) [4], Differentiated Services (DiffServ) [5], Flexible QoS Model for MANET (FQMM) [6] and Complete and Efficient QoS Model for MANETs (CEQMM) [7]. In-band signaling system for supporting QoS in MANET (INSIGNIA) [8] is a QoS signaling protocol. Service Differentiation in Stateless Wireless Ad hoc networks (SWAN) [9] is the stateless QoS model. There can be 'n' number of paths between a source and a destination. The links on the paths are expected to satisfy the QoS constraints. A path can be chosen as an optimal path, if it satisfies the QoS constraints [10]. The routing protocols in MANET can be categorized as proactive and reactive. In proactive routing, route discovery is easy but route maintenance is hard. In reactive routing, route discovery is hard but route maintenance is easy.

Some of the QoS routing algorithms for MANET are Core Extraction Distributed Ad hoc Routing (CEDAR), QoS-AODV (QAODV) and Ticket-Based Probing (TBP). CEDAR uses clustered network architecture and selects the core dynamically. In CEDAR [11], there may be chances for the core to fail due to hardware and software problems. Since more data are routed through the core node, the core node suffers from heavy traffic.

QAODV [12] is based on reactive routing. In QAODV, the source node specifies the QoS parameters in the RREQ packet. Every intermediate node checks whether it can support the specified QoS. TBP [13] is a multipath QoS routing scheme. In TBP, source sends N number of tickets to find N paths. There is no clear heuristic for computing tickets. Resource Reservation for one flow denies the availability of that resource for other flows.

The existing protocol called PMQRPMP [14] adds a power constraint along with QoS constraints mentioned in MQRPMP to select the best routing path among multiple paths between a source and a destination as to increase Packet Delivery Ratio (PDR), reliability and efficiency of mobile communication. It collects the residual battery power of each node for each path; selects a path which has nodes with good battery power for transmission to satisfy the power constraint.

PMQRPMP uses the mobility prediction formula [10] to find the Link Expiry Time (LET) between two nodes. It has better PDR than MQRPMP and TBP. The cost of communication overhead is also less than TBP. Even though there is the possibility to select ‘k’ paths among ‘n’ paths, PMQRPMP does not address multi-path routing scheme. As well as during communication, there is a chance for a mobile node to suddenly increase or decrease its speed or direction when it is moving. This is known as dynamic mobility. PMQRPMP does not address the impact of dynamic mobility.

The proposed protocol EMQRPMP is the extension of our previous work PMQRPMP. It is a source based reactive protocol for finding multiple optimal paths which satisfy a set of link constraints and node constraint, with highest LET value for disseminating packets between two nodes. EMQRPMP uses a new mobility prediction mechanism which predicts the stability of LET based on dynamic mobility of nodes for finding more optimal paths. It spreads data packets between a source and a destination on those selected paths using intelligent load distribution algorithm.

The rest of the paper is structured as follows: In Section 2, the new mobility prediction mechanism is explained.

Section 3, briefs the network model of the new protocol. In Section 4, a new protocol with path discovery and path maintenance procedures is explained with an illustration. The Section 5 gives the simulation set up and the performance comparison of EMQRPMP over PMQRPMP, MQRPMP and TBP. Finally Section 6 gives the conclusion and future scope of this research work.

2 Mobility Prediction Mechanism

This section describes a new mobility prediction formula for finding the stability of LET. The proposed routing protocol uses the location information obtained from GPS (Global Positioning System) [15] to estimate LET of a link between two adjacent nodes. Based on this prediction, routes are reconfigured before they disconnect. The proposed protocol considers free space propagation model [16]. Here node-moving pattern is random waypoint. We also assume that all nodes in the network have their clock synchronized [e.g., by using the NTP (Network Time Protocol) or the GPS clock itself]. Therefore, using the motion parameters such as speed, direction, and communication distance of two neighbors, LET can be computed using the well-known mobility prediction formula. 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 θ_i and θ_j be the moving directions of mobile hosts 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):

$$LET = \frac{-(ab+cd)+\sqrt{((a^2+c^2)\,r^2-(ad-bc)^2)}}{(a^2+c^2)} \quad (1)$$

where,

$a = v_i \cos\theta_i - v_j \cos\theta_j$; $b = x_i - x_j$

$c = v_i \sin\theta_i - v_j \sin\theta_j$ and $d = y_i - y_j$

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

2.1 Impact of Dynamic Mobility of Mobile Nodes

The equation (1) is used for identifying the stability of a link between two adjacent nodes. But if a node on a link suddenly alters its speed/direction or both, the LET associated with that link needs to be altered.

This dynamic mobility of mobile nodes is not addressed by equation (1). It 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 Energy Level (EL) and they may forward many packets. If any one of the node 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 loose 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 the EL of nodes during dynamic mobility.

2.2 Prediction of LET

The new 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 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:

$$PredictedLET = CurrentLET + MAF \quad (2)$$

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 is assumed as a normal node.

It should be noted that the constraints 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 a gain G and MAF = 1.

[2] If a good node is coming to be closer to other node, then it is assumed as a heavy gain GG and MAF = 2.

[3] If both are normal nodes and both are coming to be closer to each other, then it is also assumed as a heavy gain GGG. So MAF = 3.

[4] If both are coming to be closer to each other but one is normal node and the other is good node, then it is assumed as a positively heavy gain GGG+ and MAF = 3.5.

[5] If both are good nodes and both are coming to be closer to each other then it is assumed as a very heavy gain GGGG and MAF = 4.

[6] If a normal node is to be disconnected from other node then it is assumed as a loss L and MAF = -1.

[7] If a good node is to be disconnected from other node then it is assumed as a heavy loss LL and MAF = -2.

[8] If both are normal nodes and both are to be disconnected from each other, then it is also assumed as a heavy loss LLL. So MAF = -3.

[9] If both are to be disconnected from each other but one is normal node and the other is good node, then it is assumed as a positively heavy loss LLL- and MAF = -3.5

[10] If both are good nodes and both are to be disconnected from each other, then it is assumed as a very heavy loss LLLL and 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. Equation (2) can be applied for different types of applications.

3 The Network Model

This section describes the network model for the proposed protocol. The network model in MANET is 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. This network model considers the existence of multiple paths between any two nodes where each link on each path considers the QoS metrics namely Delay (D), Jitter (J), Bandwidth (B), and Cost(C). The model also considers the EL of each node (V_i) on each path, which meets a power threshold (P_c) for mobile communication. The EL of each node is the residual battery backup, which is collected and summed up for each routing path.

This model also includes the parameter called PredictedLET for the selection of multiple paths. Among the existence of multiple paths (P_1, P_2, P_3 … and P_n) for a source to destination, a set of paths (P_1, P_2, P_3 … and P_k) is selected which satisfies all the above said constraints. So the problem of multiple QoS constraints with power awareness and new mobility prediction mechanism for the selection of multiple paths is defined as follows:

Select P_1, P_2, P_3 … and P_k among (P_1, P_2, P_3 … and P_n) whose LET and PredictedLET > 0 where,

$\sum D_{ij} \le D_c$
$\sum J_{ij} \le J_c$
$B_{ij} \ge B_c$
$\sum C_{ij} \le C_c$
$EL\ (V_i) \ge P_c$
$MAX\ (\sum EL\ (V_i))$
MAX(PredictedLET)

4 Energy Aware Multipath QoS Routing Protocol with Mobility Prediction (EMQRPMP)

This section describes the path discovery and path maintenance procedures for the proposed protocol. It also specifies intelligent load distribution algorithm for disseminating the packets through the selected paths.

During the path discovery, multiple optimal paths are selected based on multiple QoS constraints and power constraint using the newly proposed mobility prediction formula. The paths with highest battery power and highest LET are considered as stable optimal paths for dissemination of data.

4.1 Path Discovery

In this protocol, the source broadcasts a Route Request (RREQ) with the fields Source-address, Destination-address, PacketType, RouteRequestId, B_c, and P_c. If an intermediate node (I) receives the RREQ then it forwards the received RREQ on each outgoing link only when its bandwidth is > 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 received RREQ is discarded. Otherwise, the destination node constructs a Route Reply (RREP). The fields in a RREP are as follows: Source-address, Destination-address, PacketType, RouteReplyId, P_c, D, J, B, C, LET, EL, Speed and Direction.

The destination node sets 0 to the fields D, J, C, LET and EL in that RREP. It copies P_c from received RREQ and includes its moving direction and speed into the RREP. The destination node sends RREP towards the source. If an intermediate node receives RREP, it checks whether its EL ≥ P_c. If it so, it updates the fields D, J, B, C, LET, EL, PredictedLET, P_c, Speed and Direction with the new accumulated values and constructs new RREP. Then the new RREP is forwarded towards the source.

The source maintains a table called MetricsTable with the fields namely D_{sum}, J_{sum}, C_{sum}, LET_{sum}, EL_{sum} and $PredictedLET_{sum}$ for storing the accumulated values of D, J, C, LET, 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 RREP against the thresholds D_c, J_c, and C_c. If the comparison is successful then the route mentioned by that corresponding RREP is included in a table called RouteSelectionTable at the source. Likewise, the source gathers all satisfied RREPs into RouteSelectionTable and identifies 'k' paths among 'n' available paths which meet the mentioned QoS constraints to destination. The route discovery procedure for the proposed protocol is given as follows:

Procedure for Source (S):

If Source S has no Paths to Destination D
  Set the QoS Constraints
    Construct and Broadcast Route Request packet
  Execute Route Reply Handling Procedure
  Execute Route maintenance Procedure
End if

Route Request Handling procedure:

If it is an intermediate node I
  If the received Route Request packet is not duplicate
    If (B_{ij} >= B_c)
      Forward Route Request
    End if
  Else
    Discard Route Request
  End if
End if

If it is destination D
  If the received Packet is Route Request and it is not duplicate
    Execute Route Reply Handling Procedure
  End if
End if

Route Reply Handling procedure:

If it is destination D
  If the received Packet is Route Request and it is not duplicate
    Set D, J, B, C and LET to 0
    Get its Speed and Direction from GPS
    Construct Route Reply
    Forward Route Reply towards S
  End if
End if

If it is an intermediate node I
  If the received Packet is Route Reply and it is not duplicate and EL (V_i) >= P_c
    D = ReceivedD + CurrentD
    J = ReceivedJ + CurrentJ
    C = ReceivedC + CurrentC
    EL = ReceivedEL + CurrentEL
    LET = ReceivedLET + CurrentLET
    Get its Speed and Direction from GPS
    Calculate and accumulate PredictedLET
    Construct Route Reply including the field P_c
    Forward Route Reply towards S
  End if
End if

If the node is S
  Receive the Route Reply packets
  Collect the Paths to D
  If the Collection is not NULL Sort all the paths based on their PredictedLET
    For each Path Pi
      If $\sum D_{ij} <= D_c$, $\sum J_{ij} <= J_c$, $\sum C_{ij} <= C_c$ and PredictedLET > 0
        Select the Path P_i
        Put the path in RouteSelectionTable
      Else
        Delete routing path from the Collection
      Endif
    End for
  End if
End if

4.2 Path Maintenance

Due to the dynamic changes of network topology and limitation of network resources, the computed optimal route often gets invalidated. When the link is cut off, the upstream node sends RREC to the source. Then the source once again starts the route discovery procedure. 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
  If backup path is available
    Route the packets via backup path
  Else
    Broadcast RREQ
  End if
End if
If the RREC and RREP is received at the same time from any I
  Broadcast New RREQ
End if

4.3 Dissemination of packets on selected paths

After selecting multiple paths between the source and destination, the packets can be spread on those paths from the source using intelligent load distribution algorithm. The algorithm calculates the remaining number of packets to be transmitted. It forwards Q number of packets which is equivalent to 1.5 times of the remaining the number of packets on a path, whose total EL is between 85% and 100% (i.e., threshold) when the LET < PredictedLET. Otherwise it forwards Q number of packets which is equivalent to 1.25 times of the remaining the number of packets on a path, whose total EL is less than 85% where the LET > PredictedLET.

Note that, this action and the threshold value can be modified according to the user's choice. As well as any number of actions and their threshold values can be added in this algorithm. Even if none of the 'n' paths meet the above specified EL thresholds, this algorithm sends equal number of packets via all the 'n' paths. Due to the distribution of packets intelligently among multiple paths based on their ELs, the PDR and bandwidth utilization are increased. The offered packet load for the nodes on the selected paths is reduced to less than or equal to k times with respect to the 'k' identified paths. So the traffic within the MANET is smoothened which in turn reduces congestion at intermediate nodes.

Intelligent Load Distribution Algorithm used by Source node:

Let n be the existing number of paths P_1, P_2, P_3 … and P_n
Let m be the selected number of paths P_1, P_2, P_3 … and P_k
Let k be the paths for load distribution after sorting and reserving P_k
Let N be the total number of packets to be sent
Let Q be the number of packets to be sent on each path

```
Q = (N / k) packets
If the node is S
While (N > 0)
   If (0.85 < EL (Pi) and EL (Pi) ≤ 1.0) and (LET <
   PredictedLET)
      Q = Q * 1.5
   End if
   If (0.85 < EL (Pi) and EL (Pi) ≤ 1.0) and (LET >
   PredictedLET)
      Q = Q * 1.25
   End if
   N = N – Q
   If N > Q
      Send Q on Pi
   Else
      Send N on Pi
   End if
      k = k - 1
   If N > 0
      Q = N / k
   End if
End while
End if
```

4.4 Illustration

Figure 1 depicts a graph with QoS metrics for links in EMQRPMP. Let D_c = 15, J_c = 30, B_c = 35 C_c = 40 and P_c = 70. 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 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.

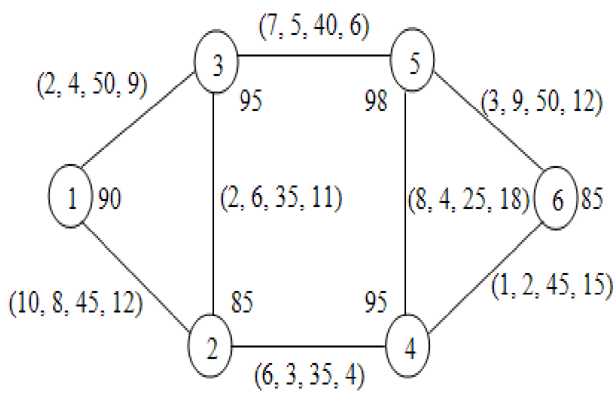

Fig.1 Example of Multiple QoS constraints network

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. Table 2 shows the CurrentLET 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 1. LET and EL values for P_6 and P_7 based on equation (1)

Path	P_6(1,3,5,6)											
Link	x_i	y_i	x_j	y_j	θ_i	θ_j	v_i	v_j	r	EL i	EL j	LET
1-3	100	100	150	150	80	70	6	60	145	90	95	1.432
3-5	150	150	250	150	45	30	10	30	125	95	98	1.3
5-6	250	150	300	100	55	30	25	15	85	98	85	1.558
											LET_{sum}	4.29
Path	P_7(1,3,2,4,6)											
Link	x_i	y_i	x_j	y_j	θ_i	θ_j	v_i	v_j	r	EL i	EL j	LET
1-3	100	100	150	150	80	70	6	60	145	90	95	1.432
3-2	150	150	150	50	60	70	40	4	150	95	85	1.53
2-4	150	50	250	50	70	40	4	40	140	85	95	1.271
4-6	250	50	300	100	70	30	60	15	135	95	85	3.75
											LET_{sum}	7.983

Table 2. CurrentLET and EL values for P_6 and P_7 based on equation (2)

Path	P_6(1,3,5,6)											
Link	x_i	y_i	x_j	y_j	θ_i	θ_j	v_i	v_j	r	EL i	EL j	CurrentLET
1-3	120	90	150	150	80	70	20	60	145	80	92	1.926
3-5	140	180	220	100	45	30	10	15	125	92	95	2.882
5-6	250	150	300	100	55	30	20	15	85	95	80	1.866
Path	P_7(1,3,2,4,6)											
Link	x_i	y_i	x_j	y_j	θ_i	θ_j	v_i	v_j	r	EL i	EL j	CurrentLET
1-3	120	90	150	150	80	70	20	60	145	75	92	1.926
3-2	140	150	140	50	60	70	40	20	150	92	80	2.853
2-4	150	80	220	60	70	40	25	40	140	80	93	3.141
4-6	280	70	250	90	120	30	45	35	135	93	75	2.984

Table 3 shows the PredictedLET values using CurrentLET (shown in table 2) based on the equation (2) for P_6 and P_7 after mobility of nodes. The PredictedLET of the link 4-6 for the path P_7 is < 0 due to the addition of MAF value -3.5. This shows that there may a chance for the link to fail based on our prediction using our equation (2). The source may get a RREC packet (at anytime) as soon as the link 4-6 is cut off. But at present, the CurrentLET of the link 4-6 is > 0 (ie., 2.984). So the link is considered for selecting the path P_7.

Table 4 is the MetricsTable used at the source. It contains the values of D_{sum}, J_{sum}, C_{sum}, LET_{sum}, EL_{sum} and $PredictedLET_{sum}$ received from the two route replies for the paths P_6 (1,3,5,6) and P_7 (1,3,2,4,6) respectively. This MetricsTable is sorted based on the $PredictedLET_{sum}$. From the Tables 1, 2, 3 and 4 it is clearly understood that the PredictedLETs of P_6 and P_7 are higher than their respective LETs after mobility. This shows that these two paths P_6 and P_7 will be more stable and existing for longer duration till the link is cut off. Therefore the paths P_6 and P_7 are selected as the most optimal paths for data transmission and included in the RouteSelectionTable as shown in table 5.

Table 3. Predicted LET values for P_6 and P_7 based on the equation (2)

Path	P_6(1,3,5,6)					
Link	Node	EL	Velocity Change	CurrentLET >= LET	MAF	PredictedLET
1-3	1	80	Y	Y	1	2.926
	3	92	N			
3-5	3	92	N	Y	2	4.882
	5	95	Y			
5-6	5	95	Y	Y	2	3.866
	6	80	N			
					$PredictedLET_{sum}$	11.664
Path	P_7(1,3,2,4,6)					
Link	Node	EL	Velocity Change	CurrentLET >= LET	MAF	PredictedLET
1-3	1	75	Y	Y	1	2.926
	3	92	N			
3-2	3	92	N	Y	1	3.853
	2	80	Y			
2-4	2	80	Y	Y	1	4.141
	4	93	N			
4-6	4	93	Y	N	-3.5	-0.516
	6	75	Y			
					$PredictedLET_{sum}$	10.404

Table 4. MetricsTable at source

Path	D_{sum}	J_{sum}	C_{sum}	LET	EL	$PredictedLET_{sum}$ (Sorted)
P_6(1,3,5,6)	12	18	27	4.29	267	11.664
P_7(1,3,2,4,6)	11	15	39	7.983	340	10.404

Table 5. RouteSelectionTable

Path	Avg($\sum EL(V_i)$ [ie., $EL(P_i)$]	Optimal Path
P_6(1,3,5,6)	89	Yes
P_7(1,3,2,4,6)	85	Yes

As per our illustration, EL of the selected paths P_6 and P_7 are > 85% and < 100%. As well as the PredictedLETs are higher than their respective old LETs. So the source node 1 distributes its routing load by spreading 750 packets on the selected path P_6 and 250 packets on the selected path P_7 based on our intelligent load distribution algorithm.

5 Simulation

The protocol is simulated in ns2 [17]. The simulation parameters and their values are shown in the Table 6.

Table 6. Simulation scenario

Simulation Parameters	Given Values
MAC Layer (DCF)	IEEE802.11
Simulation Area	1 km * 1 km
Simulation Time	500 s
Number of Mobile Nodes	45
Node Mobility Speed	0 – 10 m/s
Node Moving Pattern	Random Way Point
Traffic Type	CBR
Packet Size	512 bytes
Transmission Range	250 m

The metrics used for evaluating all these protocols are success rate of data transmission and cost of control overhead. These metrics were compared with the other metrics namely mobility speed and the number of mobile nodes. Our protocol is compared with PMQRPMP, MQRPMP and TBP in figure2, figure 3 and figure 4.

The figure 2 shows the comparison of success rate of data transmission along with the node's mobility speed. When the node's mobility speed is 3 m/s, the success rate of data transmission of MQRPMP and PMQRPMP reaches the value 0.98 which is higher than the TBP value 0.8, but lower than the EMQRPMP value 0.985. While increasing the node's mobility speed beyond 3 m/s, the performance of PMQRPMP, MQRPMP, and TBP is drastically going down. But among them, in EMQRPMP the success rate of data transmission is increasing and it is still higher than the others. It reaches 0.7 if node's mobility speed is 10, due to LET computation and load distribution algorithm.

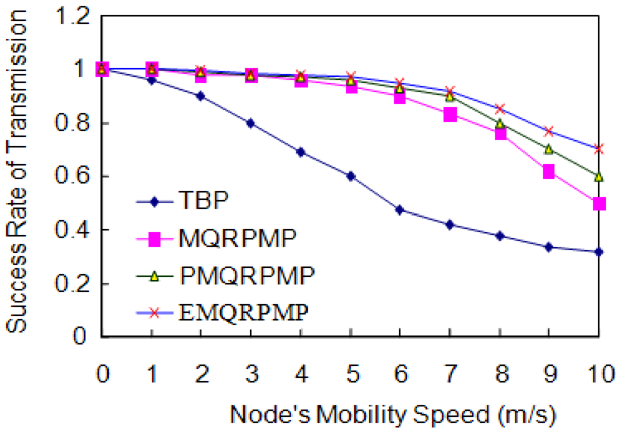

Fig. 2 Success rate of data transmission vs. Node's mobility speed

Figure 3, shows the comparison of number of nodes with cost of control overhead incurred during transmission for EMQRPMP, MQRPMP, and TBP. When increasing the number of nodes in communication, the cost of transmitting control packets also increases. Since EMQRPMP collects delay, jitter, bandwidth, cost and the energy level of each node along the path during route reply as exactly in PMQRPMP, there is no performance difference between EMQRPMP, PMQRPMP and MQRPMP. So the cost of transmitting control packets for EMQRPMP, PMQRPMP and MQRPMP are equal. But it is less than TBP and is shown in Figure 3.

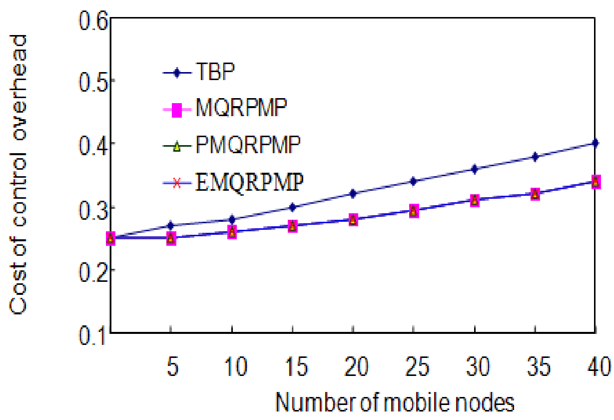

Fig. 3 Cost of control overhead vs. Number of mobile nodes

But after identification of multiple paths, the number of route discoveries can be reduced due to the reservation of backup path in case of route failure. Since there are 'k' paths, any one of the path can be kept as a reserved path. Normally, the path with lower energy level than the others is reserved as a backup path after sorting all the 'k' paths. During the link failure, this reserved path can be used for transmission without making new route discovery. So the control overhead can still be reduced. But it also has its impact in PDR. The PDR may go down. But still it is higher in EMQRPMP than the others, since load distribution is done over (k-1) paths. Figure 4, shows the comparison of number of nodes with cost of control overhead incurred during transmission for EMQRPMP, MQRPMP, and TBP. During link failure and reservation of single path, even though we increase the number of nodes in communication, the cost of transmitting control packets is reduced drastically in EMQRPMP.

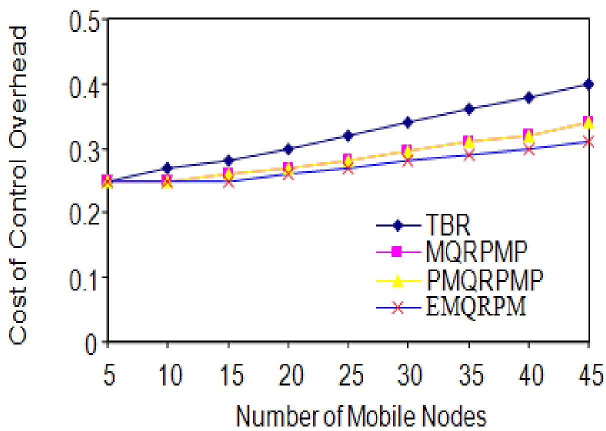

Fig. 4 Cost of control overhead vs. Number of mobile nodes (During Reservation)

It is 0.25 when the number of mobile nodes are 5, 10 and 15 in EMQRPMP which is lower than PMQRPMP, MQRPMP and TBP. It becomes 0.3, if number of mobile nodes are 40 which is very low in EMQRPMP than PMQRPMP, MQRPMP and TBP.

6 Conclusion

This paper discusses the new protocol EMQRPMP with multiple QoS constraints between source and destination. The main advantage of this protocol is that it considers power constraint for nodes for efficient packet transmission, as well as load is distributed among multiple paths to increase packet delivery ratio. It uses our new mobility prediction formula for LET calculation to select optimal stable paths with minimal cost. The EMQRPMP provides a quick response to changes in the network, reduces the waste of network resources and produces significant improvement in data transmission rate, and hence reduces control overhead for reconstructing a routing path.

Future work in this direction can be the enhancement of EMQRPMP using mobility adjustment factor for calculating accurate LETs. It can also be enhanced as a reliable and secure routing protocol by adding new constraints. Based on the residual battery backup of mobile node on the selected route, the behavior of a mobile node can be changed from reactive to proactive and vice versa. So this protocol can be enhanced as a hybrid routing protocol by fixing a threshold limit on the battery power which in turn increases PDR considerably. Since MANET applications lend themselves well to multicast operations, this protocol can also be further extended as a multicast communication protocol. We can also include a hop constraint to select the shortest path. There is a chance to intelligently spread the packets over k paths based on energy level of the path. Moreover, the number of route request packets in route discovery can be reduced to increase effectiveness of the throughput of the communication.

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