Efficient Multipath DYMO Routing Protocol with Gateway Selection for Hybrid MANETs

Yogesh Chaba, R. B. Patel, and Rajesh Gargi

***Abstract*—In the dynamic MANET on-demand (DYMO) routing protocol for hybrid mobile ad hoc networks (MANETs), the issues related to selection of internet gateways (IGW) and using a single path for communication between the sources to destination affects load balancing and increases the latency. To overcome these issues, we propose an efficient multi-path extension to DYMO with a load balancing technique for gateway selection. For gateway selection, a combined weight value is determined based on the metrics shortest distance, inter and intra MANET traffic load. Among the selected path from the multiple paths, the gateway with minimum weight is selected. If such a gateway does not exist, alternate path is selected from the multi path set. The protocol is beneficial since the delay, average number of hops and routing overhead decreases efficiently. By simulation results, we show that our proposed protocol achieves maximum packet delivery ratio with less delay and reduces the energy consumption of the nodes.**

***Index Terms*—Dynamic MANET on-demand (DYMO), mobile Ad hoc networks (MANETs), routing protocol, gateway selection.**

I. Introduction

A. Routing in Mobile Ad Hoc Network (MANET)

A mobile ad hoc network (MANET) is a dynamic wireless network which has a free movement of nodes and arranges in a random manner [1]. Without the help of any pre-existing network infrastructure, the MANETs can be setup wherever and whenever necessary. Being an autonomous system, the mobile hosts act as routers and have a random movement [2]. Multi-hop routing is used for communication in every mobile node (MN) in the MANET, since both the router and the user role is played by the MN. [3]. The dynamic nature of network topology and the resource constraints makes MANET routing a tedious process. Transmitting messages through wireless channels become a major problem due to link reliability. The minimum hop count routing selects path with less capacity rather the best paths that exist in the network and so good quality paths are not built using this routing [1]. On the basis of their reaction to topological changes, routing protocols are divided into proactive (table-driven), and reactive (on-demand). In general three issues need to be addressed in the routing protocol: route discovery, data forwarding, and route maintenance. [4]

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B. Hybrid MANET

- Hybrid MANET is imparted by the gateways (GWs) connecting the MANET with the internet which also gives advanced communication, network scalability, and pervasive sustainable environments.
- Studies related to GW management, mobility management, addressing, and routing are undergone in the hybrid MANETs. Additionally, logical and technological developments are needed for robust interconnection [3].
- With the fixed IGWs the hybrid MANET provides internet access to the MANET nodes. It also exploits mobility capability of additional mobile nodes (mobile IGWs). The benefits of the proactive and reactive approaches are also balanced by the hybrid approach.
- The dynamic network topology leads to uncertainty in the connectivity of the mobile nodes with gateway nodes and mobile nodes with other active mobile nodes. In the local MANET, there is a delay in finding route to destination due to the mobility of mobile nodes. [5]

C. Dynamic MANET On-demand (DYMO) Routing Protocol

1) DYMO routing

DYMO routing protocol is a reactive protocol developed for MANET. All the nodes between the source and destination exchange routing information through routing information accumulation [7]. Route discovery and route maintenance are the two operations of the DYMO routing protocol. The originate node, in routing discovery, multicasts a RREQ to all the nodes immediately. In order to review the freshness of the route request, the RREQ consists of a sequence number to enable other nodes. Until the request reaches the target node, the network will be flooded with the RREQs. The originating node receives an RREP which is unicast hop-by-hop from the target node. [6].

2) Gateway selection

When a mobile node sends a data packet to fixed network, the packets are transmitted to the gateway which acts as a bridge between a MANET and the Internet. On receiving RREQ, the gateway cross checks with the routing table for destination IP address which has been précised in the RREQ message. If the address is not found, then gateway sends RREP_I flag to the originator, else it unicasts a normal RREP, but may also optionally send a RREP_I back to the originator of the RREQ. [8]

Proactive Gateway Discovery, Reactive Gateway Discovery, Hybrid Gateway Discovery, Adaptive Gateway

Discovery, and Maximal Benefit Coverage are the various gateway discovery processes.

- *Proactive Gateway Discovery*: Gateway broadcasts a Gateway Advertisement message after each interval. Mobile nodes in the gateway's transmission range receive the advertisement and those without the route to the gateway, builds a route entry for it in their routing tables.
- *Reactive Gateway Discovery:* By performing expanding ring search, the node willing to communicate with the network will contact it within the ad hoc network. A new route is found towards the Internet, if there is no reply after the search.
- *Hybrid Gateway Discovery:* The TTL-limited messages are flooded by the gateways which will be forwarding only up to few hops away from the gateway. Proactive approach has been carried out by the sources within flooding area and outside that it acts as reactive.
- *Adaptive Gateway Discovery:* Information is easily provided by the gateway only if it is routing those datagrams that it would receive anyway. Also the number of hops of its active source location is maintained.
- *Maximal Benefit Coverage:* The overhead of flooding GWADV messages up to t hops plus the overhead associated to the discovery of gateways by sources at distances longer than t hops can be minimized by selecting a TTL t.
- When multiple nodes are discovered for internet access, the *Internet gateway selection* is used. We have to choose a metric for selecting the right gateway. [8]

3) Issues in DYMO routing

The DYMO protocol is comparatively simpler than the AODV protocol but mostly the routing logic layer provides ease whereas the challenges and problems are valid for both DYMO and AODV. Some of the issues are

- Since the failed connection attempt is not registered, the routes may not be known in advance when on-demand ad hoc routing protocols are used. In order to discover a route to the destination, the routing node must be notified about the connection attempts. Additionally, when the route discovery is ongoing, the packets must be buffered.
- In the current network stack architecture, the main problem is that, only after the packet crosses the boundary between the user space and the kernel space, we bother about the need for the route. So when to initiate the route discovery is not known.
- During route discovery, when and how to buffer packets: Packets must be buffered while route recovery is active if the packets are destined to hosts with unknown destination. The packets must be reinserted into the IP layer in case the route is found and then sent to the destination. The packet should be discarded in case the route is not found and then the application program should be reported.
- If a valid route does not exist then when to create an RERR**:** For a packet if no valid route table entry exists, the IP layer discards it under normal condition. Then an ICMP destination host unreachable message is returned. As an alternate, the notification is sent to the routing node about the event.
- Available routing table information within DYMO nodes is not applicable when communication between nodes breaks from repositioning of a node(s). The performance against the conventional AODV algorithm becomes poorer since the DYMO's advantage of routing path accumulation is spurned by the increase in RREQ message size from RREQ accumulation. [7]
- The speed of simulation in large scale networks are affected by the higher end to end delays of the DYMO protocol. [10].
- In the DYMO approach, the mitigation of traffic concentration on a special-gateway s-GW and the MNs around them is not done properly. [3]
- The essential timeout mechanism and link monitoring for detecting broken links are not envisioned. There is a need to consider the process for reducing the number of cases in the state space analysis which are not actually taken into account. Hence state space analysis doesn't consider the route error processing, route maintenance, and dynamic topologies [6]

D. Problem Identification and Solution

- Due to the risk of forwarding special data through an un-maintained gateway (GW) a routing protocol which allows a source node to have sensitive data forwarded to the Internet through a trusted GW as proposed in [3]. As s-Data requires particular security considerations, they must be forwarded by only Special- Gateways (s-GW), which are operated by a trusted network administrator. And as n-Data has no such requirements, they can be forwarded by Normal- Gateways (n-GWs). Though this protocol is secure, it doesn't consider load balancing of the gateways.
- DYMO has an overhead by messages that are accumulated the path information. To overcome this, a new route recovery scheme was proposed [7]. When certain nodes in Ad-hoc network relocate in the middle of transmission task, in order to maintain the transmission operation, operation of searching for destination is restarted, thus creates loads for the network with transmit time and corresponding messages. But it uses only a single path for communication between the sources to destination. This causes threats to eavesdropping, to do load balancing or to minimize the energy consumed by nodes.

In order to overcome these drawbacks, we propose a multi-path extension to [3] with a load balancing technique for gateway selection.

For route recovery, we consider multiple paths so that even though if one path is failed the data can be routed through another path. The selected paths are assigned a new metric for Internet Gateway (IGW) selection to balance the inter/intra-MANET traffic load over multiple IGWs [12].

The metric consists of three components.

- The shortest distance between the MANET node and the selected IGW
- The inter-MANET traffic load via each IGW and

- The intra-MANET traffic load within the network topology managed by each IGW.
- The residual energy of the IGW.

We estimate the IGW weight and the IGW with the minimum weight is chosen. If we do not find any such IGW, we select the alternate path from the multi path set. This results in better performance in terms of packet delivery ratio and transmission delay. This protocol is beneficial since the delay, average number of hops and routing overhead increase compared to the single path solution. This is because we find alternate paths, usually with more hops than the original single route.

II. Related Work

Kristian L. Espensen, Mads K. Kjeldsen, and Lars M. Kristensen [6] have proposed to use Coloured Petri Nets to construct a complete model of the DYMO protocol, to formally verify key properties using state spaces, and use the constructed CPN model via gradual refinement for the actual implementation of the DYMO protocol. The CPN model presented in this paper contains the basic parts of the protocol and they are currently working on a full model of the DYMO protocol. They also presented results from an initial state space analysis of the constructed model. By using different scenarios they validated the protocols ability to establish routes and judge the usefulness of the routing information contained in the routing messages.

Junho Chung, Yonghwan Kwon, Bosung Kim, Hakkwan Kim, Kyungmin Lee, Dowon Hyun and Juwook Jang [7] devise a method of more prompt recovery to enhance a performance of DYMO when each node becomes more distant and loses routing path. For this they proposed a new route recovery scheme which involves support nodes. The support node, which is assigned among the neighbors of existing route, is responsible to participate in the operation and to transmit a data packet. In addition, they evaluated the performance with number of RREQ messages, an average of route recovery time, an average of packets delivery rate with distance in hops and an average of packets delivery rate by speed of nodes.

Takeshi Matsuda ·Hidehisa Nakayama, Xuemin (Sherman) Shen · Yoshiaki Nemoto, Nei Kato [3] have proposed Conventional DYMO. It is agnostic to the character of data and trustworthiness of GWs, and only uses hop count as a metric for the route discovery process. To include the character of data and GWs into the DYMOrouting metrics, they have classified data into sensitive and normal data. The routing messages, GWs and routing entries are also classified into n-Routes and s-Routes so that the routes are individually established according to the data-type and destination.

Marga Nácher, Carlos T. Calafate, Pietro Manzoni [11] have proposed enhancements to DYMO’s route discovery and packet forwarding processes in order to support multi-path routing and traffic dispersion policies, which are tunable through a set of parameters. They had solved the cut off problem for the DYMO protocol in a simpler way. During the request phase, every intermediate node has to save the path to the request packet’s originator in order to send the corresponding reply message to it. That’s why every intermediate node registers all the paths with different last hops though they may arrive through the same neighbor. Their future work is to compare multi-path DYMO with multi-path DSR in the scope of secure and anonymous routing.

Narendran Sivakumar et al [12] have compared the Dynamic Mobile Ad hoc Network On-demand routing protocol with existing routing protocols. They used the implementation based on the specification given in Dynamic Mobile Ad hoc Network On-demand Internet Engineering Task Force for Evaluation of the protocol with respect to various quantitative performance metrics like jitter, throughput and delay and to compare this with existing Ad hoc routing protocols.

III. Efficient Multipath DYMO Routing Protocol

A. *Multi-Path Extension to DYMO*

We propose a technique for multi-path selection in hybrid MANETs so that even if one path fails the data can be routed through another path.

In the multi-path route discovery process, when several route replies arrive to the source from different nodes and path identifiers, the DYMO agent stores these nodes as next hops in the destination entry of its route table. Cut off problem is solved in easy way. In route request phase, the intermediate node registers all the paths with different last hops for sending RREP to the corresponding RREQ though they may arrive from the same neighbor.

We describe the request and the reply phase with the help of a Fig. 1 and Fig. 2. Fig. 1 shows the request phase and Fig. 2 shows the reply phase where nodes *X* and *Y* saves two paths with destination as S and the next hop.

1) The destination node receives the route request in the reply process and sends back the reply through the neighboring node from which it received the packet. The last hop value is same as the value in the request packet. The initial path used by the intermediate node with this last hop is the valid one to determine the next hop and other paths are detached though it has different last hop.
2) Suppose that, first of all, node *D* receives the route request from *X* with last hop *L*. *D* sends a route reply with last hop *L* to *X* (RREP-L).Although *D* receives another route request from *X*, with a different last hop (in this case *M*), *D* discards the packet and it does not record this path.
3) Similarly, if *D* hears a request from another node with last hop L, it obviously discards the packet too. Only if *D* receives a request from another node (*Y*) with different last hop (*M*), does it save this path and send a new reply (RREP-*M*). When node *X* receives RREP-*L* it searches the path to node *S* with last hop *L* and removes other paths with the same next hop as the selected path (e.g., it would remove the second row of the table in Fig. 2). Node *Y* removes the first row when it processes the RREP-*M*. This way we solve the route cutoff problem.

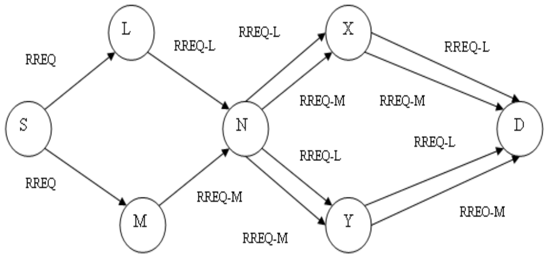

Fig. 1. Request phase.

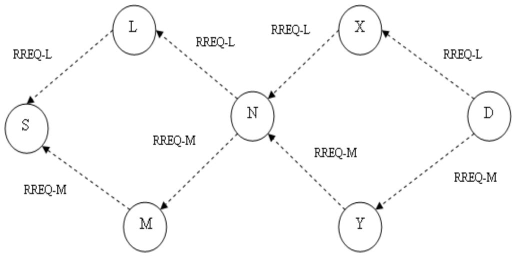

Fig. 2. Reply phase.

4) Each node has one or more routes for every possible destination, after the route discovery process. So, it must decide how to select them. The node chooses the route with lowest timeout value for every data packet. Timeout of this route is updated so that it becomes the route with largest timeout value. Then route with lowest timeout becomes different one and cyclically the routes are selected. [11].

B. *Gateway Selection*

Here, we propose a new metric for Internet Gateway (IGW) selection to balance the inter/intra-MANET traffic load over multiple IGWs. 13]. It consists of three components.

- The *shortest distance* between the MANET node and the selected IGW
- The '*inter- MANET traffic load'* via each IGW, which is represented as the number of registered MANET nodes sending/receiving traffic to/from Internet.
- The *intra-MANET traffic load* within the network topology managed by each IGW, which is related to the optimal node density to delivery traffic successfully
- The Residual energy at the IGW

The network model has multiple IGWs [IGW1, IGW2, …, IGWn] in a foreign MANET domain, and each IGWj IGW_j manages a network topology (X_j, Y_j), which can be overlapped with those managed by other IGWs.

- Each IGW_j attaches to its RREP the following information $[X_j, Y_j, \beta_{\mathrm{Reg}}(j), T_j, E(j)]$

where, (X_j, Y_j) is the managed topology size of IGWj,

$\beta_{\mathrm{Reg}}(j)$ is the number of registered MANET nodes with IGW_j for the inbound/outbound traffic from/to the Internet.

T_j is the total MANET nodes in the managed topology of IGW_j

E_j is the residual energy of IGW_j.

This RREP is sent directly to the source MANET upon receiving its RREQ.

- Each IGW_j determines $[\beta_{\mathrm{Reg}}(j), T_j, E(j)]$ by the periodic hello packet exchange of the neighbor discovery process, or by the on-demand RREQ/RREP packet exchange of the route discovery process.

whenever a visited or a local MANET node, which requires the Internet connectivity, receives RREP from multiple IGW_s in the same MANET domain we use the following formulae for selecting the IGW with lowest weight.

$L(i, J)$ is the shortest distance in terms of hop-count from the MANET i to the IGW_j. It is determined the MANET node i using either the received IGW discovery packets (RREP/solicitation) or by the corresponding MANET routing protocol (routing table, RREQ packet, or RREP packet).

TLinter is the inter-MANET traffic load which is given by the number of current registered MANET nodes $\beta_{\mathrm{Reg}}(j)$ at IGW_j that require Internet connectivity.

$$TL_{\mathrm{inter}}(j) = \beta_{reg}(j) \tag{1}$$

TLintra (i, j) is the intra-MANET traffic load in the network topology (X_j, Y_j) managed by IGW_j. It is determined based on the optimal node density ρ, and the average node degree $AvgNd$ [14]

$$TL_{\mathrm{intra}}(i, j) = \left\{ \frac{1}{AvgNd} \right\} \tag{2}$$

where $AvgNd = \rho \pi r^2$

- IGW_j does not know the existence of a visiting MANET node i in its managed network topology until a registration occurs. And so the average node degree is different from a local MANET node and a visiting MANET node.
- Each MANET node, i upon requesting Internet connectivity, register to one of the IGW_s discovered.
- *wt* (*i*,*j*) is the weight calculated as

$$wt(i, j) = \lambda_1 . L(i, j) + \lambda_2 TL_{\mathrm{inter}}(j) + \lambda_3 TL_{\mathrm{intra}}(i, j) + \lambda_4 E(j) \tag{3}$$

where, $\lambda_i, i \in r$ [1,3], is the constant to represent the contribution of each component into the metric. Thus, the sum of these constants is one.

$$\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 = 1$$

- The IGW with a minimum weight can be found using the below formula.

$$\mathrm{Min}\left\{ \mathrm{wt(i, j)} \right\}_{j \in V_{IGW}} \tag{4}$$

C. Combined Algorithm

1) In Route request phase, the Intermediate node registers all the paths with different last hops for sending RREP to the corresponding RREQ.
2) *Last hop* value = hop count in the request packet
   - If intermediate node uses the first path with this last hop

   That path is a valid path, and it determines next hop.
   Else
   They are removed by the nodes
   End if
3) In each data packet, the node chooses path with the lowest timeout value.
4) Timeout of this route is updated so that it becomes route with largest timeout value.
5) Each IGW j estimates its residual energy *E*(*j*).
6) On receiving RREQ, each IGW attaches $[X_j, Y_j, \beta_{\text{Reg}}(j), T_j, E_{(j)}]$ to RREP.
7) This RREP is sent directly to the source MANET.
8) On receiving RREP from MANET node, the path with least timeout values is selected.
9) For each IGW on the selected path
   - The distance $L(i, j)$ from the MANET node to the IGW is estimated.
   - The inter manet traffic load TLinter is determined using (1).
   - The intra manet traffic load TLintra is determined based on the node density 'ρ' and the average node degree $AvgNd$ using (2).
   - The weight wt (i, j) is calculated using (3).
   - If IGW satisfies the condition (4)
   - Select the IGW

   End if
   End For
10) If no IGW satisfies (4), then
    - Select alternate path from the multi path set.
    - Repeat from step.9.

    End if

IV. Simulation Results

A. Simulation Setup

We evaluate our efficient multi-path extension to DYMO (EM-DYMO) protocol through NS2 [15] simulation. We use ns2 version 2.28 with DYMO extension. We considered a hybrid network deployed in an area of1200×1200 m. There are 15 mobile nodes in the MANET domain. There are 5 gateway nodes connected with a fixed internet host through a router (ref. Fig. 3).

The simulated traffics are CBR and FTP. We have varied the traffic flows to increase the traffic load in the network. The following table summarizes the simulation parameters used.

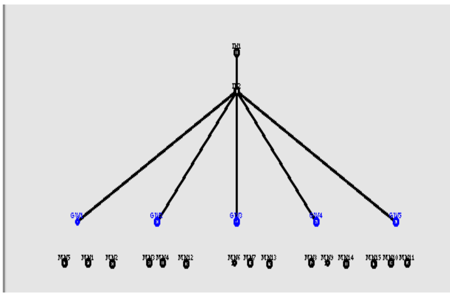

Fig. 3. Simulation topology.

TABLE I: Simulation Settings.

Mobile Nodes	15
MAC protocol	802.11
Propagation Model	TwoRayGround
Area Size	1200 X 1200
Simulation Time	50 seconds
Radio Range	250m
Wired Nodes	2
Gateway nodes	5
Traffic Source	CBR and TCP
Packet Size	512
Data Rate	250Kb
Mobility Model	Random Way Point
Speed	10m/s to 25m/s
Initial Energy	5.1 J
Transmit Power	0.66 Watts
Receiving Power	0.0695 Watts
Idle Power	0.035 Watts
Traffic Flows	1,2,3,4and5

B. Performance Metrics

We evaluate mainly the performance according to the following metrics.

Average end-to-end delay: The end-to-end-delay is averaged over all surviving data packets from the sources to the destinations.

Energy Consumption: It is the average energy consumption of all nodes in sending, receiving and forward operations

Average Packet Delivery Ratio: It is the ratio of the number .of packets received successfully and the total number of packets transmitted.

Overhead: It is the total number of control packets exchanged during the transmission.

We compare our EM-DYMO protocol with the normal DYMO protocol. We randomly select some mobile nodes as sources to get data from the internet through the gateway nodes. The nodes are set to move with a variable speed ranging from 10m/s to 25m/s.

C. Results

1) Based on CBR flows

In the first experiment, we vary the number of CBR traffic flows from 1 to 5.

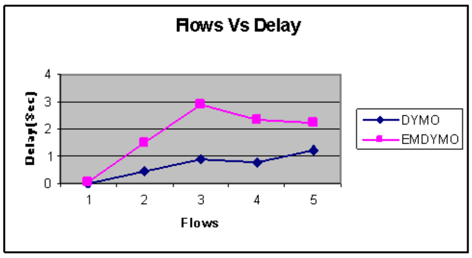

Fig. 4. Flows Vs delay.

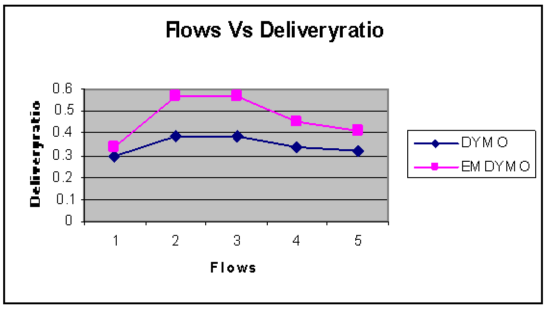

Fig. 5. Flows Vs delivery ratio.

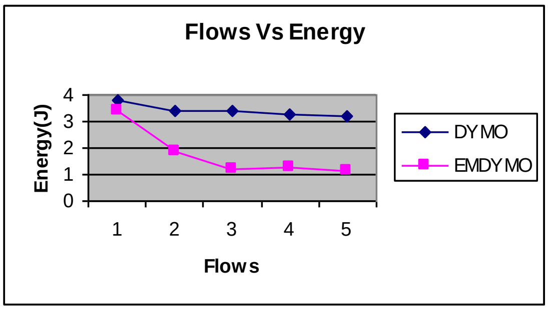

Fig. 6. Flows Vs energy.

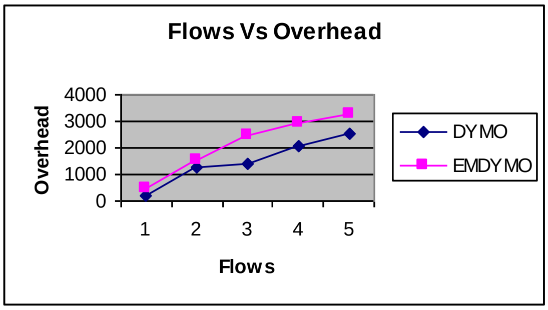

Fig. 7. Flows Vs overhead.

2) Based on TCP flows

In the second experiment, we vary the number TCP traffic flows from 1 to 5.

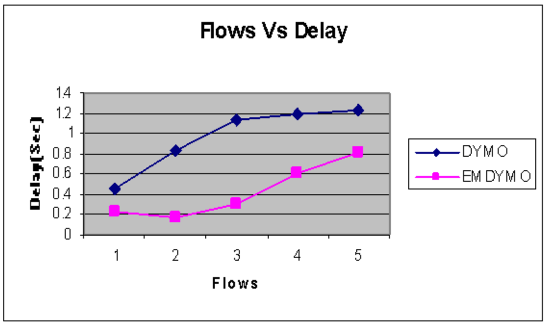

Fig. 8. Flows Vs delay.

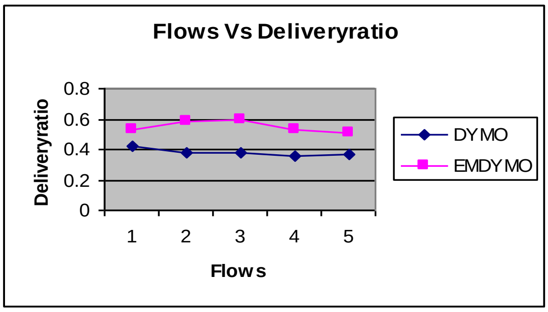

Fig. 9. Flows Vs delivery ratio.

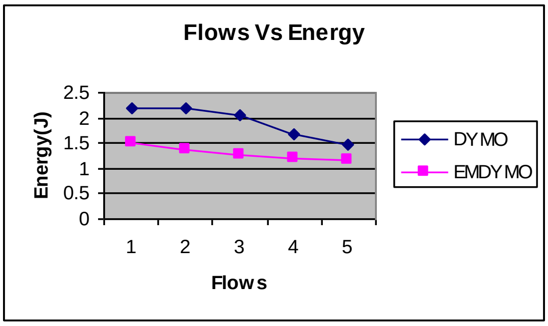

Fig. 10. Flows Vs energy.

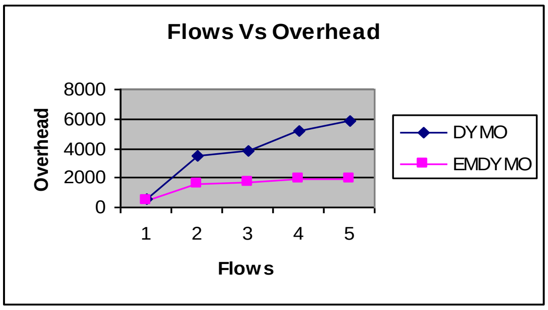

Fig. 11. Flows Vs overhead.

When the number of flow is increased from 1 to 5 the end-to-end delay increases linearly, as more number of paths has to be established. Fig. 4 and Fig. 8 depict this. The end to end delay is reduced in the EMDYMO protocol when compared to DYMO, which can be observed from the Fig. 4 and Fig. 8.

Fig. 5 and Fig. 9 show the packet delivery ratio for CBR and TCP traffic flows, respectively. The packet delivery ratio decreases gradually as the flow is increased, since it involves more packet drops. Since traffic load is considered in the gateway selection, the packet delivery ratio for the proposed EMDYMO protocol is significantly more when compared with DYMO.

Since residual energy is considered as one of the metrics for selecting the IGW, the energy consumption in EMDYMO is less when compared with the normal DYMO protocol. We can observe this, from Fig. 6 and Fig. 10 for CBR and TCP traffic respectively.

Fig. 7 and Fig. 11 show the overhead involved for the CBR and TCP traffic flows, respectively. As the number of flow is increased, more number of control packets are exchanged, resulting in increased overhead. Since EMDYMO involves multiple paths, the overhead of packet retransmission is reduced, when compared to DYMO for both CBR and TCP traffic flows.

V. Conclusion

In this paper we have proposed a multi-path extension to DYMO routing protocol for hybrid MANETs with a load balancing technique for gateway selection. In Route request phase, the Intermediate node registers all the paths with different last hops for sending RREP to the corresponding RREQ. In the Reply process, when Destination node receives a route request, it sends the reply back through the neighbor node from which it received the packet. The node chooses the route with the lowest timeout value. Then we design a new metric for Internet Gateway (IGW) selection to balance the inter/intra-MANET traffic load over multiple IGWs. For each IGW, a weight metric is determined based on the shortest distance, inter- MANET traffic load and intra-MANET traffic load. On the selected path, the IGW with minimum weight is selected. If no such IGW exists, the alternate path from the multi path set is selected. By simulation results, we have shown that our proposed protocol achieves maximum packet delivery ratio with less delay and reduces the energy consumption of the nodes.

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