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Congestion Adaptive Hybrid Multi-path Routing Protocol for Load Balancing in Mobile Ad Hoc Networks

P. Rama Devi and Dr. D. Srinivasa Rao
ECE Department of JNTU CE, Hyderabad, India

***Abstract*— In Mobile Ad Hoc Networks (MANET), the network congestion can rigorously depreciate the network throughput. Also the network congestion results in the packet losses, bandwidth degradation and energy expenditure. Hence a load balancing scheme is required to prevent the network from congestion and exhaustion of resources of congested node. In this paper, we propose a congestion adaptive multi-path routing protocol for load balancing in MANET. When the source node wants to forward the data packet to the destination, it utilizes the reactive route discovery technique where the multiple paths are established using multi-path Dijkstra algorithm. In the discovered route, when any node detects congestion, it intimates the source with congestion notice message. The source node upon receiving the message distributes the data packets through the multiple paths available in its route cache using random transmission technique. If the source does not find any routes in its route cache, then it re-establishes multiple paths and distributes the traffic. By simulation results, we show that the proposed approach alleviates the network congestion.**

***Index Terms*— Mobile Ad Hoc Networks (MANET), Congestion, Routing Protocol and Load Balancing**

I. INTRODUCTION

A. Mobile Ad hoc Network (MANET)

A Self-determining system of mobile routers and related hosts link by the wireless routes is termed as mobile ad hoc networks (MANET). It does not contain any base stations. Alternatively, a function of routing is included in every mobile host and multi-hops possibly will be essential to permit one node to interact with another node over the ad hoc network owing to the restricted transmission range. There is a possibility that wireless topology of the network may get varied randomly and quickly as the routes travel arbitrarily and systemize themselves randomly. Hence, MANETs are illustrated as active, multi-hop and continuously modifying topology [1].

Some examples of possible uses of a wireless ad-hoc network include military applications, law enforcement, emergency response efforts, commercial use, and education [2].

B. Multipath Routing

The process of discovering multiple routes among the distinct source and single destination at the time of single route discovery corresponds to multi-path routing [3]. In MANET, the prevailing issues such as scalability, security, network lifetime, etc can be handled by the multi-path routing protocols [4]. This protocol enhances the end-to-end throughput and offers load balancing in MANETs.

Multipath Routing Issues

Multipath routing has some disadvantages [4]:

Route Request Storm

A huge quantity of route request messages are created by the multipath reactive routing protocols. When the intermediate nodes requires to process the duplicate request messages, there is a chance of unnecessary overhead packets be set up in the networks.

Inefficient Route Discovery

Certain multi-path routing protocols avoid intermediate node from forwarding a reply from its route cache in order to determine node-disjoint or link disjoint paths. Hence the source has to wait till it gets a reply from destination. Thus the process of route discovery performed by the multipath routing protocol needs more time when compared with DSR or AODV protocols.

C. Congestion in MANET

When the requirements become greater than maximum capability of the communication link particularly during multiple hosts attempting to access a shared media, congestion occurs in the network. Congestion may also be caused during the following conditions.

- When the load in the link goes beyond the carrying capacity.
- When the broadcasting packets are surplus in nature
- When more number of packets field has becomes time out and retransmitted.
- When the number of node increases.
- During standard deviation of the packet delay [6].

The congestion detected in the network can rigorously worsen network throughput [5]. It results in the packet losses, bandwidth degradation and energy expenditure [7]. When the congested network is left unattended i.e., when suitable congestion control technique is not executed, it results in congestion collapse of the network. So the data will not delivered to destined node in effective manner [5]. When the routing protocols in MANET are not conscious about the congestion, it results in the following issues.

- *Long delay:* This holds up the process of detecting the congestion. When the congestion is more rigorous, it is better to select an alternate new path. But the prevailing on-demand routing protocol delays the route searching process.
- *High overhead:* More processing and communication attempts are required for a new route discovery. If the multi-path routing is utilized, its needs additional endeavor for upholding the multi-paths despite the existence of alternate route.
- *Many packet losses:* The congestion control technique attempts to minimize the excess load in the network by either reducing the sending rate at the sender side or by dropping the packets at the intermediate nodes or by executing both the process. This causes increased packet loss rate or minimum throughput.
- For a source-destination pair devoid of the demands of traffic, routes are defined priorly and the interference prevails between the links. This can lead to a congestion problem.
- When the wireless links are not shared by the transport layer flows, they start competing for the links when the flows are approaching close to each other. This results in congestion. This can be compensated with the MAC protocol that performs random access to the physical shared medium and necessitates the effective usage and sharing of the network resources.

Owing to the above mentioned reasons, congestion is treated using congestion control technique once it is detected during the routing process [8].

D. Load Balancing in MANET

For improved utility of the resources of the MANET and also to enhance the performance of the MANET, load balancing technique is employed which is the significant tool. Using the load balancing technique, the network can reduce the traffic congestion and imbalance of the load. This is possible because the technique reduces the end-to-end delay, increase the nodes lifetime and optimizes the energy expenditure [9].

The main problem with existing routing protocols is concerned with consideration of minimum hop paths as best path for transmitting the data towards destination. But the mentioned approach is short of communicating the load and path quality while creating the route. The reduced number of innermost nodes turns out to be strength for entire traffic which further causes congestion in medium access control layer (MAC). Consequently it results in increased packet delays as some nodes possess more loads. There is a possibility that heavily loaded nodes acquire more power utilization which declines the batter power. Thus the load imbalance occurs on various routes depreciating the performance causing issues such as congestion, power exhaustion and queuing delay [9].

Therefore, the importance of effective load balancing scheme is to reduce the variation among overloaded and under-loaded nodes based on workload. The load balancing scheme allocates the traffic among the mobile hosts preventing congestion and exhaustion of resources of congested nodes [10].

On the whole, load balancing scheme is required to perform following actions:

- For choosing non-congested paths or to distribute excessive load of a node to its neighbor
- Stabilizing the energy expenditure of the network
- Guaranteeing the energy efficiency and robustness.
- To minimize the end-to-end delay and packet losses caused by queue overflow.
- Improving the resource usage
- Enhancing the network performance and minimizes collision by the distribution of load [10].

E. Problem Identification

In paper [18], we proposed a hybrid QoS aware multi-path routing protocol for MANET. In this technique, topology discovery is performed proactively and route discovery is performed in the reactive manner. In proactive topology discovery phase, each node collects the battery power, queue length and residual bandwidth of every other nodes and stores in the topology information table (TIT). By exchanging the TIT among the nodes, the topology is discovered. When the source node wants to forward the data packet to the destination, it utilizes the reactive route discovery technique where the multiple paths are established using multi-path Dijkstra algorithm. When any intermediate node does not recognize the next 2-hop information from TIT towards destination, the new multi-path route discovery is performed.

The above approach does not consider the load balancing approach. The load imbalance results in end to end delay, packet dropping, imbalanced energy consumption and inefficiency. The heavily loaded nodes are also likely to incur high power consumption. Thus it degrades the performance by causing serious problems in mobile node like congestion, power depletion and queuing delay. Also the routing protocol does not take congestion into account which may lead to long delay, high overhead, packet losses, and many other congestion problems.

Hence in this paper we propose a congestion adaptive multi-path routing with load balancing technique for mobile ad hoc networks.

II. Related Works

Shruti Sangwan et al [10] have proposed adaptive and efficient load balancing schemes to achieve fair routing in mobile ad hoc networks (MANETs). They described various load balancing mechanisms that controls congestion. Also their efficient optimization techniques assist in deciding the best route in the ad hoc networks. They mainly focused on offering a better performance in terms of the processing time of the loads, nodes stability, throughput and lifetime of the network.

Valarmathi et al [11] have proposed a congestion aware and adaptive DSR algorithm with load balancing for MANET. Their protocol after supervising the congestion status informs the routing process of congestion and invokes multi-path routing. They also estimated the effects of various traffic load model on routing protocol. Their approach of multi-path-routing and load-balancing at the time of congestion enhances the QoS in MANETs for constant bit rate (CBR) multimedia applications.

Duc A. Tran et al [12] have proposed a congestion adaptive routing protocol (CRP) for MANETs. Their protocol assists in avoiding the congestion from occurring in the first place before dealing it reactively. CRP utilized bypass concept where part of the incoming traffic will be sent on the bypass, making the traffic coming to the potentially congested node less. This protocol further reduces the queuing delay and minimal packet loss rate.

Zhijing Xu et al [13] have proposed adaptive threshold routing algorithm with load balancing for ad hoc networks. Their scheme can distribute the traffic load evenly among nodes in ad hoc networks which is applied over an on-demand routing protocols. During route discovery, they judge the overloaded condition of the node by the threshold value and if the node is overloaded then the route request packet is dropped. Or else request packet will be broadcast again. The threshold value dynamically changes as per the interface queue occupancy (IQO) of nodes on and around the backward path.

R. Vinod Kumar et al [14] have proposed an effective scheme to balance the load in ad hoc network. They used ad hoc on demand multi-path distance vector (AOMDV) for selecting a path with a lower hop count and discarding the routes with higher hop count. They used a threshold value to judge whether the intermediate node is overloaded where the threshold value is changing along with the nodes' interface queue occupancy around the backward path.

P. P. Tandon et al [15] have proposed a novel congestion avoidance based load balanced routing with optimal flooding in MANET. Their approach attempts to avoid the congestion of a node by selecting the disjoint paths. This is achieved by setting a flag bit with the time limit TTL, at the node. On exceeding of this value, the flag bit is reset. Their approach limits the flooding and congestion of the node along with effective balancing of the traffic load. They did not take traffic load and hop count metric into consideration for selecting the route that reduces the network performance.

Rajbhupinder Kaur et al [16] have proposed a load balancing of ant based algorithm in MANET. Their algorithm is based on balancing the load among the routes by calculating threshold value of each routing table & ants' helps to effectively balance the loads as it find a pair of under loaded and over loaded nests. Their proposed algorithm can control the overhead generated by ants, while achieving faster end-to-end delay and improved packet delivery ratio.

Vishnu Kumar Sharma et al [17] have proposed a congestion and power control technique based on agent in MANET. They utilized mobile agent for transmitting the data packets through the path containing minimum cost and congestion. After composing the status of every node, it is delivered to the target node. Their power control technique classifies the nodes based on the power level as listening and non-listening nodes. During the packet transmission, when the node is listening, the packet is transmitted or else node checks for the adjacent listening for transmitting the packet.

III. Congestion Adaptive Multi-path Routing

A. Overview

In this paper, a congestion adaptive multi-path routing protocol for load balancing in MANET is proposed. When the source node wants to forward the data packet to the destination, it utilizes the reactive route discovery technique where the multiple paths are established using multi-path Dijkstra algorithm. When any intermediate node does not recognize the next 2-hop information from TIT towards destination, the new multi-path route discovery is performed. In the discovered route, when any node detects that congestion has occurred, it intimates the source with the congestion notice (CN) message.

Upon receiving CN message, the source node stops sending the data packet through the route containing the congested node and distributes the data packets through the multiple paths available in its route cache using random transmission technique. If the source node does not find the routes in its route cache, then it re-establishes multiple routes and proceeds with traffic distribution.

B. Estimation of Route Metrics

1) Estimation of Residual Battery Power

After time t, the power consumed by the node (P (t)) is computed as follows.

$$P(t) = DP_{tx} * \lambda + DP_{re} * \eta \qquad (1)$$

Where DP_{tx} = Number of data packets transmitted by the node after time t

DP_{re} = Number of data packets received by the node after time t

λ and η are constants in the range of [0, 1].

If P_i denotes the initial power of a node, the residual power P_R of a node at time t, can be calculated as:

$$P_R = P_i - P(t) \qquad [18] \qquad (2)$$

2) Estimation of Queue Length

The traffic load of the mobile node can be demonstrated by knowing the number of packets in the queue [17]. When excess traffic flows through the mobile nodes, it reveals that the interface queue possesses more packets. Thus average queue size that specifies the traffic load of the node can be computed as follows:

$$QL = \delta * QL_o + (1-\delta) * QL_c$$

where QL = Average queue length
QL_c = Current queue length,
QL_o = Old queue length
δ = Constant in the range [0, 1]

3) Estimation of Residual Bandwidth

Every node within the interference range holds the sufficient bandwidth for transmitting the data without congestion. Thus it is necessary to familiarize with the local and neighboring nodes within the interference range. Any node that has necessity to transmit the data must consider local bandwidth and interference range mutually. The process of predicting the bandwidth of local and neighboring nodes is explained below.

Since the bandwidth is shared among neighboring nodes, by taking channel into consideration, the nodes calculates bandwidth based on the ratio of idle and busy times projected for pre-defined interval of time (t)

The local bandwidth (B_l) is estimated as follows:

$$B_l = C_{ch} * \left(\frac{t_i}{t}\right) \quad (3)$$

Where C_{ch} = channel capacity and
t_i = idle time in t.

As the information regarding the neighboring nodes is gathered previously, the minimum bandwidth (B_{min}) of all nodes within the transmission range can be recognized. Thus the residual bandwidth (B_R) is defined as the difference between B_{min} and B_l and is stored in the residual bandwidth register.

C. Multipath Route Discovery

When the source S has a necessity to establish the route towards D through the intermediate nodes, route discovery phase is executed. The steps involved in the route discovery are as follows.

Step 1:

When S requires forwarding a data packet to D, initially it verifies the topology information table (TIT) shown below [18]:

TABLE I: TOPOLOGY INFORMATION TABLE (TIT)

Source Node ID	1-hop neighbor node ID	2-hop neighbor node ID	Residual Energy	Queue length	Residual bandwidth

Step 2:

After verification, S gathers all the information about the nodes towards D.

Step 3:

S computes the link metric (LM) using the data in its TIT which is as follows

$$LM = \frac{\eta * QL}{(\alpha * P_R) + (\beta * B_R)} \quad (1)$$

Where α, β and η represents the normalization factor.

Step 4:

S chooses the nodes with minimum LM and initiates the packet transfer through the chosen node within 2-hop. The Multipath Dijkstra algorithm (Explained in section 3.1.4) is employed to transmit the data through multiple paths with the nodes holding minimum link metric. The process is demonstrated using Fig. 1.

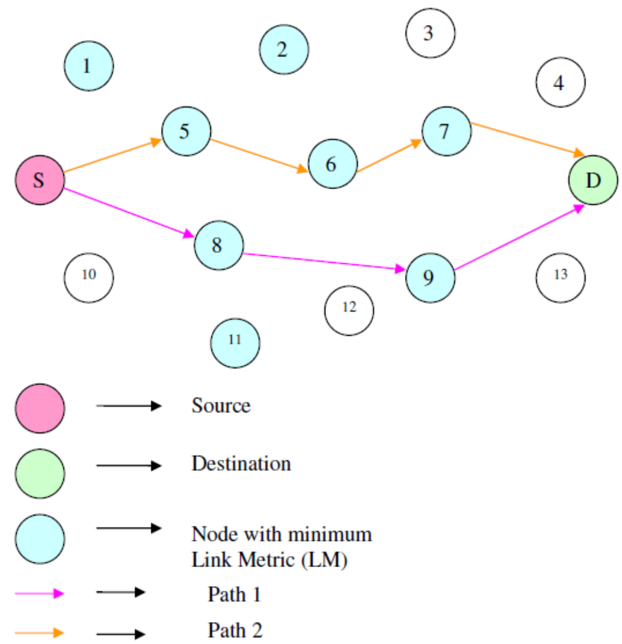

Fig. 1. Multipath Establishment using Multipath Dijkstra Algorithm

Fig. 1 represents the establishment of multiple paths using Multipath Dijkstra Algorithm. The source after computing the LM, finds that the nodes 1, 2, 5, 6, 7, 8, and 9 possess minimum LM. Then utilizing the multi-path Dijkstra algorithm, the source forwards the data packet towards the destination. The path 1 is chosen as the primary path since the destination is reached within its two hop neighbors. The path 2 is chosen as the backup path.

1) Reactive Multi-Path Routing

When any intermediate node (n_i) does not recognize the next 2-hop information from TIT towards destination, the reactive multi-path routing protocol (like AOMDV) is performed for route discovery. The steps involved are as follows:

Step 1:

The intermediate node (n_i) broadcasts route request (RREQ) message to all neighboring nodes through the eligible links towards the destination (D) and waits for the route reply (RREP) message.

$$N_i \xrightarrow{RREQ} n_{neigh}$$

Step 2:

When any n_{neigh} possessing an eligible route receives the RREQ, it replies requested n_i with the RREP message.

$$n_i \xleftarrow{RREP} n_{neigh}$$

Step 3:

On receiving the RREP, n_i computes its link metrics and compares the link metrics with the value already stored in its TIT, and if satisfies the requirement, it start sending data following that route and discard duplicate RREP packets received in other feasible paths.

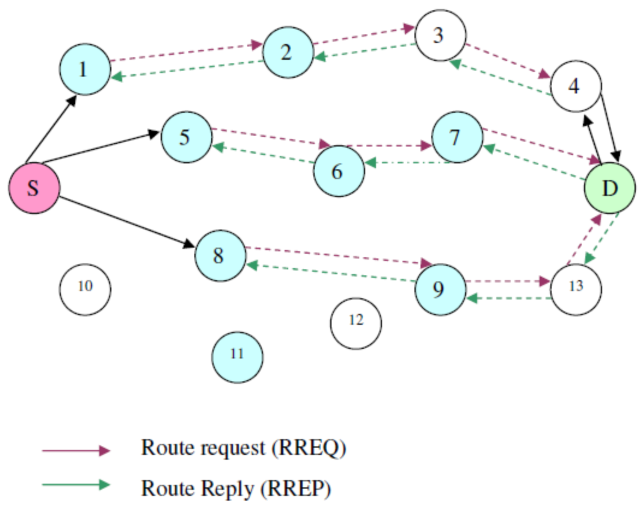

Fig. 2. Route Request and Route Reply Phase

From Fig. 2, the intermediate node 5, 1, 8 starts broadcasting RREQ packets. Upon receiving the RREQ packet, the neighbor nodes reply with the RREP packet to the requested node. The node 5, 1 and 8 verifies the RREP and computes its link metrics and if the link metrics matches with the value already stored in its TIT, it start sending data following that route and discard other duplicate RREP packets.

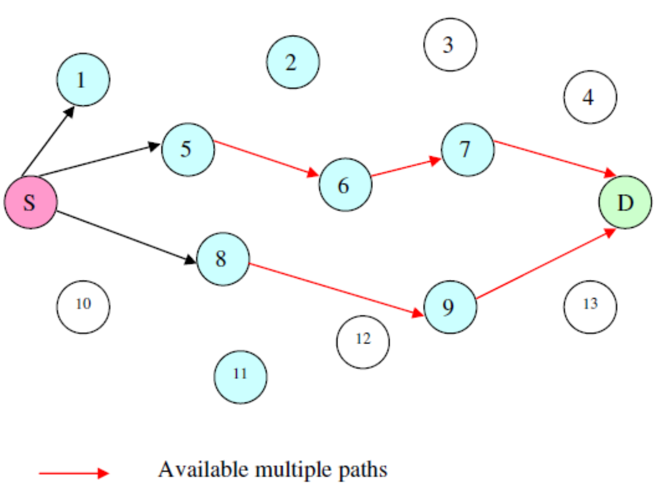

Fig. 3. Reactive Multi-path Routing

2) Congestion Detection

In the discovered route, the node is likely to be congested during any of the following cases.

Case 1

When the nodes receive excess data packets, the nodes queue length (QL) increases.

i.e.,

If $QL > QL_{th}$

Then

Congestion occurs

End if

Here QL_{th} represent the threshold value of queue length.

Case 2

When the nodes residual bandwidth is below the threshold, then the node suffers from lack of bandwidth during transmission of data.

i.e.,

If $B_R < B_{Rth}$

Then

Congestion Detected

End if

Here BR_{th} represent the threshold value of the residual bandwidth

Case 3

Congestion occurs when the nodes residual battery power is below the threshold value.

i.e $P_R < P_{Rth}$

where P_{Rth} = Threshold value of the residual battery power.

On the whole, the above condition can be simplified as follows.

If $(QL > QL_{th})$ | | $(B_R < B_{Rth})$ | | $(P_R < P_{Rth})$

Then

Congestion detected

End if

The congestion may result in increased packet loss rate, channel quality degradation, and increased delays. In order to overcome these drawbacks, the following congestion mitigating technique is considered.

3) Congestion Mitigation Technique

When any node in the discovered route detects that the congestion has occurred, it performs the following action.

- The node intimates the source with the congestion notice (CN) message.
- Upon receiving CN message, the source node stops sending the data packet through the route containing the congested node.
- Then the source verifies its route cache for other possible paths for transmitting the data packet.
- If source node finds that the routes are available in its route cache, then it utilizes the direct random transmission technique to proceed with packet transmission through the multiple paths for balancing the

load. The direct random transmission technique is explained in the section below.

- If the source node does not find the routes in its route cache, then it re-establishes multiple routes as per section III-C and section III-C(1) and proceed with traffic distribution.

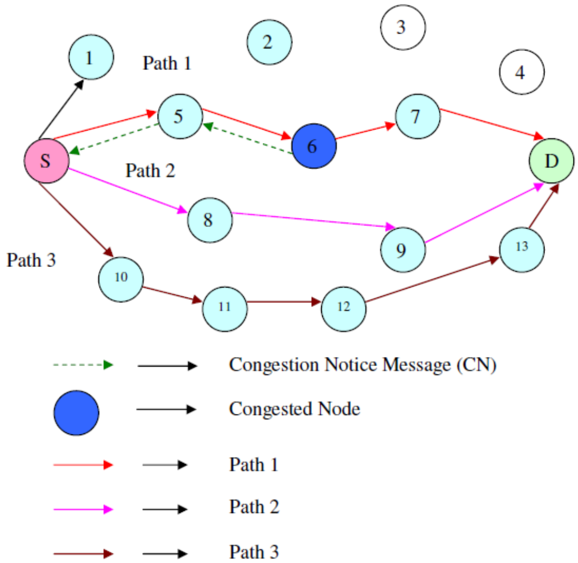

Fig. 4. Congestion Detection

From Fig 4, in path 1, congestion is detected in node 6. Then node 6 sends the congestion notice message (CN) to source node. The source node stops sending the data packet through the path 1 and checks its route cache for other possible routes. It finds the existence of path 2 and path 3 and begins the data packet transmission through both the paths utilizing the random transmission technique in order to balance the load.

4) Direct Random Transmission Technique

This technique involves the transmission of data packets via multiple paths based on the two-hop neighborhood information. Each node in the network holds the topology information table (TIT) that contains the ids of the nodes within the two-hop distance [18].

The steps involved in the direct random transmission technique is as follows

Step 1:

When a source wants to transmit the data packets to the destination, it adds a time-to-live (TTL) field to each data packet. The initial value of TTL field is set by the source node for controlling the total number of randomized transmission.

Step 2:

The source node also adds the lists of last hop neighbor nodes (H_{neigh}) to the packet header. The format of the data packet is shown in Table 2.

TABLE II: DATA PACKET FORMAT

Source Node ID	Time to live (TTL)	Last hop neighbor node

Step 3:

After updating both TTL and H_{neigh}, the source node starts transmitting the data packet.

Step 4:

When any intermediate node receives the data packet, it compares the H_{neigh} field against its own neighbor list and randomly selects one node from its neighbors that are not included in the H_{neigh}.

Step 5:

The intermediate then decrements the TTL value, updates the H_{neigh} field, and transmits the data packet to the next hop node, and this process continues till the overlapping of the H_{neigh} field occurs.

Step 6:

If H_{neigh} field completely overlaps or it possess the transmitting node's neighbor list,

Then

A random neighbor is drawn from the neighbor list and transmits the packet to it.

End if

This technique proves to be very efficient load balancing technique and improves the performance efficiency.

D. Flowchart

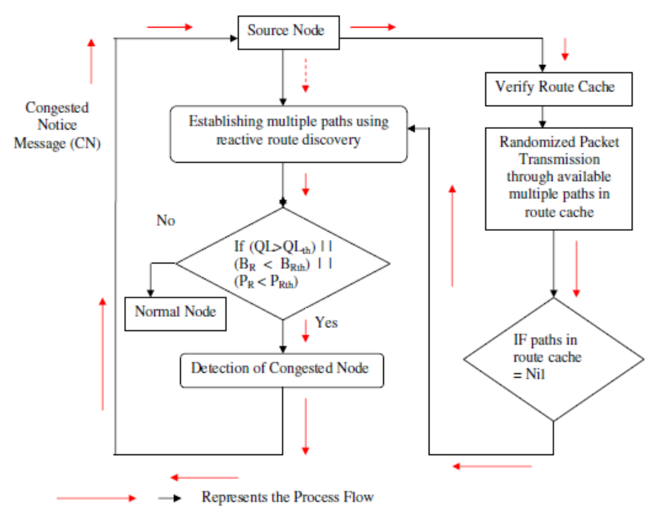

Fig. 5. Congestion Adaptive Multi-path Routing Approach

IV. SIMULATION RESULTS

A. Simulation Parameters

We use NS2 [19] to simulate our proposed Congestion Adaptive Hybrid Multi-path Routing Protocol (CAHMRP). In this simulation, the channel capacity of mobile hosts is set to the value of 2 Mbps. We use the distributed coordination function (DCF) of IEEE 802.11 for wireless LANs as the MAC layer protocol. It has the functionality to notify the network layer about link breakage. In our simulation, the number of flows is varied as 2, 4, 6 and 8. The mobile nodes move in a 1250 meter x 1250 meter square region for 50 seconds simulation time. We assume each node moves independently with the same average speed. All nodes have the same transmission range of 250 meters. In our simulation, the speed is 10 m/s and the transmission rate is varied from 250 to 500 kb/s. Random Way Point mobility model is used. The simulated traffic is Constant Bit Rate (CBR).

Our simulation settings and parameters are summarized in Table 1.

TABLE III: SIMULATION PARAMETERS

No. of Nodes	50
Area	1250 X 1250
MAC	802.11
Radio Range	250m
Simulation Time	50 sec
Traffic Source	CBR
Rate	250,300,350,400,450 and 500 kb/s
Packet Size	512 B
No. of connections	7
Mobility Model	Random Way Point
Speed	10 m/s
Pause time	5 seconds
RxPower	0.395
TxPower	0.660
IdlePower	0.035
Initial Energy	10.3
No. of Flows	2, 4, 6 and 8.

B. Performance Metrics

We evaluate performance of the new protocol mainly according to the following parameters. We compare the QAMR [18] routing protocol with our proposed CAHMRP protocol.

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

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

Control overhead: The control overhead is defined as the total number of routing control packets normalized by the total number of received data packets.

Throughput: It is the number of packets successfully received by the receiver.

The simulation results are presented in the next section.

C. Results & Analysis

1) Effect of varying Number of Flows

Initially we vary the number of flows as 2, 4, 6 and 8.

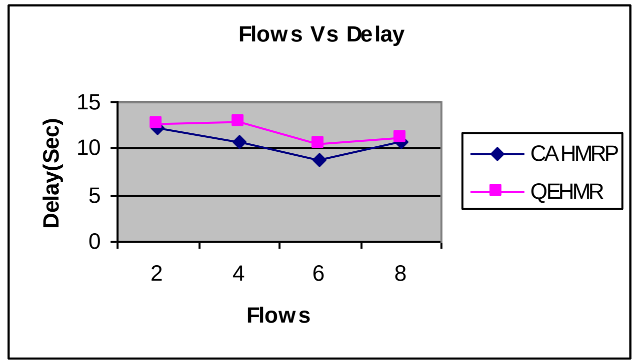

Fig. 6. Flows Vs Delay

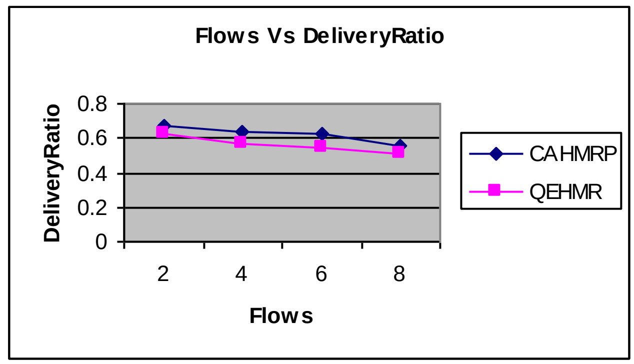

Fig. 7. Flows Vs Delivery Ratio

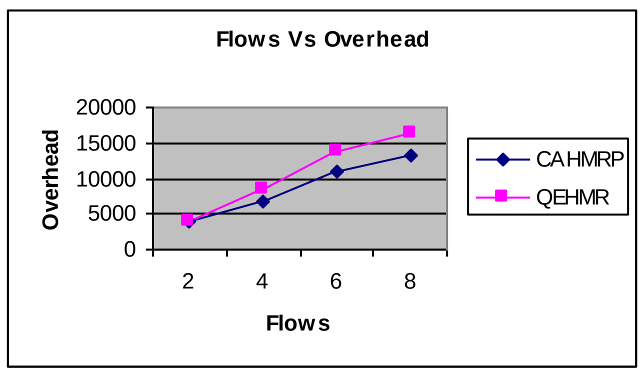

Fig. 8. Flows Vs Overhead

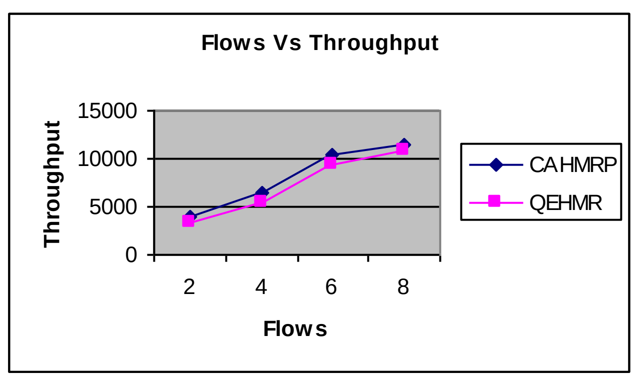

Fig. 9. Flows Vs Throughput

From Fig. 6, we can see that the average end to end delay of our proposed CAHMRP is 10% less than the existing QEHMR protocol.

From Fig. 7, we can see that the delivery ratio of our proposed CAHMRP is 9.8% higher than the existing QEHMR protocol.

From Fig. 8, we can see that the overhead of our proposed CAHMRP is 15% less than the existing QEHMR protocol.

From Fig. 9, we can see that the throughput of out proposed CAHMRP is 12% higher than the existing QEHMR protocol.

2) Based on Transmission Rate

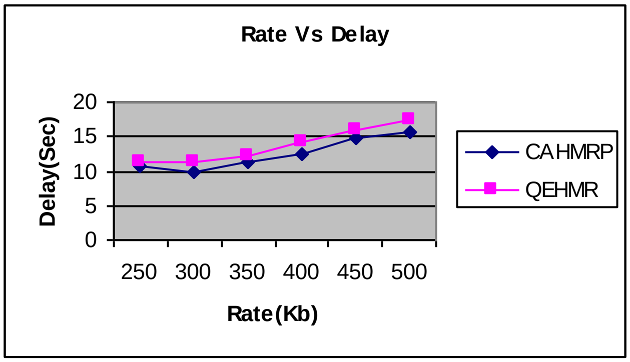

Fig. 10. Rate Vs Delay

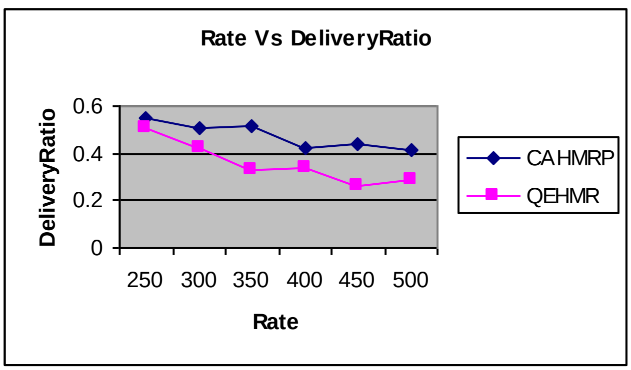

Fig. 11. Rate Vs Delivery Ratio

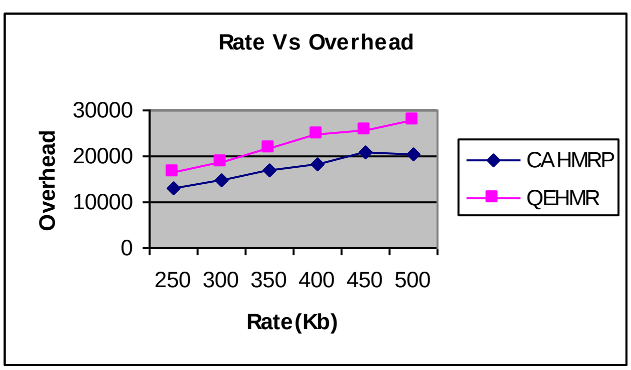

Fig. 12. Rate Vs Overhead

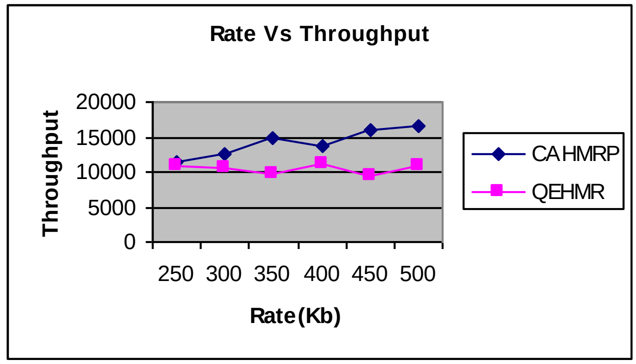

Fig. 13. Rate Vs Throughput

From Fig. 10, we can see that the average end to end delay of our proposed CAHMRP is 10% less than the existing QEHMR protocol.

From Fig. 11, we can see that the delivery ratio of our proposed CAHMRP is 31% higher than the existing QEHMR protocol.

From Fig. 12, we can see that the overhead of our proposed CAHMRP is 23% less than the existing QEHMR protocol.

From Fig. 13, we can see that the throughput of out proposed CAHMRP is 32% higher than the existing QEHMR protocol.

V. Conclusion

In this paper, we have proposed a congestion adaptive multi-path routing protocol for load balancing in MANET. When the source node wants to forward the data packet to the destination, it utilizes the reactive route discovery technique where the multiple paths are established using multi-path Dijkstra algorithm. When any intermediate node does not recognize the next 2-hop information from TIT towards destination, the new multi-path route discovery is performed. In the discovered route, when any node detects that congestion has occurred, it intimates the source with the congestion notice (CN) message.

Upon receiving CN message, the source node stops sending the data packet through the route containing the congested node and distributes the data packets through the multiple paths available in its route cache using random transmission technique. If the source node does not find the routes in its route cache, then it re-establishes multiple routes and proceeds with traffic distribution. By simulation results, we show that the proposed approach alleviates the network congestion. The proposed approach is very efficient load balancing technique that improves network performance.

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P. Rama Devi has completed her Master's degree in Applied Electronics from University of Madras. She has obtained under graduation from Institution of Engineers (India) and Diploma in Electronics and Communication Engineering (ECE). Currently working as an Associate professor in the department of ECE for JNTUH affiliated college. Her areas of interest include AdHoc wireless Networks and Optical Fiber Communication.

Dr. D. Srinivasa Rao has completed his Ph.D degree from Hyderabad Central University (HCU).His research interest are in the area of communications and computer network s Presently 12 research students are working under his guidance. He has 22 publications in various National, International Conferences and Journals. He has 20 years of teaching experience. He worked at CBIT as Lecturer in ECE Department for 6 years during 1988 – 1994. He worked at ECE Department of JNTU, Anantapur in various capacities for 11 years during 1994-2005. Presently he is working as Professor & Head in ECE Dept. of JNTU CE, Hyderabad. He has attended more than 10 Short Term Courses, Summer Schools, and Workshops, conducted by various organizations. He has organized workshops and refresher courses. He has chaired sessions at various national conferences. He is advisory committee member for GNIT, Hyderabad. He is also governing body member for Syed Hashim College of Science & Technology, member of JNTU forum for Science & Society and Coordinator for campus networking at JNTU CE, Hyderabad.