Ant-CAMP : Ant Based Congestion Adaptive Multipath Routing Protocol for Wireless Networks

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Abstract—- **The advent of mobile computing devices and wide deployment of wireless networks have led to an exponential increase in the internet traffic. Long congestion epochs and frequent link failures in wireless network lead to more number of packets being dropped and incur high end-to-end delay, thereby degrading the overall performance of the network. Congestion control, though mainly incorporated at the trans-port layer, if coupled with the routing protocols, can signif-icantly improve overall performance of the network. In this paper we propose Ant based Congestion Adaptive Multipath (Ant-CAMP) routing protocol that aims to avoid congestion by proactively sending congestion notification to the sender. The proposed Ant-CAMP routing protocol is implemented in Network Simulator-2 (NS-2) and its performance is compared with Ad-hoc On Demand Multipath Distance Vector (AOMDV) in terms of Packet Drops due to Congestion, Packet Delivery Fraction and Average End-to-End Delay.**

Keywords: Congestion Control, Ant Colony Optimization, Multipath Routing Protocols, Packet Delivery Fraction.

I. INTRODUCTION

Wide deployment of wireless networks and a high demand for continuous network connectivity has led to an expo-nential increase in the internet traffic. Efficiently alloca ting resources in wireless networks is a challenging task since the characteristics of the wireless medium vary continuously due to the interference effects. Packet drops in wireless networks are frequent events caused by congestion, link failures, channel errors, hand-offs etc. Congestion control is mainly coupled with transport protocols such as Transmission Control Protocol (TCP), Datagram Congestion Control Protocol (DCCP) etc. How-ever it has been shown that TCP as well as DCCP cannot differentiate congestion packet losses and non-congestion packet losses. Thus a lot of research has focused on design-ing congestion aware/adaptive routing protocols in wireless networks[1].Frequent link failures lead to considerable amount of packets to be dropped and incur high end to end delay in the network. Several multipath routing protocols have been proposed to reduce the overall end to end delay caused by link failures[2]. Moreover, multipath routing protocols also enhance the overall performance of the network by providing fault tolerance and load balancing features[3].

In this paper, we propose a Ant Colony Optimization (ACO)[4] based congestion adaptive multipath routing pro-tocol called Ant based Congestion Adaptive Multipath (Ant-CAMP) routing protocol that aims not only to reduce the packet drops caused by congestion but also to reduce the overall end to end delay by exploiting the advantages of multipath routing protocol.

ACO is a widely accepted branch of swarm intelligence based on which several routing protocols (including mul-tipath routing protocols) for wireless networks have been designed[5]. ACO is based on foraging principle of ants that walk randomly in search of food. On the way to destination (food source), they lay a chemical substance called *pheromone* to mark the path followed by them. When any ant finds the food source, it returns on the same path laying *pheromone* with high intensity which in turn increases the overall intensity of *pheromone* on that path. Other ants moving randomly detect and start following this path which has high probability to reach the destination. While returning back from destination, they too lay their *pheromone* on the same path which further increase the intensity of the path and attract more ants to follow this path.

The proposed Ant-CAMP routing protocol is implemented in NS-2 and its performance is compared with AOMDV[6] routing protocol. The performance comparison is based on Packet drops due to Congestion, Packet Delivery Fraction and Average End-to-End Delay. The remainder of the paper is organized as follows. Section 2 presents the motivation for designing Ant-CAMP. Section 3 gives a detailed description of Ant-CAMP routing protocol. Section 4 and 5 presents the simulation environ-ment and results respectively. Section 6 concludes the paper with future directions.

II. MOTIVATION

As mentioned above, packet drops in wireless networks can be due to several reasons such as congestion, link failures, hand-offs, channel errors etc. Packet drops not only lead to retransmissions but also increase the overall end to end delay in the network. Moreover, applications such as telnet, web browsing, etc are highly sensitive to packet loss. Several single path and multipath routing protocols have been designed so as to maximize the packet delivery ratio and reduce the overall end to end delay of the network.

Though multipath routing protocols have shown higher packet delivery ratio as compared to single path routing protocols, they are not congestion adaptive and hence cannot prevent packet drops due to congestion. To overcome this drawback of existing multipath routing protocols, we propose Ant-CAMP routing protocol that avoids the packet drops due to congestion by proactively sending congestion notification to the sender.

III. ANT BASED CONGESTION ADAPTIVE MULTIPATH ROUTING PROTOCOL (ANT-CAMP)

A. Overview

Ant-CAMP is a hybrid node disjoint multipath routing protocol which includes reactive route discovery, proactive route maintenance and aims to avoid congestion by proactively sending congestion notifications to the sender. Shortest path from sender to receiver is discovered considering "average queue length" as a routing metric. Since Ant-CAMP is a multipath routing protocol it finds multiple paths from source to destination in a single route discovery. Once the route is discovered it is proactively probed by the route maintenance phase of Ant-CAMP to update the routing table. Moreover, every node in the network calculates its average queue size and when it exceeds a predetermined threshold, it sends a congestion notification to the sender. On receiving congestion notification from the intermediate nodes, the sender switches to next optimal path available in the routing table. If there exists no path, route discovery phase is re-initiated.

B. Route Discovery

Route discovery phase of Ant-CAMP is initiated only when source wants to send data to the destination. In single route discovery multiple node disjoint paths from source to destination are discovered and stored in a routing table. Only if all these paths fail, route discovery phase is re-initiated.

Route discovery phase of Ant-CAMP uses two control packets called reactive_forward_ant (RF-Ant) and reactive_backward_ant (RB-Ant). Source initiates the route discovery phase by broadcasting RF-Ant to all its neighbours. All intermediate nodes, on receiving RF-Ant, check whether they are the destination of the RF-Ant packet. If they are the destination, they reply back to the source by converting RF-Ant to RB-Ant which propagates in the reverse path. If they are not the destination, they re-broadcast the RF-Ant. RF-Ant contains following information:

(source_address, destination_address, genera-tion_number, average_queue_size, hop_count, first_hop)

Every node maintains (source_address, gener-tion_number pair to identify duplicate RF-Ant. Each time a sender initiates new route discovery phase, generation_number is increased by one. The average_queue_size in RF-Ant contains the maximum average queue size on the path. hop_count field represents the total number of hops between source and destination.

When a node receives RF-Ant, it checks whether it is a duplicate RF-Ant or not by comparing the generation_number and source_address with information stored in its routing table. When an intermediate node detects duplicate RF-Ant it drops the RF-Ant reducing its further propagation. Before re-broadcasting RF-Ant, every intermediate node stores following information in its routing table.

(source_address, destination_address, genera-tion_number, expiration of reverse path)

This information is useful in forwarding RB-Ant from destination to the source. Thus, the reverse path (from destination to source) is set up while propagating RF-Ant towards destination.

A duplicate RF-Ant received at the destination denotes that it may have traversed disjoint paths. To ensure whether RF-Ant has traversed node disjoint path or not, destination node stores the first_hop information. If first_hop of RF-Ant is different from the one which is stored, the destination node generates the RB-Ant.

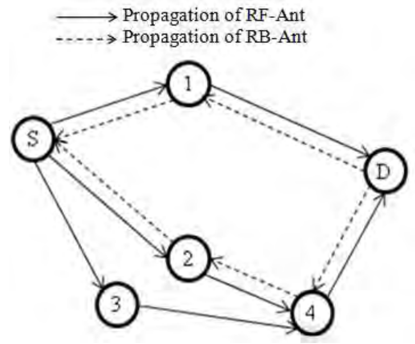

Figure 1. Path formation from Source (S) to Destination (D)

Figure 1 shows the route discovery from source (S) to destination (D). Source broadcasts RF-Ant to its neighbour nodes 1, 2 and 3. These nodes check whether the received RF-Ant is duplicate or not. If the received RF-Ant is not duplicate and they are not the destination, then they re-broadcast the RF-Ant. Otherwise if the RF-Ant is duplicate then it is dropped. Assume that node-4 receives first copy of RF-Ant from node-2. It establishes the reverse path and forwards the RF-Ant. Later when node-4 receives duplicate copy of RF-Ant from node-3 it simply discards the duplicate RF-Ant rather than re-broadcasting it. When destination (D) receives the RF-Ant from node-1 it stores the first_hop field of RF-Ant (in our example node-1) in its routing table, converts RF-Ant into RB-Ant and sends it on the reverse path which was previously set up during propagation of RF-Ant. Later when destination (D) receives duplicate RF-Ant from node-4, it checks the first_hop of RF-Ant with the one which is stored in its routing table. If the first_hop of the received RF-Ant is different, D generates RB-Ant and sends it back to the source otherwise simply discards the received RF-Ant. Thus, Ant-CAMP forms the node disjoint multiple paths between source and destination.

C. Calculating Average Queue Size

The routing metric used by Ant-CAMP to find shortest path between source and destination is average queue size. Every node in the network calculates its average queue size based on Exponential Weighted Moving Average (EWMA) as shown in equation(1)

$$avg = ((1 - q\_w) \times avg') + (q\_w \times cur\_que) \quad (1)$$

Variables:

avg: new average queue size in packets avg': old average queue size in packets

q_w: queue weight ($0 < q\_w \leqslant 1$)

cur_que: current occupied queue size in packets

The value of q_w can be set statically or dynamically. However, Ant-CAMP routing protocol dynamically sets the value of q_w based on equation(2) as shown below.

$$q\_w = \frac{current\_queue}{total\_queue} \quad (2)$$

From equation(2), it can be observed that the value of q_w mainly depends on the value of current_queue. If the queue is almost full (congestion building up), q_w value will be higher and hence more weightage will be given to cur_que in equation(1). Similarly if queue is almost empty, q_w value will be low and hence more weightage will be given to avg' in equation(1). Thus the avg value directly reflects the amount of congestion at the node. Ant-CAMP relies on the maximum average queue size (avg) of the path rather than the aggregate queue size of the entire path. The motivation for the same is explained below. Consider the scenario shown in Figure 2. Suppose each node has total queue size of 10 packets. There are two paths from source (S) to the destination (D). If RB-Ant carries aggregate of average queue size of all nodes on the path, then route table of S consists of avg (S-1-3-D) set to 7 packets and avg(S-2-4-D) set to 6 packets. Source selects the path S-2-4-D since it has less overall queue size. But the queue of node-4 is full and hence congestion occurs resulting in packet drops. Thus the aggregate queue size does not provide

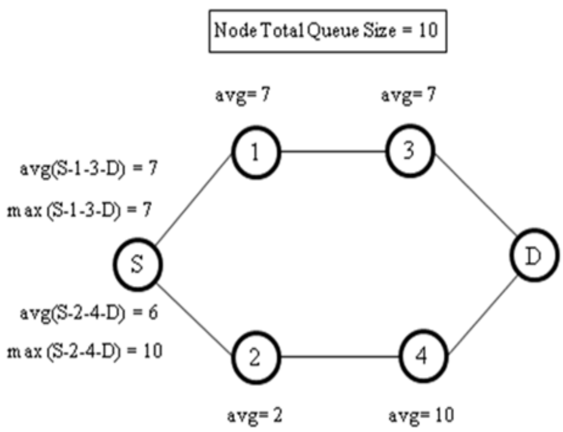

Figure 2. Difference between aggregate and maximum queue size of the path

accurate information about the amount of congestion on the path. Instead if RB-Ant carries maximum average queue size of the path, then information stored in source's routing table is: max(S-1-3-D) set to 7 packets and max(S-2-4-D) set to 10 packets. In this case, S-1-3-D path is selected since the probability of congestion occurrence on this path is less compared to other path. Thus the maximum queue size provides accurate information about the congestion on the path.

D. Route Maintenance

Route maintenance phase of Ant-CAMP uses two control packets called monitor_forward_ant (MF-Ant) and monitor_backward_ant (MB-Ant). These control packets ensure path availability and path optimality in terms of average queue size. Since the average queue size at all intermediate nodes keeps varying, frequently updating the routing table is very crucial. To update the routing table source generates MF-Ant which travels the path established during the route discovery phase. On receiving MF-Ant, the destination con-verts MF-Ant to MB-Ant and sends it back to the source which contains maximum average queue size information for that path. Thus MF-Ant ensures the path optimality by traversing all the paths periodically. The source expects one MB-Ant for each MF-Ant. If a MB-Ant is not received by source within certain period of time, it assumes that the path is not available and hence updates its routing table.

E. Congestion Notification

Ant-CAMP uses a special control packet called congestion_notification_ant (CN-Ant) to notify the sources about congestion on the path. The CN-Ants are sent by the intermediate node based on the following algorithm:

On arrival of each packet Calculate average queue size (avg)
if (avg > threshold) then
Generate CN-Ant to source
if (source receives CN-Ant) then
Mark the route as congested route
if (source is sending data)
then
Select alternate path from route table

As shown in algorithm, for arrival of each data packet, the node calculates average queue size and compares it with predetermined threshold "threshold". If the average is more than the threshold, the intermediate node sends CN-Ant to the source to notify about the congestion. If the average is less than the threshold, the incoming packet is en-queued and CN-Ant is not generated. On receiving CN-Ant from intermediate nodes, the source marks that path as congested path and switches to next optimal path in the routing table. If alternate paths do not exist, source reinitiates route discovery phase and the entire mechanism of Ant-CAMP is repeated. The propagation of CN-Ant is explained below.

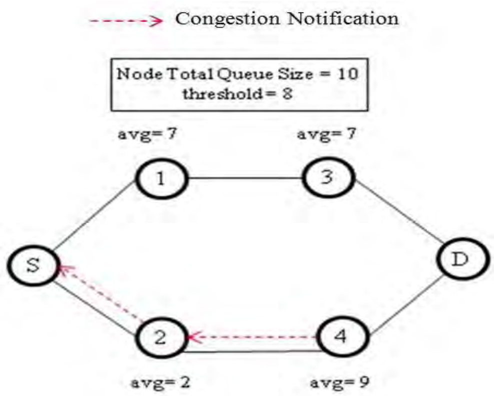

Figure 3. Congestion Notification

Consider the example shown in Figure 3. Source (S)

Is transmitting data to the destination (D) via path S-2- 4-D. When data packet arrives at node-4, it calculates its average queue size and compares it with the threshold. Assume the threshold is set to 8 packets. Thus when node-4 encounters that its average queue size (9 packets) is more than the threshold (8 packets), it notifies the source about congestion by sending CN-Ant. On receiving CN-Ant, source marks S-2-4-D path as congested and switches to an alternative path i.e. S-1-3-D. Thus by proactively sending congestion notification to the source, Ant-CAMP routing protocol avoids congestion and hence reduces the number of dropped packets.

IV. Simulation Environment

The simulation is carried out on two different topologies. One topology consists of 16 nodes placed in 4x4 grid while other topology consists of 25 nodes placed in 5x5 grid in network. The number of connections is varied across 5, 10, 15. Table I lists the details about the simulation environment.

TABLE I. SIMULATION ENVIRONMENT

Parameter	Setup
Simulator	Network Simulator 2
Total Nodes	16, 25
Simulation Time	Time 200 seconds
Simulation Area	1000m x 1000m
Data Packet Size	512 bytes
Traffic Model	FTP
Number of Connections	5, 10, 15

V. Results And Analysis

In this section, we compare the performance of Ant-CAMP routing protocol with AOMDV in terms of Packet Drops due to Congestion, Packet Delivery Fraction and Average End to End Delay.

A. *Packet Drops due to Congestion*

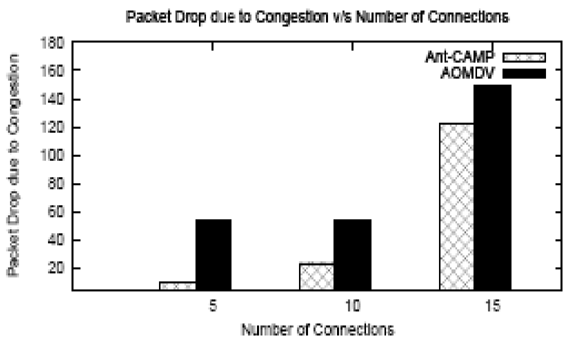

Figure 4. Packet Drops due to Congestion vs No. of Connections (16Nodes)

From Figure 4 it is observed that Ant-CAMP significantly reduces the number of packet drops due to congestion as compared to AOMDV for 16 nodes with varying number of connections (5, 10, 15). Since AOMDV is not congestion-adaptive, it continuously sends data on the path even if congestion occurs and hence results in more number of packets being dropped.

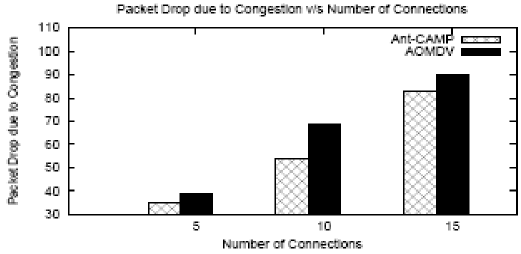

Figure 5. Packet Drops due to Congestion vs No. of Connections (25 Nodes)

TABLE II. DECREASE IN PACKET DROP DUE TO CONGESTION

No. of Connections	Improvement of Packet Drops due to Congestion (%)	
	16 Nodes	**25 Nodes**
5	81.48	10.25
10	55.55	21.74
15	17.45	7.77

Figure 5 shows Packet Drops due to Congestion in case of AOMDV and Ant-CAMP for 25 nodes with varying number of connections (5, 10, 15). Table II shows the percentage decrease in Packet Drops due to Congestion with Ant-CAMP as compared to AOMDV for 16-nodes and 25-nodes with varying number of connec-tions (5, 10, 15).

B. *Packet Delivery Fraction*

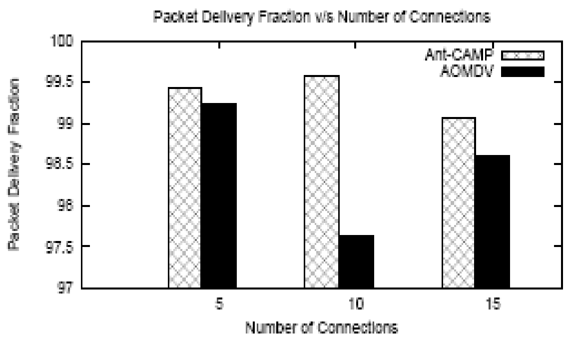

Figure 6. Packet Delivery Fraction vs No. of Connections (16 Nodes)

Figure 6 and 7 demonstrate the effectiveness of Ant-CAMP in terms of Packet Delivery Fraction for 16 nodes and 25 nodes with varying number of connections (5, 10, 15). As the number of connection increases in network, the network becomes congested. As a result, PDF of AOMDV reduces because of its congestion-un-adaptive nature. Table III shows the percentage increase in terms of PDF with Ant-CAMP as compared to AOMDV for 16-nodes and 25-nodes with varying number of connections (5, 10, 15).

C. Average End to End Delay

Figure 8 shows Average End to End Delay of AOMDV and Ant-CAMP for 16 nodes with varying number of connections (5, 10, 15).

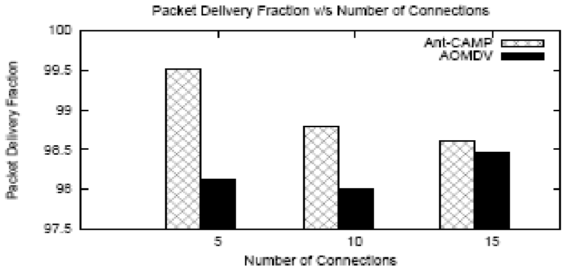

Figure 7. Packet Delivery Fraction vs No. of Connections (25 Nodes)

TABLE III. INCREASE IN PACKET DELIVERY FRACTION

No. of Connections	Improvement of Packet Delivery Fraction (%)	
	16 Nodes	**25 Nodes**
5	0.19	1.43
10	2.00	0.82
15	0.46	0.15

The Ant-CAMP monitors the path in terms of average queue size by periodically sending monitor ants. Source sends data on the path with minimal average queue size which in turn results in reducing end to end delay.

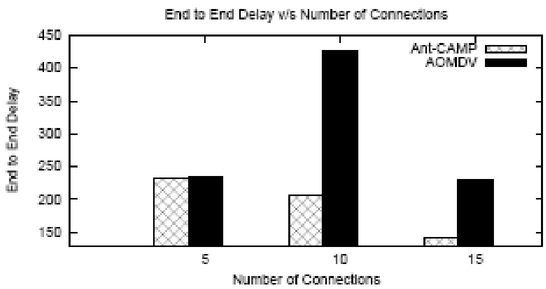

Figure 8. Average End to End Delay vs No. of Connections (16 Nodes)

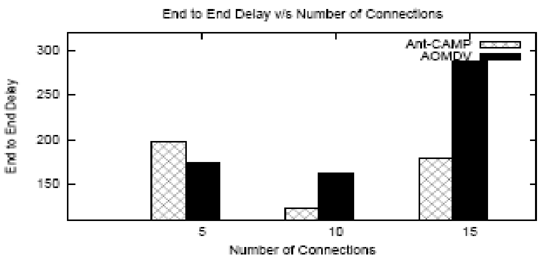

Figure 9. Average End to End Delay vs No. of Connections (25 Nodes)

TABLE IV. DECREASE IN AVERAGE END TO END DELAY

No. of Connections	Improvement of Average End to End Delay (%)	
	16 Nodes	**25 Nodes**
5	1.63	-13.60
10	51.46	23.86
15	38.33	37.82

Figure 9 shows Average End to End Delay of AOMDV and Ant-CAMP for 25 nodes with varying number of con-nections across (5, 10, 15). Table IV shows the percentage decrease in terms of PDF of Ant-CAMP compared to AOMDV for 16-nodes and 25-nodes topology.

VI. Conclusion And Future Work

In this paper, we have proposed a bio inspired congestion adaptive multipath routing protocol called Ant-CAMP that not only aims to avoid network congestion by proactively sending congestion notifications but also aims to reduce the overall average end to end delay of the network by expoiting the benefits of multipath routing protocols. The proposed Ant-CAMP routing protocol is implemented in NS-2 and its performance is evaluated based on the comparative study between Ant-CAMP and AOMDV in terms of Packet Drops due to Congestion, Packet Delivery Fraction and Average End to End Delay. Based on simulation results it is observed that Ant-CAMP routing protocol reduces the number of packet drops due to congestion and improves the overall packet delivery ratio while minimizing the average end to end delay of the network. However, Ant-CAMP can be further optimized by dynamically varying the predetermined threshold and accurately selecting queue weight for average queue size calculation.

VII. Acknowledgement

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