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Cross-Layer based Congestion Detection and Dynamic Proxy Acknowledgment Scheme for TCP in MANET

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***Abstract:** In Mobile Ad Hoc Networks, the existing transmission technique does not guarantee connectivity and congestion free transmission. Also, the static proxy nodes are not suitable during the transmission and quick as well as accurate MAC layer contention detection technique is required. Hence in this paper, we propose a cross-layer based congestion detection and adaptive proxy acknowledgement scheme for TCP in MANET. In this scheme, the underlying MANET routing protocol selects the proxy nodes along the source and destination based on link availability and link-layer transmission queue length metrics parameters. The local congestion is detected by verifying missing TCP sequence. And the end to end congestion is detected based on the frame transmission efficiency. By simulation results, we show that the proposed technique guarantees connectivity and congestion free transmission.*

***Keywords:** Cross-layer, Congestion, MANET, Proxy.*

I. INTRODUCTION

TCP Protocol

Transmission control protocol (TCP) is a connection oriented uni-cast transport protocol that offers the following features: explicit and acknowledged connection initiation and termination; end-to-end reliability; in-order, and not duplicated data delivery; flow control; congestion avoidance; and out-of-band indication of urgent data. These multifold characteristics of TCP make it by far the most used transport protocol in Internet applications such as www (HTTP), mail (SMTP), file transfer (FTP) and remote access service (Telnet).[1].

Transmission Control Protocol (TCP) is one of the main protocols in TCP/IP networks. TCP works on transport layer in OSI model. The IP protocol deals only with packets, whereas TCP enables two hosts to establish a connection and exchange streams of data. TCP guarantees delivery of data and also guarantees that packets will be delivered in the same order in which they were sent. The TCP was mainly designed for wired network, where there are a very less chances of packet loss due to transmission errors, and most of the time packet losses are due to congestion in the network. Now a days, mainly research is done on effective error and congestion control mechanism for wired and wireless network. [2].

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The factors that may cause losses and affect TCP performance in multi-hop wireless networks are:

- Frequent route failures caused by node mobility.
- High bit error rates.
- Medium access contention complicated by hidden/
- Exposed terminal problems.

Interference and collision complicated by sharing the same path. In fact, TCP is unable to distinguish between packet losses due to congestion from losses due to the specific features of multi-hop ad hoc networks. In theory, TCP should be independent of the underlying network technology. Specifically, TCP should not care whether it is running over wired or wireless connections. [1].

Instrumental in developing today's Internet. In particular, TCP has been successful due to its robustness in reacting dynamically to changing network traffic conditions and providing reliability on an end-to-end basis. This wide acceptance has driven the development of many TCP applications, motivating the extension of this protocol to wireless networks. These networks pose some critical challenges to TCP since it was not originally designed to work in such complex Environments, where the level of bit error rate (BER) is not negligible due to the physical medium [3].

Cross-Layer based Techniques

The performance of the wireless ad hoc network will be degraded if the traditional TCP protocol is utilized. The reason is that TCP congestion control has an implicit assumption that any packet loss is due to the buffer overflow. In fact, as long as the buffer size at each wireless node is reasonably large, most packet losses are due to wireless channel contention, namely, MAC (Media Access Control) layer competition. Therefore, several cross-layer schemes are proposed to alleviate congestion in the wireless channel. For example, a cross-layer ECN (Explicit Congestion Notification) scheme was proposed to perceive the link congestion according to the retransmission counter at the MAC layer. In this scheme, the retransmission counter at the MAC layer is used as the congestion metric to trigger the ECN mechanism. ECN is the explicit congestion notification mechanism of the IP layer. When network congestion occurs, the sender can adjust the congestion window and reduce the sending rate by the ECN mark from the receiver. [4].

Wireless networks, such as MANET and wireless sensor networks (WSN), are also characterized by high bit error rate (BER) channels. TCP faces some challenges over these networks since it is not inherently designed to adapt for such environments properties.

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The performance of TCP degrades with high mobility and bit error rate since it reduces the transmission rate when a segment is lost due to link breakages or bit errors and cannot distinguish between these two cases and severely congested routers buffers. [5].

Problem Identification

In the Proxy acknowledgement scheme [6] , proxy nodes are selected simply based on the hop count values only. But link availability and load should be checked in the proxy node selection phase in order to guarantee the connectivity and congestion free transmission. Moreover, the selected proxy nodes are static which do not change during the transmission. But if the link availability or load of any proxy node changes, another suitable proxy node should be selected dynamically.

Current cross-layer based congestion detection works [7] [8] mostly consider the channel occupancy ratio (COR) and contention window metrics for MAC layer contention. But frame transmission efficiency [4] is a better metric which detects MAC layer contention quickly and accurately.

In order to solve the above issues, we propose a cross-layer based congestion detection and adaptive proxy acknowledgement scheme for TCP in MANET.

II. RELATED WORKS

Huaguang He et al [4] have proposed a new congestion metric called frame transmission efficiency (i.e., the ratio of successful transmission delay to the frame service delay), which describes the medium contention in a fast and accurate manner. They further presented the design and implementation of RECN (ECN and the ratio of successful transmission delay to the frame service delay in the MAC layer, namely, the frame transmission efficiency), a general supporting scheme that adjusts the transport sending rate through a standard ECN (Explicit Congestion Notification) signaling method. Their method can be deployed on commodity switches with small firmware updates, while making no modification on end hosts.

Wesam A. Almobaideen et al [5] have introduced a new AIMD algorithm that takes the number of already received duplicated ACK, when a timeout takes place, into account in deciding the amount of multiplicative decrease. Specifically, it decides the point from which Slow-start mechanism should begin its recovery of the congestion window size. The new AIMD algorithm has been developed as a new TCP variant which they called TCP Karak. The aim of TCP Karak is to be more adaptive to mobile wireless networks conditions by being able to distinguish between loss due to severe congestion and that due to link breakages or bit errors. May Zin Oo et al [6] have proposed a sequence number checking technique to improve the performance of TCP connections in mobile ad hoc networks. While a TCP connection is initialized, a routing protocol takes the responsibility for checking the hop count between a source and destination pair. If the hop count is greater than a predefined value, the routing protocol decides to use a proxy node. The responsibility of a proxy node is to check the correctness of data packets and inform the missing packets by sending an acknowledgement from a proxy node to the source node. By doing so, the source node is able to retransmit any missing packet in advance without waiting until an end-to-end acknowledgement is received from the destination.

Sunitha et al [7] have proposed a smart acknowledgment distribute channel access (SADCA) scheme for TCP in MANET. In the proposed scheme first a separate access category for TCP acknowledgment packets is used without any data and then it is assigned with highest priority. In this way, delay during transmission of packet can be reduced and also packet can be acknowledged immediately. Also, to increase the performance delay window size can be adjusted for optimization purpose by considering the parameters such as transmission rate, number of hops, and channel occupied ratio (COR). Hence the proposed scheme helps to avoid any kind of delay and overhead for sending TCP acknowledgment.

Tarun kumar et al [8] have proposed a cross-layer based approach for improving TCP performance in Multihop Mobile Adhoc Networks (MANETs). The proposed congestion triggering mechanism triggers congestion whenever the channel occupied ratio (COR) reaches a maximum threshold value and the received signal strength is less than a minimum threshold value. Following it, the congestion control scheme controls the data sending rate of the sender by determining available bandwidth, delay of its link and COR. Further, a fair resource allocation scheme is put forwarded. Faisal Nawab et al [9] have proposed a distributed MAC protocol to alleviate the unfairness problem in WMNs. Their protocol uses the age of packet as a priority metric for packet scheduling.

III. PROPOSED SOLUTION

Overview

In this paper, we propose a cross-layer based congestion detection and adaptive proxy acknowledgement scheme for TCP in MANET. In this scheme, the underlying MANET routing protocol selects the proxy nodes along the source and destination based on link availability and link-layer transmission queue length metrics parameters. The local congestion is detected by verifying missing TCP sequence. And the end to end congestion is detected based on the frame transmission efficiency.

Estimation of Metrics

Link Availability

The link availability prediction is described below.

Let t_{pr} be the predicted time period.

Let P_t be the probability that the link lasts till the end of t_{pr}.

During each random epoch, we assume that the node velocity remains constant during each random epoch.

The link distance between two nodes is estimated as follows:

$$d^2 = a_1 t^2 + a_2 t + a_3 \quad (1)$$

where a_1, a_2, a_3 are constants

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The constants can be obtained using the following points of measurements:

(t_0, d_0), (t_1, d_1) and (t_2, d_2)

Sample time $t_i = t_0 + T_i$

d_i = distance between the two nodes.

The estimation of t_{pr} involves following solutions:

- Till the velocities of the two nodes which are in the transmission range remains constant, there is a possibility that it will travel out of this range.
- If a node travels away from primary users, then it will always be located outside the interference boundary. Then the maximum allowable time period $\bar{t}_{pr}$ is defined as follows:

$$\bar{t}_{pr} = \begin{cases} \sqrt{\dfrac{a_2^2 + 4\beta^2 - 4a_1a_2 - a_2}{2a_1}} - t_2, if\ \Delta \geq 0\, and\, \Delta \geq a_2^2 \\ \infty, \qquad otherwise \end{cases} \quad (2)$$

where α = interference boundary radius

$$\Delta = a_2^2 + 4a_1\beta^2 - 4a_1a_2$$

- ○ If the user is in the interference region of a primary user, then $\bar{t}_{pr}$ is set to 0 .

- The probability $\bar{P}_t$ to $\bar{t}_{pr}$ is defined as follows:

$$\bar{P}_t \approx e^{-\delta \bar{t}_p e^{-\delta \bar{t}_p}} + \lambda(1 - e^{-\delta \bar{t}_p}) \quad (3)$$

Where λ, δ are constants

The $[t_{pr}, P_t]$ and $[\bar{t}_{pr}, \bar{P}_t]$ pair is used to predict link duration related to interference to primary users.

The time during which the link is available is estimated using the following equation

$$T_{LA} = \min_{i=1,2;\, j\{PUs\}} \{t_p \times P_t, \bar{t}^{\,j}_{rpi} \times P^j_{ti}\} \quad (4)$$

Where i = two ends of a link

PU = set of primary users present in the network

i, j denotes that a link will be busy or unavailable if any of its ends moves into the interference region of any primary users.

Queue Length

Queue length is defined as the number of packets waiting in the interface queue for transmission. It is measured when the current packet leaves the node and it reflects the total number of packets waiting for medium access.

Frame Transmission Efficiency

Frame Transmission Efficiency is defined as the ratio of successful transmission delay to the frame service delay in the MAC layer, that is

$$\eta = d_{tx} / d_{tfs} \quad (5)$$

Where,

d_{tx} = successful data transmission delay. This indicates the time interval between initiation of data to receipt of acknowledgement

d_{tfs} = total frame service delay. This indicates the time from listening on the channel for transmitting this frame to this frame being transmitted successfully.

Proxy Selection Technique

Let S and D represent the source and destination respectively.

Let N_i be the intermediate node

Let PN_i be the proxy node

Let R_1 and R_2 be the incoming and outgoing traffic rates

Let q be the missing sequence number

Let v be the number of missing sequence numbers

Let RREQ and RREP be the route request and route reply message respectively.

Let PCN be the proxy change notification message

When source wants to transmit the TCP packet to destination node, it initiates the routing process among S and Destination. This forms the routing backbone. The process is explained the following steps.

Algorithm 1

1) S broadcast the RREQ message to its intermediate nodes (N_i).

$$S \xrightarrow{RREQ} N_i$$

The format of RREQ message is shown in table 1.

Table 1- Format of Route request message

Source ID	Destination ID	Sequence Number	Link Availability	Link Layer Transmission Queue Length

N_i upon receiving RREQ updates its routing table with the information that includes source ID, destination ID, sequence number, link availability and link layer transmission queue length. It appends its state to the node state field to RREQ message and analyzes the destination ID.

If $N_i \neq D$
Then
N_i rebroadcasts RREQ to neighboring nodes
Else

$$N_i \xrightarrow{RREP} S$$

End if

The above condition intimates that when intermediate comes to know that it is destination node, it sends RREP message to source. Otherwise, it rebroadcasts RREQ to its neighboring nodes.

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2) In case N_i receives two or more RREQ with similar destination ID, then it considers first received message and discards the other message.
3) When D receives RREQ message, it appends its state to RREP and unicasts the reply message in the reverse path towards S. D performs this similar action for every RREQ it receives.

$$D \xrightarrow{RREP} S$$

4) N_i upon receiving the RREP message appends its state to the message and also updates its routing table. Then it unicasts the RREP in the direction of S utilizing the previous hop node information which is priorly stored.
5) Step 5 is repeated till RREP reaches S.
6) The nodes with better LA and LQL metrics are deployed as PN_i along the path from S to D.
7) During transmission, if the LA or LQL metric change at any proxy nodes, then PCN message will be broadcast to S.

$$PN_i \xrightarrow{*PCN} S$$

8) On receiving PCN, S will again invoke the proxy selection process through the routing protocol from step 1.

Local Congestion Detection

Let q_e and q_c be the expected and current sequence number

The steps involved in this technique are as follows:

Algorithm 2

1) While transmitting TCP packets, PN_i will verify q.

1. q always starts at one.
2. In order to increase q_e, q_e and q_c must initially be the same.
3. When PN_i detects that q_c is equal to one, the relevant proxy node's ID is added in the current proxy field in the routing table.
4. Later, if the current proxy is not equal, a proxy change event has occurred.
5. The current_proxy field of the routing table is then updated with a new proxy, and q_e is updated with q_c.
6. While the TCP sequence number is monitored, q_e is increased by one for every received sequence number, and then q_c and q_e are compared.

- If q_c and q_e are the same, the proxy node assumes that there is no missing sequence number.
- On the other hand, if q_c is greater than q_e, then it indicates that there is missing sequence number

Note

If PN_i changes, q value will not start from one. Hence q_e will be updated as per q_c value.

2) As soon as PN_i detects that the sequence numbers are missing, it sends a PACK packet to inform S.

$$PN_i \xrightarrow{PACK} S$$

3) Also PN_i verifies R_1 and R_2.
4) If $R_1>R_2$,
Then

$$PN_i \xrightarrow{NACK} S$$

S adjusts the sending rate

End if

This implies that if the incoming traffic rate is greater than the outgoing rate, it sends a NACK packet to the source indicating a local congestion detection. S will then adjust its sending rate accordingly.

End to End Congestion Detection

Algorithm 3

Let η be the frame transmission efficiency

The steps involves in this technique are as follows:

1) When the TCP packet is received by a node, it will estimate η
2) If $\eta < \eta_{th}$

Then

$$N_i \xrightarrow{RECN} S$$

S adjusts the sending rate

Else

$$N_i \xrightarrow{G\_ACK} S$$

End if

If FTA is less than a threshold value, then the receiver send a RECN flag to the source indicating a MAC layer contention.

Otherwise, it will send a global ACK packet to the source indicating successful delivery of packets. On receiving RECN flag, the source will adjust the rate accordingly.

IV. SIMULATION RESULTS

Simulation Parameters

We use NS2 to simulate our proposed Cross-layer based Congestion Detection and Dynamic Proxy Acknowledgment Scheme (CCDDPA) protocol. We use the IEEE 802.11 for wireless networks as the MAC layer protocol.

It has the functionality to notify the network layer about link breakage.

In our simulation, the packet size is varied as 250, 500, 750, 1000 and 1250.

The area size is 1300 meter x 1300 meter square region for 50 seconds simulation time.

The simulated traffic is Transmission Control Protocol (TCP).

Our simulation settings and parameters are summarized in table 1.

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Table 1: Simulation parameters for Grid Architecture

No. of Nodes	64
Area	1300 X 1300
MAC	802.11
Simulation Time	50 sec
Traffic Source	TCP
Packet Size	250,500,750,1000 and 1250
Propagation	Two Ray Ground
Antenna	Omni Antenna
Rate	50Kb

Table 2: Simulation parameters for Non-Linear Architecture

No. of Nodes	20,40,60,80 and 100
Area	1300 X 1300
MAC	802.11
Simulation Time	50 sec
Traffic Source	TCP
Packet Size	250,500,750,1000 and 1250
Propagation	Two Ray Ground
Antenna	Omni Antenna
Rate	50Kb

4.1.1. Simulation Topologies

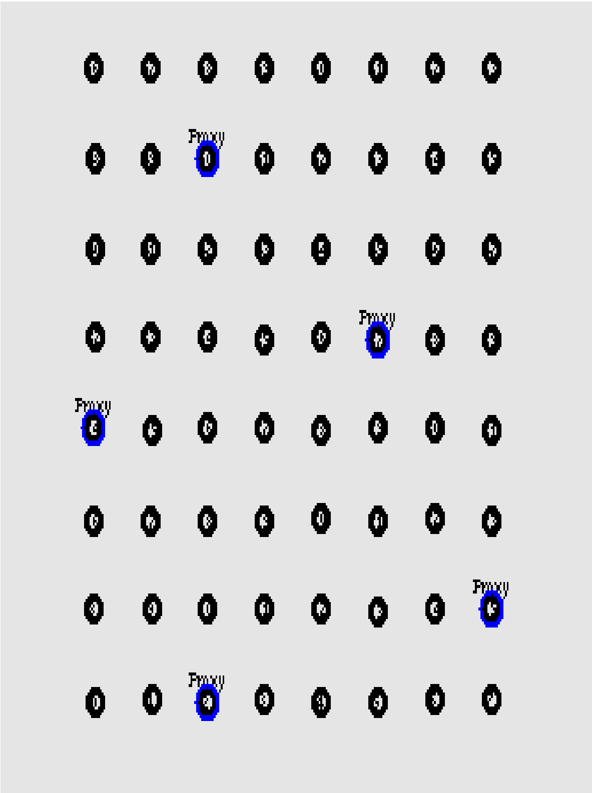

Fig. 1: Simulation Topology (Grid)

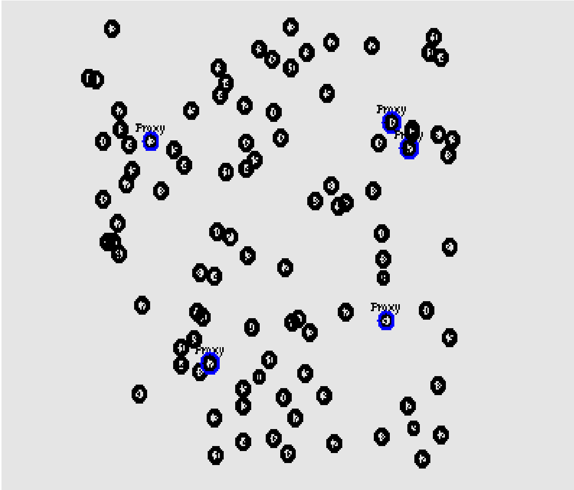

Fig. 2: Simulation Topology (Non-Grid)

Performance Metrics

We evaluate performance of the new protocol mainly according to the following parameters. We compare the PACK [6] protocol with our proposed CCDDPA protocol.

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

Throughput: The throughput is the amount of data that can be sent from the sources to the destination.

Packet Drop: It is the number of packets dropped during the data transmission

Delay: It is the time taken by the packets to reach the destination.

Results & Analysis

The simulation results are presented in the next section.

Case-1 (Grid)

A. Based on Packet Size

In our experiment we vary the packet size as 250,500,750,1000 and 1250 bytes.

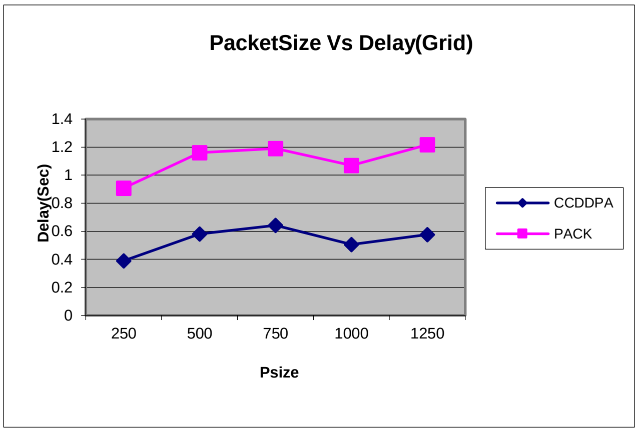

Fig. 1: Packet Size Vs Delay

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Figure 1 shows the delay measured for CCDDPA and PACK when the Packet Size is varied. The Psize is increased from 250 to 1250bytes, as we can see from the figure, the delay of CCDDPA increases from 0.38 to 0.57, the delay of PACK decreases from 0.90 to 1.21. Hence the delay of CCDDPA is 52% of lower when compared to PACK.

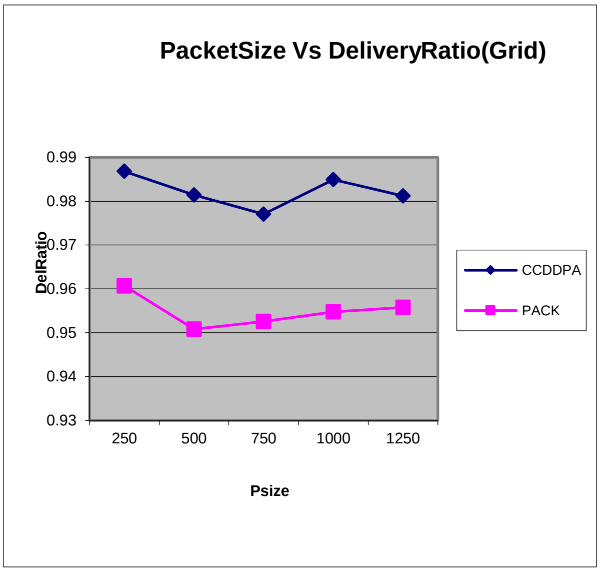

Fig. 2: Packet Size Vs Delivery Ratio

Figure 2 shows the delivery ratio measured for CCDDPA and PACK when the Packet Size is varied. The Psize is increased from 250 to 1250bytes, as we can see from the figure, the delivery ratio of CCDDPA decreases from 0.986 to 0.981, the delivery ratio of PACK decreases from 0.96 to 0.95. Hence the delivery ratio of CCDDPA is 3% of higher when compared to PACK.

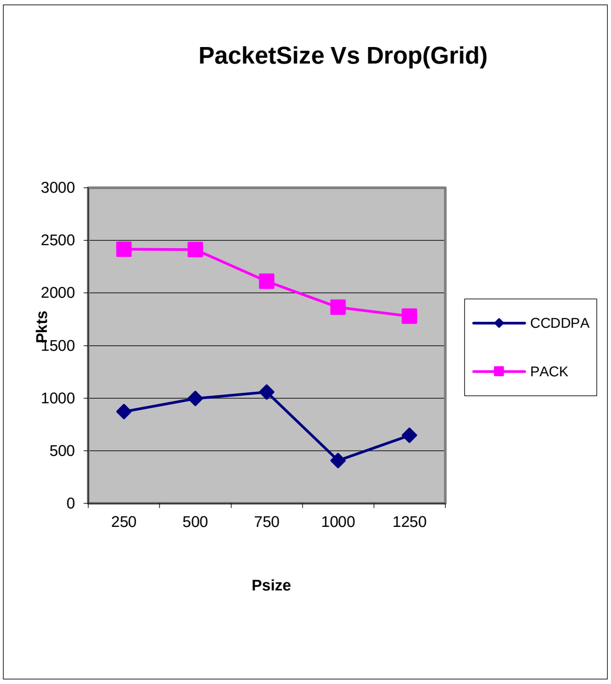

Fig. 3: Packet Size Vs Drop

Figure 3 shows the drop measured for CCDDPA and PACK when the Packet Size is varied. The Psize is increased from 250 to 1250bytes, as we can see from the figure, the drop of CCDDPA decreases from 873 to 647, the drop of PACK decreases from 2416 to 1779. Hence the drop of CCDDPA is 63% of lower when compared to PACK.

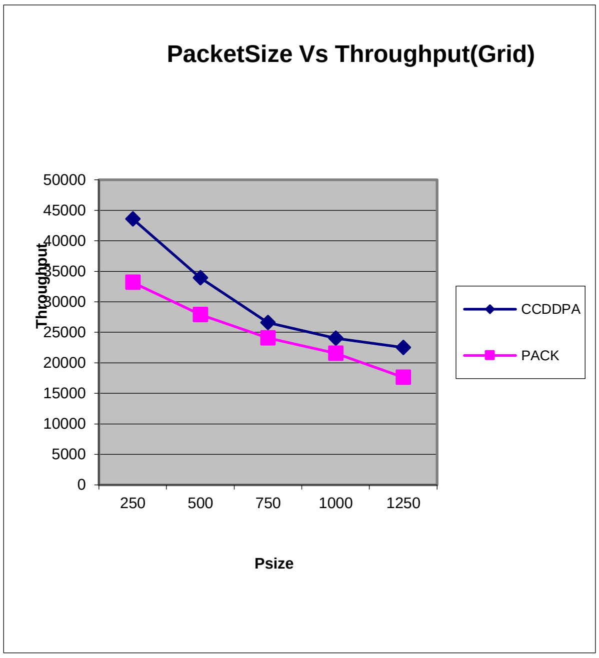

Fig. 4: Packet Size Vs Throughput

Figure 4 shows the throughput measured for CCDDPA and PACK when the Packet Size is varied. The Psize is increased from 250 to 1250bytes, as we can see from the figure, the throughput of CCDDPA decreases from 43588 to 22516 , the throughput of PACK decreases from 33176 to 17619. Hence the throughput of CCDDPA is 17% of higher when compared to PACK.

Case-2 (Non-Linear)

A. Based on Packet Size

In our first experiment we vary the Packet size as 250, 500, 750, 1000 and 1250.

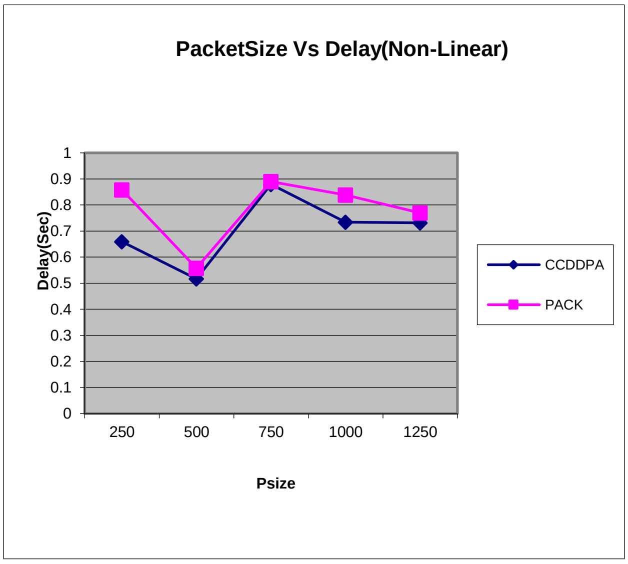

Fig. 5: Packet Size Vs Delay

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Figure 5 shows the delay measured for CCDDPA and PACK when the Packet Size is varied. The Psize is increased from 250 to 1250bytes, as we can see from the figure, the delay of CCDDPA increases from 0.65 to 0.73 , the delay of PACK decreases from 0.85 to 0.77. Hence the delay of CCDDPA is 10% of lower when compared to PACK.

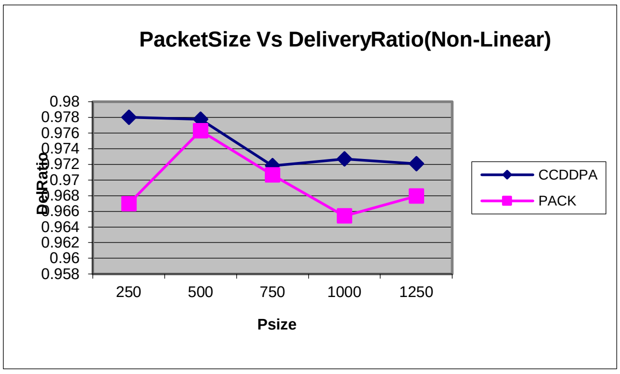

Fig. 6: Packet Size Vs Delivery Ratio

Figure 6 shows the delivery ratio measured for CCDDPA and PACK when the Packet Size is varied. The Psize is increased from 250 to 1250bytes, as we can see from the figure, the delivery ratio of CCDDPA decreases from 0.978 to 0.972, the delivery ratio of PACK increases from 0.966 to 0.967. Hence the delivery ratio of CCDDPA is 1% of higher when compared to PACK.

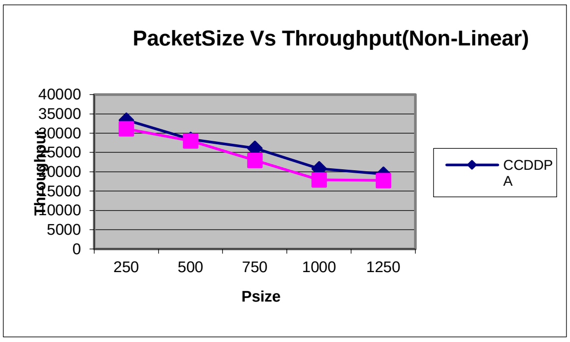

Fig. 7: Packet Size Vs Throughput

Figure 7 shows the throughput measured for CCDDPA and PACK when the Packet Size is varied. The Psize is increased from 250 to 1250bytes, as we can see from the figure, the throughput of CCDDPA decreases from 33417 to 19425, the throughput of PACK decreases from 31121 to 17764. Hence the throughput of CCDDPA is 9% of higher when compared to PACK.

B. Based on Nodes

In our second experiment we vary the number of nodes as 20,40,60,80 and 100.

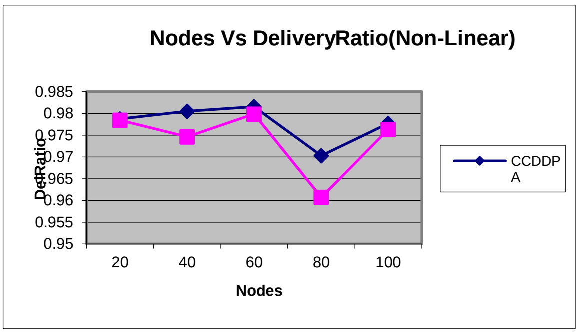

Fig. 8: Nodes Vs Delivery Ratio

Figure 8 shows the delivery ratio measured for CCDDPA and PACK when the nodes are varied. The nodes are increased from 20 to 100, as we can see from the figure, the delivery ratio of CCDDPA decreases from 0.978 to 0.977, the delivery ratio of PACK decreases from 0.978 to 0.976. Hence the delivery ratio of CCDDPA is 1% of higher when compared to PACK.

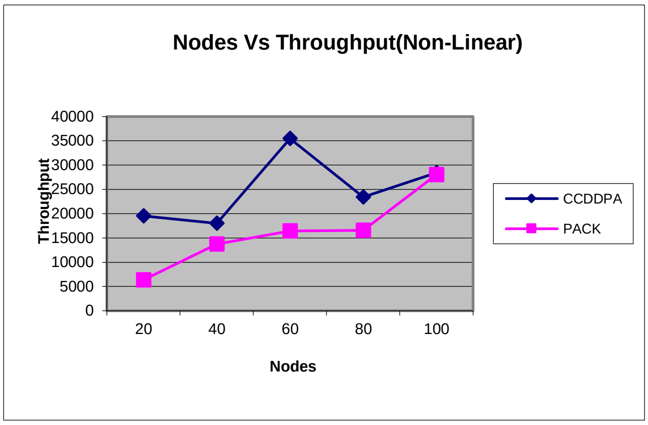

Fig. 9: Nodes Vs Throughput

Figure 9 shows the throughput measured for CCDDPA and PACK when the nodes are varied. The nodes are increased from 20 to 100, as we can see from the figure, the throughput of CCDDPA increases from 19527 to 28420, the throughput of PACK decreases from 6357 to 28043. Hence the throughput of CCDDPA is 35% of higher when compared to PACK.

V. CONCLUSION

In this paper, we have proposed a cross-layer based congestion detection and adaptive proxy acknowledgement scheme for TCP in MANET. In this scheme, the underlying MANET routing protocol selects the proxy nodes along the source and destination based on link availability and link-layer transmission queue length metrics parameters. The local congestion is detected by verifying missing TCP sequence. And the end to end congestion is detected based on the frame transmission efficiency. Thus the proposed scheme performs both intra and inter level congestions, detects both network layer and MAC layer congestions, dynamically changes the proxy based on network conditions.

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