

# A Proposal for Congestion Control in Multi – Hop Mobile Ad Hoc Networks Using Cross – Layer Based TCP Protocol Approach

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## Abstract

A Cross – Layer based approach for the improvement of TCP performance in Multi – Hop Mobile Ad Hoc Networks is proposed in this paper. The proposed congestion triggering mechanism triggers congestion whenever the Channel Occupied Ratio reaches a maximum threshold value and the received signal strength is less than a minimum threshold value. Then, 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.

*Keywords:* Ad Hoc Networks, Congestion Control, MANET, TCP.

## 1. Introduction

### 1.1 Wireless Networks

Wireless Networks are more popular among the companies and all home users world – wide. The users are searching for novel technologies that provide the service to communicate anytime and anywhere using any communication device. Hence, wireless communication plays a vital role in upcoming communication systems. The merits of Wireless Networks over Wired counterparts are flexible mobility management, quicker and cheaper operation, simpler preservation and advanced procedures. Users have started utilizing the Ad Hoc mode of IEEE 802.11 standard, apart from the infrastructure mode, in which multiple wireless hops are used to join two far – away nodes. The nodes can communicate with each other directly without any central coordinator in the ad hoc mode and can convey data to each other in an autonomous manner. This architecture is known as Multi – hop Wireless Ad Hoc Networks or Multi – Hop Wireless Networks. The network topology can change quickly and randomly as the mobile nodes change their positions or because the wireless channel's condition vary. Robust and

adaptive communication protocols that can handle the tasks of Multi – Hop Networks smoothly are required.

### 1.2 TCP Based Flow and Congestion Control

One of the Window – based Flow and Congestion Control protocol is Transmission Control Protocol. It is used to maintain the data transmission by using Sliding Window protocols. The main objective of the scheme is to ensure that the sender must level its transmission rate to satisfy their own and receiver's needs. Therefore, the TCP sender has a variable denoted window to determine the number of packets that it can send into the network prior to receive an acknowledgement (*ACK*) from the receiver. This variable vigorously varies over time to limit the connection's sending rate. The flow control and the congestion control are the two distinct techniques that can regulate the sending rate of a TCP connection. Though, these two mechanisms are similar, in the case that both try to avoid the connection from sending at an increased rate, they have unique purposes. To avoid a TCP sender from overflowing the receiver's buffer, flow control is implemented. In every *ACK* transmitted, the receiver advertises a window limit to the sender. This window is called as Receiver Advertised Window (*rwin*). It alters over time based on both the traffic conditions and the application speed while reading the receiver's buffer [ 1 ], [ 2 ], [ 3]. Congestion control is associated with the traffic inside the network contrary to flow control. The main purpose is to avoid failure inside the network when the network is slower than the traffic source in forwarding the data. In addition to that, TCP sender uses a limiting window called Congestion Window (*cwnd*). By assuming that the sender is not limited by the receiver, *cwnd* denotes the amount of data that the can be sent by the sender before an *ACK* is received. By taking into

account, both flow control and congestion control, the sender has to face two limiting factors for its window size :  $rwin$  and  $cwnd$ . The TCP sender regulates its window to the minimum between  $rwin$  and  $cwnd$  to match with both control schemes. Generally,  $cwnd$  is taken as the limiting factor of a TCP sender because the receiver's buffer is frequently large enough not to limit the sender's transmission rate. To detect the congestion inside the network and rapidly react by accurately slowing down, the congestion control is developed over the years.

### 1.3 TCP for Multi – Hop Wireless Networks

For multi – Hop Wireless Networks, TCP / IP is the best choice because most of the applications like HTTP, FTP, SMTP, and Telnet are suitable for this protocol. Also, the use of TCP / IP makes them interoperable with the internet. Nowadays, with the exclusive features of IEEE 802.11 standards addressed, some alterations are needed in the upper layer protocols used in the Internet. Especially, the trustworthy data delivery provided by the predominant internet Transport Protocol TCP is compromised in such networks. When the network is large, the degradation is higher. Adjusting the TCP to these networks is important in Wireless Networks as the bandwidth is a very limited resource. Due to the inequality between TCP and the MAC protocol, TCP degradation may happen in Multi – Hop networks. Even if the IEEE 802.11 standard has the potential to work on adhoc mode permitting the setup of a network without infrastructure, it is not optimized for networks with large number of hops. This standard denotes RTS / CTS ( Request To Send / Clear To Send ) control frames to confirm that the network transmits with a maximum of three hops are not impacted by the well – known hidden node problem. Contention collisions may take place to degrade the channel quality for more than three hops. The overhead of RTS / CTS combined with the lossy nature of the Wireless channel and mobility can cause a TCP connection to have a poor performance. This is due to the fact that TCP is designed for Wired Networks whereas this condition does not exist in Wireless Networks. We review the key challenges of TCP over Multi – Hop Wireless Networks in the next section.

### 1.4 Challenges of TCP in Multi – Hop Wireless Networks

Wireless Networks may have loss due to the lossy nature of its medium and link interruption when the nodes move, unlike, the Wired environments where a dropped packet always belongs to congestion [ 1 ]. In a conventional TCP, this may be a problem since it minimizes its

transmission rate, when a drop is seen irrespective of the loss nature. There is a mechanism at the sender which can distinguish between the original causes of a packet drop so that the sender is able to react to each of the factors that is causing the losses. The past works on this problem have severe limitations such as high processing overhead and entire dependence on network explicit signaling.

#### 1.4.1 High MAC Contention and Collisions

TCP depends on the acknowledgment packets from the receiver to the sender for establishing a bidirectional flow of data and ACKs, so as to ensure reliability [ 1 ]. It is an expensive technique in Multi – Hop Wireless Networks, because of the MAC overhead associated with an ACK transmission, in spite of the smaller ACK size as compared to the data packet. This is because of the random back off procedure that pursues any failed transmission attempt and the RTS / CTS control frames exchanged prior to any packet transmission. So far, inside the network, data and ACK flowing in different directions are highly vulnerable to collide. Under suitable conditions, on optimal bandwidth utilization, TCP must avoid sending redundant ACKs. To solve this issue, earlier techniques have proposed to minimize the number of ACKs entered into the network in a fixed manner. Under certain conditions, it is not possible because the network condition changes and redundant ACKs may be critical to the end – to – end performance.

#### 1.4.2 Low Energy Resources

Multi – Hop Wireless Networks consists of mobile nodes that are most probably powered by battery [ 1 ]. The protocols involved must have a well – saturated compromise between performance and energy utilization. The autonomous retransmissions due to the lack of interaction between TCP and IEEE 802.11 standard are the primary source of energy wastage in a TCP implementation over Multi – Hop Networks. Various energy saving mechanisms for link and network layers are arriving, which have not been analyzed on the Transport Layer.

### 1.5 Problem Identification and Solution

Daniel Scofield et al. [ 5 ] have proposed HxH, a hop – by – hop transport protocol that utilizes credit – based congestion control and reverse ACKs to work out the crisis with TCP. Congestion control algorithms do not use rate – based and pricing – based feedback. This is the major limitations of the proposed approach. The proposed technique is not improved with fast variation of the

congestion window in [ 6 ]. A set of techniques in TCP using a Cross – Layer approach is used to address the challenges are proposed. It also provides better interaction to effectively improve the end – to – end performance among TCP and IEEE 802.11 protocols. The paper is arranged as follows : Section II contains related work, Section III contains the proposed solution, Section IV contains conclusion.

## 2. Related Works

Jin Ye et al. [ 4 ] proposed an improved TCP with Cross Layer Congestion notification over Wired – Wireless hybrid networks. Being different from some of the existing TCP protocols, it takes account into the congestion of channel competition in the MAC layer. The most important concept is that, this model is built on the ECN ( Explicit Congestion Notification ) scheme, which have been proven to be effective on congestion control and widely supported in many situations. Hence, this model has good feasibility and scalability. In future, the work will be based on other congestion metrics in MAC layer and how explicitly to notify TCP sender, by which the proposed TCP model can be applied into other congestion control schemes.

Daniel Scofield et al. [ 5 ] designed HxH, a hop – by – hop transport protocol that uses credit – based congestion control and reverse ACKs to solve the problem with TCP. The problems include contention, interference, the hidden and exposed terminal problems, shared queues, half – duplex links, and route changes due to mobility. Credit – based congestion control reacts quickly whenever the network conditions change, and can improve fairness among flows competing on the same path. The drawback of the proposed approach is that congestion control algorithms that use rate – based and pricing – based feedback are not used.

Myungjin Lee et al. [ 6 ] proposed a Path Recovery Notification ( TCP – PRN ) mechanism to prevent performance degradation during a handoff. Even though Freeze – TCP achieves a performance increase during handoff, detecting accurate handoff time and the vulnerability of high variation in the Round Trip Time ( RTT ) become obstacles for deploying Freeze – TCP in a real environment. The proposed protocol, TCP – PRN, quickly recovers lost packets by restoring the congestion window, preventing the congestion window to decrease, or immediately initiating the slow start algorithm. The proposed mechanism is not enhanced with fast adaptation of the congestion window.

Jingyuan Wang et al. [ 7 ] demonstrated the performance of a new TCP congestion control algorithm in different network conditions. The analysis shows that the new TCP congestion control algorithm, namely, TCP – FIT, out – performs the existing algorithms such as Bic / Cubic, Reno, Veno, Westwood, Compound TCP, FastTCP, etc., under challenging network conditions, while maintaining good inter and intra protocol fairness.

Shengming Jiang et al. [ 8 ] proposed a semi – TCP using a hop – by – hop congestion control. Due to using hop – by – hop congestion control, the congestion control efficiency of semi – TCP will not rely on the availability of end – to – end connectivity, which makes semi – TCP more suitable than TCP for challenged networks. Besides performance improvement, semi – TCP may further reduce the overall system complexity by removing redundant congestion control and using simple congestion control rather than TCP congestion window. The issues of semi – TCP such as its impact to end – to – end behavior of transport layer, effect on high layer networking function and its inter – operability with the original TCP is not studied in the current approach.

Hongqiang Zhai et al. [ 9 ] proposed a new Wireless Congestion Control Protocol ( WCCP ) based on the novel use of channel busyness ratio along with characterization of network utilization and congestion status. In this protocol, each forwarding node along a traffic flow exercises the inter – node and intra – node fair resource allocation and determines the MAC layer feedback accordingly. The proposed scheme outperforms the traditional TCP in terms of channel utilization, end – to – end delay, fairness and solves the starvation problem of TCP flows.

Ruy de Oliveira et al. [ 10 ] proposed a smart TCP acknowledgement approach for Multi – hop Wireless Networks. The crucial challenge faced by TCP to operate smoothly with IEEE 802.11 Wireless MAC protocol renders TCP acknowledgement transmission quite costly. This paper evaluated a dynamic adaptive strategy for reducing ACK induced overhead and consequent collisions. Their approach resembles sender side’s congestion control. The receiver is self – adaptive by delaying more ACKs under non – constrained channels and less otherwise. This improves not only throughput but also power consumption. An adaptive receiver mechanism to switch between DAA and DAAP strategies in scenarios susceptible to high bit error rate is not considered in the present approach.

Xuyang Wang et al. [ 11 ] proposed a Cross – Layer hop – by – hop congestion control scheme designed to improve TCP performance in Multi – Hop Wireless Networks by solving the aforementioned false routing disruption problems and providing the on – demand routing protocol with congestion control capability. The scheme is based on a hop – by – hop approach that enables the on – demand routing protocol to be congestion – aware and actively participate in congestion control. That is, once a node infers the cause of a packet loss, the response to the loss is coordinated across the MAC, routing, and transport protocols in order to achieve higher overall system performance.

Yao-Nan Lien et al. [ 12 ] proposed the Hop – by – Hop TCP protocol for sensor networks aiming to accelerate reliable packet delivery. Hop – by – Hop TCP makes every intermediate node in the transmission path execute a light – weight local TCP to guarantee the transmission of each packet on each link. It takes less time in average to deliver a packet in an error – prone environment. In the future, they will use One – Hop TCP to serve all TCP and even UDP so that the number of packets transmitted on the air can be greatly reduced.

### 3. Proposed Solution

#### 3.1 Overview

A Cross – Layer based approach for improving TCP performance in Multi – Hop Mobile Ad Hoc Networks is proposed in this paper. 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 proposed. The resource allocation scheme is incorporated with Additive Increase and Multiplicative Decrease ( AIMD ) law and it assures fair resource allocation among flows.

#### 3. 2 Computation of Metrics

##### 3.2.1Channel Occupied Ratio ( **COR** ) Evaluation

In the standard IEEE 802.11 architecture, the Channel Occupied Ratio ( **COR** ) can be easily estimated. Since IEEE 802.11 is a CSMA – based MAC protocol, works on the physical and virtual carrier sensing mechanisms. The wireless communication channel is taken as busy or

engaged when it is sending or receiving data. To find whether the channel is busy or idle, the IEEE 802.11 has various functions. Busy channel can be denoted by its Network Allocation Vector ( NAV ). Channel Occupied Ratio ( **COR** ) is measured as the top metric for end – to – end congestion control mechanisms since it provides the early signal of network congestion. The Channel Occupied Ratio ( **COR** ) is computed as the ratio of total lengths of busy periods to the total time during a time interval  $t_n$ , [ 9 ]. Let  $T$  denote the total transmission time and  $T_B$  denote the total length of busy periods.

The **COR** can be given as,

$$COR = T_n / T \quad ( 1 )$$

Taking into account channel utilization factor, we define a threshold value  $Th_{COR}$ . This is selected in a such a way that,

$$COR \approx U_c (COR \leq Th_{COR}) \quad ( 2 )$$

Where,  $U_c$  denotes the channel utilization factor and it is the measure of ratio of channel busyness time for successful transmissions to the total time  $T$ .

##### 3.2.2 Received Signal Strength Estimation

The received signal strength (  $R_s$  ) is evaluated as [ 11 ],

$$R_s = (P_{res} * d)^{-\beta} \quad ( 3 )$$

Where,  $P_{res}$  is the reception power at a reference distance and it is usually one meter.  $\beta$  is the distance – power gradient value that differs with the surrounding terrain conditions.

##### 3.2.3 Available Bandwidth Assessment

Consider,  $BW_T$  as the total bandwidth and  $BW_A$  as available bandwidth. Then in view of  $Th_{COR}$  and **COR**, the available bandwidth for a node is calculated as,

$$BW_A = \begin{cases} BW_T (Th_{COR} - COR) Data / Avg T_s, when (COR < Th_{COR}) \\ 0, when (COR \geq Th_{COR}) \end{cases} \quad ( 4 )$$



In the above equation, *Data* represents the average payload size and  $AvgT_s$  denotes the average successful transmission time at the MAC layer.

### 3.2.4 Delay Calculation

The time interval between data transmission and reception is referred to as the delay of link ( $L_i$ ). Consider  $T_D$  as the time of data transmission and  $T_R$  as the time of data reception, then the delay incurred in link  $L_i$  can be given as,

$$Delay(L_i) = T_D - T_R \quad (5)$$

### 3.3 Congestion Triggering Mechanisms

The Wireless Network can bear various types of data losses that happen due to link failures, security attacks etc. The proposed mechanism differentiates packet loss rooted by congestion by considering the two parameters like received signal strength ( $R_s$ ) and Channel Occupied Ratio (COR). COR is a perfect metric for detecting congestion in the network, as discussed earlier. To monitor the network so as to fix the congestion in the network, the proposed congestion triggering scheme is used. Every node calculates ( $R_s$ ) and COR using the equations given in Eq. (3) and Eq. (1) respectively. Our congestion triggering scheme is incorporated in each node of the network to monitor the network. Consider  $Th_{COR}$  as the threshold value of COR and  $\min ThR_s$  as the threshold of minimum received signal strength value. Assume that every node periodically calculates COR and ( $R_s$ ). The computed values are then compared with  $Th_{COR}$  and  $\min ThR_s$  respectively. When the calculated COR reaches  $Th_{COR}$  or the received signal strength goes below  $\min ThR_s$ , it triggers congestion notification message. The created congestion notification message is transmitted to the source through a flag termed as **Con – notify flag**. While receiving **Con – notify flag**, the source initiates rate control mechanism.

The congestion triggering scheme is described in the following algorithm,

Let  $Th_{COR}$  be the maximum threshold value of COR

Consider  $\min ThR_s$  as the threshold of minimum received signal strength value.

Assume ( $n_1, n_2, \dots, n_n$ ), N as the set of mobile nodes in the network

Node  $n_i$  calculates COR using Eq. (1)

Node  $n_i$  calculates ( $R_s$ ) using Eq. (3)

COR and ( $R_s$ ) values are then compared with their threshold values

If ( $COR \geq Th_{COR}$  &  $R_s < \min ThR_s$ ) then

Data loss is triggered by congestion

$n_i$  transmits **Con – notify flag** to the source node

End if

#### 3.3.1 Congestion Control Technique

By considering three metrics such as bandwidth, delay and COR, the end – to – end congestion control technique is operated. This is operated at every node. The available bandwidth, delay of its link and COR are estimated by every node using their respective methods given in Eq. (4), Eq. (5), and Eq. (1). These estimations are taken along with the MAC header through the intermediate nodes to the destination, while transmitting data from the source to the destination. The link and physical layers headers encapsulates the cumulative bandwidth, delay and COR values of links that connect the source – destination. It regulates its traffic sending rate when the source node receives this acknowledgement packet.

Consider S and D as source and destination nodes respectively. When the source desires to transmit data to the destination, it forwards the first data packet to an intermediate node (say  $I_1$ ). When a packet is received, the data link layer of node  $I_1$  measures the bandwidth, delay for its link, and channel busyness ratio. Then, it includes this measured information with the MAC header and then forwards it to the next intermediate node  $I_2$ . The receiving node  $I_2$  will also do the same measurements for its link and determines the minimum value of delay, bandwidth and COR measurements. It then updates this bandwidth information in the MAC header. The cumulative delay of both the links is calculated and updated by  $I_2$ . When the TCP packet finally reaches the destination node D, the MAC header contains the cumulative bandwidth, delay, and COR information of all the links along the path. The destination node D sends this information along with the acknowledgement packet to the source node S, encapsulated by link and physical

layer headers. When the source node S receives this acknowledgement packet, it will adjust its traffic sending rate using the calculated bandwidth, delay, and COR information. The proposed congestion control technique is illustrated in Figure – 1.

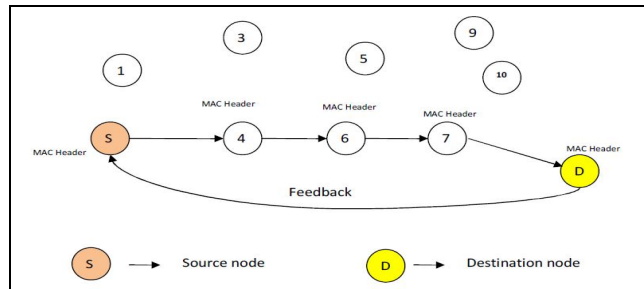


Figure – 1: Congestion Control Technique

### 3.4 Fair Resource Allocation Scheme

Using the equation given in Eq. ( 4 ), every node in the network can easily measure the available bandwidth of its neighbor by considering **COR**. In the proposed technique, **COR** is calculated at periodic intervals defined by average time interval of **COR** ( $AvgT_{COR}$ ).

In this context, we relate the available bandwidth of every node as the channel resource ( **CR** ) proportionally to its present traffic load ( $L_T$ ). Thus, the linear relationship can be expressed as follows:

$$CR = ((Th_{COR} - COR) / COR) \times L_T \quad (6)$$

In the above equation,  $L_T$  denotes the current traffic load, which is the sum of both incoming and outgoing traffics.

In order to achieve efficiency in data transmission and fairness in resource allocation, the proposed resource allocation scheme utilizes an Additive – Increase Multiplicative Decrease ( AIMD ) policy along with **COR** and **CR**.

In general, when  $CR > 0$ , flows increase data sending rate and on the other hand, when  $CR < 0$ , flows decrease their data sending rate. By increasing or decreasing the data sending rate, flows increase or decrease the throughput of network respectively.

As discussed earlier, since the channel is utilized by both incoming and outgoing traffic, the number of flows in the network is estimated to accomplish fairness in resource

allocation. In this scheme, a flow that originates or terminates at a node is considered as one flow and a flow that is processed at a node is considered as two flows. Because the flows that are processed at node consumes twice the resources consumed at an originating and terminating flows.

Consider  $ds_r$  as the data sending rate. Then, number of flows ( $nF$ ) can be calculated as,

$$nF = \sum_{k=1}^n 1 / ds_{rk} AvgT_{COR} \quad (7)$$

Where,  $k$  is the number of packets monitored by node  $i$  in  $AvgT_{COR}$ .  $nF$  is the summation of both received and transmitted packets.

When  $CR \geq 0$ , the increasing level of data sending rate for flow  $F_i$  and per packet acknowledgment ( $pACK$ ) are,

$$F_i = (CR / AvgT_{COR} * nF) \quad (8)$$

$$pACK = Fi / (ds_{rk} * AvgT_{COR}) \quad (9)$$

When  $CR < 0$ , the proposed technique reduces the flow's throughput related to its present throughput. We can observe in the equation ( below ) that per packet acknowledgement  $pACK$  is inversely proportional to the expected number of packets monitored by node  $n_i$  in  $AvgT_{COR}$ .

As a result,

$$pACK = \eta (ds_{rk} / (ds_{rk} * AvgT_{COR})) = \eta / AvgT_{COR} \quad (10)$$

Here,  $\eta$  is a constant and then,

$$\sum_{k=1}^n pACK = CR / AvgT_{COR} \quad (11)$$

$$\eta = CR / \eta \quad (12)$$

To accomplish fair channel resource, **COR** should be close to  $Th_{COR}$ , but it should never exceed  $Th_{COR}$ . To incorporate fair resource allocation with AIMD law, we define the two parameters namely  $CR^+$  and  $CR^-$  to

represent the increased and decreased traffic respectively. Similarly,  $pACK^+$  and  $pACK^-$  represent the positive and negative feedback respectively.  $pACK^+$  is measured by the increase law and  $pACK^-$  is calculated by decrease law. Therefore,

$$CR = CR^+ + CR^- \quad (13)$$

$$pACK = pACK^+ + pACK^- \quad (14)$$

*if* ( $0 < CR < \delta(L_T + CR)$ )

*then*  $CR^+ = \delta(L_T + CR)$

*if* ( $0 > CR > -\delta(L_T + CR)$ )

*then*  $CR^- = -\delta(L_T + CR)$

Thus, the incorporation of AIMD ( Additive Increase and Multiplicative Decrease ) law with our proposed scheme achieves a fair resource allocation scheme.

## 4. CONCLUSION

A Cross – Layer based approach for improving TCP performance in Multi – hop Mobile Adhoc Networks ( MANETs ) is proposed in this paper. 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.

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