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An Implementation of Cross Layer Approach to Improve TCP Performance in MANET

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Abstract
Transmission Control Protocol (TCP) is the dominant transport protocol in the Internet and supports many of the most popular Internet applications, such as the World Wide Web (WWW), file transfer and e-mail. TCP is designed to perform well in traditional wired networks with the assumptions that packet losses are mainly due to network congestion and random bit error rate (BER) is eligible. However, networks with wireless links suffer from significant packet losses due to random bit errors and handoffs. TCP optimization in mobile ad hoc networks is a challenging issue because of some unique characteristics of MANETs. Some of the main reasons behind TCP's performance degradation in these networks are lossy channels, frequent route failures, network partitions because of high mobility of nodes.

In this paper, a cross-layer approach to improving TCP performance in MANET is proposed. Medium access control (MAC) layer is responsible to decide the modulation scheme to be used at the physical layer depending on the signal strength and queue length of the receiver. This is a rate adaptive technique which changes the data rate according to available channel condition. An omnetpp-based simulation analysis of the proposed protocol which provides better TCP performance with minimum congestion than the existing wireless TCP protocols is described. The effects of mobility of nodes, number of connections on TCP parameters such as throughput, packet delivery ratio and round trip time are investigated.

***Keywords**:* Adaptive modulation, TCP new Reno, Cross layer approach, AODV, DSR.

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1. Introduction
TCP has been the most popular transport control protocol used in the networking environments including the Internet. TCP has evolved over a period of time and offers various versions. TCP is used to provide end-to-end reliable packet transfer in connection-oriented wired networks. TCP also provides congestion control mechanisms to handle traffic in highly congested networks. When a packet loss is detected, TCP's congestion control mechanism always assumes that it is due to traffic congestion in the network. Therefore it starts its recovery mechanisms. This is true for a wired network environment. However, this may not be always true in wireless networks.

The channel properties of a wireless network are quite different from wired networks. Wireless channels are noisy. Wireless networks change rapidly due to the mobility of its nodes or the interferences. Packet loss occurs more often in the wireless network than wired networks due to these reasons. Therefore, we cannot always assume that packet loss occurs due to congestion only.

TCP cannot distinguish whether packet loss occurs due to congestion in the network layer or due to noise in the channel in the physical layer. So, packet loss always indicates TCP to think that there is congestion in the network and it starts congestion control. However, packet loss in the physical layer due to noise in a wireless network cannot be corrected using congestion control mechanisms. This affects performance of TCP greatly.

In addition to the above reason, TCP also assumes that the nodes and the links between them in the network are stable. Also, it assumes that the link capacities never change. Using these assumptions, TCP can correctly measure the round trip time. Unlike in wired networks, none of these assumptions is true in wireless ad-hoc mobile networks.

In 1997, the IEEE adopted first wireless local area network standard named IEEE 802.11. This provided data rate up to 2Mbps. Since then, several task groups have extended IEEE 802.11 standard. The task group IEEE 802.11b produced a standard for Wireless Local Area Network (WLAN) operations in 2.4 GHz band with data rate up to 11Mbps. The IEEE 802.11a task group created a standard for WLAN operation in the 5GHz band with data rate up to 54 Mbps . In this paper we focus on IEEE 802.11b multi-rate standard and its use for our study. The above standards do not outline an algorithm for the sending rate at Link Layer. It is the freedom and the responsibility of the organizations to implement rate adaptation mechanisms in their network drivers. As mentioned in various publications, a rate adaptation at MAC layer can significantly improve the throughput. Therefore, to get the maximum TCP performance in wireless mobile networks, we research the MAC layer protocol to minimize the packet losses by means of using Adaptive Rate Modulation algorithm.

2. Related Work

2.1 MANET

A mobile ad-hoc network (MANET) is a collection of nodes, which have the possibility to connect on a wireless medium and form an arbitrary and dynamic network with wireless links. That means that links between the nodes can change during time, new nodes can join the network, and other nodes can leave it. A MANET is expected to be of larger size than the radio range of the wireless antennas, because of this fact it could be necessary to route the traffic through a multi-hop path to give two nodes the ability to communicate. There are neither fixed routers nor fixed locations for the routers as in cellular networks - also known as infrastructure networks.

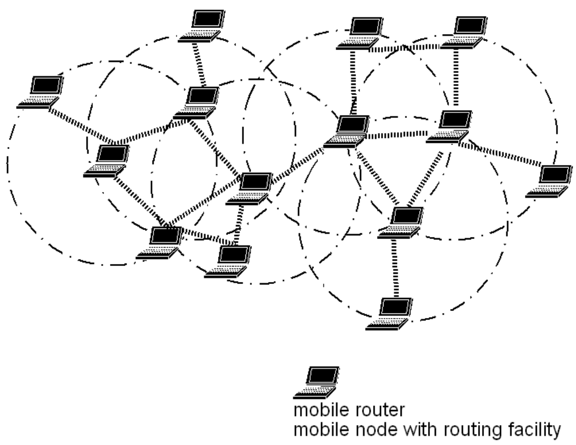

Figure 1: Mobile Ad-hoc Network

2.2 MANET ROUTING PROTOCOL(NETWORK LAYER)

Various MANET routing protocols on Network Layer which have been considered in this paper as follows:

2.2.1 DYNAMIC SOURCE ROUTING PROTOCOL

The Dynamic Source Routing Protocol (DSR) is a reactive routing protocol . By the means of this protocol each node can discover dynamically a source route to any destination in the network over multiple hops. It is trivially loop free owing to the fact that a complete, ordered list of the nodes through which the packet must pass is included in each packet header. The two main mechanisms of DSR are *Route Discovery* and *Route Maintenance*, which work together to discover and maintain source routes to arbitrary destinations in the network.

2.2.2 DESTINATION SEQUENCED DISTANCE VECTOR PROTOCOL

The Destination Sequenced Distance Vector Protocol (DSDV) is a proactive, distance vector protocol which uses the Bellmann-Ford algorithm. Compared to RIP one more attribute is added to the routing table. The sequence number as new attribute guarantees loop-freedom. It makes it possible for the mobile to distinguish stale routes from new ones and that is how it prevents loops. DSDV can only handle bidirectional links.

2.2.3 AD-HOC ON DEMAND DISTANCE VECTOR ROUTING PROTOCOL

The Ad-hoc On demand Distance Vector routing protocol (AODV) joins mechanisms of DSR and DSDV. The periodic beacons, hop-by-hop routing and sequence numbers (guarantee of loop-freedom) of DSDV and the pure on-demand mechanism of Route Discovery and Route Maintenance from DSR are combined.

2.3 MANET ROUTING PROTOCOL(TRANSPORT LAYER)

Various MANET routing protocols on Transport Layer which have been considered in this paper as follows*:*

2.3.1 TCP Reno

TCP Reno is the scheme that has been extensively used in Internet [6]. TCP Reno operates in four phases: Slow Start, Congestion Avoidance, Fast Retransmit and Fast Recovery. Slow start phase is initiated when the transmission begins or when a loss is identified. Congestion avoidance phase is initiated when the slow start phase ends or after identifying any loss by the copy acknowledgements and stops if the window size is the upper limit of packets the target receiver can receive. The Fast Retransmission and Fast Recovery begin mutually whenever the third duplicate acknowledgement is received.

2.3.2 TCP New Reno

TCP New Reno overcame the disadvantage of TCP Reno because it was not able to recover more packet losses. Time out affects the throughput because connection has to wait for time out to occur and cannot send data during that period of time. In TCP Reno, after receiving partial ACKs, it comes out of fast recovery and no option left but time out to occur. TCP New Reno introduced a new concept known as fast retransmission phase beginning with the detection of packet losses and ending when the receiver acknowledges that all data has been received at the end of the phase. As the acknowledgement arrives in the transmitter side in a random manner, TCP New Reno sometimes may direct unnecessary retransmissions. The major advantage is that it avoids unnecessary timeouts of the transmitter thereby recovering from multiple packet losses which is very important for wireless ad hoc networks.

3. Proposed Model

3.1 Cross Layer Approach to Improve TCP Performance over MANET

Extensive study on the mobile network shows that the single modulation scheme used throughout a network will not provide a good throughput, as the nodes in the network are mobile in nature. So it becomes necessary to adapt to a modulation scheme that provides high throughput at that moment. The Internodes (AP or router) separation plays an important role in providing a good throughput by using different modulation schemes. In a real time network it is not possible to determine the internodes separation so the only way is to use the power received or the signal strength. But only the signal strength will not solve the problem in choosing a modulation scheme in a network that has multiple connections, a node also requires a good knowledge about the length of queue of its neighboring node to which it is going to initiate the communication. Physical layer is responsible to decide a modulation scheme depending on a few network parameters, which is to be used in the physical layer. In the proposed protocol all the control messages such as route request, route reply, route error, request to send (RTS), clear to send (CTS) and acknowledgment from Mac layer uses same modulation scheme and only during data transfer i.e. for TCP traffic a node adapts to other modulation techniques. These types of adaptive modulation provide the better throughput as compare to single modulation during data transfer.

The flowchart in Figure 2 given below, describes the responsibility of the Mac layer to decide a modulation scheme that is to be used at the physical layer. As modified CTS packet is used, each node involved in communication has knowledge about the modulation scheme going to be used by its neighboring node. With the help of the power received and Qlen a better modulation scheme is chose at receiver end and that information is transferred via CTS to the sender in order to provide better data rate and to avoid congestion in the network.

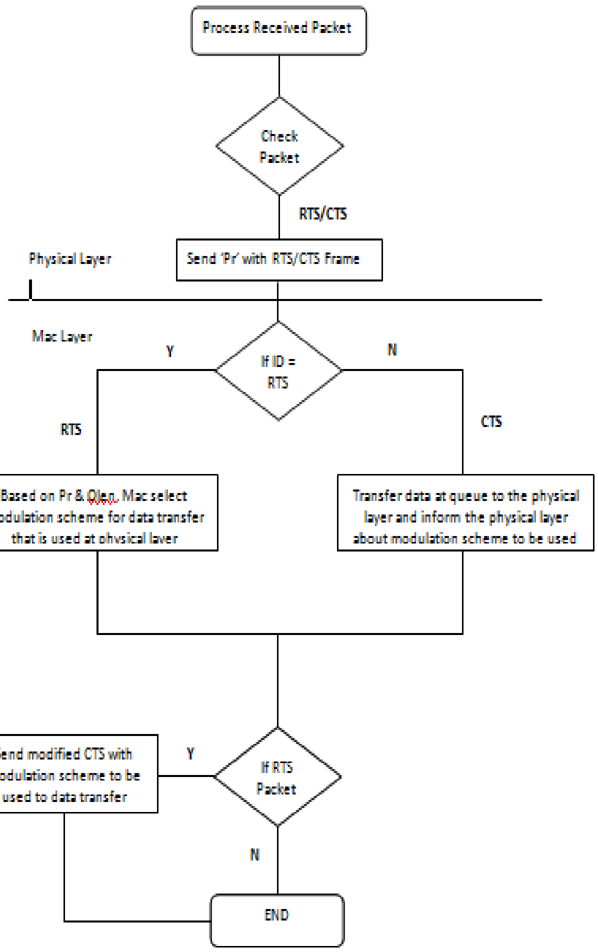

Figure 2: Flowchart for adaptive modulation technique

4. SIMULATION EXPERIMENTS AND RESULTS

This section contains the practical experimental details carried out in this thesis together with results and observations made. The experiments were carried out in OMNETPP network simulator environment. The main focus in this paper is to research on the TCP throughput when using AM at the physical layer. We have performed the comparisons of the throughput using AODV and DSR routing protocols to see the best performance in wireless ad-hoc mobile networks.

4.1 SIMULATION ENVIRONMENT

The OMNETPP simulator environment can be set according to the IEEE 802.11 standard. Using the TCL scripts, various simulation experimental scenarios like different number of nodes, various arrangements of node and different speeds of the nodes have been considered.

The nodes that are used in the experiments are mobile nodes. They move in the experimental space at random speed in random directions. The experiments were carried out with and without Adaptive Modulation implementation to compare the results. Then, the experiments were repeated for Dynamic Source Routing (DSR), Destination Sequenced Distance Vector (DSDV) and Ad hoc On Demand Distance Vector (AODV) routing protocols to measure and compare the results.

Various modulation schemes were used at physical layer such as DBPSK, which provides 1 Mbps data rate, DQPSK, which provides 2 Mbps data rate, QAM 64, which provides 6 Mbps data rate, and QAM 256, which provides 8Mbps data rate. On the network layer, AODV and DSR protocols are used as the routing protocol for ad-hoc wireless networks. TCP New Reno is chosen on the transport layer, as it is the de-facto standard used in most TCP implementations. The maximum size of the TCP congestion windows is set to 25 packets and the TCP packet size is set to 512 bytes. On the application layer, the File Transfer Protocol (FTP) is used to generate traffic over a TCP connection. All simulations were run more than 10 times for 100 seconds and the presented results were computed as the average of these multiple simulations.

Area	1200 x 1200
Number of Node	50
Number of connection	1, 4, 5, 10, 15
Mobility (m/sec)	10, 20, 30, 40, 50
Duration	100s
Application Layer	FTP
Mac Protocol	IEEE 802.11
Routing Protocol	AODV, DSR
Transport Layer	TCP NewReno
Queue	Drop tail/Priority
Queue size	20 Packets
Propagation model	Two-ray ground reflection model
Modulation techniques	DBPSK,DQPSK, QAM 64 and QAM 256

Table 1 : Simulation parameters for Omnetpp-4.5

4.2 SIMULATION RESULTS AND ANALISIS

In this section the effect of mobility and number of connections on TCP parameters such as throughput, packet delivery ratio (PDR) and round trip time (RTT) using adaptive modulation and single modulation techniques was studied. Terminologies used in graph are as follow: -

1. **AM-TCP-NR-AODV: -**Adaptive modulation with TCP newReno and Ad-hoc on demand distance vector routing protocol.
2. **AM-TCP-NR-DSR: -**Adaptive modulation with TCP newReno and distance source routing protocol.
3. **TCP-NR-AODV: -**TCP newReno with Ad-hoc on demand distance vector routing protocol.
4. **TCP-NR-DSR: -**TCP newReno with distance source routing.

In Figure 3, the performance of throughput for TCP as a function of mobility using different on demand routing protocols was analyzed.

It can be seen in all the cases the cross layer TCP with adaptive modulation provides a better throughput than the existing protocols which uses a single modulation technique throughout the simulation period. The proposed protocol at each node adapts a better modulation scheme to transfer as many packets as it can without congestion. It can also be noticed that the throughput in all the plots gradually decays as the mobility of the nodes increases. This is due to fact that when mobility increases the link failure increase and more the link failure more the packet losses. So throughput decreases as packet loss increases. In this way as the mobility increases throughput decreases.

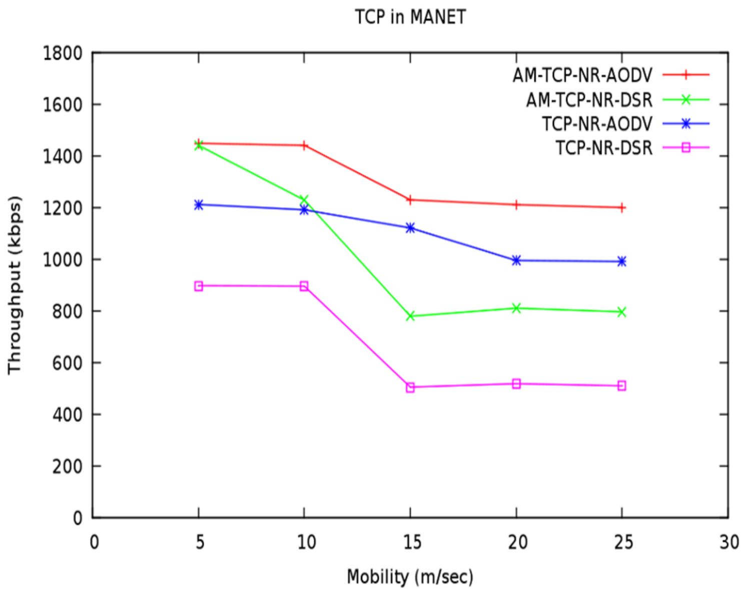

Figure 3 : Mobility V/s Throughput

In Figure 4, provides the packet delivery ratio as a function of mobility for the same setup used in Fig. 3.It can be seen that as the mobility increase packet delivery ratio (PDR) decreases. This is due to fact that link failure increases as the mobility increases and packet losses increases as link failure increases. Hence packet delivery ratio (PDR) decreases.

It can also be observed that the nodes using DSR protocol yields better PDR than AODV protocols but the throughput of DSR protocol is lesser than AODV protocol because DSR uses source routing mechanisms i.e., only the sender knows the complete route to the destination and the header of all the packets contains this route which causes delay in packet delivery and stale routes are troublesome for DSR. This property provides minimum throughput with minimum packet losses.

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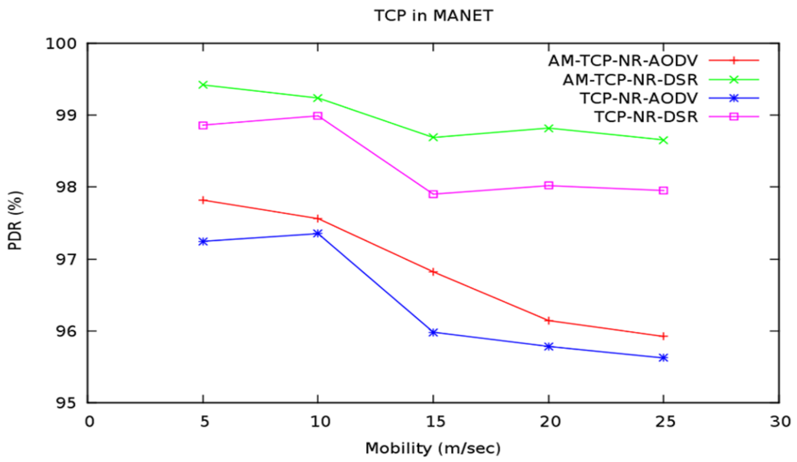

Figure 4: Mobility V/s Packet Delivery Ratio

In Fig. 5, we compare the round trip time for different protocols as a function of mobility. It can be seen that as the mobility increases the round trip time decreases because as we discussed earlier, the proposed protocol tries to transfer the TCP packets as quick as possible by adapting better modulation technique at that instants. This adaptability enhances the throughput and takes much lesser time for round trip of TCP and its acknowledgement packet than the existing protocols with single modulation. DSR protocols yields very minimum RTT.

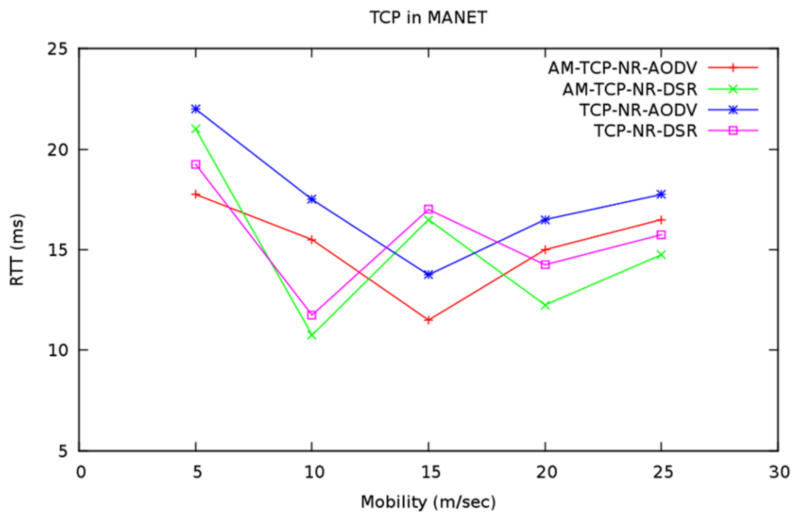

Figure 5. Mobility V/s Round Trip Time

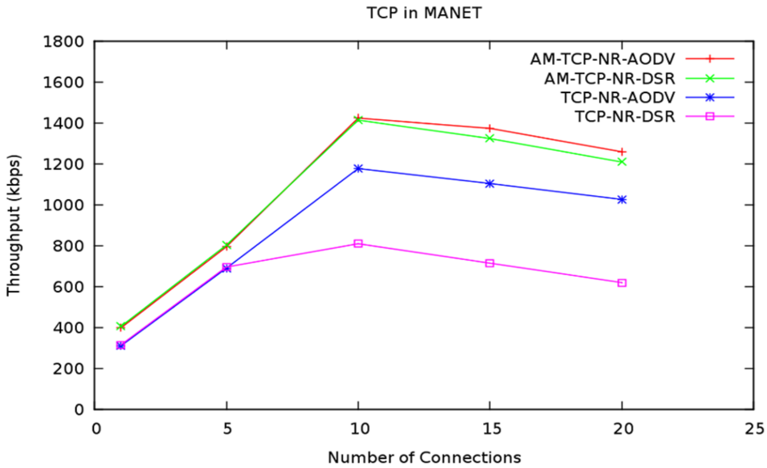

Figure 6: Number of Connections V/s Throughput

In Fig.6, throughput is provided as a function of number of connections. The network yields lowest throughput when only one connection is present. As the number of source nodes increase, it can be noticed that a gradual increase in the throughput in all the plots. The proposed protocol outperforms the existing protocols in all cases where TCP New Reno using DSR provides the highest throughput. But the increase in throughput is not linear when there are 20 source nodes. There are two reasons for this TCP performance degradation. Firstly, a congested network has more number of packet losses due to frequent collision of routing layer and link layer messages. Secondly, the channel reservation scheme of Mac 802.1 1 standard makes most of the nodes idle in a congested network. In cases of network using DSR protocol, routes in the network are more likely to be stale, and stale routes are troublesome for DSR.

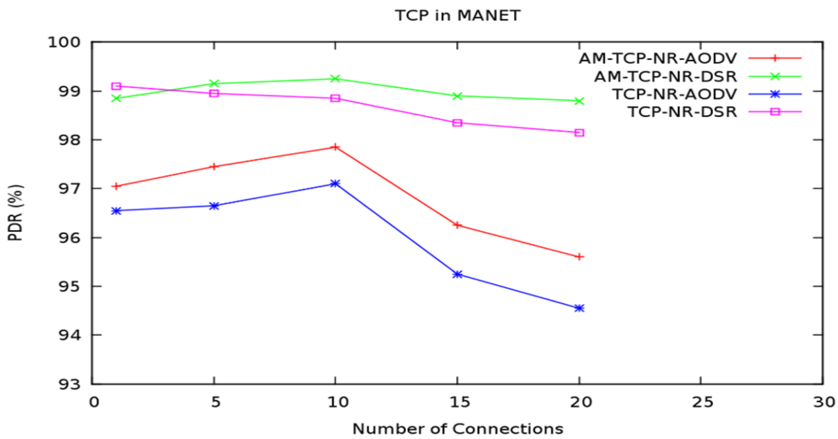

Figure 7: Number of Connections V/s Packet Delivery Ratio Time

In Fig. 7, it is compared that the packet delivery ratio as a function of increasing number of connections for the same setup used in Fig. 6. The performance is almost similar to the plot in Fig. 4. TCP versions with DSR protocol outperform TCP versions with AODV protocol. Since DSR cache more than one route to the destination, so if any link breaks the source can make use of the other. From this result, a higher reliable network can be obtained using TCP with DSR protocol.

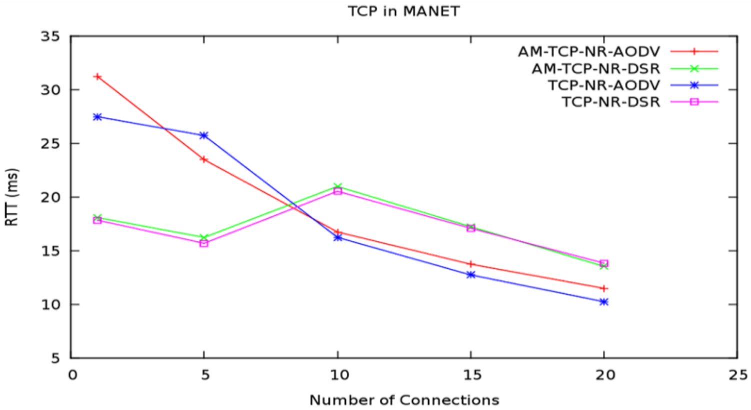

Figure 8: Number of Connections V/s Round Trip Time

In Fig. 8, TCP's round trip time against the varying number of connections is plotted. When only one is used, the source and destination are widely separated in such a way that nodes were more than three hops away. But as the number of source nodes increases TCP sender and receiver were able to reach each other frequently using the different shortest path. So it will take less time to reach at destination hence round trip time (RTT) will be decreased.

5. CONCLUSION & FUTURE WORK

TCP provides its congestion control mechanism to overcome the congestion in the network. This solution works ideally for infrastructure based fixed node network because, the packet loss is mainly due to the congestion in the network. However, in mobile ad-hoc networks many factors are involved which contribute to packet loss in addition to congestion in the physical layer and therefore, using TCP congestion controlling mechanism cannot overcome the packet loss in ad-hoc mobile networks.

The main objective of the cross-layer TCP protocol is to transfer as many packets as the channel can support without any packet loss, which is obtained by using adaptive modulation technique. The adaptive modulation technique used in this protocol adapts different modulation schemes depending on the received signal strength and queue length during data transfer provides better TCP performance by increasing the end-to-end throughput of the entire network and by maintaining the packet delivery ratio approximately above 99.5% in most of the case. Maximum transfer of data packets is obtained using suitable modulation scheme and packet loss is maintained as low as possible by avoiding the congestion in the network as queue length is monitored. From the results obtained it is clear that using adaptive modulation better throughput and packet delivery ratio (PDR) can be obtained than single modulation.

Transmission rate control at the source node has not been considered in this research work, which may cause packet loss at the interface queue. If the transmission rate is controlled then the network almost will have no packet loss, which results in much better packet delivery ratio. In the proposed protocol the number of modulation schemes used cannot exceed 8 as it require another modification in the Mac header.

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