CHAPTER 1

INTRODUCTION

1.1 GENERAL

Wireless technology is one of the fast emerging technologies in the field of networking. The basic design goals are the exchange of information between end users without having any kind of physical connectivity between the devices and also supporting mobility of the nodes. The fast growth in the field of wireless technologies is due to the emergence of devices like laptop, tablet, wireless modems and wireless routers that support wireless LAN which give the user the comfort mobility. As the number of users has increased and mobility was also involved, the design of infrastructure became costly. This was the time when the Ad hoc network emerged.

Ad hoc networks provide mobile communication capability to satisfy a need of a temporary nature and without the existence of any well-defined infrastructure. Each node plays the role of a mobile router informing a path to reach from a source to the destination. The major advantage of ad hoc networks is “On Demand Setup” where all the nodes which want to have connectivity from their own network without the dependence on any infrastructure.

This becomes a major use in places of disaster recovery, Defense applications (army, navy, air force) and Academic institutions, where there needs to be a fast communication set up. There is no need of any infrastructure like routers, as all the nodes can act as routers to establish
connectivity and start the communication process. This inherent characteristic boosts up the use of ad hoc networks.

For all those reasons, mobile ad hoc networking is one of the most innovative and challenging areas of wireless networking and this technology promises to become increasingly present in everybody’s life. There are several senders compete for link bandwidth to transmit data packets to the destination. There is a necessity for each sender to adjust the data rate according to available bandwidth for avoiding network congestion. If not, an excessive amount of packets arriving at a congested network cannot be forwarded that leads to heavy packet drops and increased delay. These dropped packets might already have traveled a long distance in the network and thus consumed considerable resources. Thus network congestion can degrade the overall network performance. If no proper congestion control is performed, this can lead to a congestion collapse of the network, where almost no packet is successfully delivered.

In wired networks, congestion control is implemented at the transport layer and is often designed separately from the functions of other layers. However, such congestion control techniques do not apply directly to ad hoc networks, which involve special challenges like limited wireless bandwidth, power constraints, and route failures due to node mobility and limited buffer size. These challenges should result in high packet loss, loss of energy and increasing delay. However, delays and packet losses need not necessarily be caused by network congestion, but these can be misinterpreted as congestion losses (Tran and Raghavendra 2006, Lochert et al 2007, Yingqun and Giannakis 2008).

This might bring a new research focus on this problem that might be to realize congestion control in Ad hoc networks. This offers many
opportunities for a protocol design to exploit both cross-layer information and sophisticated support by the intermediate hops.

1.2 MOBILE AD HOC NETWORKS

The Mobile Ad hoc Network is a collection of wireless mobile nodes that are capable of communicating with each other without the use of network infrastructure or any centralized administration. Data can be relayed via intermediate nodes. Hence in addition to acting as hosts, each mobile node does the function of routing and relaying messages for other mobile nodes. The nodes are free to move about arbitrarily resulting in a highly dynamic network topology (Perkins et al 2003). The nodes in a MANET may change position at any time causing links to be broken and reestablished. Moreover, bandwidth of wireless channel is also limited. Network hosts of ad hoc networks operate on constrained battery power, which will eventually be exhausted. In the midst of these difficulties with MANETs, are the issues concerning the determination of the rules (protocols) governing the communication between the entities (nodes) in the network.

1.3 APPLICATIONS OF AD HOC NETWORKS

Applications for MANETs are wide ranging and have use in many critical situations: An ideal application is for search and rescue operations. Such scenarios are characterized by the lack of installed communications infrastructure. Rescuers must be able to communicate through their communications equipment which is already carrying, which makes job easier.

A commercial application for MANETs includes ubiquitous computing. By allowing computers to forward data for others, data networks may be extended far beyond the usual reach of installed infrastructure.
Networks may be made more widely available and easier to use. Another application of MANET is sensor networks. This technology is a network composed of a very large number of small sensors, which can be used to measure different parameters like temperature, barometric pressure, humidity, flooding etc., when deployed in an area and communicate information to a central node through the network.

The benefits of ad hoc networks appeal to applications like conferences, meetings, disaster relief, rescue missions, and battlefield operation. Such scenarios typically lack a central administration or wired infrastructure which make use of ad hoc networks. Some of the application areas are listed in Table 1.1.

<table>
<thead>
<tr>
<th>Application Area</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tactical networks</td>
<td>Military communication and operations, Automated Battlefields.</td>
</tr>
<tr>
<td>Sensor networks</td>
<td>Collection of embedded sensor devices used to collect real-time data to automate everyday functions. Data highly correlated in time and space, e.g., remote sensors for weather, earth activities; sensors for manufacturing equipment. Can have between 1000–100,000 nodes, each node collecting sample data, and then forwarding data to centralized host for processing using low homogeneous rates.</td>
</tr>
<tr>
<td>Emergency services</td>
<td>Search-and-rescue operations as well as disaster recovery; e.g., early retrieval and transmission of patient data (record, status, diagnosis) from/to the hospital, replacement of a fixed infrastructure in case of earthquakes, hurricanes, fire, etc.</td>
</tr>
<tr>
<td>Commercial</td>
<td>Transmission of news, road conditions, weather, music local ad hoc network with nearby vehicles for road/accident guidance.</td>
</tr>
<tr>
<td>Home and enterprise</td>
<td>Home/office wireless networking (WLAN), e.g., shared white board networking application; use PDA to print anywhere, Personal Area Network (PAN).</td>
</tr>
<tr>
<td>Educational</td>
<td>Set up virtual classrooms or conference rooms applications Set up ad hoc communication during conferences, meetings, or lectures.</td>
</tr>
<tr>
<td>Entertainment</td>
<td>Multiuse games, Robotic pets.</td>
</tr>
</tbody>
</table>
1.4 CHALLENGES IN MOBILE AD HOC NETWORKS

In mobile ad hoc networks, nodes act as both routers and terminals. Each node in this network may join, or leave at any time. The one of the important issue in this network is congestion (Chlamtã et al 2003). This thesis focuses mainly on congestion issues in ad hoc networks. In this section, some of the other issues in ad hoc networks are described:

**Autonomous and infrastructure-less:** A MANET is a distributed wireless network without any fixed infrastructure. Network management has to be distributed across different nodes, which brings added difficulty in fault detection and management.

**Multi-hop routing:** No default router is available; every node acts as a router and forwards each other’s packets to enable information sharing between mobile hosts.

**Dynamically changing network topologies:** In mobile ad hoc networks, because nodes can move arbitrarily, the network topology, which is typically multi-hop, can change frequently and unpredictably, resulting in route changes, frequent network partitions, and possibly packet losses.

**Variation in link and node capabilities:** Each node may be equipped with one or more radio interfaces that have varying transmission/receiving capabilities and operate across different frequency bands. This heterogeneity in node radio capabilities can result in possible asymmetric links. Designing network protocols and algorithms for this heterogeneous network can be complex, requiring dynamic adaptation to the changing conditions (channel conditions, traffic load/distribution variations, congestion, etc.)
**Power awareness:** Since the nodes in an ad hoc network typically run on batteries and are deployed in hostile terrains, they have stringent power requirements. This implies that the underlying protocols must be designed to conserve battery life.

**Network size:** The ability to enable commercial applications such as voice transmission in conference halls, meetings, etc., is an attractive feature of ad hoc networks. However, the delay involved in the underlying protocols places a strict upper bound on the size of the network.

**Security:** Security in an ad hoc network is extremely important in scenarios such as a battlefield. The five goals of security – availability, confidentiality, integrity authenticity and non-repudiation are difficult to achieve in MANET, mainly because every node in the network participates equally in routing the packets.

### 1.5 PROBLEM DEFINITION

In mobile ad hoc networks, nodes act as both routers and terminals. Routes in ad hoc networks are multi-hop radio relaying because of the limited propagation range of wireless radios. Wireless mobile nodes are free to move about or remain at stand still. Each node may join the network, or may leave the network at any time.

Most of the researches conducted in the area of ad hoc networking to date focused on solving the routing problem; however the congestion related problem in ad hoc network has not been addressed much.

Congestion may occur in a network if the load on the network (the number of packets being sent through the network) is greater than the capacity of the network (the number of packets the network can handle). When the
network load is low, the throughput and network utilization increases as the network traffic increases. As the network load continues to increase, the queue lengths of the various nodes continue to grow. Now network enters into moderate congestion state. In this region, the throughput of the network load increases at slower rate with increased delays than the rate at which network traffic has increased. As traffic on the network continues to increase, the queue at each node becomes full and packets get discarded. Thus, the source must retransmit the discarded packets in addition to new packets. When more and more packets are retransmitted, the load on the system grows, and more queues become saturated. This is said as network enters into severe congestion state. In this region, the throughput of the network decreases with increase in network traffic and delay becomes infinite. Table 1.2 shows the various policies that affected congestion on protocol stacks.

Table 1.2 Congestion that affect on protocol stack

<table>
<thead>
<tr>
<th>Layer</th>
<th>Policies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transport Layer</td>
<td>● Retransmission Policy</td>
</tr>
<tr>
<td></td>
<td>● Out of order caching policy</td>
</tr>
<tr>
<td></td>
<td>● Acknowledgement policy</td>
</tr>
<tr>
<td></td>
<td>● Flow control policy</td>
</tr>
<tr>
<td></td>
<td>● Round-trip delay estimation algorithm</td>
</tr>
<tr>
<td>Network Layer</td>
<td>● Packet queuing and service policy</td>
</tr>
<tr>
<td></td>
<td>● Packet discard policy</td>
</tr>
<tr>
<td></td>
<td>● Packet Routing algorithm</td>
</tr>
<tr>
<td></td>
<td>● lifetime control policy</td>
</tr>
<tr>
<td>Data Link Layer</td>
<td>● Data link Level Retransmission Policy</td>
</tr>
<tr>
<td></td>
<td>● Data link Level Packet Drop Policy</td>
</tr>
<tr>
<td></td>
<td>● Data link Level Acknowledgement policy</td>
</tr>
<tr>
<td></td>
<td>● Data link Level Flow control policy</td>
</tr>
<tr>
<td></td>
<td>● Data Link Queuing and Service policy</td>
</tr>
</tbody>
</table>
Two types of congestions could occur in MANET (Ee et al 2004, Wang et al 2007) Node level congestion and Link level congestion. The Figure 1.1 illustrates types of network congestion.

The first type is node level congestion; it is caused by buffer overflow in the node and can result in packet loss, and increased queuing delay. Packet loss in turn can lead to retransmission and therefore consumes additional energy.

Figure 1.1 Congestion in MANET

The Second type is Link level congestion; wireless channels are shared by several mobile nodes using (CSMA/CA) protocol. Congestion could occur when two or more mobile nodes try to access channel at the same time. This can be referred as Link level congestion. In this, congestion increases packet service time, and decreases both link utilization and overall throughput, and wastes energy at the mobile nodes. Both node level and link level congestions have direct impact on energy efficiency, packet loss ratio, packet delay, and throughput.

Congestion control refers to techniques and mechanisms that can either prevent or remove congestion, before it happens or remove congestion,
after it happened (Tran and Raghavendra 2006, Lochert et al 2007). The main
objective of congestion control is to minimize the delay and buffer overflow
caused by network congestion and hence enable the network to perform
better. In general, the congestion control mechanism can divide into two
broad categories: open loop congestion control and closed loop congestion
control.

In open loop congestion control, policies are applied to prevent
congestion before it happens. In these mechanisms, congestion control is
handled either by the source or by the destination. The open loop congestion
control policies are Retransmission policy, Acknowledge policy and Discard
policy. Closed loop congestion control mechanisms try to alleviate congestion
after it happens. Several mechanisms have been used by different protocols.
A few of them have been described here, like back pressure, choke point,
implicit signaling and explicit signaling.

Over the past few years, the problem of congestion control has
received wide-spread attention in the Internet context, where most of this
research has focused on modeling, analysis, algorithm development of end to
end control schemes (such as TCP). However, such congestion control
techniques do not apply directly to ad hoc networks. This is because TCP has
to face new challenges due to several reasons specific to these, such as
networks lossy channels, hidden and exposed stations, path asymmetry,
network partitions and frequent route failures. It is unable to distinguish
between losses due to route failures and network congestion (Hanbali et al
2005). In consequence, the performance of TCP degrades in ad hoc networks.

The hop-by-hop congestion control has faster response. Hop-by-
Hop congestion control algorithms provide feedback about the congestion
state at a node to the hop preceding it. The preceding node then adapts its
transmission-rate based on this feedback. Feedback is typically provided
based on the queue length at the congested node. If the queue length exceeds a threshold, congestion is indicated and the preceding node is notified in order to decrease its transmission rate. It is well known that such schemes, by reacting to congestion faster than end to end schemes, result in better performance than a corresponding end-to-end scheme (Yi et al 2007).

In the initial stage, ad hoc network protocol design was largely based on a layered approach. The advantage of layered architectures is that the designer or implementer of the protocol or algorithm at a particular layer can focus on the design of that layer, without being required to consider all the parameters and algorithms of the rest of the stack (Kawadia et al 2005). This generally results in suboptimal and inflexibility performance for the users and their applications. To optimize the different protocol parameters, recently, numerous research efforts from around the globe have used cross-layer solutions to improve the performance of ad hoc networks and protocol stacks in selected application areas (Foukalas et al 2008).

Cross-layer design breaks away from traditional network design where each layer of the protocol stack operates independently. The cross-layer approach seeks to enhance the performance of a system by jointly designing multiple protocol layers. The resulting flexibility helps to improve the performance of network dynamics and limited resources. The National Science Foundation and Office of Naval Research jointly held a workshop on Cross-Layer Design in Adaptive Ad Hoc Networks (Zhang et al 2008). A working group of the Internet Engineering Task Force has been studying the interlayer interactions and performance in mobile ad hoc networks. They summarized the interlayer interaction metrics and the benefits of such information exchange between the lower layers, network layer, and transport layer (Lee et al 2003).
1.6 MOTIVATIONS

The performance of the MANETs is dependent on the effective congestion control mechanisms. It is to clear that congestion which is the leading cause for packet loss in MANETs. Hence directly using the wired network solutions (TCP based) in MANETs, may not prove good. Therefore in MANETs, TCP based congestion control have been unreliable; the well known transport protocols, such as UDP are unreliable, since no mechanism of congestion detection has been provided. This is particularly a problem in ad hoc networks. As a consequence, appropriate congestion control is widely considered to be a key issue for MANETs. A new perspective on this problem might be to realize for the development of new congestion control designs (Lochert et al 2007).

1.7 RESEARCH OBJECTIVES AND GOALS

The main objective of congestion control is to minimize the delay and packet losses caused by network congestion and hence enable the network to perform better. The main objectives of this works are

i. to propose a new cross-layer optimization framework for congestion control that provides an organized mechanism for detecting link break at physical layer, dynamic congestion detection in MAC layer and adapting the network traffic at network layer.

ii. to anticipate the likely link break by using dynamic transmission power control mechanism to predict link break with help of node’s receiving signal strength.
iii. to detect congestion well in advance by using dynamic congestion detection technique based on node’s queue occupancy and to find an alternative path prior to the congestion and divert the network traffic in non-congested route.

iv. to support hop-by-hop method for exchanging congestion information to its neighbours.

In order to achieve the above objectives, the goals set forth are as follows:

i. The proposed cross-layer optimization framework should allow modification of parameters like transmission power at physical, queuing control at Link layer and congestion adaption at network layer. Figure 1.2 illustrates the cross-layer interaction between lower and higher layers.

ii. The cross layer design for congestion control algorithm should reduce the number of nodes that participate in route discovery by constructing the Congestion Free Set

iii. Anticipate and initiate an alternative path finding technique, that fixes the congestion likely to happen in the primary path due to node’s queue occupancy, so as to achieve a non-congested route

iv. Anticipate and initiate a local route self-recovery technique that would fix the link breaks likely to occur in the active path due to mobility of a node, so as to achieve more efficient route repair and better fault resilience.
In order to achieve the above goals, a new Early Detection of Congestion and Bi-directional route discovery algorithm (EDAODV) has been proposed to effectively control congestion with high traffic. The EDAODV algorithm detects the congestion well in advance, by passes the likely to be congested node in the primary path and forms a new route. The simulation studies shows a marked improvement in packet delivery ratio and good reduction in end to end delay and requires lesser number of control packets to active these, when compared to AODV. A slightly modified version of the above, with self cure facility (EDCSCAODV) performs much better than AODV and EDAODV itself.

A new congestion control algorithm namely Dynamic Congestion Detection and Control algorithm (DCDR) has also been proposed to incorporate traffic fluctuations and categorize node’s congestion status
perfectly. This new protocol saves more control packets compared to other
protocols and gives performance in packet delivery with less time delay.

To address this receiving signal strength problem, the one more
algorithm called Cross Layer design approach for Congestion Control in
MANET (CLCC) which is an extension of DCDR. The significance of CLCC
is that it has used two mechanisms (i) dynamic transmission power control
algorithm that is processed one hop neighbours’ receiving signal strength and
adjust their transmission power. This adjustment of the transmission power
helps to minimize the control packets during discovery in high mobility
network. It also helps to forecast link breaks, replace the nodes which is likely
to move out of propagation range and add another node into primary path as
an alternative path, and (ii) dynamic congestion estimation technique, which
analyzes traffic fluctuation and categorize congestion status perfectly.

1.8 ORGANIZATION OF THE THESIS

The thesis is organized as follows: Chapter 2 presents a review of
relevant literature carried out for unicast and multicast routing protocols.
Classification of routing protocol such as Distance vector routing protocols
and Link state routing protocols, Classification of multicast routing protocol
such as Source based, Core based and Mesh based routing protocol are
discussed. The survey on various Queuing mechanisms and various
congestion control techniques dealing with route failures, coping with
wireless losses, managing a shared medium, and an alternative protocol
designs are discussed.

In Chapter 3, deals with the impact of traditional routing protocol
on congested MANETs and their drawbacks, such as packet loss and delay.
To avoid the observed draw backs, an Early Detection of Congestion and Bi-
directional route discovery in MANET (EDAODV) is proposed which detects
congestion that is likely to happen at node level and find a non-congested alternative path by using bi-directional route discovery mechanism and hence improves the network performance. In this chapter, an enhanced version namely Early Detection of Congestion and Self Cure routing in MANET (EDCSCAODV) is introduced which uses a self cure mechanism for finding a non-congested alternative path effectively. The proposed protocols are compared with EDAODV and AODV. The performance metrics measured and compared for packet delivery ratio, end to end delay and routing overhead are presented in this chapter.

In Chapter 4, a new approach called Dynamic Congestion Detection and Control routing (DCDR) in MANET is introduced. In this protocol, every node checks the occupancy of its link layer queue using the dynamic congestion estimation technique. The significance of dynamic congestion estimation technique is to incorporate traffic fluctuations. In second phase of this protocol introduces CFS (Congestion Free Set) which controls the overheads involved in non-congested route discovery and hence improves the network performance. This chapter also analyses the performance of various parameters by simulation.

Chapter 5 is presents extension of DCDR called Cross Layer Design approach for Congestion Control in MANET (CLCC), which addresses the link breaks problem and improves the network performance. Unlike traditional routing protocols, the significance of this work is that every node can alter its transmission power according to its receiving signal strength. This mechanism also has a proactive local recovery that initiates the alternative route discovery, when a link break is expected rather than waiting for the break to occur. The performances of metrics that are measured in the simulation are presented.
Chapter 6 summarizes the work done and presents the major contributions made in this thesis. It also suggests the scope for further work that could be carried out in continuation of this research.