CHAPTER 3

STARVATION AVOIDANCE IN DIFFERENTIATED SERVICES FOR MOBILE AD HOC NETWORKS

3.1 INTRODUCTION

MAC layer a sublayer of the data link layer, involves the functions and procedures necessary to transfer data between two or more nodes of the network. It is the responsibility of the MAC layer to perform error correction for anomalies occurring in the physical layer (Sunil Kumar et al 2006). The layer performs specific activities for framing, physical addressing, flow control and error control. It is responsible for resolving conflicts among different nodes for channel access. Since the MAC layer has a direct bearing on how reliably and efficiently data can be transmitted between two nodes along the routing path in the network, it affects the QoS of the network. The design of a MAC protocol should also address issues raised by mobility of nodes and an unreliable time varying channel.

In general, mechanisms of MAC protocols are divided into centralized and distributed. The centralized mechanism operates in IEEE 802.11 Point Coordination Function (PCF) mode and serves only infrastructured architecture, whereas the distributed mechanism operating in IEEE 802.11 Distributed Coordination Function mode serves both infrastructure and ad hoc architectures.
Two types of overhead are associated with contention resolution at MAC layer. One is channel idle overhead, where all stations wait to transmit and the other is collision overhead, which occurs when multiple contending stations attempt to transmit simultaneously (Jun Peng et al 2007). In 802.11 DCF, stations perform various operations in sequence. Contending stations go through contention resolution procedure to determine which station has the right to access the channel; then, the winning station transmits its packet. Only when the current transmission finishes, a new round of contention resolution begins for ease of exposition, assuming a LAN scenario here. In such a sequential procedure, both channel idle time and collisions consume the entire channel bandwidth, resulting in performance trade-offs. If a larger Contention Window (CW) is applied, 802.11 DCF can achieve better throughput in heavily contended networks due to the reduced collision probability (Nitin Vaidya et al 2005).

However in network with little contention, the channel idle overhead increases using a larger CW, which leads to a degradation in the network throughput. Traditionally, efforts have been made to dynamically adjust stations channel access behavior based on the network contention status so that both the channel idle and collision overhead can be minimized (Emma Carlson et al 2004). However, such algorithms typically require extensive channel feedback information, which may not be available in wireless networks, to infer the network contention status.

Contention for channel among the nodes is resolved using contention based protocols. In a heterogeneous network like ad hoc several problems like hidden terminal and exposed terminal problem can arise (Gaurav Sharma et al 2006). The CSMA MAC scheme and its variations such as CSMA/CD developed for wired networks cannot be used for wireless networks. Priority scheduling is a means to avoid channel contention among
the various nodes in the network. Among the several methods available for priority scheduling in ad hoc networks, the usage of Busy Tone signals or Alert Transmission and Suspend Transmission scheduling are fairly novel and are efficient methods.

In AT-ST scheme, two packets have been designed; namely, Alert Transmission and Suspend Transmission packets which form the crux of the scheme. AT packets are used as a means of notification whenever a high priority node is in need of transmitting data. ST packets are used to avoid priority reversal issue and retry count is employed to avoid starvation among the nodes. This priority scheduling is not concrete in predetermining the value of retry count and in granting the nodes the right to suspend transmission. In this research work, an enhancement to this scheme is developed as Adaptive AT-ST scheme, that guarantees an optimal retry count value and criteria for granting the rights for nodes to suspend transmission, and makes the priority scheduling much more efficient by adopting Markov Chain Model. This helps to effectively schedule priority among nodes, and resolves the arising conflicts.

3.2 MEDIUM ACCESS SCHEDULING PROTOCOLS

3.2.1 Classic CSMA Problems

CSMA based MAC protocols suffer from well known hidden and exposed terminal problems resulting in loss of channel efficiency in ad hoc networks (Ping Chung Ng and Soung Chang Liew 2007).

Different data transmissions in multihop networks have varying degrees of contention. The contention degree for a transmission is defined as the number of transmissions with which it is competing for the channel (Nitin Vaidya et al 2005). MAC schemes predominantly used are reservation and contention based schemes. Reservation based schemes usually make some
assumptions about high priority traffic. Black-burst is a typical example where a high priority node transmits black-burst signal as a notification for its transmission (Chih-Min Chao et al 2003). CSMA/CA is a type of contention based MAC protocol whose access mechanism is simple to implement. Each station sensing the transmission of the other nodes in the network is not often possible in ad hoc networks with hidden terminal and exposed terminal problems, and it is difficult to generalize ad hoc networks.

3.2.2 Busy Tone Priority Scheduling

In order to effectively perform priority scheduling among the nodes in the network, busy tone priority scheduling scheme was proposed by Vladimir M. Vishnevsky et al (2008). Whenever a high priority packet is backlogged at some high priority node, it sends a primary busy tone signal to every M slot, before it acquires the channel, where M is a time parameter in the proposed scheme (Kanodia et al 2002). When another node of lower priority hears this primary busy tone signal (BT1), it sends a secondary busy tone signal (BT2). All nodes with low priority packets that hear either BT1 or BT2 defer their transmissions for some duration. In this way, channel access priority of a high priority node can be ensured. Certainly, if there is no high priority packet backlogged at a high priority node, a low priority node does not receive any busy tone; hence, its channel access does not get affected.

3.2.3 Alert and Suspend Transmission Priority Scheduling

This scheme uses Alert Transmission packets AT1, AT2 to notify nodes in the network that the sender is going to transmit data. It proposes the usage of ST packets by high priority nodes to avoid priority reversal which can occur if a low priority node is about to send data before a high priority node can send the data (Wei Liu et al 2004). It also proposes the use of retry count to effectively keep track of the number of starvations a low priority
node is subjected, to avoid ultimately the long term starvation (Yaling Yang and Robin Kravets 2005). This scheme helps to overcome hidden and exposed terminal problems and efficiently schedule nodes based on priority in the network. Figure 3.1 shows the frame format of AT packet and Figure 3.2 shows the transmission of AT packets during handshaking.

![Frame format of AT packet](image)

**Figure 3.1 Frame format of AT packet**

### 3.2.4 Markovian Chain Model

This analytical model is developed to compute the 802.11 DCF throughput under ideal channel conditions with an assumption that each node always has a packet available to transmit (Gaurav Sharma et al 2006). Markov model for each node is obtained assuming that the probability of collision \( p \) in any slot is constant and independent of transmission history of nodes. It is intuitive that this assumption becomes more accurate as the number of nodes and the minimum contention window \( CW\text{min} \) get larger. This model is used to compute \( T \), the probability that a node transmits in a randomly chosen time slot, given the probability of collision \( p \), as denoted by the Equation (3.1).

\[
T(p)=\frac{2}{1+C W\text{min}+pC W\text{min} \sum_{i=0}^{m-1} (2p)^i}
\]

(3.1)

where \( i \) is the current backoff stage, \( m \) is the maximum backoff stage, and the conditional collision probability \( p \) with \( n \) mobile nodes is given by \( p=I-(1-T)^{n-1} \).
Figure 3.2 Handshaking sequence with transmission of AT1, AT2 packets

3.2.5 IEEE MAC 802.11 DCF

The 802.11 DCF function shown in Figure 3.3, which is subjected to several research modifications, involves giving a backoff counter to each node in such a way that every node can choose a random number between 0 to maximum contention window size. After sensing the channel to be idle for an inter-frame space the nodes start counting their backoff counters to zero, and if the channel is found to be busy they freeze the backoff counters (Bosheng Zhou et al 2007). The value of CW is constrained to be between $CW_{min}$ and $CW_{max}$.

A source station sends RTS and receives CTS following which it transmits data and gets an acknowledgement (ACK) packet. In the event of not receiving a CTS or ACK, the source is led to believe that a collision has
occurred, so it is imperative that there is adequate waiting time for the source before it arrives at some decision. There are two waiting stages in ad hoc network: the Inter Frame Space (IFS) stage and the backoff stage. The backoff counter is a random value between zero and the CW. For example, high priority source stations randomly choose the backoff interval from [0, $2^{i+1}$ -1] and low priority source stations choose from [$2^i$, $2^{i+2}$ -1], where $i$ is the number of consecutive times a station attempts to send a packet and different values of $CW_{min}$ and $CW_{max}$ are set for different priority classes. It adapts an exponential increase in backoff by a factor of 2 in the event of collision.

![Figure 3.3 Distributed coordination function](image)

### 3.3 PROPOSED SCHEME

The major limitations in 802.11 based AT-ST scheme are lack of definitive details to determine the retry count value and to deduce the criteria used to grant nodes the right to suspend transmission.
To overcome these issues an extended 802.11 AT-ST scheme adopting Probabilistic Markovian model is proposed in this work. This Adaptive AT-ST scheme addresses the issues in two phases, namely, priority reversal and starvation avoidance.

3.3.1 Priority Reversal

A priority reversal occurs when a low priority node has its backoff at zero when nodes at a higher priority are in contention. This can lead to a situation where a lower priority node grabs the channel before the higher priority nodes seize (Wei Liu et al 2004). In order to eliminate such a scenario, whenever a high priority node receives an AT packet it can compare the initial backoff value in the AT packet to check whether the source node is of higher priority than its own (Sundaramoorthy Kannan et al 2005). The high priority node will immediately send a ST packet for suspending the transmission, directed at the source node. Suspend Transmission process is represented pictorially in Figure 3.4.

![Figure 3.4 Suspend transmission packet during priority reversal](image-url)
Not all high priority nodes can however transmit the ST packet. The transmission of ST is decided based on the following criteria: original priority of the node and priority threshold determined through average packet transmission time. Only if a high priority node satisfies the criteria of higher priority and within priority threshold it can transmit the ST packet. The ST packet contains the following fields: Sender Address, Receiver Address, and Initial Backoff counter which is stored in the variable *curr* and the *duration*. The frame format is similar to Figure 3.1. Duration represents the time of sending the packet, TA is the sender address and RA is the receiver address. The right to send an ST packet for nodes will not remain constant as it can be subjected to changes based on network characteristics. An example network scenario following constant bit rate (CBR) is depicted in Figure 3.5. Nodes 1, 4 are high priority nodes and nodes 3, 5 are of low priority. At t1, the initial backoff values of nodes 1, 3, 5 are 10, 17 and 18.

![Figure 3.5 Scenario depicting priority reversal and starvation avoidance](image)

At t1, nodes 1, 3, 5 compete for channel access while 4 stays away from contention. Once the Distributed Inter Frame Space (DIFS) time expires, the backoff time of node 1 counts to zero and then, it sends an Alert Transmission packet AT1 to all its neighbors. The nodes which receive AT1 send AT2 packet to its neighbors. After the Short Inter Frame Space (SIFS) period expires, nodes freeze their backoff counters. Nodes 3, 5 have their
backoff counters frozen at 7, 8 respectively and their retry counts are increased by 1.

Node 1 after sending AT1 waits for a DIFS+SIFS period and then takes control of the channel for data transmission. At t4, nodes 4 (bc=9), 3, 5 contend for the channel access with 3 beating 4 leading to a priority reversal. To overcome this, once the AT1 packet of 3 reaches node 4, it realizes that it has higher priority than node 3. Hence, it disregards the AT1 packet and transmits ST packet to node 3 for suspending the transmission. The ST packet contains the current backoff value of the node sending ST i.e., node 4. Once node 3 receives the ST packet from node 4, it resets it backoff value as defined in Equation (3.2)

\[ \text{New Backoff} = \text{curr} + \text{slot time} \]  

(3.2)

where, curr is the current backoff value of the node sending ST. Also the backoff counter is reinitiated as follows. After sending ST, node 4 waits for an SIFS period and then starts counting its backoff timer to zero. Let backpri be a variable initialized with the value of initial backoff counter of the node. From the received ST packet, the current backoff value of the high priority node is obtained. This value is compared with the existing value of backpri and the smaller value is stored in backpri. Simultaneously, the backoff counter is frozen.

If current backoff time of node sending ST is less than backpri, then reset backpri, where \( \text{backpri}=\text{current backoff time of node sending ST} \)

Similarly, when this low priority node gets into contention in the next idle phase and if it loses the contention again by receiving an ST from a high priority node, it compares the backpri value with the current backoff value of the node sending ST and stores the smaller value in backpri. Thus, the priority reversal issue is dealt with using ST packets.
3.3.2 Starvation Avoidance

A retry count is used to prevent the excessive starvation of a low priority node. This can be fixed based on the number of nodes in the network and network characteristics. The number of times the backoff counter is frozen is the retry count. The `backpri` value of the low priority node comes in handy whenever its RC value reaches a threshold as defined in Equation (3.8). Once a node’s retry count reaches this threshold the following occurs: the initial backoff counter value is replaced with `backpri` value and a slot time is added to it. But before overwriting the initial backoff value it is imperative that a copy of it is stored as backup in the `initial backup` variable defined. Now the `backpri` value is used to overwrite the new backoff value which denotes the current or active backoff value of the low priority node as defined by the following set of Equations (3.3) to (3.5).

\[
Initial \ backup = Initial \ backoff \tag{3.3}
\]

\[
Initial \ backoff = backpri + \ slot \ time \tag{3.4}
\]

\[
New \ backoff = backpri \tag{3.5}
\]

The `backpri` value denotes the lowest current backoff value of the high priority nodes that have deprived the current node a chance to access the channel. The low priority node now enters contention as a high priority node since it has its initial backoff value reset. This backoff is applicable only till the node transmits the backlogged current information. Then RC and initial backoff are reset as defined in Equations (3.6) and (3.7)

\[
RC = 0 \tag{3.6}
\]

\[
Initial \ backoff = initial \ backup \tag{3.7}
\]
This infers that after the nodes have transmitted, the node’s priority is reverted to its original status, which is only agreeable as it cannot be promoted all the time. This scheme would thus be helpful in avoiding starvation of low priority nodes for the channel access.

Consider the example scenario as in Figure 3.5 where the nodes contend for channel access. Assume the RC threshold of the nodes to be 2. As node 1 has channel access initially winning the contention, the RC of node 3 and 5 are set to 1. Then, in the next burst, node 4 obtains the channel access after issuing a ST to node 3 where its RC is incremented to 2. If node again contends in the next burst, now to prevent further starvation of node 3, its backpri is set to backoff value and then the backoff is reset to the backoff of node 4 (bc =2). Thus, in the next burst, node 3 has a higher possibility of obtaining channel access. Thus, the starvation of node 3 is avoided.

Once node 3 finishes its transmission, its backoff is reset to its backpri value. The objective here is to calculate an optimum value for fixing the ST criteria in AT-ST scheme. The Markovian chain model has been adopted to obtain the value of ST. With reference to Equation (3.1), let \( Th \) be the ST threshold of a high priority node and \( Wh \) be the maximum waiting period of a high priority node as defined by Equation (3.8).

\[
Th = \frac{2}{1 + Wh}
\] (3.8)

Let \( Wl \) be the minimal waiting time of the low priority node and \( Wmean \) refers to the mean waiting period as defined by Equation (3.9).

\[
Wmean = a \times CWmin
\] (3.9)

where \( a \) is a constant denoting a fixed waiting period. A high priority node will definitely wait for a time period in the interval \( 0 \) to \( Wmean \) while a low priority node waits for a period in the interval \( Wmean \) to \( Wl \).
Now if $Wh < Wmean$,

$$Th = \frac{2}{(1+P)}$$

(3.10)

where $P$ refers to priority. The Equation (3.10) is the modified markovian formula which is used to calculate the criteria for ST and probability value of 1 indicates highest priority for sending ST. Similarly, for $Wl > Wmean$, $Tl = 2/(Wl-Wmean)$ where $Tl$ is the ST threshold of the low priority node. This is used for computing retry count value as shown in Equation (3.11) which has also been an issue in 802.11 AT-ST scheme.

$$RC = mean\ (Th + Tl) \ast n$$

(3.11)

Here $n$ is the number of nodes. Mean of $Th$ and $Tl$ gives the mean probability of a node to transmit in a randomly chosen time slot, both for the high priority and low priority nodes put together in the network. Using the Markovian model formulae it is possible to get optimum values for RC and fixing the criteria for ST. Thus, the accuracy of the scheme improves manifold.

3.4 IMPLEMENTATION

The proposed 802.11 adaptive AT-ST scheme is simulated using ns2 and the results of the simulation analysis are illustrated in the following graphical representations. Figure 3.6 indicates the comparison in aggregate throughput between the 802.11 AT-ST scheme with the Adaptive AT-ST scheme. The number of nodes is used as the measuring criteria. The simulation is carried out with 20, 40, 60… 140 nodes. The results exhibit that the proposed scheme produces better throughput when markovian model is applied.
Figure 3.6 Comparative analysis on aggregate throughput

The comparative results on the delivery ratio of high priority packets between the 802.11 AT-ST scheme and adaptive scheme with markovian model extensions is shown in Figure 3.7. The results show that the high priority packets are delivered at a much better rate if markovian model extensions are incorporated into the AT-ST scheme. Figure 3.8 shows the throughput as a function of delay in the arrival rate of packets. The 802.11 AT-ST scheme is compared with the Adaptive AT-ST scheme, and it is observed that with the use of Markovian model the throughput increases as a function of delay in the arrival rate of packets.

Figure 3.7 Comparative analysis on delivery ratio of high priority packets
Figure 3.8 Throughput analysis as a function of rate of arrival of packets

Figure 3.9 Comparative analysis on latency in accessing the channel

The comparative results on the access latency of the low priority nodes in an environment of 100 nodes including nodes of both low and high priority is shown in Figure 3.9. Starvation avoidance mechanism employed for the low priority nodes in Adaptive AT-ST scheme reduces this latency considerably when compared to AT-ST. The graph also reveals that, with less number of high priority nodes, starvation caused by them is very low and thus the access latency is also considerably low. Analysis on maximum latency of low priority nodes is carried out similar to the analysis and simulations performed by Lenagala and Zeng (2006) and Eun Byol Koh and Chong-kwon Kim (2007)
Figure 3.10 Comparative analyses on maximum latency of low priority nodes

Lesser degree of starvation of low priority nodes in Adaptive AT-ST scheme compared to AT-ST scheme is established from Figure 3.10. Maximum access latency of low priority nodes get reduced extensively when there is an increase in participation of high priority nodes and this reveals that the starvation of low priority nodes are avoided considerably.

3.5 CONCLUSION

In IEEE 802.11 MAC, AT-ST priority scheduling scheme was not robust in addressing issues like retry count values. Thus Adaptive AT-ST scheme is developed using probabilistic Markovian model which provides optimum values for retry count and the criteria needed for fixing ST packet value, thereby improving the performance of the scheduling overall. This is validated by the simulation results comparing the various parameters between the existing and developed schemes. It is concluded that Adaptive AT-ST scheme performs much better if markovian model is adopted. It employs provisions to enhance the quality of service by avoiding the starvation of nodes and providing an efficient channel allocation. A discussion on an efficient misbehavior diagnosis method developed to attend to the selfish behavior nodes in MANETs is provided in Chapter 4.