CHAPTER 3

BANDWIDTH CONSTRAINED ROUTING

3.1 INTRODUCTION

To realize the potential benefits of MANETs, they must be able to deliver multimedia-based services. To accomplish this, best-effort protocols are not adequate. Routing protocols supporting QoS are required. There are many QoS metrics (Hanzo 2007) to be met by routing protocols for path evaluation and selection in order to improve all-round QoS or to meet the specific requirements of application data sessions. Among these many metrics, bandwidth is the fundamental criteria (Lin 1999) (Ravi Prasad 2003) to be satisfied by most of the multimedia-based applications. This chapter presents an on-demand routing based on Modified AODV (M_AODV) routing algorithm that establishes a path meeting the application stipulated bandwidth requirement. Section 3.2 presents the description of M_AODV. Bandwidth constrained admission control process of M_AODV is explained in Section 3.3. Necessary parameter evaluations are explained in the Sections 3.4, 3.5 and 3.6. Section 3.7 describes the M_AODV packet formats and its routing table components. Route discovery process as per the M_AODV is given in Section 3.8. Protocol simulation and the results obtained are discussed in Section 3.9.

3.2 MODIFIED AODV PROTOCOL DESCRIPTION

AODV is a well-known wireless ad hoc network protocol. It makes its routing decision based on DSDV. AODV assumes symmetric links between neighbors. It uses routing table which maintains the destination
node, next hop node and the destination sequence number. Each routing table entry has an entry lifetime that is updated when it is being used. AODV requires nodes to maintain next-hop information only. Each node maintains a list of nodes to reach each destination node. This list is later used to find alternate paths. Basic AODV (Perkins 2001a) is based on flooding the network with RREQ packets. The source node broadcasts a RREQ packet with a time-to-live value equal to 1 that is the broadcast is limited to one hop neighborhood. Each RREQ is uniquely identified through a sequence number. When a node receives the RREQ it records the address of the node that sent the packet. When the first RREQ reaches the desired destination, a RREP packet is generated and sent back to the source node through the recorded reverse path, ensuring a path from the source to the destination. M_AODV differs from normal AODV in the way the route discovery process is changed to provide QoS support by performing bandwidth based admission control at each node in the network. Similar to AODV, the M_AODV also uses the RREQ, RREP and Route Error (RERR) packets for the route discovery and maintenance processes.

3.3 BANDWIDTH CONSTRAINED ADMISSION CONTROL

The proposed QoS aware routing protocol utilizes a cross-layer design. In a networked environment, the network layer considers resources along the entire route of communication where as the MAC layer is responsible for resource allocation at individual nodes. The main problem of the MANETs comes from the shared nature of the wireless medium in single-channel networks. The physical nature of the channel in MANETs imposes many difficulties (Chakrabarti 2001) in providing QoS guarantees. Essentially, nodes that cannot communicate with each other directly may still contend with each other for the common resources. This extended contention area beyond the transmission range of a node is known as neighborhood
contention area. Neighborhood contention greatly affects resource allocation decisions made at individual nodes. Allocation decisions at an individual node require bandwidth information of nodes outside of its communication range and along the entire route. Contention for resource may involve multiple nodes along a route. M_AODV performs admission control based on the knowledge of these characteristics of MANETs. Ad hoc networks based on single-channel MAC layer standard IEEE 802.11, are considered in this work.

The physical characteristics of wireless channel introduce two challenges. First challenge is available bandwidth estimation at a node; second challenge is estimation of flow bandwidth requirement in a shared medium. In the shared wireless medium, when a node starts to transmit a flow, it consumes bandwidth from its contention neighbors. Because each node has a different view of the network, the node cannot decide on its own whether its contention neighbors have sufficient unused bandwidth for the new flow. Also obtaining contention neighbor information is not easy since a node may consume the bandwidth of contention neighbor but not able to directly communicate with those neighbors if those neighbors are located outside transmission range but inside carrier sensing range.

Two ways are proposed for estimating bandwidth in MANETs. In the first method nodes listen to the channel and estimate the available bandwidth based on the ratio of free and busy times (‘Listen’ bandwidth estimation) (Yang 2005). The other way is every node to disseminate information about the bandwidth it is currently using in the ‘Hello’ messages (Chen 2005), and for a host to estimate its available bandwidth based on the bandwidth consumption indicated in the ‘Hello’ messages from its two-hop neighbors (‘Hello’ bandwidth estimation). ‘Hello’ bandwidth estimation method incurs additional control message overhead to disseminate information to neighbors. This will consume additional bandwidth and create
delay. Hence this work has preferred ‘Listen’ bandwidth estimation, which is a passive method of bandwidth estimation.

The objective of admission control is to determine whether the available resources can meet the requirements of a new flow while maintaining bandwidth levels for existing flows. The available bandwidth in the network is not a local concept. To tackle this condition, two terms are introduced: local bandwidth available (BW_{local}), contention neighborhood bandwidth available (BW_{c-neigh}). Local bandwidth available is the amount of unconsumed bandwidth as observed by a given node. Contention neighborhood available bandwidth is the maximum amount of bandwidth that a node can use for transmission without affecting the reserved bandwidth of any existing flows in its carrier sensing range. Since, a node may consume the bandwidth of nodes that are within its contention range, the contention neighborhood available bandwidth available for a given node is equal to the smallest local available bandwidth of all its contention neighbors. Hence, in order to admit a flow, each node must have both local bandwidth and contention neighborhood bandwidth at the required level.

3.4 ESTIMATION OF LOCAL BANDWIDTH AVAILABLE

It is the unconsumed bandwidth at a given node. Each node in the MANETs can determine its BW_{local} by passively listening network activities. This approach proposes to use the fraction of channel idle time based on the past history as an indication of local available bandwidth at a node. A node can perceive the channel as either idle or busy. The channel is idle if the node is not in any of the following three states: First, the node is transmitting or receiving a packet. Second, the node receives a Request To Send (RTS) or a Clear To Send (CTS) message from another node, which reserves channel for a period of time specified in the message. Third, the node senses a busy carrier with signal strength larger than a certain threshold, called the carrier
sensing threshold, but the node cannot interpret the contents of the message. Idle time calculation requires estimation of channel busy time ($T_{busy}$) within the stipulated time period ($T_p$). Normally the medium is busy with the control messages like RTS, CTS, ACK and the transmission, reception, detection of data frames. Hence the amount of time required for single data packet transmission (Cerveira 2006) at the network layer is computed as given in Equation 3.1.

$$T = T_{c\_msg} + T_{mac} + T_{frame}$$ (3.1)

Where,

- $T_{c\_msg}$ - time consumed by the routing control messages like RTS, CTS, ACK.
- $T_{mac}$ - time consumed by DIFS, SIFS, backoff intervals (MAC layer overhead).
- $T_{frame}$ - time needed for single data frame transmission.

![Figure 3.1 IEEE 802.11b DCF operations](image)
Figure 3.1 depicts the role of control messages, DCF (Distributed Coordination Function) Inter Frame Spacing (DIFS) and Short Inter Frame Spacing (SIFS) durations as per IEEE 802.11b DCF mode of operation. The RTS, CTS and ACK messages including all the physical preambles have 120 bytes that is 960 bits which are transmitted at the basic rate of 1 Mbps, taking 960μs. As per IEEE 802.11 specification (2003), the DIFS time duration is 50μs and the SIFS time duration is 10μs. Normally three SIFS frames are involved in each transmission. Back off time is the product of a slot time (20μs) and a random number from 0 to 31. The data frame preamble (192 bits) is also taken into consideration. Preamble bits are transmitted at the basic rate. Data frame contains the payload and also the IP and MAC headers which sum upto 48 bytes. The accuracy of the estimation depends on the interval $T_p$ between successive measurements. Larger the value of $T_p$, the estimate is more accurate. Smaller the value of $T_p$, the estimate is transparent to the channel dynamics. Hence, choosing the value of it is a trade-off between accuracy and transparency. The $T_{busy}$ estimation, when ‘L’ number of packets are transmitted, received or detected for the duration of $T_p$ is given in Equation 3.2.

$$T_{busy} = T_{c, msg} + L \times (T_{mac} + T_{frame})$$ (3.2)

If contention occurs, nodes involved in it are entering into the backoff state. Nodes also start decreasing their chosen backoff counter value. When the node hears a next transmission, it pauses its backoff counter and restarts it when the medium remains idle again for DIFS duration. Also, backoff time value is very small when compared with $T_{frame}$. So, it can be neglected from the calculation of packet transmission time. Channel idle time ($T_{idle}$) within the period $T_p$ is deduced as shown in Equation 3.3.

$$T_{idle} = T_p - T_{busy}$$ (3.3)
By monitoring the amount of $T_{idle}$, during every period of time $T_p$, the $BW_{local}$ of a node is computed using a weighted moving average (Yang 2005) as specified in Equation 3.4.

$$BW_{local} = \omega BW_{local} + \left(1 - \omega\right)\frac{T_{idle}}{T_p} BW_{channel}$$  \hspace{1cm} (3.4)

Where,

$BW_{channel}$ is the capacity of the channel and $\omega$ is the weight factor, $0 < \omega < 1$.

### 3.5 ESTIMATION OF CONTENTION NEIGHBORHOOD BANDWIDTH AVAILABLE

Each node in MANETs perceives the network in a different state. Hence node's local bandwidth available cannot provide information about its contention neighbors since it does not know the amount of $BW_{local}$ available at other nodes. In Figure 3.2, the inner circle covers the transmission range of node X. The outer circle shows the carrier sensing range of node X. Normally carrier sensing range is twice the transmission range of a node. Within the transmission range nodes can communicate directly. Even though the node X unable to communicate directly with the nodes in the carrier sensing range, but their transmissions will consume the bandwidth available at X. To node X, the nodes I, J and K are its contention neighbors.

In Figure 3.3, the inner most circle shows the transmission range of node A. Outer circles indicate the carrier sensing range of nodes B, A and C respectively. Contention carrier sensing threshold refers the range that covers the carrier sensing ranges of all of the sensing node’s contention neighbors. Hence it is set to a value much lower than the carrier sensing threshold. During the normal IEEE 802.11 operations, node listens to the medium using a threshold value known as contention carrier sensing threshold, which is set to a value much lower than the carrier sensing threshold.
Figure 3.2 Contention neighbors of a mobile wireless node

Figure 3.3 Different sensing ranges of a mobile node
If the signal strength of the carrier sensed by a node is smaller than the contention carrier sensing threshold, there is no communication in its contention neighborhood and also contention neighbors of the node experience idle channels. The amount of time that the channel is in this idle state, denoted as $T_{\text{idle}}^{\text{contention}}$ for every period of time $T_p$, contention neighborhood available bandwidth ($BW_{c-neigh}$) is calculated (Yang 2005) using the weighted moving average given in Equation 3.5.

$$BW_{c-neigh} = \omega BW_{c-neigh} + (1-\omega) \frac{T_{\text{idle}}^{\text{contention}}}{T_p} BW_{\text{channel}} \tag{3.5}$$

Where,

$BW_{\text{channel}}$ is the capacity of the channel and $\omega$ is the weight factor, $0 < \omega < 1$.

In Equation 3.4 and Equation 3.5, the weight factor $\omega$, can assume the value from zero to one. With a large value of $\omega$, the old estimates are given more importance and the network system is considered more stable. But agility is attained by keeping $\omega$, a small value. Neither of these situations is advantageous all the time. As per the specification given by Hunter in Section 6.3.2.4 of Engineering Statistics Handbook released in the year 2010, the value of $\omega$ is usually set between 0.2 and 0.3. In this proposed approach, the value of $\omega$ is set to 0.25 to estimate both $BW_{\text{local}}$ and $BW_{c-neigh}$.

### 3.6 ESTIMATION OF FLOW BANDWIDTH REQUIREMENT

$M_{\text{AODV}}$ needs to quantify the bandwidth that a new flow requires so that it can be decided whether the bandwidth available at a node will satisfy the requirements of the new flow. Foremost, the application’s data rate has to be converted into the corresponding channel bandwidth requirement. This conversion includes the protocol overhead incurred in the MAC layer and the network layer. As per IEEE 802.11, for every application data packet,
the MAC layer performs handshaking. During this RTS, CTS and ACK control packets are involved. Hence, each data packet's transmission time is calculated as per Equation 3.6.

\[ T_{data} = T_{rts} + T_{cts} + T_{ack} + T_{difs} + 3T_{sifs} + \frac{(P+Q)}{BW_{channel}} \]  \hspace{1cm} (3.6)

Where,

- \( T_{data} \) - transmission time of each data packet
- \( T_{rts} \) - time for transmitting RTS
- \( T_{cts} \) - time for transmitting CTS
- \( T_{ack} \) - time for transmitting ACK
- \( T_{difs} \) - DCF inter frame space defined in the IEEE 802.11 protocol standard
- \( T_{sifs} \) - short inter frame space defined in the IEEE 802.11 protocol standard
- \( P \) - size of the data packet
- \( Q \) - IP and MAC packet header length
- \( BW_{channel} \) - channel capacity

If, at every second the application generates ‘R’ packets with average packet size ‘P’, the corresponding flow bandwidth requirement (\( BW_{flow} \)) is computed as given in Equation 3.7.

\[ BW_{flow} = R \times T_{data} \times BW_{channel} \]  \hspace{1cm} (3.7)

3.7 FORMATS OF M_AODV PACKETS

The format of RREQ packet used in the M_AODV is given in Figure 3.4. Meanings of individual fields involved in it are following the format.
Figure 3.4 Route Request Packet Format

<table>
<thead>
<tr>
<th>Type</th>
<th>J</th>
<th>R</th>
<th>Reserved</th>
<th>Hop Count</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Broadcast ID</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Destination IP address</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Destination Sequence Number</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Source IP Address</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Source Sequence Number</th>
</tr>
</thead>
</table>

Type - 1

J - Join flag; reserved for multicast.

R - Repair flag; reserved for multicast.

Reserved - Sent as 0, ignored on reception.

Hop Count - The number of hops from source IP address to the node handling the request.

Broadcast ID - A sequence number uniquely identifying the particular RREQ when taken in conjunction with the source node’s IP address.

Destination IP address - The IP address of the destination to which a route is desired.

Destination Sequence Number - The last sequence number received by the source for any route toward the destination.

Source IP Address - The IP address of the node that originated the route request.

Source Sequence Number - The current sequence number to be used or route entries pointing to the source of the route request.

The format of RREP packet used in the M_AODV is given in Figure 3.5. The interpretations of individual fields involved in it are given following the format.
The format of the RERR packet used in the M_AODV is given in Figure 3.6. The field descriptions are mentioned following the format.
Figure 3.6 Route Error Packet Format

| Type     | 3 |
| Reserved | Sent as 0, ignored on reception. |
| Dest Count | The number of unreachable destinations included in the packet; it must be at least 1. |
| Unreachable Destination IP Address | The IP address of the destination that has become unreachable because of a link break. |
| Unreachable Destination Sequence Number | The last known sequence number, incremented by 1, of the destination listed in the previous Unreachable Destination IP Address field. |

The RERR packet is sent whenever a link break causes one or more destinations to become unreachable. The unreachable destination addresses included are those of all lost destinations that are now unreachable because of the loss of that link. Figure 3.7 shows the extension added in the RREQ packet to carry the bandwidth requirement information.

Figure 3.7 Bandwidth Request Extension Format
Type - 7
Length - 2
Minimum Bandwidth - The amount of bandwidth (Kilobits/Sec) needed for acceptable transmission from the source to the destination.

Each node maintains route information in its routing table. Information obtained through RREQ and RREP packets is kept with other routing information in the routing table.

M_AODV maintains the following fields in each route table entry:

- destination IP address
- destination sequence number
- interface number
- hop count
- last hop count
- next hop
- list of precursors
- lifetime (expiration or deletion time of the route)
- routing flags (used for multicast routes)
- bandwidth reserved

Sequence numbers are used to eliminate stale routes. Precursor list is maintained for the purpose of route maintenance if the link breaks. Lifetime field is updated whenever a route is used. If a route has not been used within its lifetime, then it becomes expired.

3.8 M_AODV ROUTE DISCOVERY PROCESS

Like AODV [12], M_AODV is a reactive unicast routing protocol for MANETs. It needs to maintain the routing information about the active
paths. In M_AODV, routing information is maintained in the routing table of every node. Each node constructs a next-hop routing table which contains the destination to which it currently has a route. An entry in the table automatically expires, if it has not been used for a specified amount of time. Route discovery is purely on-demand.

During the route discovery process, the source node broadcasts RREQ packet. Each RREQ packet contains the addresses of source and destination, broadcast ID, the last seen sequence number of the destination as well as the source node's sequence number. Broadcast ID is used as an identifier. Sequence numbers are utilized to ensure loop-free and up-to-date routes. The value of $\text{BW}_{\text{flow}}$ is computed by the source as given in Equation 3.7 and included in the RREQ packet. In M_AODV, each node computes $\text{BW}_{\text{local}}$ and $\text{BW}_{\text{c-neigh}}$ as per Equation 3.4 and Equation 3.5 respectively.

Every intermediate node, on receiving RREQ performs admission control as shown in Figure 3.8. If the value of $\text{BW}_{\text{flow}}$ is lower than the values of $\text{BW}_{\text{local}}$ and $\text{BW}_{\text{c-neigh}}$, then the admission control succeeds otherwise it fails. In case of failure, the RREQ packet is discarded. On success of the admission control, the node sets up a reverse route entry in its routing table, adds its identifier in the RREQ packet and rebroadcasts the route request. When the intended destination receives a route request, it receives the full route. Using this information, destination node constructs RREP packet and sends it back to the source along the same route. If different routes arrive at the destination, it chooses the path having less number of hops.
Figure 3.8 Admission Control Process

3.9 M_AODV SIMULATION

The proposed M_AODV routing protocol is implemented using the NS-2 version 2.30 (Mc Canne 1995). The proposed M_AODV protocol is applied in the network layer. The IEEE 802.11 based MAC detailed in the IEEE standard (2003) is the commonly used channel access scheme for
ad hoc networks. In this implementation, for medium access IEEE 802.11b at DCF mode is used. NS-2 uses Phy/WirelessPhy object to simulate wireless channel. The default rate of 1Mbps for control frames is assumed without modification. The following code shows the way of specifying bandwidth, Constant Bit Rate (CBR) traffic and packet size details in NS-2 implementation.

```
#setting the data rate of an application 2Mbps
Mac/802_11 set dataRate_ 2.0Mb

#To setup a CBR flow over UDP
set cbr [new Application/Traffic/CBR]
$cbr attach-agent $udp
$cbr set type_ CBR

#setting the packet size to 512 bytes
$cbr set packetSize_ 512
```

NS-2 uses thresholds to determine whether the receiver receives one frame correctly. To determine whether one frame is detected by the receiver, NS-2 sets signal strength threshold parameter (CS Thresh_) to an appropriate value. If the signal strength of the frame is less than CS Thresh_, then this frame is discarded in physical (PHY) module and will not be visible to MAC layer. To properly receive frames on the receiver side, NS-2 applies another threshold (Rx Thresh). If one frame arrives and the received signal strength of the frame is larger than Rx Thresh_, then only it is concluded that the frame is received correctly. Otherwise, the frame is treated as corrupted and the MAC layer will discard it. When multi-frames are received simultaneously by one mobile node, it calculates the ratio of the strongest frame’s signal strength to the signal strength sum of other frames. NS-2 applies another threshold (CPThresh) for this ratio. If the calculated ratio is larger than CPThresh_, then the frame is treated that it is received correctly and all other frames are
ignored. Otherwise it is treated that all frames are collided and hence they can be discarded. The following code shows the various threshold values set as per the simulation parameters considered.

```plaintext
#transmit power for transmission range of 200m and
carrier sensing range of 400m
Phy/WirelessPhy set Pt_ 0.28183815
Phy/WirelessPhy set CPThresh_ 10.0 //Collision Threshold
#Carrier Sense Power equivalent to -78dBm
Phy/WirelessPhy set CSThresh_ 1.559e-11
#Receive Power equivalent to -65dBm
Phy/WirelessPhy set RXThresh_ 3.652e-10
```

To get the channel status, the PHY layer performs a Clear Channel Assessment (CCA) checking which returns idle state as the value of the CCA indicator if the channel is free. This denotes the case when the energy level received is lower than a carrier sense threshold (CSThresh_). For IEEE 802.11 variants (Xiuchao 2004), the typical range of -60dBm to -80dBm is set against the wireless received signal power. To know the status of contention neighbors, CSThresh_ parameter of PHY layer is used. It is set to a value much lower than the carrier sensing threshold. As per the specification given by the suppliers of WiFi interface (Chalhoub 2008), it is assigned a value of -94dBm. Following code depicts the power level assigned to CSThresh_ parameter to assess the transmission status of contention neighbors.

```plaintext
# setting contention carrier sensing threshold equivalent to -94dBm
Phy/WirelessPhy set CSThresh_ 3.1622777e-14
```
In M_AODV, the packet structure of RREQ is changed to carry additional information. The routing table structure is also changed to hold the extra details. Simulations are run for different scenarios. Different scenarios are created using 10, 20, 30, 40 and 50 nodes. Protocol evaluations are based on the simulation of wireless nodes forming an ad hoc network, moving over a rectangle. Scenarios are run for different node pause time values. Table 3.1 shows the values set to the various simulation parameters.

<table>
<thead>
<tr>
<th>Parameter (units)</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulation area (m x m)</td>
<td>1000 x 1000</td>
</tr>
<tr>
<td>Simulation time (s)</td>
<td>200</td>
</tr>
<tr>
<td>Number of nodes</td>
<td>10,20,30,40,50</td>
</tr>
<tr>
<td>Mobility model</td>
<td>Random way point</td>
</tr>
<tr>
<td>Node speed (m/s)</td>
<td>5</td>
</tr>
<tr>
<td>Node pause time (s)</td>
<td>10, 20</td>
</tr>
<tr>
<td>Propagation model</td>
<td>Two-ray ground</td>
</tr>
<tr>
<td>Transmission range (m)</td>
<td>250</td>
</tr>
<tr>
<td>Carrier sense range (m)</td>
<td>550</td>
</tr>
<tr>
<td>Channel capacity (Mbps)</td>
<td>2</td>
</tr>
<tr>
<td>MAC</td>
<td>802.11b DCF</td>
</tr>
<tr>
<td>Data packet size (B)</td>
<td>512</td>
</tr>
<tr>
<td>Session duration (s)</td>
<td>40 – 120</td>
</tr>
<tr>
<td>Session start time (s)</td>
<td>0 – 150</td>
</tr>
</tbody>
</table>

The performance of the M_AODV is compared with Available Bandwidth Estimation (ABE) approach proposed by Sarr et al (2005) and normal AODV (Perkins 2001a). ABE is a non-intrusive technique to estimate the remaining bandwidth between two neighbor nodes on a per node basis. Bandwidth estimation is based on watching the medium to get its total idle
time duration within the stipulated observation period. Medium idle time includes periods during which no frame is ready to transmit as well as periods of backoff time and inter frame spacing. Idle times shorter than DIFS are not considered in this approach to improve estimation accuracy. Solution to deal with bandwidth utilization in MANETs by the node’s contention neighbors, is not suggested in this work.

The performance of M_AODV is assessed in terms of throughput, overhead requirement, number of packets dropped, average end-to-end delay of data packets, session admission ratio and QoS effectiveness ratio. Throughput is the number of data packets received by the destination nodes in second. Control message overhead is the total number of routing control packets transmitted during the simulation time. It includes the number of RREQ, RREP and RERR packets of both active flows and new flows seeking admission. It is evaluated using Equation 3.8.

\[
\text{Control message overhead} = \frac{\text{No. of control message packets (bytes)}}{\text{Total No.of packets in transmission (bytes)}}
\]  

(3.8)

\[
\text{Session admission ratio} = \frac{\text{No. of flows granted admission}}{\text{Total No.of flows arrived for admission}}
\]  

(3.9)

Packets dropped measure gives an indication of the effectiveness of admission control process of the proposed M_AODV. It is calculated as the ratio between the number of packets dropped and the total number of packets offered. End-to-end delay is defined as the difference between the arrival time of a packet at the destination node and the time by which the packet was generated at the source node. Session admission ratio of the approach is computed as per Equation 3.9. This measure is used to indicate the call blocking nature of the approach under consideration.
QoS effectiveness is calculated as the ratio between the number of successful flows and the number of generated flows. This metric evaluates how far the proposed algorithm is able to guarantee the QoS through its admission process.

### 3.10 M_AODV RESULTS ANALYSIS

To assess the throughput performance of M_AODV, MANETs scenarios made up of 10, 20, 30, 40 and 50 nodes are created. Based on the number of nodes in the scenario three to ten CBR flow connections are established between different nodes. For each scenario 10 rounds of simulations are run. Throughput as per M_AODV, ABE and normal AODV routing methods are evaluated and averaged. Table 3.2 shows the throughput achieved in these three methods. Last column of the table presents the percentage of improvement in the proposed approach when compared with normal AODV and ABE for different size of networks.

<table>
<thead>
<tr>
<th>S.No.</th>
<th>No. of nodes</th>
<th>No. of packets transmitted</th>
<th>% of improvement in M_AODV compared with AODV</th>
<th>% of improvement in M_AODV compared with ABE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>AODV</td>
<td>ABE</td>
</tr>
<tr>
<td>1</td>
<td>10</td>
<td>28</td>
<td>32</td>
<td>32</td>
</tr>
<tr>
<td>2</td>
<td>20</td>
<td>52</td>
<td>50</td>
<td>52</td>
</tr>
<tr>
<td>3</td>
<td>30</td>
<td>66</td>
<td>68</td>
<td>72</td>
</tr>
<tr>
<td>4</td>
<td>40</td>
<td>74</td>
<td>86</td>
<td>92</td>
</tr>
<tr>
<td>5</td>
<td>50</td>
<td>72</td>
<td>80</td>
<td>88</td>
</tr>
</tbody>
</table>

Figure 3.9 presents graphical representation of throughput performance obtained in these three approaches for different size of MANETs. From the results, it is observed that throughput of M_AODV gets increased significantly. MANETs which are constructed using 10 and 20 nodes, the throughput obtained in M_AODV, normal AODV and ABE
approaches are almost the same. But in the large sized networks, throughput of proposed M_AODV is increased from 9% to 24% when compared with normal AODV and from 5% to 10% when compared with ABE approach.

**Figure 3.9 Throughput of M_AODV**

Performance of M_AODV in terms of overhead involved for data transmission is presented in Figure 3.10 and Figure 3.11. Overhead calculation includes number of RREQ, RREP and RERR packets generated during traffic simulation. Figure 3.10 illustrates the overhead involved in different size of networks for the node pause time value of 10 seconds and Figure 3.11 illustrates the overhead involved in different size of networks for the node pause time value of 20 seconds. The comparative evaluation of control message overhead in the proposed M_AODV with normal AODV and ABE is shown in Table 3.3. For each size of network, there is a considerable reduction in the control message utilization in M_AODV. This is made possible because of less number of route breaks and packet drops of M_AODV. Applying routing based on this proposed approach results in 10% to 30% control message overhead reduction in the case of large sized networks (40, 50 no. of nodes).
Overhead requirement of M_AODV compared with ABE is reduced to 8% and 16% on an average for the pause time value of 10sec and 20sec respectively. Higher overhead is involved in the ABE due to its over estimation of available bandwidth. Also as the nodes’ pause time value
increases, control message overhead decreases drastically. Comparing the performance of M_AODV in the case of pause time value set to 10 seconds with pause time value set to 20 seconds, the later case gives 8% average reduction in the overhead. This indicates that higher pause time value causes less route breaks.

Table 3.3 M_AODV overhead evaluation

<table>
<thead>
<tr>
<th>S.No.</th>
<th>No. of nodes</th>
<th>Pause time = 10sec</th>
<th>Pause time = 20sec</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Overhead reduction % in M_AODV compared with AODV</td>
<td>Overhead reduction % in M_AODV compared with AODV</td>
</tr>
<tr>
<td></td>
<td></td>
<td>AODV</td>
<td>ABE</td>
</tr>
<tr>
<td>1</td>
<td>10</td>
<td>9.38</td>
<td>9.38</td>
</tr>
<tr>
<td>2</td>
<td>20</td>
<td>8.62</td>
<td>3.64</td>
</tr>
<tr>
<td>3</td>
<td>30</td>
<td>3.70</td>
<td>3.70</td>
</tr>
<tr>
<td>4</td>
<td>40</td>
<td>30.88</td>
<td>18.97</td>
</tr>
<tr>
<td>5</td>
<td>50</td>
<td>11.29</td>
<td>8.33</td>
</tr>
</tbody>
</table>

Simulation parameters values of radio transmission range and carrier sensing range values are changed to 200m and 400m respectively for the remaining metrics assessment. Figure 3.12 depicts the number of packets dropped in three approaches for various transfer rates. When compared with normal AODV packets dropped percentage in M_AODV is reduced by 10% to 20% for transmission rate up to 750kbps and reduced by 20% to 43% for higher transmission rates. When compared with ABE packets dropped percentage in M_AODV for higher rates of data transmission is reduced by 10% to 19%.
Average end-to-end packet delay achieved for different rates of node movements is shown in Figure 3.13. All the three approaches show higher delays for increased rate of node mobility. M_AODV realizes 26% of reduction on an average in end-to-end packet delay time when compared with normal AODV. The proposed approach achieves 7% of reduction on an average when compared with ABE. Figure 3.14 reports session admission
performance of M_AODV. The normal AODV admits almost all the incoming sessions if its routing method is able to find the path between the sending and the receiving nodes. This is happening because of the lack of admission control procedure in its routing methodology. As per the admission control algorithm M_AODV blocks nearly 30% of the incoming requests due to the deficit of bandwidth. Though 30% of incoming requests are denied in M_AODV, QoS effectiveness is considerably boosted in the proposed approach. This aspect is illustrated in Figure 3.15. When compared with normal AODV, M_AODV shows 20% of improvement in the QoS effectiveness. M_AODV achieves 8% of improvement in the QoS effectiveness when compared with the admission control process of ABE.

Figure 3.14 Session admission ratio of M_AODV
In this chapter, QoS supportive M_AODV routing algorithm for ad hoc networks is proposed. The existing AODV performs routing with low control overhead and effective packet transmission. But it does not have QoS support. The normal AODV is enhanced to perform path finding that meets the application stipulated bandwidth requirement. M_AODV is designed in such a way that it deals with common medium sharing problem of the ad hoc networks effectively. It implements path finding with less overhead by adopting passive approach of listening to the medium. Simulation results show that it performs better than normal AODV and ABE approach in terms of throughput and control message overhead. In the proposed approach, number of packets dropped due to heavy load condition and the average end-to-end packet delay are considerably reduced in comparison with ABE. QoS effectiveness of the proposed M_AODV is increased significantly when compared with ABE approach.