Quality of Service (Qos) Neighbor Routing In Grid and Triangular Mesh Topologies of Wireless Mesh Network

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ABSTRACT: Quality of Service routing is constructing a route with enough resources for the QoS parameters. The routing protocols play a crucial part in providing quality service for Wireless Mesh Network (WMN). In this paper, the existing AODV protocol is enhanced to provide QoS in routing the packets as it may lead to node failure, congestion due to loss of energy and increased queue length. In the route construction process, initially the protocol focus on selecting a best forwarding node based on the node’s maximum net energy. Second, AODV is enhanced to construct a route by selecting a forwarding neighbor based on minimum queue length. Finally, the EEQ-AODV (Efficient Energy and Queue AODV) protocol selects the efficient path based on energy and queue length factors. The above mentioned tasks have been analyzed in Grid and Triangular Mesh topologies of Hybrid WMN architecture by considering the metrics Packet Delivery Ratio(PDR), dropped packets, average end-end delay, routing overhead and average throughput using NS-2. EEQ-AODV protocol is analyzed with the metrics energy consumed/packet and lifetime of the network.

KEYWORDS: QoS Routing, Energy, Wireless Mesh Network, Queue, Grid Topology, Triangular Mesh Topology, Energy Consumption and Network Lifetime

1. INTRODUCTION

Wireless Mesh Networks(WMN) are constructed with multihop way in which nodes are communicated easily through mesh routers. The Mesh Routers, Mesh Clients and Gateway are included in WMN architecture. The mesh routers form a mesh backbone through which the mesh clients access the network. One or more mesh routers can act as gateways to connect the network to the Internet using wired connection whereas the mesh backbone linked with wireless connection. The mesh routers and the gateways are placed in statically and the mesh clients are dynamic devices. WMN provides low cost internet access in countryside, large coverage area and to all users due to its less wireless functionality[1]. Fig. 1 shows the architecture of WMN.

The applications of WMN includes Health Care, Industrial Applications, Disaster recovery, Fast and easy Broadband Access in Rural Areas, Extended Wireless Coverage, Remote Monitoring and Multimedia Home Networking etc[2][3].

![Figure 1. Architecture of Wireless Mesh Network](Image)

A. Motivation of the Study

The current applications of WMN needs distant area network coverage, fast internet access and less utilization cost to provide effective networking service to the society[4][5]. The efficient route construction process plays a vital role in WMN for providing above to the users in the network. One way of constructing an efficient route from the source to the destination is by choosing a best neighbor for forwarding the packets in the transmission.

WMN uses AODV(Ad-hoc On-demand Distance Vector)[6] routing protocol to achieve better transmission in the network. In this protocol, the routing metric hop count is used for choosing the route between source and destination. This hop count metric does not assure AODV to select best route for the transmission. The default route construction process of AODV is not assured that will always lead to quick and successful delivery of packets to the destination. Occasionally the nodes in the route may be dead due to less energy and failed failure and bottleneck may be happened because of congestion.
Hence, in this paper, the problem of node failure, congestion and delay occurred during the transmission and it can be reduced by considering the QoS factors energy and queue length. Initially, the node failure problem is reduced by considering the energy as a metric to select an efficient neighbor during the transmission. Subsequently, the congestion and delay problems can be reduced by considering the queue length in the neighbor selection process. Finally, energy and queue length factors are combined to select an efficient forwarding neighbor in the transmission.

The paper is organized as follows: Section 2 presents the review of literature, section 3 deals with the QoS metrics; section 4 shows Experimental Setup of the Proposed Work; section 5 discusses proposed AODV in WMN. Section 6 describes simulation process and results and section 7 presents the conclusion and future scope.

II. REVIEW OF LITERATURE

This section discusses the energy-based and queue or load-aware routing approaches and algorithms which are available in WMN.

In 2018, Tawfik Al-Hadhrami et al[7] analyzed the various routing selection schemes based on power and they proposed a power aware routing algorithm (PARA) for Wireless Mesh Networks. The proposed algorithm checks the power of next node and constructs optimal paths for sending packets. The work considered the total power of a channel and selects the channel which is guaranteed to send packets without any power loss. The simulation results proved that the PDR values were increased and there was a reduction in the overhead and delay. In 2016, Hui Lin et al[8] proposed a new protocol called PSGR, which is a privacy-aware, secure and energy-aware green routing protocol. This protocol implemented in software-defined HWMMNs and it provided security and robust privacy protection and reduces energy consumption. The protocol consists of dynamic reputation mechanism and a multi-level hierarchical key management to protect against the identity attacks and provide privacy protection in HWMMNs. The experimental analysis showed that the PSGR provides better performance in terms of Packet Delivery Ratio, throughput and energy efficiency.

In 2015, Chih-Min Yu et al[9] proposed an energy-aware routing protocol P-AODV. This protocol designed with Passive Power Control algorithm for the purpose of increasing efficiency of energy in wireless mesh networks. It includes two phases such as signal detection and power setting. In signal detection phase, during the route discovery phase the optimum power level of the upstream nodes are calculated by the downstream intermediate nodes using RSSI. In the second phase, RREP packet adjusts the energy level of upstream nodes with the optimum power level of downstream nodes. The simulation results indicated that the proposed protocol reduced energy consumption as more than 30% than traditional AODV. In 2013, Maria Zogkou et al[10] proposed a new energy aware routing metric for the IEEE 802.11 Hybrid Wireless Mesh Protocol. This protocol by default uses Air Time Link metric and it does not take into account the energy of nodes during the route construction process. The proposed routing metric considers the residual energy of nodes for the route construction process with maximum energy. The simulation results showed that the proposed metric provides increased network lifetime though it has tiny higher delay in the network.

In 2018, Shota Kubota et al[11] proposed a hybrid load balancing routing method for large-scale WMNs. In this method, the distributed routing algorithm and route reconstruction are designed based on OpenFlow. The forwarded control packets of distributed routing algorithm are added with the delay time taken in relation with the load of the node. The traffic flow details are collected frequently from the network and heavily loaded paths are reconstructed. The performance of the proposed OpenFlow based route construction method is better than the without reconstruction process.

In 2015, Kruti.N.Kapadia et al[12] proposed a new protocol called EAOMDV-LB for multi-radio multiple interface wireless mesh networks. This new protocol reduces the congestion problem using proposed airtime link cost metric and provided a load balancing scheme to evade heavily loaded nodes by computing queue utilization of multiple interfaces to provide optimal path for the transmission. In 2011, Mohammed Gumel et al[13] proposed a modified AODV routing protocol with a load balancing technique. The modified protocol constructs a route by considering the present load of the intermediate nodes and gateways. The performance of the modified protocol is compared against conventional AODV and the observed results indicated that the modified protocols work well and they proved that all nodes in the network are equally balanced and it utilized all gateways efficiently.

The energy based and queue based routing processes are discussed in above research approaches. Though the load based and energy based routing schemes provides better performance separately in WMNs the combination of energy and queue routing scheme can provide better results than the single approach. The energy and queue based route is constructed in multi-channel multi-interface wireless mesh network was carried out in [14]. In this paper, the proposed research work paid more attention to develop the combination of energy and queue aware routing approach in conventional WMN.

III. QUALITY OF SERVICE (QOS) METRICS

A. Energy

The node’s energy decreases when it sends or receives packets in the transmission. Energy is an important factor for solving the node failure problem. During the transmission process, if the nodes participate in more traffic leads to congestion in the network and the nodes loose its energy quickly. This cause makes the nodes detached from the path at the earliest and it increases the route discovery process and it leads to the performance degradation of the network[15].

Further, the nodes with maximum energy may sit idle and nodes with large queue length create congestion, packet loss, huge delays and unbalanced traffic.
The reactive or on-demand routing protocols construct a route based on the demand basis. The earlier disconnection of node from a route makes the protocol to discover a new route for the transmission. The WMN applications require strong and healthy route to transmit the packets in short span of time. The process of selecting the maximum net energy node as forwarding neighbor in the route discovery process achieves the stable and active route for the transmission and it progresses the performance in terms of network throughput.

The energy-support capability of node is provided by Energy Model Update[16] in NS-2. It informs node its current energy level. The Table 1 shows the values of energy parameters [17] set in the proposed work.

| Option       | Values    |
|--------------|-----------|
| energyModel  | EnergyModel |
| initialEnergy| 100 Joules |
| rxPower      | 35.28e-3W  |
| txPower      | 31.32e-3W  |
| idlePower    | 712e-6W    |
| sleepPower   | 144e-9W    |
| transitionTime| 0.003 s   |

The energy values are represented in joules. The following equation (1) is used for converting power(W) to energy(J):

\[ \text{Energy}_{\text{joules}} = \text{Power}_{\text{watt}} \times \text{Time}_{\text{seconds}} \]  

(1)

Each node depletes its txPower and rxPower energy when a packet sends and receives. The pkt_size and bandwidth are used to find the time required to transmit(txTime) and receive a packet(rxTime). The calculation of txTime and rxTime is shown in equations (2) and (3).

\[ \text{txTime} = \frac{\text{pkt}_{\text{size}}}{\text{bandwidth}} \]  

(2)

\[ \text{rxTime} = \frac{\text{pkt}_{\text{size}}}{\text{bandwidth}} \]  

(3)

The energy spent at the transmission and reception of a packet is determined by the following equations (4) and (5).

\[ \text{TxEnergy} = \text{txPower} \times \text{txTime} \]  

(4)

\[ \text{RxEnergy} = \text{rxPower} \times \text{rxTime} \]  

(5)

B. Queue Length

During the packet transmission, the packets are waiting in the queue buffer before it gets process. The number of packets waiting in the queue is called as queue length. This factor solves congestion and transmission delay issues and it reduces these problems by selecting the best neighbor based on the node’s queue length. The default minimum hop count routing decision, selects the route only by considering the hop count irrespective of its queue length. Due to this, the same node may participate in more than one route leads to congestion in the routes and raises delay of sending the packets to the destination. Thus, Load Balanced Routing is necessary to decrease a delay and to provide a congestion free route in the network. In ad-hoc networks, many routing protocols [18][13] have been proposed to accomplish a load balancing scheme. These protocols can balance only the traffic among the gateway nodes[19][20] but our proposed work considers nodes queue length to assess the load among the entire network nodes.

IV. EXPERIMENTAL SETUP OF THE PROPOSED WORK

The proposed work considers the Hybrid Wireless Mesh Network architecture with Multi-Channel Multi-Interface approach. The mesh routers in the network model are equipped with two interfaces and the transmissions are carried out through two channels. In this paper, two different scenarios - Grid topology and Triangular Mesh topology are used for analyzing the performance of the proposed work in WMN environment.

A. Grid Topology

In the first scenario, mesh routers are positioned in a Grid Topology of size 7X7 which is shown in Fig. 2. All the routers are placed in an equal distance of 100m.

![Fig. 2. Grid Topology](image)

B. Triangular Mesh Topology

In the second scenario, the mesh routers are arranged in a Triangular Mesh topology[21] as shown in Fig. 3. In this topology, the mesh routers are arranged in triangle shapes in such a way that each mesh router has six nearest neighbors.

![Fig. 3. Triangular Mesh Topology](image)
In both the topologies, the network further consists of 100 randomly placed mesh clients. The mesh clients are placed as one or two hop neighbors of mesh routers. The concurrent CBR flows are established between mesh clients. The simulation area of 1200 x 1200 meters is used for placing the mesh routers and mesh clients. The transmission rate, transmission range, packet size and the simulation time are set as 1MB, 250m, 512 bytes and 200s respectively.

V. ENHANCEMENTS OF AODV PROTOCOL

- Task 1: Selection of Forwarding Neighbor based on Maximum Net Energy - EAODV
- Task 2: Selection of Forwarding Neighbor based on Minimum Queue Length - QAOVD
- Task 3: Selection of QoS Neighbor based on Energy and Queue - EEQ-AODV

Neighbor List Maintenance

In the proposed work, the protocols collect node’s neighbor information by sending periodic HELLO messages to its immediate neighbors. The neighbors store id (node-id) of nodes which send the HELLO messages. The active neighbors receive RERR packet during the link break of a node.

RREQ and RREP Packet

A Source disseminates RREQ packet when it requires a path to a destination. This can happen if the source sends packets to the destination as a first time or if a path constructed between them is invalid or expires. A RREP packet is used for sending the HELLO messages to its neighbors. The nodes receives RREQ packet sends RREP packets if it is a destination otherwise it is having a route to the destination. The RREQ and RREP packets act a crucial part for discovering the routes in AODV.

To enhance AODV, in the proposed tasks, the control packets RREQ, RREP and Neighbor table needs modification according to the QoS requirements.

A. Task 1: Selection of Forwarding Neighbor based on Maximum Net Energy

As the first task, the problem due to energy loss is considered which is addressed by enhancing the AODV protocol as EAODV for constructing the route based on the selection of maximum net energy neighbor for the transmission. This task involves with the following steps.

- Modified of RREQ and RREP Packets
- Neighbor Selection Based on Maximum Net Energy

Modified RREQ and RREP Packets

The proposed EAODV protocol modified the RREQ and RREP control packets of AODV with inclusion of fields RREQST_ENRGY and FR_NEBR and RREPY_ENRGY.

- ENERGY_THROLD value is assigned to RREQST_ENRGY field.
- The id of neighbor which has maximum energy will be stored in FR_NEBR field.
- The energy value of a node at the time of reply will be stored in RREPY_ENRGY field in RREP packet.

The HELLO message is sent through the RREP packet. The HELLO message is modified to maintain the information such as node’s net energy in addition to the existing information such as msgtype, hop_count, dst, dst_seqno and lifetime. The HELLO message format is shown below. The neighbors store dst as NBR_id and net_energy as NBR_Energy in their neighbor table.

HelloMsg(msgtype, hop_count, dst, dst_seqno, lifetime, net_energy)

Neighborhood Selection Based on Maximum Net Energy

The main task of EAODV protocol[22] is selecting the maximum energy neighbor as forwarding neighbor for transmission. Initially, the nodes are assigned with 100J energy. The minimum energy value which is required to transmit the packet is assigned to ENERgy_THROLD. The following are the tasks involved in this process.

- Modifying Neighbor Table
- Adding MaxNetNBR() procedure for the selection of Maximum Net Energy Neighbor

Modifying Neighbor Table

The net energy value of each node is sent through the HELLO message. The node receives HELLO message and it records the NBR_id, NBR_Expire and NBR_Energy values in their neighbor table. Hence, the node’s neighbor table is added with the NBR_Energy field.

Adding MaxNetNBR() procedure for the selection of Maximum Net Energy Neighbor

A new MaxNetNBR() procedure is integrated in the EAODV protocol. When route discovery process starts, the source examines routing table for the availability of route to the destination, if a route is available for that destination, it starts its transmission towards that available route. If a route is not available in the routing table, the RREQ packet will be sent by the source to its immediate neighbors. Prior this broadcasting process, the source or the node which receives a RREQ packet, calls the MaxNetNBR() procedure by passing current node-id as a parameter. This procedure first checks whether the neighbors are having enough energy for the transmission by comparing their net energy value with ENERGY_THROLD. The neighbors those satisfying the above condition are stored in the ABOVE_THRNBR list. Next, the procedure determines a neighbor which has maximum net energy among the ABOVE_THRNBR list. The id of neighbor which has maximal net energy is returned by the procedure MaxNetNBR(). The FR_NEBR field of RREQ packet receives returned neighbor-id.

In the route discovery process of EAODV, the neighbor’s energy value is compared against RREQST_ENRGY and if it is lower than RREQST_ENRGY and it is not a destination then it discards the packet. If it is below the RREQST_ENRGY and it is a destination, then it is included in the route. If the neighbor’s energy is greater than the RREQST_ENRGY, then it compares its node-id with the FR_NEBR field in RREQ packet. If both are equal, the neighbor does the same above process until it reaches a destination. Once the destination is reached, the RREP packet is sent towards the source by assigning the net energy of destination to Net_Energy field. The proposed EAODV protocol establishes maximal net energy route for the transmission.
As the second process, the existing AODV protocol is enhanced by incorporating a load balancing mechanism to select an efficient forwarding neighbor based on node’s queue length.

B. Task 2: Selection of Forwarding Neighbor based on Minimum Queue Length

The existing AODV protocol is enhanced as QAODV by incorporating a load balancing scheme for the selection of an efficient relay node based on node’s queue length. It considers the congestion and delay problems in the transmission and reduces these problems by selecting the forwarding neighbor based on minimum queue length. This task involves the following tasks.

- Modification of RREQ and RREP control packets
- Load Balancing Scheme Based on Minimum Queue Length

Modification of RREQ and RREP Packets

**RREQ Packet**

The QAODV protocol modified RREQ packet by including the RREQ_QLEN and SEL_RLY fields. The RREQ_QLEN field contains the current queue length of a node at the time of transmission. Each node has been assigned with an initial queue length which identifies the number of packets that could be buffered in the queue at a time. The node which has this maximum length will not allow any more packets buffering on the queue. Prior to the transmission, the buffer has no packets, and it is empty.

**RREP Packet**

The RREP packet is modified in QAODV by adding the Cur_QLen field. This field contains the current queue length of a node during the transmission. The nodes send HELLO message through RREP packet to record the neighbor’s details of each node. The information such as NBR_id, NBR_Expire and its current queue length as NBR_QLen are recorded by each node. The HELLO message format is as follows. The cur_qlen is a newly added field in HELLO message.

HelloMsg(msgtype, hop_count, dst, dst_seqno, lifetime, cur_qlen)

Load Balancing Scheme Based on Minimum Queue Length

The main aim of this task is selecting minimum queue length neighbor for transmission. The queue length of each node is initially assigned with 50. The following are the tasks involved in QAODV protocol.

- Modifying Neighbor Table
- Adding Eff_Relay() procedure for the selection of Minimum Queue Length Neighbor

Modifying Neighbor Table

The nodes transfer the HELLO messages with their current queue length. The fields NBR_id, NBR_Expire and NBR_QLen are recorded in node’s neighbor table.

Adding Eff_Relay() procedure for the selection of Minimum Queue Length Neighbor

The QAODV protocol is modified with a load balancing scheme using procedure Eff_Relay(). When the route discovery process starts, the source checks whether a route exists in the routing table. If it is available, it starts its transmission towards the destination through that route. If a route is not found, the RREQ packet will be sent by the source to its immediate neighbors. Prior to this broadcasting process, the source or the node which receives a RREQ packet, calls the Eff_Relay() procedure by passing current node-id as a parameter for finding out the neighbor which has minimum queue length. The neighbor which has minimum queue length is returned in SEL_RLY field of RREQ packet.

The node which receives a RREQ packet compares its node-id with the destination-id in the RREQ packet. If both are equal, RREP packet is sent towards the source. If it is not a destination, compare its node-id with the SEL_RLY field of RREQ packet. If both are equal then the node is the forwarding node and thus the RREQ packet is forwarded to its neighbors by repeating the above procedure. Otherwise, it drops the RREQ packet. This task repeats until the destination is reached.

The performance of the network can be further increased to improve the QoS in the transmission by selecting the forwarding neighbor in the route selection process with more than one constraint. The forwarding neighbor selection based on the above mentioned constraints (energy and queue length) may increase the network lifetime and decrease packet loss to a greater extent. Hence, the above proposed works have been combined by selecting the QoS neighbor with maximum net energy and minimum queue length in the route construction process.

C. Task 3: Selection of QoS Neighbor based on Energy and Queue - EEQ-AODV

The AODV protocol is modified as an EEQ-AODV (Efficient Energy and Queue AODV) protocol by selecting the QoS neighbor with maximum net energy and minimum queue length in the route construction process. Due to this selection process, the proposed protocol increases the route as well as network lifetime, decreases delay and packet loss and minimizes energy consumption.

The following are the tasks involved in EEQ-AODV protocol.

- Modification of Control Packets
- QoS Neighbor Selection

Modification of Control Packets

**RREQ Packet**

In EEQ-AODV protocol, the fields RREQST_ENRGY, RREQ_QLEN and MEMQL_NBR are newly included in RREQ packet. The modified RREQ packet format is shown in Table 2. The bolded entries indicate the newly added fields.

- ENERY_THROLD value is assigned to RREQST_ENRGY field.

The RREQ_QLEN field contains the current queue length of a node at the time of transmission.

- The neighbor which has maximum energy and minimum queue will be stored in MEMQL_NBR field.

Table 2 EEQ-AODV - Modified Format of RREQ Packet

| Type   | Flags | Reserved | Hop Count |
|--------|-------|----------|-----------|
| RREQ_ID|       |          |           |
|         |       | Destination IP Address |          |
|         |       | Destination Sequence Number |       |
|         |       | Originator IP Address |           |
|         |       | Originator Sequence Number |       |
| RREQST_ENERGY |   |           |           |
| RREQST_QLEN   |   |           |           |
| MEMQL_NBR     |   |           |           |

**RREP Packet**

The RREP packet is modified to include Net_Energy and Cur_QLen fields for sending node’s net energy and queue size. The Table 3 shows the format of revised RREP packet.

- Net_Energy field in HELLO message has been assigned with a net energy of a node. It is used for sending the net energy at the time of sending HELLO message/reply.
- Cur_QLen field contains the current queue length of a node during the transmission.

Table 3 EEQ-AODV Modified Format of RREP Packet

| Type   | Flags | Reserved | Prefix | Hop Count |
|--------|-------|----------|--------|-----------|
|        |       | Destination IP Address |        |           |
|        |       | Destination Sequence Number |    |           |
|        |       | Originator IP Address |         |           |
|        |       | Lifetime |         |           |
|        |       | Net_Energy |       |           |
|        |       | Cur_QLen |         |           |

The HELLO message is modified to maintain the information node’s energy and queue size in addition to the existing information such as msgtype, hop_count, dst, dst_seqno and lifetime. The HELLO message format is shown below. The neighbors store dst as NBR_id, net_energy as NBR_Energy and cur_qlen as NBR_QLen in their neighbor table.

HelloMsg(msgtype, hop_count, dst, dst_seqno, lifetime, net_energy, cur_qlen)

**QoS Neighbor Selection Process based on Energy and Queue Length**

The enhanced EEQ-AODV protocol selects maximum energy and minimum queue length neighbor for the transmission. In EEQ-AODV protocol, the nodes energy is initialized with 100J and queue length as 50. The following are the tasks involved in this process.

- Modifying Neighbor Table
- Adding QoS_NBR() procedure (Efficient Neighbor) for the selection of QoS neighbor with Maximum Energy and Minimum Queue Length

**Modifying Neighbor Table**

The nodes transfer the HELLO messages with their current net energy and queue length. The fields NBR_id, NBR_Energy and NBR_QLen are recorded in node’s neighbor table. The modified neighbor details are shown in Table 4.

Table 4 EEQ-AODV - Neighbor Details

| NBR_id | NBR_Energy | NBR_QLen |
|--------|------------|----------|

**Adding QoS_NBR () procedure for the selection of QoS Neighbor**

When route discovery process starts, the source calls QoS_NBR() procedure with current node-id as a parameter. In this procedure, first it finds the neighbors of current node which has the energy value above ENERGY_THRESHOLD and stores its id in the ABOVE_THRESHOLD list.

ABOVE_THRESHOLD = NBR,(NBR, NBR Energy > ENERGY_THRESHOLD)

The neighbor which has minimum queue length (minq_nbr) is selected from ABOVE_THRESHOLD list.

\[ \text{minq_nbr} = \min(\text{ABOVE_THRESHOLD} \rightarrow \text{NBR QLen}) \]

The difference of queue lengths between all nodes and minimum queue length is calculated. The neighbors which have less than THR_QLen are stored in the ENQNB list.

\[ \text{ENQNB} = \{ \text{ABOVE_THRESHOLD} \rightarrow \text{NBR QLen} - \text{minq_nbr} \} < \text{THR_QLen} \]

Finally, the procedure selects a node which has maximum net energy from the ENQNB list and returns its node-id. The selected nbr-id is stored in the MEMQL_NBR field of RREQ packet.

\[ \text{MEMQL_NBR} = \text{ENQNB} \rightarrow \text{NBR id} \] (max \( \text{(ENQNB} \rightarrow \text{Net Energy}) \))

\( 1 \leq i \leq n, 1 \leq k \leq m \)

\( (E_{\text{TH}} = \text{Energy Threshold}; \ n \text{ represents the number of neighboring nodes of current node}; \ m \text{ represents the nodes which are above } E_{\text{TH}}; \ \text{THR QLen is the minimum difference queue length value}; \ k \text{ represents number of nodes below THRLen in ABOVE_THRESHOLD list}; \ l \text{ is the index of selected NBR id}, \)

a neighbor which has maximum net energy and minimum queue length.)
After this process, the RREQ packet is sent by source towards its neighbors. If the destination is one of the neighbors, it sends RREP packet to the source node even if it has low net energy or else it checks whether the energy of node, if it is lesser value than ENERY_THROLD, it discards the packet. If the node’s energy is above the ENERY_THROLD and it is not a destination and current node-id is compared with the value of MEMQL_NBR. If both are equal, the RREQ packet is forwarded by the current node to its neighbors. The above task is repeated until the destination is reached. The RREQ_ENRGY and RREQ_QLEN field of RREP packet has been assigned with the energy and the queue length of the current node after the destination is reached. The complete route is constructed by sending a RREP towards the source. Thus the enhanced EEQ-AODV protocol constructs a steady and balanced traffic flow route for the transmission. The algorithms of EEQ-AODV protocol’s route discovery process and its neighbor selection process are shown in Fig 4 and 5.

**Algorithm**

```c
begin
  //initialize node’s energy and queue length
  Node->Energy = 100 Joules;
  Node->QLength = 50;
  RREQ->RREQST_ENRGY=ENERY_THROLD;
  RREQ->RREQST_QSZE = node’s current queue size;

  //neighbor connectivity
  //Hello Packet hp(msgtype, hop_count, dst, dst_seqno,
  //lifetime, net_energy, cur_qlen)
  Node->sendHello();
  NBR->recvHello(hp);

  while (!NBR) {
    // NBR receives a hello; 1≤j≤k
    NBR->NBR_id = hp->dst;
    //k is the list of neighboring nodes
    NBR->NBR_Energy = hp->net_energy;
    // Neighbor stores id, energy, and queue length in neighbor table
    NBR->NBR_QLen = hp->cur_qlen;
  }

  //route discovery process
  RREQ->MEMQL_NBR = QoS_NBR (CurrentNode->id);
  do {
    if (CurrentNode->id == src) 
      sendRequest ();
    else
      forward ();
    if (CurrentNode->Net_Energy < RREQ->RREQST_ENRGY
      and CurrentNode->id != RREQ->Dest_id)
      discard(pkt);
      return;
    }
    if (CurrentNode->Net_Energy > RREQ->RREQST_ENRGY
      and CurrentNode->id != RREQ->
      Dst_id))
  }
```

**Fig 4. EEQ-AODV Route Discovery Process**

```c
// QoS _NBR(CurrentNode->id)
begin
  while (!NBR) { //Neighbor list contain nodes
    if (NBR->Net_Energy > ENERY_THROLD)
      ABOVE_THRNBR_m = NBR->NBR_id;
    //extract minimum queue length value from
    //ABOVE_THRNBR list
    minq_nbr=min(ABOVE_THRNBR_m->NBR_QLen);
    if (((ABOVE_THRNBR_m->NBR_QLen-inq_nbr)<THR_QL) { 
      // THR_QL minimum queue length difference
      ENQNBR_s=ABOVE_THRNBR_m;
      id = ENQNBR_s->NBR_id(max(ENQNBR_s->NBR_Energy))
    }
    return(id);
  }
end:

//ABOVE_THRNBR, is the array of nodes greater than energy threshold.
//ENQNBR is the list of neighbor’s queue length < THR_QL.
//id is the selected neighbor which has maximum energy
//from ENQNBR_s.
```

**Fig 5. EEQ-AODV Neighbor Selection Process**

VI. SIMULATION PROCESS & RESULTS

A. Metrics Used for Analysis

The following metrics are considered in the analysis process.

**Packet Delivery Ratio (PDR)**

It is the proportion of the number of packets transmitted by sources and the number of packets received by destinations. The packet delivery ratio is similar to network throughput.

\[
PDR = \frac{N_{pkts\_received}}{N_{pkts\_sent}} \times 100
\]

**Packet Loss**

It is the total number of packets lost during transmission.

\[
N_{pkts\_lost} = N_{pkts\_sent} - N_{pkts\_received}
\]

**Average End-to-End Delay**

It is the proportion between the cumulative delay and the number of packets received(Npkts_received).

\[
\text{Avg. End-to-End Delay} = \frac{\text{Total_Delay}}{N_{pkts\_received}}
\]
Average Throughput (Kbps)
This is the average rate of packets delivered over a communication channel to the destination. The higher the throughput, the higher the performance.

\[
\text{Avg. Throughput} = \frac{N_{\text{Delivered Bits}}}{1000}
\]

Routing Overhead
It is the proportion of the number of control packets created for transmission and the number of data packets received during the simulation time.

\[
\text{Routing overhead} = \frac{N_{\text{data pkts received}}}{N_{\text{control pkts generated}}}
\]

B. Observed Results
For the evaluation of EAODV, QAODV and EEQ-AODV protocols in WMN architecture, a network model of grid topology as well as the triangular mesh topology has been created. The Table 1 and Table 5[2] shows the parameters used for the analysis process. The connections are established among mesh clients using CBR. The performance of EAODV, QAODV, EEQ-AODV protocols are analyzed using the results of existing AODV for the considered metrics.

Table 5 Simulation Parameters

| Parameter          | Value                        |
|--------------------|------------------------------|
| Simulation         | NS-2                         |
| Simulation area    | 1200 x1200m                  |
| Mac Protocol       | IEEE 802.11                  |
| Antenna            | OmniAntenna                  |
| Simulation time    | 200 s                        |
| Transmission range | 250 m                        |
| Channel Capacity   | 9 MB                         |
| Packet Size        | 512 bytes                    |
| Transmission rate  | 1Mb                          |
| Connection         | CBR(UDP)                     |
| No. of Mesh Clients| 100                          |
| No. of Mesh Routers| 49(Grid), 46(Trimesh)        |
| Routing Protocol   | EAODV, QAODV, EEQ-AODV and AODV |

Scenario 1: Grid Topology
The charts in Fig 6.1 to 6.5 shows the performance of the enhanced protocols EEQ-AODV, EAODV, QAODV and existing AODV by varying CBR connections for the considered metrics.
Fig 6.4 Routing Overhead Vs CBR Connections

Fig 6.5 Average Throughput Vs Connections

Fig 6.6 Packet Delivery Ratio Vs CBR Connections

Fig 6.7 Packet Loss Vs CBR Connections

Fig 6.8 Average End-End Delay Vs CBR Connections

Scenario 2: Triangular Mesh Topology

The charts in Fig 6.6 to 6.10 indicates the experimental outcome of the enhanced EEQ-AODV, EAODV, QAODV and existing AODV protocols by changing CBR connections in triangular mesh topology in the form of graphs.
Quality of Service (Qos) Neighbor Routing In Grid and Triangular Mesh Topologies of Wireless Mesh Network

of energy consumed per packet and the network lifetime is performed in both Grid and Triangular Mesh topologies of EEQ-AODV protocol and compared with the AODV protocol.

Energy Consumed per Packet

The energy consumed per packet is the division of total energy consumed in the network and the number of packets received.

Figures 6.11 and 6.12 show the observed results of energy consumption in Grid and Triangular Mesh topologies of EEQ-AODV and AODV protocols. The charts indicate that the EEQ-AODV protocol consumes less energy than AODV protocol in all CBR connections to provide green networking.

Network Lifetime

The network lifetime is known as the time at which a node in the network loses its energy during the transmission which means the first appearance of a dead node in the network. The network lifetime of EEQ-AODV and AODV protocols in both Grid and Triangular Mesh topologies is shown in Tables 6 and 7.
In the above table at CBR Connections 5, the EEQ-AODV protocol has no dead node, i.e. no node loses its energy during the simulation.

The percentage improvement of EEQ-AODV protocol in Grid and Triangular mesh topologies for the considered performance metrics is shown in Tables 8 and 9.

**Table 6 Network Lifetime in Various CBR Connections - Grid Topology**

| CBR Connections | Network Lifetime (sec) | AODV | EEQ-AODV |
|-----------------|------------------------|------|----------|
| 5               | 165.30                 | Nil  |          |
| 10              | 166.08                 | 188.26 |         |
| 15              | 167.06                 | 182.57 |        |
| 20              | 166.03                 | 175.25 |        |
| 25              | 167.06                 | 177.94 |        |
| 30              | 167.32                 | 179.49 |        |

In triangular mesh topology, the EEQ-AODV protocol reduces the routing overhead by 23.17%, average end-to-end delay by 24.35%, and also it increases the network throughput by 62.01% and packet delivery ratio by 23.17%. Furthermore, the EEQ-AODV protocol reduces the energy consumption by 42.95% and it increases the network lifetime by 5.16% in Triangular Mesh topology.

**Table 7 Network Lifetime in Various CBR Connections - Triangular Mesh Topology**

| CBR Connections | Network Lifetime (sec) | AODV | EEQ-AODV |
|-----------------|------------------------|------|----------|
| 5               | 131.76                 | 138.87 |        |
| 10              | 139.74                 | 142.0 |        |
| 15              | 139.74                 | 143.68 |        |
| 20              | 161.74                 | 170.21 |        |
| 25              | 150.60                 | 170.21 |        |
| 30              | 135.53                 | 138.53 |        |

In this paper, the node failure, congestion and delay problems that are occurred during the transmission are considered. The QoS factors Energy and Queue length are used for reducing the above problems. Initially, these two parameters are applied independently. As the first process, the existing AODV protocol is enhanced as EAODV, which constructs the route by selecting an efficient forwarding neighbor based on maximum remaining energy. Next, the AODV protocol is enhanced as QAODV protocol by incorporating with a load balancing scheme. The QAODV protocol constructs a route by selecting an efficient forwarding neighbor based on minimum queue length. Finally, the features of both EAODV and QAODV protocols are combined and it is enhanced as EEQ-AODV protocol. As the EEQ-AODV protocol considers the energy and queue are the factors in the selection of QoS neighbor, it creates congestion-free and stronger route for the transmission. The performance evaluation of EEQ-AODV was analyzed in both topologies of the Wireless Mesh Network and compared with the EAODV, QAODV and AODV protocols. Hence, from the observed results, the EEQ-

**Table 8 Percentage of Improvement in EEQ-AODV - Grid Topology**

| Performance Metrics | Grid Topology | AODV (%) | EEQ-AODV (%) | Percentage of Improvement (%) |
|---------------------|---------------|----------|--------------|-------------------------------|
| PDR                 |               | 42.26    | 64.83        | 53.43                         |
| Packet Loss         |               | 57.74    | 35.18        | 39.08                         |
| Avg. End-to-End Delay |            | 97.07    | 77.34        | 20.33                         |
| Routing Overhead    |               | 0.53     | 0.37         | 29.29                         |
| Avg. Throughput     |               | 2460.23  | 4064.89      | 65.22                         |
| Energy Consumption  |               | 0.09     | 0.05         | 44.31                         |
| Network Lifetime    |               | 166.48   | 183.92       | 10.48                         |
| Overall Percentage of Improvement | | 37.45% | | |

From the observed results, the EEQ-AODV protocol route selection process increases the route lifetime with decrease in routing overhead by 29.29%, average end-to-end delay by 20.33% and packet loss by 39.08%, and increase in the network throughput by 65.22% and packet delivery ratio by 53.43% in Grid Topology. Moreover, the EEQ-AODV protocol reduces the energy consumption by 44.31% and it increases the network lifetime by 10.48% in Grid Topology.

**Table 9 Percentage of Improvement in EEQ-AODV Protocol - Triangular Mesh Topology**

| Performance Metrics | Triangular Mesh Topology | AODV (%) | EEQ-AODV (%) | Percentage of Improvement (%) |
|---------------------|--------------------------|----------|--------------|-------------------------------|
| PDR                 |                          | 50.46    | 62.15        | 23.17                         |
| Packet Loss         |                          | 60.20    | 37.85        | 37.13                         |
| Avg. End-to-End Delay |                        | 114.19   | 86.38        | 24.35                         |
| Routing Overhead    |                          | 0.52     | 0.36         | 29.87                         |
| Avg. Throughput     |                          | 2593.50  | 4201.78      | 62.01                         |
| Energy Consumption  |                          | 0.07     | 0.04         | 42.95                         |
| Network Lifetime    |                          | 143.19   | 150.58       | 5.16                          |
| Overall Percentage of Improvement | | 32.09% | | |
AODV protocol creates the route with small delay, higher PDR value, decreased overhead, minimum loss of packets, better throughput and less energy consumption in both Grid and Triangular Mesh topologies. In future, the factors such as transmission rate, link quality and bandwidth may be considered for the selection of forwarding neighbor in the route construction process of WMN.

The overall percentage of improvement in EEQ-AODV increases by 37.45% in Grid Topology and 32.09% in Triangular Mesh Topology.

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