International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-8 Issue-11, September 2019

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

I. 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.

Manuscript published on 30 September 2019.
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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].

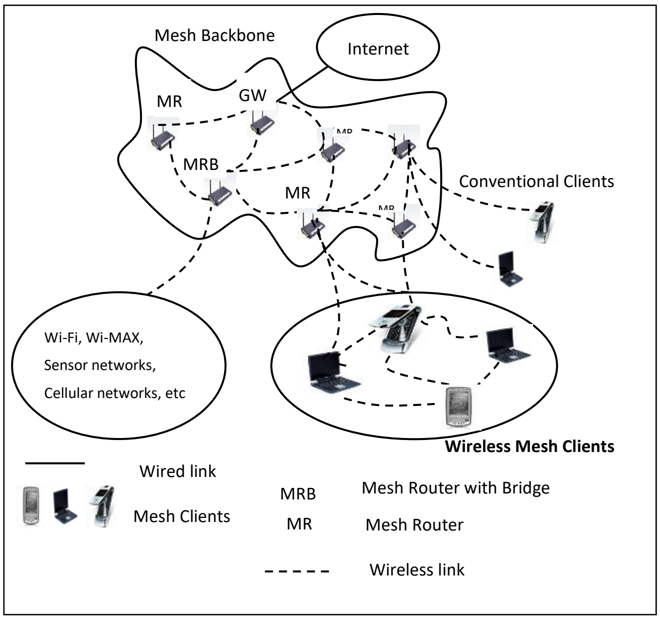

Figure 1. Architecture of Wireless Mesh Network

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 HWMNs 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 internal attacks and provide privacy protection in HWMNs. 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 multiradio 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].

Retrieval Number: K15850981119/19©BEIESP
DOI: 10.35940/ijitee.K1585.0981119
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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.

Table 1 Energy Parameters Details

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):

$$Energy_{jolues} = Power_{watt} * Time_{seconds} \quad (1)$$

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).

$$txTime = pkt\_size/bandwidth \quad (2)$$

$$rxTime = pkt\_size/bandwidth \quad (3)$$

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

$$TxEnergy = txPower \times txTime \quad (4)$$

$$RxEnergy = rxPower \times rxTime \quad (5)$$

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.

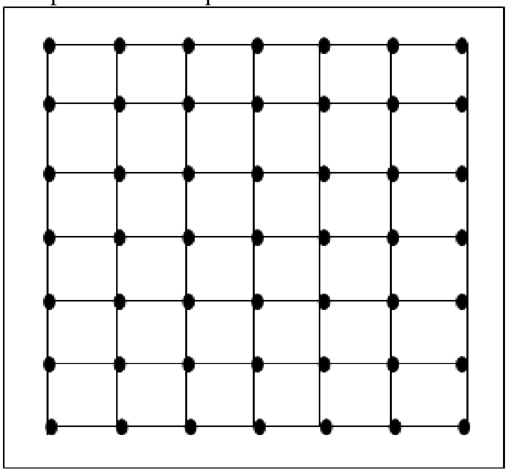

Fig. 2. Grid Topology

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.

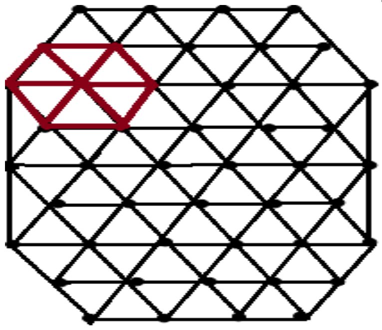

Fig.3. Triangular Mesh Topology

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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 - QAODV
- 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.

- ENERY_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)

Neighbor 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 ENERY_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 ENEGY-THROLD. The neighbors those satisfying the above condition are stored in the ABOVE_THRNBR list. Next, the procedure determines a neighbor which has maximal 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.

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DOI: 10.35940/ijitee.K1585.0981119
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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 QoSe 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 RREQST_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_ENRGY			
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_Expire
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 ENERY_THROLD and stores its id in the ABOVE_THRNBR list.

$$ABOVE\_THRNBR_m = NBR_i(NBR_i \rightarrow NBR\_Energy > E_{TH}$$

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

$$minq\_nbr = min(ABOVE\_THRNBRm \rightarrow NBR\_QLen)$$

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

$$ENQNBRk = (ABOVE\_THRNBRm \rightarrow NBR\_QLen - minq\_nbr) < THR\_QL$$

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

$$MEMQL\_NBR = ENQNBRl\ NBR\_id\ (max\ (ENQNBRk \rightarrow Net\_Energy))$$
$$1 \leq i \leq n,\ 1 \leq k \leq m$$

(E_{TH}-Energy Threshold; n represents the number of neighboring nodes of current node; m represents the nodes which are above E_{TH}; THR_QL is the minimum difference queue length value; k represents number of nodes below THR_QL in $ABOVE\_THRNBR_m$ list; l 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 neighbor, 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 RREPY_ENRGY and RREP_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

begin
//initialize node's energy and queue length
 Nodei->Energy =100 Joules;
 Nodei ->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)
     Nodei ->sendHello();
     NBRj->recvHello(hp);
                              // NBRj receives a hello;  1≤j≤k
    NBRj ->NBR_id =hp->dst;
                           //k is the list of neighboring nodes
    NBRj ->NBR_Energy =hp->net_energy;
                          // Neighbor stores id, energy, and
                              queue length in neighbor table
    NBRj ->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  CurentrNode->id != RREQ->Dest_id)
 {
                 discard(pkt);
                 return;
   }
 if (CurrentNode->Net_Energy > RREQ->
RREQST_ENRGY and  CurrentNode->id != RREQ->
                                                  Dst_id))
 {
      if (RREQ->MEMQL_NBR == CurrentNode->id)
     {
        Do rear route entry process
     } }
 }while(CurrentNode->id != RREQ->Dst_id);
 sendReply();            //destination sends route
 end;                        //reply towards source
```

Fig 4. EEQ-AODV Route Discovery Process

```
// QoS _NBR(CurrentNode->id)
begin
 while (!NBRi)    {      //Neighbor list contain nodes
  if (NBRi->Net_Energy >ENERY_THROLD)
            ABOVE_THRNBRm = NBRi->NBR_id;
 } //extract minimum queue length value from
//ABOVE_THRNBR list
 minq_nbr=min(ABOVE_THRNBRm ->NBR_QLen);
if ((ABOVE_THRNBRm->NBR_QLen-inq_nbr)<THR_QL) {
// THR_QL minimum queue length difference
 ENQNBRk =ABOVE_THRNBRk;
id = ENQNBRl ->NBR_id(max(ENQNBRk-> NBR_Energy))
}
 return(id);
end;
//ABOVE_THRNBRi is the array  of nodes greater than
energy threshold.
//ENQNBRk is the list of neighbor's queue length <
THR_QL.
//id is the selected neighbor which has maximum energy
from ENQNBRk.
```

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.

$$PDR = N_{pkts\_received}/N_{pkts\_sent} * 100$$

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).

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Avg. End-to-End Delay $=Total\_Delay/N_{pkts\_received}$

. ***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.

Avg. Throughput $= N_{Delivered\_Bits}/1000$

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.

Routing overhead $= N_{data\_pkts\_received}/N_{control\_pkts\_generated}$

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.

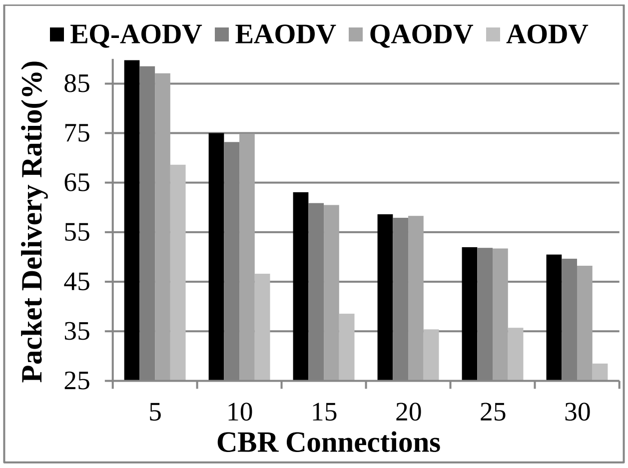

Fig.6.1 Packet Delivery Ratio Vs CBR Connections

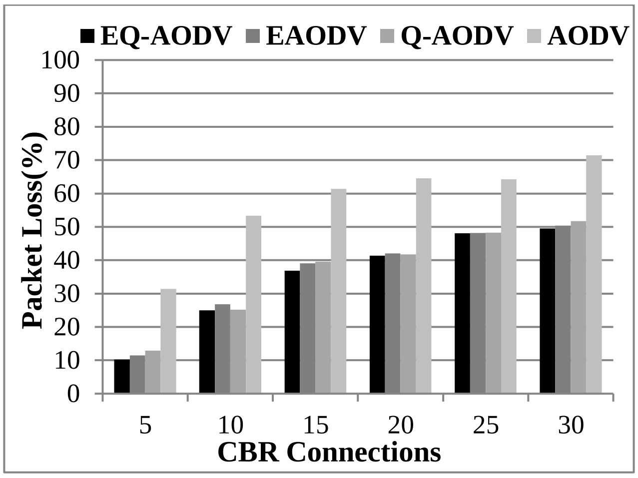

Fig 6.2 Packet Loss Vs CBR Connections

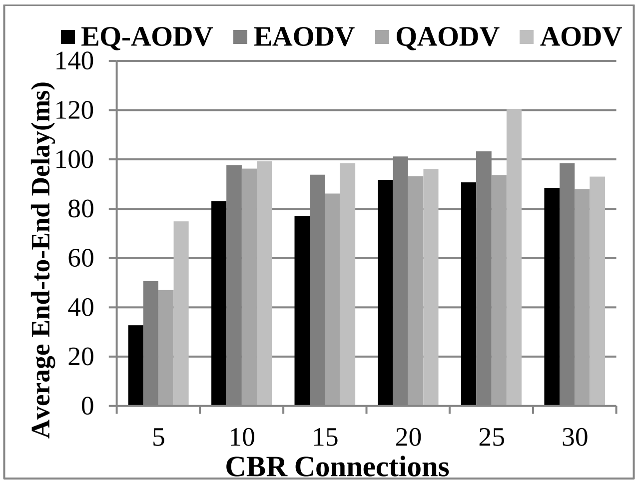

Fig 6.3 Average End-End Delay Vs CBR Connections

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International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-8 Issue-11, September 2019

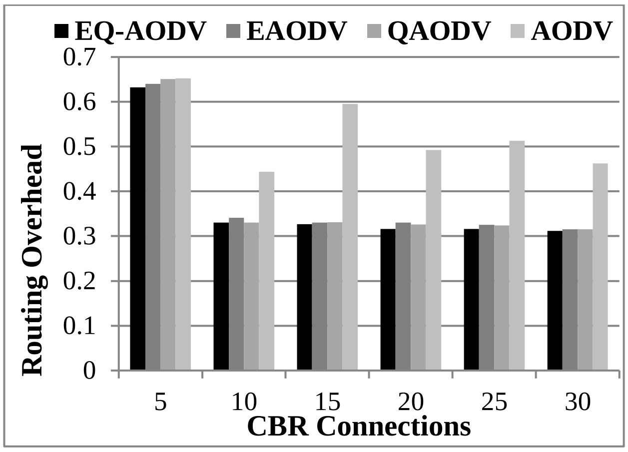

Fig 6.4 Routing Overhead Vs CBR Connections

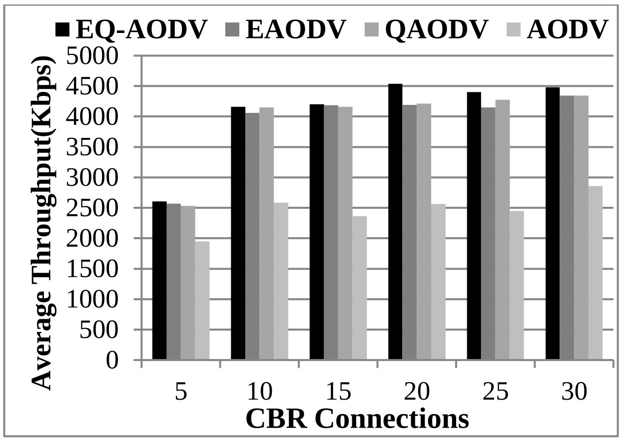

Fig 6.5 Average Throughput Vs Connections

Fig. 6.1 indicates the packet delivery ratio of EEQ-AODV, EAODV, QAODV and AODV protocol for varying CBR connections. The analysis process indicated that the PDR decreases when the CBR connections increases; Conversely, a less CBR load provides comfortable communication by producing higher PDR. However, the PDR value of the proposed protocol EEQ-AODV outperforms well when compared to other protocols in all CBR connections. When considering the packet loss, the number of dropped packets increased for increasing CBR connections. For all the traffic loads, the packet loss of EEQ-AODV is modest than EAODV and QAODV but it is significantly reduced than the AODV which is shown in Fig 6.2. Fig 6.3 shows the experimental outcomes of end-to-end delay of EEQ-AODV, EAODV, QAODV and AODV protocols. It clearly indicates that, the average end-to-end delay is decreased in EEQ-AODV than the others in the considered CBR connections except 5. However, for all traffic loads, EEQ-AODV is reduced more than AODV. From Fig 6.4, it is observed that the routing overhead is decreased when the CBR connection increases. Though the routing overhead of AODV has more variation, the EEQ-AODV has continuously decreased. Besides that, EEQ-AODV outperforms well in all traffic loads when related with the existing AODV. Fig 6.5 reveals the mean throughput by varying the CBR connections. From the analysis process, it is clearly seen that the increased CBR connections produce improved throughput. The throughput of EEQ-AODV is better in all connections to some extent than EAODV and QAODV and it is considerably increased than AODV.

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.

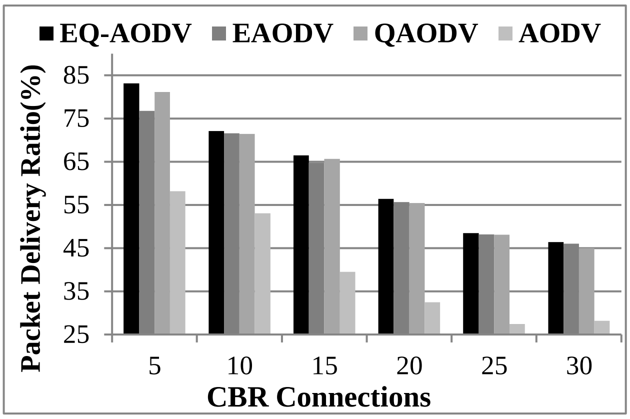

Fig 6.6 Packet Delivery Ratio Vs CBR Connections

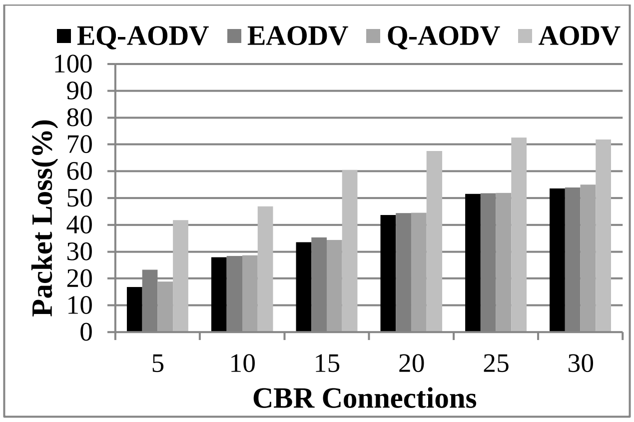

Fig. 6.7 Packet Loss Vs CBR Connections

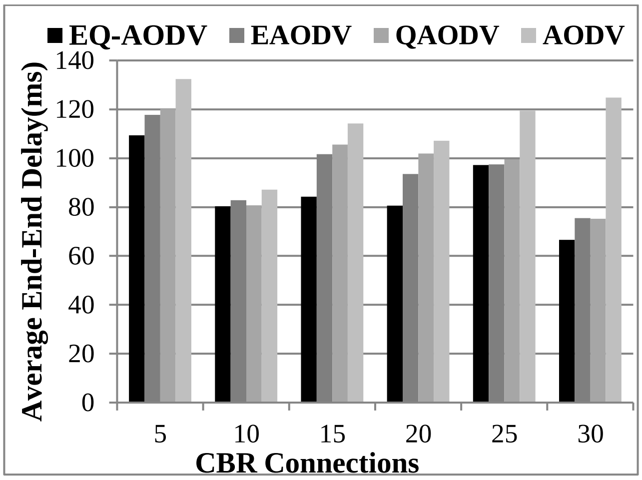

Fig 6.8 Average End-End Delay Vs CBR Connections

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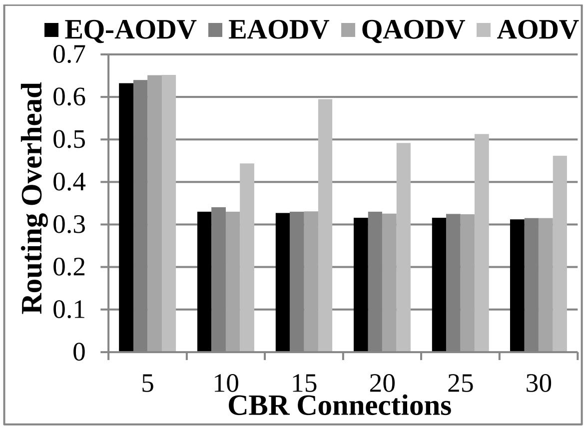

Fig 6.9 Routing Overhead Vs CBR Connections

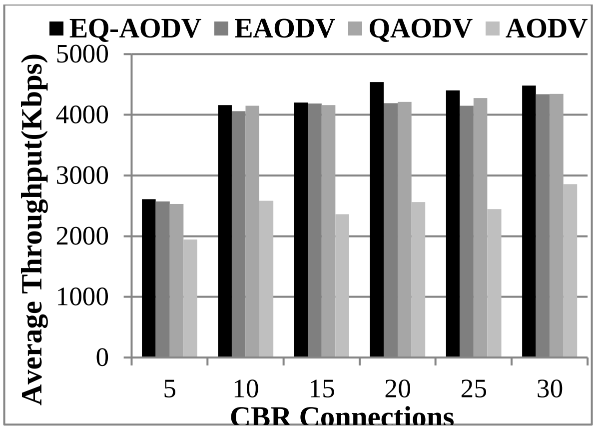

Fig 6.10 Average Throughput Vs CBR Connections

From Fig 6.6 it is revealed that the PDR of EEQ-AODV protocol increases a little bit than EAODV and QAODV. However, the PDR value of the proposed protocol EEQ-AODV outperforms well when compared to other protocols in all CBR Connections. Fig 6.7 shows the packet loss of the analyzed protocols, which is decreased well when the traffic loads are less. However, for all the traffic loads, the packet loss of EEQ-AODV is smaller than EAODV and QAODV but it is significantly reduced than the AODV. The mean value of end-end delay is decreased in EEQ-AODV protocol than other protocols in all CBR connections except 15. It is directly proportional to CBR connections which are shown in Fig 6.8. From the chart shown in Fig. 6.9, it is observed that the routing overhead of AODV is decreased than other protocols in CBR Connections 5; However for the increasing number of CBR Connections, EEQ-AODV performs well than other protocols. Form the analysis results of throughput in Fig 6.10, it is observed that the average throughput is increased when the CBR connections are increased. The throughput increases in EEQ-AODV for all CBR connections to some extent than EAODV and QAODV and it is considerably increased than AODV.

Energy Consumption

Energy consumption is recently a major concern in wireless communications to provide green networking area. Lower energy consumption in the network industries would create an impact on the environment. Though the proposed protocol EEQ-AODV considers maximum net energy neighbor for the transmission, it uses minimum energy for a packet transmission. It also increases the network lifetime by increasing the existence of the node due to the maximum net energy node for the transmission. To prove this, analysis 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.

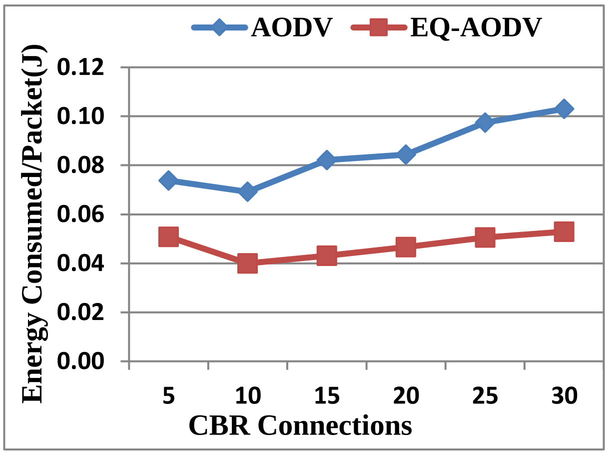

Fig 6.11 Energy Consumed per Packet Vs CBR Connections(Grid Topology)

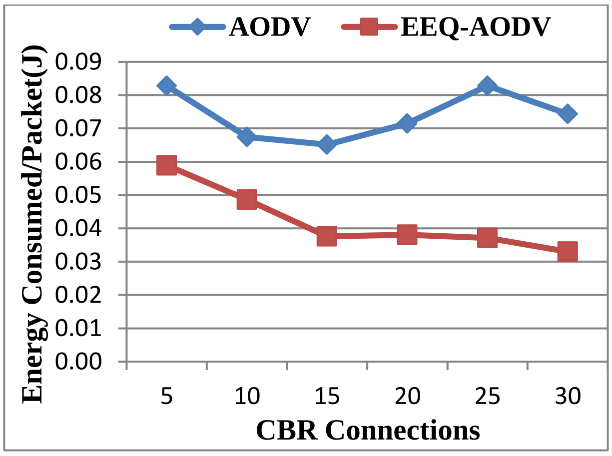

Fig 6.12 Energy Consumed/Packet Vs CBR Connections (Triangular Mesh Topology)

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.

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International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-8 Issue-11, September 2019

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 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.

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

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 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%

In triangular mesh topology, the EEQ-AODV protocol reduces the routing overhead by 29.87%, packet loss by 37.13% and 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.

VII. CONCLUSION

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.

Retrieval Number: K15850981119/19©BEIESP
DOI: 10.35940/ijitee.K1585.0981119
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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-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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