I. J. Computer Network and Information Security, **2024, 6, 20-31**
Published Online on December 8, 2024 by MECS Press (http://www.mecs-press.org/)
DOI: 10.5815/ijcnis.2024.06.02

Delay-sensitive Quality of Service Routing with Integrated Admission Control for Wireless Mesh Network

Satish S. Bhojannawar*
Department of Computer Science and Engineering, S.G. Balekundri Institute of Technology, Belagavi, India
E-mail: satishsb2007@gmail.com
ORCID iD: https://orcid.org/0000-0001-8690-978
*Corresponding author

Shrinivas R. Managalwede
Department of Computer Science and Engineering, S.G. Balekundri Institute of Technology, Belagavi, India
E-mail: srmangalwede@gmail.com
ORCID iD: https://orcid.org/0000-0003-4681-8505

Carlos F. Cruzado
Professional School of Systems Engineering, Autonomous University of Peru, Lima Peru, Peru, South America
E-mail: carlos.cruzado@autonoma.pe
ORCID iD: https://orcid.org/ 0000-0001-7471-3140

Received: 26 May 2023; Revised: 17 July 2023; Accepted: 22 August 2023; Published: 08 December 2024

Abstract: Wireless mesh networks (WMNs) extend and improve broadband Internet connectivity for the end-users roaming around the edges of the wired network. Amid the explosive escalation of users sharing multimedia content over the Internet, the WMNs need to support the effective implementation of various multimedia applications. The multimedia applications require assured quality of service (QoS) to fulfill the user requirements. The QoS routing in WMNs needs to guarantee the QoS requirements of multimedia applications. Admission control (AC) is the primary traffic control mechanism used to provide QoS provisioning. AC admits a new flow only if the QoS requirements of already admitted flows are not violated, even after the admission of a new flow. We propose a new QoS routing protocol integrated with AC called Delay-Sensitive QoS Routing with integrated Admission Control (DSQRAC) to control the admission of delay-sensitive flows. A delay-aware cross-layer routing metric is used to find the feasible path. DSQRAC is implemented using ad-hoc on-demand distance vector (AODV) routing protocol, where a delay-sensitive controlled flooding mechanism is used to forward the route request packets. In the proposed work, we adjust/reassign the channels to aid the QoS routing to increase the likelihood of accepting a new flow. The simulation results show that the performance of the proposed QoS routing protocol is better than the existing schemes.

Index Terms: Wireless Mesh Network, QoS Routing, Admission Control, Channel Reassignment, Cross-layer.

1. Introduction

WMNs are self-organizing, self-healing networks that deliver Internet services across broad coverage areas [1]. WMNs extend and improve broadband Internet connectivity for end-users roaming around the edges of the wired network. Owing to the rapid growth in the use of different real-time multimedia applications, the WMNs must fulfill QoS requirements of such applications [2]. Due to fluctuating capacity of wireless links, multi-hop transmission, and wireless channel contention, the QoS provisioning over WMN is more challenging. The use of multi-radio nodes and multiple channels in the multi-radio multi-channel WMN (MRMC-WMN) alleviates network interference and increases network capacity. But the time-varying wireless environment and real-time multimedia application's high demand for QoS repeatedly leaves the users unsatisfied with present network performance. So, the critical difficulties in developing the MRMC-WMN backbone is how to design relevant algorithms and protocols to fairly satisfy the QoS requirements of multimedia applications. Routing decisively contributes to the provision of QoS and improves the network performance. The routing protocol with QoS provisioning needs to employ a self-serving strategy to find an end-to-end routing path that meets the QoS demands of real-time multimedia applications. AC is the primary traffic control mechanism deployed to provide QoS provisioning [3]. AC accepts new flow only if sufficient network resources are available to fulfill the requirements of new and existing flows.

Here, we focus on end-to-end delay requirements of delay-sensitive multimedia applications such as live video streaming, voice over IP. These applications require a lower end-to-end delay to preserve their interactive and streaming characteristics [4]. For the delay-sensitive multimedia applications, we aim to discover a path with minimum end-to-end delay. For this, we propose a routing protocol called Delay-Sensitive QoS Routing with integrated Admission Control (DSQRAC), which is implemented using AODV [5] routing protocol. A delay-aware cross-layer routing metric is used to find the feasible path with minimum end-to-end delay. During route discovery, DSQRAC protocol uses route request (RREQ) packets to discover the path that satisfies the delay requirements of a new flow. The node forwards RREQ packets if it is able to fulfill the delay requirement. As the RREQ packets are forwarded only by the nodes that guarantee the required delay requirement, DSQRAC avoids the unnecessary flooding of RREQ packets and makes provision to save the possible network resources to be consumed by such RREQs. The availability of network resources affects the existence of a feasible path. The routing and channel assignment algorithms control the resource availability [6]. As part of route discovery, we adjust/reassign available network resources to increase the likelihood of finding a feasible path. The prime purpose is to maximize the flow acceptance rate through the interaction of routing and channel assignment. Hence, we propose a joint QoS routing and channel assignment with an integrated admission control scheme for WMNs

The rest of the paper is organized as follows. Section 2 describes the related work. Section 3 presents the system model and problem statement. DSQRAC routing protocol is presented in Section 4. In Section 5, we evaluate the performance of DSQRAC. Finally, Section 6 concludes the paper.

2. Related Works

QoS routing is a fundamental research problem in the WMNs. Many studies on QoS routing protocols have been proposed to satisfy end-to-end QoS requirements for real-time multimedia applications. Some protocols are with admission control, and some are without admission control. Here, we review the QoS routing with admission control.

The protocol proposed in [7] computes the end-to-end delay. As a stream of dummy packets used for the end-to-end delay estimation, this protocol has significant control overhead and affects the network throughput. Since the protocol does not employ a bandwidth estimation mechanism at intermediate nodes, it cannot guarantee the delivery of all the packets of every admitted flow. The protocol takes more time for path discovery. The protocol proposed in [8] has a residual bandwidth-based distributed hop-by-hop AC solution. The interference is captured using the conflict graph. Authors have assumed fixed channel capacity. Under the local maximum clique constraints, each node uses more transmission power to communicate its flow information; this extra power causes significant overhead and consumes a substantial part of the available bandwidth. The protocol proposed in [9] uses a dual threshold-based approach, where nodes regularly share their traffic statistics and estimate their available bandwidth. It uses extended-range transmission to exchange messages. The protocol is not capable of coping with multi-rate nodes and could not account for the possibility of concurrent transmissions, resulting in an underestimation of the node's available bandwidth. A joint QoS routing and centralized channel assignment protocol proposed in [10] uses with greedy approach to find a path. It uses an interference-based routing metric to find k paths. For each of the k paths, the feasibility in terms of available bandwidth is checked. If a path is infeasible, the channel assignment algorithm tries to remap the channels among nodes to make it a feasible path. The proposed group channel change procedure treats all violated links as out-of-path violated links and tries to reassign channels. The path discovery time is more and the entire process is more complex. The protocol proposed in [11] uses a distributed AC algorithm to discover two node-disjoint paths. As the protocol does not consider path stability, it subdues the performance of channel allocation mechanism. Protocol is not suitable for multi-channel networks. The protocol assumes flow demands are stable and known well in advance. This presumption is unrealistic, and it doesn't react to any network changes.

The multi-path routing protocol proposed in [12] classifies traffic into three groups and finds several high-quality paths. For load balancing and path reservation, it employs a feedback-based approach. The protocol assumes flow demands are stable and known well in advance and takes more time for path discovery. The protocol proposed in [13] uses interference-aware clique and cross-layer distributed AC protocol to support QoS in WMNs. Nodes share traffic statistics regularly and estimate their available bandwidth based on local maximal clique constraints. The AC technique only involves cluster heads and uses a feedback-based mechanism to control the congestion. Establishing a maximal clique in real-time is challenging, even for a small network, so the use of the maximum clique is quite complex. This protocol does not take into account link breakdown and dynamic channel assignment. The protocol proposed in [14] uses bandwidth estimation at each node along with delay-constrained admission control from multi-rate WMN. First, it estimates available bandwidth at each node. Then AC estimates the bandwidth to be consumed by flow and decides to admit the new flows. It also makes sure that delay requirements of real-time flows are satisfied. The protocol assumes static channel assignment and makes an effort to admit the flows on the assigned channels only. Energy-aware cross-layer-based protocol proposed in [15] uses a bandwidth-aware AC mechanism for allocating bandwidth to support different applications. It uses a cross-layer design to collect routing information such as node's available energy, node ID, congestion information from a different layer to build a shared database and shares its database to its neighbors. Based on the received details, it allocates bandwidth for flows. Due to a lot of information exchange, the proposed mechanism has a lot of control overhead. The queuing mechanism used may result in the starvation of non-real-time applications. The protocol proposed in [16] uses bandwidth and delay-aware routing-based AC integrated with a dynamic link schedule (LS). Whenever flows enter/exit, the network LS is updated. The AC decides to accept/reject a new flow based on the global network state information. Each gateway maintains scheduling matrices of the network and exchanges their schedule matrices to have up-to-date matrices. This AC mechanism with LS has a significant control overhead and has complex operations.

In all the existing protocols except [10], with available resources only, each protocol proposed in [7-9, 12-16] try to find a feasible path that satisfies the end-to-end requirements of flows. If they did not find a feasible path, none of the protocols makes an effort to adjust the network resources to increase the likelihood of finding a feasible path. The protocol in [14] tries to find k paths and investigate their feasibility, so it takes more time to find a feasible path. It uses a centralized algorithm and uses only interference-based routing metric. On the other hand, due to exchange of large amount of control information, the QoS routing protocols proposed in [7, 8, 13, 15, 16] with AC have lot of control overhead. The multipath routing protocols proposed in [11, 12] have out-of-order packet delivery. We need a QoS routing protocol with admission control that tries to adjust the network resources to increase the likelihood of finding a feasible path and also has simple operations with low complexity.

3. Problem Statement and System Model

3.1. Problem Statement

Here, we investigate the problem of enhancing network performance, assessed in terms of acceptance rate of delay-sensitive flows. The new data flow i, $QSD_i = \{s_i, d_i, e_i, t_i\}$ arrives at any time t_i with its end-to-end delay requirement e_i. For new flow 'i', we need to discover a feasible path from source s_i to destination d_i. To assure the end-to-end QoS requirements, we need to estimate available resources on the end-to-end path. To fulfill the end-to-end delay requirement, estimated path delay should be smaller than the required delay (e_i). An end-to-end path with lowest end-to-end delay results in a high throughput. The end-to-end delay is a total delay experienced at each hop on its source to destination path. Resource availability such as available bandwidth of link is the main factor that affects existence of feasible path. Routing scheme distributes traffic over network paths, while CA scheme assign channels based on traffic knowledge. The routing scheme determines how flows utilize the network bandwidth. The channel assignment scheme determines how much bandwidth is available on each link. If the routing scheme requires extra bandwidth on a link, the channel assignment scheme can furnish it by redistributing channels among competing links. So, to increase the likelihood of finding feasible paths, both routing and channel assignment need to be optimized together.

3.2. System Model

We consider MRMC-WMN with the IEEE 802.11 DCF MAC protocol. Each router is assigned with a unique ID. Each router is equipped with R radio interfaces. WMN has C orthogonal channels. Our routing strategy is for wireless mesh backbone. Packets are forwarded via multi-hop packet forwarding over the mesh backbone routers. As part of initial configuration, we use interference-aware and network-connectivity-aware channel assignment scheme to assign orthogonal channels to radios of routers (nodes), such that the resulting wireless mesh backbone is highly connected with minimum co-channel interference. The node 'i' and 'j' have a common channel C_{ij}^{k} between them. We consider network traffic between users connected to mesh routers and the gateway nodes. All flows enter network at random time and each flow has its end-to-end delay requirement.

4. Delay-Sensitive QoS Routing with Integrated AC Routing Protocol

4.1. Overview of Proposed Protocol

We propose a cross-layer QoS routing protocol to discover the path to fulfill the end-to-end delay requirement of delay-sensitive multimedia applications. The protocol is implemented using AODV routing protocol. It uses AODV RREQ control packet based admission control mechanism to discover a path to destination. We use Interference, Traffic Load and Delay Aware (ITLDA) cross-layer routing metric proposed in [22] to estimate a delay of each link on path between source and destination. The one-hop delay is the sum of the transmission delay, average channel access (contention) delay, and queuing delay. The delay experienced at each hop should be carefully determined. The available bandwidth of the link determines the one-hop delay. Interference among different nodes affects the link's available bandwidth. The intra-flow interference has an impact on the available bandwidth of in-path links, and inter-flow interference has an impact on the available bandwidth of out-of-path links. So, the available bandwidth of link (per-hop basis) under the influence of interference is to be estimated properly. In ITLDA, the available bandwidth of the link used for the one-hop delay calculation is estimated using logical and physical interference models. In AODV, the source node runs the route discovery process for a maximum of *RREQ_RETRIES* number of times [8]. During each attempt, the proposed DSQRAC protocol tries to discover a feasible path that satisfies the end-to-end delay.

Due to a lack of required resources, DSQRAC protocol may not be able to find a feasible path. In the proposed DSQRAC, when the source node fails to discover feasible path till the *(RREQ_RETRIES)-1* attempt, then for the *(RREQ_RETRIES)*th attempt, the resource available in the vicinity of the source/intermediate/destination nodes will be adjusted to maximize the likelihood of finding feasible path. The routing and channel assignment schemes determine resource availability. The traffic distribution over links is determined by routing and channel assignment. To increase the likelihood of finding feasible paths, we initiate the channel adjustment process to reassign the channels to the links for the path determined on the *(RREQ_RETRIES)*th attempt. It increases the available bandwidth of each hop, which in turn reduces the one-hop delay and overall path's end-to-end delay. The Fig. 1 shows the solution framework.

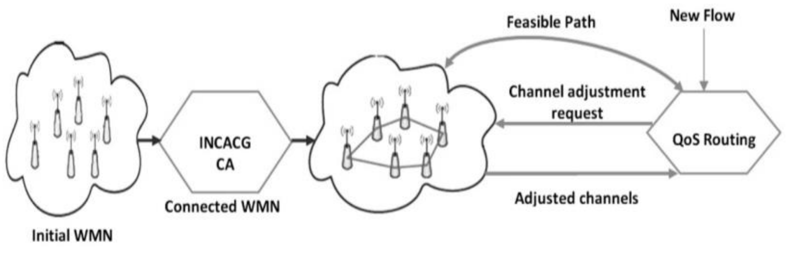


Fig.1. Solution framework

4.2. *Delay-sensitive QoS Routing with Integrated AC Routing Protocol*

We present a new QoS routing protocol called Delay-Sensitive QoS Routing with integrated Admission Control to find a feasible path to satisfy the end-to-end delay requirement of the delay-sensitive flow. We assume users have a set of video and audio applications that require a specific end-to-end delay. The user data is transmitted between the user's connecting backbone router (Mesh Access Point) to the gateway. The routing algorithm may choose the path with the shortest end-to-end delay and the longest hop-count to reduce the likelihood of QoS violations. It may hurt long-term system performance as measured by the admission ratio. So, algorithm has to consider this concern while selecting a path.

For end-to-end delay estimation, the delay experienced at each hop should be carefully determined. We use cross-layer routing metric ITLDA proposed in [22] to estimate a delay of each link on path between source and destination. Based on the packet delay model presented in [23], ITLDA estimates the one-hop delay of packet as sum of the average contention delay, transmission delay and queuing delay. As the queuing delay carries a noticeable part of the end-to-end delay [24], queuing delay has to be considered for estimating one-hop delay.

We implement DSQRAC by extending the AODV protocol. We run the protocol on top of network topology which is highly connected with minimum co-channel interference. The existence of common channel between two neighboring nodes (backbone mesh routers) defines a link between them. Each node keeps a table called Neighbor State (NS) table to store the state information of its connected neighbors. Table 1 shows structure of the table.

Table 1. Neighbor state table

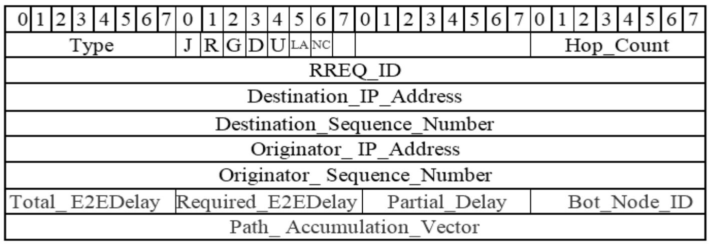
Node	Interface Used (IU)	Channel Used(CU)	Link Delay (msec)
N_0	IU_0	CU_0	LD_0
.	.	.	.
.	.	.	.
N_{n-1}	IU_{n-1}	CU_{n-1}	LD_{n-1}

Each entry maintains information like neighbor node ID, node's radio interface used, the common channel used to connect, delay of a link that exists between itself and its neighbor. Periodically each node broadcasts HELLO packets on all its radio interfaces to learn about the neighboring nodes and their corresponding neighbor state information. The ITLDA routing metric is used to update link delay that exists between itself and its neighbor. The link delay information is bi-directionally updated via the periodic exchange of HELLO message.

In the proposed DSQRAC protocol, to admit a new flow, we use admission controlled route discovery process. For this purpose, AODV's RREQ control packets are used. In the route discovery process, the source node broadcasts a modified RREQ packet on all its radio interfaces. In the route discovery process, *RREQ_RETRIES* attempts will be carried out by the source for find feasible path. Before forwarding the RREQ packet, each node checks whether it has sufficient resources to serve the new flow without causing QoS violations of existing flows. Since DSQRAC uses only RREQ to discover a feasible path, it has simple operation and has low complexity.

To support the QoS routing, we modify the RREQ as follows. The modified RREQ packet is shown in the Fig.2. We add two new flags. i) *LA* (Last Attempt) flag →In our protocol, we want channel adjustment/reassignment to be initiated only for the (*RREQ_RETRIES*)th attempt, for this attempt, we set *LA=1* and for other attempts we set *LA=0*. ii) *NC* (Non-Confirmation of QoS) → For the RREQ with non-satisfying QoS, we set *NC=1*. We add 5 new fields. i)

Required_E2EDelay (RE2ED) →This field stores the end-to-end delay that a user can tolerate for his/her application (User's QoS bounds). ii) *Total_E2EDelay* (TE2ED) →This field stores cumulative end-to-end delay of partial path the from source to the current node. iii) *Path_Accumulation_Vector* →This field records all the nodes so far traversed by the RREQ packet. iv) *Partial_Delay* →This field stores end-to-end delay from source to node (bottleneck node) that fails to achieve the required QoS. v) *Bot_Node_Id*→This field stores the bottleneck node ID.



0 1 2 3 4 5 6 7	0 1 2 3 4 5 6 7	0 1 2 3 4 5 6 7	0 1 2 3 4 5 6 7
Type	J R G D U LA NC		Hop_Count
RREQ_ID			
Destination_IP_Address			
Destination_Sequence_Number			
Originator_ IP_Address			
Originator_ Sequence_Number			
Total_ E2EDelay	Required_E2EDelay	Partial_Delay	Bot_Node_ID
Path_ Accumulation_Vector			

Fig.2. Modified RREQ control packet

When user flow arrives at Mesh Access Point (MAP), the receiving MAP acts source and tries to discover route to destination. Before sending RREQ packet, apart from filling all the pre-existing fields of the RREQ packet, the source node adds it ID into *Path_Accumulation_Vector*. In view of QoS routing, expect for the *(RREQ_RETRIES)*th attempt, for all *(RREQ_RETRIES)-1* attempts, the source node sets flags $D=1$ and $LA=0$ and for last attempt we set flags $D=1$ and $LA=1$. For all attempts, the *Required_E2EDelay* is initialized with maximum end-to-end delay that user can tolerate and *Total_E2EDelay*=0. The source node then broadcasts RREQ packet on its radio interfaces.

When intermediate node receives RREQ packet, it checks whether the same RREQ is received previously. If received previously, the node discards the received RREQ. If not received previously, then it checks the value of flags *D, LA* and *NC*. Intermediate node has to handle the following cases.

i) If $D=1$, $LA=0$ and $NC=0$, for each of its connected neighbor NN_i, it fetches the link delay l_i between itself and the node NN_i. The link delay l_i is added to *the Total_E2EDelay* field of the RREQ packet. If new value of *Total_E2EDelay* is less than the value *of Required_E2EDelay*, *the Total_E2EDelay* is updated with new value and intermediate node appends its ID to the *Path_Accumulation_Vector*. The intermediate node updates its routing table and forwards the updated RREQ (feasible) packet to NN_i. If new value of *Total_E2EDelay* is more than the value of *Required_E2EDelay* field, intermediate node does not forward RREQ to neighbor NN_i. This means that the end-to-end path through that neighbor NN_i cannot guarantees the required end-to-end delay. Once checked for all its connected neighbors, intermediate node discards current RREQ packet.

ii) If $D=1$, $LA=1$and $NC=0$ (for the last attempt), as done previously, for each connected neighbor NN_i, intermediate node fetches the link delay l_i and adds l_i to *Total_E2EDelay*. If the new value of *Total_E2EDelay* is less than the value of *Required_E2EDelay*, the *Total_E2EDelay* is updated and intermediate node appends its ID to the *Path_Accumulation_Vector* and forwards the updated RREQ (feasible) packet to the neighbor NN_i. On other hand, if intermediate node fails to identify any of its connected neighbors to satisfy the required end-to-end QoS, the current intermediate node is labeled as one of 'bottleneck node' which has failed to achieve the required QoS. In this case, the intermediate node chooses the neighbor node Min_NN_i which has shortest link delay among its connected neighbors. The intermediate node sets $NC=1$ to indicate that propagation through it is Non-Confirmation of QoS. Intermediate node then puts its ID in the *Bot_Node_ID* to indicate that, it is a one of possible node where channel reassignment can be done. Later it stores the value of *Total_E2EDelay* in the *Partial_delay* field. Finally, it appends its ID into *Path_Accumulation_Vector*, forwards the updated RREQ packet to the neighbor Min_NN_i.

iii) If $D=1$, $LA=1$ and $NC=1$(for the last attempt with Non-Confirming RREQ), among its connected neighbors, the intermediate node selects the neighbor Min_NN_i that has the least link delay. It appends its ID into Path_Accumulation_Vector, updates its routing table and finally forwards the updated RREQ packet to the neighbor Min_NN_i.

The algorithmic steps for RREQ packet processing at intermediate node are shown in Algorithm 1.

Whenever a RREQ packet reaches the destination node, destination checks that value of *LA* and *NC* flags. For the following three possible cases, the destination then generates the route reply (RREP) packet as per the modified format shown in the Fig.3. Similar to the modified RREQ packet format, the modified RREP has same *NC* flag, and other fields *Partial_delay*, *Total_ E2EDelay*, *Required_E2EDelay*, *Bot_Node_ID*, *Path_Accumulation_Vector*. The purpose of flags and new fields is same as that of modified RREQ packet.

Algorithm 1. RREQ packet processing at intermediate node

```
Process_RREQ_At_Intermdiate_ Node (New_RREQ)
 1: if ($D==1$ and $LA==0$ and $NC==0$) then      // case i
 2:   for each connected neighbor router $NN_i$ do
 3:     $New\_Delay = Total\_E2EDelay$ + Link_Delay $l_i$
 4:     if ($New\_Delay < Required\_E2EDelay$) then
 5:     appends $NN_i$ ID to Path_Accumulation_Vector and forward RREQ via $NN_i$
 6:    Once done for all neighbor and not found $NN_i$, then discard RREQ
 7: elif (D==1 and LA==1 and NC==0) then        // case ii: last attempt
 8:   for each connected neighbor router $NN_i$ do
 9:     New_Delay=Total_E2EDelay + Link_Delay $l_i$
10:     if (New_Delay < Required_E2EDelay) then
11:     appends $NN_i$ ID to Path_Accumulation_Vector and forward RREQ through $NN_i$
12:    else
13:     find the neighbor node Min_$NN_i$ that has the least link delay
14:     set NC=1 and copy the Total_E2EDelay value into Partial _Delay
15:     puts $NN_i$ router ID into Bot_Node_ID
16:     appends $NN_i$ router ID to Path_Accumulation_Vector and forward RREQ via Min_$NN_i$
17:    elif (D==1 and LA==1 and NC==1) then      // case iii: last attempt
18:     find the neighbor router Min_$NN_i$ that has the least link delay
19:     appends $NN_i$ router ID to Path_Accumulation_Vector and forward RREQ via Min_$NN_i$
```

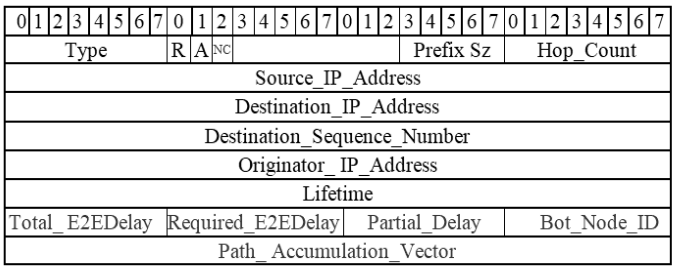


Fig.3. Modified RREP control packet

The destination node has to handle the following cases.

i) If *D=1, LA=0 and NC=0*, it means that received RREQ is not part of last (*RREQ_RETRIES*)th attempt to find feasible path, the destination node waits for *3*NODE_TRAVERSAL_TIME* to receive more feasible RREQ packets. With policy of the intermediate nodes discarding RREQ packet if they do not satisfy required end-to-end delay, only RREQ packets that satisfy the requirement reach the destination node. Once *3*NODE_TRAVERSAL_TIME* time is over, destination node selects the path P_i that has the least end-to-end delay and also satisfies required end-to-end delay of user application. It sets flag *NC=0*. Then the destination node makes a routing table entry to the source and generates required RREP packet and unicast it back to source over the selected path. When each intermediate node receives the RREP packet, it creates/updates its routing table entry for the destination and sends the updated RREP packet towards the source.

ii) If *D=1,LA=1 and NC=0* , it means that received RREQ is part of last (*RREQ_RETRIES*)*th* attempt to find feasible path, the destination node processes the RREQ packet as processed in previous case and unicast the RREP packet back to source node.

iii) If *D=1, LA=1 and NC=1*, it means that received RREQ is part of last *(RREQ_RETRIES)th* attempt to find feasible path and received RREQ with non-confirming QoS, the destination node then waits for *3* NODE_TRAVERSAL_TIME* time to receive all non-confirming RREQ packets. Once waiting time is over, among the received RREQs, the destination selects a path that has the least end-to-end delay. From the corresponding RREQ packet, the destination node learns i) the bottleneck node that did not satisfies the required QoS, ii) the partial path from source to bottleneck node and the related partial delay. Destination node then copies the values of *Partial_delay*, *Path_Accumulation_Vector, Total_E2EDelay, required_E2EDelay, Bot_Node_ID*, from respective fields of RREQ packets into the corresponding fields of RREP packet and set *NC=1*. Finally, destination node unicast RREP packet back to the bottleneck node.

The algorithmic steps for RREQ packet processing at destination node are shown in Algorithm 2.

Algorithm 2. RREQ packet processing at destination node

```
Process_RREQ_At_Destination_Node(New_RREQ)
1: if (New_RREQ == First_Received_RREQ) then
2: if (D==1 and LA==0 and NC==0) then        // case i
3:   wait for 3*NODE_TRAVERSAL_TIME to receive RREQ packets
4:   from all the received RREQ packets do
5:   find the path $P_i$ that has the least end-to-end delay and satisfies end-to-end QoS
6:   make the routing table entry for source node
7:   generate the RREP packet, set NC=0 and unicast it back to source over the path $P_i$
8: elif (D==1 and LA==1 and NC==0) then      // case ii: last attempt
9: Repeat steps from 3 to 7
```

```
10: elif (D==1 and LA==1 and NC==1) then       // case iii: last attempt
11:   wait for 3*NODE_TRAVERSAL_TIME to receive RREQ packets
12:   from all the received RREQ packets do
13:   find the path $P_i$ that has the least end-to-delay
14:   copy the Partial_delay, Path_Accumulation_Vector, Bot_Node_ID, Total_ E2EDelay,
      Required_E2EDelay from received RREQ packet to RREP packet and set NC=1
15:   unicast RREP back to bottleneck router over the path $P_i$
```

When RREP packet arrives at intermediate node, it checks the value of *NC* flag. If *NC=0*, it forwards the RREP packet as done in normal AODV operation. If *NC=1* and the intermediate node is not the bottleneck node, it finds next hop node on reverse path from the *Path_Accumulation_Vector* field of the received RREP and forwards the RREP packet to the next node. Once the RREP packet with *NC=1* reaches the bottleneck node, that node will triggers the channel reassignment to adjust the channels and tries to find the feasible path. The algorithmic steps of RREP packet processing at the intermediate node are listed in Algorithm 3.

Algorithm 3 Algorithm for RREP packet processing at intermediate node

```
Process_RREP_At_ Intermdiate_Node( )
  1: if (NC==0) then
  2: forward the RREP packet as done in AODV
  3: elif ((NC==1 and intermediate_node != bottleneck_ node) then
  4: forward the RREP packet to next router on reverse path
  5:  elif ((NC==1 and intermediate_ node == bottleneck_ node) then
  6: triggers the channel reassignment to adjust the channels
```

As routing and channel assignment schemes are interdependent on each other, by adjusting the channels on different links, we can increase the available bandwidth of links and hence enhance the likelihood of discovering a feasible path. For the simplified channel adjustment at bottleneck node, adjustment process should use only local information and should have only the local impact. Along with these requirements, adjustment process should have a smaller number of channel switches/changes. Through the *Path_Accumulation_Vector* bottleneck of RREP packet, bottleneck node ‘*e*’ gets to know it’s neighbor node ‘*f*’ through which the path is existing between given source and destination. Once neighbor ‘*f*’ is identified, node ‘*e*’ will change the channel on the link l_{ef} that exist between bottleneck node ‘*e*’ and its neighbor ‘*f* ’. When node ‘*e*’ is about change its channel to any other channel, node ‘*e*’ first it checks the existence of chain puzzle problem. Fig.4. illustrates the chain puzzle problem in the given network topology, where each node has two radio interfaces. If node ‘*e*’ changes channel from C_1 to C_2, then to maintain connectivity with node ‘*g*’, node ‘*f*’ has to change channel from C_1 to C_2 between itself and ‘*g*’. Similarly, node ‘*g*’ also has to change channel from C_1 to C_2 between itself and ‘*h*’ and node ‘*h*’ also has to change channel from C_1 to C_2 between itself and ‘*i*’. The change of channel from C_1 to C_2 on link l_{ef} will result in chain of channel changes on the other neighboring links. Such chain of channel change is called as chain puzzle problem. If more numbers of nodes are involved in chain puzzle, then it may lead to large overhead. The large size chain interrupts lot of flow transmissions. So, because of its practical impacts, before a bottleneck node is allowed to change the channel, node has to check the existence of chain puzzle problem. When a node '*e*' selects a new candidate channel C_i and discovers that a node not within its 2-hop distance also requires changing the channel to maintain their link connectivity, then this results in a chain puzzle and C_i is not a feasible channel.

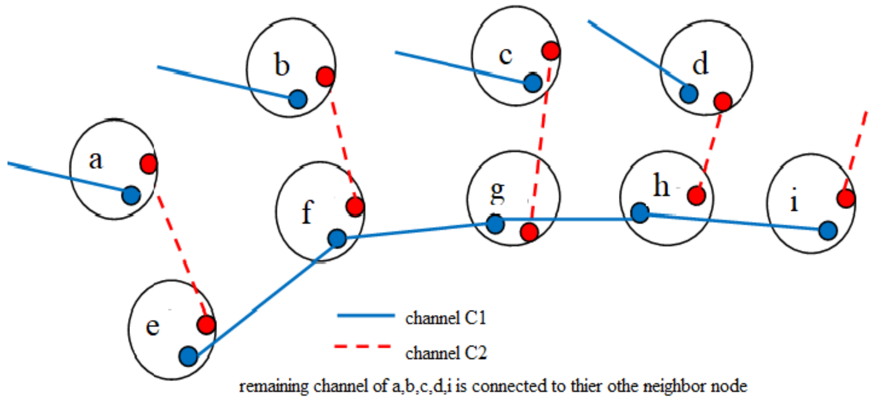

a
b
c
d
e
f
g
h
i
channel C1
channel C2
remaining channel of a,b,c,d,i is connected to thier othe neighbor node

Fig.4. Chain puzzle problem

For QoS routing, along with checking of chain puzzle problem, the channel adjustment process has to check whether the channel change of bottleneck node results in the drastic change of link delay of nearby 2-hop links. Such change may violate QoS of existing flows. The channel used on 2-hop links determines bandwidth available on each of the link. So, the change of channel on one link should not reduce the other link's available bandwidth and hence the increase link delay. Hence, before node makes such channel change it should check whether such change increases link delay of any of its 2-hop links. If it does, then intermediate node should abort the channel adjustment process. If not then, it should go for the change of channels on respective links. Before the bottleneck node changes the current channel to the new channel, it follows the mechanism similar to that of [25] and send channel request message *Ch_Change_Reqest* to all its neighbor nodes to confirm that currently none of them are involved in any channel change. It prevents simultaneous channel changes. If the neighbor node is not involved in the channel change, then it sends her *Ch_Change_Accept* message, otherwise it sends the *Ch_Change_Reject* message. If bottleneck node does not receive any *Ch_Change_Reject* message then, through the *Update_Channel* message requests all the corresponding nodes to change the channel. Once all the channels are changed, then the bottleneck node resumes route discovery process. For this, a new RREQ packet is created. In new RREQ, from the *Path_Accumulation_Vector* field of received RREP packet, partial path from source to bottleneck node is calculated and copied into *Path_Accumulation_Vector* field of new RREQ packet. Set $LA=1$, $D=1$ and $NC=0$. Then copy the value of *Partial_Delay* of RREP into *Total_E2EDelay* field of new RREQ, this value helps in calculating the final end-to-end delay. Finally copy the required other fields form RREP into respective fields of new RREQ and start processing the New RREQ in normal way.

5. Performance Evaluation

Through the simulations results, we compare the performance of proposed DSQRAC protocol with existing schemes. The ns-3 simulations are used to verify the effectiveness of DSQRAC. The details of the simulation are tabulated in Table 2.

As the performance of the proposed QoS routing protocol is to increase the flow acceptance rate of delay-sensitive flows without affecting the already admitted flows, we evaluate the performance using the acceptance rate and average throughput and end-to-end delay with lower routing overhead. First, we measure the flow acceptance rate. The DSQRAC tries to find a feasible path from source node to destination for maximum of *RREQ_RETRIES* attempts. For the *(RREQ_RETRIES)*th attempt the channel adjustment is initiated to adjust the channel to increase the chance of finding the feasible path. To show how channel adjustment aids in finding the feasible path, we compare the performance of DSQRAC with channel adjustment (DSQRAC_DCA) with modified version of the DSQRAC i.e DSQRAC_SCA without the channel adjustment (Static Channel Assignment) and with EstQoS [14]. For this comparison, we conduct simulation as per the details tabulated in Table 2, with number of radio interfaces R=2 and number of orthogonal channels C=4. The average of 5 simulations is used for comparison. Neither DSQRAC_SCA nor EstQoS make an effort to adjust the channels to increase the acceptance rate. DSQRAC_DCA tries to adjust the channels to increase the acceptance rate. The Fig. 5 shows the performance of all the protocols. The flow acceptance rate of DSQRAC_DCA is 14% and 19% better than EstQoS and DSQRAC_SCA respectively.

Fig. 6 shows the effect of the number of available channels. We compare the performance with R=2 and C=3,4,5,6, with arrival rate of 4 demands per minutes. As seen from the Fig. 6, it is clear that with a greater number of channels available for channel allocation, there is increase in the acceptance rate of all the protocols, especially with DSQRAC and EstQoS.

Table 2. Simulation details

Parameter	Value
Simulation Time	240 seconds(4 mins.)
Network Area	1000*1000 sq.mt
Topology	Grid topology of size 7*7
Number of nodes	49, with 1 node acting as gateway
Max. Data Rate	11Mbps
Queue Type and Size	Drop Tail and 50
Traffic and Packet size	Video streaming and 1024 bytes
Transmission/ Interference Range	250M/550M
Max. number of channels(m) / radio interfaces (R)	12/4
CWmin and CWmax	32 and 1024
Target Delay	100ms
AODV RREQ_RETRIES	2
AODV NODE_TRAVERSAL_TIME	8ms

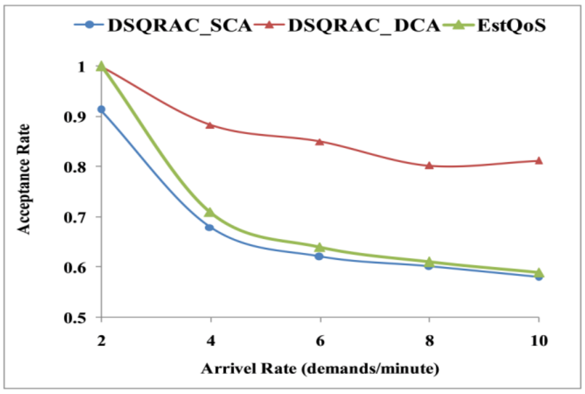


Fig.5. Acceptance rate

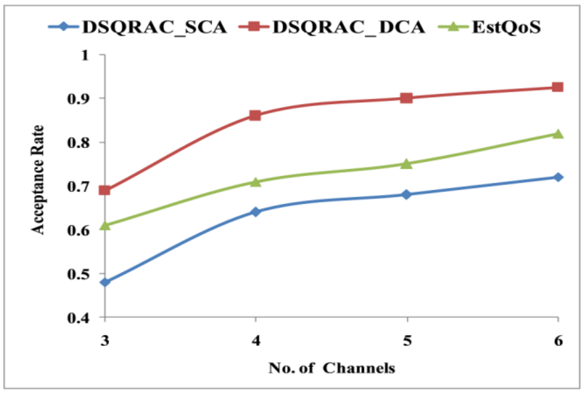


Fig.6. Acceptance rate with C=3,4,5,6

Further we will evaluate the performance of DSQRAC with EstQoS [18] and AODV-MR [26] multi-radio AODV which uses hop-count as routing metric. We use average throughput, average end-to-end delay and routing overhead to compare the performance of three protocols. We simulate WMN with 20 different UDP real-time data flows arriving randomly from different source nodes. The flow transmission rate is 30 packets/sec.

In DSQARC, as RREQ packets are forwarded only through the intermediate nodes that have enough resources to support the admission of new flow, a smaller number of RREQ packets are gets transmitted in the network. With a smaller number of RREQ packets, more bandwidth will be available bandwidth for data transmissions. More available link bandwidth results in more throughput and less packet delay.

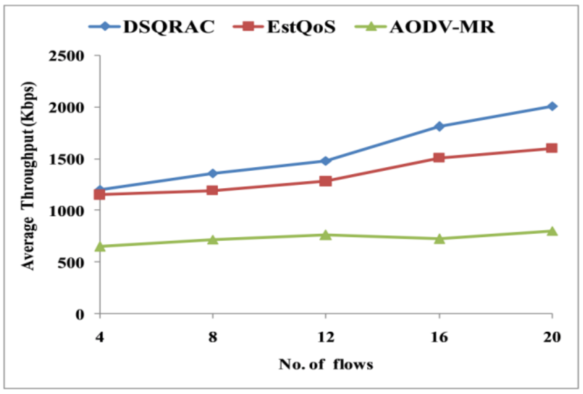


Fig.7. Average throughput

The Fig.7 shows average throughput of all three protocols. Initially with a smaller number of flows, the performance of protocols is almost the same. With increasing number of data flows, the interference among the flows increases. Since AODV-MR uses minimum hop-count to discover the paths, its average throughput is the worst among the three protocols. In EstQoS, only transmission delay and channel access delay are used to compute the link delay without considering loads of the forwarding nodes. Because of this, EstQoS may discover path through the congested nodes. With increasing number of data flows, the contention among the nodes increases and results in degrading of throughput. As the link delay computation of DSQRAC is based the transmission delay and channel access delay and loads of the forwarding intermediate node, it discovers the lightly loaded paths. Due the proper load distribution, the average throughput of DSQRAC is better than other two protocols. The average throughout of DSQRAC is 14.4 % and 53% better than EstQoS and AODV-MR respectively.

Figure 8 shows average end-to-end delay of all three protocols. The end-to-end delay of packet depends on the channel access, transmission and queuing delays. If path is selected only on the basis channel access delay and transmission delay (i.e. MAC service time), more packets will get transmitted through the already loaded forwarding node and hence increase the packet queuing delay. As DSQRAC link delay computation includes all three possible delays, it selects a path through the lightly loaded nodes. So, the average end-to-end delay of DSQRAC is less among the other protocols. The average end-to-end delay of DSQRAC is 21.18% and 51.9% less than EstQoS and AODV-MR respectively.

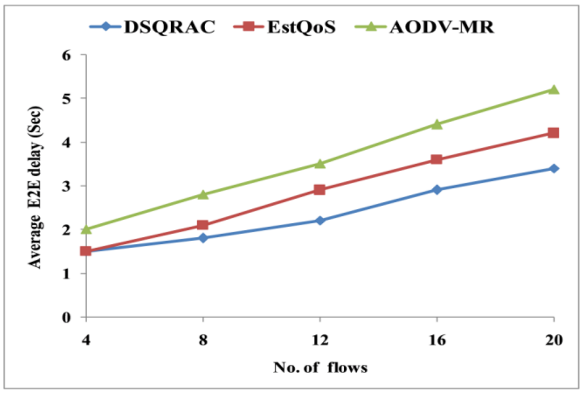


Fig.8. Average E2E delay

Figure 9 shows the routing overhead of three protocols. As DSQRAC implemented with AODV and EstQoS implemented with OLSR, almost same number of HELLO packets are used for maintaining node/link status. As RREQ gets forwarded only on QoS fulfillment, a smaller number of RREQ packets are used for path discovery. In OLSR implementation of EstQoS, a greater number of TC and MID routing control packets are transmitted for route maintenance, the routing overhead of EstQoS is more. In AODV-MR RREQ control packets are transmitted on all the radio interfaces of node. It has more routing overhead as compare to the DSQRAC. DSQRAC produces 29.4% and 43.8% less routing overhead as compared to the EstQoS and AODV-MR respectively.

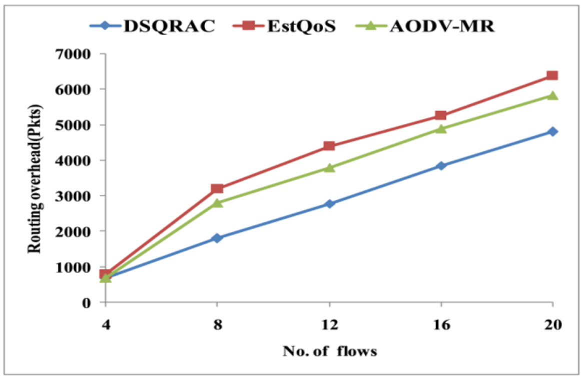


Fig.9. Routing overhead

6. Conclusions

WMNs need to support the effective implementation of various multimedia applications. The multimedia applications require assured QoS to fulfill the user requirements. The QoS routing in WMNs needs to guarantee the QoS requirements of multimedia applications. The admission control is the primary traffic control mechanism deployed to provide QoS provisioning. A new QoS routing protocol with admission control called delay-sensitive QoS routing with integrated admission control i.e. DSQRAC, is designed to control the admission of delay-sensitive flows. The primary focus is on the end-to-end delay requirements of delay-sensitive multimedia applications. A delay-aware cross-layer routing metric is used to find the feasible path. The QoS routing protocol is implemented using the AODV routing protocol. Since the RREQ packets consume a noticeable amount of network resources, the RREQ packets are forwarded only by the few nodes that guarantee the required delay requirement. Such a delay-sensitive controlled flooding mechanism avoids the unnecessary flooding of RREQ packets and makes provision to save the possible network resources to be consumed by such RREQs. As channel assignment and routing together define the availability of network resources, when required, the channels are adjusted to aid the QoS routing to increase the likelihood of accepting a new flow. The simulation results confirm that the performance of the DSQRAC routing protocol outperforms the existing protocols. The flow acceptance rate of DSQRAC_DCA is 14% and 19% better than EstQoS and DSQRAC_SCA respectively.

References

[1] I. F. Akyildiz, X. Wang, and W. Wang, “Wireless mesh networks: a survey,” Computer Networks, vol. 47, no. 4, pp. 445–487, Mar. 2005, doi: 10.1016/j.comnet.2004.12.001.

[2] Md. I. Hussain, N. Ahmed, Md. Z. I. Ahmed, and N. Sarma, “QoS Provisioning in Wireless Mesh Networks: A Survey,” Wireless Pers Commun, Aug. 2021, doi: 10.1007/s11277-021-08893-3.

[3] L. Khoukhi, H. Badis, L. Merghem-Boulahia, and M. Esseghir, “Admission control in wireless ad hoc networks: a survey,” J Wireless Com Network, Vol. 2013, No. 1, p. 109, Dec. 2013, doi: 10.1186/1687-1499-2013-109.

[4] L. Chen and W. Heinzelman, “A Survey of Routing Protocols that Support QoS in Mobile Ad Hoc Networks,” IEEE Network, Vol. 21, No. 6, pp. 30–38, 2007, doi: 10.1109/MNET.2007.4395108.

[5] C. Perkins, E. Belding-Royer, and S. Das, “Ad hoc On-Demand Distance Vector (AODV) Routing,” RFC Editor, RFC3561, Jul. 2003. doi: 10.17487/rfc3561.

[6] O. M. Zakaria et al., “Joint Channel Assignment and Routing in Multiradio Multichannel Wireless Mesh Networks: Design Considerations and Approaches,” Journal of Computer Networks and Communications, Vol. 2016, pp. 1–24, 2016, doi: 10.1155/2016/2769685.

[7] V. Kone, S. Das, B. Y. Zhao, and H. Zheng, “QUORUM—Quality of Service in Wireless Mesh Networks,” Mobile Netw Appl, Vol. 12, No. 5–6, pp. 358–369, Dec. 2007, doi: 10.1007/s11036-008-0050-8.

[8] X. Cheng, P. Mohapatra, S.-J. Lee, and S. Banerjee, “MARIA: Interference-Aware Admission Control and QoS Routing in Wireless Mesh Networks,” in 2008 IEEE International Conference on Communications, Beijing, China, 2008, pp. 2865–2870. doi: 10.1109/ICC.2008.540.

[9] D. Manikantan Shila and T. Anjali, “An Interference-Aware Admission Control Design for Wireless Mesh Networks,” J Wireless Com Network, Vol. 2010, No. 1, p. 106520, Dec. 2010, doi: 10.1155/2010/106520.

[10] B. Bakhshi, S. Khorsandi, and A. Capone, “On-line joint QoS routing and channel assignment in multi-channel multi-radio wireless mesh networks,” Computer Communications, Vol. 34, No. 11, pp. 1342–1360, Jul. 2011, doi: 10.1016/j.comcom.2011.02.001.

[11] P. Zhao, X. Yang, J. Wang, B. Liu, and J. Wang, “Admission control on multipath routing in 802.11-based wireless mesh networks,” Ad Hoc Networks, Vol. 11, No. 8, pp. 2235–2251, Nov. 2013, doi: 10.1016/j.adhoc.2013.05.006.

[12] I. Hussain, N. Ahmed, D. K. Saikia, and N. Sarma, “A QoS-aware multipath routing protocol for WiFi-based long distance mesh networks,” in 2014 2nd International Conference on Emerging Technology Trends in Electronics, Communication and Networking, Surat, India, Dec. 2014, pp. 1–8. doi: 10.1109/ET2ECN.2014.7044990.

[13] S. K. Dhurandher, I. Woungang, M. S. Obaidat, K. Kumar, M. Joshi, and M. Verma, “A Distributed Adaptive Admission Control Scheme for Multimedia Wireless Mesh Networks,” IEEE Systems Journal, Vol. 9, No. 2, pp. 595–604, Jun. 2015, doi: 10.1109/JSYST.2013.2296336.

[14] D Chakraborty, “EstQoS: establishing quality of service in multirate multihop wireless mesh networks through available bandwidth computation and efficient admission control”, Int. J. Ad Hoc and Ubiquitous Computing, Vol. 22, No. 4, pp.265–273, Jul. 2016, doi:10.1504/IJAHUC.2016.078116.

[15] P. Reddy and P. V. Krishna, “Energy aware Cross- layer-based connection admission control mechanism for wireless mesh networks,” IJSGGC, Vol. 1, No. 1, p. 73, 2016, doi: 10.1504/IJSGGC.2016.077301.

[16] J. Dromard, L. Khoukhi, R. Khatoun, and Y. Begriche, “Towards combining admission control and link scheduling in wireless mesh networks,” Telecommun Syst, Vol. 66, No. 1, pp. 39–54, Sep. 2017, doi: 10.1007/s11235-016-0273-0.

[17] S. Bhojannawar and S. Mangalwede, “Interference, Traffic Load and Delay Aware Routing Metric for Wireless Mesh Network,” Adv. Electr. Comp. Eng., Vol. 21, No. 1, pp. 57–64, 2021, doi: 10.4316/AECE.2021.01006.

[18] P. Raptis, V. Vitsas, K. Paparrizos, P. Chatzimisios, and A. C. Boucouvalas, “Packet delay distribution of the IEEE 802.11 distributed coordination function,” in Proc. 6th IEEE International Symposium on a World of Wireless Mobile and Multimedia Networks, Taormina-Giardini Naxos, Italy, 2005, pp. 299–304, doi:10.1109/WOWMOM.2005.74.

[19] H. Li, Y. Cheng, C. Zhou, and W. Zhuang, “Routing metrics for minimizing end-to-end delay in multiradio multichannel wireless networks,” IEEE Trans. Parallel Distrib. Syst., Vol. 24, No. 11, pp. 2293–2303, Nov. 2013, doi:10.1109/TPDS.2012.327.

[20] B.-J. Ko, V. Misra, J. Padhye, and D. Rubenstein, “Distributed Channel Assignment in Multi-Radio 802.11 Mesh Networks,” Jan. 2007, WCNC 2007. [Online]. Available: https://www.microsoft.com/en-us/research/publication/distributed-channel-assignment-multi-radio-802-11-mesh-networks/

[21] A. A. Pirzada, M. Portmann, and J. Indulska, “Performance analysis of multi-radio AODV in hybrid wireless mesh networks,” Computer Communications, Vol. 31, No. 5, pp. 885–895, Mar. 2008, doi: 10.1016/j.comcom.2007.12.012.

Authors' Profiles

Satish S.Bhojannawar received the B.E. degree in Computer Science and Engineering from Visvesvaraya. Technological University, Belagavi, India, in 2002, the M.E degree in Computer Science and Engineering, from Shivaji University, Kolhapur, India, in 2008 and the Ph.D. degree from Visvesvaraya Technological. University, Belagavi, India, in 2023.Currently working as Associate Professor in the Department of Computer Science and Engineering, S.G. Balekundri Institute of Technology, Belagavi, India. His research interests include QoS, Wireless Mesh Networks, AI and Machine Learning.

Shrinivas R. Mangalwede received the B.E. degree in Computer Science and Engineering from Karnataka University, Dharwad, India, in 1994, the M.Tech. degree in Computer Network Engineering, from Visvesvaraya Technological University, Belagavi, India, in 2004 and the Ph.D. degree from Visvesvaraya Technological University, Belagavi, India, in 2012. Currently he is working as Professor in the Department of Computer Science and Engineering at S.G. Balekundri Institute of Technology, Belagavi, India. His research interests include E-Learning, M-Learning, Agent Technology and Wireless Networks.

Carlos F. Cruzado received Master Degree in Direction and Management of Information Technologies in 2020. He is Systems Engineer specialized in Computer Security and Software Engineering with Ethical Hacking and EC-Council Chief Information Security Officer Certifications. He has experience in areas of computer networks in Linux Centos Operating Systems, Windows Server, Social Engineering, Computer Security, ISO 27001, ISO 9126, Tailor-made solutions in Cyber security. Presently he is working as Director of the software engineering degree program.

How to cite this paper: Satish S. Bhojannawar, Shrinivas R. Managalwede, Carlos F. Cruzado, "Delay-sensitive Quality of Service Routing with Integrated Admission Control for Wireless Mesh Network", International Journal of Computer Network and Information Security(IJCNIS), Vol.16, No.6, pp.20-31, 2024. DOI:10.5815/ijcnis.2024.06.02