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Dynamic Channel Assignment MAC Protocol for Cognitive Radio Ad Hoc Networks (CRAHNs)

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Abstract: In Cognitive Radio Ad Hoc Networks (CRAHNs), the Medium Access Control (MAC) protocol should handle the diverse Quality of Service (QoS) requirements of data packets of various classes generated by the nodes. The delay and reliability requirements of various applications should be considered while assigning the channels to the nodes. Hence in this paper, we propose to design a channel quality based MAC protocol for CRAHNs. In this technique, a channel with best Channel Quality Indicator (CQI) is chosen as the Common Control Channel (CCC). The CCC is assigned dynamically in each round. The channels with higher weights are assigned to higher priority traffic classes. Initially backup channels are assigned only to the nodes with higher priority real-time traffic. If a data channel is not available for any lower priority traffic, then the backup channels of higher priority traffic can be temporarily assigned to the lower priority traffic nodes. By simulation results, we show that the proposed technique reduces packet drop rate, error rate and increases packet delivery ratio and throughput.

Keywords: CRAHN; Cognitive; Ad-Hoc; MAC; Channel

I. INTRODUCTION

Cognitive radio skill has taken a radical conversion in communication archetype and is getting a rising consideration in contemporary era. This skill is able to afford earlier and more dependable wireless amenities by exploiting the prevailing spectrum band more proficiently and short of intrusion to main customers. As cognitive radio is a subordinate customer, it has to evacuate the band instantly the moment when there is entrance of main customer. [1]. Cognitive radio (CR) is the modern skill in wireless communication by which the band is energetically used every time the main customer, the official owner of the band, is not usedup. [2]. CRs can unscrupulously utilize for the time being permitted authorized bands when the approved customers are not utilizing them. CR transceivers have the ability of entirely altering their aerial factor centered on deviations in the atmosphere in which it works [3]. In a cognitive radio network (CRN), a subordinate user (SU) divides the approved band of a main system in order to diminish any damage or intrusion to principal users (PU). To achieve this objective, a cognitive customer attempts to recognize chances rising in the course of principal system process and energetically adjusts its process factors to use them effectively [4].

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In CRAHNs, every single customer should have CR abilities and is answerable for its verdicts created on the native surveillance. The chief variation amid outdated ad hoc network and CRAHN are the varying band atmosphere and defending the broadcast of the approved customers [5].
In CRN, identification of band is the procedure of sensing the band chances of main customer's permitted authorized bands. As soon as they are sensed, they are able to be charted into coherent networks. Prevailing network consignment systems for CRN practice the connection centered method that undergo from applied boundaries.
Besides the tasks inborn from ad hoc networks, there are certain exclusive tasks associated to CRN together with descriptions of network, network accessibility, network heterogeneity network excellence, switch network consignment and broadcast network consignment. Therefore an effective MAC etiquette ought to manage the band detecting admittance and band flexibility which are the chief purposes of the cognitive sequence [6].
Channel consignment is done so as to regulate which network will be made use of by which nodule. Intermediate admission stops disagreement and impact difficulties in a specific network. Multichannel MAC procedures ought to discourse channel consignment and moderate admission problems [7].
As witnessed from prevailing experiments on CRAHN, majority of the experiments have been completed on band organization functionalities than planning MAC procedures. As there is no integrated unit in ad hoc networks, the prevailing MAC functionalities enforce an additional task on ad hoc networks.
In CRN, every single movable nodule has two networks: a regulator network and a statistics network. Each of them has two transceivers that pay attention on both the common control channel (CCC) and the statistics network concurrently. Due to the time changing band sources and the nonappearance of a dominant supervisor, the purpose of a CCC in CRAHN is more challenging than in the outdated dispersed multichannel wireless networks [7].
This motivates the design of a new medium access mechanism for CRAHN that can cope with all these challenges.

1.1 Problem Identification

When the number of channels is small, assigning one CCC for control messages becomes expensive. On the other hand, if the number of channels is large, the CCC becomes a bottleneck and prevents the data channels from being fully utilized. In [7], monitor nodes have to be pre-deployed and remain static, which becomes challenging when the number of nodes becomes higher. Moreover, the common control channel (CCC) used by both PU and SU is static which leads to congestion. In [8], all SUs exchange their sensing results with each other via the fixed control channel.

Though the CCC is dynamically changed in [9], it still does not consider the channel quality for selecting CCC.
The MAC protocol should handle the diverse QoS requirements of data packets of various classes generated by the nodes. The delay and reliability requirements of various applications should be considered while assigning the channels to the nodes.

II. RELATED WORKS

A Distributed MAC (DMAC) protocol [7] for CRAHNs has been proposed which uses monitoring nodes to enable PUs to efficiently use the available spectrum. It overcomes the hidden and exposed terminal problems in multichannel CRAHNs. They have developed Markov chain model to characterize the performance of DMAC protocol.
A p-persistent CSMA-based cognitive MAC protocol [8] is proposed to enable efficient spectrum sharing among SUs. Here the parameter p denotes the access probability to the chosen channel.
Mahdi Zareei et al [9] proposed a novel cross-layer mobility-aware MAC (CMCS) protocol for CRSN. It integrates spectrum sensing at the physical (PHY) layer with packet scheduling at the MAC layer.
Satish Anamalamudi et al [10] suggested an Interference-aware fusion CCC perceptive MAC etiquette with maneuvering RTS/CTS and data broadcast. It practices harmonized TDMA based Slotted Co-ordination Function (SCF) for intellectual governing message conversation and outdated CSMA/CA based Distributed Coordination Function (DCF) for maneuvering data broadcast.
Zaw Htike et al [11] have suggested MAC etiquette for intellectual radio systems with dynamic control network consignment, known as DYN-MAC. In DYN-MAC, a governing network is energetically allotted depending on the accessibility of band. Therefore it is able to abide principal customer actions. DYN-MAC also helps impact permitted network-wide distribution and discourses other key issues like principal/subordinate customer unseen mortal issues.
Le Thanh Tan et al [12] have examined the combined ideal detecting and dispersed Medium Access Control (MAC) procedure strategy difficulty for cognitive radio (CR) systems. They take into consideration both situations with solitary and manifold networks. For every situation, they intended a harmonized MAC procedure for active band distribution amongst numerous secondary users (SUs), which joins band detecting for defending energetic primary users (PUs).
S. M. Kamruzzaman [13] has planned a TDMA based dynamism effective cognitive radio multichannel MAC etiquette (ECR-MAC). It needs only a sole half-duplex radio transceiver on every nodule that assimilates the band identifying at physical (PHY) layer and the package planning at MAC layer. Besides this, ECR-MAC familiarizes frivolous clear period compromise that feats the benefit of both numerous networks and TDMA, and attain violent energy investments by permitting nodules that are not intricate in communication to go into snooze type.
Le Thanh Tan et al [14] have suggested a semi-distributed cooperative spectrum sensing (SDCSS) and channel admittance outline for multi-channel CRNs. In this system, SUs achieve recognizing and interchange detecting results with one another to trace band gaps. Besides, they planned the p-persistent CSMA-based cognitive MAC etiquette assimilating the SDCSS to allow effectual band distribution amongst SUs.
Saptarshi Debroy et al [15] have planned a argument based dispersed medium access control (MAC) etiquette for the subordinate operators' network admittance. The planned MAC etiquette lets collision-free entree to the accessible data networks and ultimately their exploitation by subordinate operators, with band detecting portion being controlled by limited detecting nodules. To upsurge exploitation deprived of producing risky intrusion to primaries, they familiarized the establishment of registration of permitted networks by SUs furthermore for prolonged times.

III. DYNAMIC CHANNEL ASSIGNMENT MAC PROTOCOL (DCAMAC)

In this paper, we propose to design a dynamic channel assignment MAC protocol for CRAHNs. Figure 1 shows the block diagram of the proposed DCAMAC protocol.
Here a channel quality indicator (CQI) is used as a utility function for each channel. The CQI is estimated in terms of the signal to noise ratio (SINR). Then a channel with best CQI is chosen as the CCC by the CH. The CCC is assigned dynamically in each round. Then along with the channel state (idle, busy or collision) the CQI is also considered to derive a combined weight for each channel. Then the channels with higher weights are assigned to higher priority traffic classes. Primarily, standby networks are allotted merely to the nodules with advanced primacy actual congestion. If a data network is unobtainable for any inferior primacy congestion, the standby networks of advanced primacy congestion can be momentarily allotted to the inferior primacy congestion nodules.

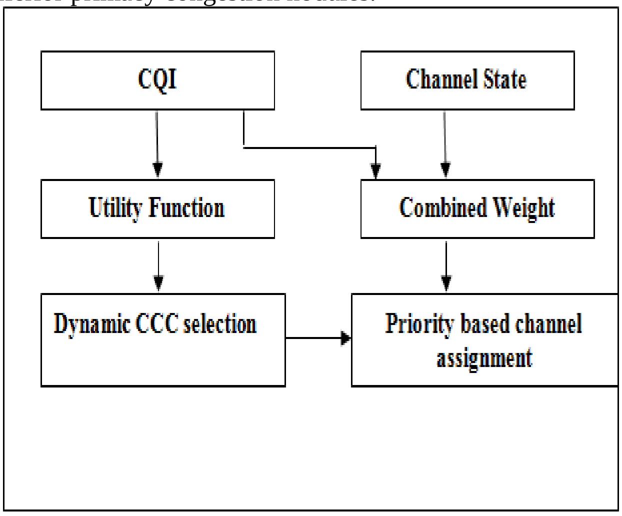

Figure 1 Block Diagram of DCAMAC protocol

3.2 Dynamic CCC selection

Let PU and SU be the primary and secondary user

Let W be the super frame duration

Let T be the broadcast timeslot

Let H be the broadcast interval

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Let Z be the channel availability

Let L_{CH}^{K} be the channel status information list of K channels

The CQI is estimated in terms of the signal to noise ratio (SINR) as follows:

$$CQI = \frac{Q}{|CR_j|} \sum_{n \in CR_j} \log_2 (1 + SINR_{nj}) \quad (1)$$

where,

Q is the channel bandwidth
CR_j is j^{th} cognitive radio

The Channel availability Z is defined using the following equation

$$Z = \frac{E[PU_{off}]}{E[PU_{On}] + E[PU_{Off}]} \quad (2)$$

Where, PU_{Off} and PU_{On} is the expected fraction of time when the channel is in Off and On state.

Then utility function is derived as

$$U_j = w_1 . CQI_j + w_2 . Z_j \quad (3)$$

The processes involved in CCC selection is illustrated in the following algorithm:

Algorithm- CCC Selection

```
For each W
  For each channel Cj, j=1,2…K
    While (H not expired)
      CQI value of Cj is broadcast during relevant T.
      SU broadcasts the channel availability Zj at T.
      Utility function Uj is estimated as Eq.(3)
      Store Uj in LCH^K
    End While
  End For
  Sort all Cj in descending order of Uj
  Select C1 as the CCC
End For
End
```

At the end of H, all SU will gather the CQI and Z of each channel and estimate the utility function of each channel. Create the channel information list and store utility functions of all channels. Sort all the channels in the descending order of the utility function. Then the channel which has lowest PU activities and best CQI is selected as CCC. That is, the channel with highest U is selected as CCC. The updated CCC will be used for next incoming W. The process is repeated for each W.

Note that as CCC selection is updated on every W, the best channel will always be selected as CCC.

1.3 Traffic classification

The Table 1 illustrates the traffic classification where a value between 1 and 4 is assigned to each traffic class to prioritize the nodes when accessing channels and allocating transmission slots.

Traffic Class	Traffic Class Value
Real-time reliable (RR)	1
Real-time Non-reliable (RnR)	2
Non-Realtime Reliable (nRR)	3
Best effort traffic (BE)	4

Table 1 Priority of various traffic classes

Here, higher class values indicate lower priority.

The brief description of traffic classes are as follows

- RR traffic is both deferral and reliability-constrained. It agrees to acute data packages that must attain the sink with great dependability and surrounded by a severe delay-deadline.
- *RnR* traffic, as well called as delay-constrained packages, essentially should attain the sink surrounded by a severe delay-deadline. On the other hand, certain package fatalities possibly will be accepted. This kind of congestion may perhaps move, for instance, multimedia data and visual flowing.
- *nRR* congestion is extremely reliability-constrained, not delay-constrained.
- *BE* congestion is neither delay-constrained nor reliability-constrained. They are called standard packages as well and only need finest attempt aid.

3.4 Weight Based Channel Assignment

Along with the channel state (idle, busy or collision) the CQI is also considered to derive a combined weight for each channel as follows:

Let e_i represent the reward or penalty to the i^{th} channel state

The weight of i^{th} channel is updated using the following equation

$$V_i = V_i + e_i + \delta . CQI \quad (4)$$

Here, $e_i \in \{0.1, -0.1, -0.2\}$ and δ is the normalization constant in the range of {0,1}

State i be the idle, busy, collision state of the channel

The channel with higher V_i is assigned to higher priority traffic class.
The steps involved in the channel assignment process are illustrated in the following algorithm.
Algorithm Weight based channel assignment

```
For each channel Ci
    Estimate the weight Vi of Ci
    Let Vi' = Int(Vi)
    If (Vi ' > 0) then
      If (Vi' < L1) then
          Assign Ci to traffic class 4
      Else If (Vi' > L1 and Vi' <=L2) then
            Assign Ci to traffic class 3
      Else If (Vi' > L2 and Vi' <=L3) then
            Assign Ci to traffic class 2
       Else If(Vi' > L3) then
            Assign Ci to traffic class 1
       End if
    Else
        Ignore Ci
    End if
End For
```

In this algorithm, the weight of each channel is checked against three upper bounds L_1, L_2 and L_3 , where $L_1 < L_2 < L_3$.
If the weight V is non-negative, it indicates the channel availability. Then the integer value of the weight is taken and compared with the upper bounds. If V is below the lowest bound L1, then it is assigned to the least priority traffic (priority 4). If V is between (L_1 , L_2) , then the channel is assigned to priority class 3. If V is between (L_2 , L_3), then channel is assigned to priority class 2. If V is above the highest bound L3, then the channel is assigned to the highest priority class 1. On the other hand, if V is negative, it indicates the non-availability of that channel and hence it is ignored and next channel is taken for consideration. The process is repeated until all the traffic classes are assigned with suitable channels.
During the channel assignment process, backup channels are assigned to the priority class 1, if available. If a data channel is not available for any lower priority traffic, then the backup channels of higher priority traffic can be temporarily assigned to the lower priority traffic nodes.

3.5 Outcomes of the research

- Reduced Packet drop rate
- Reduced packet error rate
- Increased packet delivery ratio
- Improved throughput for high priority (video) traffic
- Guaranteed throughput for low priority (CBR) traffic

IV. EXPERIMENTAL RESULTS

4.1 Experimental Settings

The simulation of proposed DCAMAC is conducted in NS2. The experimental settings are listed in Table 2 and the simulation topology is shown in Figure 2. The performance of DCA-MAC is compared with Multi constrained QoS Aware MAC (MQMAC) protocol [17] and Distributed MAC(DistMAC) [7] protocol. The performance metrics measured are throughput for different types of traffic, packet delivery ratio (PDR) and end-to-end delay (E2D).

Network size	100 nodes
Size of the topology	1000 X 1000m
Traffic Source	CBR, Video, Exponential
Number of data flows between SU	10 to 20
Data Rate	0.25 to 1.0 Mb
Propagation model	Two Ray Ground
Antenna model	Omni Antenna
Initial Energy	10 Joules
Transmit Power	0.8 watts
Receiving Power	0.3 watts

Table 2 Simulation parameters

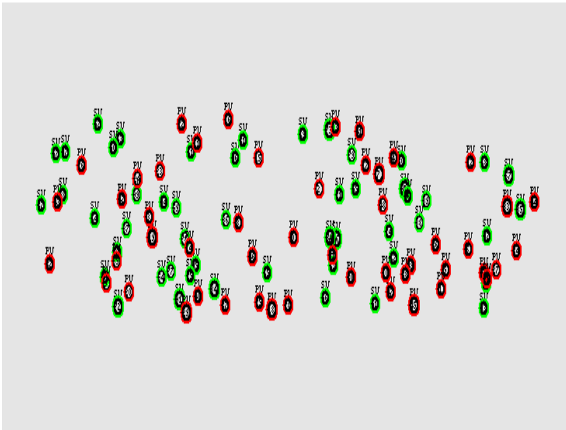

Figure 2 Simulation Topology

4.2 Results and Description

A. Varying the Data Rate

In this section, the performance of all the 3 protocols is evaluated by varying the data rate from 0.25 to 1.0 Mb.

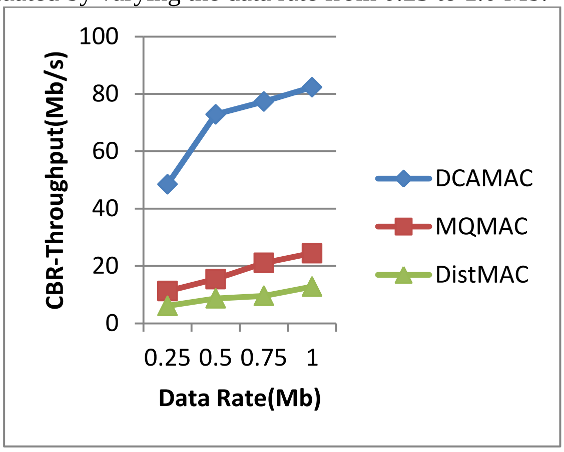

Figure 3 Results of CBR Throughput for varying data rate

The result graph of CBR Throughput for all the techniques for different rates, is shown in Figure 3. It can be observed that the CBR throughput of DCAMAC ranges from 48.4 to 82.3 Mb/s, the CBR throughput of MQMAC ranges from 11.2 to 24.4 Mb/s and the CBR throughput of DistMAC ranges from 6.0 to 12.7 Mb/s. Ultimately, DCAMAC has 75% higher CBR throughput than MQMAC and 87% higher CBR throughput than DistMAC.

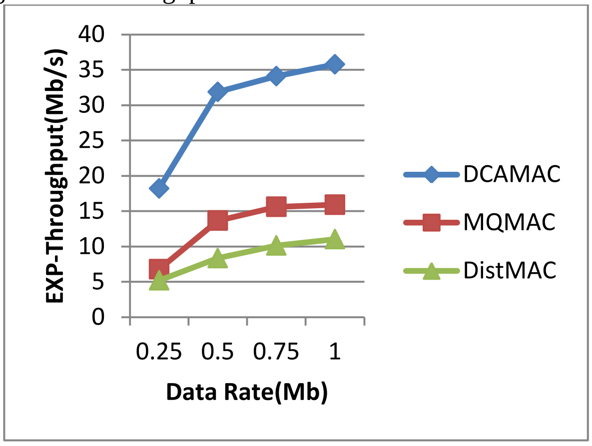

Figure 4 Results of EXP Throughput for varying data rate

The result graph of EXP throughput for all the techniques for different rates, is shown in Figure 4. It can be observed that the EXP throughput of DCAMAC ranges from 18.2 to 35.7 Mb/s, EXP throughput of MQMAC ranges from 6.7 to 15.9 Mb/s and the EXP throughput of DistMAC ranges from 5.2 to 11.0 Mb/s. Ultimately, DCAMAC has57% higher EXP throughput than MQMAC and 71% higher EXP throughput than DistMAC.

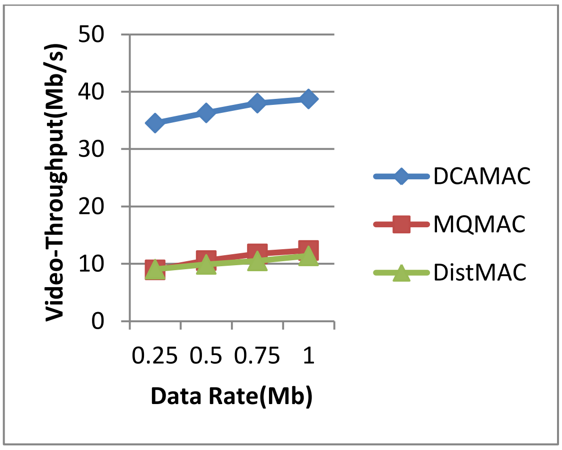

Figure 5 Results of Video Throughput for varying data rate

The result graph of Video throughput for all the techniques for different rate, is shown in Figure 5. It can be observed that the Video throughput of DCAMAC ranges from 34.5 to 38.3 Mb/s, the Video-throughput of MQMAC ranges from 8.9 to 12.3 Mb/s and the Video-throughput of DistMAC ranges from 9.0 to 11.3 Mb/s. Ultimately, DCAMAC has 71% higher video-throughput than MQMAC and 72% higher video-throughput than DistMAC.

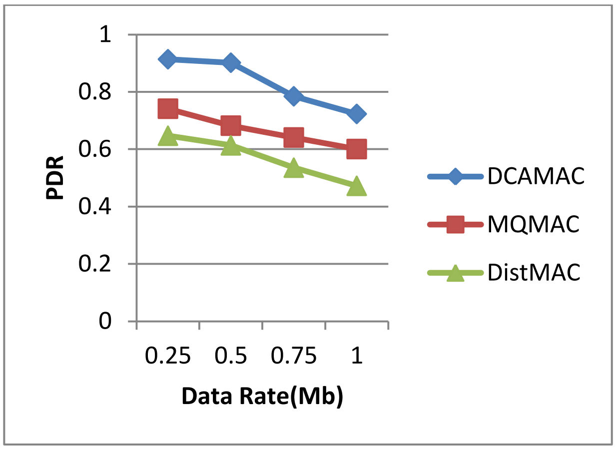

Figure 6 Results of PDR for varying data rate

The result graph of PDR for al the techniques for different rate, is shown in Figure 6. It can be observed that the PDR of DCAMAC ranges from 0.91 to 0.72, PDR of MQMAC ranges from 0.74 to 0.60 and the PDR of DistMAC ranges from 0.64 to 0.47. Ultimately, the PDR of DCAMAC is 20% higher than MQMAC and 32% higher than DistMAC.

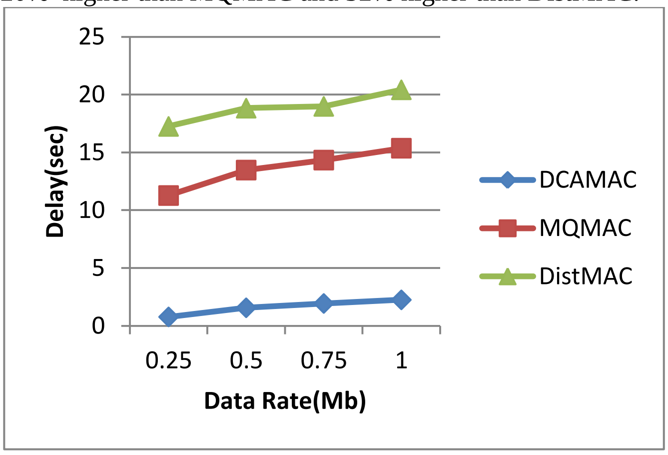

Figure 7 Results graph of E2D for varying data rate

The result graph of E2D for both the techniques for different rate, is shown in Figure 7. It can be observed that the E2D of DCAMAC ranges from 0.77 to 2.2 seconds, E2D of MQMAC ranges from 11.2 to 15.3 seconds and the E2D of DistMAC ranges from 17.2 to 20.4 seconds. Ultimately, DCAMAC has 88% lesser E2D than MQMAC and 91% lesser E2D than DistMAC.

B. Varying the Number of Data Flows

In this section, the performance of all the 3 protocols is evaluated by varying the number of data flow from between the SUs from 10 to 20.

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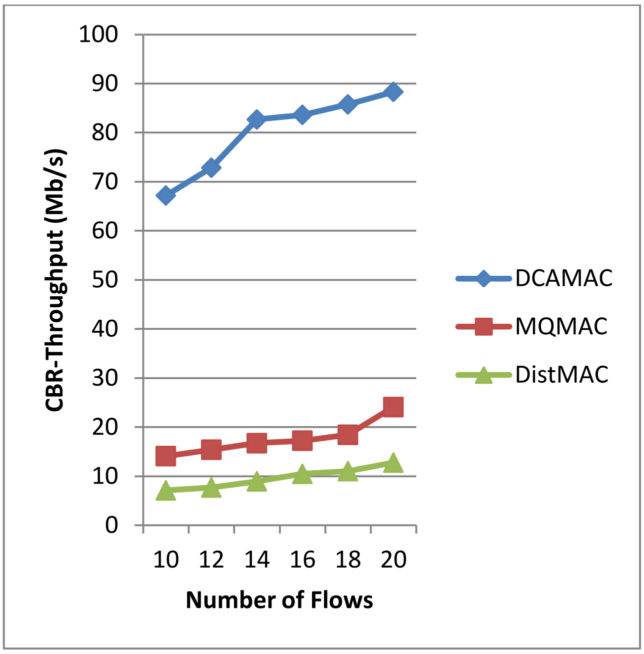

Figure 8 Results of CBR Throughput for varying data flows

The result graph of CBR Throughput for all the techniques for different flows, is shown in Figure 8. It can be observed that the CBR throughput of DCAMAC ranges from 67.1 to 88.3 Mb/s, the CBR throughput of MQMAC ranges from 14.0 to 24.0 Mb/s and the CBR throughput of DistMAC ranges from 7.1 to 12.7 Mb/s. Ultimately, DCAMAC has 78% higher CBR throughput than MQMAC and 88% higher CBR throughput than DistMAC.

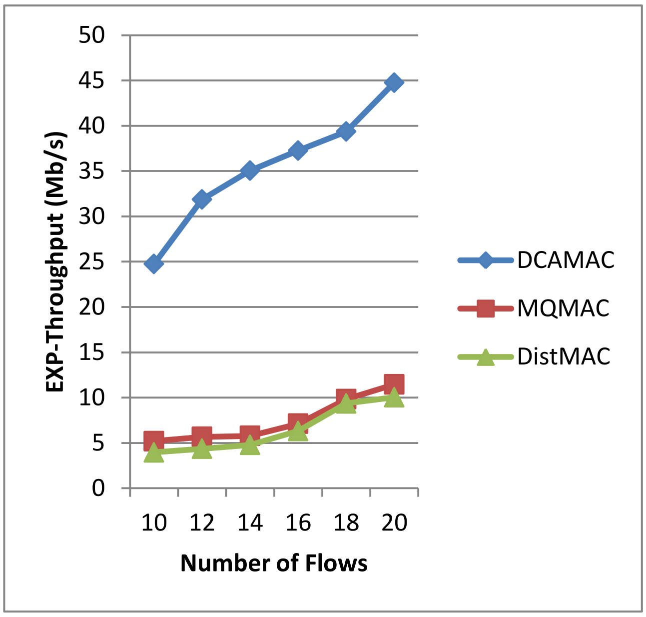

Figure 9 Results of EXP Throughput for varying data flows

The result graph of EXP throughput for all the techniques for different flows, is shown in Figure 9. It can be observed that the EXP throughput of DCAMAC ranges from 24.7 to 44.7 Mb/s, EXP throughput of MQMAC ranges from 5.1 to 11.4Mb/s and the EXP throughput of DistMAC ranges from 3.9 to 10.0 Mb/s. Ultimately, DCAMAC has 80% higher EXP throughput than MQMAC and 82% higher EXP throughput than DistMAC.

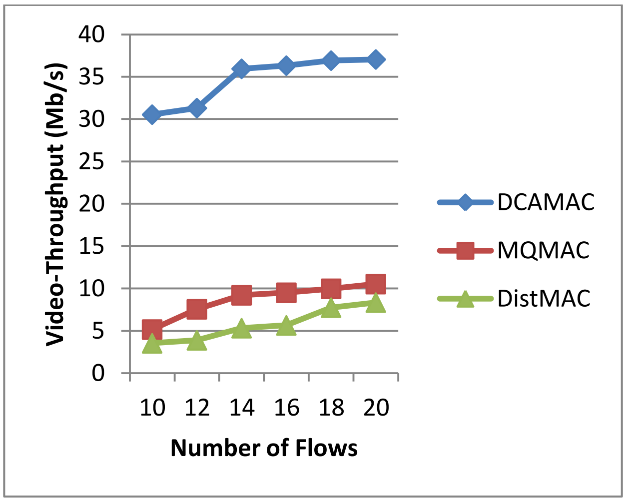

Figure 10 Results of Video Throughput for varying data flows

The result graph of Video throughput for all the 3 techniques for different flows, is shown in Figure 10. It can be observed that the Video throughput of DCAMAC ranges from 30.5 to 37.0 Mb/s, the Video-throughput of MQMAC ranges from 5.1 to 10.5 Mb/s and the Video-throughput of DistMAC ranges from 3.5 to 8.3 Mb/s. Ultimately, DCAMAC has 76% higher video-throughput than MQMAC and 84% higher video-throughput than DistMAC.

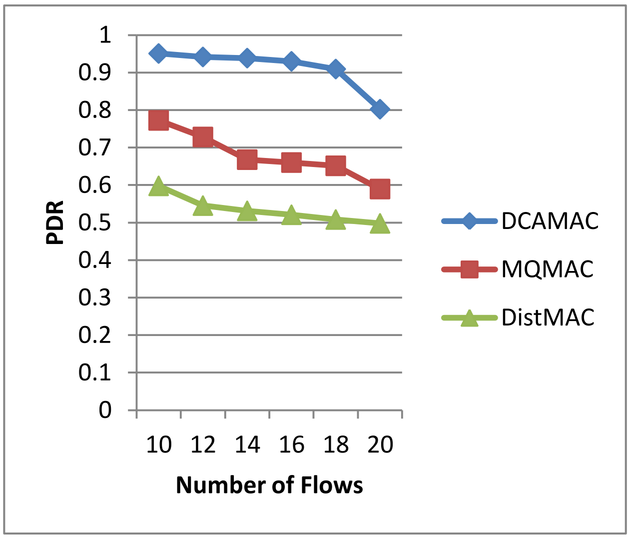

Figure 11 Results of PDR for varying data flows

The result graph of PDR for all the 3 techniques for different flows is shown in Figure 11. It can be observed that the PDR of DCAMAC ranges from 0.95 to 0.80, PDR of MQMAC ranges from 0.77 to 0.58 and the PDR of DistMAC ranges from 0.59 to 0.49. Ultimately, the PDR of DCAMAC is 25% higher than MQMAC and 41% higher than DistMAC.

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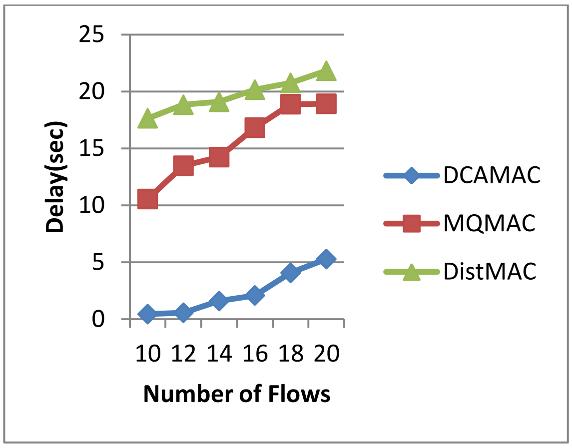

Figure 12 Results graph of E2D for varying data flows

The result graph of E2D for all the 3 techniques for different flows, is shown in Figure 12. It can be observed that the E2D of DCAMAC ranges from 0.45 to 5.2 seconds, E2D of MQMAC ranges from 10.5 to 18.9 seconds and the E2D of DistMAC ranges from 17.1 to 21.8 sconds. Ultimately, DCAMAC has 86% lesser E2D than MQMAC and 89% lesser E2D than DistMAC.

V. CONCLUSION

In this paper, we have proposed to design a channel quality based MAC protocol for CRAHNs. In this technique, a channel with best CQI is chosen as the CCC by the CH. The CCC is assigned dynamically in each round. The channels with higher weights are assigned to higher priority traffic classes. Initially backup channels are assigned only to the nodes with higher priority real-time traffic. If a data channel is not available for any lower priority traffic, then the backup channels of higher priority traffic can be temporarily assigned to the lower priority traffic nodes. By simulation results, we have shown that the proposed technique reduces packet drop rate, error rate and increases packet delivery ratio and throughput.

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