A Cluster-Based Connected Dominating Set Routing Protocol in Mobile Ad Hoc Networks

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Abstract: The nodes in Mobile Ad-hoc Network are randomly deployed and nodes can enter and leave network anytime. The topology control because of the mobility of the nodes in MANET is a great challenge. The efficient way to address the issue is to use Connected Dominating Set (CDS) which constructs the virtual backbone network for achieving efficiency and scalability in MANETs. In this paper, we propose a connected dominating set based efficient routing protocol (CDSERP) in multichannel MANET. The protocol was proposed to achieve a high Packet Delivery Ratio, minimum delay, less control overhead, and less power consumption when the node is in mobility. The proposed CDSERP protocol under a multi-channel wireless network has the clustering phase and routing phase. The clustering phase has a selection of CDS, minimize CDS size and algorithm based on Clustering to create clusters and to provide a set of intermediate nodes for routing. The routing phase will establish an efficient route from the dynamic selection of intermediate routes avoiding the user affected area. The CDSERP is implemented in NS-2 to experiment with its dominance over the traditional AODV protocol in terms of Packet Delivery Ratio, delay, control overhead, and power consumption.

Keywords: MANET, Efficient Routing, Dominating Set, PDR, Control Overhead

I. INTRODUCTION

A mobile ad-hoc network is a set of autonomous nodes that are self-organized and creates a network with their radio ranges. The nodes are joined and leave the network at any time and communicated with each other through self-participation. The administration of nodes in MANET does not have any centralized control. Here the nodes may act as a router to forward the packets of other nodes along with sending of own packets in the network. The deployment of MANET is cost-effective, easy, and faster when compared with wired networks. The major characteristics of MANET are Decentralized Architecture, Multihop routing, Resource constraints, and Dynamic Topology.

In MANET there are many challenges such as infrastructure-less, no centralized control, low bandwidth, fewer resources, low data transmission rate and quality, frequent connection, disconnection of links, and dynamic topology. These factors affect clustering and routing in MANET. In this paper, our main focus is on clustering and routing issues at the network layer in MANET. The issues related to the lower layer may also affect routing in the network layer. They are energy-efficiency, delay, throughput, packet loss, QoS, mobility, control overhead, security, traffic optimization, routing, and data collection. However, our primary focus is to achieve a high Packet Delivery Ratio, minimum delay, less control overhead, and less power consumption. The lower layers of the network are also supported by the above issues.

In MANET the infrastructure is not fixed and no centralized control dependency among the nodes deployed in it. The clustering of the network is an efficient and suitable approach to design a stable routing by creating virtual infrastructure [1]. In this paper, we have focused to improve the network performance by addressing issues related to multi-channel clustering and routing approach. During the routing process, the routes selected in the higher layer may affect the primary user's licensed channel allocation which may affect the guaranteeing of quality of service in MANETs. This issue may be addressed using Clustering and routing with an appropriate selection of channels and proper direction of transmission flow. Further, the problems of selection of channel and transmission direction in MANETs clustering and routing has opened up many research challenges and attracted researchers. The detailed review of the literature on clustering and routing in wireless networks is carried out in the following section.

II. LITERATURE REVIEW

In this section, the detailed review in the previous works carried by researchers on clustering and routing in wireless networks. The survey in [2] has classified the clustering algorithms as DS based clustering, mobility-based clustering, load balancing clustering, energy-efficient clustering, metrics-based clustering, and low maintenance clustering. In DS based clustering the connected dominate set of nodes with the minimum size is used for clustering and routing. The idea behind mobility-based clustering is to group the nodes based on the movement history of nodes and framed a stable cluster. In the energy-efficient clustering, the energy needs to be saved to enhance the lifetime of the network. The cluster heads usually do more tasks and the energy gets exhausted so fast. In this method the cluster head is changed periodically to other nodes and eliminating fewer energy nodes from the cluster will enhance the lifetime of the network. The low-maintenance clustering, the minimum number of re-clustering are used to provide stability in clustering. The system performance is improved through the use of a minimum number of clusters and balancing the load among them in load-balanced clustering. The metric-based clustering uses different metrics like speed, energy, and degree of nodes to create clusters. The cluster head is chosen with the best performance value of the metrics. The probabilistic clustering algorithm [3] is proposed by authors to choose cluster heads which have high vacant channels. The cluster head sends a message to find the number of vacant channels and chooses to find the best channel for communication. The authors in [4] proposed a weighted function to select the cluster head based on the mobility, total time of being cluster head, degree of connectivity, and distances of its neighbors. The power of the cluster head is adjusted efficiently to select the cluster head and proposed a distributed weighted clustering algorithm [5]. The weighted clustering algorithm was extended in [6] with transmission range, power, battery energy power, and mobility of nodes for electing the cluster head. The EWCA has very good load balancing and increased stability in MANETs. The authors have proposed mobility-based clustering [7] for MANET with topology control management and with multicast routing. The connected dominating set is used to design the clusters. The distributed algorithm based on CDS was proposed to reduce the size of CDS based on node ID's. In [8,9], the reduction-based method with nodes vertex is considered to lower the size of CDS. The authors have proposed a CDS routing protocol algorithm based on the degree of nodes and level of energy [10]. The energy-efficient and scalable routing algorithm were proposed based on the residual energy and length of the route in MANET. The algorithm provides more stable and efficient communication in MANET.

Further, some research studies on routing are carried out and presented here. The authors in [11] have proposed a new channel MAC control protocol for medium access control and channel assignment in an integrated environment. Here, the mobile node uses a channel for control message and all other channels for data transfer. In [12] the authors have proposed an optimization method to accurately calculate the throughput under multihop networks. The proposed algorithm finds more accurate throughput by using interference, multi-rate terminals, and hidden node collision. The spectrum allocation by dynamically in cognitive mobile ad-hoc networks and the selection of path is based on activities of the main user [13]. To model multi-channel networks in [14] the authors have used layered graphs and model spectrum allocation problems were resolved using colored graphs [15]. The authors have proposed a SEARCH protocol algorithm for MANETs to find a route from source to destination with a minimum delay and without disturbing any activities. To reduce the spectrum utilization and also to join the interference from primary users and cognitive users by the introduction of mixed-integer non-linear programming [16]. A routing and dynamic spectrum allocation method were proposed in [17] to maximize the throughput and minimize the physical interference by using spectrum allocation, transmission control, and scheduling. There are many prediction algorithms are presented in [18] to find the location of nodes. These algorithms show an improvement in the performance of the network. In [19] authors have predicted the movement of nodes like when will be the next movement and its location using prediction technique in a wireless network. The authors in [20] an energy reduction multipath routing protocol to improve the system performance. It uses a recoil off time technique to find the route using geographical information between source and destination. The change is topology frequently may affect routing and choosing a suitable routing protocol is important for the performance of routing. The authors in [21] have proposed a change of topology-aware based routing protocol in MANETs. The changing characteristics of network topology

in MANETs result in security attacks. To overcome this, the split key exchange technique using MANET roaming characteristics was proposed to reduce the number of attacks and improve performance.
From the above literature review it is observed that clustering and routing have their advantages as well as disadvantages. To find an effective routing path with less cost, clustering is found to be an effective solution. It will minimize the cost, reduces the routing process time and effective balance of energy for improving the performance of the network. This paper proposes a connected dominating set based efficient routing protocol (CDSERP) in multichannel MANET. The proposed algorithm to improve the PDR, less delay and, minimal control overhead with nodes moving at high speed.

III. SYSTEM MODEL

The system model consists of nodes, clusters, cluster head, gateway node, and links arranged randomly. The source node and destination node are chosen from different clusters for data transmission. The Random Way Point mobility model is used in our network. The mobile node in this network has the following properties:

- The mobility of nodes is based on RWP and can move independently
- The location of each node and the destination will be known through GPS
- The range of its transmission is fixed for each node.
- The node can choose the channel to send a packet and it's not fixed.

Here the nodes in the network categorized as clusters and each cluster contain Head of Cluster (HC), Members of Cluster (MC), and Gateway of Cluster (GC). The Head of Cluster acts as the main node and represents all other cluster Members with a one-hop transmission of packets within the cluster. The Head Cluster can directly communicate with other HC and GC. The GC has freedom of one-hop communication as an intermediate node with HC and other clusters HC/GC. The MC is a node in a cluster that can communicate with its HC in a single hop.

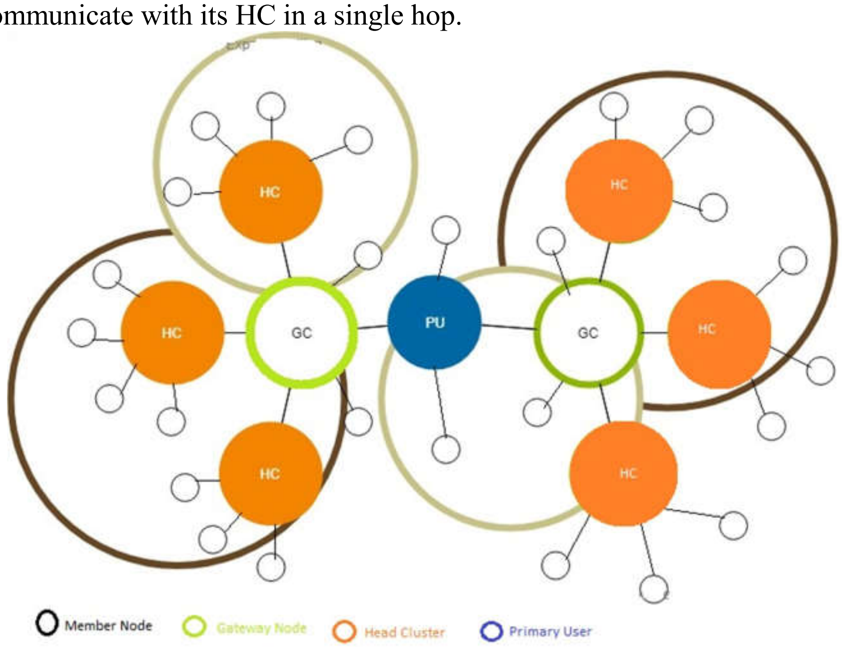

Figure 1: System Model with HC, GC, MN

Figure 1 shows the system model describing different clusters, Head clusters, and Gateway clusters and its operations. In this paper, we mainly focus routing in the network layer which exchanges the information through control packets. The usage of energy for transmission of data between source and destination mainly depends on the sender and receiver energy. We consider only the transmission energy and receiver energy of the network layer in this paper. Another layer energy proposed in [22, 23] is used for calculating the efficiency of our protocol with existing schemes. In recent MANET, MAC protocols support multiple channels [24]. It provides 14 channels and for communication with other nodes each of which can use multiple channels. Usually channel 0 is reserved for control information and anyone channel between 1 to n-1 for data transmission among n channels.

IV. PROPOSED CRD ROUTING PROTOCOL

The proposed routing protocol is divided into the cluster phase and routing phase. In the initial phase, the HELLO packet is sent with all the information by each node to its neighbor nodes. The proposed CDS algorithm selects a set of CDS intermediate nodes. The number of CDS nodes is minimized using a minimize CDS size algorithm and select the Head Cluster using the clustering algorithm. In this phase finally the Gateway Cluster and Head Cluster nodes are selected. In the routing phase, let us assume HCn as Head Cluster of n and Ch(n) as the receiving channel. The proposed routing algorithm works as Source S creates the RREQ packet and the same is sent to its Head Cluster HCs. The HCs will send to another HC of GC based on the routing protocols. The RREQ packet may reach the destination node through these routing techniques and the destination will generate the RREP packet and sends back to the source with route establishment.

In this section we will define a few definitions which are used in the proposed algorithm such as mobility function, balance energy ratio, stability factor, and speed ratio.

Mobility Association Function: Mobility Association function MA between two nodes u and v is

$MA_v(u)=1-d(u,v)/K$, where d(u,v) is Euclidian distance between u and v and $K=\beta R$, R represents the radius of transmission range. If a node u moves away from node v, the value $MA_v(u)$ is smaller and if node u moves near to v, the value of $MA_v(u)$ is higher.

Stability Ratio: The stability ratio is of node v is measured as ST(v)=sum of $MR_v(1..m)/m$, where m is the total number of neighbor nodes of v.

Balance Energy Ratio: The balance energy ratio is the residual energy of the node v and is calculated as $BE(v)=E_v/Emax$

Speed Ratio: The speed ratio SR of node v is expressed as SR(v)=1-Speed(v)/max-speed of nodes

Weighted Ranking Function: The weighted ranking WR function is enumerated for node v is expressed as $WR(v)=x_1ST(v)+x_2BE(v)+x_3SR(v)$

Where x_1,x_2,x_3 are selected randomly as constraints whose sum is equal to 1.

4.1 Packet Format

In this section we present the generalized packet formats for both information and control packet for the clustering phase and routing phase. In the clustering phase, the types of packets are used to discover neighbor nodes, advertisement of the head cluster, invitation packet to join the cluster, and information packet. The structure of the packet in the clustering phase is shown in figure 2. In the routing phase, the different types of packets used are RREQ, RREP, and data packet. The structure of the packet used in the routing phase is shown in figure 3.

Sender ID	Receiver ID	Type (HC,GC,MC)	Sender Location	Sender Energy	Speed	Direction	Neighbour ID's List	Sender Channel

Figure 2: The clustering phase general structure of the packet

Type	Source IP	Destination IP	Broadcast ID	Hop Count	Source SeqNum	Destination SeqNum	Data

Figure 3: The routing phase general structure

4.2 Proposed Algorithms

Here, we consider a system model as an undirected graph G={V, E}, where V specifies the number of nodes, and E specifies the number of links. The {u,v} specifies the link between two nodes u and v in the wireless environment. These nodes are in the coverage range within the cluster. Let us assume G is a connected graph and D is a subset of Vertex graph V(G). A set D is said to be dominating set if every vertex which is contiguous to at least one vertex in D and not in D. The dominating set D is called connected dominating set if and if the induced graph of D is connected in G. The node is called intermediate node v if it has two nodes u and w which are not connected with each other [9].

Algorithm: Selection Process of CDS

Step 1: Initially specify nodes as unmarked

Step 2: Send information packet to all its neighbors through the same channel
Build a neighbor node list N(u) based on the packets received from its neighbors.

Step 3: Node v sends information packet to all its neighbor's list N(v)
The node u stores the information received from node N(v).

Step 4: The connected dominating set CDS is built as an intermediate node that has two unconnected neighbor nodes.

Algorithm: Size reduce of CDS

Step 1: Let us assume two nodes u and v is in CDS. Check the node u and v are equal and check the weighted ranking value. If it is same and based on the arrival time remove node v

Step 2: Let us assume v and w are intermediate nodes of v and are in CDS.
Calculate the number of intermediate nodes and Weighted ranking of u and w and compare it with v. If it same then remove node v from CDS.

Step 3: Each node v removed from the CDS list will send the status message to all its neighbors. The node v updated its neighbor's list based on the reply it has received.

Algorithm: CDS based Clustering

The primary aim of the CDS clustering algorithm is to create clusters and identify the cluster heads. These clusters should satisfy main properties such as connectivity between nodes, stability among the links, reducing the control overhead, less delay, and high PDS with energy-saving.

Step 1: Initially we will build CDS using the CDS selection algorithm and we will minimize the number of CDS nodes using CDS size reduce algorithm.

Step 2: The Head Cluster will be selected if there is no Head cluster available in the neighbor list. The non-intermediate node will get updated with the new Head Cluster.

Step 3: Any of the non-intermediate node v's neighbor list has got one Head Cluster then the Join Cluster packet may be sent to the best HC_u.

Step 4: The node becomes HC once it receives a packet containing join cluster from node v, it sends the acceptance message through the common channel and the cluster table is updated with sender information.

Step 5: The Head cluster will be elected or chosen by every intermediate node.

Finally, the CDS includes intermediate nodes as gateways and Head Clusters.

4.3 THE PROPOSED ROUTING PROTOCOL— CDSERP

The proposed CDSERP uses Head Cluster and Gateway Cluster. The Head Cluster (HC) is a cluster representation which transmits the packets with other nodes in a single hop. It can also communicate with other Head clusters and gateways. The Gateway Cluster can communicate with HC and other HC/GC in a single hop.

The proposed CDSERP algorithm works as follows.

Step 1: A node S creates an RREQ packet and send to HC in its cluster

Step 2: If the RREQ packet received by HC_v from source node S or GC node. It chooses the best signal channel for forwarding the RREQ packet. The details of the channel and next hop are added into the cluster table once if the RREQ packet is forwarded.

Step 3: Once the RREQ packet reaches destination D, the channel and next-hop details are stored in the cluster table and sends the RREP packet back to the source.

If a multiple RREQ packet is received by a node v then the following cases decide which RREQ should be forwarded by node v.

i. If the $RREQ_{new}$ seq_num is greater than $RREQ_{old}$ seq_num, then it will forward $RREQ_{new}$.

ii. If the seq_num of $RREQ_{new}$ and $RREQ_{old}$ is the same then based on the latest broadcast_id the $RREQ_{new}$ packet will be forwarded.

iii. If the seq_num and broadcast_id are the same then based on the hop count information the RREQ packet is forwarded. It the hop count value is less in $RREQ_{new}$ then it will be forwarded.

iv. In contrast to the above choices the $RREQ_{old}$ is forwarded and drops $RREQ_{new}$.

Step 4: For every node v which receives the RREP packet, the same will be sent based on the stored information in the routing table and records the details of routing.

Step 5: Finally, the data transfer begins from the sender side using the routing table once the source receives the RREP packet.

The algorithm has more advantages once it receives the route from source to destination. Since, the clustering phase is no more required which will minimize the control overhead, energy, and delay of the network.

V. EXPERIMENTAL SETUP AND RESULTS

The proposed algorithm performance is evaluated by varying the mobile node speed ratio each time. The results of the proposed algorithm are compared with AODV modified protocol called CR-AODV. The following describes the simulation setup and its parameters.

The size of the network deployed for simulation in the area of 1000x1000m2 with 50 nodes. There are 6 channels and each node transmission range is up to 250m. The size of the data packet is 2048 bits and the control packet is 1024 bits. The mobility model used in our simulation is Random way point and the channel switching time is around 5ms. The initial energy of the nodes is around 25000 joules and the values of x_1, x_2, x_3 parameters are 0.4, 0.3, and 0.3 respectively. The speed ratio used for simulation is 20, 40, 60, and 80 kilometers per hour. The total simulation time is around 1500 seconds.

The following metrics are evaluated to test the performance of our proposed CDSERP protocol. They are the number of head clusters, number of control packets, delay, PDR, energy usage, and number of channels and switched.

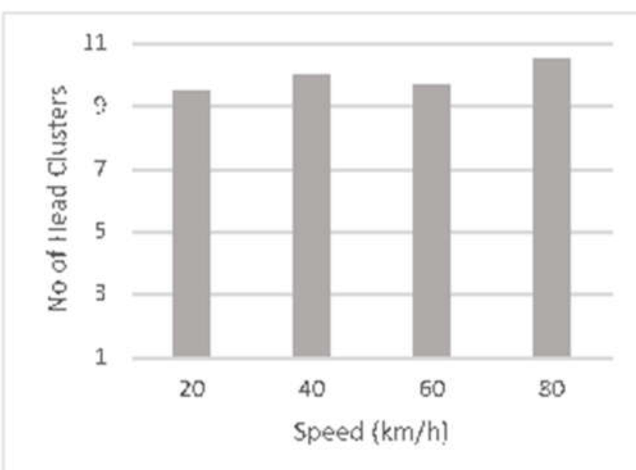

Figure 4: Head Clusters v/s Speed

Figure 4 shows the variation of a number of Head Clusters when speed is varied from 20 to 80KM/h which causes node mobility in the network. The number of nodes in each cluster is around 5 and the average number of clusters is around 10. Which provides a stable set of Connected Dominating Set nodes.

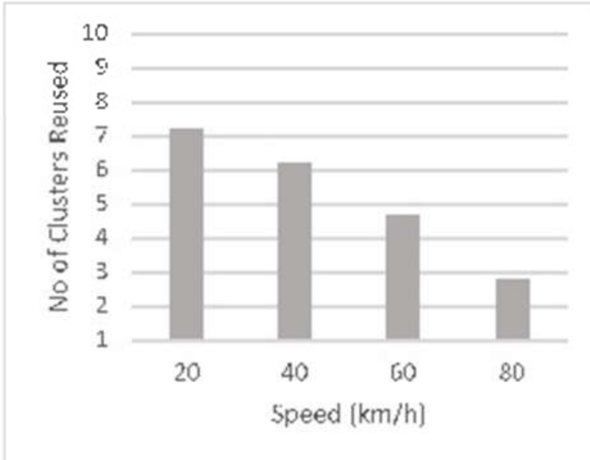

Figure 5: Reused Clusters v/s Speed

Figure 5 shows the mobility of nodes how many number of clusters are reused. When more clusters are reused then the stability of the network is more. The figure shows that with the increase of speed of nodes the reuse of clusters is reduced which means the stability of the network is also reduced.

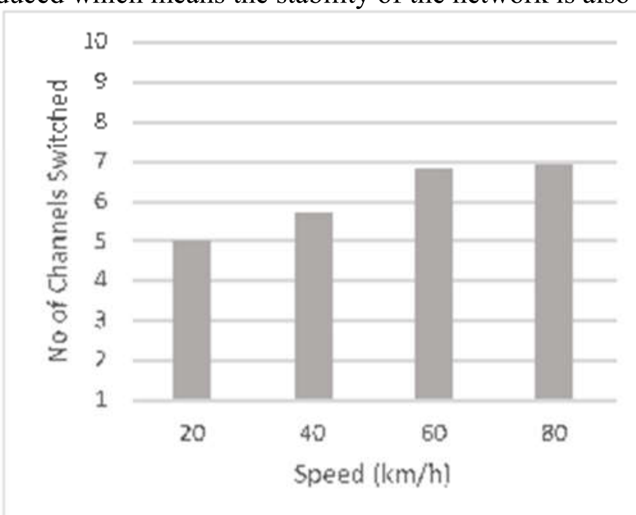

Figure 6: No of Channels Switched v/s Speed

Figure 6 shows how the node mobility is affected by the switching of channels during data transmission. The results show that the switching of channels is comparatively acceptable when the speed varies. Also, the number of channel switching is increased with the speed increase.

Another set of evaluations is carried for our proposed algorithm and the same is compared with existing AODV protocol. The different performance metrics for evaluation are control overhead, Delay, PDR, and Energy.

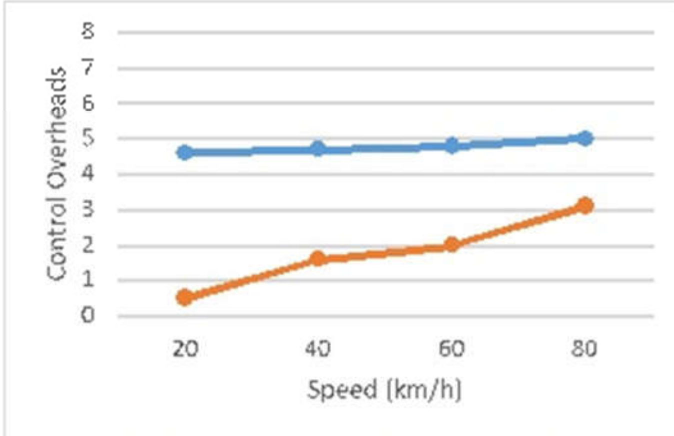

Figure 7: Control Overheads v/s Speed

Figure 7 shows the control overhead caused due to the mobility of nodes. The control overhead is less when compared with AODV because of the reuse of the cluster phase for multiple sessions. The number of control message exchanges are reduced when compared with existing protocols. The existing protocol floods the control message to all nodes which causes more overhead.

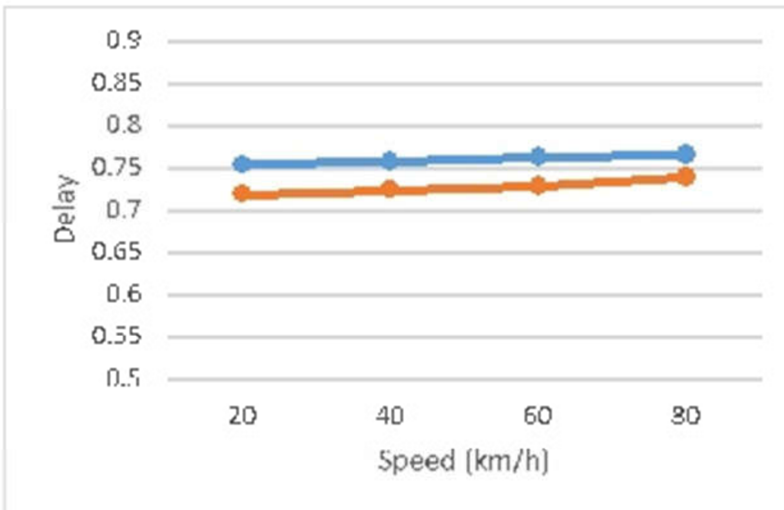

Figure 8: Delay v/s Speed

Figure 8 shown the delay concerning the node mobility. The diagram clearly shows that both the protocols have a marginal increase in delay with speed. The delay in our proposed protocol is less compared with the AODV protocol. The proposed protocol uses the clustering phase to provide a routing environment. Also, the proposed protocol is more stable and requires less number of restructuring the cluster which reduces the delay. The routing time in less when compared with the AODV protocol.

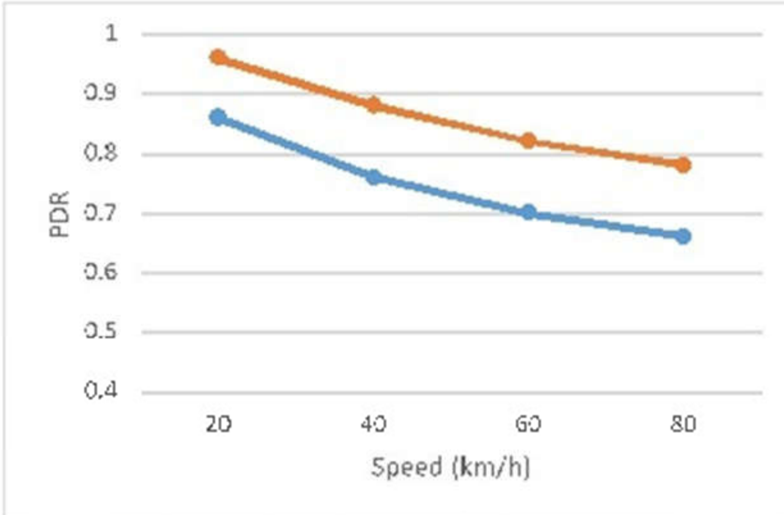

Figure 9: Packet Delivery Ratio v/s Speed

Figure 9 shows the packet delivery ratio with the mobility of nodes. As shown in figure both the protocols have decreased PDR with the speed. Our proposed protocol packet delivery ratio is good when compared with the AODV. This is due to the stability in routing and the routing from source to destination with cluster heads is more efficient.

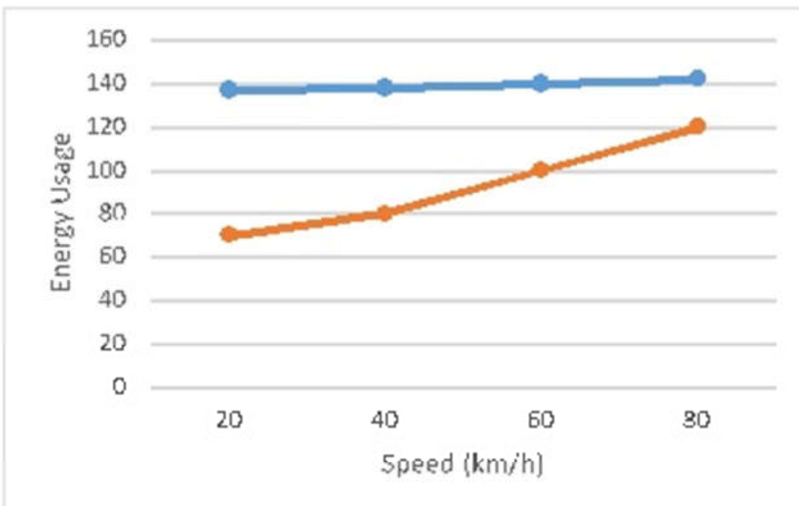

Figure 10: Energy Utilization v/s Speed

Figure 10 shows the utilization of energy with the mobility of nodes. The energy utilization of nodes has increased with speed in both the protocols. Our proposed scheme shows an improvement in the utilization of energy when compared with AODV. This is due to the delay and the control head of the proposed protocol is lower than the AODV protocol. This will prolong the network with lower energy consumption.

VI. Conclusion

In this paper, we proposed a connected dominating set based efficient routing protocol (CDSERP) in multichannel MANET. To achieve a high Packet Delivery Ratio, minimum delay, less control overhead, and less power consumption when the node is in mobility we have proposed different algorithms. Initially, we have proposed to create clusters using CDS based clustering algorithm later we choose Head Clusters through the CDS selection algorithm and reduced the number of head clusters through CDS to reduce size algorithm. The Weighted Ranking function was designed which is a combination of stability, balance energy, and a speed ratio of the network. This function plays an important role in the selection of head cluster and CDS based clustering with a high stable cluster. Secondly the CDSERP based routing protocol was designed keeping in view of the sending channel quality and increased the possibility of finding the best route from source to destination. The experimental results show that our proposed protocol has good performance in terms of PDR, Delay, Energy, and Control Overhead when compared with existing AODV protocol. This work can be extended by limiting the bandwidth and bringing security factors in MANET. Further, the work can be extended with a more complex and challenging solution for multicast multichannel MANETs. Also, it can be extended with the application of machine learning techniques for better results.

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