A CROSS-LAYER QOS AWARE NODE DISJOINT MULTIPATH ROUTING ALGORITHM FOR MOBILE AD HOC NETWORKS

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ABSTRACT

Future mobile Ad hoc networks (MANETs) are expected to be based on all-IP architecture and be capable of carrying multitudinous real-time multimedia applications such as voice, video and data. It is very necessary for MANETs to have a reliable and efficient routing and quality of service (QoS) mechanism to support diverse applications which have variances and stringent requirements for delay, jitter, bandwidth, packet loss. Routing protocols such as AODV, AOMDV, DSR and OLSR use shortest path with the minimum hop count as the main metric for path selection, hence are not suitable for delay sensitive real time applications. To support such applications delay constrained routing protocols are employed. These Protocols makes path selection between source and destination based on the delay over the discovered links during routing discovery and routing table calculations. We propose a variation of a node-disjoint Multipath QoS Routing protocol called Cross Layer Delay aware Node Disjoint Multipath AODV (CLDM-AODV) based on delay constraint. It employs cross-layer communications between MAC and routing layers to achieve link and channel-awareness. It regularly updates the path status in terms of lowest delay incurred at each intermediate node. The performance of the proposed protocol is compared with single path AODV and NDMR protocols. Proposed CLDM-AODV is superior in terms of better packet delivery and reduced overhead between intermediate nodes.

KEYWORDS

AODV, Cross Layer, MANET, MAC, NS2, QoS.

1. INTRODUCTION

MANETs are self-organizing, rapidly deployable wireless network that require no fixed infrastructure. It is composed of wireless mobile nodes that can be deployed anywhere, and can dynamically establish communications using limited network management. Real time applications have been most popular among the applications run by ad hoc networks. It strictly adheres to the QoS requirements such as overall throughput, end-to-end delay and power level. Traditionally multihop wireless network protocol design is largely based on a layered approach. Here each layer in the protocol stack is designed and operated independently with interfaces between layers that are rather static. This paradigm has greatly simplified network design and led to the robust scalable protocols on the internet. However, the rigidity of this paradigm results in

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poor performance for multihop wireless networks in general, especially when the application has high bandwidth requirements and/or stringent delay constraints [1]-[4].

1.1 RELATED WORK

To meet these QoS requirements, recent study on multihop networks has demonstrated that cross-layer design which can significantly improve the system performance [5]-[6]. To guarantee QoS in MANETs for delay sensitive applications two factors are considered. Firstly, route selection criterion must be QoS-aware i.e., it must consider the link quality before using the link to transmit. Secondly, the instantaneous response to the dynamics of MANET topology changes must be considered so that the route changes are seamless to the end user over the life time of a session. Generally, a QoS model defines the methodology and architecture by which certain types of services can be provided in the network. Protocols such as routing, resource reservation signaling and MAC must cooperate to achieve the goals set by the QoS model. QoS routing is one of the most essential parts of the QoS architecture [7]–[9]. Multipath approach has many advantages such as load balancing, QoS assurance and fault tolerance [10]- [12]. Several multipath routing protocols have been proposed so far in the literature. One of the earliest multipath routing protocols is Ad hoc On demand Multipath Distance Vector (AOMDV) [13]. AOMDV is a variant of Ad Hoc On Demand Distance Vector (AODV) [14] which establishes loop-free and link-disjoint paths based on the minimum hop count. QoS AODV (QS-AODV) in [15] extended the basic AODV routing protocol to provide QoS support in MANETs. It uses hop count as criterion for choosing the route with an assumption that NODE_TRAVERSAL_TIME (NTT) is constant. Stephane Lohier et al.[16] proposed reactive QoS routing protocol that also deals with delay and bandwidth requirements. In his proposal, QoS routes are traced by node to node and NTT is an estimate of the average one-hop traversal time, which includes queue, transmission, propagation, and other delays.

Cross-layered multipath AODV (CM-AODV)[17]**,** selects multiple routes on demand, based on the signal-to-interference plus noise ratio (SINR) measured at the physical layer**.** Load Balancing AODV (LBAODV)[18] is a new multipath routing protocol that uses all discovered path simultaneously for transmitting data. By using this approach data packets are balanced over discovered paths and energy consumption is distributed across many nodes throughout the network.

Xuefei Li et al. [19] proposed Node-Disjoint Multipath Routing protocol (NDMR) by modifying and extending AODV to enable the path accumulation feature of DSR in route request packets. Multiple paths between source and destination nodes are discovered with low broadcast redundancy and minimal routing latency. A delay aware protocol proposed in Boshoff et al. [20], uses end-to-end delay, instead of hop count, as metric for route selection. Upon route failure, the route table which contains multiple paths, along with the end-to-end delay is first searched for an alternative route to the destination before a new route discovery process is initiated. Even though it reduces both routing overhead and end-to-end packet delay, the route delay information might not always be upto date. Perumal Sambasivam et al. [21] modified the AODV protocol's route discovery mechanism by incorporating multiple node-disjoint paths for a particular source node along with mobility prediction**.**

Thus, it is found that most approaches to multipath routing protocols consider the end-to-end delay. They do not emphasize on considering the processing delay incurred at each node which may indicate the congestion or link quality along the path which is node disjoint. They also do not have a mechanism to handle expiry of stale cached routes in the route table before making their selection. Hence we propose a new algorithm CLDM-AODV with cross-layer communications between MAC and Routing layers to achieve link and channel-awareness. In section II, we describe the proposed algorithm. We present simulation results in section III followed by conclusion.

2. PROPOSED CLDM-AODV ROUTING ALGORITHM

The proposed algorithm considers only node disjoint routes which satisfy the end-to-end delay specified in the route request. For calculating end-to-end delay, the algorithm estimates inter-node packet processing delay at each node. Source node makes a selection of primary path out of available multiple QoS enable paths. The proposed algorithm includes calculation of inter-node packet processing delay at each mobile node, initiation of route discovery and route reply processes.

2.1. END-TO-END DELAY

In general, total latency or delay experienced by a packet to traverse the network from source to destination may include routing delay, propagation delay and processing or node delay. Routing delay is the time required to find the path from source to destination. Propagation delay is related to propagating bits through wireless media. Processing delay involves the protocol processing time at node x for link between node x and node y. The end-to-end delay of a path is the sum of all the above delays incurred at each link along the path [17]. For MANETs, propagation delays are negligibly small and almost same for each hop along the path. The major factors involved in computation of processing delay are the queuing delay and delay incurred at the MAC layer processing.

In the proposed method, we have named processing delay as Packet Processing Delay (PPD) which includes queuing delay and delay incurred at the MAC contention. IEEE 802.11 MAC with the distributed coordination function (DCF) is used as MAC protocol and the access method is Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA) with acknowledgments. To transmit packets, nodes make use of request-to-send (RTS), clear-to-send (CTS), data and acknowledgement (ACK) packets. The amount of time between the receipt of one packet and the transmission of the next is called a short inter frame space (SIFS). Average queuing Delay at the node i is $\overline{D}_i$ is given by equation [22],

$$\overline{D_i} = \alpha \overline{D_{j-1}} + (1-\alpha)\overline{D_j} \tag{1}$$

where,

$$\alpha = \frac{(queue_{size} - queue_{length})}{queue_{size}} \tag{2}$$

$queue_{size}$ is the current size of the queue at node *i*, $queue_{length}$ is the length of the queue at node *i* and j is the current period.

The channel occupation due to MAC contention is given by,

$$T_{mac} = T_{RTS} + T_{CTS} + 3 * T_{SIFS} + T_{acc} \tag{3}$$

T_{RTS} and T_{CTS} are the time periods on RTS and CTS respectively and T_{SIFS} is the SIFS period. T_{acc} is the time for channel contention. The Packet Processing Delay (PPD) is given by:

$$PPD = \overline{D}_i + T_{mac} \tag{4}$$

2.2. ROUTE DISCOVERY

Generally in reactive protocols[1], when a source node 'S' has to communicate with destination node 'D', it initiates path discovery by broadcasting a route request packet RREQ to its neighbours. The <source-address, broadcast-id> pair is used to identify the RREQ uniquely. In the proposed system, during initial route discovery phase, more than one node disjoint path between the source and destination is determined and optimal path which satisfies QoS delay requirement is chosen for the data transmission. When this primary path breaks due to nodes mobility or path fails to satisfy QoS requirement, then one of the alternate path is chosen as the next primary path and data transmission can continue without initiating another route discovery thus reducing the overhead of additional route discovery. In the proposed algorithm, the RREQ packet is modified to contain the address of the source through which it is forwarded. The packet header contains additional field for PPD and Thresh_Delay. PPD is initialized to zero and subsequently updated at each intermediate node as per Eq.(4). Thresh_Delay is set to the maximum allowable time delay for any path from source to destination. Since RREQ is flooded network-wide, a node may receive multiple copies of the same RREQ. After receiving the first RREQ, an intermediate node can receive and collect subsequent RREQ copies for the predetermined time duration, RREQ_WAIT_TIME, which is assumed as 20ms. The intermediate node also maintains RREQcounter to limit the number of RREQ that it can receive. In our proposed system, we initialize RREQcounter to three which is as shown in Figure 1. On receiving up to three RREQs, the route with minimum PPD selected which ensures the path with highest quality. Before forwarding the RREQ, intermediate node computes its PPD and compares it with Thresh_Delay. If the difference between the Thresh_Delay and current value

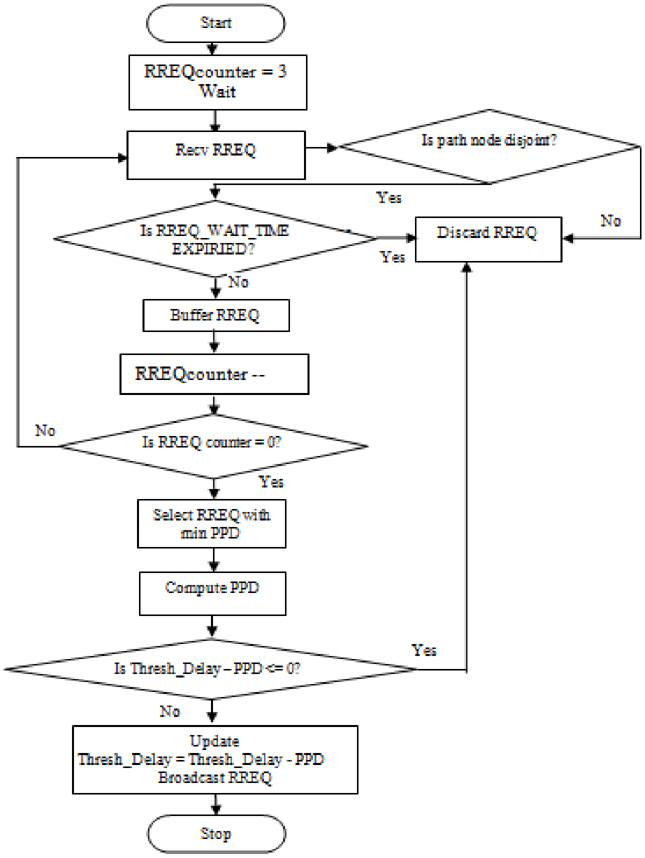


Fig. 1: RREQ Flowchart of proposed CLDM-AODV

of its PPD is zero or negative, it drops the RREQ packet avoiding unnecessary flooding into the network. If it satisfies, node broadcasts the packet by updating Thresh_Delay value less by currently computed PPD value of the node. Since every intermediate node forwards only one RREQ towards the destination, each RREQ arriving at the destination has traveled along a unique path from source to destination. Figure 2 shows an example of the delay based route discovery. Source node S initiates route request by updating the Thresh_Delay in RREQ Packet to acceptable delay say 100ms and PPD to zero. On receiving RREQ, node 1, 2 and 3 computes their PPD and updates Thresh_Delay in respective RREQ packet. Node 4 receives three RREQs, from node 1, node 2 and node 3 respectively. PPD values of these RREQs are compared and minimum PPD path from node 2 is chosen. Node 4 broadcast the RREQ, since it's computed PPD value satisfies the QoS constraint i.e. the difference between Thresh_Delay and PPD of node 4 is greater than zero. On the other hand, at node 5, RREQ packet gets dropped as difference between Thresh_Delay and PPD at node 5 do not satisfy the QoS criteria. Destination node D receives two RREQs from node 6 and node 4 respectively. D buffers both the paths for the route reply. Figure 3 shows another example of node disjoint path selection. Destination node D receives the two RREQ from node 4 and node 6 respectively. Since both the routes shares a common node i.e. node 1, destination node D chooses route based on greater value of Thresh_Delay in RREQ.

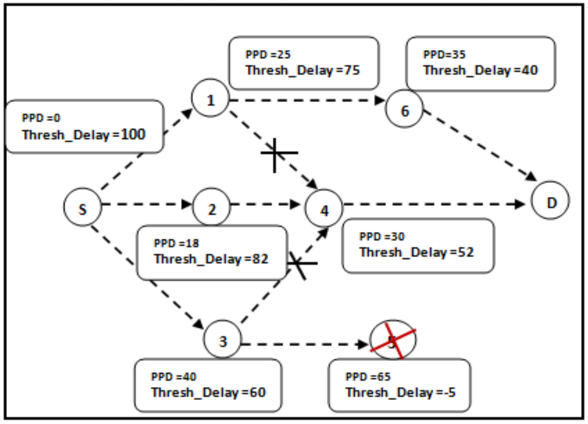


Fig. 2: Route Discovery of proposed CLDM-AODV

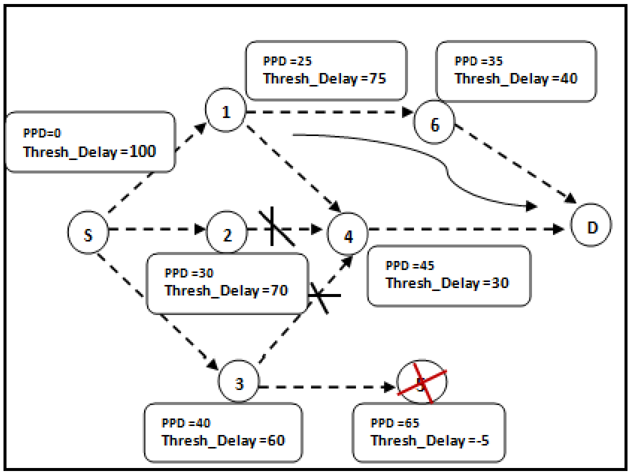


Fig. 3: Route acceptance by Destination

2.3. ROUTE REPLY

In proposed CLDM-AODV destination node D can collect up to RREQcounter times RREQ packets within time duration RREQ_WAIT_TIME, which is assumed to 20 ms. Node D generates a route reply RREP packets in response to every RREQ copy that arrives from the source S via loop-free and node disjoint paths to the destination. RREP packet is an extension of AODV RREP packet with additional field Max_PPD, which will hold the maximum packet processing time at intermediate nodes along the reverse path. Before destination node forwards the RREP, it computes the PPD and updates it in the Max_PPD field as shown in Figure 4. On reaching the next node, the intermediate node computes its PPD and compares it with the value in the Max_PPD field of RREP packet if current PPD computed is more than value in the Max_PPD. On receiving the RREP from all the disjoint routes, the source selects the primary route with minimum Max_PPD value. This signifies that the packet travelled through the less congested network, and possibility of packet incurring extra delay or getting dropped on the path is very low. Figure 5 shows an example of node disjoint route reply procedure. Destination node D calculates its PPD which is 25 ms and initializes Max_PPD with that PPD. Node D then sends RREP packets to all QoS qualified RREQ routes. Intermediate nodes 4 and 6, on receiving the RREP compute their own PPD i.e. 45 ms and 15 ms respectively. This value is compared with Max_PPD field of RREP packet. If PPD value is less or equal to Max_PPD, it ignores else it replaces the Max_PPD value in RREP packet. Node 6 does not modify Max_PPD as its computed PPD value is less than Max_PPD whereas node 4 replaces Max_PPD with 45 ms as its computed PPD value is greater than Max_PPD. Source node S on receiving the multiple RREP, it buffers them in the route table. Source S chooses the path with minimum value of Max_PPD as primary path i.e. path which source receives from node 1 as its Max_PPD value is 25 ms. If source does not receive RREP in RREP WAIT_TIME from destination, then it restart route discovery with new session Id.

2.4. ROUTE MAINTENANCE.

Route maintenance is very essential as there are high chances of route failure and QoS constraint violation due to mobility. Route failure due to link breakage is handled by the method using periodic *Hello* packets [15]. Any node which detects either a QoS violation or a link failure, informs the source by sending a route error packet (RERR). If a source node itself moves, restart the route discovery procedure to find a new route to the destination. If a node along the route moves so that it is no longer reachable, its upstream neighbor sends a link failure notification message to each of its active upstream neighbors through RERR until reaches the source node. QoS violation due to end-to-end delay constraint is detected by the intermediate nodes by computing one way delay experienced by the data packets from the sender's timestamp on the received data packets. During data transmission, source node appends the Thresh_Delay information to the data packets. Intermediate nodes on receiving the data packets, finds the difference between current time and time stamp of data packet. If value is less than Thresh_Delay, it generates the RERR packet to the source, or else forwards the packet to the next hop in the route table.

In our proposed CLDM-AODV, we introduce a method to validate other alternate node disjoint paths already discovered. At regular interval of time, Life Line Packets (LLP) is forwarded through alternate paths which contain Thresh_Delay. Intermediate nodes on receiving LLP, verifies the eligibility of packet forwarding by computing difference between current time and time stamp of data packet. If it is less than Thresh_Delay, it generates the RERR packet to the source indicating that the path is no longer QoS compliance link and corresponding path entry is deleted from route table. Destination node replies to these LLP by the same procedure as followed during RREP packets. On receiving the fresh route quality, source updates the primary path with highest quality.

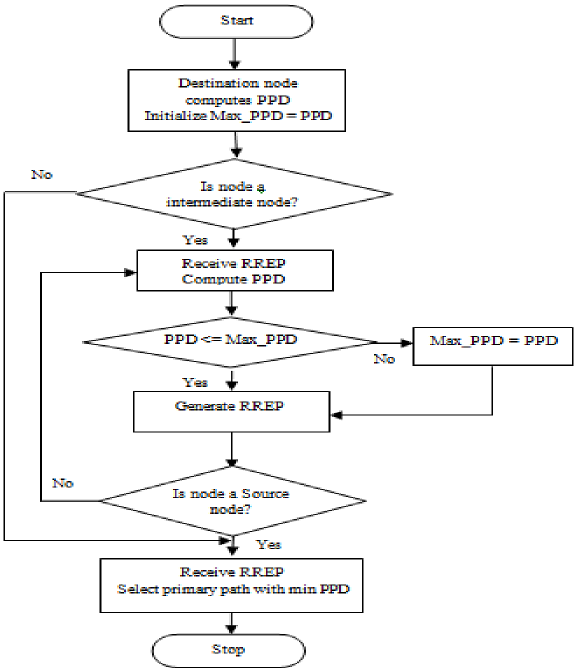


Fig. 4: RREP Flowchart of proposed CLDM-AODV

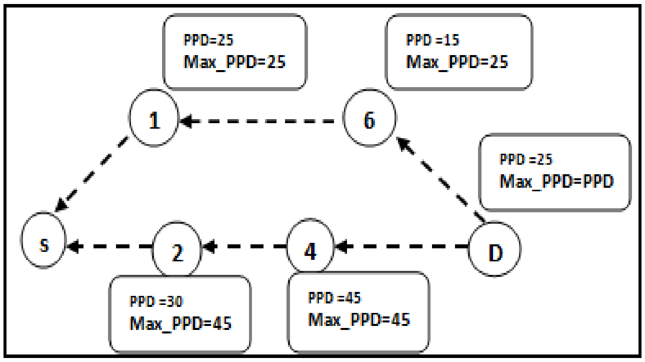


Fig. 5: Route Reply of proposed CLDM-AODV

3. SIMULATION EXPERIMENTS

3.1 Simulation Environment

The performance of the proposed CLDM-AODV protocol is evaluated and compared with AODV and NDMR. Simulations are conducted on the Network Simulator (ns-2) with network comprising of 50 wireless ad hoc nodes moving over an area of 1500m x 300m for 900s of simulated time. Physical layer is a bi-directional link and channel transmission rate is 2Mbps. At MAC layer, the DCF of IEEE 802.11 standard for wireless LANs is assumed. RTS and CTS packets are exchanged before the transmission of data packets. The channel propagation model we used two-ray ground reflection model. Constant Bit Rate (CBR) traffic is used. A 512-byte data packet with 2 packets/second sending rate is assumed for all the experiments. Inter packet time is assumed to be 35 ms. Radio transmission range of each node is set to 250m. The initial

placement of nodes is random and random waypoint mobility model [24] is used to simulate node movements. Simulation is run for seed value of 1 to 9.
The simulation parameters are shown in table 1.

Table 1

Parameters	Value
NS version	Ns –allinone-2.35
Number of nodes	50
Simulation Time	900 sec
Radio transmission range	250m
Traffic	CBR(Constant Bit Rate)
CBR Packet size	512 bytes
Simulation Area size	1500m * 300 m
Node Speed	4m/s to 20 m/s
Mobility model	Random WayPoint mobility

We compare the performance of AODV, NDMR and CLDM-AODV using the following three metrics:

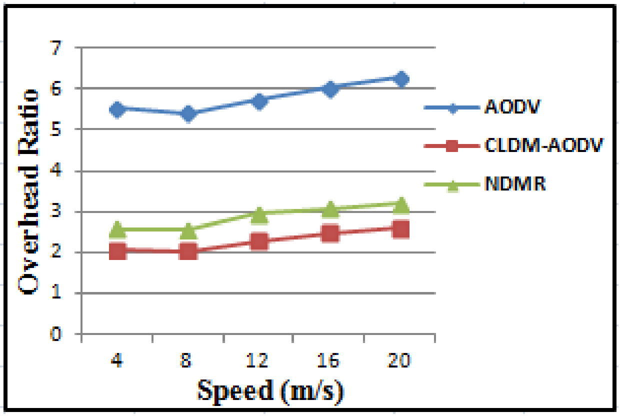
1. *Control Overhead* is the ratio of the number of protocol control packets transmitted to the number of data packets received.
2. *Packet Delivery Fractions (PDF)* is the ratio of the data packets delivered to the destination to those generated by the CBR sources.
3. *Average end-to-end delay* is an average end to delay of all successfully transmitted data packets from source to destination.

3.2 Simulation Results

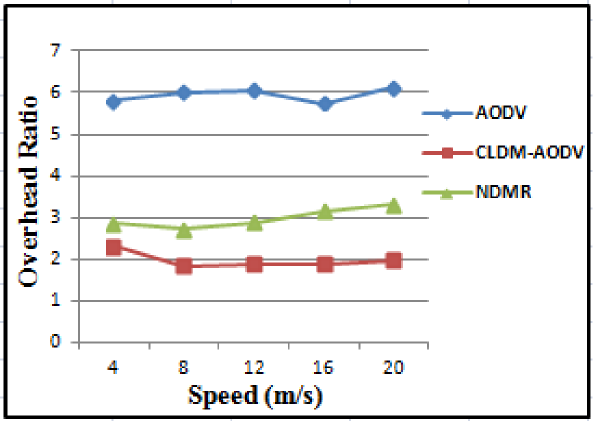
Example 1*:* In this example, we analyze the effect of speed on control overhead, PDF and average end to end delay for different number of source nodes in the network. In the simulation we assume the number of sources to be 30, 35 and 40 and mobility of nodes is 4 meters/sec to 20 meters/sec.

Figure 6(a)-(c) shows the plot of control overhead vs. speed. It is evident from the result that CLDM_AODV has minimum control overhead compared to AODV and NDMR. In Figure 7, average control overhead ratio for sources 30, 35 and 45 is plotted. It is easily inferred that CLDM_AODV has smaller overhead than AODV and NDMR in harsh operation environments. This improvement is mainly because multiple QOS compliance routes are discovered in single route discovery phase, which significantly reduces frequent route discovery on route failure.
Figure 8(a)-(c) shows the plot for End-to End delay vs. speed. It can be seen from the plot corresponding to AODV that there is an increase in delay which is due to high mobility of nodes which in turn results in increased probability of link failure that causes an increase in the number of routing rediscovery processes. This makes data packets to wait for more time in its queue until a new routing path is found. Average end-to-end delay in NDMR does not show much variation over varying speed and shows better results compared to AODV.
In Figure 9, average End-to End delay vs. speed for sources 30, 35 and 45 is plotted. In proposed CLDM-AODV protocol, delay curve remains consistently low compared to AODV and NDMR even though extra waiting time, RREQ_WAIT_TIME, is added in route discovery process. Addition of RREQ_WAIT_TIME has little effect on the overall performance since CLDM-AODV has multiple alternate node disjoint paths satisfying the delay constraint, leads to less route discoveries. Also source regularly uses the primary path with optimal quality.

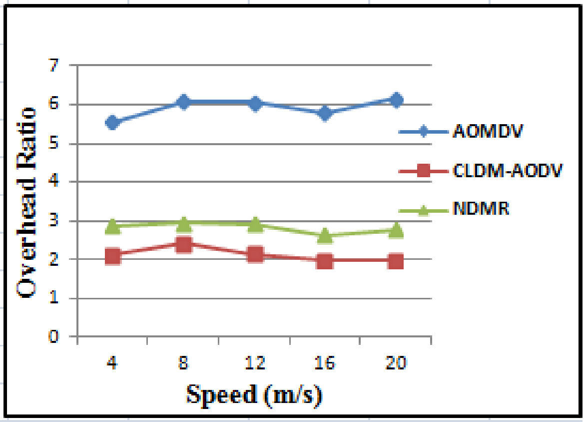
A packet delivery ratio for AODV, NDMR and CLDM_AODV is as shown in Figure 10(a)-(c). In Figure 11, average Packet delivery ratio vs. speed for sources 30, 35 and 45 is plotted. Since CLDM_AODV attempts to use optimal QoS enabled node disjoint path among available multiple alternate paths for data delivery, the protocol is able to deliver more packets to the destination compared to AODV and NDMR.



(a) 30 source nodes



(b) 35 source nodes



(c) 40 source nodes

Fig. 6(a)-(c): control packet overhead vs. speed (m/s).

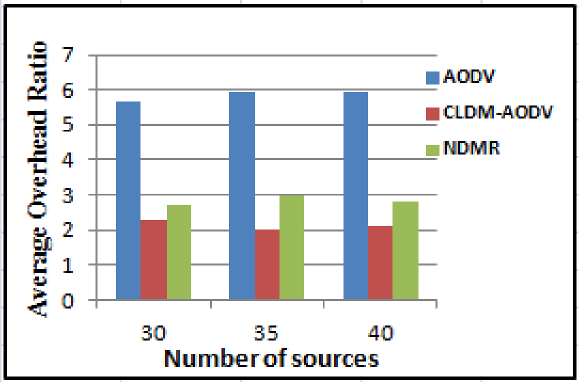
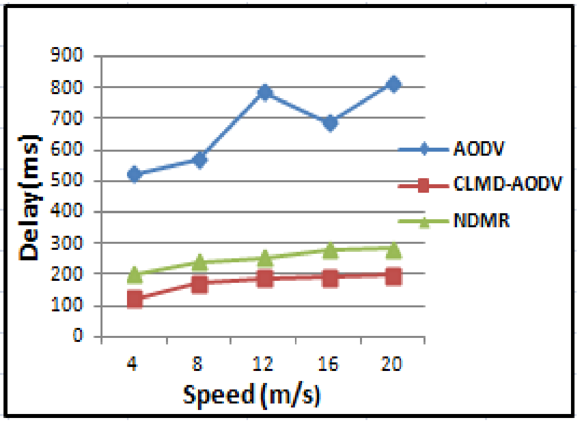
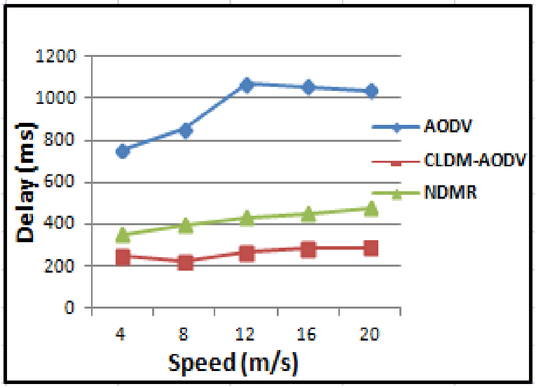


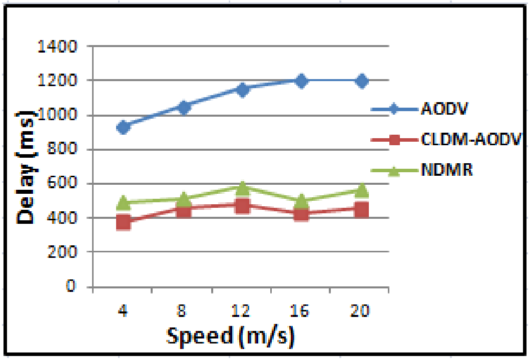
Fig. 7: Average Control overheads for varying number of sources for speed 4m/s to 20 m/s



(a) 30 source nodes



(b) 35 source nodes



(c) 40 source nodes

Fig. 8(a)-(c): End-to-End delay (ms) vs. speed (m/s).

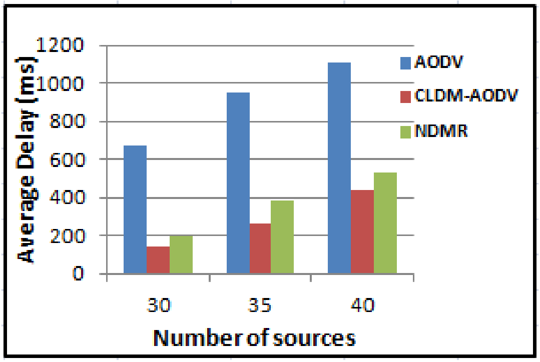
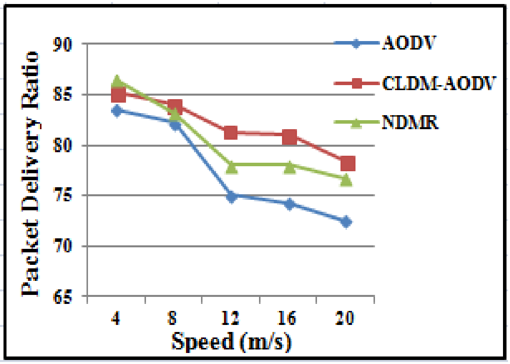
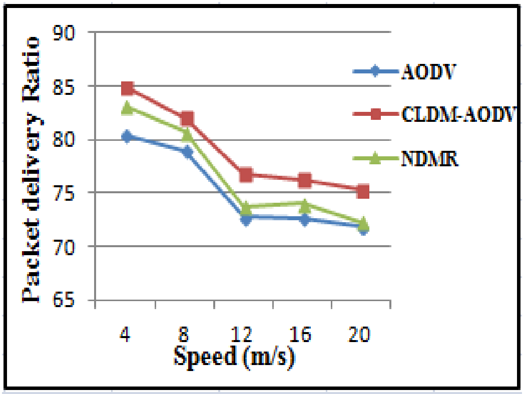


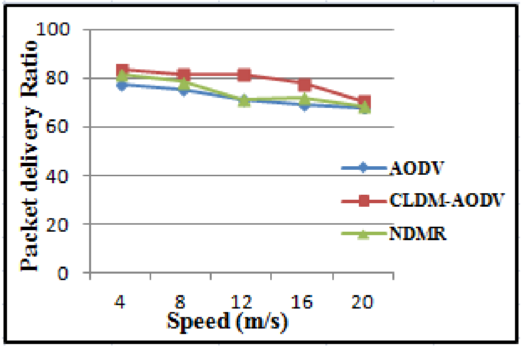
Fig. 9: Average end-to-end for varying number of sources from speed 4m/s to 20 m/s



(a) 30 source nodes



(b) 35 source nodes



(c)40 source nodes

Fig. 10(a)-(c): Packet delivery ratio vs. speed (m/s).

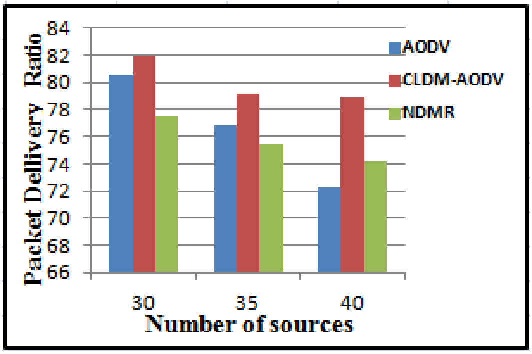


Fig. 11: Average Packet delivery ratio for varying number of sources from speed 4m/s to 20 m/s

AODV simply drops data packets when routes are disconnected, as it has to resort to a new discovery when the only path fails. Proposed CLDM_AODV algorithm performs better as data packets travel through less congested and delay compliance.

IV. CONCLUSION

A new algorithm CLDM-AODV suitable for delay sensitive application is presented. Proposed CLDM-AODV algorithm with multipath capability effectively deals with high mobility traffic route failures in MANET. Proposed algorithm ensures that the multiple paths are loop-free and is node disjoint. Comparative study of CLDM-AODV, classical AODV and NDMR is performed using ns-2 simulations under varying mobility and traffic scenarios. The results indicate that CLDM-AODV has lower average end-to-end delay even by including extra fields to RREQ and RREP packets to provide QOS support. The routing overhead is low compared to its counter parts as route discovery process is minimized by providing QOS compliance alternate routes. The added advantage of the proposed algorithm is, it periodically checks the paths obtained during route discovery process and uses optimal link for data communication.

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