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Ant Based Multi-objective Routing Optimization in Mobile AD-HOC Network

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Abstract

In recent years, Mobile Ad-hoc NETwork (MANET), a flexible and rapidly deployable communication network is widely being used. The mobile nodes often create link changes that demand reconstruction of the already identified routes. The route discovery and the successive route maintenance is performed by the routing algorithm. In order to determine an efficient, robust and scalable routing in MANET, there is a need to develop a routing algorithm that is fully aware of the current network topology and available resources. A multi objective unicast MANET route optimization problem that uses network performance measures such as delay, hop distance, load, cost and reliability is addressed in this study. A multi-objective version of the traditional Ad hoc On-Demand Vector (AODV) routing protocol and an ant based routing algorithm is presented to solve this NP hard problem by employing this objective vector. Simulation is carried out in NS2 and the results revealed that the proposed algorithms yield good results in terms of delay, packet delivery ratio and throughput when compared with the AODV protocol.

Keywords: Ant Colony Optimization (ACO), AODV, MANET, MOAODV, NS2, Routing

1. Introduction

Mobile Ad-hoc NETwork (MANET) is extensively used in crisis management services such as military operations and disaster rescue programs, and also in satellite communication and Personal Area Networks. The application of MANET for commercial purposes is currently being explored. Recently MANET is also being employed in Internet of Things (IoT), Body Area Networks (BAN) and 5G devices[1–5]. Its self-creating, self-organizing and self-administering capability and infrastructure less feature makes it advantageous than contemporary networks such as wired, wireless and mobile network[6,7]. The performance characteristics of MANET such as security and reliability, Quality of Service (QoS), inter-networking, power consumption and multicasting have attracted more attention in academic research[8].

Many routing protocols are reported in the literature and the network performance largely depends on the performance of these protocols[9–12]. The conventional protocols adopt Dijkstra's and Bellman-Ford Algorithms that yield good routing solutions, however with high computational complexity increasing with the increase in search space and solution space[13,14]. The hop count based routing strategy adopted in classical routing protocols lead to high failure rate in the network and subsequently the packet drop rate and overhead increases[15]. Recently evolutionary and swarm intelligent routing protocols are developed to solve this problem that include Genetic Algorithm[16], Particle Swarm Optimization[17], Bird-flight algorithm[18], Bee Colony Optimization[19] and Ant Colony Optimization (ACO)[20]. However, it appears that the study of this hard problem under the influence of a multi-objective optimization function consisting of QoS, energy

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and stability metrics using evolutionary algorithms is scarcely reported in the literature. Multi-objective Ad-hoc On-Demand Vector (AODV) routing protocol and an Ant based optimization algorithm have been proposed to solve this complex route optimization problem.

2. The Background

Dynamic topology in MANET poses challenges in establishing uninterrupted network communication such as scalability, QoS, connectivity control, neighbor discovery, traffic distribution, reliability and topology control[15]. These issues have to be addressed to ensure reliable and efficient communication. Routing is a mechanism that takes the data from source to destination nodes in a network through a loop-free path with minimum computational time, memory overhead using an optimal routing strategy[11]. The routing overhead due to the periodic or on-demand route maintenance contributes to computational complexity, memory complexity, data complexity, packet complexity and convergence time. The complexity increases with the increase in the network size and dynamics in the network and hence, this route optimization problem in MANET is a complex NP-complete and NP-hard problem[21,22]. The design of routing protocol to generate an optimal route with the best network performance is a challenge. MANET is a network with self-administered mobile nodes that often experiences link/route failures leading to unreliable communication[23]. The MANET routing protocols are classified into Proactive, Reactive and Hybrid routing route discovery schemes.

Reactive routing scheme searches route only during the communication start (if the destination is not known yet) and during a communication failure (if the topology changes). Control packets are flooded across the network to construct an optimal route between a communicating pair[24]. The various routing metrics that are considered while making routing decision define the quality of the route. Initial routing protocols that performed reactive routing were distance vector based like Routing on-demand acyclic multi-path (ROAM)[25], Temporally ordered routing algorithm (TORA)[26], Dynamic source routing (DSR)[27] and Ad hoc on-demand distance vector (AODV)[28]. Hop count based route selection adopted by the standard AODV and DSR protocols are outperformed by Associativity Based Routing (ABR)[29], Signal Stability Adaptive (SSA) protocol[30] that consider the link stability in making routing decisions. There are several variants of AODV protocol that use other routing metrics such as QoS Ad-hoc On demand Distance Vector (QoS AODV)[31], Energy Multi-path Ad-hoc On-demand Distance Vector routing (EM-AODV)[32], Reduce AODV (RAODV)[33], Energy Aware Reverse Reactive Routing Protocol (EA-RAODV)[34] and Route Stability and Energy Aware Routing (RSEA-AODV)[35]. Jain *et al.* made a review of Energy and Delay-Constrained AODV (EDC-AODV) and Energy and Delay AODV (EDAODV) which showed remarkable improvement than the traditional AODV protocol in the simulation experiments[36]. Cluster based reactive routing is reported in the literature viz., Cluster Switch Gateway Routing (CSGR)[37], Cluster-based routing protocol (CBRP)[38], Enhanced Distributed Weighted Clustering Routing Protocol (EDWCRP)[39] and Efficient Neighbor Coverage Routing Protocol (ENCRP)[40]. These protocols disintegrate the network into clusters, each cluster having a cluster head. Though clustering method is advantageous in aspects like distribution, it has high complexity and overhead in maintaining the clusters. Moreover the reliability of the cluster head has serious impact on the network performance. Flow oriented routing protocol (FORP) that incorporates current position of nodes, velocity, direction of node movement, and transmission range to estimate link/route expiration time[41], Reliable on-demand routing protocol (RORP)[23] and Link Failure Prediction (LFP) algorithm[42] that uses received signal strength and battery power status are other reactive protocols reported in the literature.

On contrast to reactive routing type, proactive routing floods periodic updates through which the algorithm realizes a topology change and update the route between a communicating pair to sustain communication. Initially Destination-Sequenced Distance Vector (DSDV) protocol[43] is developed that considers the routing metrics - hop count and distance for route selection. The study of DSDV protocol conducted out by He (2002) revealed that this protocol incurs high delay, high communication overhead due to the periodic routing updates. The storage complexity is estimated to be $\theta(V^2)$. Further it does not support multipath routing and with the increase in the network diameter and number of nodes, the computational effort increases leading to high packet loss. The count-to-infinity problem and indefinite looping effect in DSDV protocol are eliminated in Wireless Routing Protocol (WRP), Global State Routing (GSR) and Fisheye State Routing (FSR) protocols. The comparison of GSR and FSR protocols, Link state method and DSDV protocol revealed that the computational time complexity of these algorithms is found to be $\theta(V^2)$. and the routing inaccuracy is found to be very less in GSR and FSR protocols when compared to other protocols. The study also revealed that the control overhead of FSR protocol is lesser than GSR protocol and packet delivery rate of FSR protocol is high in GSR protocol when the network size is varied between 100 to 1000 nodes[44]. Source-Tree Adaptive Routing (STAR), Multimedia support in Mobile Wireless Networks (MMWN), Cluster-head Gateway Switch Routing (CGSR), Hierarchical State Routing (HSR), Optimised Link State Routing (OLSR), Open Shortest Path First (OSPF) routing, Topology Broadcast Reverse Path Forwarding (TBRPF) are other proactive routing protocols[45]. According to Chang *et al*, there is a conceived overhead that consumes considerable bandwidth available in the network because of the periodic route updates and flooding of control packets. Especially when the network is large, the augmented bandwidth utilization is tremendous and the algorithms do not scale well[46]. Literature also reveals that this class of protocols reports accelerating bandwidth consumption as the problem size and mobility increase. There is also a considerable drop in Packet Delivery Ratio since the time period between the route failure and route discovery suffers packet loss. It is found from the literature that, Global State Routing (GSR)[49] and Fisheye State Routing (FSR)[44] are more suitable for large mobile networks and Optimised Link State Routing (OLSR) protocol for dense networks[50].

The hybrid type routing protocols takes the advantages of both reactive and proactive methods. These protocols use reactive approach for route discovery and proactive approach for route maintenance[51]. Some of the hybrid protocols are Zone routing protocol (ZRP), Zone-based hierarchical link state (ZHLS), Scalable location update routing protocol (SLURP), Distributed spanning trees based routing protocol (DST), Distributed Dynamic Routing (DDR) and Location Aided Routing (LAR)[46,51]. Mobility Aware Hybrid routing protocol is developed that excelled in packet delivery ratio and minimized the control overhead when compared with AODV and OLSR protocols[56]. A hybrid multi-path routing algorithm in industrial wireless mesh networks is developed for enhancing the reliability of data transmission and to reduce link failures by incorporating enhanced Dijkstra's algorithm[57]. The computational effort required by these hybrid protocols is high and they are more suitable for larger and diverse networks. Moreover, fixing an optimal zone radius contributes to the network performance that is difficult to decide[58].

Many researchers have attempted to compare the performance of these protocols incorporating Quality of Service (QoS) metrics (viz., delay, throughput, jitter, packet delivery ratio), and other performance metrics like memory/overhead metrics and Stability based metrics. Studies reveal that AODV protocol is wisely preferred due to its ability to generate a route with minimal delay and overhead, high packet delivery ratio and throughput[35,59]. However Mobile Ad-hoc Network demands 'long lived routes' that surpasses mobility to minimize the possible route maintenance. It is also required to conserve energy in order to maximize the node lifetime[60]. In order to overcome some of these limitations, this study proposes a Multi-Objective Ad-hoc On Demand Vector (MOAODV) routing protocol that considers a combined metric based routing strategy for MANET with metrics viz., delay, hop distance, cost, load and reliability.

Research has also addressed the applications of evolutionary algorithms to discover efficient routes in networks. Genetic Algorithm[61] and Artificial Neural Network[62] are used to perform MANET routing with good routing solutions. Self-organized natural system has many desirable aspects that are suitable to routing problem in MANET. Researchers have used the foraging behavior of swarms like ants, bees[63], termites[64] and bats[65]. Existing ant based routing protocols[66–88] yield promising results when compared to the classical protocols. However, these algorithms are reported to have high routing overhead and the initial discovered route has a significant influence on the successive route selections in the maintenance phases. Also it is observed that there is a need to extract a combined performance criterion from Medium Access Control layer and Network layer details which would minimize the routing overhead, delay, packet loss, energy and bandwidth consumption. In this paper, an attempt has been made to select stable and efficient routes through Multi-objective Ant Optimized Routing algorithm (MAOR). The simulation results obtained by both are compared and discussed.

3. Multi-Objective Routing Optimization

The routing problem in Mobile Ad hoc Network (MANET) under study is a Multi-objective Optimization problem. It is observed from the literature that,

i. The problem of Connectivity Management in MANET is multi-objective[89]
ii. QoS routing in MANET is multi-objective[16,80,90]
iii. Multicast routing problem in MANET is multi-objective[84,91]
iv. Energy efficient clustering in MANET is multi-objective[17]
v. Routing problem in Satellite MANET is multi-objective[92]

The unicast routing protocols that could optimize more than one routing qualities or routing metrics are to be developed[93].

Since MANET consists of mobile nodes, the mobility characteristics and the residual power of the nodes that form a communication link have significant impact on the link characteristics. Moreover each link has various capacities and hence there is a flow constraint that restricts the traffic demand and the current load of the link within the capacity of the corresponding link. Also the overall route from the source node to the destination node should lead to minimal delay and distance. Considering these requirements, the problem is formulated in order to determine the Pareto-optimal or non-dominated set of paths from a source node to a destination node which would minimize the link metrics viz., distance, cost, delay, and load and maximize the reliability of the link.

A network represented as a graph, $G = (V, A)$ is considered where V is the vertex set, A is the Adjacency Matrix. P^* is the set of non-dominated solutions that contains optimally assigned links x_{ij}'s that connects the source node, S to the destination node, D. The optimization problem considered in the study is as follows:

Minimize Distance,

$$D_p = \sum_{(i,j)\in A} d_{ij} x_{ij} \quad (1)$$

Minimize Cost,

$$C_p = \sum_{(i,j)\in A} C_{ij} x_{ij} \quad (2)$$

Minimize Delay,

$$De_p = \sum_{(i,j)\in A} de_{ij} x_{ij} \quad (3)$$

Minimize Load,

$$L_p = \sum_{(i,j)\in A} l_{ij} x_{ij} \quad (4)$$

Maximize Reliability,

$$R_p = \sum_{(i,j)\in A} r_{ij} x_{ij} \quad (5)$$

Subjected to,

$$\sum_{\substack{j\in|V| \\ j\neq i \\ \forall i}} x_{ij} - \sum_{\substack{j\in|V| \\ j\neq i \\ \forall i}} x_{ij} = \begin{cases} 1 & if\ i = S \\ -1 & if\ i = D \\ 0 & otherwise \end{cases} \quad (6)$$

$$x_{ij} \in \{0,1\} \forall (i,j) \in A \quad (7)$$

$$t_{ij} + \varphi_{ij} \le z_{ij} \quad (8)$$

where

d_{ij} - Distance of the link (i,j)
c_{ij} - Cost of the link (i,j)
de_{ij} - Delay of the link (i,j)
t_{ij} - Traffic Load on the link (i,j)
r_{ij} - Reliability of the link (i,j)
z_{ij} - Capacity of the link (i,j)
φ_{ij} - Demand of the link (i,j)

3.1 Delay Calculation

Delay of data transmission (n bits) from a node i to node j through a link (i,j) of bandwidth b is given by[6],

$$de_{ij} = P_i + P_j + Q_i + Q_j + P + T \quad (9)$$

Here,

de_{ij} - Delay of the link (i,j)
P_i, P_j - Processing delay at node i and j respectively
Q_i, Q_j - Queuing delay at node i and j respectively
P - Propagation delay
T - Transmission delay given by,

$$T = \frac{n}{b} \quad (10)$$

3.2 Distance Calculation

It is the Euclidean distance between the pair of nodes (i,j) placed at positions (x_i, y_i, z_i), (x_j, y_j, z_j)respectively which is given by,

$$d_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2 + (z_i - z_j)^2} \quad (11)$$

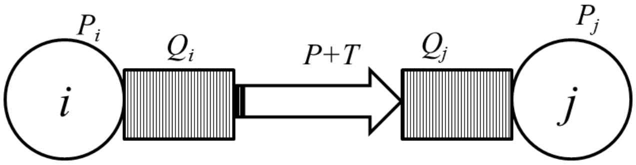

Figure 1. Delay of a link (i,j).

3.3 Load Calculation

The load of a link (*i,j*) is calculated by keeping in track of the number of data packets that have been routed through this link and considering the bandwidth of the link.

3.4 Cost Calculation

The data rate of the link (*i,j*) in bps is assumed for each link which is given by b_{ij}. Unit cost of transmitting a bit over a link is given by c_{ij} and packet size is given by *psize* (fixed).

$$C_{ij} = psize * c_{ij} \tag{12}$$

3.5 Reliability Calculation

The unstable network configuration in MANET makes the consideration of reliability very vital that leads to longer route lifetime which in turn reduces delay and control overhead maximizing the bandwidth utilization[23]. Frequent disconnection in links and route often makes reliable routing a challenging problem. The reliability in connection depends on the durability of the link given by the connectivity period[94]. Through prediction schemes, link lifetime assessment can be made to reduce such failures in network connectivity and maximize the connectivity period[95]. MANET is confronted with dynamic topology changes and hence reliability of the route is a significant component that affects the network performance[94,96–98].

Mobility based reliability prediction model is given in[23,97] is considered in this study however with few modifications. Consider a node pair (*i,j*). Their current positions, velocities and directions are given by $\left[(x_i, y_i, z_i), (x_j, y_j, z_j)\right], (v_i, v_j)$ and (θ_i, θ_j) respectively where, $0 \le \theta_i, \theta_j \le 2\pi$. The possible position of the nodes after duration Δt can be given as,

$$x_i(t+\Delta t) = x_i(t) + \Delta t v_i \cos\theta_i \tag{13}$$

$$y_i(t+\Delta t) = y_i(t) + \Delta t v_i \sin\theta_i \tag{14}$$

$$x_j(t+\Delta t) = x_j(t) + \Delta t v_j \cos\theta_j \tag{15}$$

$$y_j(t+\Delta t) = y_j(t) + \Delta t v_j \sin\theta_j \tag{16}$$

The reliability of node *i* is given as,

$$R_i = \begin{cases} 1 \ \text{if } lifetime_i > MIN_{THRESHOLD_{VALUE}} \\ 0 \qquad Otherwise \end{cases} \tag{17}$$

where,

$$Lifetime_i = \frac{Residual\ Energy}{Energy\ depletion\ rate} \tag{18}$$

Therefore, Mobility based Reliability of link (*i,j*) is calculated as,

$$R^1_{ij} = \begin{cases} \dfrac{d_{ij}(t+\Delta t)}{transmisison\ range} \ if\ d_{ij}(t+\Delta t) \\ 0 \ \ if\ R_i = 0\ or\ R_j = 0\ or\ d_{ij}(t+\Delta t) \end{cases} \tag{19}$$

$> \text{transmission range and } A_{ij} = 1$

$> transmission\ range$

Signal strength based stablity model[99] is given below: Relative signal strength of the link (*i,j*) is given by,

$$RSS_{ij} = \left|SS^{old}_{ij} - SS^{new}_{ij}\right| \tag{20}$$

where,

RSS_{ij} - Relative signal strength
SS^{old}_{ij} - Recent signal strength
SS^{new}_{ij} - Current signal strength

Signal strength based Reliability is given by,

$$R^2_{ij} \frac{RSS_{ij} - Thresh_{\min}}{Thresh_{\max} - Thresh_{\min}} \tag{21}$$

where,

R^2_{ij} - Signal strength based reliability of the link (*i,j*)
$Thresh_{\min}$ - Lower bound for acceptable variation
$Thresh_{\min}$ - Upper bound for acceptable variation

Overall reliability of the link is given by,

$$\square R_{ij} = Average\left(R^1_{ij}, R\square^2_{ij}\right) \tag{22}$$

4. Routing Strategy

4.1 Multi-Objective AODV Algorithm

AODV protocol converges to shorter routes and gives high bandwidth utilization with low data drop in the simulation study. However additional information such as reliability of the link and energy of the nodes are required for effective and reliable routing. This will minimize the frequent route maintenance and thereby effectively minimize the overhead. This study proposes a multi-objective version of the existing AODV protocol to incorporate the multiple routing criteria in the routing process. The variables used are as follows:

S	-	Source node, D-Destination node $\in V$;
RREQ	-	Route request packet; RREP-Route reply packet;
NH_i	-	Neighbor nodes j of node i where (i,j) are live links;
RT_i	-	Next-hop node, j, and the link characteristics of node i including
$\overline{De}_{ij}$	-	Normalized delay of the link (i, j)
$\overline{C}_{ij}$	-	Normalized cost of the link (i, j)
$\overline{L}_{ij}$	-	Normalized Load of the link (i, j)
$\overline{D}_{ij}$	-	Normalized hop distance between the two nodes i and j in the link (i, j)
$\overline{R}_{ij}$	-	Normalized Reliability of the link (i, j)
W_{ij}	-	Combined weight estimate of the link (i,j)

$$W_{ij} = S_{\downarrow}ij * (\overline{(De)}_{\downarrow}\, ij + \overline{C}_{\downarrow}\, ij + \overline{L}_{ij} + \overline{D}_{ij} - \overline{R}_{ij}) \quad (23)$$

During the control phase, the control packets (Route-Request RREQ) flood across the network from the source node to all the other nodes. Every node forwards RREQ to all its neighbors and refresh the routing table of itself incorporating the changes occurred in the topology. After receiving the Route-Requests, the destination node sends back control packet (Route-Reply RREP) to the source node through the discovered route. The RREQ and RREP packet format for MOAODV is shown in Figure 2.

1. If node $i == S$, then //Source node
   - 1.1 For all nodes j in $|NH_i|$
     - 1.1.1. Send RREQ in broadcast mode
     - 1.1.2. $F_T=0$;
   - 1.2. End For
   - 1.3. If RREQ received
     - 1.3.1. Drop RREQ // Sender received the packet
   - 1.4. End If
   - 1.5. If RREP received
     - 1.5.1. Start the CBR traffic session
   - 1.6. End If
2. Else
   - 2.1. k = RREQ_SRC; //Sender of RREQ - source/intermediate node
   - 2.2. i = receiver of RREQ // not a source node
   - 2.3. If RREQ received
     - 2.3.1. If check_neighbor_list(k)==0
       - $NH_i=NH_i \cup \{i\}$
     - 2.3.2. End If
     - 2.3.3. Calculate $W_{ki} = \overline{De}_{ki} + \overline{C}_{ki} + \overline{L}_{ki} + \overline{D}_{ki} - \overline{R}_{ki}$
     - 2.3.4. If $w_{ji} < w_{ki}$
       - $j=k$; //Replace the new node k with the existing next-hop node j
       - $F_T=F_T+w_{ki}$;
     - 2.3.5. Else j is unaltered
     - 2.3.6. End If
     - 2.3.7. If $i==D$ //Destination reached
       - 2.3.7.1. Send RREP in unicast mode to S through its next-hop of node D.
     - 2.3.8. Else // Intermediate node
       - 2.3.8.1. Forward RREQ to all j in NH_i
     - 2.3.9. End If
   - 2.4. End If
   - 2.5. If RREP received // Intermediate node
     - 2.5.1. Forward RREP to the next hop node of i
   - 2.6. End If
3. End If

4.2 Ant Based Multi-Objective Routing Algorithm

Inspired by the nature of ants, formally the Ant-cycle algorithm was proposed and an Ant system that uses a positive feedback from the previous iteration for the computations in the current iteration was developed[100]. Ant's behavior in finding a path from its hill to food is quite interesting wherein, it deposits a chemical substance called pheromone, throughout the path it traverses. This substance evaporates at a particular rate as time increases. The follower ants take a path which has higher pheromone density and thereby over a period of time, the ants converge to the shortest path. In this study the ant's foraging behavior is encompassed in the routing protocol for MANET.

The RREQ and RREP packet format for this algorithm is shown in Figure 3.

1. If node $i == S$, then //Source node
   - 1.1 For all nodes j in $|NH_i|$
     - 1.1.1. Send RREQ in broadcast mode

Source Address	Destination Address	Hop Distance	Cost	Delay	Load	Reliability	………..

Figure 2. RREQ/RREP packet format for MOAODV Algorithm.

Source Address	Destination Address	Probability	Pheromone intensity	Hop Distance	Cost	Delay	Load	Reliability	…

Figure 3. RREQ/RREP packet format for Ant based Routing algorithm.

1.2. End For
1.3. If RREQ received
  1.3.1. Drop RREQ // Sender received the packet
1.4. End If
1.5. If RREP received
  1.5.1. Start the CBR traffic session
1.6. End If
2. Else
2.1. If RREQ received
  2.1.1. k = RREQ_SRC; //Sender of RREQ - source/intermediate node
  2.1.2. i =Receiver of RREQ // not the source node
  2.1.3. If check_neighbor_list(k)==0
    $NH_i = NH_i \cup \{k\}$
  2.1.4. End If
  2.1.5. Calculate

$$\eta_{De_{ki}} = \frac{1}{De_{ki}}; \eta_{C_{ki}} = \frac{1}{C_{ki}}; \eta_{L_{ki}} = \frac{1}{L_{ki}}; \eta_{D_{ki}} = \frac{1}{D_{ki}}; \eta_{R_{ki}} = \frac{1}{R_{ki}}$$

  2.1.6. Calculate

$$P_{ki} = \frac{\tau_{ki}^{\alpha}\left(\{\eta_{D_{ki}}\}^{\lambda_D}\{\eta_{C_{ki}}\}^{\lambda_C}\{\eta_{L_{ki}}\}^{\lambda_L}\{\eta_{De_{ki}}\}^{\lambda_{De}}\{\eta_{R_{ki}}\}^{\lambda_R}\right)^{\beta}}{\tau_{ki}^{\alpha}\left(\{\eta_{D_{ki}}\}^{\lambda_D}\{\eta_{C_{ki}}\}^{\lambda_C}\{\eta_{L_{ki}}\}^{\lambda_L}\{\eta_{De_{ki}}\}^{\lambda_{De}}\{\eta_{R_{ki}}\}^{\lambda_R}\right)^{\beta}}$$

  2.1.7. Calculate $w_{ki} = \overline{L}_{ik} + \overline{C}_{ik}\overline{D}_{ik} + \overline{De}_{ik} - \overline{R}_{ik}$
  2.1.8. If $P_{ji} > w_{ki}$
    2.1.8.1. $j=k$ (replace the new node k with the existing next-hop node j)
    2.1.8.2. $F_{best} += w_{ji}$
    2.1.8.3. $\tau_{ji} = \tau_{ji} + \Delta\tau$ where, $\Delta\tau = \frac{1}{F_{best}}$
    2.1.8.4. For all k in $|NH_i|$ and $k \neq j$
      $\tau_{kj} = (1-p)\, \tau_{kj}$;
    2.1.8.5. End For
  2.1.9. End if
  2.1.10. If i==D //Destination reached
    2.1.10.1. Send RREP in unicast mode to S to its next-hop j.
    2.1.10.2. $F_t = F_{best}$
  2.1.11. Else Forward RREQ to all j in NH_i // Intermediate node
  2.1.12. End If
2.2. End If
2.3. If RREP received && $i \neq D$ // Intermediate ndoe
  2.3.1. Forward RREP to next-hop node of i
2.4. End If
3. End If

5. Simulation Results

This section presents the results obtained from the simulation experiments of MOAODV and MAOR algorithms for MANET in Network Simulator NS 2. Simulation is also performed with AODV protocol, the de facto standard for MANET. The initial position and destination position of the nodes that construct a topology in the simulation area are taken in a random fashion. The nodes are always kept alive and they start with an initial energy of 1000 joules. The parameters used for the experimental setup are given in Table 1.

With these configurations, simulation is carried out and the performance is evaluated in terms of average delay, throughput and packet delivery ratio. Initially MANET is configured with 20 nodes at a node speed of 20 m/s. The routes obtained from the three algorithms viz., AODV, MOAODV and MAOR are given in Table 2.

Table 1. NS2 Simulation Parameters

Platform	Linux (Fedora 14)
NS version	NS Allinone 2.35
Simulation time *(minutes)*	5
Number of nodes	{20,50,100,200,300}
Node speed *(m/s)*	{20,50,100,150,200}
CBR packet size *(bytes)*	{1000,1500,2000,2500,3000}
Simulation area *(sq. m.)*	1500x1500
Traffic	Constant bit rate (CBR)
Mobility model	Random way point / Energy Model
Transmission range *(meter)*	250
Protocol	{AODV, MOAODV, MAOR }
Initial Energy *(joules)*	1000

Table 2. Routes obtained from AODV, MOAODV and MAOR algorithms

ALGORITHMS	ROUTES
AODV	2-4-18-15-10-3 2-14-18-11-6-3 2-14-18-15-10-3 2-14-13-15-10-3 NO_ROUTE 2-12-13-11-10-3
MOAODV	2-0-5-6-3 2-4-16-7-6-3 2-12-13-11-6-3
MAOR	2-12-16-7-6-3 2-4-16-17-10-3 2-14-16-7-6-3 2-0-5-6-3

It is found that AODV protocol when implemented experienced six CBR traffic sessions and during the fifth session, there was no optimal solution retrieved by the algorithm, thereby leading to a high packet loss. It is observed that the number of non preemptive CBR sessions or the number of times the corresponding routing algorithm is called due to a topology change varies and the overall routing overhead seems to be relatively low for MAOR and MOAODV algorithms, which implies that they provide long-lived routes or stable routes when compared with AODV algorithm. It can be also derived that the reduction in the number of routing updates considerably reduces the cost of bandwidth, energy and power expenditure due to the control message broadcasts.

5.1 Effect of Node Velocity on the Network Performance

The performance of the proposed algorithms with the variation in the node velocity is evaluated and presented in Figures 4, 5 and 6.

Simulation revealed that the average delay is high for low velocity networks. For high mobility, MOAODV and MAOR decrease the average delay in data transmission. Throughput and packet delivery ratio values are high when MOAODV and MAOR are employed. Average Delay decreases with the increase in node velocity. However throughput and packet delivery ratio and throughput remain unaffected by node velocity in case of MOAODV and MAOR protocols unlike AODV protocol.

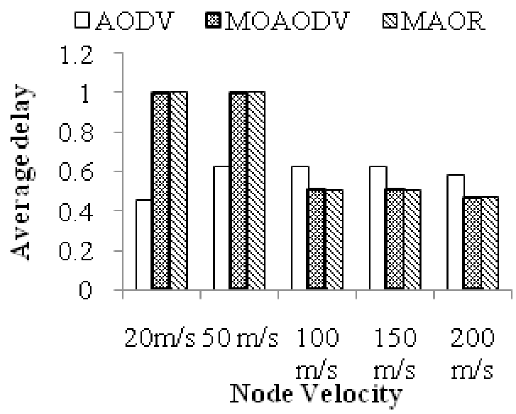

Figure 4. Average delay with variation in Node Velocity.

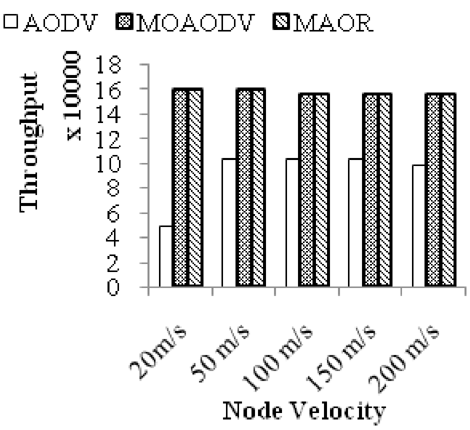

Figure 5. Throughput with variation in Node Velocity.

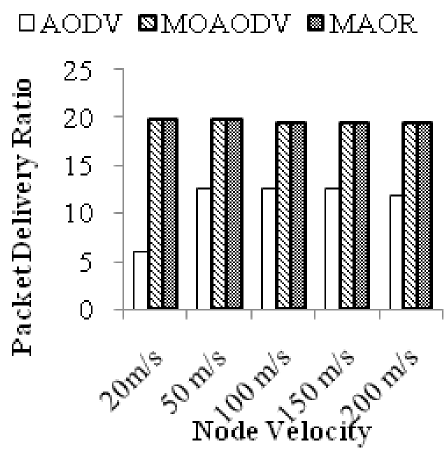

Figure 6. Packet Delivery Ratio with variation in Node Velocity.

5.2 Effect of Traffic on the Network Performance

Simulation experiments are carried out by varying the packet size of the traffic pattern. The results so obtained in terms of the network performance metrics such as average delay, throughput and packet delivery ratio are shown in Figures 7, 8 and 9. The average delay is reduced with the increased traffic in the network. It is observed that with the increase in the network traffic packet delivery ratio and throughput is found to increase. Moreover it appears that ACO algorithm performs better than AODV protocol and MOAODV algorithm under high traffic.

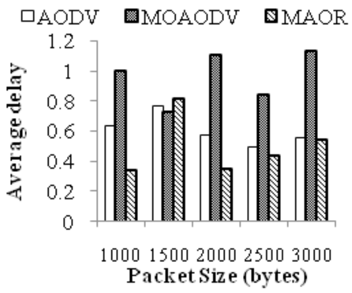

Figure 7. Average delay with variation in Packet Size.

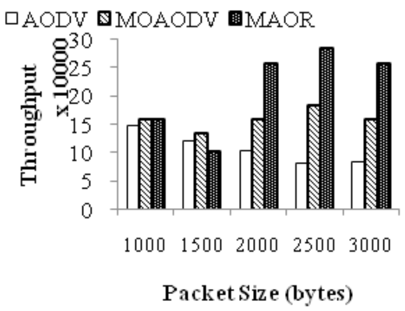

Figure 8. Throughput with variation in Packet Size.

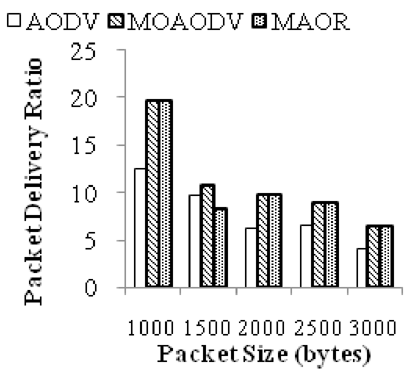

Figure 9. Packet Delivery Ratio with variation in Packet Size.

5.3 Effect of Network Size on the Network Performance

Network size plays an important role in the performance of routing algorithm which reveals the scalability characteristics. The delay, throughput and packet delivery ratio with the variation in network size are studied. The results are presented in Figures 10, 11 and 12.

The study revealed that AODV protocol could not yield seamless communication with the increase in network size. This is revealed by the reduced throughput and packet delivery ratio values of AODV protocol. However MOAODV and MAOR algorithms could perform well in larger networks.

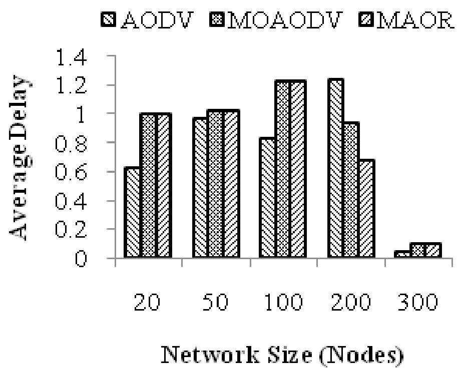

Figure 10. Average Delay with variation in Network Size.

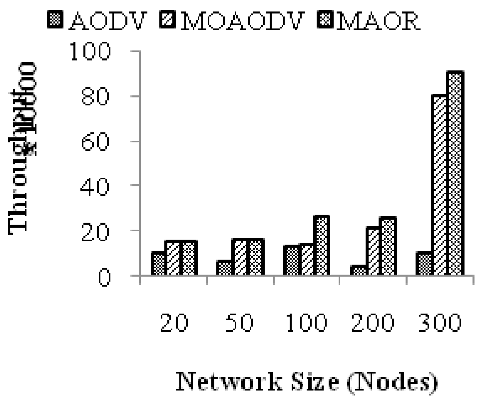

Figure 11. Throughput with variation in Network Size.

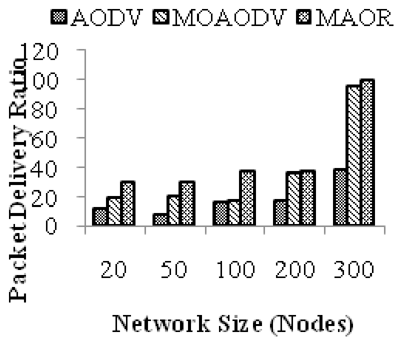

Figure 12. Packet Delivery Ratio with variation in Network Size.

6. Conclusion

In this paper, routing problem in MANET is considered as a multi-objective optimization problem and solved by Multi-Objective Ad-hoc On-Demand Vector (MOAODV) routing algorithm and Multi-objective Ant Optimized Routing (MAOR) algorithm. It is found from the study that these algorithms yield better solutions than that of the state-of-the-art AODV protocol. The MOAODV algorithm uses the estimated objective vector that includes metrics like delay, hop distance, cost, load and reliability, while the MAOR algorithm exploits the heuristic approach of ACO algorithm along with the proposed objective vector. The comparison studies through simulation reveal that the routing approach considering the QoS, power and energy constraints yields better output with minimum delay and maximum throughput and Packet Delivery Ratio. The multi objective vector considered in this study enables the proposed routing algorithms to converge to better routes when compared to the AODV protocol. The application of other meta-heuristics to implement this multi-objective optimization model can be explored and their comprehensive performance can be studied in future.

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