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# A New Multi-Objective QoS Multicast Routing Protocol Based on Ant Colony Optimization for Mobile Ad Hoc Networks

Ghazwan Raya [1], Mothanna Alkubeily [2], Sadek Ali [3], Boushra Maala [4]
PHD Thesis Student [1], Assistant Professor [2], [3] & [4]
Department of Telecommunication Engineering
Faculty of Mechanical and Electrical Engineering,
Tishreen University Lattakia
Syria

## ABSTRACT

In this paper, we modified our previous published protocol SROQRP, Stable and Reliable On-Demand QoS Routing Protocol based on Ant Colony Optimization for mobile Ad-hoc networks (MANET), to support group oriented routing. The advent of ubiquitous computing and the proliferation of portable computing devices have raised the importance of mobile and wireless networking, at the same time, the popularity of group-oriented computing has grown tremendously. Our new protocol named MSROQRP, Stable and Reliable On-Demand QoS Routing Protocol based on Ant Colony Optimization for Multicast in MANET, our main goal is to benefit from our previously published protocol advantages in multicast (group oriented) applications for MANET. The new protocol bringing together the technologies for group-oriented communication and mobile networking with full support of quality of service, the major challenge lies in adapting multicast communication to environments where mobility is unlimited and outages/failures are frequent. This protocol considers the multicast routing as a multi-objective problem, as it minimizes the cost of the multicast tree under multiple constraints, prolongs the network lifetime and increases routing reliability. It estimates path stability in order to use it in the transition probability to increase routing stability and it combines the bandwidth, delay and hop count in the pheromone updating rule to satisfy the QoS requirements.

***Keywords*** **:-** MANET, Multicast, QoS Routing Protocols, Ant Colony Optimization, Energy Factor, Stability Factor.

## I. INTRODUCTION

A Mobile Ad-hoc Network MANET can be defined as a decentralized, infrastructure-less network that uses multi-hop radio relaying and self-organizing [1]. All nodes in MANETs are mobile and communicate with each other via wireless connections. They can join or leave the session at any time, and there is no central control or overview, no designated routers; nodes serve as routers for each other, and data packets are forwarded from node to other in a multi-hop fashion. MANETs are useful to bring wireless connectivity in infrastructureless areas, or to provide instantaneous connectivity free of charge inside specific user communities and/or geographic areas.

Multicasting is the ability of a communication network to accept a single message from an application and deliver copies of this message to multiple recipients at different locations [2]. With the rapid development of the commercial use in internet, multimedia multicast application that satisfies the QoS constraints attracts more and more research attention. For delay-sensitive multimedia applications, such as real-time teleconferencing, …etc, it seems more important to find a delay-constrained minimum-cost multicast tree, which has been proven to be a NP-complete problem [3].

Currently many heuristic algorithms have been proposed, most of which are centralized in nature such as BSMA (bound shortest multicast algorithm) [4], KMB [5] and CBT [6], …etc. Recently, some algorithms based on genetic algorithm are also proposed [7-9], which are centralized algorithms, too. The research on distribution algorithms is relatively less.

Ant colony optimization (ACO) is an agent-based heuristics algorithm inspired by the behaviour of real ants finding food [10,11]. The ACO has the distributed and adaptive characteristics, which endow it with excellent performance in solving the NP-hard problems.

This paper presents a novel multicast routing scheme using ant colony optimization. Our scheme tries to construct the minimum-cost tree using the local information in the case that the source node does not possess the whole network information. Combined the characteristics of multicast routing, the algorithm was improved, which accelerated the convergence speed and obtained better result.

Several algorithms based on ACO consider the multicast routing as a mono-objective problem, minimizing the cost of the tree under multiple constraints. Liu and Wu [12] proposed the construction of a multicast tree, where only the cost of the tree is minimized using degree constraints. On the other hand, Gu et al. [13] considered multiple parameters of QoS as constraints, minimizing just the cost of the tree. It can be clearly noticed that previous algorithms treat the multicast traffic engineering problem as a mono-objective problem with several constraints. The main disadvantage of these approaches is the necessity of an a priori predefined upper bound that can exclude good practical solutions.

Hiroshi Matsuo et al. [14] discused accelerated Ants-Routing which obtain good routing path. Experiments on dynamic network showed that this method learns the optimum routing in terms of convergence speed and average packet latency.

Ravindra Vaishampayan et al. [15] proposed a protocol for unified multicast through announcements (PUMA) in ad-hoc networks, which establishes and maintains a shared mesh for each multicast group, without requiring a unicast routing protocol or the preassignment of cores to groups. PUMA achieves a high data delivery ratio with very limited control overhead, which is almost constant for a wide range of network conditions.

In this paper, we improve the traditional ant colony algorithm, and apply it in QoS multicast routing protocol, which is named Stable and Reliable On-Demand QoS Routing Protocol (MSROQRP) for Multicast in mobile ad-hoc networks.

Our protocol considers the multicast routing as a multi-objective problem, as it minimizes the cost of the multicast tree under multiple constraints and prolongs the network lifetime and increases routing reliability. It estimates path stability in order to use it in the transition probability to increase routing stability and combines the bandwidth, delay and hop count in the pheromone updating rule to satisfy the QoS requirements.

The reminder of this paper is organized as follows: In section II, we study ant colony optimization algorithm.. In section III, we introduce our proposed algorithm in detail with the mathematical model. In section IV, we compare our proposed protocol with MAODV routing protocol under a range of various scenarios. Finally, conclusion is presented in section V.

## II. ANT COLONY OPTIMIZATION

In the process of food-searching, ants attempt to find the shortest path to the food. They can release a kind of volatile secretion called pheromone which will volatilize gradually until it disappears; the concentration of pheromones of the path is proportional to the number of passed ants. Other ants can sense the pheromones in the process of path-finding and select the path according to the number of pheromones. The higher the concentration of pheromones is; the more ants will be attracted. Gradually, the ants will find the shortest path to the food source after some whiles.

Based on the study of the foraging behaviour of ants in the nature, Marco Dorigo proposed the Ant Colony Optimization (ACO) protocol [16, 17], and adopted the algorithm to solve the Travelling Salesman Problem (TSP).

The basic ACO is briefly described as follows, ants choose the next hop node according to the transition probability. Assuming the total number of ants is m, then the transition probability of the k-th ant transferring from node i to node j in the t-th search period is $P_{ij}^k(t)$, and its computation formula is defined as:

$$P_{ij}^k(t) = \begin{cases} \dfrac{[\tau_{ij}(t)]^{\alpha}.[\eta_{ij}(t)]^{\beta}}{\sum_{u \in allowed_k}[\tau_{iu}(t)]^{\alpha}.[\eta_{iu}(t)]^{\beta}} & , j \in allowed_k \\ 0 & , \text{otherwise} \end{cases} \quad (1)$$

Where, $\tau_{ij}(t)$ is the concentration of pheromone on link (i, j) between node i and node j in the t-th search period, and each link has the same pheromone at the beginning time, which means $\tau_{ij}(0) = \tau_0$.

$\eta_{ij}(t) = 1/d_{ij}$ is the heuristic function, which denotes a presupposed local information, and $d_{ij}$(i, j = 1, 2, … , n) is the distance between node i and node j, in which n is the number of nodes. $allowed_k$ is the nodes set of next allowed selection of the k-th ant; if $allowed_k = \emptyset$, the ant will die which means the path-searching is failed. $\alpha$ and $\beta$ are constants, and they respectively reflect the relative influence of pheromone concentration and heuristic factor.

When ants complete a cycle trip, the pheromone on each path will be updated according to the following formula:

$$\tau_{ij}(t+n) = (1-\rho)\tau_{ij}(t) + \Delta\tau_{ij} \quad , \quad 0 < \rho < 1 \quad (2)$$

Where:

$$\Delta\tau_{ij} = \sum_{k=1}^{m} \Delta\tau_{ij}^k \quad (3)$$

Where, $\rho$ is constant. $\Delta\tau_{ij}$ is the increment of pheromone on link (i, j). $\Delta\tau_{ij}^k$ is the increment of pheromone left by the k-th ant on link (i, j).

## III. PROPOSED ALGORITHM

### *A. Overview*

Our proposed algorithm Stable and Reliable On-Demand QoS Routing Protocol based on Ant Colony Optimization for Multicast in MANET (MSROQRP) inspired by ant food foraging intelligence, is a QoS Multicast routing algorithm for MANETs to overcome requirements of various applications that may vary with time.

The proposed approach has two phases, Multicast Route construction and Multicast Group Maintenance. Core node announces itself as the core by flooding the announce message. Core accepts the join requests from the other node in the network and regularly floods the core announce message to announce group existence. A sender (Source) plays the role of the core, and the algorithm applies the methodology of CBT to detect the breaks of multicasting routes with some adaptation for MANET.

The proposed algorithm incorporates positive feedback, negative feedback, and randomness into routing computation. Ant-like packets, analogous to ant foragers, are used to locally find new paths. Artificial pheromone is laid on communication links between adjacent nodes and route reply, and data packets are inclined toward strong pheromone, whereas next hop is chosen probabilistically.

Positive feedback is initiated from destination nodes to reinforce existing pheromone on recently learned good paths. To prevent old routing solutions from remaining in the current network status, exponential pheromone decay is adopted as negative feedback.

Each node running this algorithm contains three tables: neighbour, path priority, and routing table.

*In neighbour table*, each neighbour is listed along with pheromone substance indicating goodness of outgoing link to various destinations, available bandwidth, link expiration time and node trust factor.

*In routing table*, desired destinations for which source node has data will be listed with best next hop.

While in *path priority table*, each entry for a destination is associated with a list of neighbour nodes. A probability value in the list expresses goodness of a neighbour node as next hop on the path to destination. The neighbour node which has a higher path priority value will be copied to routing table for the related destination on desire.

### *B. Group Construction*

***1) Core Announce:*** The source announce itself as the core by flooding the announce message. Core accepts the join requests from the other node in the network and regularly floods the core announce message to announce group existence. A sender (source) plays the role of the core.

***2) Join Request:*** If a node wants to join the currently existing group, the node forwards the Join request message to a selected node of its neighbouring nodes. If the selected node is not the core, the selected node again forwards the message to the one of its neighbour's nodes. Else, the selected node is the core, then it forwards join acknowledge message to accept the join request.

***3) Join Acknowledge:*** If a node receives the join request message, it sends the join acknowledge message. The message moves along the opposite direction by which the join request message has been delivered. If a node which received a join request message is not a member of the multicast group maintained by the core, the node is included as one of forwarding node in the group.

***4) Join request and Ack:*** If the message is delivered finally to the node that sent the join request message, the node becomes a member of the group. Any node including the core in a multicasting group can accept the join requests made by the other nodes in the group.

### *C. Route exploration*

When a node i receive core announce message, and wants to join the currently existing group, it searches its routing table for next best hop to reach the core node. Since network follows on-demand routing approach, off the rack route will not be available in all cases. So, node i initiates a join request message JREQ_ANT through all its neighbours about which it has learned from periodic core announce messages.

While traveling to destination (core node), JREQ_ANT checks available capacity of each link, and identity of hops it has visited and check link expiration time of each link. If available capacity of visited link is lower than that of in JREQ_ANT message, the available bandwidth field in JREQ_ANT message is updated by recently visited link's capacity. If link expiration time of visited link is lower than that of in JREQ_ANT message, the path stability field in JREQ_ANT message is updated by recently visited link's expiration time. This will make request message to carry minimum available bandwidth and minimum link expiration time of a link along the path it has travelled.

Finally, when JREQ_ANT reaches the destination, it will be converted as Join Acknowledge called JACK_ANT which will take same path of corresponding JREQ_ANT, but in reverse direction. For this, JACK_ANT replicates and converts stack of visited nodes by JREQ_ANT as stack of nodes to be visited. At every node from JACK_ANT's starting point, stack is popped to see next hop to forward JACK_ANT.

At intermediate nodes and at node i, information coming along with JACK_ANT such as pheromone and path stability factor in addition to neighbour trust factor coming along with core announce message are used to calculate path preference probability to reach destination. The node i updates path preference probability to destination d through its entire neighbours provided, it has received JACK_ANT through these neighbours.

The neighbour node which contributes a higher path preference probability over all neighbours of node i is selected as best next hop to reach the core node. Once routing table is updated with best next hop for desired destination d, data transmission starts through it.

### *D. Mathematical model*

Mobile Ad-hoc Network (MANET) is usually modelled as a connected graph G (V, E) [18] with node set V and link set E. n = V is the number of nodes and l = E is the number of links in G. A link e ∈ E which connects v1 and v2 will be denoted by (v1, v2). Each node is associated with reliability factor named neighbor trust value TV (v). Each link is associated with link bandwidth B(e) and delay D(e), hop count H(e), and link expiration time (stability factor) LET(e). s ∈ V is source node, M ⊆̇V - {s} is the set of destination nodes, di ∈ M is destination node, and M={d1,d2,…,di,…,dm}, P(s,di) is the path from source node to destination node di. *The objective of the problem is to find a best path between the source node s and destination node di.*

The objective function of proposed work is to find a path from source to destination through a neighbor with maximum path preference probability. Path preference probability from source i to destination d through i's neighbor j is calculated as

$$P_{ijd} = \frac{[\tau_{ijd}]^{\alpha}.[\eta_{ij}]^{\beta}.[Pst_{ijd}]^{\gamma}}{\sum_{u \in allowed_{Ni}}[\tau_{iud}]^{\alpha}.[\eta_{iu}]^{\beta}.[Pst_{iud}]^{\gamma}} \quad , j \in allowed_{Ni} \qquad (4)$$

where $allowedNi$ is a set of allowed selection neighbor nodes of i, $\tau ijd$ relative weight of pheromone trail on link (i, j), $\eta ij$ is a neighbor trust factor of the neighbor node j, $Pstijd$ is the path stability factor on the path from i to d through j, α, β and $\gamma$ are tunable parameters which represent the importance of pheromone decay, neighbor trust factor and path stability factor.

In order to calculate relative metrics, the additive metrics delay, hop count, and non-additive concave metric bandwidth are considered. Since additive metrics have to be minimized for shortest paths, reciprocal values are used while calculating relative metrics. Owing to the desire of maximizing bandwidth, it is considered as in (4).

*1) Pheromone:* Initially when there is no neighborhood relation between $i$ and $j$, pheromone on link $(i, j)$ is made as $\tau ij$= 0.0. When $j$ is detected as neighbor of $i$ through hello message, an initial pheromone is deposited as $\tau ij$= 0.1. Whenever a Join Acknowledge message is received from $j$ to $i$, it is considered that link $(i, j)$ contributes to a possible path from source $i$ to destination d. So, it is positively reinforced as

$$\tau_{ij} = \tau_{ij} + \Delta\tau_{ij} \qquad (5)$$

Where:

$$\Delta\tau_{ij} = \frac{B_{ijd} + \frac{D - D_{ijd}}{D}}{H_{ijd}} \qquad (6)$$

Where D is the Delay constraint, $Bijd$ is the available bandwidth of the path from i to d through neighbor j, $Dijd$ is the experienced end-to-end delay from source i to destination d through j, $Hijd$ is the number of nodes from source i to destination d through j.

Though link $(i,j)$ contributes for a possible path from $i$ to d, if no data transmission is detected on that path, it is considered as a path with insufficient QoS requirements. In such case, pheromone on link (i, j) is decreased by a factor ρ as follows.

$$\tau_{ij} = (1 - \rho)\tau_{ij} \qquad (7)$$

*2) Delay:* The delay between source and destination is considered as

$$D_{ijd} = delay(path_j(i, d)) \qquad (8)$$

Where $delay(pathj(i,d))$ is experienced end-to-end delay from source i to destination d through neighbor j by join request message at the time of route exploration.

*3) Hop count:* The measure hop count indicates the number of nodes visited by join request message from source to destination. A destination node finds this from join request message it receives in which first 96 bits indicate source, destination identity, and QoS measure information whereas remaining bits contain list of nodes' IP addresses through which request message has traveled. Hop count can be measured as

$$H_{ijd} = hopcount(path_j(i, d)) = \frac{size\ of(received\ JREQ_{ANT}) - 96}{32} \qquad (9)$$

Where $hopcount(pathj(i,d))$ is the number of hops seen by join request message along the path i to d through j.

*4) Bandwidth:* The available bandwidth of the path from i to d is calculated as minimum of available bandwidth of all links along that path.

$$B_{ijd} = \min\{available\_bandwidth(l)\}\ \forall\ l \in path_j(i, d) \qquad (10)$$

Whereas available bandwidth of a link is calculated as

$$available\_bandwidth(link) = \frac{HPS}{HPST - HPRT} \qquad (11)$$

Where HPS is hello packet size, HPST is hello packet starting time, and HPRT is hello packet receiving time. Because hello messages are frequently transmitted to keep neighborhood alive connectivity, they can better reflect current available bandwidth of outgoing links rather than route exploration messages.

*5) Path Stability factor:* In MANET, the reliability of a path depends on the stability or availability of each link of this path because of the dynamic topology changes frequently. It supposes a free space propagation model [19], where the received signal strength solely depends on its distance to the transmitter. Therefore, using the motion parameters (such as speed, direction, and the communication distance) of two neighbors, the duration of time can be determined in order to estimate that two nodes remain connected or not. Suppose two nodes 'i' and 'j' are within the transmission distance '$ra$' between them, let $(xi, yi)$ and $(xj, yj)$ be the coordinate of mobile host 'i' and mobile host 'j'. Also let $(vi, \theta i)$ be the speed and the moving direction of node 'i', let $(vj, \theta j)$ be the speed and the moving direction of node 'j'. The link expiration time (LET) of is predicted by

$$LET_{ij} = \frac{-(ab+cd) + \sqrt{((a^2+c^2)r_a^2 - (ad-bc)^2)}}{a^2+c^2} \qquad (12)$$

Where: $a = vi\cos\theta i - vj\cos\theta j$, $b = xi - xj$, $c = vi\sin\theta i - vj\sin\theta j$, and $d = yi - yj$. Note also that the Eq.(12) cannot be applied when $\theta i = \theta j$ and $vi = vj$ and then LET is ∞ [20].

The path stability ($Pstijd$) is the minimum of the LETs along the path and can be written as the following

$$Pst_{ijd} = \min\{Link\_Expiration\_Time(l)\}\ \forall\ l \in path_j(i, d) \qquad (13)$$

*6) Neighbor Trust factor:* The computation formula of neighbor trust factor is:

$$\eta_{ij}(t) = \frac{\left(\frac{RM}{TM}\right) + \left(\frac{TP+CP}{TN}\right)}{2} \qquad (14)$$

Where RM and TM are residual and total memory of node j respectively, CP is computational power of node j, TP is transmitter power of node j, TN is total power of node j.

### *E. Multicast Group Maintenance*

Whenever a node learns that it cannot reach a particular destination for which it has an entry in its routing table, the node updates its routing table and sends route error message, RERR. After receiving this message, intermediate nodes will update their routing table and path priority table for the unreachable destination.

## IV. SIMULATION AND RESULTS

The goal of the simulation is to evaluate the performance of MAODV with MSROQRP under a range of various scenarios. The simulation model was built in GloMoSim, a network simulator that provides support for multicasting multi-hop wireless networks.

The simulations were carried out using a wireless ad-hoc environment consisting of 100 wireless mobile nodes roaming over a simulation area of 1000 meters x 1000 meters flat space operating for 200 seconds of simulation time with a radio transmission range of 250 meters.

Random-Waypoint model is chosen as a network mobility model, all nodes move in specified speeds to randomly specified destinations directions.

Constant Bit Rate (CBR) model is used for data flow and each data packet size is taken to be 512 Bytes, with maximum speed from 0 m/s to 20 m/s. each node starts its journey from a random location to a random destination with a randomly chosen speed. The pause time is taken as 500ms. For fairness, identical mobility and traffic scenarios are used across the compared protocols. Only one multicast group was used for all the experiments.

TABLE I
SIMULATION PARAMETERS VALUES

| **Parameters** | **Values** |
|---|---|
| Simulation Time | 200 sec |
| Environment Size | 1000X1000 |
| Number of nodes | 100 |
| Packet Size | 512 bytes |
| Mobility model | Random Waypoint |
| Node placement | Random |
| Traffic-Type | CBR |
| Radio type | Radio-ACCNOISE |
| Radio-Frequency | 2.4 GHz |
| MAC Protocol | IEEE 802.11 |
| Network Protocol | IP |
| Routing Protocol | MAODV, MSROQRP |

### A. *Packet Delivery Ratio*

It is defined as the percentage of data packets received correctly by the receivers. This ratio represents the routing effectiveness of the multicast protocol. To evaluate the effects of mobility the speed is varied from 0 m/s to 20 m/s. It shows that packet delivery ratio of the protocols slightly decreases with the increase in speed.

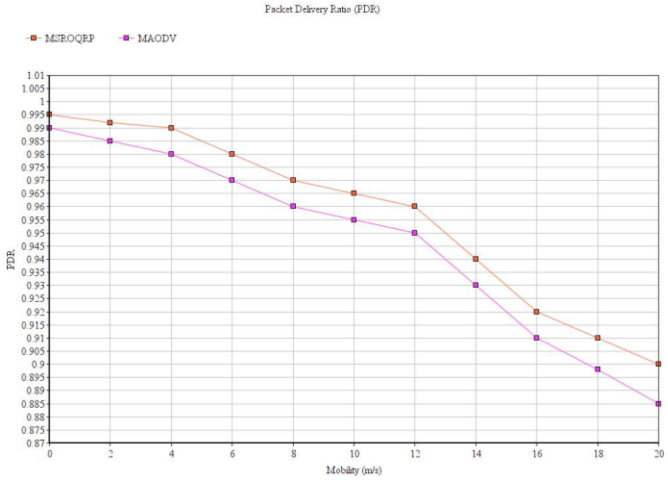

Fig. 1 Analysis of Packet Delivery Ratio (PDR)

Figure 1 shows the analysis of packet delivery ratio as a function of mobility. It was observed that PDR of MSROQRP is improved than that of MAODV. For example, at speed value equal to 20 m/s, we have improvement in PDR Value equal to 0.015

### B. *Group Reliability*

Group reliability decreases with increase in mobility. MSROQRP shows better group reliability than MAODV as illustrated in fig.3. Reduction in group reliability takes place at higher speeds due to either a group member moving out of range of reliable node or change of reliable nodes and intermediate nodes.

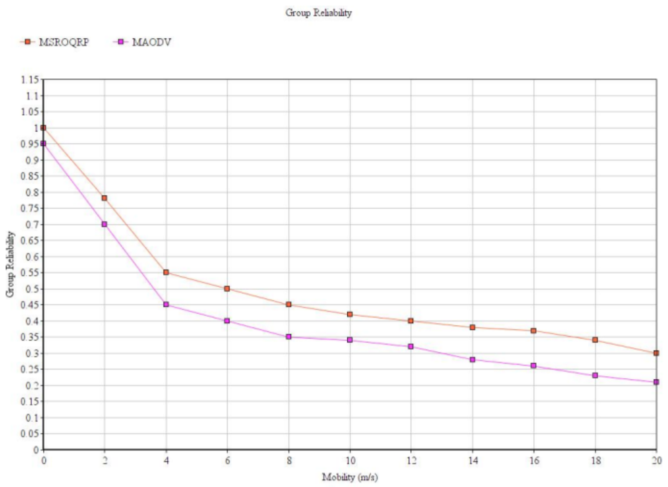

Fig. 3 Analysis of Group Reliability

### C. *Packet Latency*

Latency is an expression of how much time it takes for a packet of data to get from one designated point to another. In some usages, latency is measured by sending a packet that is returned to the sender and the roundtrip time is considered the latency. Packet latency value of MAODV is much higher than that of MSROQRP as shown in fig.4. Owing to reliable node selection in backbone, MSROQRP is efficient in packet delivery for groups with larger size.

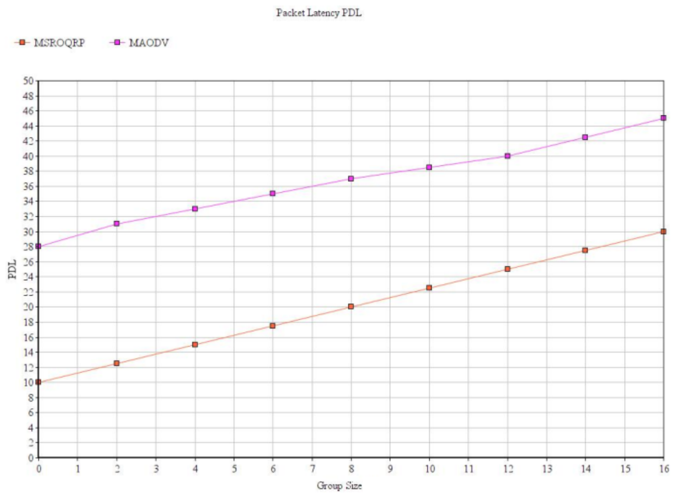


Fig. 4 Analysis of Packet Latency

## V. CONCLUSIONS

We have presented MSROQRP, a new ant-based algorithm for Multicast routing in MANETs. It is the modified version of our previously published protocol SROQRP.

The path with higher path probability offers an optimized consideration of multiple QoS metrics delay, bandwidth, and shortest hop count and offers high level of stability and reliability values. In case of any link failure leading to path breaks, alternate possible paths with next higher path probability are immediately considered and data transmission will be continued.

From simulation experiments we show that MSROQRP can outperform MAODV in terms of packet delivery ratio, packet latency and group reliability especially in difficult scenarios.

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