MANET Routing Protocols Based on Ant Colony Optimization

Anuj K. Gupta, Harsh Sadawarti, and Anil K. Verma

Abstract—**Apart from tremendous research being done all around the globe, still ad hoc networks are a big challenge for the researchers. Routing in an ad hoc network is extremely challenging because of its dynamic nature, limited bandwidth and power energy. Somehow, Swarm Intelligence based techniques such as ant colony optimization (ACO) algorithms have shown to be a good technique for developing routing algorithms for ad hoc networks. ACO based routing is an efficient routing scheme based on the behaviour of foraging ants. The collective behaviour of ants helps to find the shortest path from the nest to a food source, by deposition of a chemical substance called pheromone on the visited nodes. This mechanism from collective intelligence is applied to the ad hoc network by researchers. In this paper, we have brought some characteristics as well as performance analysis of the proposed ACO based ad hoc routing protocols and compare them with the well-known ad hoc routing protocols. The results presented in the last also help the researchers to understand the differences among various ACO based routing algorithms and to choose appropriate protocol for their research work. Our study shows how this approach has significantly improved the performance of the ad hoc networks.**

Index Terms—**MANETs, ACO, routing protocols, ant-AODV, ant-DSR, ant-DYMO, HOPNET, AD-ZRP.**

I. INTRODUCTION

In this section we have described the mobile ad hoc networks. Also we have discussed the Ant Colony Optimization technique which is implemented on existing ad hoc routing protocols to enhance their performance.

A. MANETs

In mobile ad hoc network (MANET), the nodes work together in a distributed fashion to enable routing among them [1]. Because of the lack of centralized control, routing becomes a central issue and a major challenge as the network topology is constantly changing. It is a collection of mobile nodes that are dynamically and arbitrarily located in such a manner that the interconnections between nodes are capable of changing on a continual basis. Each node can act as a receiver, transmitter or router. The main problem of the ad-hoc network is mobility of the nodes resulting in fast variations of their availability. At one time the node is in range and while at other that node is out of the range. Another problem is the power and battery lifetime of each device in the network. There are many applications for MANET. For example, in a military field, search and rescue operations, or any remote geographical area where is no base station for communication.

B. ACO

ACO, a famous swarm intelligence approach, has taken the inspiration from real ants which are wandering around their nests to forage for search of food [2]. Upon finding food they will return back to their nests and simultaneously deposit pheromone trails along the paths. The ant selects its next hop based on the amount of pheromone deposited on the path to the next node. The problem of finding shortest paths maps quite well to the problem of routing in networks. The ants are nothing but small control packets, which have the task to find a path towards their destination and gather information about it. In recent years, the interest of the scientific community in ACO has risen sharply. Because of its robustness, and adaptive nature, ACO can find its applications in routing, assignment & scheduling [3].

There are lots of similarities between mobile ad hoc networks and ants shown in the Table I. Ant based routing algorithms exhibit a number of desirable properties for MANET routing: they work in a distributed way, are highly adaptive, robust, and provide automatic load balancing.

TABLE I: COMPARISON BETWEEN AD HOC NETWORKS AND ANTS

Parameters	MANETs	Ants
Physical structure	Unstructured, dynamic & distributed	-do-
Origin of route	Route Requests are sent from source to get local information	Pheromones are used to build new routes
Multipath support	Single path, partially multipath	Provide multipath
Basic system	Self-configuring &self-organizing	-do-
Goal	To find the shortest path	Guaranteed shortest path

The foraging behaviour of ants, bees and the hill building behaviour of termites has inspired researchers in developing an efficient routing algorithm for mobile ad hoc networks discussed in later section. Furthermore, the number of mobile nodes in the network can range from a few to several hundreds or thousands. Because of the diverse envisioned working conditions, several MANET routing protocols have been proposed. Following section discusses the various types of routing protocols.

II. AD HOC ROUTING PROTOCOLS

A routing protocol for ad hoc networks is composed of a routing algorithm with a set of rules that monitor the operation of the network. Routing protocols of ad-hoc

Manuscript received December 01, 2011; revised February 15, 2012.

Anuj Kumar Gupta is with Punjab Technical University, Punjab, India (e-mail: anujgupta21@hotmail.com).

Harsh Sadawarti and Anil Kumar Verma are with the Department of Computer Science and Engineering, RIMT-IET, Punjab, India.

networks are separated in three groups: Table driven - Proactive, on demand driven - Reactive and Hybrid [4]. On demand protocols do not store all paths, but paths are created each time they need to send a data. If source node wants to send a data to destination node then this source node evokes process to search a path. After the path is created, it is maintained by nodes. These are DSR, AODV, ABR, TORA, DYMO and others [5]. In a proactive routing protocol, each node periodically broadcasts its routing table to its neighbours, allowing all nodes to have a consistent network view. Due to the up to date network topology in each node these protocols have the short response time in determining a good route from source to destination. Protocols such as DSDV, WRP fall into this category. A hybrid protocol, such as Zone Routing Protocol (ZRP) combines the advantages of both proactive and reactive protocols [6]. Each node proactively maintains a routing table for nodes within its zone and reactively finds a route to its destination if the destination node lies beyond its zone [7].

A. *Proactive Protocols*

Proactive protocols continuously learn the topology of the network by exchanging topological information among the network nodes. Thus, when there is a need for a route to a destination, such route information is available immediately. These protocols require each node to maintain one or more tables to store up to date routing information and to propagate updates throughout the network. As such, these protocols are often also referred to as table-driven. These protocols try and maintain valid routes to all communication mobile nodes all the time, which means before a route is actually needed. Periodic route updates are exchanged in order to synchronize the tables. Some examples of table driven ad hoc routing protocols include Dynamic Destination Sequenced Distance-Vector Routing Protocol (DSDV) [8], Optimized Link State Routing Protocol (OLSR) [9] and Wireless Routing Protocol (WRP) [10]. These protocols differ in the number of routing related tables and how changes are broadcasted in the network structure.

TABLE II: PROACTIVE PROTOCOLS COMPARISON

Protocol	**Routing tables**	**Route Updates**	**Route metric**	**Overhead**
DSDV	2	Periodic	Shortest path	Low
OLSR	3	Periodic	Shortest path	High
WRP	4	Periodic	Shortest path	Low
CGSR	2	Periodic	Shortest path	Low

B. *Reactive Protocols*

The major goal of on demand or reactive routing protocols is to minimize the network traffic overhead. These routing protocols are based on some type of "query-reply" dialog. They do not attempt to continuously maintain the up-to-date topology of the network. Rather, when the need arises, a reactive protocol invokes a procedure to find a route to the destination; such a procedure involves some sort of flooding the network with the route query. As such, such protocols are often also referred to as on demand. The common element in reactive protocols is the mechanism used for discovering routes. The source node emits a request message, requesting a route to the destination node. This message is flooded, i.e. relayed by all nodes in the network, until it reaches the destination. The path followed by the request message is recorded in the message, and returned to the sender by the destination, or by intermediate nodes with sufficient topological information, in a reply message. Thus multiple reply messages may result, yielding multiple paths - of which the shortest is to be used. Some examples of source initiated ad hoc routing protocols include the Dynamic Source Routing Protocol (DSR) [11], Ad Hoc On-Demand Distance Vector Routing Protocol (AODV) [12], and Temporally-Ordered Routing Algorithm (TORA) [1]. No periodic updates are required for these protocols but routing information is only available when needed.

TABLE III: REACTIVE PROTOCOLS COMPARISON

Protocol	**Path type**	**Route metric**	**Route storage**	**Overhead**
AODV	Single	Newest route	Routing Table	High
DSR	Multiple	Shortest path	Route Cache	High
TORA	Multiple	Shortest path	Routing Table	High
ARA	Multiple	Shortest path	Routing Table	Medium
ABR	Single	Strongest associativity	Routing Table	Medium

C. *Hybrid Routing Protocols*

These protocols try to incorporate various aspects of proactive and reactive routing protocols. They are generally used to provide hierarchical routing; routing in general can be either flat or hierarchical [8]. The difficulty of all hybrid routing protocols is how to organize the network according to network parameters. The common disadvantage of hybrid routing protocols is that the nodes that have high level topological information maintains more routing information, which leads to more memory and power consumption. Some examples of Hybrid Routing Protocols include CEDAR [13], ZRP [14] and SRP [15]. In what follows, we present a few of the proposed routing protocols from each class developed for the ad hoc networks. The most important protocols and those which dominate recent literature are AODV, DSR, DYMO, ZRP, DSDV and TORA [23].

TABLE IV: HYBRID PROTOCOLS COMPARISON

Protocol	**Path type**	**Route storage**	**Route metric**	**Complexity**
ZRP	Single	IntraRT & InterRT	Shortest path	Medium
FSR	Single	Routing tables	Scope range	Low
DDR	Multiple	IntraRT & InterRT	Stable routing	Low
HOPNET	Single	IntraRT & InterRT	Shortest path	High
ANSI	Multiple	Routing table	Shortest path	Medium

III. ACO BASED ROUTING PROTOCOLS

The nature of swarms largely resembles mobile ad-hoc networks (MANETs) and that is why ideas from swarm animals like ants and bees are used for creating suitable routing protocols for MANETs as well as wireless sensor networks. They are more efficient, more robust and are able to discover multiple paths. There exist a number of swarm intelligence based protocols but the most important are ant based protocols [16]. Table below enlists a few of the proposed ant based routing algorithms.

TABLE V: ANT BASED ROUTING PROTOCOLS FOR AD HOC NETWORKS

Algorithms	Year	Authors	Routing type	Path type
ABC	1997	Schoonerwood	Proactive	Single
AntNet	1998	Di Caro et al	Proactive	Single
ARA	2002	Gunes et al	Reactive	Multipath
Ant-AODV	2002	Marwaha et al	Hybrid	Multipath
MABR	2003	Heissen & Bruan	Proactive	Single
PERA	2003	Baras & Mehta	Proactive	Single
Termite	2003	Roth &Wicker	Proactive	Multipath
AntHocNet	2004	Di Caro et al	Hybrid	Single
ANSI	2005	Rajgopalan et al	Hybrid	Unicast
BeeAdHoc	2005	Wedde et al	Reactive	Broadcast
GPSAL	2006	Camara et al	Proactive	Single
Ant-DSR	2007	Aissani et al	Reactive	Broadcast
HOPNET	2008	Wanga et al	Hybrid	Multicast
PACONET	2008	Osagie et al	Reactive	Single
PAR	2009	Prasad et al	Hybrid	Multicast
MAARA	2010	Kannan et al	Hybrid	Multicast
ANT-E	2010	Sehi et al	Hybrid	Single
SAMP-DSR	2011	Sivakumar et al	Reactive	Single
ODASARA	2011	Ramesh et al	Reactive	Single
AD-ZRP	2011	Okazaki et al	Reactive	Multicast

The idea behind routing protocols based on ACO is to apply it to discover and maintain the best routes among the nodes. These protocols can thereby maintain the routing table efficiently updated due to the proportionate dynamism of ants to adapt, by pheromone, to topology changes [17].

Ant algorithms are inspired by the observation of real ant colonies. An important behaviour of ant colonies is their foraging behaviour i.e. how ants find the shortest paths between food sources and their nest [18]. While searching for food, ants deposit on ground an amount $\Delta\tau$ of special substance called pheromone at each visited node, where

$$\Delta\tau \propto \frac{1}{L^{\Delta}(t)}$$

The amount of pheromone deposited is proportional to the quality of the route found by the ant depositing pheromone. The quality of the route is inversely proportional to the route length, $L^d(t)$. The pheromone trail helps ants to find their way back to the food source. The ants which traverse through the shortest path reinforce the path with more amount of pheromone that helps other ants to follow. However the deposition of amount of pheromone diverges from the observed behaviour of real ants [19]. As ad hoc networks have dynamic topologies it is necessary to develop a mechanism for eliminating the old routes. In ACO [20] this is achieved by evaporating the pheromone exponentially over time. The pheromone values at any edge (i, j) are updated by all the ants that have completed the path length as follows:

$$\tau_{ij} = (1-\lambda)\times\tau_{ij} + \sum_{k=1}^{m}\tau_{ij}^{k}$$

where m is the number of ants that have completed the path. $\lambda \in (0,1)$ is the evaporation constant that determines the evaporation rate of the pheromone. τ_{ij}^{k} is the quantity of pheromone deposited by ant k on edge (i, j).

A. Ant-AODV

Ant- AODV is a hybrid protocol that is able to provide reduced end-to-end delay and high connectivity as compared to AODV. AODV does the reactive part and an ant-based approach does the proactive one. The main goal of the ant algorithm here is to continuously create routes in the attempt to reduce the end-to-end delay and the network latency, increasing the probability of finding routes more quickly, when required [21]. Ant-AODV's artificial pheromone model is based on the number of hops and its goal is to discover the network topology, without any other specific functions, as opposed to most ACO algorithms. Route establishment in conventional ant-based routing techniques is dependent on the ants visiting the node and providing it with routes. The nodes also have capability of launching on-demand route discovery to find routes to destinations. The use of ants with AODV increases the node connectivity (the number of destinations for which a node has un-expired routes), which in turn reduces the amount of route discoveries and also the route discovery latency. This makes Ant-AODV hybrid routing protocol suitable for real-time data and multimedia communication. Ant-AODV uses route error messages (RERR) to inform upstream nodes of a local link failure similar to AODV. Routing table in Ant-AODV is common to both ants and AODV. Frequent HELLO broadcasts are used to maintain a neighbour table.

Parameters	AODV	Ant-AODV
Routing type	Purely Reactive	Hybrid
End-to-end delay	High	Low
Connectivity	Low	High
Route type	Single path	Multipath
Overhead	Low	High

Parameters	DSR	Ant-DSR
Routing type	Reactive	Reactive
Throughput	Low	High
End-to-end delay	High	Low
Energy & Jitter	Low	High
Overhead	Low	High

B. Ant-DSR

Ant Dynamic Source Routing (Ant-DSR) is a reactive protocol that implements a proactive route optimization method through the constant verification of cached routes [22]. This approach increases the probability of a given cached route express the network reality. Mobile nodes are required to maintain route caches that contain the source routes of which the mobile is aware. Entries in the route cache are continually updated as new routes are learnt. The protocol consists of two major phases: route discovery and route maintenance. In Ant DSR (ADSR) the Forward ant (FANT) and backward ant (BANT) packets are added in the route request and route reply of DSR respectively. Forward ants are used to explore new paths in the network. Ants measure the current network state for instance by trip times, hop count or Euclidean distance travelled. Backward ants serve the purpose of informing the originating node about the information collected by the forward ant.

C. Ant-DYMO

Ant-DYMO is a hybrid protocol that uses an ant-based approach in its proactive phase while DYMO is the basis for the reactive one [24]. Ant-DYMO is a hybrid and multi hop algorithm. Nodes acquire information on their neighbourhood by the limited flooding of Hello messages [24]. Each node creates its routing probability table similar to ACO's pheromone table. Ant-DYMO defines two types of artificial ants: explorer ant (EANT), responsible for creating routes to its source and search ant (ARREQ), responsible for searching for a specific destination. The EANTs carry the information on the destination node and create (or enforce) pheromone trails along the way. The EANTs carry the address of the source node and also a list containing every intermediate node it has passed by. ARREQ has main goal to search for a specific destination, and it inherits the format of DYMO's RREQ, adding a probabilistic search mechanism that takes into account the level of pheromones on the paths.

Parameters	DYMO	Ant-DYMO
Routing type	Reactive	Hybrid
Routing overhead	Low	Medium
End-to-end delay	High	Low
Packet delivery ratio	Low	High

D. HOPNET

The HOPNET algorithm also involves characteristics of Zone Routing Protocol, a hybrid protocol which combines benefits of proactive and reactive protocols. HOPNET [25] is a hybrid routing algorithm for MANETs which involves Swarm Intelligence to solve routing problems. The algorithm has features extracted from ZRP and DSR protocols. The network is divided into zones which are the node's local neighbourhood. The size of the zone is not determined locally but by the radius length measured in hops. Boundary nodes are at a distance from the central node. All other nodes less than the radius are interior nodes. In order to construct a zone, a node, and determining border nodes, a node needs to know its local neighbours. It has two routing tables, Intrazone Routing Table (IntraRT) and Interzone Routing Table (InterRT). IntraRT is a routing table maintained proactively by HOPNET. Its goal is to map the deposit of pheromone on each node within its zone. InterRT is a responsible routing table for storing routes to a destination out of its zone i.e. when a node fails to find the destination within its zone in the IntraRT table. The route discovery within a zone is accomplished by using IntraRT. There are four elements in the routing table for a particular (row, column) pair: Pheromone, Visited times, Hops, SeqNum. The pheromone value gets updated by the ants as they traverse the links. The ants change the concentration of the pheromone value on their journey to the destination and on their way back to the source. The data structure of the ant contains six fields: Source, Destination, SeqNum, Type, Hops and Path.

Src	Dest	SeqNum	Type	Hops	Path

An ant chooses a node that produces the best path from the node to the destination. The table consists of four fields: Destination, SeqNum, Path and Expire. The external forward ants are first sent by the node to its peripheral or border nodes. At the boundary, the peripheral nodes check to see if the destination is within its zone by searching for the destination or path in its IntraRT table or InterRT table if the destination is outside the zone. If the destination is not within its zone and the path has expired, the ants are forwarded to the next zone via the other peripheral nodes within its zone. This process continues until the destination is found. The amount of pheromone increase along entry ($v_{i,}$ v_s) is given by:

$$\varphi(v_i, v_s) = \varphi(v_i, v_s) + \frac{\varepsilon}{T(v_s, v_i) + W(v_i, v_j)}$$

The pheromone concentration on all other entries not equal to v_i in the same column (v_s) in v_j's routing table is decremented using the evaporation equation below:

$$\varphi(v_l, v_s) = (1-E)\ \varphi\ (v_l, v_s)\ ,\ \forall l \neq i$$

where the pheromone value is decremented on all entries (v_l, v_s), $\forall l \neq i$ in the source column.

On its way back to the source, an ant again updates the pheromone concentration. However, the ant updates it for the destination column. An ant at node v_k traveling backwards from node v_b looks at the rows of v_b's neighbouring nodes and column v_D. The pheromone concentration update for entry is (v_b, v_D) is

$$\Phi(v_b, v_D) = \Phi(v_b, v_D) + \frac{\varepsilon}{T'}$$

where T' is $T(v_s, v_D) - T(v_s, v_k)$.This emphasizes more pheromone concentration on the path that is closest to the destination. [26]

HOPNET is highly scalable for large networks. It is able to find multiple paths from any source to a particular destination. Optimal path can be chosen thereafter. Table 6 below shows a brief comparison of HOPNET against the existing ad hoc routing protocols.

TABLE VI. COMPARISON OF HOPNET AGAINST THE EXISTING AD HOC ROUTING PROTOCOLS

Parameters	HOPNET	ZRP	AODV	DSR
Multiple routes	No	No	No	Yes
Route metric	Shortest path	Shortest path	Newest route	Shortest path
Route repository	Intrazone and Interzone Routing Tables	Intrazone and Interzone Routing Tables	Routing table	Route cache
Overhead	High	Medium	High	High

E. AD-ZRP

A self-configuring reactive routing protocol for Wireless Sensor Networks based on HOPNET AD-ZRP also consists of ZRP similar to HOPNET, but it is based on dynamic zones which, acting together with ACO, deals with the restrictions of WSNs and yet improves the route discovery and the route maintenance through pheromone [27]. It helps us to handle important routing problems in ad hoc networks such as route discovery and broken routes. But HOPNET is not a suitable routing protocol for WSNs. AD-ZRP is proposed as a reactive routing protocol to avoid sending ants periodically into their zones and thus bringing additional overhead to the sensor network. Different from HOPNET, which uses fixed-sized zones defined by the zone radius, our approach uses dynamic zones to minimize the latency while reducing the network overhead. They are defined by the presence of pheromone on routes between the source nodes and any other node in the network. Initially all zones in the network are empty. After each data packet transmission to an unknown destination, a new route is added to the zone. HOPNET uses two routing tables to perform intrazone and interzone routing separately, whereas Ad-ZRP uses only IntraRT as routing table structure. To accomplish these routing operations, a new collection of ants is presented: internal transport ant (ITA) and exploratory transport ant (ETA). Each ant category share a common data structure as shown below

Src	Prev	HInfo	Dest	SeqNum	Type	Hops

The ant structure includes address fields as Source and Destination. The Previous field is responsible for storing the address of the previous node. The HInfo field is responsible for storing the necessary heuristic information to calculate the pheromone deposit ratio. The SeqNum field is used for control. The Type field indicates the ant category, and the Hops field indicates the number of hops that the ant has done. Both ITA and ETA perform data delivery while they deposit pheromone on the route which they travel. In AD-ZRP, the data packet is sent along with the ant to ensure that sudden changes in the network do not interfere with the transportation of the data towards the destination. ETAs are responsible for discovering routes to unknown nodes. ITAs are responsible for delivering data packets only within their zone. Each ant selects a node v_j as the next hop from the current node v_i. At the node v_j , the ant updates the pheromone $\tau_{i,s}$ on the entry (v_i, v_s) in IntraRT, where v_s is the source node, as follows [mmt]:

$$\tau_{i,s} = (1-\varphi).\tau_{i,s} + \varphi.\tau_0$$

where τ_0 is the initial value of pheromone, and $\varphi \in (0,1]$ is the pheromone decay coefficient which is calculated from the heuristic information of the node v_i.

The evaporation occurs periodically to all nodes in the network, using the following equation:

$$\tau_{i,j} = (1-\rho).\tau_{i,j}\ , \ \forall i \in N,\ \forall j \in Z$$

where $\rho \in (0,1]$ is the evaporation ratio, N is the set of neighbour nodes, and Z is the set of nodes which, together with neighbour nodes, define entries (v_i, v_j) in IntraRT.

TABLE VII: COMPARISON BETWEEN HOPNET AND AD-ZRP

Parameters	**HOPNET**	**AD-ZRP**	**ZRP**
Routing type	Hybrid	Reactive	Hybrid
Designed for	MANETs	WSNs	MANETs
Zone type	Fixed-size	Dynamic	Not fixed
Routing table	InterRT & IntraRT	IntraRT	InterRT & IntraRT
Ants	FA & BA	ITA & ETA	No
Heuristic Info	No	Keeps track	No

Although, both HOPNET and AD-ZRP are based on ACO and ZRP, and they share some similarities. But there exists certain differences among the both. Table 7 below shows the comparison between HOPNET and AD-ZRP.

F. SDVR

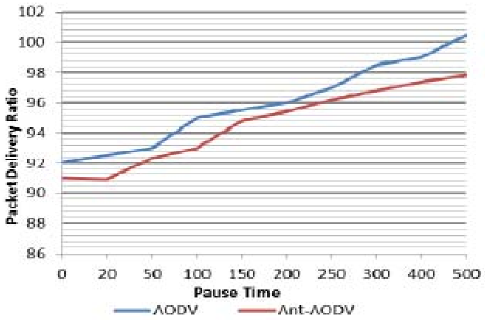
Swarm Distance Vector Routing Protocol is a unicast on-demand routing algorithm based on optimization of three QoS parameters delay, jitter and energy [28]. This avoids the overhead of having three independent routing algorithms, one for each QoS metric. The mechanism was based on information obtained from periodically transmitted backward ANTs resulting in reinforced path-pheromone levels. The main purpose of QoS routing is to find a feasible path that has sufficient resources to satisfy the constraints. A fundamental problem in QoS routing is to find a path between a source and destination that satisfies two or more end-to-end QoS constraints. The source nodes maintain a routing table that contains entries of neighbouring nodes to reach destination nodes. When the source receives the BANT, it has an entry for reaching the destination through one of its neighbours. Since duplicate FANTs are not discarded, the destination node may send multiple BANTs back to the source. Once the destination receives the FANT, it sends a BANT back to the source using the same path the FANT has travelled.

Parameters	**DSDV**	**SDVR**
Routing type	Proactive	Reactive
Packet delivery ratio	Low	High
End-to-end delay	High	Low
Routing overhead	Low	Medium
Throughput	Low	High
Network lifetime	Shorter	Longer

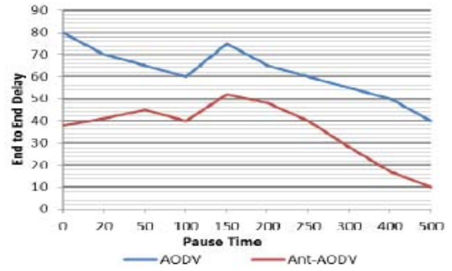
IV. COMPARISON AND EXPERIMENTAL RESULTS

This section presents an overall comparison of all the categories of ad hoc routing protocols and various existing ant based routing protocols for ad hoc networks. Table 8 and table 9 shows the major differences among the three main categories of ad hoc routing protocols [29] and ant based routing protocols for ad hoc networks [30] respectively.

Some of the proposed algorithms considered in this work are compared by their developers to traditional ad hoc routing algorithms such as AODV etc. This section presents some results as shown below. The metrics used to measure the performance of the presented MANET routing protocols are mainly packet delivery ratio, number of packets and end to end delay. Figure 1, 2, 3 show the packet delivery ratio, end-to-end delay of AODV, DSR, DYMO & Ant-AODV, ADSR, Ant-DYMO versus varying pause time respectively.



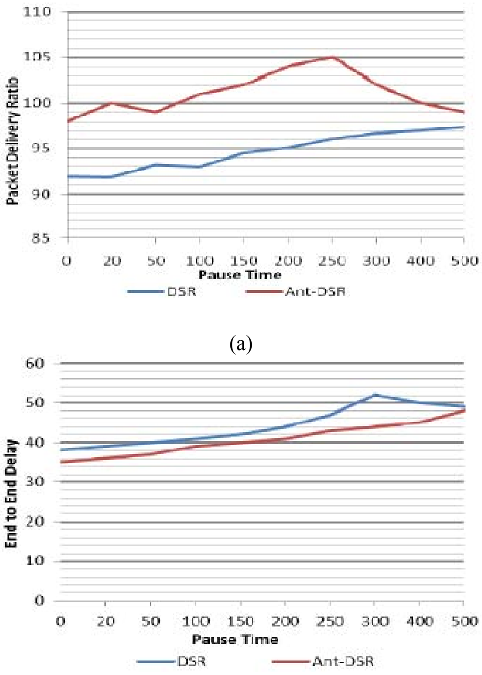
(a)



(b)

Fig. 1. Comparison between AODV & Ant-AODV

It is evident from the simulation results that by combining ant-like mobile agents with the on-demand route discovery mechanism of AODV, the Ant-AODV hybrid routing protocol would give reduced end-to-end delay and high packet delivery ratio at large pause times. High packet delivery fraction in Ant-AODV and AODV is because they make use of link failure detection and route error messages. Whereas in case of ant-based routing there is no such feature and so the source nodes keep on sending packets unaware of the link failures. This leads to a large amount of data packets being dropped which reduces the packet delivery fraction and the good put. It can be observed that the end-to-end delay is considerably reduced in Ant-AODV as compared to AODV. Ants help in maintaining high connectivity in Ant-AODV hence the packets need not wait in the send buffer till the routes are discovered. Even if the source node does not have a ready route to the destination, due to the increased connectivity at all the nodes the probability of its receiving replies quickly from nearby nodes is high resulting in reduced route discovery latency. Ant-AODV hybrid protocol is able to provide reduced end-to-end delay and high connectivity as compared to AODV. As a result of increased connectivity the number of route discoveries is reduced and also the route discovery latency. This makes Ant-AODV hybrid routing protocol suitable for real-time data and multimedia communication.

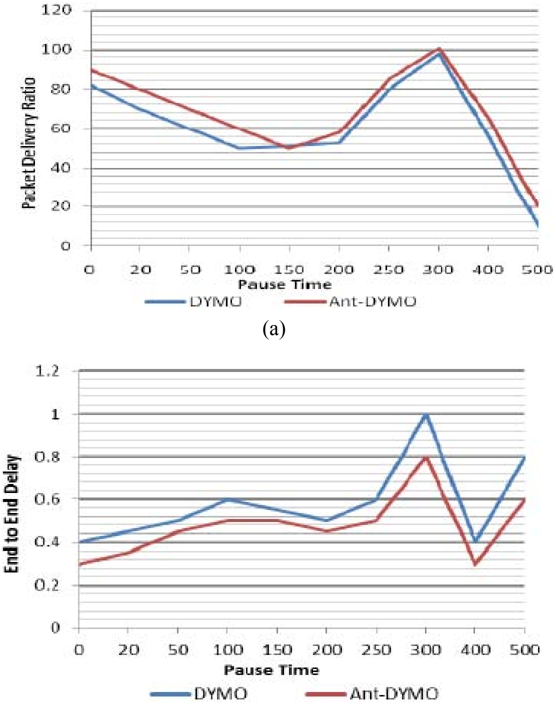


(a)

(b)

Fig. 2. Comparison between DSR & Ant-DSR

End-to-end delay tends to increase as the pause time increases in both protocols. The end-to-end delay is reduced by applying Ant-DSR. This is mainly due to adding of delay pheromone in the RREQ and RREP packets. The reduction in delay is maximum (15-20%) when the pause time reaches beyond 300 seconds. Both protocols have same delay for higher pause time. The packet delivery ratio shows an improvement over DSR. It is high for low pause time. It can be seen that increase in node speed results in significant decrease in both the protocols. This is due to more link breaks. Ant-DSR shows around 10% improvement in throughput over DSR. We can say that Ant-DSR produced better results than the existing DSR in terms of packet delivery ratio and end-to-end delay.

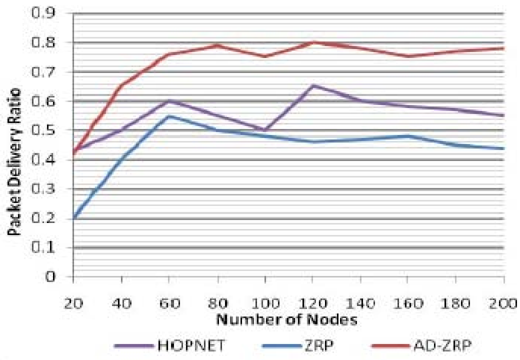


(a)

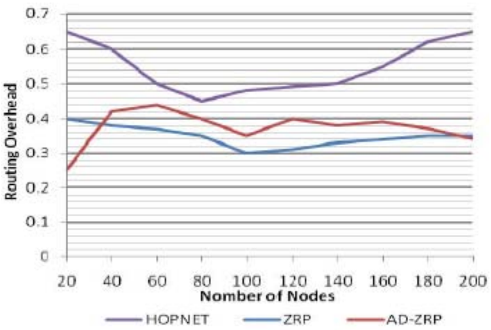
(b)

Fig. 3. Comparison between DYMO & Ant-DYMO

According to above figures the Ant-DYMO protocol takes less time, in average, to deliver its packets. In overall, the Ant-DYMO protocol has been shown to be superior to DYMO regarding the effective packet delivery in a smaller amount of time. It was also shown that it is possible to directly influence its performance by tuning its configuration parameters.



(a)



(b)

Fig. 4. Comparison between ZRP, HOPNET & AD-ZRP

Fig. 4 shows the comparison between ZRP, HOPNET and AD-ZRP for packet delivery ratio & routing overhead against varying number of nodes [27]. It can be seen that with a fewer and a very large number of nodes, HOPNET generates huge overhead whereas ZRP and AD-ZRP perform better. This may be due to use of a single table in AD-ZRP and ZRP is simpler that HOPNET. Also because HOPNET is proactive within a zone and the proactive packets create extra overhead. AD-ZRP has a better packet delivery ration that other two in very large size networks.

As seen in all the cases, Ant based protocols produced better results than the existing MANET protocols in terms of packet delivery ratio, end-to-end delay and residual energy at node. Even though they result in a slightly high routing overhead, they perform well in route discovery with dynamic changes in the network topology and produce much better throughput. Ant based routing protocols are able to provide reduced end-to-end delay and high connectivity as compared to their traditional counterparts. As a result of increased connectivity the number of route discoveries is reduced and also the route discovery latency. This makes them more suitable for real-time data. Higher connectivity and reduced end-to-end delay are achieved at the cost of extra processing of the ant messages and the slightly higher overhead occupying some network capacity. However this does not adversely affect the packet delivery fraction. Also the ants keep providing routes all the time, increasing the probabilities of quickly finding an alternate path in case of route errors.

Ants help in maintaining high connectivity in ACO based routing protocols hence the packets need not wait in the send buffer till the routes are discovered. Even if the source node does not have a ready route to the destination, due to the increased connectivity at all the nodes the probability of its receiving replies quickly from nearby nodes is high resulting in reduced route discovery latency. That way it is possible to improve the latency and increase the network connectivity. Thus we can say that Ant colony optimization technique is an efficient and comparatively better way to enhance the overall performance of a MANET routing protocol in terms of overhead and connectivity. This study emphasizes the importance of using ACO in the routing algorithm for MANETs. ACO allows us to deal with the restrictions of MANETs and yet improve the route discovery and the route maintenance through pheromone.

TABLE VIII: COMPARISON BETWEEN THE CATEGORIES OF AD HOC ROUTING PROTOCOLS

Parameters	Table-Driven (Proactive)	On-Demand (Reactive)	Hybrid
Storage Requirements	Higher	Dependent on no. of routes maintained or needed	Depends on size of each zone or cluster
Route Availability	Always available	Computed as per need	Depends on location of destination
Periodic Route Updates	Required always	Not required	Used inside each zone
Delay	Low	High	Low for local destinations and high for interzone
Scalability	100 nodes	> 100	> 1000
Control Traffic	High	Low	Lower that other two types
Routing Information	Keep stored in table	Doesn't store	Depends on requirement
Routing Philosophy	Mostly flat	Flat	Hierarchical

TABLE IX: COMPARISON BETWEEN ACO BASED ROUTING PROTOCOLS FOR AD HOC NETWORKS

Protocols	Ant-AODV	Ant-DSR	Ant-DYMO	SDVR	HOPNET	AD-ZRP
Ants	Forward ant	Forward & Backward ants	Explorer & Search ants	Forward & Backward ants	Forward & Backward, Notification & Error ants	Internal & exploratory transport ants
Routing type	Hybrid	Reactive	Hybrid	Unicast on-demand	Hybrid	Multihop reactive
Works for	MANETs	MANETs	MANETs	MANETs	MANETs	WSNs
Information storage	Pheromone table	Pheromone table	Pheromone table	Pheromone table	InterRT & IntraRT	IntraRT

V. CONCLUSIONS

The highly dynamic topology of Ad Hoc networks and their limited bandwidth makes the routing task more difficult. An efficient network management solution is required that are scalable and can cope with large, and increasing, traffic volumes. Also, it should provide decentralized and adaptive routing strategies that cope with the dynamics of the network topology. A number of state of the art ACO inspired ad hoc routing protocols are considered in this work and put to partial comparison. Some of them are proactive, reactive or hybrid. And it can be evaluated that some of them may outperform the standard ad hoc routing protocols like AODV, DSDV, DYMO, DSR etc.

Depending on application needs the presented protocols could be chosen. A number of state of the art swarm-intelligence inspired MANET protocols are considered in this work and put to partial comparison. This paper aims to provide a platform for researchers worldwide to get an overview of the existing ACO based routing protocols. To know about their performance against traditional ad hoc routing protocols. This would rather help them consider appropriate protocol for their research work. The authors have tried their best to present a comparative study of various proposed ad hoc routing protocols based on ant colony optimization techniques. We have evaluated and compared various ACO based algorithms to the original ones and obtained better results in terms of end to end delay and routing overhead etc. for environments of dynamic topology. In future a more critical performance evaluation of these protocols shall be done on the basis of simulations and varying performance metrics.

ACKNOWLEDGEMENT

The authors would like to thank all the anonymous reviewers and experts for their valuable and critical comments in bringing out more useful information and enhancements to the present study.

REFERENCES

[1] K. A. Gupta, Harsh Sadawarti, K. A. Verma, “Performance analysis of AODV, DSR and TORA Routing Protocols,” *International Journal of Engineering and hnology (IJET),* ISSN: 1793-8236, Article No. 125, Vol.2 No. 2, April, pp. –Yaode 2010.

[2] M. Dorigo and C. Blum, “Ant colony optimization theory: a survey,” *Theor. Comput. Sci.,* vol. 344, no. 2-3, pp. 243–278, 2005.

[3] G. D. Caro, F. Ducatelle, and L. Maria Gambardella 2005. AntHocNet: an Ant-Based Hybrid Routing Algorithm for Mobile Ad Hoc Networks. 2005.

[4] B. Liang, Z. J. Hass, Hybrid routing in ad hoc networks with a dynamic backbone, *IEEE Transactions on Wireless Communications* 5 (6) 1–14. 2006.

[5] M. Abolhasan, T. Wysocki, and E. Dutkiewicz, “A review of routing protocols for mobile ad hoc networks,” *Elsevier Journal of Ad Hoc Networks*, 1–22, 2004.

[6] K. Anuj Gupta, H. Sadawarti, K. Anil Verma, “A Review of Routing Protocols for Mobile Ad Hoc Networks,” *WSEAS* Transactions *on Communications*, ISSN: 1109-2742, Issue 11 Vol. 10, November 2011, pp. – 331-340.2011.

[7] C. Chakeres, Perkins, Dynamic MANET On-demand (DYMO) Routing, *RFC draft, Boeing, Nokia*, February 2008.

[8] C. Perkins and P. Bhagwat, Highly dynamic destination-sequenced distance-vector routing (DSDV) for mobile computers, in: *ACM SIGCOMM*, August–September 1994, pp. 234–244.1994.

[9] T. Clausen, P. Jacquet, A. Laouiti, P. Muhlethaler, A. Qayyum, and L. Viennot, Optimized link state routing protocol for ad hoc networks, in: *Proceedings of IEEE INMIC*, December 2001, pp. 62–68.2001.

[10] S. Murthy and J. J. Garcia-Luna-Aceves, An efficient routing protocol for wireless networks, *MONET* 1 (2) (1996) 183–197.1996.

[11] D. B. Johnson, D. A. Maltz, and Y. Hu, The Dynamic Source Routing Protocol (DSR) for Mobile Ad Hoc Networks for IPv4, *IETF RFC 4728*, February 2007.

[12] C. E Perkins, E. M. Royer, and S. Das, —Ad hoc On-demand Distance Vector (AODV), *RFC 3561*, July 2003.

[13] C. E. Perkins, “Ad hoc Networking”, *Pearson Publication.*

[14] S. Mittal and P. Kaur, "Performance Comparison of AODV, DSR and ZRP Routing Protocols in MANET'S," *International Conference on Advances in Computing, Control and Telecommunication Technologies, 2009 (ACT '09),* pp.165-168, 28-29 Dec. 2009.

[15] L. Abusalah, A. Khokhar, and M. Guizani, “A Survey of Secure Mobile Ad Hoc Routing Protocols,” *IEEE Communications Surveys and Tutorials*, Vol. 10, No. 4, Fourth Quarter 2008.

[16] S. Prasad, Y.P. Singh, and C.S. Rai, Swarm Based Intelligent Routing for MANETs, *International Journal of Recent Trends in Engineering*, Vol. 1, No. 1, May 2009.

[17] M. Dorigo and L. Gambardella, “Ant colony system: A Cooperative learning approach to the traveling salesman problem,” *IEEE Transaction on Evolutionary Computation*, Vol. 1, N1, pp53-66

[18] M. Gunes, U. Sorges, and I. Bouazizi, “Ara-the ant-colony based routing algorithm for Manets,” in *Parallel Processing Workshops*, pp. 79 – 85. 2002.

[19] K. Anuj Gupta, K. Anil. Verma, and H. Sadawarti, “Analysis of various Swarm-based and Ant-based Algorithms,” in *Proc. of International Conference on Advances in Computing and Artificial Intelligence (ACAI 2011), an ACM Chapter Event, Chitkara University, Punjab,* 21-22 July 2011, pp – 39-43.2011.

[20] M. Dorigo, M. Birattari, and T. Stutzle, “Ant colony optimization”, *Computational Intelligence Magazine, IEEE*, vol. 1, no. 4, pp. 28 – 39,nov. 2006.

[21] S. Marwaha, C. Khong, and T. Srinivasan, “Ant-Aodv - Mobile agents based routing protocol for mobile ad hoc networks,” in Proceedings *of IEEE Globecom*, 2002.

[22] M. Aissani, M. Fenouche, H. Sadour, and A. Mellouk, “Ant-DSR: cache maintenance based routing protocol for mobile ad-hoc networks,” *AICT 2007. The Third Advanced International Conference* in *Telecommunications*, pp. 35–35. 2007.

[23] K. Anuj Gupta, H. Sadawarti, K. Anil. Verma, “Review of various Routing Protocols for MANETs,” *International Journal of Information and Electrical Engineering,* ISSN: 1109-2742, Vol. 1 Number 3, Article No. 40, pp. – 251-259, November 2011.

[24] J. Alex Pontes Martins, S. Luis O. B. Correia, J. Celestino J´unior, “Ant-DYMO: A Bio-Inspired Algorithm for MANETS”, 2010 *17th International Conference on Telecommunications*.2010.

[25] J. Wang, E. Osagie, P. Thulasiraman, R. Thulasiram, Hopnet: a hybrid ant colony optimization routing algorithm for mobile ad hoc network, *Ad Hoc Networks* 7 (4) (2009) 690–705.

[26] M. T. Islam, P. Thulasiraman, R. K. Thulasiram, Implementation of antcolony optimization algorithm for mobile ad hoc network applications: openmp experiences, *Parallel and Distributed* Computing *Practices* 2 (5) (2004) 177–191.2004.

[27] A. Massayuki Okazaki and A. Augusto Frohlich, “AD-ZRP: Ant-based Routing Algorithm for Dynamic Wireless Sensor Networks,” 2011, *18th International Conference on Telecommunications.*

[28] R. Asokan, A. M .Natarajan, and A.Nivetha, “A Swarm-based Distance Vector Routing to Support Multiple Quality of Service (QoS) Metrics in Mobile Adhoc Networks,” *Journal of Computer Science* 3 (9): 700-707, 2007.

[29] A. Boukerche, B. Turgut, N. Aydin, Z. Mohammad Ahmad, and L. Bölöni, D. Turgut, Routing protocols in ad hoc networks: A survey, *Elsevier Computer Networks* 55 (2011) 3032–3080.

[30] M. Dorigo and T. Stützle. *The Ant Colony Optimization*.

Anuj Kumar Gupta is a PhD Scholar in Punjab Technical University, Punjab, India. His research area is Mobile ad hoc networks, wireless networks & Data Communication. He has a teaching experience of more than 10 years. He has published over 10 research papers in national and international journals of repute. He is a member of IACSIT.
Email: anujgupta21@hotmail.com

Dr. Harsh Sadawarti is Director cum Professor in Dept. of Computer Science & Engg. at RIMT-IET, Punjab, India. He has a vast teaching and research experience of more than 20 years in the field of computer science. His areas of research are ad hoc networks, parallel computing & Distributed systems. He is a member of IEEE.
Email: harshsada@yahoo.com

Dr. Anil Kumar Verma is faculty in Computer Sci. & Engg. Dept. at Thapar University, Patiala, Punjab, India. He has a vast teaching & research experience of more than 20 years. His areas of research are mobile ad hoc networks, wireless sensor networks & Network Security.
Email: akverma@thapar.edu