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Ant Colony Optimization based Hybrid Routing Protocol for MANETs

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ABSTRACT

An ad hoc mobile network 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. Routing in MANET is extremely challenging because of MANETs dynamic features, its limited bandwidth and power energy. The routing protocol is used to discover routes between nodes. Routing is a challenging task in ad hoc network due to mobility of nodes that frequently changes network topology. Nature-inspired algorithms (swarm intelligence) such as ant colony optimization (ACO) algorithms have shown to be a good technique for developing routing algorithms for MANETs. In this paper, we propose a new routing algorithm for MANETs called Ant-HRP which based on ACO, proactive and reactive routing protocol capability and is simulated on NS2. Results indicate that Ant-HRP effectively improve the connectivity, packet delivery ratio and reduce the end-to-end delay as compared with the Ant Net, AODV and DSDV routing protocols.

Keywords: *MANETs, AntNet, ACO, AODV and Ant-HRP*

1. INTRODUCTION

Mobile Ad hoc Networks (MANET) is a communication network of a set of mobile nodes, placed together in an ad hoc manner, without any fixed infrastructure that communicate with one another via wireless links. The devices used to form an Ad Hoc Network possess limited transmission range; therefore, the routes between a source and a destination are often multi hop. As there are no separate routers, nodes that are part of the network need to cooperate with each other for relaying packets of one another towards their ultimate destinations as they do not have central administration, it is easy to deploy and expand. This kind of network is very flexible and suitable for applications such as temporary information sharing in conferences, military actions and disaster rescues [1].

A fundamental problem in MANET is how to deliver packets among mobile nodes efficiently without predetermined topology or centralized control, which is the main objective of routing protocols. Since MANETs change their topology frequently, routing in such networks is a challenging task. So far, much work has been done on routing in MANETs and can be divided into: proactive protocols and reactive protocols [20].

Proactive routing protocol includes: Destination Sequenced Distance Vector (DSDV) etc. They attempt to maintain a correct view of the network topology add the time and build routes from each node to every other node before they are needed, hence they are also called table-driven protocols. Any changes in topology are propagated through the network, so that all nodes know of the changes in topology. Thereby, proactive protocols maintain routing information about the available paths in the network even if these paths are not currently used. The major drawback of these approaches is that the maintenance of unused paths may occupy an important part of the available bandwidth if the topology of the network changes frequently [5 and 21].

Reactive routing protocols includes: Ad hoc On-demand Distance Vector (AODV) Routing etc. Reactive maintain only the routes that are currently in use, thereby trying to maintain low control overhead, reducing the load on the network when only a small subset of all available routes is in use at any time. However, they still have some inherent limitations. First, since routes are only maintained while in use, it is usually required to perform a route discovery before packets can be exchanged between communication peers. This leads to a delay for the first packet to be transmitted. Second, even though route maintenance for reactive algorithms is restricted to the routes currently in use, it may still generate an important amount of network traffic when the topology of the network changes frequently. Finally, packets to the destination are likely to be lost if the route to the destination changes [19].

In general, reactive protocols are more efficient than proactive routing protocols in terms of control overhead and power consumption since routes are only established when required. By contrast, proactive protocols require periodic route updates to keep information current and consistent. In addition, many routes maintained might never be needed, which significantly adds to routing overhead in the bandwidth-constrained network. As routing overhead grows exponentially with network size, it prevents the application of these protocols in large-scaled networks.

Proactive protocols generally provide better quality of service than reactive protocols. As in proactive protocols, routing information is constantly updated, routes to every destination are always available and up-to-date, and, hence, end-to-end delay can be minimized. For reactive protocols, the source node has to wait for the route to be discovered before communication can happen. This latency in route discovery might be intolerable for real-time communications. However, we will investigate this aspect in our work.

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Recently, there is an increasing interest in the use of swarm intelligence (SI) [3, 10 and 14] or nature inspired algorithms for routing in MANET. SI is a computational intelligence technique that involves collective behavior of autonomous agents that locally interact with each other in a distributed environment to solve a given problem in the hope of finding a global solution to the problem. Ant colonies, bird flocking, animal herding and fish schooling are examples in nature that use swarm intelligence. The foraging behavior of ants [5], bees [8] and the hill building behavior of termites [16] has inspired researchers in developing an efficient routing algorithm for MANETs.

There are lots of similarities between MANETs and ants. MANET environment is unstructured, dynamic and distributed like the ants environment. In MANETs, the route request packet interact with each node locally to get routing information similar to ants that use pheromones to get local information. The traditional protocols for MANETs and ant based algorithms provide multiple paths.

They are both self configuring and self organizing systems. The foraging behavior of ants and the interaction behavior of MANETs to deliver packets from source to destination are similar. The goal for both systems is to find the shortest path.

ACO [6, 7, 9, 15 and 17] is based on the behavior of a group of artificial ants in search of a shortest path from the source to the destination. These artificial ants mimic real ants in nature in search of food from the nest to the destination. The ants deposit a chemical substance called pheromone that other ants can sense on their journey to the destination. The ants interact with each other and the environment using the pheromone concentration. As with any perfume, if not reapplied, the scent evaporates. As the ants travel, the longer paths lose their pheromone concentration making the ants to choose the shortest path.

ACO can be used for efficient routing in a network and discover the topology, to provide high connectivity at the nodes. The nodes depend solely on the ant agents to provide them routes to various destinations in the network. This may not perform well when the network topology is very dynamic and the route lifetime is small. In ACO nodes have to wait to start a communication, till the ants provide them with routes. In some situations it may also happen that the nodes carrying ants suddenly get disconnected with the rest of the network. This may be due to their movement away from all other nodes in the network or they might go into sleep mode or simply turned off. In such situations, the amount of ants left for routing are reduced in the network which leads to ineffective routing [13].

This paper tries to overcome these shortcomings of ACO, proactive and reactive routing protocol by combining them to develop a hybrid routing scheme called Ant-HRP this algorithm proactively creates routes and reactively maintenance of used paths only. The Ant-HRP is able to reduce the overhead, the delay and packet dropped by providing high connectivity also, increase the packet delivery ratio as compared to AODV, DSDV and Ant Net routing protocols.

The rest of this paper is organized as follows. In Section II provides an overview of the related work. Proposed routing protocol is introduced in Section III. Section IV shows the simulation model and performance metrics. Performance summary is demonstrated in Section VI. Finally Section VII concludes the paper.

2. RELATED WORK

2.1 AODV

AODV [2 and 18] routing protocol is a reactive routing protocol which establish a route when a node requires sending data packets. AODV is capable of both unicast and multicast routing. The operation of the protocol is divided in two functions: route discovery and route maintenance. When a route is needed to some destination, the protocol starts route discovery. Then the source node sends route request message to its neighbors.

And if those nodes do not have any information about the destination node, they will send the message to all its neighbors and so on. And if any neighbor node has the information about the destination node, the node sends route reply message to the route request message initiator.

On the basis of this process a path is recorded in the intermediate nodes. This path identifies the route and is called the reverse path. Since each node forwards route request message to all of its neighbors, more than one copy of the original route request message can arrive at a node.

A unique id is assigned, when a route request message is created. When a node received, it will check this id and the address of the initiator and discarded the message if it had already processed that request. Node that has information about the path to the destination sends route reply message to the neighbor from which it has received route request message. This neighbor does the same. Due to the reverse path it can be possible. Then the route reply message travels back using reverse path. When a route reply message reaches the initiator the route is ready and the initiator can start sending data packets.

2.2 DSDV

DSDV [18] is a table-driven routing scheme for mobile ad hoc networks which maintains a table to store the routing information. Each node will maintain a routing table in which all of the possible destinations within the network and the number of hops to each destination are recorded. Each entry in the routing table is marked with a sequence number which will avoid the formation of loops.

In a very large population of mobile nodes, adjustments will likely be needed for the time between broadcasts of the routing information packets. To reduce the amount of information carried in these packets, two types of route packets are used. The first is the full dump packet carries all available routing information and these packets are transmitted in frequently manner. The second packet is the incremental packets which are used to carry the information that has changed since the last full dump.

2.3 Ant Net

Ant Net [4] is a meta-heuristic ant based routing protocol in which, two types of routing agents have been used like forward ants and backward ants. At regular intervals, forward ants are launched towards randomly selected destination. The backward ant is generated after the forward ant reach at the destination point and to utilize useful information gathered by the forward ants. The backward ants inherit route information from the forward ant and use it to update the pheromone values in the node's routing tables as it travels back on the same path of the forward ant. The amount of pheromones deposit is dependent on the trip time of the forward ants. Ant Net is slow in terms of end-to-end delay which is a main disadvantage.

3. PROPOSED ROUTING PROTOCOL

Ant-HRP is a hybrid ant based routing protocol proposed in the effort to combine the advantages from both of Ant Net, proactive and reactive routing protocol.

Ant-HRP reactively finds a route to the destination on demand, and proactively maintains and improves the existing routes or explores better paths. In Ant-HRP, ant maintains a list of nodes it has visited to detect cycles. The source node sends out forward ants and when it receives all the backward ants, one generation is completed. Each node I keeps the identity of the forward ants, the path computation, number of hops, of the ant from the source to node I, and the time the ant visited node I. Note that more than one ant may have reached node I and therefore the identity of the ant is important. When an ant arrives at a node, the node checks the ant's path computation and the time it reached node I. If the path computation and time are within a certain limit of those produced by another ant of the same generation then the ant is forwarded. Otherwise, the ant is discarded. In case of a link failure at a node and no alternative paths are available, the node sends a reactive forward ant to repair the route locally and to determine an alternative path. If a backward ant is received for the reactive forward ant, the data packets are sent along the newly found path and all its neighbors are notified about the change in route.

Otherwise, the node sends a notification to all its neighbors of the lost destination paths which in turn initiate forward ants from the neighbors.

To overcome some of the inherent drawbacks of ant-based, proactive and reactive routing protocols the proposed technique forms a hybrid of them. The hybrid routing protocol enhances the packet delivery ratio and the node connectivity, decreases the delay. In conventional ant-based routing techniques route establishment is dependent on the ants visiting the node and providing it with routes. If a node wishes to send data packets to a destination for which it does not have a fresh enough route, it will have to keep the data packets in its send buffer till an ant arrives and provides it with a route to that destination. Hence when a route breaks the source still keeps on sending data packets unaware of the link breakage. This leads to a large number of data packets being dropped. In conventional proactive routing protocol on the other hand is that the maintenance of unused paths may occupy an important part of the available bandwidth if the topology of the network changes frequently.

Ant-HRP adopts the behavior of a real ant colony to maintain a broken path efficiently and quickly. Ant-HRP consists of two processes, namely routing discovery and route maintenance. In the routing discovery process, a mobile node launches QUERY packets (forward ants) to find multiple paths to destination (food sources). If a destination is found, a REPLY packet (backward ant) is returned from the destination to the mobile node to set up the paths (lay pheromone). Destination packets are then routed stochastically according to pheromone intensity once the destination routing paths are established. In the routing maintenance process periodically sends EXPLORE message to destinations to monitor the quality of existing routes, and to explore new routes to destinations.

Ant-HRP utilizes ants working independently and providing routes to the nodes. Once a route is established, it must be maintained as long as it is needed. Because of the mobility of the nodes, links along paths are likely to break. However, breaks in routes must be quickly repaired so that data packets are not dropped. When the link break, the node upstream sends EXPLORE message. In this message it lists all of the destinations that are now unreachable due to the loss of the link. After creating the EXPLORE message, it sends this message to its upstream neighbors that were also utilizing the link. These nodes, in turn, invalidate the broken routes and send their own EXPLORE messages to their upstream neighbors that were utilizing the link. The EXPLORE message thus traverses the reverse path to the source node. Once the source node receives the EXPLORE, it can repair the route if the route is still needed.

Local connectivity in Ant-HRP is maintained by using EXPLORE message. The routing table in Ant-HRP routing scheme is common to both ants and proactive routing protocol. Frequent HELLO broadcasts are used to maintain the neighbor table like the technique used in reactive protocols. This table is used to select a randomly chosen next hop from the list of neighbors by the ant.

The use of ants with proactive routing protocol increases the node connectivity, which in turn reduces the maintenance of unused paths. Lastly, as ant agents update the routes continuously, a source node can switch from a longer (and stale) route to a newer and shorter route provided by the ants. This leads to a considerable decrease in the end-to-end delay as compared to traditional routing protocols.

4. SIMULATION MODEL AND METRICS

4.1 Simulation Model

The Ant-HRP protocol proposed in this paper is compared with the AODV, DSDV and Ant Net routing protocols. Network Simulator (NS-2) [11] is a discrete event simulator used to simulate these protocols which can model and simulate multi-hop MANETs was used for the simulations. The physical layer for the simulation uses two-ray ground reflection as the radio propagation model.

The link layer is implemented using IEEE 802.11 Distributed Coordination Function (DCF), Media Access Control protocol (MAC). Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) is used to transmit these packets. Packets sent by routing layer are queued at the interface queue till MAC layer can transmit them.

Simulations were run for 100 simulated seconds. Our simulation models the network with variable size 10, 20, 40, 50 and 100 nodes migrating within an area of 1500x1000m^2 with a speed of 20 m/s. Radio propagation range for each node is 250 m and channel capacity is 2 Mbps. Pause time can be defined as time for which nodes waits on a destination before moving to other destination.

The pause time is 0 s which means the node is always moving in the entire simulation period. The simulations have been carried using the parameters mentioned in Table 1.

Table 1: Scenario for NS-2 topology

Parameter	**Value**
Number of simulated nodes	10-20-40-50-100
Area size of topography	1500x1000m2
Wireless range	150 m
Packet size	512 byte
Send rate of traffic	1 packets / s
Traffic type	CBR
Number of traffic sources	5-10-20-25-50
Speed Mobility Model	RWP
Pause Time (s) at simulation	0s
Simulation Time	100 s
Simulated Routing Protocols	Ant-HRP, Ant Net, AODV and DSDV

4.1.1 Mobility and Traffic Model

A mobility model should attempt to mimic the movements of real Mobile Networks. Changes in speed and direction must occur and they must occur in reasonable time slots. There is several mobility models supported. The mobility model uses the random waypoint (RWP) model in the rectangular field. Rectangular area is used to force the nodes to create long routes and this help in studying the effect of the proposed modifications. In this model, at every instant, each node is randomly placed in the simulated area and remains stationary for a specified pause time. It then randomly chooses a destination and moves there at a velocity chosen uniformly between a minimum velocity and a maximum velocity. Each node independently repeats this movement pattern through the simulation. We chose our traffic sources to be constant bit rate (CBR), Each CBR package size is 512 bytes and one second transmits one package which used varying the number of CBR source was approximately equivalent to varying the sending rate. We have chosen this value because smaller payload sizes penalize protocols that append source routes to each data packet.

4.2 Performance Metrics

In this subsection, we present performance metrics that have been proposed for the performance evaluation of MANET routing protocols. The following metrics are applied to comparing the routing protocols performance. Some of these metrics are suggested by the MANET working group for routing protocol evaluation [12].

- Packet Delivery Ratio: The ratio between the number of data packets originated by the CBR sources and the number of data packets received by the CBR sink at the final destination.
- End to End Delay: This includes all possible delays caused by buffering during routing discovery latency, queuing at the interface queue, and retransmission delays at the MAC, propagation and transfer times.
- Routing Packet Overhead: The total number of transmissions routing packets transmitted during the simulation. For packets sent over multiple hops, each transmission of the packet counts as one transmission.
- Connectivity: is the average number of nodes in the network for which a node has un-expired routes.

5. SIMULATION RESULTS AND PERFORMANCE ANALYSIS

This section presents an attempt was to compare all of the considered routing protocols under the same simulation environment, we will try to discuss the behavior of the considered routing protocols depend on a constant pausing time and variable network size.

5.1 Packet Delivery Ratio

Figure 1 shows the packet delivery ratio for Ant-HRP, AODV, DSDV and Ant Net routing protocols. There are two reasons an intermediate node will not be able to deliver packets: the pheromone concentration along the neighboring links is zero or the node has moved away. In the latter case, the upstream node of the broken link will conduct a local repair procedure, trying to find an alternative path to the destination while buffering all the packets it receives for Ant-HRP and AODV. If the node successfully finds a new path to the destination, it will send all the buffered packets to the destination via the newly found route, meanwhile, a notification ant will be sent to the source to let the source node know the change of route. In the former case, the ants cannot select any links to travel if all their links, upstream and downstream are zero and the data packet is dropped at that node, hence

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higher delivery ratio in AODV than other routing protocols. Note that as the network size increases and with more neighbors for a node, the delivery ratio for Ant-HRP is better than AODV. This is because the ants can choose from multiple paths rather than a single path as in AODV.

The reason for high packet delivery ratio is that they make use of link failure detection and route error messages. Whereas in case of DSDV 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 ratio.

5.2 End to End Delay

Figure 2 shows the Ant-HRP produces better end to end delay results than compared routing protocols.

Comparing Ant-HRP with AODV, DSDV and Ant Net routing protocols it can be observed that the end-to-end delay is considerably reduced in Ant-HRP. In Ant-HRP, ants help in maintaining high connectivity 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. Lastly, the dynamic natures in which routes are kept updated by the ants leads to the source node switching from a longer route to shorter ones hence reducing end-to-end delay. For the AODV, the source node has to wait for the route to be discovered before communication can happen. But for the Ant-HRP, routing information is constantly updated, routes to every destination are always available and up-to-date, and, hence, end-to-end delay can be minimized.

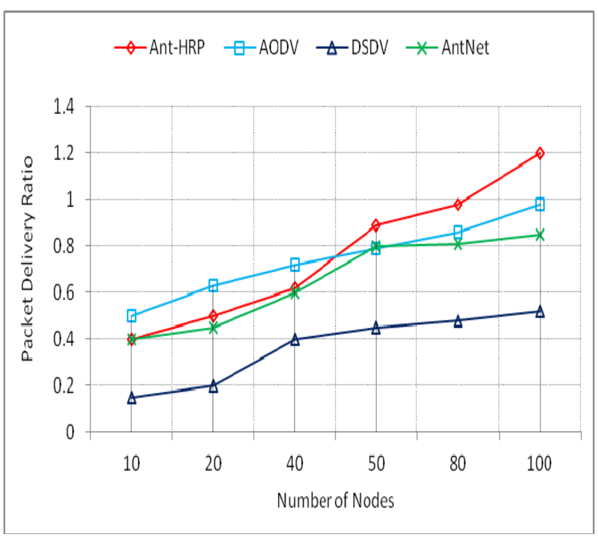

Figure 1: Packet delivery ratio vs. number of nodes

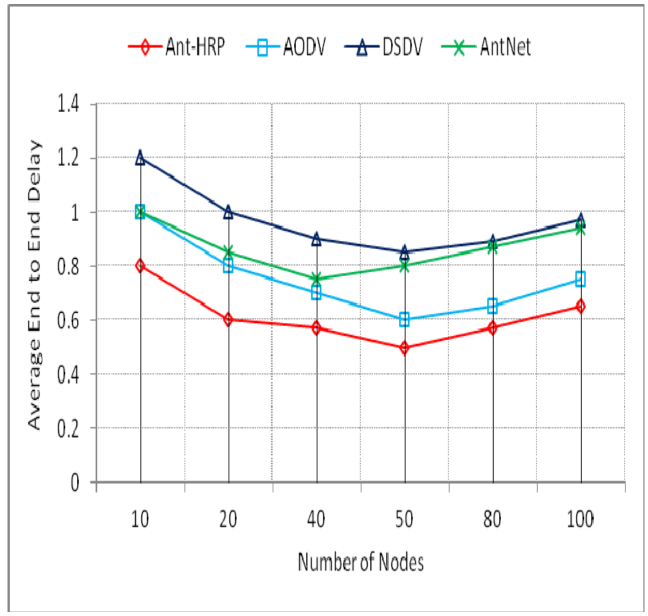

Figure 2: End to end delay vs. number of nodes.

5.3 Routing Packet Overhead

Figure 3 shows the routing packet overhead of Ant-HRP in comparison to AODV, DSDV and Ant Net routing protocols. The control packets are periodically sent out to maintain the routes. This is a major contributing factor to the overhead in Ant-HRP. As the network size increases with more neighbors for a node, the node has more choices for paths to destination and therefore, the routes between nodes have multiple paths.

The total routing overhead in case of Ant-HRP is independent of the traffic. Even if there is no communication the ants would still is traversing the network and update the routing tables this behavior increase the control message overhead. However in case of AODV, the overhead is dependent on the traffic and if there is no communication then there will be no control messages generated in the network. In Ant-HRP the overhead has two components: (i) the ants traversing in the network, (ii) each node maintains a route to every other node in the network and update routing tables. Every time interval, each node broadcasts to its neighbor after receiving an update message, the neighboring nodes utilize this information to compute their routing table entries using an iterative distance vector approach. From the comparison results it is seen that the overhead is too high in case of Ant-HRP because of the continuous movement of ants in the network and each node maintains a route to every other node in the network (multipath route). The continuous drop in routing packet overhead for all the three routing protocols is attributed to the increased packet delivery ratio.

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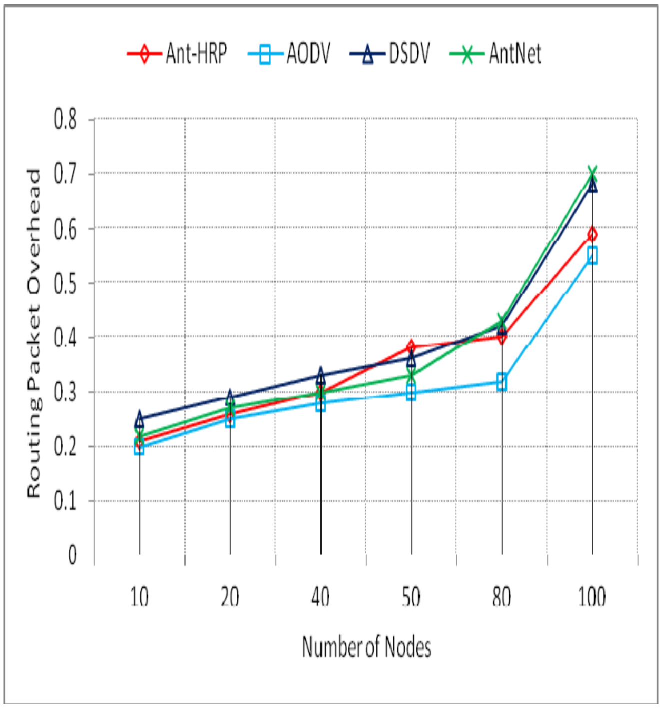

Figure 3: Routing packet overhead vs. number of nodes.

5.4 Connectivity

Figure 4 shows the connectivity of Ant-HRP in comparison to AODV, DSDV and Ant Net routing protocols.

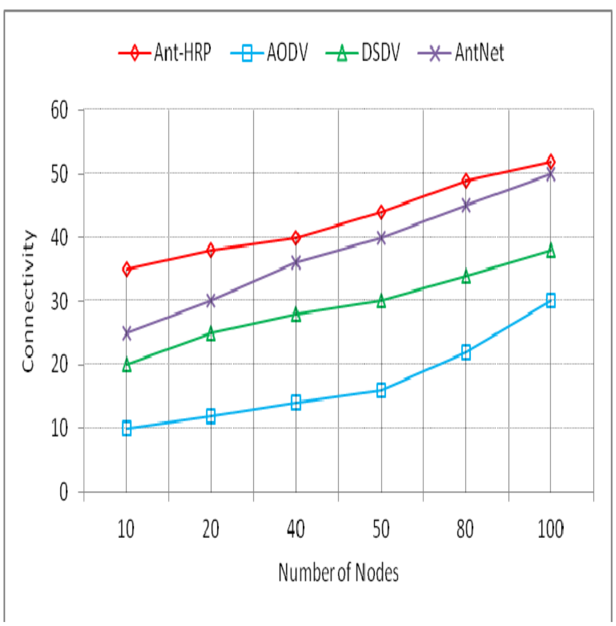

Figure 4: Connectivity vs. number of nodes.

In case of Ant-HRP agents continuously traverse the network and update the routing table entries. Due to this, a node has fresh enough routes to a large number of nodes in the network at any given point of time. The connectivity in Ant-HRP is more than DSDV and AODV routing protocols. Higher connectivity leads to lesser route discoveries and reduced end-to-end delay.

6. PERFORMANCE SUMMARY

An important characteristic of ant agents for routing in MANETs was observed during the simulations.

After a certain period, the ant activity would almost subside. This could be due to various reasons such as: (i) the ant packets could be lost in wireless transmission, (ii) the next node which was to receive the ant packet moves out of the wireless range of the sending node, or (iii) the ant bearing node goes out of wireless range of every node in the network and there is no next hop node available for the ant. In such situations the number of ants actually available for routing purpose decreases.

To overcome this decrease in number of ants available for routing, a "minimum ant visit period" was set. If no ant visited a node within this period the node would generate a new ant and transmit it to one of its neighbors selected randomly. This way the ant activity would never subside and the network would not become devoid of ants.

The simulations carried out used a minimum ant visit period of 5 seconds. The reduction in end-to-end delay and higher connectivity are achieved at the cost of extra processing of the ant messages and the slightly higher overhead occupying some network capacity. This however does not adversely affect the packet delivery fraction

Finally, Table 2 summarizes the performance evaluation of the considered routing protocols mentioned in this paper. It provides the performance matrices and the protocol name, where G, M and W mean Good, Medium and Worst performance respectively. As can been seen, from the above results, it is observed that, the proposed routing protocol Ant-HRP outperforms over the AODV, DSDV and Ant Net routing protocols.

Table 2: Summary of performance results

Performance Matrices	**Ant-HRP**	**AODV**	**DSDV**	**Ant Net**
Packet delivery ratio	M	G	W	M
End to end data delay	G	W	M	M
Routing packet overhead	W	G	M	M
Connectivity	G	W	M	M

7. CONCLUSION

This paper tries to overcome the shortcomings of the proactive, reactive and ACO by combining them to enhance their capabilities and alleviate their weaknesses.

Ant-HRP hybrid protocol is able to provide reduced delay and high connectivity as compared to proposed protocols. As a result of increased connectivity the number of packets dropped is reduced. This makes Ant-HRP hybrid routing protocol suitable for real time data and multimedia communication.

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