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AN EFFICIENT BIO-INSPIRED ROUTING SCHEME FOR TACTICAL AD HOC NETWORKS

PIMAL KHANPARA AND SHARADA VALIVETI *

Abstract. Ad hoc networks are temporary networks, created mainly for applications that are infrastructure-less. Such networks and network nodes demand special characteristics like mobile nodes having dynamic topology, wireless medium, heterogeneous deployment environment, and reactive or proactive routing depending on the nature of the network which includes network parameters such as node placement, mobility model, number of participants in the network, patterns of mobility, etc. Due to these characteristics and the mobility of network nodes, the process of routing is quite challenging in the ad hoc environment, especially when the node mobility is high. Bio-inspired routing can be an effective solution to meet all the design requirements and deal with the issues of tactical ad hoc networks. Different types of nature-inspired routing mechanisms are possible to use for tactical networks. This paper proposes the design of a novel Ant Colony Optimization-based routing strategy for ad hoc networks. Ant-based algorithms are dynamic and have adaptive behavior. Hence, they are competent for routing in ad hoc networks. Our proposed routing scheme is evaluated based on the network's performance by varying different parameters. The performance of our proposed ACO-based routing approach is also compared to some existing ad hoc routing mechanisms. Different metrics in different deployment scenarios that can affect the efficiency of our proposed protocol are taken into consideration to evaluate the performance.

Key words: Bio-inspired Routing, Ant Colony Optimization, Ad hoc Networks, Hybrid Routing

AMS subject classifications. 68M14, 68T05

1. Introduction.

In ad hoc networks, participating nodes are mobile and have dynamic connections with one another. Such nodes communicate information through wireless links and are organized in a decentralized manner. Participating nodes in ad hoc networks can become a part of the network or exit any time and thus form a topology, which keeps changing depending on the mobility of the participating nodes, i.e. the topology is dynamic. Hence, the position of nodes at any given time, cannot be known or assumed to be precisely available. The transmission range is fixed for every node in the network. There are no specific designated routers in ad hoc networks. To send messages to the destination nodes that are not in the transmission range, intermediate nodes act as routers and forward messages. Mobility of nodes, dynamic topology, and decentralized control are the fundamental properties of ad hoc networks. Due to these characteristics, one of the major challenging issues in ad hoc networks is routing. [18]. Participating nodes need to update their routing tables frequently, resulting in flooding control packets in the network which consume precious network resources. As a result, in ad hoc networks, it is hard to construct and maintain routes [26].

Enhancing routing process in ad hoc networks is an evergreen domain for study. As the network is decentralized, nodes themselves act as routers, as they move. So, routing is very important in ad hoc networks [15]. Routing strategies for ad hoc networks are mainly classified as Proactive (Table-driven), Reactive (On-demand), and Hybrid [1]. Table-driven routing protocols require each node to keep up-to-date route-related information. Updates are propagated through the network to modify nodes' routing tables in response to topological changes. In on-demand routing approaches, a node finds a route to its destination, only when there is a need to do so. Hybrid routing strategies integrate features of proactive and on-demand routing mechanisms [18].

The next section highlights the working of a Bio-inspired Routing strategy, Ant Colony Optimization, in a nutshell. Section III presents the proposed algorithm (MyANT) for ad hoc networks. Section IV discusses the experimental outcomes. Section V briefs the conclusions drawn, based on the experiments.

*Computer Science and Engineering Department, Institute of Technology, Nirma University. (pimal.khanpara@nirmauni.ac.in, sharada.valiveti@nirmauni.ac.in)

2. Related Literature. Ant Colony Optimization (ACO) [10] is a nature-inspired probabilistic approach for solving computational problems that can be mimimized to finding optimized routes.ACO's fundamental concept is based on observations of how ants choose the best path between their habitat and a food source. Artificial ants are used as agents to iteratively construct an optimized solution. ACO depends on heuristic values which are maintained in the form of pheromone trails [9]. In ACO, to find an optimal route, a group of ants moves on adjoining routes simultaneously and asynchronously. Each ant (agent) determines the next hop based on a probabilistic computation using the pheromone values available on the links and heuristic information [20]. The solution is formed progressively as the ants traverse from one hop to another hop. While traversing the route, an ant agent assesses this solution and leaves pheromone on the path. The use of the pheromone trail is to make a routing decision by the future ants [9].

Due to the escalation in the use of various mobile and electronic devices, Ad hoc wireless networks are becoming more and more common. These devices need to communicate with each other, without a designated infrastructure [17]. For providing such communication in an ad hoc environment, the concept of swarm intelligence can be considered to address issues with routing optimizations. Many routing mechanisms take benefit of this concept, i.e. AntNet [8], ARAMA [13] , and AntHocNet [7]. Dynamic topology, dependency on local information, integration of path quality to determine pheromone concentration, and support for multi-path are the fundamental features of ant-based algorithms which make them a good choice to implement routing logic in ad hoc networks [6] [23] [28].

AODV [21], DSR [14], and AntHocNet [11] are popular routing protocols, against which this proposed implementation is compared. AODV and DSR are reactive routing protocols. This work is compared against AODV, DSR, and AntHocNet. AODV and DSR are the most sought-after routing protocols, subject to modification by researchers to improve the efficiency of the routing strategy and also to embed other functionalities like intrusion detection, etc. AntHocNet is a hybrid multipath ant-based routing protocol that combines both reactive and proactive components. AntHocNet is based on a very popular ant-based routing protocol AntNet.

Ad hoc On-Demand Distance Vector routing (AODV) is a reactive routing approach for MANETs. In this protocol, three types of control packets are used for the process of routing: Route Request (RREQ), Route Reply (RREP), and Route Error (RERR). Each node maintains a routing table to store path-related information. For each data transmission request, the RREQ packets are broadcasted by the source node to establish a communication route. Upon discovery of the path, the destination issues an RREP packet which is to be traversed back to the source. RERR packets are used for route maintenance and to deal with link failures.

The Dynamic Source Routing protocol (DSR) is a reactive, and efficient routing approach designed especially for use in MANETs. DSR uses the concept of source routing technique in which the source node decides the whole sequence of nodes to be used in order to forward the packets to the destination node. The benefit of this technique is that intermediate nodes do not require to have latest routing data for forwarding the packets. There are two major components in DSR: Route Discovery and Route Maintenance. Each node maintains a route cache to store all the existing source-destination pairs [30]. This cache is used in the route discovery process to obtain the required route. If there is no path found in the cache, the algorithm initiates a route discovery phase to establish a new path.

AntHocNet is an ACO-based routing mechanism for MANETs. It is a hybrid algorithm that combines proactive and reactive elements: the protocol establishes, maintains, and enhances routes in a proactive manner following a reactive path setup phase. AntHocNet is based on the ACO optimization framework and stigmergy-driven shortest pathways following ant colony behavior.

In general, ant-based routing approaches use one or more types of ant agents for facilitating the communication in the network. Table 2.1 depicts the analysis of some classic ACO-based routing techniques. For this analysis, important factors affecting the routing performance, such as how many ants are used, how they participate in the routing process, the frequency of pheromone deposition, routing data storage structures, etc., [16] are taken into consideration.

3. Proposed Approach: MyANT. MyANT is a hybrid routing protocol for ad hoc networks that uses the concept of Ant Colony Optimization. As it is a hybrid algorithm, it contains the good features of both, the reactive and proactive routing strategies. The route setup process is done in a reactive manner while the route maintenance and improvement process are proactive. There are two kinds of mobile agents in each phase:

Table 2.1: Analysis of ACO-based Routing Approaches

Routing Protocol	**Type of Routing**	**Storage Structures**	**Next-hop Selection Parameters**	**Factors affecting Pheromone Deposition**	**Key Features**
AntHocNet [7]	Hybrid	Routing Table, Pheromone Table,	One-hop neighbors of forward ants	Hop-count and communication delay	Forward ants identify destination nodes and hop-distance
Ant Routing Algorithm for MAnet (ARAMA) [13]	Table-driven	Routing Table	Pheromone amount, lifetime of nodes, queuing delay	Route-quality	Ants compute queuing delay and route-cost
AntNet [5]	Table-driven	Routing Table	Node-queue length and pheromone amount	Amount of network traffic	Forward ants keep a track of total communication time for each destination node
Hopnet [27]	Hybrid	Zone-specific routing tables	hop-distance, amount of pheromone	Queuing delay and hop-count	Forward ants are responsible for finding the destination node along with its zone
Ant colony based Routing Algorithm (ARA) [12]	On-demand	Routing table	one-hop neighbors of forward ants	Queuing delay and hop-count	Ants consider hop-count for finding the best route
Ant Based Control (ABC) [2]	On-demand	Routing table	Network statistics	Lifetime of ants	Packet forwarding is based on shortest distance and pheromone deposited
Ad hoc Networking with Swarm Intelligence (ANSI) [22]	On-demand	Ant-decision table, routing table	Amount of pheromone and no.of hops	Communication delay and hop-count	Based on the amount of pheromone deposited on links, ants computes the link quality

Forward ants and Backward Ants. The forward ants in the reactive phase explore the network to search the paths from a source to a destination. The role of the backward ants is to establish the path information which is gathered by the forward ants. As the agents move along the path, they leave a pheromone amount starting from its source. The path for transmitting the data packets is selected based on the higher pheromone concentrations for the particular paths.

In this algorithm, routing-related data are kept and maintained in pheromone tables. The pheromone tables are maintained by each participant node i of the network. An entry Pdij in the pheromone table holds the routing information from node i to destination d over neighbor j. The routing data contains the pheromone value for every path from source node i to destination node d. In addition to pheromone tables, every network node is required to have an up-to-date neighbor table to retain information about neighboring nodes. Neighboring nodes are the nodes with which the node has a wireless link.

3.1. Route Discovery. In the initial stage of the communication process, the source node checks the entries available in its pheromone table, to find whether it has any data available, related to routing for the requested destination node. If there is no entry for the particular destination, the new route is formed through the reactive path setup process. The source node generates and transmits a packet called forward ant, which is to be forwarded to each intermediate node. The forwarding of this packet is accomplished using uni-casting if information for routing to the destination is present in the node's pheromone table; otherwise, forwarding takes place via broadcasting. All the visited nodes are stored in an array. When the forward ant is received by the destination node, a copy of it is generated which is called a backward ant. The backward ant retraces the exact route that was traversed by the forward ant but in the reverse direction. The backward ant modifies the pheromone tables based on the pheromone concentration. This helps in determining the best route among the available paths. The benefit of executing this update is that whenever another ant proceeds to find the route, it can find the optimal path easily. The pheromone value is obtained by the forward ant using the following equation:

$$PH_d^i = PH_d^i + \frac{\alpha}{T_i^d + T'^j_i}$$

where PH_d^i is the total pheromone value from source node i and destination node d. T_i^d is the total time the forward ant has travelled and T'^j_i is the time interval during which the link between node i and j is used for the connection. α is a user defined run-time parameter.

The backward ant revises the pheromone value at node k while traversing backward from node b, by using the following equation:

$$PH_b^k = PH_b^k + \frac{\alpha}{\tau}$$

Here, $\tau = T_d^i - T_i^k$.

3.2. Proactive Route Maintenance. After the construction of the first path using the on-demand path setup process, the proposed protocol initiates the proactive path maintenance process, in which it attempts to modify, expand and enhance the available routing-related data. This process executes as long as the communication session is active.

In the route maintenance process, the pheromone information, provided by the ants is broadcasted. The best available pheromone values are broadcasted periodically by all the nodes of the network. When the neighbor nodes derive the new pheromone values, they forward these new values as their periodic broadcast. The best available pheromone value is used by the forward ants in the proactive phase. The difference between reactive forward and the proactive forward ant is that the proactive forward ant is unicasted to the destination, unlike the reactive forward ant. The proactive backward ant is generated at the destination and traverses the same route covered by the forward ant from destination to source.

3.3. Managing Link Failures. Link failures can occur in ad hoc environments because of either physical changes like node mobility or unavailability of a node, or modifications that affect the topology and connections of the network, such as changing the radio range. As ad hoc networks are highly dynamic, link failures can occur frequently so the routing algorithm should be capable of dealing with such problems effectively. The proposed algorithm offers a solution for the link failures. In this algorithm, the reactive path setup process permits the source nodes to reconstruct the whole path if required. The on-demand path maintenance process lets the creation of new paths. This way, it provides backup path routing. Link failures are discovered through the disrupted transmission of either data or routing packets or using periodic short messages. These messages are transmitted by all the network nodes asynchronously after a fixed time interval. When node i gets such a message from node j, it assumes that j is its direct neighbor and marks the same in its neighbor table. It also adds a record in the pheromone table, specifying that there is a path from i to j with hop count 1 and the link between the nodes i and j is still alive. So, now node i expects a message from node j within a fixed time interval. If the message is not received, node i believes that the connection to j has expired or the link is broken.

When a node i finds that the link to its neighbor node j is broken, it deletes the entry for node j from its neighbor table. Then, it also modifies the pheromone table by generating the link failure notification message. For this, it checks the pheromone table to find destinations having a non-zero pheromone value. Through this, it can get the idea about the nodes which have the path to the next neighbor node currently. For the other nodes, node i sets the pheromone value to 0. Then, it generates a link failure notification message, which contains the source and the destination node addresses.

The link-failure message is constructed and broadcast to all the neighbors of node i. So, all the neighbors of node i will receive this message and modify their pheromone tables for the paths going through i to the specified destinations.

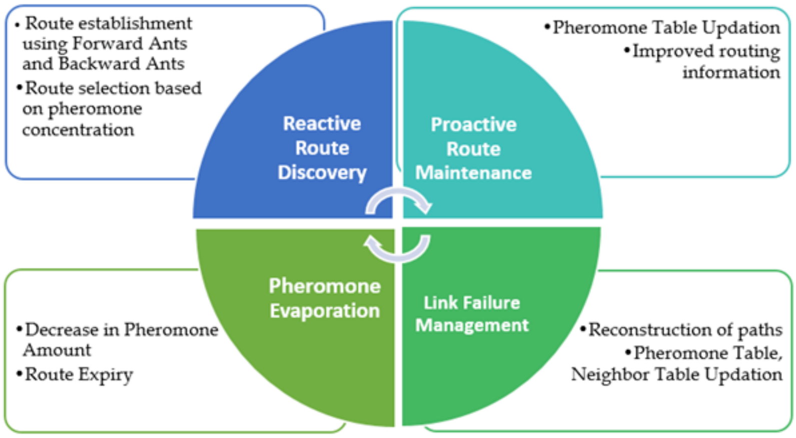

Fig. 3.1: Functional Blocks of MyAnt Framework

3.4. Pheromone Evaporation. Pheromone value along each path is decremented with time due to the pheromone evaporation process. When the amount of pheromone for a path becomes less than the pheromone threshold value, that path is declared as expired and a new path is required to be set up. If there is no evaporation in the algorithm then the routes selected by the first ant would tend to be overly enticing to the subsequent ants.

The framework of the proposed routing algorithm, MyAnt along with its functional blocks is shown in Figure 3.1.

4. Implementation Results. The performance of MyAnt is analyzed by varying different parameters under different simulation scenarios. The results are also compared with three routing algorithms: AODV [21], DSR [14], and AntHocNet [11]. The Glomosim [19], [4], [24], [3] simulator is used for experimentation.

In the simulation setting, 50 nodes are taken which are placed in the rectangular area of 2000mX1200m in GlomoSim under different node placement scenarios. The Random Way Point model is chosen for node mobility. In this model, initially, when the simulation starts, a node stays at a specific location for a fixed time duration. This time is defined as the pause time. Then, the node travels towards the destination at the maximum speed specified. Upon arrival at the destination, the node keeps its movement on hold for the specified period and then starts proceeding again. This procedure is repeated during the specified simulation time. Here, the simulation time is taken to be 30 minutes. FTP/GENERIC protocol is used for data packet transmission. The radio range is set to 180 meters. 802.11 protocol is used at the MAC layer and free space signal propagation model at the physical layer. The important configuration parameters used for the simulation are available in Table 4.1.

Different scenarios can be considered by varying the node placement and node movement. The main metrics affected by changing these parameters are Packet delivery ratio (ratio of total packets that were successfully delivered to their destinations to all packets that were sent from their sources), End-to-End delay (the amount of time it takes a data packet to get from source to destination) and the Throughput (total number of packets transmitted) during one simulation [29] [25].

The performance of MyANT is compared with AODV, DSR, and AntHocNet. The node mobility parameter is changed by varying the Random Way Point Mobility model parameters like maximum node speed or pause time. The mobility of nodes increases as pause time decreases. If the pause time is higher, the movement of nodes decreases. It may be observed from Figure 4.1 that, the proposed approach works optimally and the packet delivery ratio is in line with the AntHocNet. The packet delivery ratio of MyAnt seems to be better than other routing protocols.

Different values of node pause times are considered to compute the packet delivery ratio as shown in Figure 4.2. Here also, MyAnt and AnthocNet show similar performances. The delivery ratio is higher for MyAnt compared to AODV and DSR when the pause time is longer.

Table 4.1: Simulation Configuration Parameters for MyAnt

Parameter	Value
PROMISCOUS-MODE	No
MAC-PROTOCOL	802.11
NETWORK-PROTOCOL	IP
ROUTING-PROTOCOL	MYANT
APP-CONFIG-FILE	app.conf
SIMULATION-TIME	30 Min
TERRAIN-DIMENSIONS	2000x1200
RADIO-RANGE	180 Meters
NUMBER-OF-NODES	50
NODE-PLACEMENT	Random
MOBILITY	RANDOM-WAY-POINT
TRAFFIC GENERATOR	FTP/GENERIC

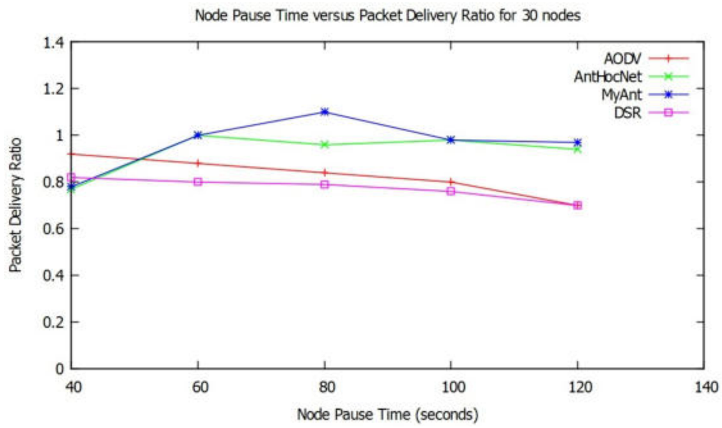

Fig. 4.1: Packet Delivery Ratio measured against node pause time (for 30 nodes)

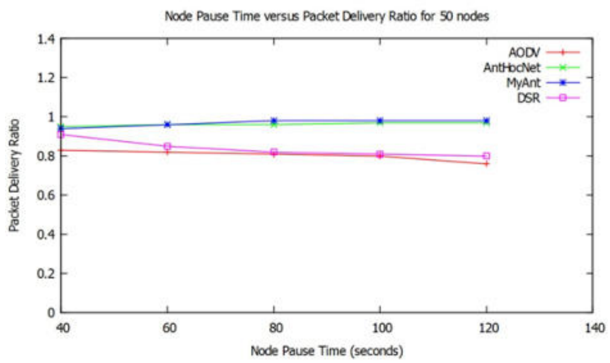

Fig. 4.2: Packet Delivery Ratio measured against node pause time (for 50 nodes)

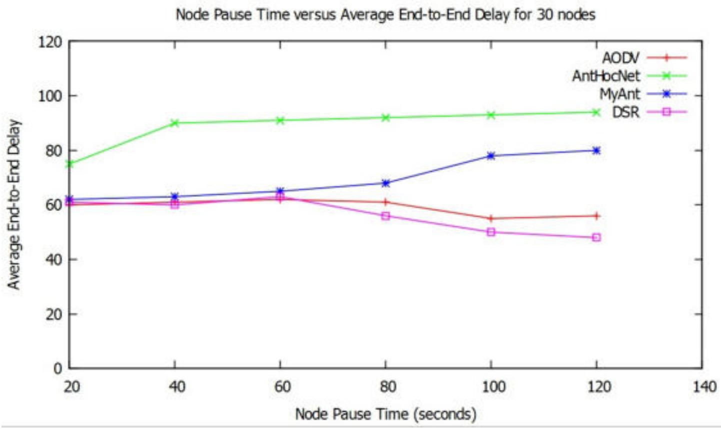

Fig. 4.3: Average End-to-End Delay measured against node pause time (for 30 nodes)

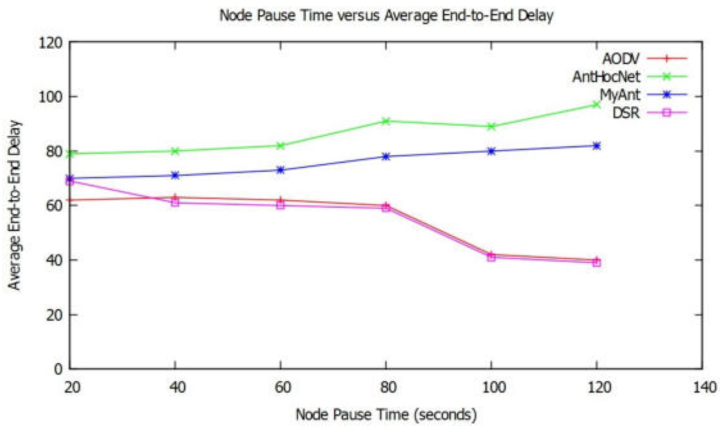

Fig. 4.4: Average End-to-End Delay measured against node pause time (for 50 nodes)

End-to-end delay is more in MyAnt than in AODV and DSR as shown in Figure 4.3 and Figure 4.4, while it is less than the delay in Anthocnet. The reason is, in AODV and DSR, intermediate nodes reply to route requests, so the time required for finding a path is less. While in MyAnt, the source node must wait until the destination node sends a backward ant.

Figure 4.5 and Figure 4.6 show the throughput of MyAnt compared to the other protocols. It is observed that the throughput of MyAnt is better than AntHocNet in both cases.

Figure 4.7 represents the statistics for the total number of packets transmitted and the total number of packets dropped due to the link failure for 49 nodes by varying node placement strategies. In grid placement, the whole physical terrain is divided into grids based on the number of nodes. Each node is placed within a grid unit. The number of nodes must be a square of an integer for grid placement. In the random placement scenario, nodes are scattered throughout the actual physical terrain at random. The physical terrain is divided into a number of cells in the uniform placement of the nodes depending upon the number of nodes in the simulation. A node is placed at random inside a cell.

Figure 4.8 presents the percentage of packets dropped in each scenario. The grid placement has a lower percentage value for dropped packets. While in the uniform node placement, more packets are dropped compared to the other strategies. The probable reason for these results is that as the node placement changes, the

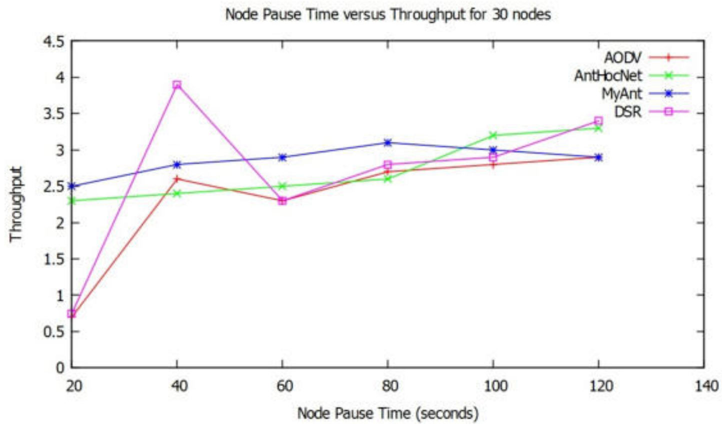

Fig. 4.5: Throughput measured against node pause time (for 30 nodes)

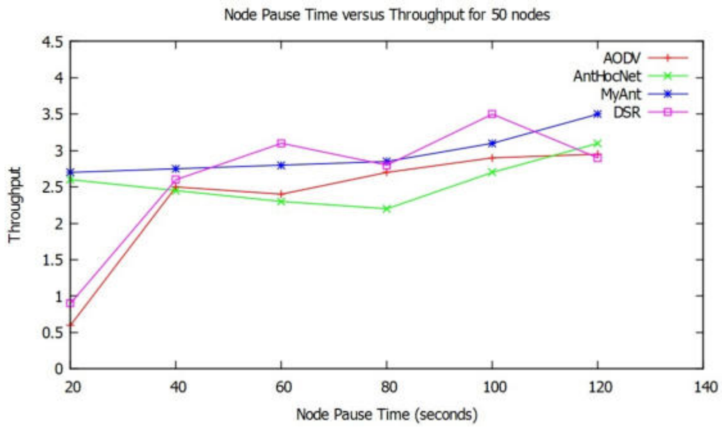

Fig. 4.6: Throughput measured against node pause time (for 50 nodes)

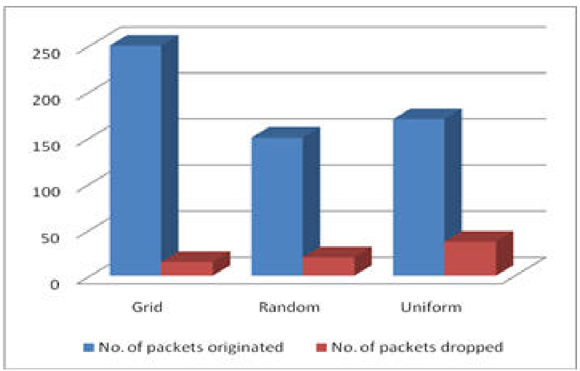

Fig. 4.7: No. of Packets Originated and No. of Packets dropped under different node placement

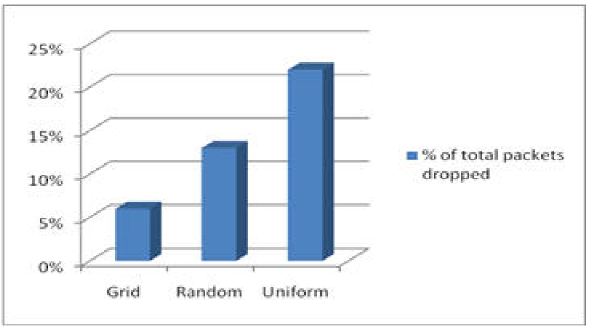

Fig. 4.8: Percentage of the total number of packets dropped under different node placement

distance between nodes keeps varying. Hence, it may happen that the nodes are out of transmission coverage and hence, the connection cannot be established between the nodes.

5. Conclusion and Future Scope. In this paper, a new nature-inspired improved routing protocol for Ad Hoc networks is proposed. This algorithm is motivated by the idea of Ant Colony Optimization and is suitable for the dynamically changing topology requirements. The high mobility of nodes is considered in this algorithm, so it is highly adaptive for ad hoc networks. It also contains the ability to deal with link failures in the network. The performance of the proposed protocol, MyAnt, is evaluated against popular routing protocols, such as AODV, DSR, and Anthocnet, under the GlomoSim simulator environment. Based on the results obtained, we can state that our proposed routing algorithm outperforms conventional reactive or proactive routing approaches for ad hoc networks. Our proposed routing algorithm can be easily integrated with any existing ad hoc network and can also be extended for multipath routing. There is a scope of improvement in the behavior of proactive ants to reduce the routing overhead.

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