A Hybrid Routing Protocol Based on Bio-Inspired Methods in a Mobile Ad Hoc Network

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Summary
Networks in Mobile ad hoc contain distribution and do not have a predefined structure which practically means that network modes can play the role of being clients or servers. The routing protocols used in mobile Ad-hoc networks (MANETs) are characterized by limited bandwidth, mobility, limited power supply, and routing protocols. Hybrid routing protocols solve the delay problem of reactive routing protocols and the routing overhead of proactive routing protocols. The Ant Colony Optimization (ACO) algorithm is used to solve other real-life problems such as the travelling salesman problem, capacity planning, and the vehicle routing challenge. Bio-inspired methods have probed lethal in helping to solve the problem domains in these networks. Hybrid routing protocols combine the distance vector routing protocol (DVRP) and the link-state routing protocol (LSRP) to solve the routing problem.

Keywords: *Ant colony optimization, Mobile Ad-hoc Networks, Distance Vector Routing Protocols, Link-state routing protocols*

1. Introduction

Networks in Mobile ad hoc are created from mobile devices that are wireless [1]. These networks contain distribution and do not have a predefined structure, I.e., network modes can play the role of being clients or servers. Wireless links are often created and destroyed since the nodes can join or leave the network freely. Nodes directly in contact with each other communicate directly, whereas those with no direct connection communicate using intermediate nodes. Mobile ad hoc networks face a major challenge, such as routing and autoconfiguration. The routing protocols used in MANETs are characterized by limited bandwidth, mobility, limited power supply, and routing protocols [2]. The routing process is considered an important task in MANETs, and its purpose is finding the best paths from sender to destination nodes. The network topology of MANETs varies with time due to the dynamic nature of the environment.

2. Ad-Hoc Networks

2.1 Bio-Inspired Methods in Ad-Hoc Networks

The natural behaviour in animals such as bees, ants, and hill-climbing termites have inspired researchers to develop efficient routing algorithms in ad-hoc networks [3]. Mobile Ad-hoc network is multihop, centralized networks that are wireless which require to be independently organized due to lack of common infrastructure. Bio-inspired methods have probed lethal in helping to solve the problem domains in these networks. This is due to the similar nature of biological systems such as localized decision making, self-organization, and routing decisions, which is evident, especially in ants. Ants can search for the path that is shorter among the nest and food source [4]. The objective of self-organization can only be achieved by cooperation between agents in the network.

Using the case of Ants here are some comparative aspects of ants and ad-hoc networks.

1. Both ants and ad-hoc systems have self-configuring and self-organization systems.
2. Ad-hoc networks provide both single and multipath systems while ant only have single path systems.
3. In terms of the origin of routes, in ants' pheromones are used to create new paths, while in ad-hoc networks, route requests are sent from nodes to get local information.
4. Both ants and ad-hoc networks have an unstructured, distributed, and dynamic physical system.

Mobile ad hoc protocols of conducting routing are broadly grouped into routing protocols that are proactive, routing reactive protocols, and protocols of routing that are hybrid [4]. The protocols of routing that are proactive are characterized by:

• Best suited for small scale

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- Routes are updated as the network topology changes
- Increased overhead as a result of maintaining more up-to-date information.
- Less delay due to already defined routes.
- They are not convenient for large networks since they maintain node entry for all nodes on the routing table.

The examples of these protocols are the wireless routing protocol (WRP), destination sequenced distance vector (DSDV), and optimized link-state routing protocols (OLSR) [5] [11]. Reactive or On-demand Protocols characterized by:

- Have less overhead and more delay
- Flooding the route requests throughout the network helps achieve route discovery.
- Protocols used for route discovery are temporarily ordered routing algorithm (TORA), dynamic source routing (DSR), Ad-hoc on-demand distance vector (AODV).

2.2 Hybrid Routing Protocols

These are network protocols of routing formed from features that are the best of proactive protocols of routing and those of routing protocols that are reactive [6]. It combines the distance vector routing protocol (DVRP) and the link-state routing protocol (LSRP) to solve the routing problem. Hybrid routing protocols solve the delay problem of reactive routing protocols and the routing overhead of proactive routing protocols. Some of the routing protocols used for discovering routes include hybrid cluster routing protocol, zone routing protocol, and ANTHOCNET. These hybrid routing protocols will be discussed in detail in the sections below.

There are several approaches to solving the routing problem. One of the approaches for developing routing protocols used in MANET networks is by using bio-inspired algorithms. These algorithms are adaptive to the dynamism of ad hoc mobile networks. These algorithms focus on animals' behaviour, especially insects, to solve complex routing problems. Biological systems are characterized by adaptation, reliability, and robustness in several environments. These are similar characteristics exhibited in ad hoc wireless mobile networks; therefore, they provide useful resources for designing routing schemes for MANETs where individuals should operate without a central point of control.

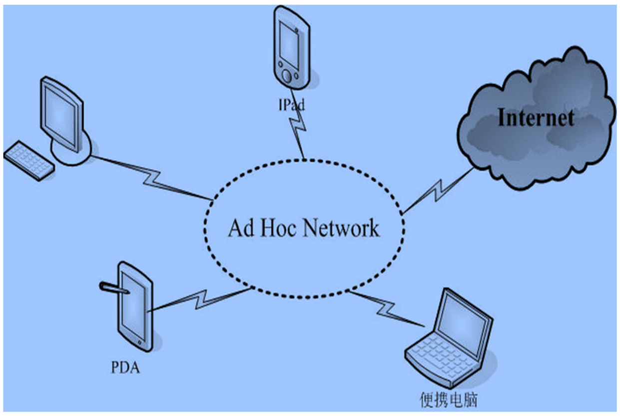

Fig 1 wireless ad hoc network

3. Hybrid Routing Protocols and their Bio-Inspired Algorithms Used in MANET Networks

3.1 Ant Colony Optimization (ACO) Routing Protocol

It applies swarm intelligence, a kind of artificial intelligence that aims to simulate swarm's behaviour such as honeybees, ant colonies, and a flock of birds [7]. The following are the major properties of the ant colony optimization routing problem:

I. They make use of stochastic components.
II. They don't allow local approximations to have a global effect.
III. They provide traffic adaptive and multipath routing
IV. They favor load balancing by setting up paths in a generous way compared to shortest path schemes.

This algorithm developed from observation of real-life ants to develop algorithms that solve the shortest path route problem [8]. The ACO algorithm is also used to solve other real-life problems such as the travelling salesman problem, capacity planning, and the vehicle routing challenge [9]. This technique provides a probabilistic technique for finding the optimal paths. It's an algorithm based on the learning behaviour of ants for identifying a path from the source of food to their colony. In our case, the colony and the food can be compared to the source and the destination nodes. If an ant comes across an intersection, it randomly selects the path which has not been traversed and releases pheromones. Pheromone sizes are related to the length of each path, I.e., longer paths tend to have smaller pheromones. Ants elaborate on adaptive behaviour whereby environmental changes may cause them to change their paths and encounter obstacles [8]. This behaviour should be exhibited in ad hoc mobile networks. Through the releasing of pheromones, ants can obtain path information and enable them to find the optimal path through the collective behavior of the ant colony.

The ACO algorithm uses an ant decision table which is made up of the probability of selecting a node from a path and the necessary local data [9]. The evaporation mechanism updates the pheromones of each node, making it quickly adapt to the dynamic changes in MANET networks [2]. Nodes use routing decision tables to guide the search for the optimal routes. The ACO algorithm can be defined as the following:

Input: A variable y of a combination of the optimization problem
While: The condition to be terminated has not been me do:
plan Activities
Ant-based solution construction ()
Pheromone update ()
Daemon actions ()
End Planned Activities
S best --> most viable solution among the available options
End while
Output: S Most viable candidate to the best solution for y

Fig. 2 ant colony optimization algorithm

Explanation

In figure 1, each time the solutions construct picks a subset from the components. The feasible solution starts with a partial empty solution; at every construction step, a feasible component is added. The path selection equation is used to choose the next feasible component depending on the ant colony algorithm system.

Update Pheromones () aims at the following things: increasing the value of the pheromone good components and decreasing the pheromone values of the components which are bad. The pheromone decrease is acquired through evaporation.

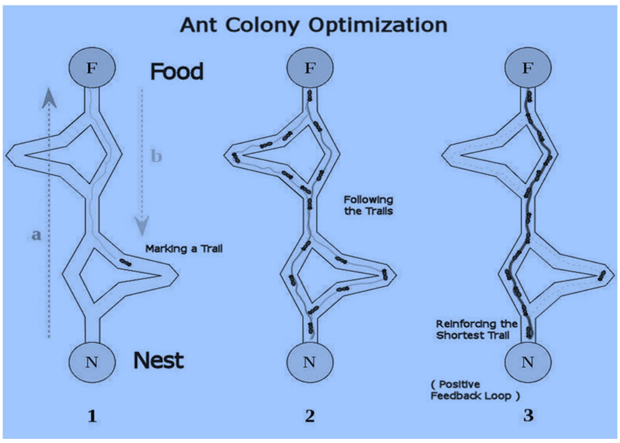

Fig. 3 diagrammatic representation of the ant colony optimization

The distributed and dynamic nature of ad hoc networks is well-matched with the multi-agent nature of ant colony optimization. The main attributes that characterize ACO instances for routing problems are:

- Reliance on active and passive information gathering and monitoring
- Local estimates should not affect or cause global effects.
- Showing low sensitivity to parameter setting.
- Making use of stochastic components.
- Favouring load balancing and setting up routes in generous means.

The major traits that are exhibited by hybrid ACO bio-inspired algorithms are explained below.

Management of routes update

This involves replacing the evaporated pheromones to update the old routes. This process is accomplished by triggering an event after few seconds frequently. Every time a register is created in the routing table, a time-stamp field with the present time is saved. A register is deleted from the routing table if the specific route's time-stamp field is less than the current time minus the set time limit. The implementation of the time limit is different in each system. Low time limit values imply slow convergence to premature routes and high time limit values imply fast convergence when establishing new routes, but the old routes are kept for a longer period.

Managing of Data packets

This functionality is achieved by periodically checking the buffer for delayed packets. When forwarding packets each node checks on the routing table if the destination route exists. If it doesn't exist the corresponding packet is enqueued. Frequently checking the buffer and sending failed packets again generally increases the number of delivered packets.

Applications of ACO

The ant colony optimization algorithm has been used in solving several optimization challenges, including:

1. Solving the travelling salesman problem- The travelling salesman problem is where a salesman has to identify the shortest route by which he can visit a specific number of cities and visit each city only once.

2. Job-shop Scheduling problem – In this problem a given number of machines and a given number of tasks must be assigned to intervals of time so that no two jobs are processed at the same time on the same machine and the optimal time of accomplishment of all works is reduced.
3. Vehicle routing solution – is a challenge that tries to find the solution of the routes that are best to take from a depot to a group of destinations where each has constraints that are specified by a business. It is a generalization of the travelling salesman problem.
4. Sequential ordering problem – involves obtaining the lowest weight Hamiltonian path 2 on a directed graph which has weights on the node and arcs, subject to model constraints among the nodes.

3.2 HOPNET Routing Algorithm (Hybrid Ant Colony Optimization Algorithm for MANETs)

The Swarm intelligence concept could also be applied in the HOPNET routing protocol [4]. The definition of swarm intelligence is the intelligence mechanism of computers which entails the general independent agents behaviour that ensures interaction with one another in an environment distributed to come up with the solution of a specific problem hoping to attain an optimal solution to the problem. The HOPNET routing algorithm is a hybrid algorithm that rests on the zone routing mechanism and (ACO) ant colony optimization [4]. The concept is obtained from the hoping of ants from one zone to another. It is made of the proactive local routes identification that is in a neighborhood of a node and communication that is reactive among neighbouring nodes. These algorithms' characteristics are derived from the zone routing protocol and dynamic source routing protocol. In comparison with routing protocols such as AntHocNet, it's clear that the HOPNET routing protocol is best suited for large networks that need to be scalable [13].

3.3 AntHocNet Hybrid Routing Protocol

This is a hybrid protocol of routing whose aim was to form a combination of the benefits of ARA and AntNet. AntHocNet puts together the features of both reactive and proactive routing protocols [1]. This is by reactively finding a destination route when there is a demand for it and proactive maintenance and improved routes or exploration of better paths.
Some of the distinct features of AntHocNet are:

- It has reactive features because the operating agents that are on-demand are used to make the routes to the destination.
- It is multipath due to the different routes' provision to ensure that the information is sent to its destination.
- It offers adaptability to the changes in network topology and traffic conditions within the network.

This routing protocol has the inspiration of the ant's social behaviour. When they move from one place to another, they leave pheromones in their way, which is the substance that leads other ants to the food source. Ants that find the shortest path to get to the food source return fastest to their nest and reinforces others to follow the path using the food trail pheromone they deposited on their way back to the nest. These routes eventually attract other ants, and this repeatedly happens [14]. When source node t sends data, it checks the routing table, if it's not up to date reactive ant-like agents called forward ants are sent.
Operations of AntHocNet can be broken down into four distinct phases:

1. Setting up of the information for routing – The source's node ensures that the reactive agents are sent so that the route that is available to the destination is discovered first.
2. Routing of data – Using route information, ensures the sending of data to the nodes. This can be achieved through a technique referred to as multihop, which ensures that the data is sent through the intermediate nodes.
3. Maintaining existing paths and exploration of new paths.
4. Handling of failures in links – failures of links occurs when there is a node outside the network scope, or there is no reception of the control messages.

In antiHocNet, ants can be able to detect cycles through the maintenance of a string of the nodes that they have visited. The node at the source ensures that forward ants are sent, and after the reception of backward ants, the process of generation is terminated after completion. The forward ants' identity is kept by every node and a computation of the path that the ants take from the source to the node *l* and the time taken to travel when the ant visited node *l*. On the anta arrival at â node, the node makes sure that it checks the computation of the path of the ant and the time taken during the travel to reach node i. If the production of the ants' computation of the path and time is ranging within a particular limit with the computation of the path and time from another ant that was generated in the same period, then forwarding of ante.

If a failure of a link takes place on a node or any of the paths are available, the ants that are forward are forwarded by the node to ensure repairing of the route are conducted within and to find a path that is alternating. After the reception of the backward ants, the data packets of the ants that are forward are sent along the path that has been currently found, and a notification is sent to all its neighbours to inform them about the changes in the routes. At other times, nodes send a notification to their neighbours, updating them about the paths to the lost destinations, thus making them flood the network with forwarding ants [4]. AntiHocNet algorithm faces the challenge of route maintenance due to flooding of the network by the reactive forward ants. A table is kept by each node containing the destination routes that could be taken. This eventually might cause a scalability problem.

3.4 Zone Routing Protocol

This is a hybrid routing protocol that is used for route discovery. It is characterized by the following:

(I) Has a flat structure – this is essential to avoid the problem of congestion localization which occurs in hierarchical structures.
(ii) Can carry out link-state routing which enables Quality of service QoS.
(iii) Identifies loop-free routes to the destination.
(iv) changes in network topology have local effects only
(v) the search for nodes on-demand and outside the zone is done by running query statements on a node subset.
(v) proactive routing is only limited to a node's local scope.
(vi) the network is broken down into zones. Each zone size is calculated by the length, such that the zone perimeter is equal to the number of hops.

It uses Intrazone Routing protocol (IARP) to discover the route in a zone and Interzone routing protocol (IERP) for outside the zone. Interzone Protocol of Routing is a protocol of conducting routing proactively while the Interzone protocol of routing is a protocol for routing reactively [15]. The routing zone is known as the hop of a number of the nodes which should not be more than the zone radius. Nodes in this network send messages to the peripheral nodes through border casting, enabled by the border cast resolution protocol. (BRP). Peripheral nodes can be defined as nodes that contain minimum distance from the node and is equal to the radius of the zone.

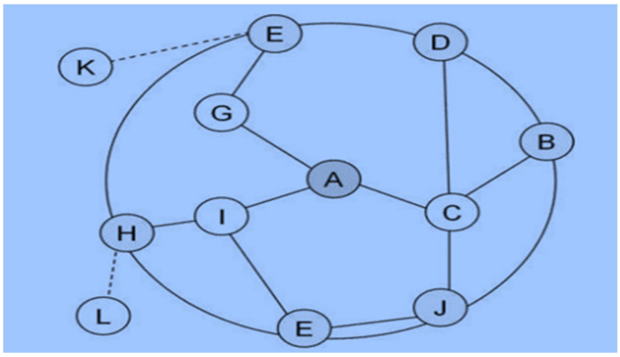

Fig. 4 The workability of nodes in the routing protocol

In figure 3, Nodes in the zone use both the Neighbor discovery protocols (NDP) and media access control (MAC) to gather information on the surrounding neighbours. Zone routing protocol has the advantage of the overheads of control being less as in a protocol that is pro-active or a protocol that is on-demand. Its biggest disadvantage is the shortness in latency for identifying the new routes.

3.5 Hybrid Cluster Routing Protocol

It is characterized by the following:

- Mostly used in the ad hoc networks for mobile that is on a large scale.
- The organization of the nodes is in a hierarchical structure containing clusters that are multihop by use of table distributed cluster algorithms.
- Every cluster in the protocol comprises a head of clusters, nodes of the gateways, and other ordinary nodes.
- The cluster head is tasked with ensuring there is the maintenance of the topology information that is global and local membership.

These routing protocols majors on finding the solution to the problem of conserving energy within the sensor networks that are wireless. Clustering provides a viable solution to this energy conservation problem and can prolong the lifetime of the network. Using a technique that combines two algorithms, i.e., ant colony optimization and c-means of fuzzy [10]. The fuzzy C-means constructs several predefined clusters, while the algorithm of Ant colony optimization is used in the formation of the chains that are shortest in every cluster. There is a random selection in the leader node during the start due to the similarity in the energy amount of all the nodes. When the following transmission takes place, the energy that remains remaining is used to choose the node that becomes the leader.

Transmission of data by the leader nodes is conducted in a single hop to the base station (BS) that is distant. At the same time, the algorithm of ant colony optimization is used in the formation of a chain that is global between the base station and the nodes that are the leaders [4]. The result gives positive feedback that there is less energy consumed, and the network's lifetime is effectively prolonged.

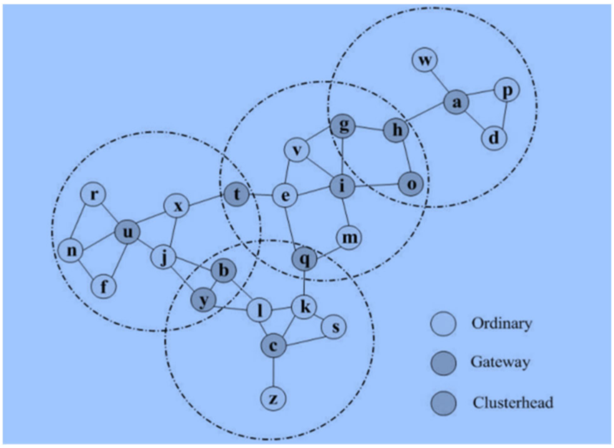

Fig. 5 hybrid cluster routing protocol

In figure 5, it shows that the routing protocol of the hybrid cluster generally has the advantage that the scalability is better; it allows for robustness. It is more adaptable to mobile ad hoc network that is large scale compared to other protocols of routing like the DSR (the dynamic source routing), AODV(the Ad-hoc on-demand distance vector), and CBRP [15].

4. Conclusion

The protocols of hybrid routing are increasing and have become very popular in ad-hoc networks that are mobile. Most protocols of hybrid routing are formed from a combination of positive features of protocols of reactive routing and protocols of proactive routing to solve challenges encountered in wireless mobile ad-hoc networks which are, limited bandwidth, limited power supply, mobility, and routing overhead. Bio-inspired methods help researchers in analyzing and breaking down the routing challenge encountered in mobile ad-hoc networks. Different fields use the MANETS such as Military use, Search and rescue missions, vehicle to vehicle communication in AI-powered transport systems, and airports. This paper has given a summary of various major hybrid routing protocols and the underlying bio inspirations. We can also conclude that each hybrid protocol shows different performance under dissimilar circumstances. However, still, mobile ad-hoc networks pose a big challenge to researchers since there are dynamism and frequent changes in topology.

References:

[1] Di Caro, G., Ducatelle, F. and Gambardella, L.M., 2005. AntHocNet: An adaptive nature-inspired algorithm for routing in mobile ad hoc networks. European Transactions on Telecommunications, 16(5), pp.443-455.

[2] Roy, B., Banik, S., Dey, P., Sanyal, S. and Chaki, N., 2012. Ant colony-based routing for mobile ad-hoc networks towards improved quality of services. *Journal of Emerging Trends in Computing and Information Sciences*, *3*(1), pp.10-14.

[3] Ohta, M. and Koizumi, T., 1968. General statistical treatment of response of the nonlinear rectifying device to stationary random input.

[4] Wang, J., Osagie, E., Thulasiraman, P. and Thulasiram, R.K., 2009. HOPNET: A hybrid ant colony optimization routing algorithm for mobile ad hoc network. *Ad Hoc Networks*, *7*(4), pp.690-705.

[5] Clausen, T., Jacquet, P., Adjih, C., Laouiti, A., Minet, P., Muhlethaler, P., Qayyum, A. and Viennot, L., 2003. Optimized link-state routing protocol (OLSR).

[6] Marwaha, S., Tham, C.K. and Srinivasan, D., 2002, November. Mobile agents based routing protocol for mobile ad hoc networks. In *Global Telecommunications Conference, 2002. GLOBECOM'02. IEEE* (Vol. 1, pp. 163-167). IEEE.

[7] Wang, J., Osagie, E., Thulasiraman, P. and Thulasiram, R.K., 2009. HOPNET: A hybrid ant colony optimization routing algorithm for mobile ad hoc network. *Ad Hoc Networks*, *7*(4), pp.690-705.

[8] Dorigo, M., Birattari, M. and Stutzle, T., 2006. Ant colony optimization. *IEEE computational intelligence magazine*, *1*(4), pp.28-39.

[9] Di Caro, G. and Dorigo, M., 2004. *Ant colony optimization and its application to adaptive routing in telecommunication networks* (Doctoral dissertation, PhD thesis, Faculté des Sciences Appliquées, Université Libre de Bruxelles, Brussels, Belgium).

[10] Cañas, D.R., Orozco, A.L.S., Villalba, L.J.G. and Kim, T.H., 2011, December. A comparison study between AntOR-disjoint node routing and AntOR-disjoint link routing for mobile ad hoc networks. In *International Conference on Multimedia, Computer Graphics, and Broadcasting* (pp. 300-304). Springer, Berlin, Heidelberg.

[11] Clausen, T., Hansen, G., Christensen, L. and Behrmann, G., 2001, September. The optimized link-state routing protocol, evaluation through experiments and simulation. In *IEEE symposium on wireless personal mobile communications* (Vol. 12). Denmark: Aalborg.

[12] García Villalba, L.J., García Matesanz, J., Sandoval Orozco, A.L. and Márquez Díaz, J.D., 2011. Auto-configuration protocols in mobile ad hoc networks. *Sensors*, *11*(4), pp.3652-3666.

[13] Zheng, X., Guo, W. and Liu, R., 2004, June. An ant-based distributed routing algorithm for ad-hoc networks. In *2004 International Conference on Communications, Circuits and Systems (IEEE Cat. No. 04EX914)* (Vol. 1, pp. 412-417). IEEE.

[14] Di Caro, G., Ducatelle, F. and Gambardella, L.M., 2005. AntHocNet: An adaptive nature-inspired algorithm for routing in mobile ad hoc networks. *European Transactions on Telecommunications*, *16*(5), pp.443-455.

[15] Lee, S.J. and Gerla, M., 2001, June. Split multipath routing with maximally disjoint paths in ad hoc networks. In *ICC 2001. IEEE International Conference on Communications. Conference Record (Cat. No. 01CH37240)* (Vol. 10, pp. 3201-3205). IEEE.

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