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A Survey On Nature Inspired Routing Algorithms For Ad Hoc Network

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Abstract

Although establishing correct and efficient routes is an important design issue in mobile ad hoc networks (MANETs), a more challenging goal is to provide energy efficient routes because mobile nodes' operation time is the most critical limiting factor. They minimize either the active communication energy required to transmit or receive packets or the inactive energy consumed when a mobile node stays idle but listens to the wireless medium for any possible communication requests from other nodes. However, with the wide implementation of wireless networks, routing. For example, for ad hoc network or sensor networks, the devices used in these networks are all lightweight, and battery operated. Then how to conserve the energy to maintain the network functionality and connectivity is a key issue so that battery life is maximized. In this paper, we will mainly describe the techniques used in energy efficient routing in wireless ad hoc networks and sensor networks as well.

Keywords: Mobile Ad Hoc Network; Energy Efficient Routing; Energy Balance; Transmission Power Control; Load Distribution; Sleep Mode Operation

Introduction

Mobile devices coupled with wireless network interfaces will become an essential part of future computing environment consisting of infrastructure and infrastructure-less mobile networks [1].

Wireless local area network based on IEEE 802.11 technology is the most prevalent infrastructure mobile network, where a mobile node communicates with a fixed base station, and thus a wireless link is limited to one hop between the node and the base station. Mobile ad hoc network (MANET) is an infrastructure-less multihop network where each node communicates with other nodes directly or indirectly through intermediate nodes. Thus, all nodes in a MANET basically function as mobile routers participating in some routing protocol required for deciding and maintaining the routes. Since MANETs are infrastructure-less, self organizing, rapidly deployable wireless networks, they are highly suitable for applications involving special outdoor events, communications in regions with no wireless infrastructure, emergencies and natural disasters, and military operations [2][3].

Routing is one of the key issues in MANETs due to their highly dynamic and distributed nature. In particular, energy efficient routing may be the most important design criteria for MANETs, since mobile nodes will be powered by batteries with limited capacity. Power failure of a mobile node not only affects the node itself but also its ability to forward packets on behalf of others and thus the overall network lifetime. For this reason, many research efforts have been devoted to developing energy-aware routing protocols.

All nodes in such networks take two roles: producer/consumer of data packet streams, and routers for data packets destined for the other nodes. The most important challenges in MANETs are: mobility and limited battery capacity of the nodes. Mobility of nodes results in continuously evolving new topologies and the routing algorithms have to adapt the routes according to these changes. The limited battery capacity poses yet anotherchallenge for the routing algorithms: to distribute the packets on multiple paths in such a manner that the battery of different nodes deplete at an equal rate, as a result, the life time of the network could be increased [4] [5]. The metrics for energy efficient routing are also introduced in [5] and it is evident that an energy aware routing algorithm is expected to degrade the traditional performance metrics of a routing algorithm i.e. throughput and packet delay [6]. The real dilemma in MANETs is: how to to design a routing algorithm which is not only energy efficient but also provides the same performance as that of the existing state-of-the-art algorithms

The routing algorithms for MANETs can be broadly classified as proactive algorithms or reactive algorithms[7]. Proactive algorithms periodically launch control packets which collect the new network state and update the routing tables accordingly. On the other hand, reactive algorithms find routes on-demand only. Reactive algorithms look more promising from the perspective of energy consumption in MANETs. DSR (Dynamic Source Routing) is a reactive source routing algorithm while AODV (Ad-Hoc On-demand Distance Vector Routing) is a reactive next hop routing algorithm. DSDV (Dynamic Destination-Sequenced Distance-Vector) is a proactive next hop routing algorithm .

Current literatures about energy efficient or power aware routing protocols can generally be divided into three categories: (i) switching on/off radio transmitters to conserve energy [8][9], (ii) power and topology control by adjusting the transmission range (power) of transmitters [10][11], and (iii) routings based on the energy efficient metrics [12].

In the first approach, the radio is turned off for an adaptively varying period to save power when there is no traffic, since listening to the channel consumes significant power. However, turning off the radio means more and faster network topology change. Routing uncertainty increases with more frequent routing update and extra routing messages, which can be severe in highly mobile networks.

Topology control is another approach, in which the transmission power is adjusted to achieve energy efficiency. The node battery life is extended by using the radio's minimum power level. However, in sparse networks, there may be network partition and high end-to-end delay, while a dense network can cause limited spatial reuse and network capacity. In a distributed power control scheme, power control level is established by exchanging control messages, according to the estimated minimum and maximum power level. There will be frequent link ups and downs, causing more link errors from MAC layer due to interference and unexpected channel collision. Retransmission due to link breakage will consume extra energy and network bandwidth.

For metric-based routing , different kinds of metrics are used to maximize the lifetime of networks by evenly distributing the energy consumption among all nodes. MBCR (Minimum Battery Cost) algorithm incorporates the battery capacity into the metric. In addition, the expected energy spent in reliably forwarding a packet over a specific link. In order to maximize the network life time, the cost function takes into account energy expenditure for one packet transmission and available battery capacity. Furthermore the queue load condition and the estimated energy spent to transmit all packets in the queue are considered. Idle time is introduced to the battery activity, which can help the charge recovery. However, due to the problems of routing protocols, critical nodes with very little battery capacity are not guaranteed to be protected. And most energy efficient algorithms are analyzed mathematically, and it becomes difficult to evaluate the performance with real routing protocols.

To reduce the energy consumption in mobile devices, there have been efforts in physical and data link layers as well as in the network layer related to the routing protocol. The physical layer can save energy by adapting transmission power according to the distance between nodes. At the data link layer, energy conservation can be achieved by sleep mode operation.[03ic_8]

The purpose of power-aware routing protocols is to maximize the network lifetime. The network lifetime is defined as the time when a node runs out of its own battery power for the first time [03ic_8]. If a node stops its operation, it can result in network partitioning and interrupt communication. The power-aware routing protocols should consider energy consumption from the viewpoints of both the network and the node levels. From the network point of view, the best route is one that minimizes the total transmission power. On the other hand, from the viewpoint of a node, it is one that avoids the nodes with lower power. It is difficult to achieve these two objectives simultaneously. Minimizing the total energy consumption tends to favor min-hop routes. However, if the min-hop routes repeatedly include the same node, the node will exhaust its energy much earlier than the other nodes and the network lifetime will decrease.

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Energy Efficient Routing Algorithm For HOC Network

Energy Optimized AODV

It is a new energy efficient algorithm, which is readily implementable to current routing protocols such as AODV. This energy efficient extension is a metric based algorithm, which integrates the runtime battery capacity and the estimated real propagation power loss, obtained from sensing the received signal power[13]. So it is independent of location information and terrain-based, permitting power loss by terrain profiles such as large building blocks. Optimized cost functions are derived to combine the available information into one routing metric, which is optimized in two ways: local optimization among neighbor nodes and global optimization between end-to-end nodes. To protect critical nodes, an adaptive low-battery alert mechanism is introduced to force new route update.

Adaptive Low-battery Alert Mechanism: Current on demand routing protocols including AODV have a problem of overusing existing routes[13]. Once a valid route is setup, before it is outdated, the source will be not able to discover newer and more efficient routes, although there may be better route available. The worst case is that under heavy load, if the network topology is not changing fast, the route discovered first will be overused and the nodes along this route will be drained out of energy rather quickly. To overcome this problem, we propose an adaptive low-battery alert mechanism to enforce new route update when relay nodes are drained below certain low-battery alert level, for example, 50% or 40% of the new battery capacity. To avoid excessive link breakage, this low battery alert level is adjusted adaptively lower and lower. The first node that reaches its alert level will initialize a special route error (RERR) message for route update. Every time the alert level is reached, this alert level will be decreased by a small amount, called alert adjustment step, which reflects the willingness of a node to relay a data packet. The alert level is decreased uniformly, for example, 1% or 5% of the new battery capacity (actually, only crude measures of residual battery are practical). If a new efficient route is discovered, the routing protocol will use the new route, else the old route is used until a newly adjusted alert level is reached. In the implementation with AODV, a special route error (RERR) message with local route repair function is generated when the alert level is reached, which means there are recoverable errors in the route. In AODV RERR message, when the 'N' bit is set to '1', whoever receives this RERR will not delete the current route entry, and just disable it to wait for the repairing of this route. The source will try to find a newer route if this RERR is received. Due to the new route update, there may be delay or even lost of data packets, and therefore will cause a little decrease of the network throughput.

Ant colony

Ants are community insects. They live in colonies and their goal is colony survival rather than individuals' survival. Ants when exploring for food source, they initially search the area adjacent their nest in a random manner. When they find food, during the come back to nest put a chemical pheromone trail on the earth. Ants can smell pheromone. When selecting their way, ants tend to choose, paths with more pheromone. Also this ants when are sent to food sources, during come back to nest, put pheromone on the earth. In this way, the indirect communication between the ants via pheromone enables ants to find shortest paths between their nest and food sources [18].

BeeAdHoc

BeeAdHoc, which is primarily designed for energy efficient routing. The algorithm proposes a solution to the energy performance dilemma[7]. BeeAdHoc achieves similar/better performance as that of DSR, AODV, DSDV but consumes significantly less energy as compared to these state-of-the art algorithms. The algorithm achieves the objectives by sending less control packets and distributing data packets on multiple paths. Such a behavior is made possible by taking inspirations from the foraging behavior of honey bees. A honey bee colony has many features that are desirable in MANETs: efficient allocation of foraging force to multiple food sources, different type of foragers for each commodity, foragers evaluate the quality of visited food sources and then recruit optimum number of foragers for their food source by dancing on a dance floor inside the hive, no central control, foragers try to optimize the energetic efficiency of nectar collection and foragers take decisions without any global knowledge of the environment.

A colony of bee can extend itself over wide distances in order to search for food sources at the same time. The foraging process begins in a colony by scout bees that being sent to search for hopeful flower patches. Scout bees move randomly from one path to another [18]. Flower patches with greater amounts of nectar or pollen that can be collected with less challenge tend to be visited by more bees, whereas patches with less nectar or pollen receive fewer bees. Through the harvesting season, a colony continues its search, keeping a percentage of the population as scout bees. When scout bees return to the hive go to the dance floor to do a dance known as the waggle dance. This dance have three pieces of information about a flower patch: (a) the direction in which flower will be found (b) distance from the hive (c) its quality. This information helps the bee colony to send its bees to flower patches specifically, without using guides or maps. When bees are sent to flower patches, in return to hive, by dance inform other bees in hive about new quality of a flower patch that visited. In this way, information of bees about nature are updated [18].

- **Bee Agent Model**

Bee Agent Model is inspired from the foraging principles of a honey bee colony. The agent model consists of four types of agents: packers, scouts, foragers, and swarms.

Packers

Packers mimic the task of a food-storer bee. They always reside inside the node, receive and store the data packets from the transport layer. Their major job is to find a forager for their data packet and they die once they hand over it to the foragers.

Scouts

Scouts discover new routes from their launching node to their destination node. A scout is transmitted using the broadcasting principle to all the neighbors of a node with an expanding time to live timer (TTL), which controls the number of times a scout could be re-broadcasted. Each scout is uniquely identified with a key based on its id and source node. Once a scout reaches at the destination then it starts the backward journey on the same route that it followed to the destination. A destination node sends back all of the received scouts to ensure discovery of multiple paths. Once a scout returns to its source node then it recruits the foragers for its route by using the metaphor of dance (as scout bees do in Nature). A dance is abstracted as the number of clones that could be made of a scout (equivalent of recruiting forager bees in Nature).

Foragers

Foragers are the main workers in *BeeAdHoc* algorithm. They receive the data packets from packers and then transport them to their destination. Each forager has a special type: delay or lifetime. The delay foragers collect the delay information from the network while the lifetime foragers collect the remaining battery capacity of the nodes that they visit. The first ones try to route packets along a path that has a minimum delay while the second ones try to route packets in such a manner that the life time of the network is increased. A forager gets the complete route, in the form of a sequence of nodes leading to a destination, from a scout or another forager. A forager follows point-to-point mode of transmission till the destination and collects the information about the network state depending upon its type. Once a forager reaches at the destination then it remains there until it could be piggybacked on the network traffic from the destination node to its source node. This optimization reduces the overhead of control packets and hence saves energy as well. A reliable transport protocol, like TCP, acknowledges the received packets and *BeeAdHoc* piggybacks in the acknowledgments the waiting foragers. The foragers also use the metaphor of dance once they return to their source node in a similar way as scouts do.

Swarms

An unreliable transport protocol, like UDP, sends no explicit acknowledgments for the received data packets. Such a protocol may not be able to provide an implicit return path to a waiting forager and therefore it could never return to its source node. Consequently, its source node might run out of the foragers and unable to continue the communication. We solved this problem with the help of swarms. Once the difference between the incoming foragers from a certain node *i* and the outgoing foragers to the same node *i* reaches above a threshold value at a node *j* then the node *j* launches a swarm of foragers to the node *i*. We put one forager in the header of the swarm while the others are put in the payload part of the swarm. Once the swarm arrives at the node *i* then the foragers are extracted from the payload part and they are stored like they would have arrived at the node in a normal fashion.

NISR Routing Protocol

NISR [18] is a new routing protocol which is inspired from bee and ant colonies and acts as follows:

- QRY packets are broadcasted from source to various paths.
- When QRY packet arrives at destination, UPD packets are sent from destination to source. These UDP packets contain three pieces of information about route: direction of routes, hop counts of routes from source to destination and level of energy in routes.
- By using this information, data packets are sent over routes with high energy level and low hop count and high scalability.
- Every time data packets arrive at destination, energy level and number use of route are update by sending a special packet.
- When new routes created, using UPD packet new routes announced to source.

Step 3, step 4 and step 5 are repeated while there is any data to be sent from source node to the destination node.

NISR based on TORA[18]. NISR do the routing process in four phases: (1) creating routes, (2) maintaining routes, (3) erasing routes, (4) updating energy level and pheromone of routes.

B-REMiT

A distributed algorithm called B-REMiT [19] is proposed for building an energy efficient shared tree in ad hoc network. The algorithm BREMiT focuses on the metric TEC (*Total Energy Consumption*) while its refining is guided by the metric SL (*System Lifetime*) of shared tree. Such a nice integration seems to well balance the two metrics by improving SL of multicast trees efficiently with little sacrifice on TEC.

In ad hoc networks, multicast tree is divided into the source-based tree and group-shared tree. A group-shared multicast tree is a common backbone tree which is used by all the sources to forward multicast messages to all the receivers in a multicast group. The CBT (Core Based Tree) is the typic form of group-shared tree for multicasting, in which the multicast tree spans all the multicast receivers and senders. The construction of energy efficient group-shared multicast trees in wireless ad hoc networks has received considerable attention recently

a distributed algorithm BREMiT for building energy-efficient group-shared multicast trees in ad hoc networks. The B-REMiT considers both reducing TEC and extending lifetime of bottleneck nodes for multicasting in a group-shared tree. Simulation results show that the algorithm can reduce the TEC of group-shared tree, which is very close to that of G-REMiT, but its SL is far greater than that of G-REMiT [19].

The B-REMiT algorithm consists of three major steps.

1) *Building an initial tree*: in this step, all nodes run a distributed algorithm to build a tree.
2) *Refining the multicast tree*: this phase is organized in rounds. Each round of refinement is led by the multicast core node s, which is taken as the root node of the tree. It is performed on the nodes of the multicast tree in the order of Depth First Search. The node s remains as the root of the multicast tree, and terminates the B-REMiT algorithm when no further refinement occurs in the previous round.
3) *Eliminating all non-member redundant transmissions by pruning the multicast tree*

Distributed Energy-efficient Ad hoc Routing

Generally in on-demand routing protocols [15][16], the source floods an RREQ (Route-Request) packet to search a path from source to destination. The destination node receives the RREQ packet and unicasts an RREP (Route-reply) packet to the source to set up a path. Likewise, DEAR is an on-demand algorithm [14]. DEAR doesn't use additional control packets to acquire necessary information for power aware routing but utilizes RREQ packets which are already used in on-demand routing protocols. DEAR only requires the average residual battery level of the entire network, which can be obtained without any control packets other than RREQ packets. In our proposed algorithm, intermediate nodes control the rebroadcast time of the RREQ packet, where retransmission time is proportional to the ratio of average residual battery power of the entire network to its own residual battery power. In other words, nodes with relatively larger battery energy will rebroadcast RREQ packets earlier. Because on-demand routing protocols drop duplicate RREQ packets without rebroadcasting them, DEAR can set up the route composed of the nodes with relatively high battery power.

Basically the nodes use their residual battery power for the rebroadcast time of RREQ packets. If the time is determined only by the nodes' absolute residual battery power, then the retransmission time will increase as time passes by. Therefore, the relative measure should be used. As a relative measure, here used the average residual battery power of the entire network. The exact value of this average power can be acquired by periodic control packets, but using periodic control packets isn't an on-demand method and it also consumes more energy.

Power Aware Routing

Just as its name implies, power aware routing is to choose appropriate transmission range and routes to save energy for multihop packet delivery[17].

the author[17] first discusses the five metrics for power aware routing:

- Minimize Energy consumed per packet: the most intuitive metric, however not optimal for maximum lifetime;
- Maximize Time to Network Partition: important for mission critical applications, hard to maintain low delay and high throughput simultaneously;
- Minimize Variance in node power levels: balance the power consumption for all the node in the network, i.e., all nodes in the network have the same importance;
- Minimize Cost per packets: try to maximize the life of all the nodes;
- Minimize Maximum Node Cost: try to delay the node failures.

Then the authors used them as the new power aware metric for determining the routes, which shows that the per packet cost is reduced by 40-70% and mean time node failure increase significantly. Assuming the lifetime for each node is inversely proportional to the information going through that node, the authors in use the optimal lifetime as the key metric, trying to maximize the minimum lifetime for individual nodes under the constraints of information flows at each nodes. In order to solve this problem, the authors proposed distributed algorithms using bisection search. One is the heuristic flow redirection algorithm, whose basic idea is to start from a feasible routing strategy, then redirect the flows from nodes with low lifetimes to nodes with higher lifetimes. Another algorithm in uses bisection search for successive feasible routing strategies.

Conclusion

Mobile Ad-hoc Networks provide a wide array of challenges in routing and network management due to their dynamic and distributed nature and various protocols have been studied and implemented in view of these needs and challenges. This paper only throws a light on various algorithms that are used to improve the routing in ad hoc networks.

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