TBRA: Termites Based Routing Algorithm in 3D Wireless Sensor Networks

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Abstract—**This paper proposes a new algorithm, TBRA (Termites-Based Routing Algorithm), for use in three-dimensional mobile wireless sensor networks. The TBRA is a routing selection strategy based on the concept of the ant colony optimization algorithm. It is difficult to establish and maintain optimal routes in a 3D space because the RSSI, energy of sensor nodes, vary with time. This routing selection strategy can be used for various traffic conditions by measuring and counting the average energy of nodes, RSSI value. The main contribution of this study combines ACO algorithm and Durkin's propagation model to derive an efficient routing scheme for wireless sensor networks in a 3D space.**

Keywords- 3D, Ant Colony Optimization (ACO), antsense, Durkin's propagation model, IEEE 802.11, MANET, RSSI, wireless sensor networks

I. INTRODUCTION

In mobile wireless sensor networks (WSNs), the optimal route can be determined by considering the special network characteristics, such as the dynamic topology, multi-hop routing, limited energy, limited bandwidth, distributed control and lack of load balancing capability, and received signal strength indicator (RSSI). For unicast, it is highly related to the node and link status, which requires an optimal method to perform routing. Several traditional routing protocols, such as AODV, DSDV, DSR, OSLR, and TORA were previously studied, and their performance was compared for wireless networks. However, they were not efficiently designed for specific requirements. Several new routing protocols were proposed for energy efficiency or robust path. Maximum PA route determines the route that has maximal total Power Available (PA). Minimum energy (ME) route selects the route that consumes minimal energy to transmit the data packets between the sink and the sensor node. Minimum hop (MH) route determines the route that requires minimal hops to reach the sink. Most reliable path (MRP) selects the most reliable path from source to the sink. In some situations the source node may choose the path with the maximal power, although it is not the shortest path. In addition, the source may select the shortest path with low RSSI values. Considering the various traffic demands, in a number of situations, we hope that the message can transmit to the destination quickly; however, at other times, we focus on the quality of the message and not the time delay. Since the existing protocols are not well designed for wireless sensor networks in a special 3D terrain, a new routing protocol for this special situation is required.

The biological inspiration algorithm can be used to solve routing problems in a MANET and WSNs. Ant System (AS) was initially proposed by Marco Dorigo (1992) in his Ph.D. thesis. Ant Colony Optimization (ACO) is a meta-heuristic method that was successfully applied to several combinatorial optimization problems [1]. Ants, modelled as a society of mobile agents, were the main motivation. They determine the shortest path from source node to destination node in ad hoc network routing. Based on the local information, it deposits a substantial amount of pheromones on the trail. Ant-based routing protocols offer a considerable contribution to assist in the maximization of the network lifetime.

Most articles and simulations are studied in a 2D environment. However, nodes in the real world are deployed in a 3D space. The unrealistic 2D terrain assumption, in which communication and sensing is not blocked because of neglected topographic formations, result in optimistic and unrealistic WSN performance. Because current protocols were not efficiently designed for MANETs or WSNs in a special 3D terrain, our aim was to combine ACO algorithm and Durkin's propagation model to select a suitable and robust path in various 3D terrains.

This paper is organized as follows. Section II briefly describes the related works. Section III demonstrates AntSense module and the Durkin's propagation model. In Section IV, the potential of using ACO algorithms in the mobile WSNs over 3D environment and how the TBRA solves the optimization problem in different traffic conditions is presented. In Section V shows the simulation results. Session VI summarizes the concluding remarks from this paper.

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II. RELATED WORKS

Unlike the usual 2D considerations, Durkin's propagation model extension for the NS-2 network simulator calculates the distance between the nodes depends on all three coordinates [2][3]. H. Babaei et al. proposed a new signal obstruction sub-model used in realistic mobility models. It considers all obstacles of environment in 3D and simulates obstruction of the signals by 3D obstacles [4].

Up to now, there are many popular biological inspiration algorithms are proposed. But few researches apply the ACO algorithm to 3D mobile wireless sensor networks. Ru Huangl et al. presented a predication mode based routing Algorithm based on ACO (PRACO) to achieve the energy-aware data-gathering routing structure in WSNs. PRACO checks the load factor in heuristic factor and guided by novel pheromone updating rule, artificial ants can foresee the local energy state of networks and the corresponding actions could be adaptively taken to enhance the energy efficiency in routing construction [5]. S. Sethi and S. K. Udgata introduce a novel metaheuristic on-demand routing protocol Ant-E, using the Blocking Expanding Ring Search (Blocking-ERS) to control the overhead and local retransmission to improve the reliability in term of packet delivery ratio (PDR) [6].

III. ANTSENSE MODULE AND THE DURKIN'S PROPAGATION MODEL

A. *AntSense module*

T. Camilo et al. proposed AntSense project contains extensions to NS-2 (versions 2.27 and 2.28) which enables the ant colony optimization (ACO) behavior in WSNs [7]. In ACO approach ants are considered as packets that travel the network changing routing information in order to find the best path towards the sink node. The idea behind this behavior is to build a better pheromone distribution (nodes near the sink node will have more pheromone levels) and will force remote nodes to find better paths. Such behavior is extremely important when the sink node is able to move, since the pheromone adaptation will be much quicker.

B. *Durkin's propagation model*

We use the terrain data via a USGS 7.5 DEM file. It enables us to place and move the ad hoc network nodes in an irregular 3D terrain defined by the means of a DEM file that holds the digitalized elevation values for a specified terrain [8][9]. S. Filiposka and D. Trajanov created an implementation of the Durkin's propagation model as an extension for the NS-2 simulator [10][11], thus allowing us to conduct more realistic simulation scenarios and analyze the way the terrain profile affects the ad hoc network performances. For testing purposes the authors provide several artificial terrains: flat, hillside, hill, ravine and pyramid. Their dimensions are 1000x1000m with the highest relative point of 200m. Figure 1 shows the distance between two nodes in 3D terrain.

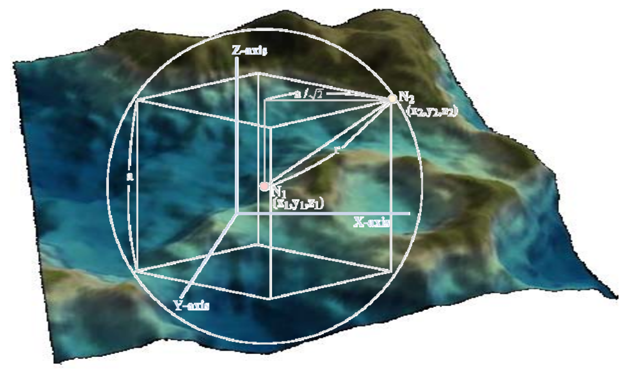


Figure 1. Distance between two nodes in 3D terrain.

Give the coordinates of two nodes v_i and v_j : (x_1, y_1, z_1) and (x_2, y_2, z_2), make d_{ij} the actual distance d.

$$d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2}$$

IV. DESIGN OF TBRA

It is preferable to transmit data over links that have a high probability success in MANET and wireless sensor network. TBRA inspirits from termites looking for food and focus on how to find a robust route from source node to destination node in mobile wireless sensor networks over 3D space. We use the node's energy, RSSI value as the pheromone information to select the most suitable route. TBRA track RSSI and node's energy to select suitable path in real-world sensor networks, when wireless channel conditions vary significantly over time and space. By calculating several RSSI and the residual power of nodes in the path values, an estimate of the probability of successful transmission is available to the route selection algorithm. TBRA makes an effort on reducing potential route discoveries and contributes on improving network performances such as average end-to-end delay and packet delivery ratio.

An example of path selection from source node to destination node with different traffic conditions is shown is figure 2. The numbers shown on the double arrow line represent RSSI and node's energy. Considering the different traffic demand, it could transmit to destination by different path.

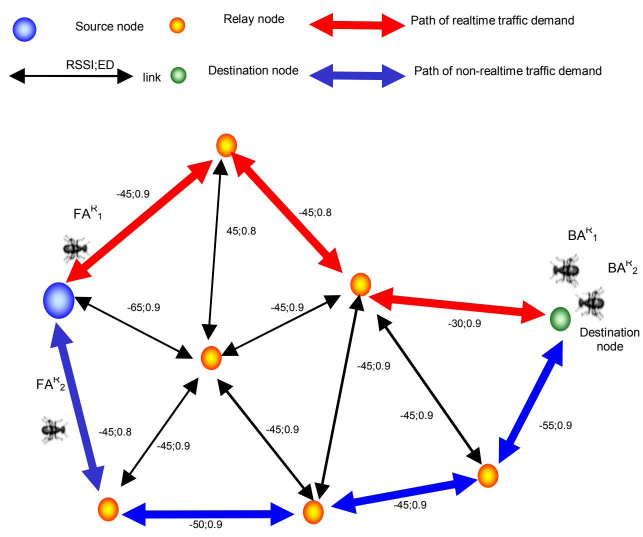


Figure 2. Example of path selection from node *i* to node *j* with different traffic conditions.

TBRA selects effective path when the average energy or RSSI value is under a certain threshold according to different traffic conditions. When the energy of nodes on the path decreases under its threshold, then the path can be changed. We can select the most suitable path as long as the link status is over a certain threshold.

Given a mobile wireless sensor network, we model it by a graph $G=(V, E, w, \upsilon)$, where V is the set of nodes, E contains all communication links between nodes in V, w is the weight of links in E, υ is the weight of nodes in V.

We introduce the following notations:

V : the set of all nodes

E : the set of all links

$RSSI(i, j)$: RSSI between node i, j

$ED(i)$: Energy Detection of node i

$RSSI_{th}$: the received signal strength indicator threshold of all links

ED_{th} : the energy detection value threshold of all nodes

$N[x]$: sum of nodes which routing path selected

$w_{RSSI}(i,j) = \frac{\sum_{i,j\in V} RSSI_{th}}{|N[x]|}$: average of node's RSSI value

$\upsilon_{ED}(i) = \frac{\sum_{i\in V} ED_{th}}{|N[x]|}$: average of node's energy value

The flow denotes ψ, is a function of edge, must satisfy these conditions:

$\psi(i, j) >= w_k(i, j)$, $k \in RSSI$, for each edge

$\psi(i, j) >= \upsilon_k(i, j)$, $k \in ED$, for each vertices

The following steps are taken in this approach.

1. The source node starts sending forward ants to all connected relay nodes according to the traffic conditions and the probability of packet delivery on the link.
2. The receiver computes the weight (RSSI, ED) values and checks at the receiver against a threshold.
3. When any RSSI, ED values is below a threshold, it will be removed from the routing table. Otherwise the receiver sends backward ants to source node.
4. When the sender receives backward ants from the receiver, it updates the pheromone value (routing table entry). Pseudo-code for selecting a node from *i* to *j* shows as follows.

begin

for (int i=1;i<inewNum;i++)

{

initialize globalvalue, localvalue;

calculate $p^{k}_{ij} = \frac{w_{(RSSI)_{ij}}^{\alpha} \cdot w_{(ED)_{ij}}^{\beta}}{\sum_{c_{ij\in N(s^p)}} w_{(RSSI)_{ij}}^{\alpha} \cdot w_{(ED)_{ij}}^{\beta}}$

}

do {

if w > threshold then

Select j using probability p_{ij}

$\tau_{ij} = (1 - \rho).\ \tau_{ij} + \rho.\ \tau_0$ */* update pheromone*

else

Randomly choose j using probability p_{ij}

end if

} while not dest(n_j)

selecting Next Hop

Figure 3 shows the process of our simulations. We use setdest.cc scenario and node-movement file generator to generate mobility scenario file. We also use cbrgen.tcl connection pattern file generator to generate CBR connections from NS2 independent utility. TCL file imports hill.dem file contained 3D hill terrain. TBRA uses AntSense module and Durkin's propagation model for IEEE 802.11b (NS-2.31) in our simulation.

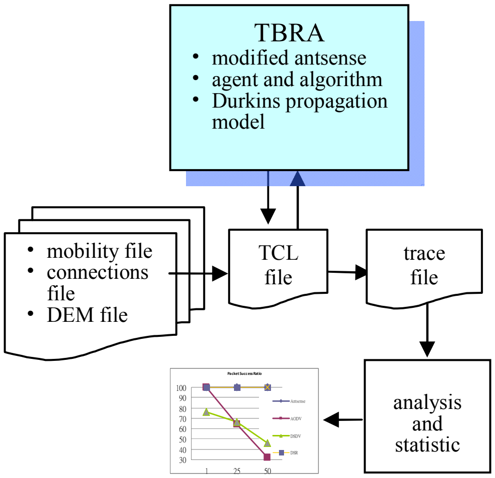


Figure 3. The process of simulation.

V. SIMULATION RESULTS

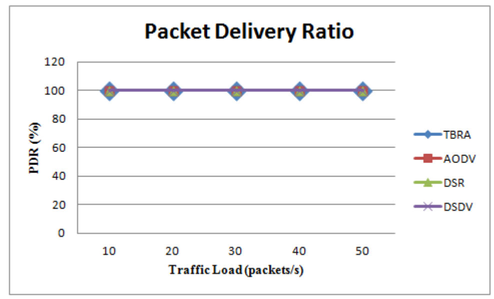
The solution performance evaluation is carried out under the NS2 simulator. We implement AntSense module on NS-2.31 and modify some C++ codes to combine Durkin's propagation model.

Table 1 shows the general simulation settings. We send CBR traffic from 10 to 50 packets/s. Twelve mobile nodes are deployed randomly over hill terrain. The average node speed is varied from 0 to maximum 10m/s. During the simulations, the nodes are moving according to the random direction model in the terrain boundaries.

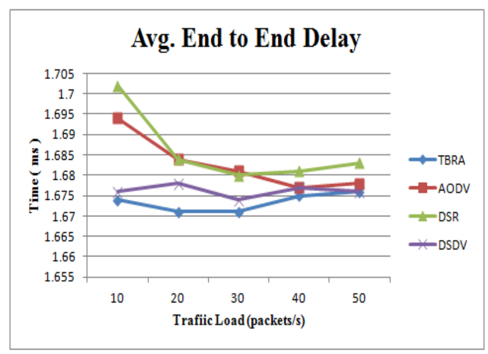
TABLE I. GENERAL SIMULATION SETTINGS

name	Setting values
MAC layer protocol	802.11b
network dimension	1000m x 1000m x 200m
no. of nodes	12 mobile nodes
Propagation model	Durkin's model
terrain	hill
traffic type	CBR
Max. speed	1, 10 m/s
traffic loads	10, 20, 30, 40, 50 packets/s
routing protocol	TBRA, AODV, DSR, DSDV
transmission range	250 m
packet Size	1000 byte
simulation time	100 s

Ant-based routing protocols can add a significant contribution to assist in decreasing the network end-to-end delay. Figure 4a shows packet delivery ratio metric using TBRA doesn't have any difference between other routing protocols when node's maximum moving speed is 1m/s. Figure 4b shows average end-to-end delay metric using TBRA obviously outperforms than the other traditional routing protocols. TBRA gets the lowest end-to-end delay 1.674 ms when traffic load is 10 packets/s.



(a) packet delivery ratio

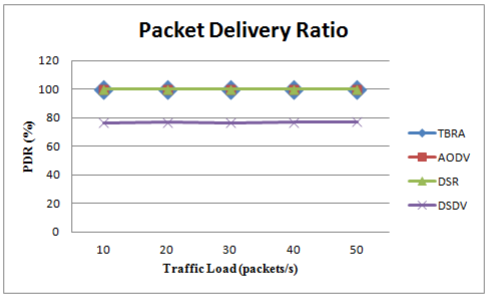


(b) average end-to-end delay

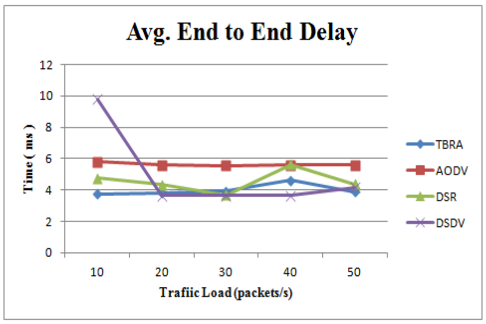
Figure 4. Mobile nodes max. moving speed is 1m/s.

Figure 5a shows packet delivery ratio metric using DSDV routing protocol gets lower PDR when node's maximum moving speed is 10m/s because that table-driven routing scheme requires a regular update of its routing tables. Despite TBRA doesn't have any differences between other routing protocols on PDR metric, it still outperforms than the other routing protocols on average end-to-end delay. Figure 5b shows average end-to-end delay metric. When node's maximum moving speed increases, the delay time is also increased. TBRA gets the lowest end-to-end delay 3.747 ms when traffic load is

10 packets/s. TBRA almost gets the lowest end-to-end delay in all our simulations.



(a) packet delivery ratio



(b) average end-to-end delay

Figure 5. Mobile nodes max. moving speed is 10m/s.

VI. CONCLUSIONS

In this paper, we propose TBRA routing protocol for MANET and WSNs in a 3D environment based on Ant Colony Optimization techniques. TBRA uses the RSSI and energy of nodes as the pheromone information. The main contribution of this study combines ACO algorithm and Durkin's propagation model to derive an efficient routing scheme in a 3D hill terrain according to different traffic conditions. Simulation results show that, using the pheromone as the information of selecting path can significantly guarantee lower end-to-end data delivery delay and achieve better packet delivery ratio than three well established traditional routing protocols (AODV, DSR, and DSDV) in a 3D hill terrain. In the future, we plan to evaluate the efficiency when applying the proposed TBRA scheme to a cluster-based topology with dense nodes over various 3D terrains, such as hillside, ravine and pyramid.

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