An Immunity-based Ant Colony Optimization Topology Control Algorithm for 3D Wireless Sensor Networks

Dequan Yang
School of automation, Beijing Institute of Technology, Beijing 100081, China
E-mail: yangdequanbit@gmail.com

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Abstract: Wireless Sensor Networks (WSNs) have been attracting the attention of both academic and industrial research communities for the past few years. To find an optimal topology control strategy in 3-dimensional (3D) WSNs is a new challenge. In this paper, we discuss issues related to the topology control in 3D WSNs, review a 2D model for WSNs, and introduce a 3D model for WSNs. An Immunity-Based Ant Colony Optimization Topology Control Algorithm for 3D WSNs is introduced, which has better performance with the nature of feedback and paradigm of ant colony and immunity algorithm reducing the redundancy iteration. The advantage of both the Ant Colony Optimization algorithm (ACO) and Connected Dominating Set (CDS) are fully taken in this algorithm. Simulation results show that the CDS-ACO has the better performance in WSNs.

Keywords: Topology control, Three dimensional, Wireless sensor networks, Immunity-based ant colony optimization, Connected dominating set.

1. Introduction

Many challenges are faced just like: energy conservation, low-quality and so on. Topology control is the art of coordinating nodes’ decisions regarding their transmitting ranges, in order to generate a network with the desired properties while reducing node energy consumption and/or increasing network capacity [1, 2]. Since nodes consume energy to receive and send data, reducing the energy consumed can is an important issue. Most existing works on sensor topology control focus on the two-dimensional (2D) plane. But, some 2D topology algorithm does not function correctly in three-dimensional. And, in fact, three-dimensional (3D) Wireless Sensor Networks are supposed to be deployed for many applications, just like the underwater, atmospheric [3]. The design of 3D networks is surprisingly more difficult than the design of 2D networks. For example, proofs of Kelvin's conjecture and Kepler's conjecture required centuries of research to achieve breakthroughs, whereas their 2D counterparts are trivial to solve [4]. [5] transform the 3D underwater sensor network (USN) localization problem into its 2D counterpart by employing sensor depth information and a simple projection technique. [6] proposes the Reuleaux tetrahedron model to characterize k-coverage of a 3D field and investigate the corresponding minimum sensor spatial density. A three-dimensional greedy anti-void routing (3D-GAR) protocol is proposed to solve the 3D void problem by exploiting the boundary finding technique for the unit ball graph (UBG) [7]. [8] gives the critical density \( \lambda_{\text{cov}} \) above coverage, \( \lambda_{\text{con}} \) above connectivity and \( \lambda_{\text{cov-con}} \) above which both coverage and connectivity in 3D WSNs.
Several approaches have been proposed for topology control in 3D WSNs. [9, 10] extend several existing 3D topologies to a set of new 3D topologies with bounded node degree based on Yao-Graph. [11] provides an efficient fault tolerant topology control protocols for 3D wireless networks which can guarantee the kappa-connectivity and ensure the bounded node degree. [12] proposes an interference-aware 3D topology control algorithm by considering the practical implementation of the WSNs. Due to the energy constraint and some nodes may not work correctly, the protocol should be energy-efficient and fault-tolerant. The topology control problem in WSNs is known as a NP hard problem. Recently, some routing protocols for wireless sensor networks have been proposed according to the principles of ant colony, and so on [2]. To study the topology control in 3D model, we propose an algorithm called Immunity-based Ant Colony Optimization Topology Control Algorithm in 3D WSNs (3D-IBACOTC) which combine the advantages of ACO and Immune. Ant Colony Optimization algorithm (ACO) has the limitations of poor convergence, and is easy to fall in local optima. Meanwhile, Artificial Immune has the limitations of feedback, and is easy to have massive redundancy iteration in later period. 3D-IBACOTC can avoid local optima and redundancy iteration.

The paper is organized as follows. Section 1, we have briefly described the whole view of Topology Control in 3D WSNs. In Section 2, we are focusing on the issues on 3D model of WSNs. The topology control algorithm in 3D WSNs is presented in Section 3. In Section 4, we evaluate the performance of the TC algorithm. Finally, we conclude our work.

2. Model of 3D WSNs

2.1. Difference of 2D and 3D in WSNs

In 3D model, suppose node \( u \) must send a packet to node \( v \), which is at distance \( d \). Radius \( r \) is the distance of radio. Node \( v \) is within \( u \)'s transmitting range at maximum power, so direct communication between \( u \) and \( v \) is a choice. However, there exists also node \( w \) in the roll region \( R \) by the ball of diameter \( d \) that intersects both \( u \) and \( v \).

A wireless sensor network is modeled as a graph \( G(V, E) \), where \( V = \{v_1, v_2, ..., v_n\} \) is the set of nodes, \( E \) is the set of edges which link by transmits. In 2-Dimension, the model of WSN is homogeneous network, but in 3-Dimension, the model of WSNs is scale-free network, meanwhile, the number of neighbors node in 3-Dimension is larger than neighbors in 2-Dimension. So some algorithm will easy to get into the local best. [13] gives a probability model in two kinds of WSNs.

In 2-Dimension, the probability of the node \( u \) is defined as follows:

\[
P_{2d} = \frac{\pi R^2}{A}
\]  

(1)

\( R \) is the range of transmit distance, \( A \) is the \( x \times y \) field which deployment of sensor nodes.

The probability of node which have k-connect is:

\[
p_k = \frac{(N-1)}{k} p_{2d}^k (1-p_{2d})^{N-1-k}, k = 1, 2, ..., N
\]  

(2)

So, the average of neighbor of node is:

\[
z_2 = \sum_{k=0}^{N-1} k p_k = \sum_{k=0}^{N-1} k \left(\frac{(N-1)}{k} p_{2d}^k (1-p_{2d})^{N-1-k}\right)
\]  

(3)

From (1) and (3), we can get:

\[
z_2 = (N-1) \frac{\pi R^2}{A}
\]  

(4)

In 3-Dimension, the probability of the node \( u \) is defined as follows:

\[
P_{3d} = \frac{4}{3} \frac{\pi R^2}{V}
\]  

(5)

where \( V \) is the \( x \times y \times z \) field.

\[
z_3 = (N-1) \frac{4}{3} \frac{\pi R^2}{V}
\]  

(6)

Suppose that: \( x = y = z = 100 \) m, \( N = 10, ..., 100; R=15.81; \) we can get the Figs. 1and 2 as follows:

Fig. 1. The average number of neighbor node about 2D and 3D (b);

Fig. 2 is an enlarged view of the Fig. 1.
2.2. Basic Ant Algorithm

The ant colony optimization (ACO) have been applied to solve the topology control problem in WSNs [14, 15].

In ACO based approach, each ant tries to find a path in the network, to achieve minimum cost. Ants need to move from node $i$ to node $j$, according to a probabilistic decision rule.

\[
P_{ij}^{k}(t) = \begin{cases} 
\prod_{j \in \text{allowed}_k} \left[ \tau_{ij}^{k}(t) \right]^{\alpha} \left[ \eta_{ij}^{k}(t) \right]^{\beta}, & j \in \text{allowed}_k \\
0, & \text{otherwise} 
\end{cases}
\]

(7)

where $\tau_{ij}$ is the value of pheromone and $\eta_{ij}$ is the value of heuristic related to energy. $\alpha$ and $\beta$ are two parameters that control the relative weight of pheromone trail and heuristic value.

$M^k$ is the set of the previously visited nodes which is used to prevent cycling in a routing path. The higher $P_{ij}^{k}$ is, the higher is the node $j$ is being selected. The heuristic value for the node $j$ is as follows:

\[
\eta_{ij}^{k} = \frac{e_{j}}{\sum_{n \in N_i} e_{n}}
\]

(8)

where $e_j$ is the energy level of node $j$ and $N_i$ is the set of neighbors of node $i$. This enables an ant to make a decision based on the energy level of the neighbor nodes which can prevent the decision on lower power nodes.

When the forward agent arrives at its destination node, a backward ant is created and the memory of the forward ant is transferred to the backward ant.

The forward agent is then discarded. The backward ant traverses the same path as the forward ant except in the reverse direction. While traveling hop by hop back to the source, the backward ant deposits a quantity of pheromone, $\Delta \tau^{k}$, on each node given by

\[
\Delta \tau^{k} = w \cdot \left( \frac{1}{L^k} \right)
\]

where $L^k$ is the path length of the $k^{th}$ ant in terms of the numbers of hops and $w$ represents the weighting coefficient.

In WSNs, $L^k$ represents the total number of nodes visited by the ant $k$. These pheromone values are saved in the node memory to be used in future decision making for the next hop by this node. Based on these values, each node has the information about the amount of pheromone on the paths to its neighbor nodes. Node that the values of the variables $M^k$ and $L^k$ have been put in a memory reserved for each ant in each node. In general, this space is not more than several bytes. This data is inserted to the frame corresponding to the forward ant.

The operation of pheromone evaporation is used to avoid unlimited accumulation of the pheromone trails and enables the algorithm to “forget” previously done bad decisions. The operation is performed in similar intervals using

\[
\tau_{ij} \leftarrow (1 - \rho) \tau_{ij}
\]

where $0 < \rho \leq 1$ is the pheromone trail evaporation rate.

2.3. Ant algorithm in WSNs

In this section, we discuss related works. In [16], the authors introduce the Energy-Balanced Ant-Based Routing Protocol (EBAB) which describes a new adaptive dynamic algorithm based on ant algorithm. [17] presents an ant routing optimization (ARO). The ARO searches energy-efficient routing trees by considering the energy consumption of sensing, data transmission and reception.

In [18], the paper put ant colony algorithm in existing LEACH protocols, the results show that can improve the network lifetime.

In [19], swarm intelligent algorithms are used to meet the dynamically changing environments, the pheromone gradient algorithm is proposed. [20] present an ant colony-based routing protocol. The protocol divided into two stages, first, the protocol uses ant-based intelligence to find and enforce the shortest path and , in second phase, when the actual many-to-one sensory data transmission takes place, the protocol combines the knowledge gained during the first phase with the congestion control mechanism...
to avoid packet loss and traffic while routing the sensory data.

3. An Immunity-Based Ant Colony Optimization Topology Control Algorithm

3.1. Basic Idea of CDS-ACO

The 3D environment is taken into consideration. The first stage, cluster is produced by Connected Dominating Set (CDS)[21]. In $G$, a node $i$ dominates another node $j$ if and only if $i = j$ or $i$ and $j$ are adjacent. Then, the second phase is between in group head. The CDS plays a key role in topology constructor. [22]

First of all, the CDS is constructed to provide the virtual backbone in whole networks. Assume that nodes in WSNs are in a three-dimensional ball and have the same transmission ranges. The network topology is modeled as a Unit Ball (UB).

The second phase of the algorithm is to transfer data from source node to end node by ACO algorithm.

The CDS-ACO is constructed as follows:

Step:
1) Choose the group head by CDS algorithm;
2) Build the topology structure between group head by ACO.

After generate the backbone by CDS, each nodes of backbone of WSNs was put ant parameters for initialization. Then, the next node is selected by probability. This cycle run until topology structure was constructed. If the nodes can not support the whole structure, the algorithm will go into the CDS phase until the whole network was down.

Fig. 3. shows the sensor nodes in 3D environment.

3.2. Flowchart of CDS-ACO

Fig. 4. shows the flowchart of the algorithm.

4. Experiment

In this section, we access the efficacy of the proposed algorithm. The reference network used in our simulations had 2000 nodes with 100×100×100 space. Simulations are performed by matlab and vc++. Fig. 5. shows the result of experiment.

Horizontal axis shows the number of rounds, unit is (×200), ordinate axis shows the survival rate of nodes.

5. Conclusions

In this paper, a distributed approach of Topology Control Algorithm for 3D WSNs CDS-ACO is proposed. The performance of simulation shows that this method is useful in WSNs. Based ACO and CDS can construct a topology structure.
References


