Measurement 54 (2014) 83–91

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

Range expansion of cooperative mobile wireless network based on swarm intelligence optimization

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ARTICLE INFO

Article history:
Received 26 January 2014
Received in revised form 3 April 2014
Accepted 8 April 2014
Available online 21 April 2014

Keywords:
Range expansion
Cooperative transmission
Swarm intelligence
Improved Ant Colony Algorithm
Glowworm Swarm Optimization

ABSTRACT

We research maximum range expansion using a fixed number of mobile wireless nodes along a line which do distributed MIMO (Multiple Input Multiple Output) in diversity configuration, also known as cooperative transmission (CT). The emphasis is on optimal clusters and locations of these clusters to maximize the multi-hop reach along the line based on the swarm intelligence algorithms which are the Glowworm Swarm Optimization (GSO) and Improved Ant Colony Algorithm (IACA). We build the CT model which cannot be solved by conventional method, so we solve it by using GSO and IACA algorithms to get the optimal result. In GSO algorithm, every mobile wireless node is considered as a glowworm, and the intensity of signs is the intensity of luciferin. The direction of movement is determined as well as the direction of movement function under the constraint of outage probability in CT model. The contribution to the IACA is to modify the heuristic function and the pheromone update rule based on the optimization function to avoid local optimal result. Simulation experiments compared GSO, IACA with ACA and Exhaustive Attack Method (EAM), which proves GSO and IACA are effective, and the advantage of IACA is high accuracy and GSO is time saving.

1. Introduction

Wireless sensors can be used in many applications, such as health monitoring or disaster rescue. Mobile robots can be combined with wireless sensors and expand the applications [1–11]. In this paper, we research how to best deploy a fixed number of relays along a line, to cover the longest distance (the measurement distance), when the network is capable of cooperative transmission (CT). The cost function is the end-to-end outage probability, when there is only CT per hop or one transmission (i.e., no retransmissions are considered). The original motivation for this research was a robotics path planning problem, where the robots need to stay in contact with a fixed access point or station, but can move themselves out as far as possible in some specified direction. We also note that a linear network arrangement may be a low-cost way for a team of robots to periodically monitor a large circular area by sweeping the line of robots around.

This robot deployment problem was studied in [1] only in the non-CT case. In this paper we consider only the final locations of the robots; we do not address the robot motion control how to achieve those locations. To our knowledge, no one has addressed the relays deployment and robot issue in the CT case, when the hop distances and cluster sizes can be un-equal but the total number of nodes is fixed [2,3]. Fig. 1 shows the range expansion system model by CT technology, through this new model, the transmission range would be extended than the traditional method.

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http://dx.doi.org/10.1016/j.measurement.2014.04.003
0263-2241/

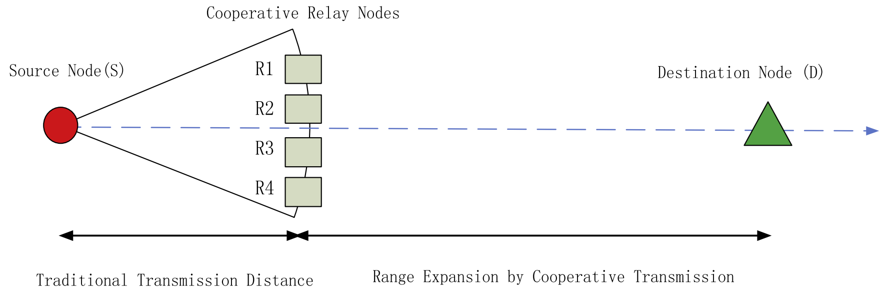

Fig. 1. Basic cooperative transmission range model.

While there have been many research of the SNR advantage [4,5], including using the SNR advantage for range extension [6], most of these studies consider only two hops (from source node to relay cluster to destination node) [7,8]; they do not address the question of whether re-arranging the same fixed number of nodes into a 3+ hop topology would extend range further. Other studies address coverage area when CT is used [9–11], however, the two dimensional nature of the coverage area problem makes its solution not applicable to the line strip network. We note that other authors have considered how to arrange nodes into equi-spaced, same-sized clusters along an infinite line network with CT [11,12]; while this yields some insights into what cluster sizes yield the lowest outage probability per unit distance as a function of path loss exponent, the quasi-stationary method of analysis in those papers makes their results not directly applicable to the fixed small number of nodes (e.g., ten nodes), which might be more likely in a robotic deployment. As we will later show in this paper, the optimal clusters are not equi-spaced and not always same-sized [13].

As there is no normal solution of the CT model, we have to use an optimization algorithm to get the optimal result. There are many researchers used different optimization algorithms such as particle swarm optimization, neural network and genetic algorithm to solve the problem, but they have poor quality and slow convergence speed to get the optimal solution [14,15]. GSO is proposed by Krishnanad and Ghose [16,17]. GSO is obtained mainly based on the natural glowworms' activities at night. The glowworms exercise in group in nature, the interaction and inter-attraction with each other by the luciferin. If a glowworm's luciferin is brighter than others, this glowworm can attract more glowworms move toward it. Through simulation this phenomenon, the GSO algorithm's characteristics are gained, every glowworm would search its vision field for the glowworm which release the strongest luciferin and move toward it. Refs. [17,18] use GSO to solve the Traveling Salesman Problem (TSP), the GSO is a probabilistic method for discrete optimization problems to solve the non-linear functions. Refs. [19,20] use GSO to deploy the sensor nodes which is close to our research. This research has proved that GSO algorithm is useful and effective, and has a strong versatility and high performance for solving TSP problem. However, there are some drawbacks in GSO algorithm, such as premature convergence and search accuracy is not high enough, low efficiency in later iterations.

Dorigo proposed the Ant Colony Algorithm (ACA) to solve the TSP, the ACA is a probabilistic method for discrete optimization problems [21]. ACA is imitating the behavior of real ants on their way to find the shortest path to arrive at the food sources. ACA has been successfully applied to various problems. But there are some limitations in ACA, the max–min ant algorithm is proposed to prevent premature convergence, combining with other optimization algorithms, optimal the parameters, and so on [22–26]. Refs. [27,28] use the ACA to tracking the wireless network nodes, and a new kind IACA was applied in [29] to optimize the operating life of the nodes in network. Ref. [30] completed the path planning of robots by using ACA, but our study should consider more constraints based on ACA, which is more complex and difficult.

The contribution of this paper is to get the maximum range expansion of all nodes in a straight line, while the whole network can achieve the maximum communication distance. We improve the heuristic function and the pheromone update rule of ACA to get the optimal deployment under the constraint of outage probability. We use the discrete continuous space and iteration to find the optimal solution, but in the GSO algorithm, we combined GSO and tabu search algorithm together and applied to CT model to get the optimal deployment. To our knowledge, our research is the first time use GSO to solve this kind of robotic deployment problem.

2. Model

In this section, we build the cooperative transmission (CT) model under the constraint of outage probability.

Consider an N single-antenna nodes wireless network deployed along a straight line. An $N = 7$ 3-hop example is shown in Fig. 2. The first node, the source, is always isolated, but the other $N-1$ nodes can be in clusters. The first hop is the links between the source and Cluster 1. The second hop is the links between Clusters 1 and 2, and so forth. In Fig. 2, Cluster 1 has two nodes, Cluster 2 has three nodes, and the destination is isolated. We refer to this as a 1–2–3–1 topology. We also consider the case when the destination is part of a cluster.

We assume all transmitters have exactly one antenna with the same emitting power P_t, and that the transmissions within a cluster are in orthogonal channels [5]. A receiving node is assumed to be able to do Maximal Ratio Combining (MRC) of the copies in each orthogonal channel. We note that this type of CT is practical and was demonstrated using software defined radios in [6,13].