An Optimal Tree-Based Routing Protocol Using Particle Swarm Optimization

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Abstract Wireless sensor networks (WSNs) contain many sensor nodes which are deployed in the various geographical areas to perform various tasks like monitoring, data aggregation and data processing. For performing all these operations, energy is highly consumed, thus sensor nodes begin to die soon and also creates energy holes in some of the geographical locations. All the sensor nodes are powered by battery, and it is quite difficult to replace the battery, and so energy consumption is prime objective to increase the network lifetime. Clustering and tree-based routing like LEACH, PEDAP, TBC and TREEPSI solves most of the energy consumption problem as it saves energy during a lot of operations in WSNs. In this paper, we propose an optimal tree-based routing protocol (OTBRP) that is efficient in terms of stability period (time period before first node dead) and therefore offers good network lifetime. The parameters like first node dead, half node dead and last node dead are considered for the measurement of network lifetime. In order to evaluate the performance of OTBRP, the comparison is made with the GSTEB and PEGASIS. Simulation results show that there is a gain of approx. 200 and 150% in stability period in comparison with PEGASIS and GSTEB, respectively.

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1 Introduction

Wireless sensor networks (WSNs) have influenced many researchers because of its enormous uses in various fields like environmental monitoring, disaster relief systems health applications, surveillance, habitat monitoring, industrial applications and many more [1, 2]. A WSN contains relatively huge number of small sensor nodes that are randomly or manually deployed in the sensor field. Sensor node consists of sensing unit, processor, communicating devices having power unit. The sensor nodes are efficient in sensing the target area, after that processes the data and transfers that data to the sink which is located far away. The main limitation of WSNs is limited power supply. Moreover, in many applications, it is a challenging task to replace batteries so energy consumption is foremost needed in these networks [3–5].

2 Background and Motivation

WSNs mainly send the sensed information to base station (BS) that aggregates part or all of the information. A bottleneck challenge is to create energy efficient communication with low cost on-node processing and self-organizing connectivity. Low power consumption is the main factor for ensuring long operations for energy constrained systems [6]. Hierarchical routing protocols are also termed as cluster-based routing, asserted in WSNs. These routing techniques are having special advantages in terms of scalability and efficient communication. Clustering solves the problem of energy consumption up to some extent [7, 8]. In clustering, the sensor nodes form a group called clusters and the cluster member with the highest energy is chosen as cluster head (CH), only CHs are allowed to communicate with BS [9]. In the chain-based approach like in PEGASIS, all the nodes are arranged in the chain-type fashion, one node associates with other node next to it and data fusion is done [10]. In the recent past, the routing was emphasized with clustering, but nowadays tree-based routing is more popular because of its inherent property of efficient routing by using different tree branching techniques. Tree-based clustering (TBC) is also considered to be an improvement to LEACH protocol [11]. It forms several clusters likewise in LEACH, and every cluster has cluster members as well as CH. PEDAP [12] makes use of minimum spanning tree, and it is a tree-based routing protocol. Minimum spanning tree leads to loop-free topology which costs minimum for the transmitting of data. A tree-based power saving routing protocol [13] considers the maximum capacity of a node to have s number of children and the maximum tree depth as parameters to control the tree construction. In tree-based efficient protocol for sensor information (TREEPSI) protocol, a root node is chosen before data transmission [14]. General self-organizing tree branching energy balancing protocol (GSTEB) [15] aims to achieve prolong network lifetime for distinct applications in WSN environment.

3 OTBRP Routing Protocol

WSN consists of spatially distributed autonomous sensor nodes, and these nodes are have limited battery life and storage capacity [16]. Many protocols are introduced to work efficiently against the high energy consumption of nodes which in return increases the network lifetime. In this work, an optimal tree-based routing protocol (OTBRP) for WSN is proposed in order to increase the stability period of network.

3.1 Communication Model

The radio model used in OTBRP is shown in Fig. 1. Both the multi-path fading (d^4 power loss) and the free space (d^2 power loss) models are used on the basis of distance between transmitter and receiver. If the distance is more than the threshold distance then multi-path (mp) model is used, otherwise, free space (fs) model is used.

For transmitting k number of bits, the energy consumed will be:

$$E_{TX}(k, d) = E_{elec} \cdot k + E_{amp}(k \cdot d), \tag{1}$$

where E_{elec} is energy consumed in electronic circuit to transmit the bit.

If $d < do$, then

$$E_{TX}(k, d) = k \cdot E_{elec} + k \cdot \varepsilon_{fs} \cdot d^2. \tag{2}$$

And if $d > do$, then

$$E_{TX}(k, d) = k \cdot E_{elec} + k \cdot \varepsilon_{amp} \cdot d^4. \tag{3}$$

Here threshold

$$do = (\varepsilon_{fs} / \varepsilon_{amp})^{1/2}, \tag{4}$$

where ε_{fs} is the amplifier energy consumption to transmit at a smaller distance and ε_{amp} is the amplifier energy consumption to transmit at a larger distance.
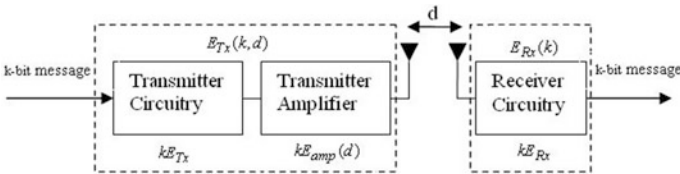

Fig. 1 Energy dissipation radio model

To receive k number of bits, the radio spends energy

$$E_{TX}(k,d) = E_{elec} \cdot k. \tag{5}$$

3.2 Proposed Fitness Function

Let us assume network consists of N sensor nodes which are divided into K number of branches, the number of candidate parent node (PN) is denoted by M generally greater than K, and there can be C_M^K ways of clustering.

Fitness function for parent node selection is defined as:

$$f = \alpha f_1 + \beta f_2 + \gamma f_3. \tag{8}$$

Here $\alpha, \beta, \gamma \in [0, 1], \alpha + \beta + \gamma = 1$.

In the fitness function, f_1 is the reciprocal of the total sum of the energy of the present round PN and sum of energy of all the sensor nodes in the network, f_2 is the maximum of the Euclidean distance average, how much distance is found from every cluster sensor nodes to this PN and f_3 is the distance ratio of the average distance from the PN to the BS and the Euclidean distance from the BS to the centre of the network.

$$f_1(p_j) = \frac{\sum_{i=1}^{N} E(nj)}{\sum_{i=1}^{N} E(PNP_{j,k})} \tag{9}$$

$$f_2(p_j) = \max_{\forall k = 1, 2, 3 \ldots N} \frac{\sum_{\forall ni \in Cpj,k}^{N} d(ni, PNP_{j,k})}{BP_{j,k}} \tag{10}$$

$$f_3(p_j) = \frac{\sum_{i=1}^{N} d(BS, PNP_{j,k})}{K * d(BS, NC)}. \tag{11}$$

3.3 OTBRP Protocol Phases and Operation

OTBRP is a tree-based routing protocol. The aim of OTBRP is to attain a prolong network lifetime for various applications. In every round, BS assigns itself as root node and broadcasts its ID and coordinates to all sensors. The operation of OTBRP is divided into four phases as follows (Fig. 2):

Initial Phase: In the initial phase, the network parameters are initialized. BS broadcasts a packet to all the sensor nodes to inform them of beginning time, time slot length and the number of nodes.

Fig. 2 OTBRP operation
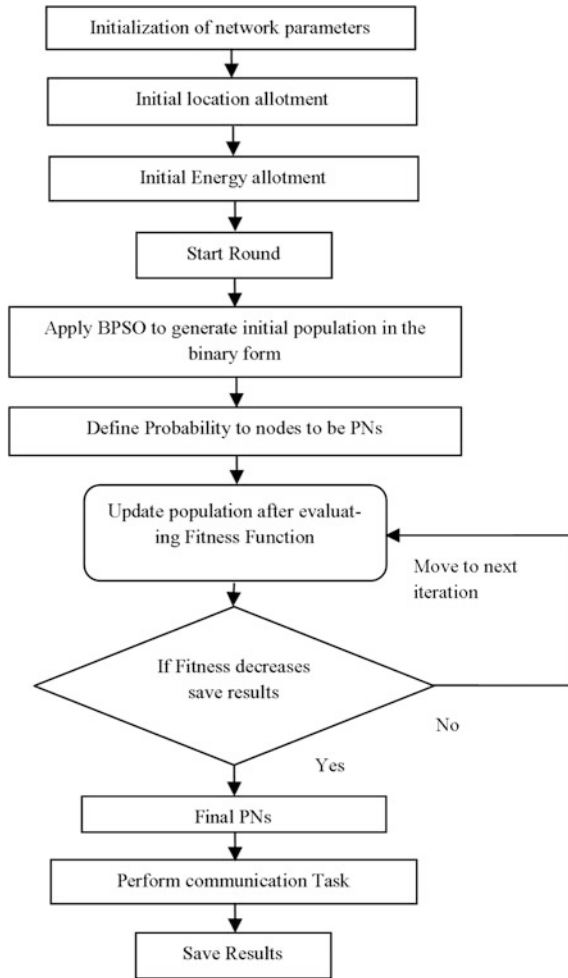
Tree Constructing Phase: In the tree constructing phase, sensor nodes are selected as parent nodes with some predefined parameters termed as fitness function (described in Sect. 3.2) using BPSO. It starts with the initial population in the binary form on the basis of probability of nodes to become parent nodes. The number of parent nodes varies in each round.

Data Transmitting Phase: Every node selects its parent by considering energy as well as distance optimal values. There may be many leaf nodes sharing one parent node in the same time slot. If all the leaf nodes try to send the data to the parent node at the same time, the data messages may interfere and cause routing overhead and thus decrease throughput. By applying code division multiple access (CDMA) or frequency division multiple access (FDMA), these access techniques are efficiently meant to avoid collisions.

Information Exchange Phase: In the initial phase, BS can collect the energy and coordinate information of all the sensor nodes. For each round, BS builds the

routing tree and network schedule by using coordinates and energy information. The BS exchange information by sending DATA-PKT to sensor nodes and in return receives CTRL-PKT from them.

4   Simulation Results

The performance of OTBRP protocol is explored in terms of network lifetime and stability period (the time internal or the rounds before the first node dead) against the GSTEB and PEGASIS protocols. The performance evaluation of OTBRP is done on 10 different WSN networks. To make a fair comparison between the protocols, characteristics of the network are used for the proposed protocol are made identical and are described in Table 1.

Figure 3a, b show the average results of 10 simulations of PEGASIS, GSTEB and OTBRP both for setup 1 and setup 2, respectively. These figures clearly show OTBRP is better than the two protocols for first node dead (FND) and half node dead (HND). Due to large instability period, last node dead (LND) is better for GSTEB. Network lifetime is increased by using OTBRP protocol, and thus, less amount of energy is consumed per round. Tables 2 and 3 present the number of rounds taken for FND, HND and LND together with stability and instability periods

Table 1 Network parameters used in MATLAB simulation for OTBRP

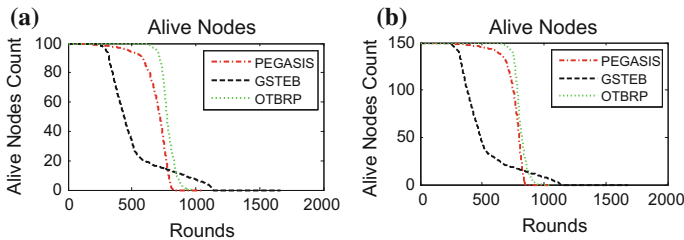| Parameter	Setup 1	Setup 2
Number of nodes, N	100	150
Network size	100 m $\times$ 100 m	
Location of BS	(50, 175)	
Initial energy of normal node, E_0	0.25 J	
Number of CH nodes, K	5% of nodes	
Radio electronics energy, $E_{Tx} = E_{Rx}$	50 nJ/bit	
Energy for data aggregation, E_{DA}	5 nJ/bit	
Radio amplifier energy, ε_{friss_amp}	100 pJ/bit/m^2	
Radio amplifier energy, $\varepsilon_{two\_ray\_amp}$	0.0013 pJ/bit/m^4	

Fig. 3 Number of alive nodes per round using OTBRP for **a** setup 1 and **b** setup 2

Table 2 Comparison of network lifetime of protocols together with stability and instability periods (setup 1)

Protocol	FND	HND	LND	Stability period	Instability period
PEGASIS	215.2	718.2	804.3	215.2	589.1
GSTEB	**277**	436.1	**1131.1**	277	854.1
OTBRP	**641.9**	**771.9**	931	**641.9**	**289.1**

Table 3 Comparison of network lifetime of protocols together with stability and instability periods (setup 2)

Protocol	FND	HND	LND	Stability period	Instability period
PEGASIS	192.7	700.8	758	192.7	565.3
GSTEB	265.8	428.2	**1133.7**	265.8	867.9
OTBRP	**661.8**	**799**	953	**661.8**	**291.2**
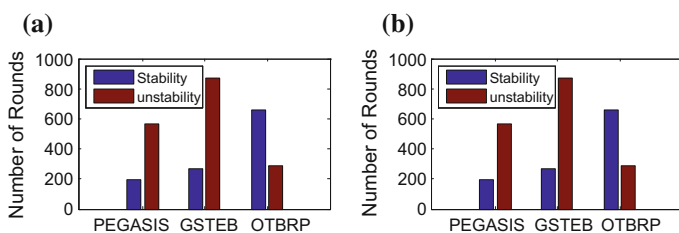
Fig. 4 Performance results for GSTEB, OTBRP and PEGASIS for **a** setup 1 and **b** setup 2

of PEGASIS, GSTEB and OTBRP protocols for setup1 and setup 2, respectively. The use of PN selection using residual energy helps to get longer stability and smaller instability periods as shown in Fig. 4.

5 Conclusion and Future Work

In WSNs, the major design issues in the research of routing protocols are energy consumption and network lifetime. In tree-based routing protocols, parent node selection is an NP-hard problem. Therefore, nature-inspired optimization algorithms may be applied to tackle parent node selection in WSN. In this work, we have proposed OTBRP, in that parent nodes are selected using BPSO on the basis of residual energy of nodes, distance between parent node and root node, and the distance between parent node and child node. Simulation results show that the application of BPSO optimization technique in the GSTEB improves the energy efficiency and prolongs the stability period of the network. Future work can be done to decrease the routing overhead and transmission delay. Though load balancing is not a major problem in OTBRP but still one can work on it.

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