Energy efficient teaching-learning-based optimization for the discrete routing problem in wireless sensor networks

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Wireless sensor networks (WSNs) are composed of sensor nodes, having limited energy resources and low processing capability. Accordingly, major challenges are involved in WSNs Routing. Thus, in many use cases, routing is considered as an NP-hard optimization problem. Many routing protocols are based on metaheuristics, such as Ant Colony Optimization (ACO) and Particle Swarm Optimization (PSO). Despite the fact that metaheuristics have provided elegant solutions, they still suffer from complexity concerns and difficulty of parameter tuning. In this paper, we propose a new routing approach based on Teaching Learning Based Optimization (TLBO) which is a recent and robust method, consisting on two essential phases: Teacher and Learner. As TLBO was proposed for continuous optimization problems, this work presents the first use of TLBO for the discrete problem of WSN routing. The approach is well founded theoretically as well as detailed algorithmically. Experimental results show that our approach allows obtaining lower energy consumption which leads to a better WSN lifetime. Our method is also compared to some typical routing methods; PSO approach, advanced ACO approach, Improved Harmony based approach (IHSBEER) and Ad-hoc On-demand Distance Vector (AODV) routing protocol, to illustrate TLBO's routing efficiency.

INTRODUCTION :

Wireless Sensor Networks (WSNs) are network systems formed by sensors able to communicate without using any specific network infrastructure [1]. There are various categories of sensors, depending on the environmental situation (temperature, humidity, pressure, etc. . .) [2]. Thus, WSNs are used in many applications such as disaster relief, environmental control, precision agriculture, medicine and health care [3]. Nonetheless, there are some intrinsic limitations for the sensors like low process capacity or power [4], and limited lifetime [5]. Hence, new issues appeared in operations research and optimization field [6, 7].

Particularly, many researchers have tended to focus on routing problems.

Routing in WSN differs from routing in traditional communication networks by the lack of infrastructure, unreliable links, and energy consumption [8]. On the other hand, it's qualified as an NP-hard optimization problem [6], which means the necessity of metaheuristics to deal with it [9]. Metaheuristics are robust techniques that start with a set of initial solutions called initial population in the context of evolutionary algorithms. Then step by step explores a sequence of solutions to reach the near-optimal solution. Recently, researchers have addressed these challenges by adopting optimization strategies.

There is a diverse range of metaheuristic algorithms used to optimize routing in wireless sensor networks including the Genetic Algorithm (GA) [10] used to create energy efficient clusters for routing in wireless sensor networks. The Particle Swarm Optimization (PSO) [11–13] which is a simple, effective and computationally efficient optimization algorithm, investigated to address WSN issues such as optimal deployment, node localization, clustering, dataaggregation, and routing. The Artificial Bee Colony (ABC), proposed in [14, 15] is an energy-efficient cluster based ABC procedure, for selecting the optimal cluster heads in order to reduce the consuming energy. Harmony Search (HS) used by Zeng, B. and Dong, Y. in [16] to propose an Improved Harmony Search Based Energy Efficient Routing Algorithm (IHSBEER) for WSNs. And Ant Colony Optimization (ACO) [17], etc

The choice of the right optimization algorithm can be crucially important in finding the best solutions for a given optimization scenario. In fact, the ACO metaheuristic has been successfully applied to solve routing problems in WSN [17, 18]. Some examples of ant-based applications are: Sensor-driven Cost-aware Ant Routing (SC), the Flooded Forward Ant Routing (FF) algorithm [19], the Flooded Piggy-backed Ant Routing (FP) algorithm, the Adaptive ant-based Dynamic Routing (ADR) [20], the Adaptive Routing (AR) Improved Adaptive Routing (IAR) algorithm [21], and E&D ANtraTS [22]. In addition, the authors in [23] proposed Improved Ant Colony Optimization Routing protocol named IACOR, which was shown to be competitive with state-of-the-art approaches.

All the evolutionary and swarm intelligence based algorithms require controlling parameters, which affect the performance of the algorithm. Considering this fact, a new metaheuristic have been developed recently does not require any algorithm parameters to be tuned. Thus, making its implementation simpler and easier. This metaheuristic is known as Teaching-Learning-Based Optimization (TLBO) [24, 25]. TLBO algorithm is based on the teacher's influence on learners output in a class. This new method is originally designed for continuous optimization problems [26, 27]. Since its appearance, TLBO has been used successfully for many multi-objective problems [28, 29] and in different sectors [30, 31]. In this work, we use TLBO for routing in WSN, which is a discrete optimization problem. For this fact, we have proposed a redefinition of the TLBO's equations basically by using the Edge Recombination Operator (ERO) [32]. All the evolutionary and swarm intelligence based algorithms require controlling parameters, which affect the performance of the algorithm. Considering this fact, a new metaheuristic have been developed recently does not require any algorithm parameters to be tuned. Thus, making its implementation simpler and easier. This metaheuristic is known as Teaching-Learning-Based Optimization (TLBO) [24, 25]. TLBO algorithm is based on the teacher's influence on learners output in a class. This new method is originally designed for continuous optimization problems [26, 27]. Since its appearance, TLBO has been used successfully for many multi-objective problems [28, 29] and in different sectors [30, 31]. In this work, we use TLBO for routing in WSN, which is a discrete optimization problem. For this fact, we have proposed a redefinition of the TLBO's equations basically by using the Edge Recombination Operator (ERO) [32].

This paper presents a new communication protocol for WSN based on TLBO, namely TLBOR. The proposed protocol uses packets request through the WSN looking for paths between the sensor nodes and sink. Then, teaching and learning phases are applied to find the path that at the same time short in length and energy efficient, contributing in that way to maximize the lifetime of the WSN. After some iterations, the TLBO protocol is able to build a routing path with optimized energy

Our TLBO-based model provides a good performance in terms of energy consumption, data delivery and reliability. To demonstrate that fact, many comparisons to other protocols such as IACOR, PSOR based routing, AODV and IHSBEER have been performed using MATLAB and C++. Basically, the comparisons environment is varied by changing the number of nodes, coverage areas, number of packets sent and other intrinsic parameters related to the position of the source node and the random deployment. The main objective of the simulations is to confirm the credibility of our routing protocol TLBOR.

The main contributions of this work are the foundation of a new approach for the discrete routing problem in WSNs using the TLBO metaheuristic that was proposed for continuous optimization problems, the integration of the ERO in the operation of this new routing approach and the comparisons with well known routing protocols in literature such as IACOR, PSOR, AODV and IHSBEER.

The remainder of this paper is as follows. Section 2 presents the routing in WSN. Section 3 introduces TeachingLearning-Based Optimization (TLBO). Section 4 describes TLBO adaptation to routing problem in WSN. Section 5 shows the performance evaluation of our algorithm. Finally, Section 6 concludes our work.

Routing problem in wireless sensor networks :

Forwarding data from source to destination in wireless sensor networks differs from that in classical networks in various ways. There is no infrastructure, wireless links are unreliable, sensor nodes may fail, and routing protocols have to meet strict energy saving requirements. Many routing algorithms developed for wireless sensor networks depend on the mobility of sensors or sinks, application field, and network topology. Overall, routing techniques are categorized according to the network structure or the protocol operation (routing criteria) [8].

As shown in Fig. 1, networks structure gathers three different kinds of routing protocols: flat, hierarchical and location based routing. While negotiation, multipath, query and coherent based belong to protocol operation category. Recently, many works in WSNs focus on intelligent optimization using nature inspired metaheuristics systems. Many routing protocols are based on metaheuristics, the ones considered in this work for comparisons are:

• IACOR [23], the proposed routing protocol for a flat network. Using stable sensors and sink, the object is to locate the ideal way, with negligible vitality utilization and solid connections. When an event occurs, source node parts information to N parts, every part is transmitted to the base station by an insect. Ants choose the next hop by using probabilistic choice tenets, and so on until sink. This approach gives great results, comparing to routing protocol EEABR (Energy-Efficient Ant-Based Routing) and original ACO approach [18]

• PSOR [12], the PSO routing protocol which is a population based protocol. It required an initial population (a number of paths from the source node to the sink) and redefined PSO equations to present an adequate adaptation for the discrete routing problem, then found the best path from the source to the destination. PSOR results are better than IACOR in terms of energy consumption and WSNs lifetime as illustrating the comparisons made using the same settings and experimental conditions.

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• IHSBEER [16], is an Improved Harmony Search Based Energy Efficient Routing Algorithm for WSNs, which is based on harmony search (HS) algorithm with several key improvements to address the WSNs routing problem. Such improvements include the encoding of harmony memory, the improvisation of a new harmony and an effective local search strategy is proposed to enhance the exploitation ability, so as to improve the convergence speed and the accuracy of the IHSBEER routing algorithm.

To add more credibility and show the efficiency of the new routing approach proposed in this paper we compare it also with the Ad-hoc On-demand Distance Vector (AODV) routing protocol:

• The AODV [33] is a reactive routing protocol, where the routes are determined just when required. Figure 2 shows the message exchanges of the AODV protocol.

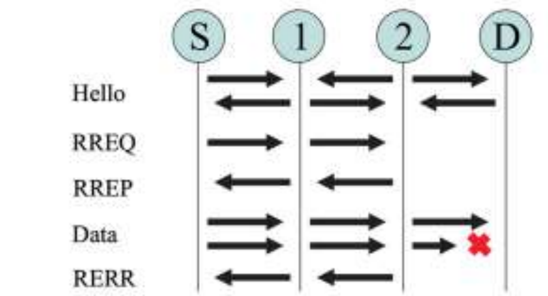
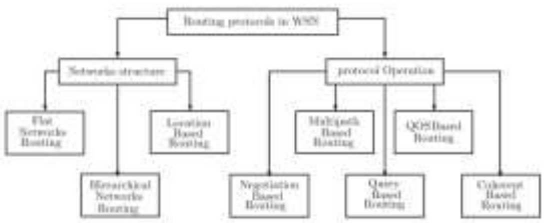


Fig. 2 AODV Protocol Messaging



AODV-node informs its neighbors about its own particular presence by continually sending ”hello messages”. Thus, every node knows the states of its neighbors. To find a route to another node AODV sends a request (RREQ) to its neighbors. A RREQ contains the source node address and the last sequence number received. The receiving node verifies if a route exists and if the sequence-number is higher than the route found then, a route reply (RREP) is sent to the requesting. On the other hand, if the route does not exist, the receiving node sends a RREQ itself to try to find a route for the requesting node. If an error is detected, a route error (RERR) is sent to the source of data.

Teaching-learning-based optimization :

Teaching-Learning-Based Optimization algorithm (TLBO) is a novel optimization method proposed by Rao et al. This approach has been inspired by the teacher’s influence and learners interaction [24, 25]. It outperforms some of the well-known metaheuristics regarding constrained benchmark functions, constrained mechanical design, and continuous nonlinear numerical optimization problems [25]. TLBO has been applied to various problems such as the QoS multicast routing problem [34] and optimal reactive power dispatch problem [35]. It could be split into two basic parts: Teacher phase and Learner phase. Figure 3 describes the TLBO process.

Teacher phase :

Like many other nature-inspired algorithms, TLBO uses a population of solutions to proceed to the global solution. An initial population is a group of learners and the studied matters are design variables. Evaluated the entire population using “fitness” the best solution is considered as a teacher. In this phase, teacher

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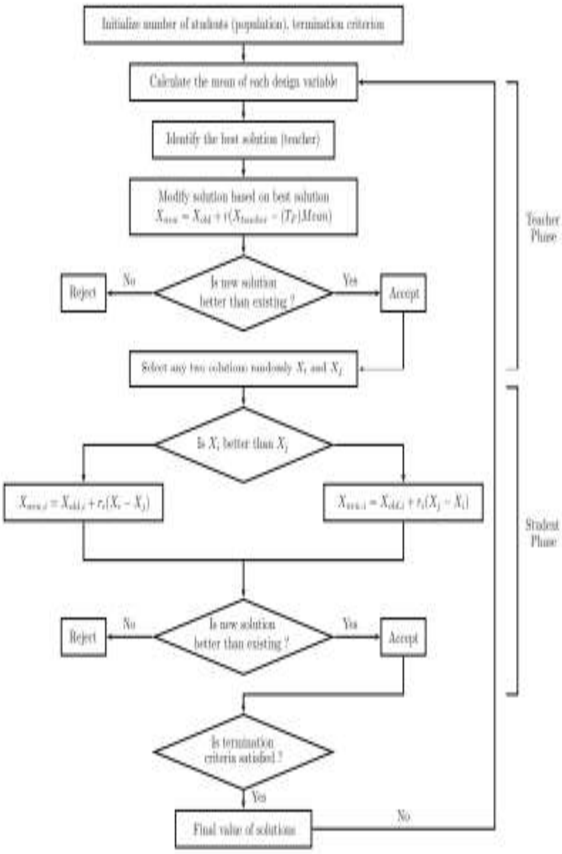
influence is presented by shifting the mean of learners to its level of knowledge (1). Then get

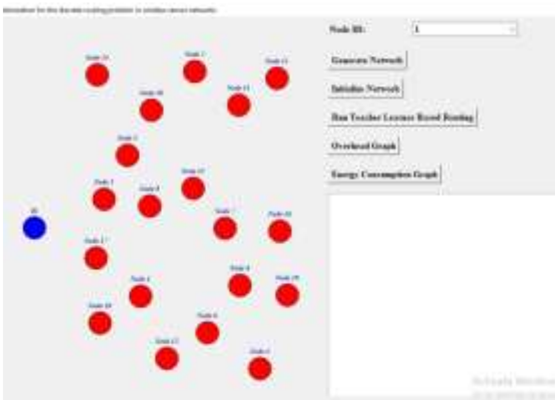


The proposed approach based on TLBO :

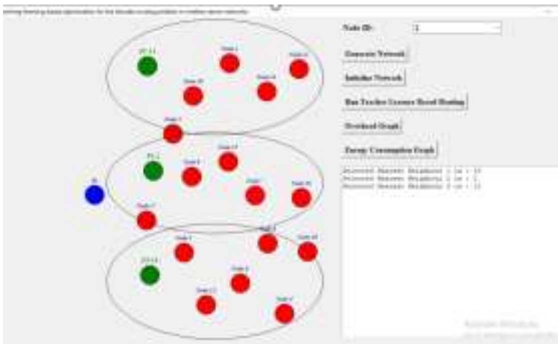
WSNs are known by the strict energy constraint and the limited energy replenishment capabilities. Thus, it is important to optimize the energy consumption for routing, so as to prolong the network lifetime as far as possible. In this section we propose a new routing protocol for WSNs, Teaching-learning-based optimization based routing (TLBOR). This new protocol is not centralized, which means that the algorithm should operate in each node. Its process begins by the initialization of the population of paths, then finding the optimum path using TLBO algorithm, then sending data through it. Herein, the proposed methodology which adapts TLBO to WSN routing is detailed.

To run project double click on 'run.bat' file to get below output screen

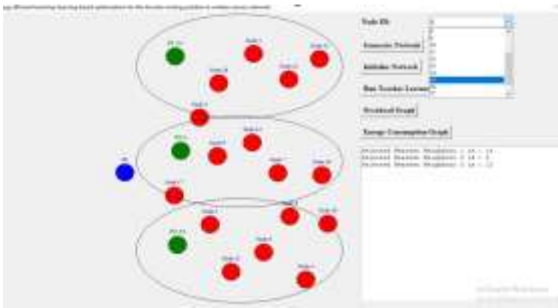
In above screen click on 'Generate Network' button to generate some dummy sensors like below screens



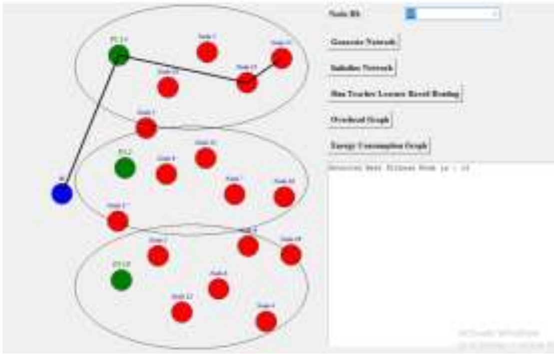
In above screen all red colour circles act like sensors and blue colour node is the base station and all red colour sensor will sense and send data to base station by using nearest routing nodes. Now click on 'Initialize Network' button to find parent nodes which are closer to base station or to find node which accept data from sensor and send to base station



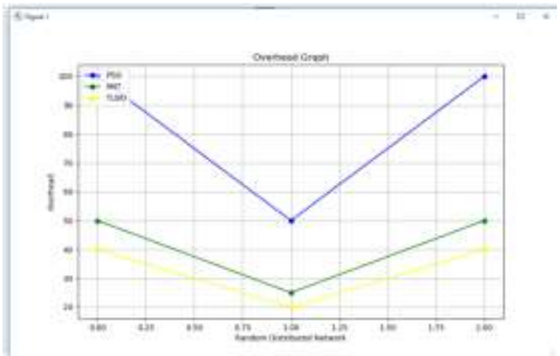
In above screen green colour nodes are the closer nodes to base station which will take data from red colour sensor and send to base station as base station always received data from head node so all green colour nodes are the head nodes and big oval represents which sensors will used which head node to send data to base station. Now select any sensor from drop down box to send data to base station



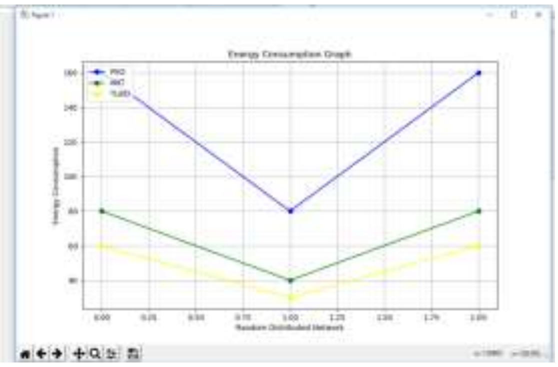
In above screen I am selecting 15th sensor to send data to base station and now TLBO algorithm will select best routing neighbours or optimize neighbours to send data to head node and head node will send to base station. Now after selecting sensor click on 'Run Teacher Learner Based Routing' button to send message like below screen



In above screen we can see sensor 15 chosen Node 11 as the best routing node and node 11 send data to head node P1-14 and P1-14 sending data to base station. Similarly you can select any sensor and then routing will perform using TLBO algorithm and now click on 'Overhead Graph' button to get below graph



In above graph blue line represents ANT overhead and green line represents PSO over and yellow line represents TLBO and in all algorithms TLBO has less overhead and now click on "Energy Consumption" graph button to get below graph



In above graph we can see PSO and ANT consume more energy compare to TLBO algorithm so TLBO is better than PSO and ANT

CONCLUSION :

Routing in WSN has introduced many challenges compared to traditional data routing in wired networks. This paper presents a new routing protocol using a novel optimization method based on the philosophy of the teaching-learning process combined with the edge recombination operator. That TLBO approach ensures a robust optimization of the energy consumption, thus increases network lifetime as validated by simulation results. By performing experimentation in the same simulation conditions, TLBOR protocol is compared to some routing protocol in WSNs such as: ACO, PSO and IHSBEER approaches and AODV protocol. Then overall the results show that our TLBOR protocol is better in terms of energy consumption and network lifetime. As a future work, it is planned to improve our routing approach by incorporating other quality of service (QoS) metrics and performing the experimentation in real WSN. Additionally, the improved approach will be applied to mobile nodes and networks with multiple sinks.

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