Scalarizing Metaheuristics for Effective Routing in Wireless IoT Environment

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Abstract

Energy efficiency is a major concern in certain specialized IoT environments. A scalable routing protocol that is energy efficient can effectively aid in extending the lifetime of a network. This work presents a metaheuristic based routing model that can be used for energy efficient routing in IoT environment. The particle swarm optimization algorithm has been scalarized to enable reactive routing. Scalarization ensures selection of node dynamically based on the current situation. This ensures that the transmission is successful irrespective of failure of any nodes. Hence reduces the need for retransmission. Every transmission generates a single initial node to which the packet is to be transferred. Further routes are identified as the packet getting transferred. This process of reactive routing highly reduces retransmission, and also ensures that the packet is transferred to a capable node. Experiments have been conducted and comparison with existing state of the art model indicates that the Scalarized PSO (S-PSO) model exhibits very low overhead and effective load balancing.

Keywords: *Routing; Metaheuristics; Scalarization; Reactive Routing; IoT*

1. Introduction

The current decade has seen a huge increase in wireless networks [1]. This has eventually resulted in the emergence of ad hoc networks. Wireless networks can be homogeneous or heterogeneous in nature and are usually created for specific applications [2, 3]. Some major applications that are heavily dependent on wireless sensor networks include health care, home security, environment monitoring systems and military applications [4]. Internet of Things (IoT) is a special case of wireless sensor networks that have currently increased in usage. In IoT environment, multiple objects or sensors are deployed to collect and exchange information [5]. These objects are generally heterogeneous in nature. Hence challenges arise when the need for information integration arises. Since the information are in different formats, it becomes mandatory to develop an integration system for effective aggregation and processing of information.

Sensors used in wireless sensor networks are usually low cost and resource constrained models with look complicated circuits. They are deployed anonymously and work in an ad hoc manner. They can be static or dynamic in nature [6]. They are self configuring in nature and the type of routing performed by them is usually ad hoc. Issues arise when these networks are deployed in remote locations [7]. In such cases, power depletion becomes a major issue. Routing is the process that generally constitutes highest power consumption in networks. Wired networks do not have this issue. Hence existing routing models concentrate only on providing effective routes and are not concerned about the power consumption. It becomes necessary to provide effective routing protocols especially on wireless and power constrained networks.

In case of time sensitive applications time based synchronization of messages becomes highly important. In case of resource constrained environment, energy efficiency becomes a major challenge. Routing is the process that requires highest amount of energy [8, 9]. Using same nodes for routing generally results in power depletion in certain nodes. This situation is not desirable in a wireless network, as it sometimes becomes difficult to add batteries to sensors [10]. Hence, distribution of traffic becomes an important requirement when routing in

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wireless sensor networks. Standard routing protocols consider distance as the only metric. Hence, specialized routing models are required in wireless sensor networks [11]. This work presents an energy effective routing model that uses metaheuristic techniques to perform routing using multiple objectives. The model concentrates on providing energy efficient routing, and also focusses towards reducing retransmission. Usage of metaheuristic models also ensures faster route detection.

2. Related works

Improving network lifetime has been one of the major areas of research in domains involving interconnected heterogeneous devices. This section presents some of the latest researches in the field of IoT involving energy efficient routing.

A metaheuristic based model to improve network lifetime and to reduce energy consumption has been presented by Maheshwari et al. [12]. This work uses Butterfly Optimization Algorithm (BOA) for the clustering process. Cluster based routing that is managed by cluster heads is the major contribution in this work. Communication between cluster heads is performed using Ant Colony Optimization (ACO). Another clustering based routing protocol for multipath routing has been presented by Wang et al. [13]. This work improves on the existing LEACH protocol to improve performance. The routing technique creates multiple disjoint paths for effective routing. An energy efficient clustering based routing protocol has been proposed by Han and Zhang [14]. This work analysis multiple clustering factors prior to the selection of the cluster head. Harmony search based routing model integrated with clustering techniques has been proposed by Lalwani et al. [15]. The fitness function of the harmony search algorithm has been modified to include additional factors like distance para meters and energy. The model aims to mainly provide energy efficiency. Other similar techniques that use metaheuristic models for routing include Simulated Annealing based model by Mekonnen et al. [16] and Upendran et al. [17].

An IoT based routing model specifically designed for time sensitive applications has been proposed by Jane et al. [18]. This is an ad hoc routing model that performs packet based time synchronization. The model aims to reduce network overhead and transmission exchanges. A randomized routing model aimed at incorporating privacy preserving techniques in the routing process has been proposed by He et al. [19]. Source location privacy is enabled by using multiple phantom nodes. Further, the model also reduces energy consumption during the routing process. Similar techniques concentrating on source location privacy includes the energy constrained routing models by Ozturk et al. [20, 21], and Tan et al. [22].

A multihop routing protocol has been proposed by Nivedhitha et al. [23]. The work mainly concentrates on energy efficiency by providing a balance between the reliability levels of a node and energy contained in the node. This is a clustering based routing protocol that proposes the concept of super cluster head, which maintains all the records of cluster heads and its members. Another technique that concentrates on energy optimization in a dynamic environment was proposed by Raj et al. [24]. It is a decentralized routing process, which identifies the nodes based on local information. Energy efficiency and load balancing are considered as the major components in this work. A reliability based routing model has been proposed by Javaid et al. [25]. The model has been designed to provide energy efficiency by considering direct communication routes. Thermal aware routes where also used to ensure effective delivery. A fractional particle lion algorithm to improve energy efficiency has been proposed by Bhardwaj et al. [26]. This work uses multi objective optimization for the selection of nodes to ensure energy effective routing.

3.Scalarized PSO (S-PSO) based Routing for Improved Network Lifetime

Improving the network lifetime is one of the major requirements in the IoT environment. Better network lifetime and effective load balancing can result in highly effective communication and sustainability in IoT environment. This work presents a scalarized particle swarm optimization model to identify routes in an IoT environment. The proposed work is composed of 4 major sections; search space creation, particle distribution, scalarized reactive node selection and temporal memory maintenance for load balancing. Algorithm for the proposed model is provided below.

Algorithm for S-PSO:

1. *Network Initialization and device configuration*
2. *Search space creation for PSO*
3. *If transmission is initiated*
    a. *Particle distribution in the search space*
    b. *Initialize velocity component*
    c. *Trigger movement of particles based on identified velocity*
    d. *Determine pbest and gbest*
    e. *Modify velocity based on pbest and gbest*
    f. *If convergence is not reached goto step c*
    g. *Add converged node to traversal list*
    h. *Reset pbest and gbest*
    i. *If destination not reached goto step b*
4. *Reset traversal list and search space*

3.1 Network Initialization and Search Space Creation

IoT environment contains multiple heterogeneous devices. Connecting and communicating between the heterogeneous devices is one of the major challenges in IoT. The first face is to deploy and connect all the devices. After the initialization of nodes, and the identification of node coordinates using the hello packets, the search space is created for the PSO environment. The search space encompasses coordinate of the nodes and their upper and lower bounds. The search space serves as the base navigating environment for the particles in PSO. This work assumes that the nodes in the network are static in nature. Hence, the identification of node coordinates is performed only during the initialization phase.

3.2 Particle Distribution

The process of path identification begins when transmission is triggered. Particles are the active agents that move around in the search space to identify the most optimal solution. The particles are distributed in the search space in random, and the process for identification of the optimal solution begins. PSO uses two parameters, the pbest (particle best solution) and the gbest (global best solution). Along with these two parameters, traversal list is also used as an additional parameter. the best solution so far identified by every particle is stored in the pbest parameter. Every particle maintains its own pbest value. The overall best solution identified in the environment is stored as gbest. One gbest value exists for a single search space. Traversal list is a queue that maintains the last n notes that has been traversed. This list has been maintained to ensure load balancing and for balanced energy consumption. During the initial transmission, the traversing list, pbest and gbest are initialised. In further transmissions, only the pbest and gbest are reset.

3.3 Scalarized Reactive Node Selection

PSO is generally used to identify paths in a network. This model has been scalarized to perform reactive routing. The process of next node selection is performed only when a transmission request arises, and not prior to the transmission. The transmitting node only knows the details about next node, and not the entire path. The path is identified only during the transmission process. This is due to the fact that IoT devices are independent in nature. Even if a complete path has been initially established, the nodes contained in the path can also accept other traffic. In case of long paths, nodes at the end of the path have a huge possibility of getting depleted before the network packet arrives. This eventually results in retransmission. Scalarisation ensures that the next node for transmission is selected by the previous node. Hence, the possibility of retransmission due to node depletion is effectively avoided.

After the distribution of particles, the movement of particles is determined by the velocity component. The initial velocity of particles is identified by,

$$V_i \sim U(-|b_{up} - b_{lo}|, |b_{up} - b_{lo}|)$$

Where b_{up} and b_{lo} refers to the upper and lower bounds in the search space.

After the initial movement, the particle occupies a position in the search space. As PSO is continuous in nature, the particle has to be manually moved to the nearest node. The nearest node is identified based on the location of the particle using the Euclidean distance formula given by,

$$dist_{m,n} = \sqrt{(x2 - x1)^2 + (y2 - y1)^2}$$

After every particle occupies a standard node, the pbest and gbest are calculated based on the fitness of the nodes. Fitness of nodes is determined based on it's distance from the current node and the residual charge contained in the node. This work considers energy efficiency as a major component in determining the fitness. However, the fitness function can be extended to add trust, node type and other factors. The fitness function used by this work is given by,

$$fitness_{m,n} = \frac{charge_n}{dist_{m,n}}$$

Where $charge_n$ is the charge of the node n and $dist$ is the Euclidean distance between the source node m and the destination node n.

After determining the fitness of each node, the pbest and gbest values are calculated. Further movements are determined by the velocity function that includes the pbest and gbest values. The new velocity function is given by,

$$V_{i,d} \leftarrow \omega V_{i,d} + \varphi_p r_p (P_{i,d} - X_{i,d}) + \varphi_g r_g (g_d - X_{i,d})$$

where $P_{i,d}$ and g_d are the pbest and gbest values, r_p and r_g are random values, $x_{i,d}$ is the current position of a particle, and ω, φ_p, and φ_g represents the importance level of velocity, *pbest* and *gbest* values.

After the movement of the particle from the current solution, the movement of the particle is again discretized and it is moved to the nearest node. The process of identifying the pbest and gbest values is performed again, the new velocity component is identified and movement is triggered. This process is repeated until stagnation is reached, where all the particles are concentrated in the same node. The gbest value at this point is considered as the final solution. Packet transmission is performed to the node that has been identified as the current gbest.

3.4 Temporal Memory Maintenance for Distributed Node Selection

Temporal memory maintenance is the component that has been added in the current work to ensure distributed node selection. The traversal list maintains a temporal memory of the nodes being traversed. After every node is selected, it is added to the traversal list. Traversal list is maintained as a temporary queue of fixed size. As every recent node is added, the node that is at the end of the list is removed. A node is selected only if it is not contained in the list. This additional condition is checked prior to selecting a node using the modified PSO model. This process ensures that no node is frequently selected, hence providing effective load balancing.

5. Results and discussion

The proposed model has been verified by constructing a search space with 30 nodes. Each node is considered as a different IoT device and is distributed at a random location in the search space. Every node is also provided with a different configuration to ensure heterogeneity in the search space. The proposed S-PSO model has been implemented using C#.Net. Two types of transmissions where performed and the results were recorded. In the initial type, transmissions where initiated from random nodes, and also directed towards random nodes, in the next type of transmissions, starting and ending nodes were fixed and the different paths identified where recorded. Node properties and identified paths have been recorded by initiating 100 random transmissions.

The selection overhead incurred during specific path based transmissions is shown in figure 1. Selection overhead refers to time taken by the algorithm to determine the node for transmission. Selection overhead for 100 transmissions has been recorded and is shown in figure 1. The selection overhead varies between 1 millisecond to 8 milliseconds. The average selection overhead has been identified to be 4 milliseconds. This shows that on average every packet requires 4 milliseconds prior to transmission. This is a very low time requirement which is almost equivalent to immediate transmission.

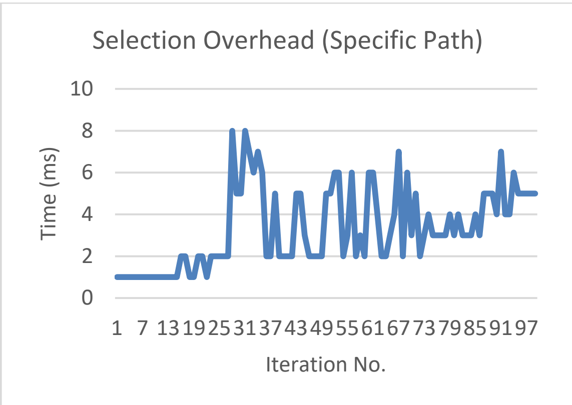

Figure 1: Selection Overhead of S-PSO

Distance covered while traversing through a specific path has been recorded and is shown in figure 2. It could be observed that the distance covered varies between the minimal distance and also a maximum distance of 300. These variations can be attributed to the presence of traversal list, which has been deployed to ensure load balancing between nodes.

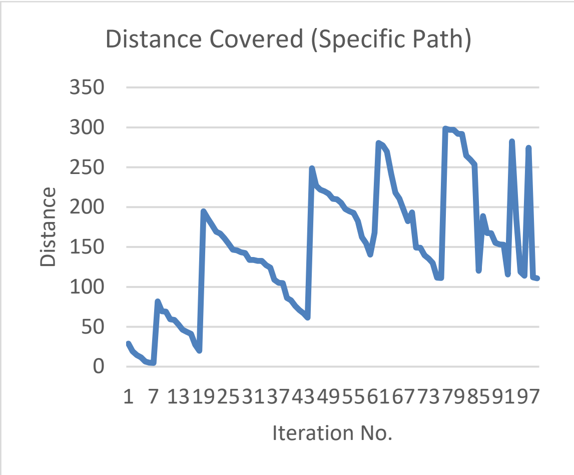

Figure 2: Overall Distance Covered (S-PSO)

Performance of the proposed model has been compared with the routing model proposed by Upendran et al. [17]. The average path length obtained in the S-PSO model has been identified to be less than 150, while the path length from Upendran et al. reaches to more than 170. This shows that the S-PSO model exhibits better routing strategies.

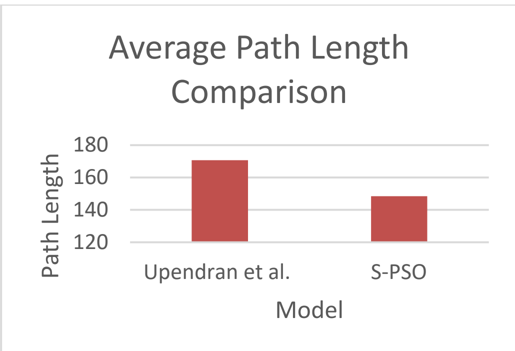

Figure 3: Average Path Length Comparison of S-PSO

A comparison of the node usage levels is shown in figure 4. Distributed usage signifies better model, while skewed usage signifies ineffective load balancing techniques in the model. The variations in S-PSO model is found to be very minimal, while variations in the model by Upendran et al. is found to be very high. This signifies that the S- PSO model exhibits better load balancing.

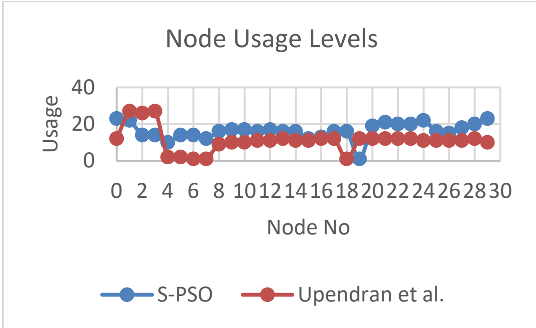

Figure 4: Comparison of Node Usage Levels of S-PSO

6. Conclusion

Routing in IoT environment is one of the major factors that can effectively reduce energy depletion and can extend the network lifetime. This work presents a metaheuristic model that aids in routing that is energy efficient in nature. PSO algorithm has been scalarized and its fitness function has been modified to include multiple criterion based decision making. The process of reactive routing is included during the route selection process. This ensures that retransmission is avoided due to failed nodes in the path. Temporal memory is maintained to provide load balancing, hence ensuring extended network lifetime. The model has been specifically designed for static environment, however, it can be extended to a dynamic environment. The limitation identified in this model is that the distance covered is slightly higher. Future extensions of this model will aim to reduce the path distance.

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