An Energy-Efficient Table Driven routing protocol with increased throughput using Distributed Heuristic algorithms for Wireless Sensor Networks

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Abstract— Open vehicle routing is an effective area in operations research based on similar assumptions compared to wireless sensor networks. It's appropriate to make use of these techniques to fix certain difficulties in the WSNs. To show the feasibility of this approach, a table driven routing protocol is developed. Hence distributed heuristic approach is proposed. Distributed heuristic makes the algorithm suitable for large-scale network operations using Ant Colony Optimization technique. This approach is evaluated by comparing its performance to similar protocol through simulation using NS-2.

Index Terms— Ant Colony Optimization, energy efficiency, heuristic algorithm, Open vehicle routing, operations research, routing protocol, wireless sensor networks.

1 Introduction

IN the latest years, wireless sensor network (WSN) has arrived as a modern kind of communication systems with restricted computation, connection capabilities, and repository supplies. A WSN contains of a set of sensors that is distributed to hear natural conditions used for a vast area of operations. Number of sensor nodes is deployed to cover the curious area in order to meet the observing requirements. Such networks are mainly designed to sense a field of interest, process the sensed values, and transport the data to a destination node (sink). The locality of sensor nodes need not be predetermined. This allows random deployment in unreachable areas or emergency relief operations**.**

Due to their limited power and short area, sensor nodes need to collectively work in multi-hop wireless communication architectures to allow the transference of the sensed and collected information to the nearby base station. Unlike wired networks in which the physical wires avoids an attacker from negotiating the security of the network, wireless sensor networks face many security challenges that serve a needful to a successful deployment of wireless sensor networks especially for military applications. Moreover, the resource-malnourished nature of sensor nodes makes the security issue very critical.

WSNs are also developed for the observing critical civilian or military infrastructures that are endowed with many unique features which are not available in conventional wireless networks. Most of the infrastructures, such as bridges, buildings and tunnels, have extensively long life cycle in the order of years or decades, with very slow changing rates. Its application includes surrounding observation [1], experimental monitoring [2], accidental exposure [3], terrain examination [4], and system observation [5]. Ensuring the delivery of packets in such applications is required to achieve adequate QOS (Quality of Service).

In many of the sensing applications, source or root nodes sends packets to destination nodes through a number of intermediate nodes that lead to the problem in finding paths which allows to transmit all the packets in specified time frame. At the same time, a factor such as energy efficiency has to be taken into account. The major motive for the paper uses OVR (Open Vehicle Routing) difficulties that have similar presumptions and limitations in comparison to WSNs [8], [9], [10]. In Open Vehicle Routing on goods shipping, the main goal is to transmit goods to required clients in given time period with minimum cost of shipping. Here a packet delay is treated as goods transmission time, and energy cost as goods transmission cost.

Inspired by the observation, the work in this paper develops a routing protocol.The protocol is formulated by considering cost of energy in sending packets. The problem addressed by the protocol is considered to be NP-hard. Distributed heuristic algorithm using ant colony optimization is introduced to decrease the overhead involved and in order to obtain correct solutions. The approach is evaluated through large simulation with Network Simulator-2 [12] and evaluation outputs are presented.

The remaining section of the paper is set up as follows. Section 2 includes the related work of open vehicle routing problem. Section 3 explains the detail design of the distributed heuristic algorithm. Section 4 presents the simulation results on NS-2 in comparisons to baseline protocol. Section 5 finally concludes the paper.

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2 Related work

This section describes the background theory on the vehicle routing problems.

2.1 Vehicle Routing Problem

VRP (Vehicle routing problem) [8] is a NP hard problem in operational research. VRP obtain paths in-between terminal and clients with specified cost in such a way that the transportation cost is reduced with involving minimal number of vehicles, considering capacity limitations. With extra limitations, VRP is stretched out to solve various problems. One of such problems is the VRPTW (vehicle routing problem with time windows) [9]. Such sort of difficulty exists generally in transmitting the services where any number of like vehicles along with pre-set capacity delivers a group of clients with costs at various time intermissions. VRPTW attempts in reducing the overall transmission cost with minimal number of vehicles, without disobeying time limitations in distributing goods. VRPTW in addition can be prolonged to OVR problem with time deadlines (OVRP-TD) [10] where vehicles aren't necessary to come back to terminal or destination, and time windows are restored by timing constraints.

Ozyurt*et al.* [10] introduced the closest insertion technique, in which the extreme or last node is selected first to be linked with path. Each selected node later selects immediate neighbour which hasn't been set a path repeatedly and links to that neighbour. The steps are imitated till all clients are linked by paths. Solomon [14] proposed PFIH (push forward insertion heuristic) algorithm that chooses the client repeatedly with minimum extra addition cost as next intermediate node as long as all clients are linked. Once basic paths are obtained, many algorithms [10], [15], [16], [17] are refined in order to obtain close-optimum results using Tabu search [11], simulated annealing [18] or genetic programming [19].

3 Design of Algorithm

In this section, the distributed algorithm is proposed. Initially the problem model is explained and how to modify present approaches in OVR research to WSNs. Given that the problem is NP-complete, distributed heuristics is developed for getting approximate solutions.

3.1 Problem Model

N sensors are distributed that are created by a connected graph G= (V, E), where E indicates wireless connections in-between nodes. Each connection is considered directional. Node M is selected as source to conduct sensing activity. All the packets should be transmitted to the destination within a given time limit d. The main goal of the reaching action is to deliver packets with minimal overall cost.

The weight of the link l_{ij} i.e. c_{ij} is set for links with correct values. A higher cost is assigned to connections linking nodes with lower remaining energy to meet the objective of lifetime balancing, so that those links will be less rarely chosen by the algorithm. The optimization goal is to send all packets to the sink such that the packet deadline constraint is not violated.

3.2 Distributed Heuristic Algorithm

The algorithm uses the ant colony optimization [19] and topological transmitting techniques. It contains two stages: status intimation and path generation. In the status intimation stage, sender node transmits forward ants circulating present condition, which includes remaining energy, to nearby nodes within I hops. The status information of neighboring nodes is gathered by sender node with the collected backward ants. At the status intimation stage, ants are sent with an altered topological transmitting routing protocol that selects the node having the highest remaining energy at the same time making geographical movement to the sink as next intermediate hop. Once a node gathers status data of every neighboring node, the path generation stage is started i.e. RPFIH is executed in a distributed manner based on gathered neighbor status. The algorithm of ant colony gossiping is presented in Algorithm 1. Particularly, the design operates in following way. At the starting of every period, sender node guesses which neighboring nodes will be the sender node, according to given arbitrary seed to every neighbor node. The node then creates forward ants aiming at every neighboring sender nodes. The function of forward ant is to identify the route and gather data while travelling, and the function of backward ant is to return to the sender node and notify about nearby nodes to modify data with gathered information.

If a conveying node receives a forward ant, it chooses the neighbor node having the highest remaining energy making movement to sink as next intermediate node and forwards out ant. The forward ant gathers data of the current condition and remaining energy of every node that it meets via the path. The backward ant is created with one among the three conditions: First, forward ant come across one more ant transmitted by another sender node in which they exchange data instantly; second, starting destination of ant is reached and it's known to be a sender node; third, starting destination is reached, but it's not a sender node. If any one of these condition is met, backward ant is transmitted through traversed route of forward ant and every node is modified with gathered data collected by backward ant along the path. One benefit with ant colony gossiping is that the information gathered by nodes can be reduced by making sure the gathered status to be more relevant. Finally, sender node s gathers a set of sender nodes S, and weight of e edges W_s. Every node in S is added to path in the path generation stage. It consists of weights of edges for W_s passed by ants transmitted or received by node.

In distributed approach, the path generation stage incorporates RPFIH. For the sender node, it starts RPFIH when no pass by sender node is found with longer distance to destination in ant colony gossip phase. Since every node initiate with specific quantity of energy based on type of node, sender node correctly guess the condition of neighboring nodes. Here, the minimum cost route from a sender node to passby sender node is computed with presently obtained data. Every sender node initially calculate the minimum cost route to every other nodes on the border of gossip range making topological

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movement to the destination and estimate approximate cost of route from that node to the destination, such that the node with minimum overall route cost is chosen.

Distributed design is presented in Algorithm 2. The algorithm ends once all the sender nodes are added in the optimized route.

Algorithm 1: The Ant Colony Gossiping Algorithm

Input: Topology graph G, the sender node s, the passby sender nodeset S_s
Output: s spread status to passby neighbors, and gathers status of passby neighbors
1: **for all** $s_i \in S_s$ **do**
2: s obtains a forward ant to s_i , where the ant carries a tuple as <*sender, sink, intermediate node*>, where *intermediate node* is a tuple < *ID, role, energy level* >
3: **end for**
4: **if** Node $n \notin S_s$ gets the forward ant a **then**
5: n creates an *intermediate_node* tuple in, and stores in into payload of a
6: n sends a with the modified topological transmitting routing protocol
7: **end if**
8: **if** Two forward ants from sender nodes s_i and s_j meet at node $n \notin S$ **then**
9: Ants interchange information
10: n creates backward ants towards s_i and s_j
11: **else if** Node $n \in S_s$ **then**
12: n creates backward ants towards s
13: **else**
14: n selects $s_{new} \in S_n$, where DISTANCE (s_{new}, s)> DISTANCE(n, s)
15: Repeat the procedure, till a sender node is found
16: **end if**
17: **if** A backward ant travels to a node n **then**
18: n updates neighbor status with backward ant payload
19: **end if**

4 Evaluation Based on Simulation

This section describes the performance evaluation results that are presented on huge network topology using a simulation platform. The distributed heuristic algorithm is implemented to evaluate the proposed protocol and its performance is compared in terms of computational overhead, average energy consumption and packet delivery ratio to selected baseline.

4.1 Experimental Settings

The design is simulated in NS-2 to realise the network performance of the proposed protocol under various delay requirements. In the simulation, a uniform network topology with 50 sensors is selected as simulation environment. Every node must have atleast four adjacent neighbours to interact. It is assumed that a data collection procedure is distributed, that is executed regularly with a length of period 2 min. At starting of every period, an arbitary node is chosen as source.

Algorithm 2: The Distributed Heuristic for Proposed Protocol

Input: Topology graph G, the sender node s, the neighbor sender node set S, the deadline set D, the remaining time of packets RT, and the destination node t
Output: Constructed paths with $s_i \in S$ with the minimum addition cost such that D is not violated
1: Execute ant-colony gossip to gather status of neighbors
2: Estimate the minimal route cost of s and all $s_i \in S$ to the destination t using the Dijkstra's algorithm
3: Put all nodes in the sender set S into the intermediate list L
4: **if** $\forall$ DISTANCE$(s, t) >$ DISTANCE(s_i, t) **then**
5: goto 14
6: **end if**
7: **if** path generation packet rc is received **then**
8: Extract partially constructed route pr from rc, and the minimal remaining time of packets d_m of pr
9: **If** s is already assigned a path **then**
10: Transmit a packet to inform the previous sender node, and terminate
11: **end if**
12: Remove $n \in pr$ from S, and goto 14
13: **end if**
14: **for all** Node $s_i \in L$ **do**
15: Calculate the additional overall delay d_{incr} = DELAY(s, s_i) +DELAY(s_i, t)
16: Calculate the additional cost as PATHCOST(s, s_i)+ PATHCOST(s_i ,t)
17: If the additional cost is the lowest, and the delay $d_{incr} \leq d_m$, append s_i to pr
18: Update the remaining time of each packet i as $r_i = r_i$ –DELAY(s, s_i)
19: Send a construction packet to s_i with payload pr and $d_m = \min r_i$
20: **end for**
21: **if** No intermediate s_i is found **then**
22: Select t as the next node, and transmit construction packet to t
23: Send construction packets with empty path to each $s_i \in S$
24: **end if**

Once sensing data is ready to report, distributed algorithm is called to obtain new routes according to the current selection of sender node. The gossip range is assigned to 3 hops. The performance of distributed protocol is compared with routing baseline.

- Minimum spanning tree (MST) routing: It is an extensively utilized, traditional routing algorithm in WSNs, where a minimum spanning tree is generated to gather information to destination.

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As the objective of the protocol is to join sender node having minimal overall cost with limitation which tends to achieve balance in-between packet time constraints and energy efficiency, the protocol is compared with relative protocol on these metrics.

- Computational overhead: It is an excess or indirect usage of memory, computation time, or any other resource which is needed to achieve a specific objective.
- Average energy consumption: It's computed as average energy consumed by entire network each time.
- Packet delivery ratio: It is measured as the number of packets transmitted to the destination successfully.

4.2 Algorithm Overhead

The average time used to complete one round of algorithm calculation is evaluated to show scalability of algorithm in this section.

The average time utilized by every sender node is determined for generating the paths in a distributed manner according to time overhead versus gossip range, as presented in Fig.1.

The computational overhead of distributed heuristic in every node is correlated with gossip range and algorithm finishing time is firmly related with size of network. In this case, the time for completing algorithm computation is gathered on every node with various gossip ranges in a uniform network of 50 nodes. Certainly, when there is a larger gossip range, more network information is to be gathered. This results in longer time to end the calcuation, and in fact, will be too long for gossip ranges more than 5. The gossip range is chosen as 3 in this section.

4.3 Experimental Results for WSN

In order to evaluate energy efficiency of the proposed protocol, a set of experiments is performed to run the protocol under various delay constraints. The delay constraints of packets are assigned to 9, 19, 38, 54 and 82ms independently for each execution of experiments. As selected baseline does not consider delay constraints, the results dont have greater deviations on consumption of energy under various delay constraints.

To evaluate the performance of energy efficiency of the design, the average consumption of energy in entire network is computed in every period, as presented in Fig. 2. It is seen that the distributed protocol takes less energy on average in comparison to the baseline. It is because on average only fewer nodes are used to send packets in every period. Similarly the packet delivery ratio is computed for different network size in each period, as shown in Fig. 3. It is seen that the distributed protocol has a better packet delivery ratio in comparison to the baseline

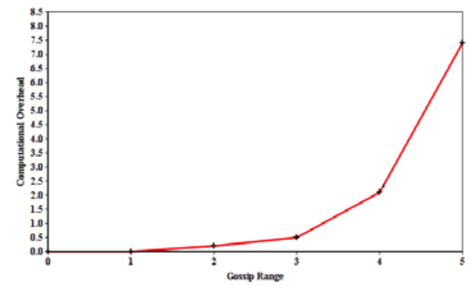

Fig. 1. Computation overhead of distributed heuristic approach with different gossip ranges in a network with 50 nodes.

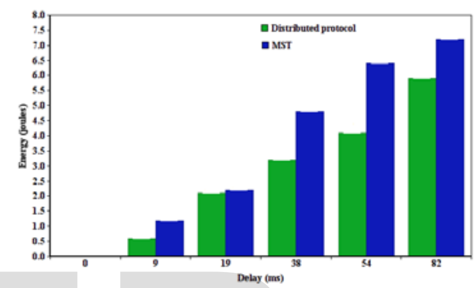

Fig. 2. Average energy consumption of the network executing different routing algorithms.

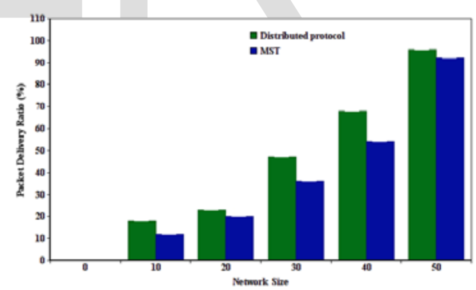

Fig. 3. Packet delivery ratio for different routing algorithms under different network sizes.

5 Conclusion

Energy Efficient table driven routing protocol has been proposed with increased throughput for wireless sensor networks, which is influenced by modern techniques developed for open vehicle routing problems with time deadlines (OVRP-TD) in operational research. The goal of the research work is to generate routes that connect source node with optimal total path cost, under the packet delay requirements constraints. Therefore, distributed heuristic approach is developed to reduce computational overhead and average energy consumption in case of large-scale network operations. It is also shown that the proposed approach delivers an increased packet delivery ratio in comparison to relative protocol.

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