

Multi-objective routing optimizations in cluster based Sensor Networks

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Abstract— Wireless sensor networks have many objectives to be addressed to. These objectives have to be satisfied in order to obtain sufficient excellence in the application of the wireless sensor networks. The multi-objective optimization method proves to be a very efficient tool in the application of these objectives in the wireless sensor fields. The multi-objective optimization methods are implemented onto the wireless networks and an observation is done so as to determine how the objectives are adhered to.

Keywords— Wireless Sensor Network, Clustering, Optimization

I. INTRODUCTION

The wireless sensor networks (WSNs) is an issue that possesses multiple objectives and all these objectives [3,4,7,8,9] have to be addressed to equally so that the needs of the WSN is satisfied i.e. an efficient network of the sensor nodes is established. Multi-objective optimization works in the manner of mathematical application [6]. The objectives' requirements are defined to be as certain variables and the objectives themselves as certain constraints. These constraints or functions are thus solved to get an optimal solution which shall effectively reduce the problems of WSNs.

II. OBJECTIVES OF WSN

Certain objectives of the wireless networks are apt for consideration. These include:

1. Traffic density
2. Proximity of the routes defined
3. Overall length of the route
4. Minimization of routes
5. Load balancing
6. Energy efficient connections.

But these conditions if dealt with independently can create obstacles for the other constraints. Thus we need to solve these or emphatically reduce these problems in the sense that there is consideration of the other constraints mentioned. The best option would be of approaching in the manner using the Multi-Objective Optimization.

In order to design efficient cluster based routing protocol [8,9] for large scale wireless sensor network we adopt the multi objective problem formulation for vehicle routing

problem in [1]. In the present scenario we shall consider the following the constraints for WSN clustering:

1. *Number of routes*: the total maintenance of the network is on the number of the routes created. If these are more than the optimal requirement, then problems related to efficiency are created.

2. *Total route length*: it is important to reduce the total route length to create better connectivity.

3. *Load balancing*: it is a direct emphasis on the efficient utilization of the bandwidth capacity provided and also the limit the nodes possess.

4. *Length balancing*: this reduces the overall variation of the length of the routes traversed.

5. *Node - cluster head distance*: this is a direct relation of a closed compact cluster formation.

III. FORMULATION

The following sets are defined:-
SETS,

S = Set of cardinality 1 representing the base station. The base station being the singular representative for data reception and also for the data processing unit, the cardinality shall be taken as 1.

B = Potential Cluster Heads. We shall assume this to be a set for the convenience in the fact representing the main outlet point of a cluster. The set shall denote all the potential nodes that are apt for performing the task of the cluster heads. The members for this set shall be defined as the process continues.

I = All potential Cluster Heads including nodes. This set includes all those nodes that are present in the network. This includes the nodes being considered as cluster heads also.

J = set of nodes

K = set of routes

The following parameters are defined:-

PARAMETERS,

W = bandwidth of the route i.e. load capacity

C_{ij} = distance of the nodes from each other or of the nodes to potential CH

S_j = maximum distance to reach a cluster head from a node

V_j = load of the nodes that it can accumulate and transmit, assuming around 0.5j if the packet is an advertisement packet and j if it is a data packet as an advertisement packet is small in size as compared to that of the data packet. Thus it is

assumed here that it is half of the actual data packet size which shall be defined by the authority.

n = number of nodes = $|I|$

The variables defined during the process are:-

VARIABLES

$Z_{ij} = 1$; if node $j \in J$ is allotted to a cluster under any cluster head $i \in I$, 0 otherwise,

$U_i = 1$ if the cluster head is located in the site $I \in B$, 0 otherwise,

$Y_{ik} = 1$ if routing point $i \in I$ is serviced by a route defined $k \in K$, 0 otherwise,

$x_{ijk} = 1$ if node or infact CH $i \in I$ immediately follows $j \in J$ on route $k \in K$, 0 otherwise

The following measures are taken into consideration:-

$$\begin{aligned} f_1 &= \sum_{i,j \in I; k \in K} c_{ij} x_{ijk} \\ f_2 &= \sum_{i \in B; j \in J} c_{ij} z_{ij} \\ f_3 &= \sum_{k \in K} \left(\sum_{i \in B; j \in J} v_j y_{ik} z_{ij} \right)^2 \\ f_4 &= \sum_{k \in K} \left(\sum_{i,j \in I} c_{ij} x_{ijk} - \frac{\sum_{i,j \in I} c_{ij} x_{ijk}}{|K|} \right)^2 \end{aligned}$$

Where,

f_1 is the total route length. This is a summation over the factors of distance of the nodes, provided with the probability of the factor checking the availability of the node in a particular route. The summation denotes the overall distance traversed through all nodes.

f_2 is the communicative distance for the nodes to actively in range for communication.

f_3 being the load balancing function. This defines the factor of load balancing as per the factors of the load being accounted for using the packet sizes defined and also the probability of whether the node is already assigned to any cluster and also of whether it is allotted to any route.

f_4 being the length balancing function.

These equations form the basis of the defined multi objective problem. But these cannot be directly used to solve any conditions as they are too independent in nature and cannot be determined with respect to others. Conditions that need further consideration are of the fact that we need to determine exactly when we shall effectively define the nodes that belong to a cluster to form a route. This condition is best handled in the form using Heuristic Methods.

IV. HEURISTIC APPROACHES

Since we are considering this approach, we shall create sub-problems from the present constraints and thus clarify the locations where we need scrutiny. These can be that of location of the nodes in the network, the allocation of the nodes into clusters, routing between these nodes, and location of cluster heads and so on. Since routing between the nodes is based on the nodes' positions, we shall consider the referring analysis to be of the form of a Location Routing Problem.

Using this technique, we can react to these problems in 2 methods, Location-Allocation-Routing Algorithm and the Allocation-Routing-Location Algorithm.

Location-Allocation-Routing algorithm (LAR):

In this the nodes are handpicked and allotted to the clusters without any reference to the nearest cluster head or any other condition. These nodes are then allotted to a cluster head and clusters are formed on the basis of these nodes. A simple standard routing algorithm can be used for routing.

Allocation-Routing-Location algorithm (ARL):

This algorithm prescribes a creation of clusters first and then the routing and the allocation done simultaneously. The nodes are allocated dynamically on the basis of the constraints and the routes shortest to the base station are determined.

Amongst both these techniques, the second algorithm fits the condition better as it takes into the account of bandwidth. Efficient clusters are also formed and are energy constraint to a certain limit. But the main advantage is stated in the fact that the location of the nodes and the route formation are completely independent. Thus, the ARL algorithm can be emphasized upon.

V. GROUPING OF THE NODES INTO CLUSTERS

There are certain criteria that need to be addressed before the creation of the clusters. Firstly the minimizing the number of routes should be the sole important feature. Minimizing the length of the route is also an important aspect that needs to be gathered about with load balancing. Minimizing the number of routes leads to the main emphasis of the formation of clusters from the given nodes. For load balancing and route length, we can use weighted method. The weights are arbitrarily chosen by the user and the overall function can be defined as:-

$$\hat{f} = w_a f_a + w_b f_b$$

where,

$\hat{f}$ = the overall function that shall define the objective states

w_a = the weight determined for the sub problem of the route length

f_a = the routing length from the nodes

w_b = weight of the load balancing units i.e. the bandwidth that is supported

f_b = the load balancing condition

The functions f_a and f_b can be defined as:-

$$f_a = \sum_{k \in K} \left(\sum_{i,j \in I} c_{ij} x_{ijk} - \frac{\sum_{i,j \in I} c_{ij} x_{ijk}}{|K|} \right)^2$$

i.e. the length balancing condition defined earlier and

$$f_b = \sum_{k \in K} \left(\sum_{i \in B; j \in J} v_j y_{ik} z_{ij} \right)^2$$

i.e. the load balancing condition defined earlier.

Based on these it shall be defined for the formation of the clusters as they are dependent on each other indirectly.

But the cluster number is also a constraint that needs consideration. A simple consideration shall be put up as,

$$M(k) = (\text{Number of nodes}) / (\text{Total capacity})$$

To generate the clusters, multi objective routing problem is defined and the use of heuristic method to generate solutions to the problem. This method used the number of nodes assigned to each potential cluster head as the demand that has to be observed. The solution provided is that each node is assigned to a route and this assignment is used later to form clusters. Thus the above conditions as defined can be solved to obtain the routes and the nodes assigned and in turn obtain the clusters.

Solving f directly would yield to inefficient solutions as the conditions are of varied ranges. Thus to get them into a similar range, it is needed to simplify the equations in the form as shown:

$$f = w_a \left(\frac{f_a - f_a^*}{f_a - f_a^*} \right) + w_b \left(\frac{f_b - f_b^*}{f_b - f_b^*} \right)$$

Where,

f_i^* is the best obtainable solution for any individual objective. (i = a, b)

f_i is the average value that can obtain for any individual objective.

This is mainly done to standardize the fields of the objectives into a similar level.

Formation of clusters could be done using the clustering – VRP method, but it is disregarded as it could not solve for nodes more than 500 and was very slow in generating clusters. Moreover, the algorithm was also not designed to solve the multi objective problems. Thus the Space Filling Curve with Optimal Partitioning heuristic [2] shall be used. This algorithm is very fast in creating clusters. It works on the fundamentals of ordering the demand points that a route shall travel on and total length is partitioned into a minimal number of routes using dynamic programming techniques. This objective function is merged to the function defined above to yield a set of all the clusters that can be evaluated. The SFC OP heuristic generates the inter-mediate solution values by choosing different initial points for the creation of the routes and these values are used to calculate the average value of each objective defined in the equation above.

This results in each standardized objective having values of 0 as its minimum and 1 as its average. Any solution that minimizes is called a Pareto Optimal as long as there are no zero weights assigned by the decision maker. It is easy to prove that the minimiser of this combined function is Pareto optimal. It is up to the user to choose appropriate weights. Until recently, computational expense forced users to restrict themselves to performing only one such minimization. Newer, more ambitious approaches aim to minimize sums of the objectives for various settings of the weights, therefore generating various points in the Pareto set. Though computationally more expensive, this approach gives an idea of the shape of the solution and provides the user with more information about the trade-off among the various objectives.

Now, as each node randomly allotted to a cluster, the main factor remains of efficient routing between them. This will be taken care by the routing in clusters.

VI. GENERATING ROUTES

The main objectives that shall be under scrutiny are that of:

1. Total length of the route
2. Distance of the nodes from the cluster head.

Here again the usage of the weighted method shall be beneficial. If w_1 and w_2 are the related weights for the length criteria and the distance of the nodes respectively, f_1 being the route length and f_2 being the total distance of the nodes, then the overall objective for the routing can be shown as:

$$f = w_1 f_1 + w_2 f_2.$$

These objectives are interrelated. The reduction of the distances of the nodes to the cluster head can create an impact on the route length. Thus the algorithm can be explained as:

1. Find P covering sets of the potential cluster heads.
2. For each set of these nodes, generate a route on this set of nodes.
3. Find the distance from the previous step that has the least total weighted distance and as potential cluster heads to reduce the total distance.

This can be defined as the overall procedure. Detailed explanation is provided below.

Find P covering sets for CH

This step finds a set of cluster heads for each route so that every node in a cluster is assigned to a cluster head within the distance allotted for communication. This procedure can be emphasized as:-

Algorithm 1

1. Repeat the following procedure P times, where P is the number of the nodes that are potential cluster heads. Let p be the current iteration number.
2. Mark all those nodes that are unassigned to any cluster heads.
3. Select the potential CH that has the p^{th} most nodes within the maximum communication distance and assign the nodes to this CH.
4. Select the remaining CH with the largest unassigned nodes within the communication distance and assign them to this CH. Repeat this till all nodes have a CH.
5. Execute the next procedure to obtain the weighted distance of the corresponding route.

Algorithm 2

1. Since the previous algorithm might not have optimally formed the clusters, reassign them to the nearest cluster heads and calculate the total student walking distance
2. Perform a 2-opt procedure on the selected CH and the nodes to form a tour that visits the selected CH and base station. Calculate the total length of this route.
3. Calculate the total weighted distance associated with the route f .

The algorithm in the previous section selects the route that has the least total weighted distance and performs the heuristic described in the following section to reduce the total weighted distance.

When w_2 is not equal to 0, then the procedure attempts to decrease the weighted distance obtained in the above algorithm by adding cluster heads into the route. This is a

problem since sufficient decrease in the distance of the nodes to the cluster head can still reduce the total weighted distance even if the length of the route increases. The algorithm is based on insertion heuristic and is described as shown below.

Algorithm 3

1. Pick one of the currently unselected CH and add this to the present route using the Algorithm 2.

2. Calculate the amount of the nodal distance saved, δf_2 , by adding this CH to the route. Note that δf_2 is the reduction of the total nodal distance to the CH.

3. Calculate the total route increase, δf_1 , caused by the addition of the CH.

4. After performing all the steps 1 to 3 on all unselected CH, select that CH that gives the best improvement to the route based on the following criteria.

Maximum Improvement – select the CH that decreased the objective function the most, i.e. the largest negative value of-

$$w_1 \delta f_1 - w_2 \delta f_2.$$

Best Ratio – select the CH that yields the maximum savings in terms of the distance to the CH from the node, i.e. maximizes-

$$\frac{w_2 \delta f_2}{w_1 \delta f_1}.$$

5. If no CH improves the route, then stop the iteration. Otherwise repeat step 1

VII. CONCLUSION

The whole process is divided into 2 phases. The first phase groups the nodes into clusters that can be serviced. In the second phase methods were implemented so that routes are defined through cluster heads that are chosen in the clusters provided in the first phase.

The decision makers can examine the effects of the different parameter weights to find a desired set of routes. If attempting to load balance introduces large or unwieldy routes then the emphasis placed on load balancing can be reduced.

Similarly if the clustering route criterion does not result in sensible clusters then the weighting of the compactness measure can be increased to force the clusters to become more compact.

Even the ratio of w_1/w_2 measures the importance of reducing the distance compared to the nodal distance. The importance placed on the nodes' distance can be varied so that increasing the length of the route length and produces a significant reduction in average distance the nodes need to communicate with.

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