Placement of Actors in Wireless Sensor Networks

S.Periyanayagi ,
Assistant Professor ,
Department of ECE
Angel College of Engineering and Technology, Tirupur.

Ramya kulandaivel,
Assistant Professor ,
Department of ECE
Angel College of Engineering and Technology, Tirupur.

S.Susikala
Assistant Professor ,
Department of ECE
Angel College of Engineering and Technology, Tirupur.

ABSTRACT
A wireless sensor network (WSN) consists of two sets of nodes: sensors and actors, where the set of sensors performs all the sensing (data collection) from their surrounding environment. Since sensors operate by batteries, then they are limited with their processing and communication capabilities due to the short life-span of the batteries. On the other hand, the set of actors has more capabilities with extended life-span batteries, and their roles are to collect and process the raw data from the sensors to determine the next action for WSN. The actor placement problem is to select a minimal set of actors and their optimal locations in WSN keeping in mind the communication requirements between sensors and actors. We have encoded the actor placement problem into the evolutionary approach, where the objective function is to find the minimal total number of actors covering as many sensors as possible to improve the performance of WSN. The experimental results demonstrate the feasibility of our evolutionary approach in covering 77% of 61 sensors by three actors and its performance is compared for various parameters.

Key Words
Wireless Sensor Networks, Genetic Algorithm

1. INTRODUCTION
A. Wireless sensor networks (wsn)
A wireless sensor network (WSN) constitutes a set of light-weight devices called sensor nodes. It has least energy resources for carrying out the process such as environment sensing, information processing, and communication. A sensor network consists of wireless ad hoc network which means that each sensor supports a multi-hop routing algorithm (quite a few nodes forwards data packets to a base station). Each node in the sensor network is equipped with a radio transceiver or wireless communication device, microcontroller and an energy source (battery) in addition to one or more sensors. The wireless sensor network field provides prosperous, multi-disciplinary area of research where a various tools and concepts are engaged for addressing diverse set of application.

The requirement for intelligent interaction with the environment has lead also to the emergence of distributed wireless sensor and actor networks (WSANs). WSANs refer to a group of sensors and actors linked by wireless medium to perform distributed sensing and acting tasks. Sensors are low-cost, low power devices with limited sensing, computation and wireless communication capabilities. While actors are resource rich nodes equipped with better processing capabilities, higher transmission powers and longer battery life. Moreover, the number of sensor nodes deployed in a target area may be in the order of hundreds or thousands, where such a dense deployment is usually not necessary for actor nodes.

A sensor node comprises of five units: power, communication (receiver and transmitter), processor, analog-to-digital converter (ADC) and sensing. An actor node has two additional units: decision-making and actuation. According to sensor and actor nodes capabilities, their roles in WSANs are fairly divided. The role of sensor nodes is to collect data about the physical world while the role of actor nodes is to process the data, take decisions, and to perform appropriate actions based on the collected data. This allows users to effectively sense and act from a distance, and perform appropriate actions on the monitored area.

We have formulated the automatic placement of actors as a optimization problem and an evolutionary approach to search the required design space for minimal number of actors to be bound with as many sensors as possible. In this paper we have incorporated the advanced results when compared to the previous results. Two different constraints such as static versus dynamic binding of total sensors with an actor is taken as a objective function. The computational experiments have been obtained for the dynamic constraint of maximum of eight actors for 61 sensors. In comparision with the normal wireless sensor network, the placement of actors have produced better packet delivery ratio, packet loss ,energy consumption and end to end delay.

2. RELATED WORK
The actor placement problem is very similar two classical problems called the capacitated K-center problem and capacitated P-median problem. The CKC problem is a fundamental facility location problem where it is used to locate K facilities in a graph and to assign vertices to facilities so as to minimize the maximum distance from a vertex to a facility to which it is assigned. The CPM problem is a facility location problem which can be applied to telecommunicate, transportations, scheduling and distribution problems. The goal of p median problem is to determine p facilities in a predefined set within n candidate facilities such as the total sum of Euclidean distance between each demand point and its nearest facility is minimized (n>p). FSM model models our actor location problem as a variation of CKC and CPM problems. It acts some more constraints to WSN.
The problem of placing sensors in NP complete problem according to [3-7] .Some researchers have attempt to utilize genetic algorithm to cope up with near optimal solutions for the actor location problem. Genetic algorithm goes through the generation of population , fitness calculation , cross over and mutation stations until coverages is achieved until maximum number of iterations is reached [3].The actor placement

problem can be formulated as finding a set of head clusters[1].For each cluster there will be one actor to collect the data. These clusters may be formed according to the following factors 1) The event transmission time from sensor to actor is minimized.2)The events from the sensor to the actor are transmitted to energy paths.3)The action region of the actors should cover the entire event area.

In [2] they present a real time communication frame work for WSN. It provides the efficient reporting algorithm which reduces the network traffic and minimizes the transmission delay by dividing the event area into smaller pieces of maps. However a minimal transmission delay is not guaranteed for a valid data that meet certain application requirements.

One of the core problems that should be considered by deployment of any wireless sensor network is the coverage problem. The coverage problem is to place the sensor devices in the service area so that the entire service area is covered. In the previous work [8] we proposed a model that covers two sub problems floor plan and placement which are embedding the placement and the integration module of integrated circuits into a circuit board. The floor plan problem is to divide the circuit board into well defined geometric cells and then placement problem determines the best cells to place the IC modules into them with minimal wire connections.

3. PROBLEM FORMULATION

We are given a service area A with two dimensions: width W and height H as shown in figure 1 .The service area A is an obstacle free and it is already divided into MxN cells, where each cell can be possibly contain a sensor device and its center of mass. All the center of mass represent demand points which were considered as the candidate location for the sensor device for the coverage problem. All the intersection points of the cells are considered as the candidate location for the actor devices. In this paper our objective is to find the minimal set of intersection points so that it can be utilized for actor placement.

The set of placed sensors for the coverage problem, B is given as an input to actor placement problem. Each element in the set B is a tuple, b_i consist of six ordered parameters b_i= <S_j , C_{MxN} , RC , SC , CR , BL >.The parameter S_j - sensor identification

C_{MxN} - physical cell location of the placed sensor within the service area.

M and N - column and row numbers of the floor plan of the service area.

RC - radius of coverage in meters of placed sensor S_j .

SC - initial installation and deployment cost of placed sensors S_j

CR - Communication radius

BL - Current battery level of the placed sensor.

TC - Total coverage of non overlapping radius of coverage of all placed sensor over total area of service WxH is given as the input to actor placement problem. A library of actor device C is given as a input, were the search algorithm has to allocate its actors from the library.

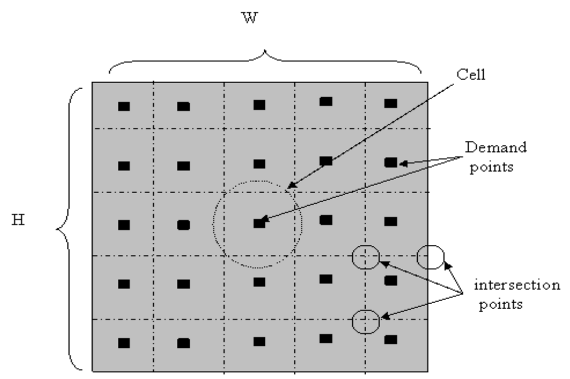

Figure 1 A service area to be monitored by WSAN

3.1 Mathematical formulation

The actor placement problem as a single objective optimization problem with six constraints.

3.1.1 Objective Function

The objective function is to frame the minimal set actors and which will be allocated and placed at the intersection points to be able to communicate with the coverage sensors

$$\min \sum_{j \in C} \beta j \qquad (1)$$

β_j represents binary allocation variable of an actor j . β_j= 1 indicates that the actor j has been allocated to be placed in a intersection point represents the actor library.

3.1.2 Constraints

We have utilized a number of constraints to ensure that the outcomes of proposed evolutionary approach are feasible WSN.We have guaranteed that the number of allocated actors cannot exceed the total number of intersection points and it is not less than one actor.

$$1 \le \sum_{j \in C} \beta j \le n/k \qquad (2)$$

Constraint2 guarantees that the number of allocated actors does not exceed (1/k) of the total number of intersection point n where k is the given value and it is not less than one actor.C represents the list of allocated actors in WSN.We have ensured that no two actors are more can have same location .Therefore, each allocated actor will have a unique location.

$$LOC(j) \neq LOC(m) \text{ where } j \neq m , \forall j , m \in C \qquad (3)$$

Constraint (3) ensures that no two actors can have the same interaction point on the grid, where LOC (j) represents a function that determines the location (intersection point) for actor j.

A sensor in either bounded to one actor or not bounded at all as stated in (4)

$$\sum_{j \in C} \alpha\, i,j \beta j = \begin{cases} 0 \\ 1, \end{cases} \qquad (4)$$

for a given sensor i∈B

Constraint (4) ensures that a sensor is either bounded to a single actor or not bounded at all.$\alpha_{i,j}$ represents a binding variable. $\alpha_{i,j}$ =1 indicates that a sensor i is bounded to an actor j. Hence this constraint ensures that the sensor sense its collected data only to one actor. We have made sure that total number of unbounded sensors is not to exceed a given threshold value as

$$(\mid \beta \mid - \textstyle\sum_{i \in B} \alpha\, i,j) \le U_{max} \qquad (5)$$

Constraint (5) ensures that the total number of unbounded sensors is not to exceed a given threshold value U_{max}. By subtracting the total number of bounded sensors from the total number of sensors given as a input to the problem (| B |) ,we obtain the total number of unbounded sensors.

The threshold value U_{max} is given as the input to the actor placed problem. In order to balance the workload on each actor constraint (6)

$$1 \leq \sum_{j \in B} \alpha\, i,j \leq Lmax \qquad (6)$$

for a given actor i∈C.

Constraint (6) states that every actor must have at least one sensor bounded to it, and almost, a threshold value of maximum sensors bounded to it. (L_{max}). L_{max} is either given as an input to the actor placement problem (a static constraint) or dynamically calculated at each generation (a dynamic constraint).The dynamic values are estimated by dividing the total number of sensors over the current number of allocated actors as stated in

$$Lmax = |B| / \sum_{j \in C} \beta j \qquad (7)$$

4. An Overview of Genetic Algorithm

The genetic algorithm starts with an initial population P(t=0) of solutions encoded as shown in figure 1.An initial population is most often generated randomly but a heuristic can used. Each chromosome is made of sequence of genes and every gene controls the inheritance of specific attributes of the solution characteristics. A fitness function in line 4 and 11 measures the quality of chromosome in terms of various design variables of the solution. A more fitted chromosome suggests a better solution. The while loop in lines 5-12 represents the evolution process, where relatively fit designs reproduce new designs and inferior design die. This process continues until a design with desirable fitness is found. Line 8 selects the best designs within the current generation based on fitness values. These selected designs known as parents are used to reproduce the next generation of designs known as offsprings.The evolution process involves two genetic operations namely mutation in line 9 and cross over line 10.A mutation operator are arbitrarily alters one or more genes of randomly selected chromosome. The intuition behind the mutation operator is to introduce a missing feature in the population.

```
Genetic Algorithm
1 begin
2 t=0;
3.initialize P(t);
4.evaluate P(t);
5.while ( termination condition are unsatisfied) do
6.begin
7.t=t+1;
8.select P(t) from P(t-1);
9.mutate some of P(t);
10.cross over some of P(t);
11.evaluate P(t);
12.end
13.end
```

Figure 2 The structure of Genetic Algorithm

A cross over operator combines the features of two selected chromosomes (parents) to form two similar chromosomes (offspring) by swapping genes of parent chromosome. The intuition behind the cross over operator is to exchange information behind different potential solution.

In this work we have used only mutation to evolve the population of the genetic algorithm. The mutation operators we have implemented include 1) Adding actors from the actor library to the solution grid at random positions.2) Removing the randomly chosen actors from the grid.3) Replacing some of the actors with others that are selected from actor library. These operations are sufficient to modify the structure of selected gene and thus evolve our solutions in genetic algorithm.

5. Experimental Results

To test our evolutionary methodology for the actor placement problem in wireless sensor actor network (WSAN).The coverage problem code which was developed where used first to find a good solution in the wireless sensor network[8].Table 1 illustrates the initial seed which was selected from coverage problem for the actor placement problem.

TABLE I
The Characteristics of the Initial Seed

Initial seed	Value
Service Area Size	15cells by 15 cells
Cell size	25 by 25 meters
Number of sensors	61
Coverage ratio	75.5%

On comparing with normal wireless sensor network the placement of actors have placed a vital role in improving the performance of WSN.The performance has been analyzed using packet delivery ratio, energy consumption, packet loss and end to end delay. The packet deliver ratio of normal wireless sensor network and wireless sensor actor network is shown in figure 3. During the time of 20 seconds the number of packet delivered is 5% higher than results obtained in wireless sensor network.

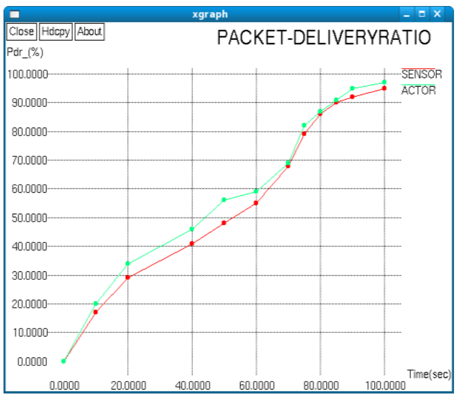

Figure 3 Packet delivery ratios

The second parameter compared in our paper is energy consumption as shown in figure 4. The time in sec and energy in joules are plotted for different values. For examples at 60 sec the energy consumed by wireless sensor network is 55 joule and energy consumed by wireless sensor actor network is 49 joule. We infer that the placement of actors have considerably reduced the energy consumed.

In figure 5 the number of packets that are lost when it is delivered to the destination at particular time in WSN and WSAN is compared and the graph reveals that the placement of actors has reduced the packet lost to 30 bytes when compared to 40 bytes produced in WSN at a time of 40 seconds.

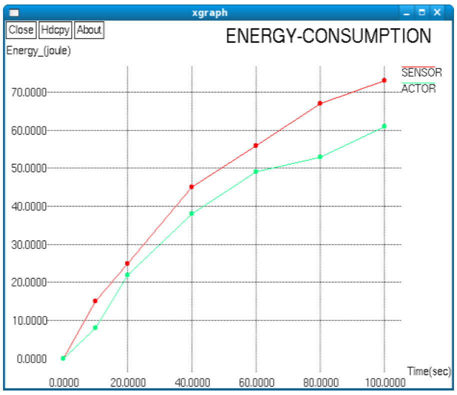

Figure 4 **Energy Consumption**

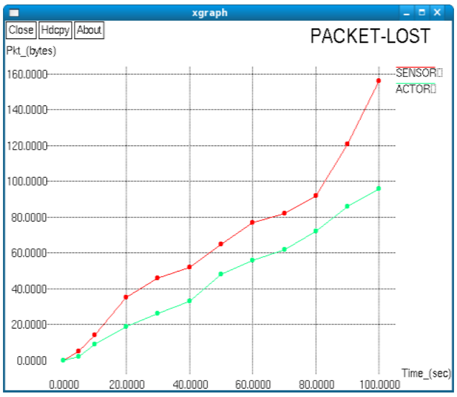

Figure 5 Packet delay

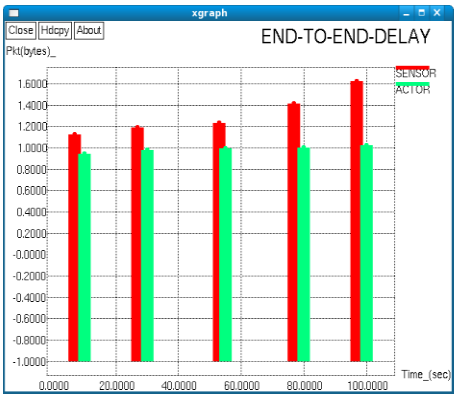

Figure 6 End to end delay

The end to end delivery ratio in WSAN is less on comparing with WSN and it is clearly high lightened in figure 6. From the experiment results demonstrate a feasibility of our evolutionary approach in covering 77% of 61 sensors by three actors. After placement of actors the overall performance of WSAN based on energy consumption and packet loss is improved.

6. CONCLUSION

In this work we have presented various experimental results for automatic actor placement problem. The actors have served the majority of all the coverage sensors in the network. The main constraints are packet delivery ratio, Energy consumption, Packet Loss, End to End delay. The main contribution of this work is to optimize the placement of actors in WSN. Our experiments with evolutionary approach demonstrate very promising results. To improve our performance a simple network model to serve as a bench mark in evaluating the performance of the optimizer (GA) is assumed. In our future we will consider more sophisticated network models.

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