MOBILITY ASSISTED COVERAGE RESTORATION SCHEME IN WIRELESS SENSOR NETWORKS

Eman AlQuraishi, Paulvanna N. Marimuthu and Sami J. Habib
Kuwait University, Computer Engineering Department, P. O. Box 5969, 13060, Safat, Kuwait

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Abstract: In this paper, we have examined the problem of simultaneous failure of sensors within the wireless sensor networks (WSN), whereby the sensors failures are due to malfunction or electrical faults. We have proposed a mobility assisted coverage restoration algorithm, which restores the coverage of the failed sensors without adding new sensors. The proposed algorithm follows two phases; clustering and restoration. The clustering phase groups the failed sensors with their proximity, and then it relocates them into cluster. The restoration phase moves the nearby active sensor with higher energy to the center of the cluster of failed sensors and doubles its sensing area to restore the coverage. The restoration scheme exploits the mobility of the sensors to form clusters of failed sensor, which reduce the number of restoring sensors, thereby prolonging the lifespan of the network. Experimental results indicate that for a small size WSN comprising of 25 nodes and nine nodes of it failing simultaneously, our restoration algorithm is able to increase the coverage area from 34% to 86% at the expense of small reduction in the lifespan estimated to be 24% of the network.

1 INTRODUCTION

We are concerned with the restoration of multiple sensor failures due to electrical faults or malfunctions in mobile wireless sensor network. In a work by Habib and PaulvannaNayaki (2010), the sensors are fixed and a neighborhood active sensor is utilized to double its sensing radius to restore the area of the failed sensors. However, the coverage restoration by doubling of neighboring sensing radius results in additional energy consumption with increasing overlapping area, and it further increases energy consumption with increase in sensor failures.

In this paper, we have considered a wireless sensor network with mobile sensors, and we have proposed a mobility assisted coverage restoration scheme to restore the uncovered area with minimal active sensors. The simultaneous failure of more than one sensor results in the development of uncovered area. The restoration scheme comprises of two phases. The clustering phase groups the failed sensors together to form an immediate neighboring set. The restoring phase moves active sensors with higher energy to the location of cluster of failed sensor and doubles its sensing radius to restore uncovered area. Clustering followed by restoration reduces the number of active sensors necessary to double their sensing radius, thus our restoration method maximizes the coverage area with minimal energy consumption. Our simulation results show that for a given wireless sensor network comprised of 25 sensors and 9 sensors failing simultaneously, our restoration algorithm increases the total coverage area by 52% on comparison with the non-restoration environment.

2 WSN MODEL

The service area to be monitored by sensors is divided into N x N cells and the given K sensor nodes denoted by black dots are placed at the center-of-mass of each cell to cover the service area more efficiently as illustrated in Figure 1. The sensing area is assumed to be circular and the sensing range of each sensor node is confined within its cell by gray circles. The area of each cell is presented as width (W) x height (H) sq. units. The total service area is N^2 x W x H. For simplicity, we assume that each cell is a square (W=H) and the area of each cell is equal to W^2 (or H^2). We follow the coverage restoration model in (Habib and PaulvannaNayaki, 2010) to estimate the coverage area.

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The area covered by each sensor with circular sensing area is given by Equation (1) and the total area covered by the given sensors is represented by Equation (2).

$$\pi * (r)^2 = \pi * \left(W/2\right)^2 \text{, where } r=w/2 \tag{1}$$

$$\text{Total area covered by } K \text{ sensors} = K * \pi * \left(\frac{W}{2}\right)^2 \tag{2}$$

In Equation (2), we assume that each cell is occupied by a sensor, thereby K equals N^2 and the total covered area is $N^2 * \pi * W^2/4$. The coverage area is computed as the ratio of the total area covered by the sensors to the total area of the grid.

In this paper, we assume that each sensor has the capability to move from one cell to another cell (mobility). Initially, the sensors are with equal sensing radius, but with various energy levels; therefore, the sensors possess diverse lifespan. The source of power for each sensor depends on three AAA batteries as in the case of a prototype mobile sensor. According to Wang et al., (2005), initial residual energy of the sensors is distributed between 10000J and 16000J and mobile sensor can have a speed of 2m/s with the energy consumption of moving one meter is estimated to be equal to 27.96J. Furthermore, we assume that the sensing radius is adjustable, and it can be increased or decreased. However, the increase in the sensing range increases the power consumption.

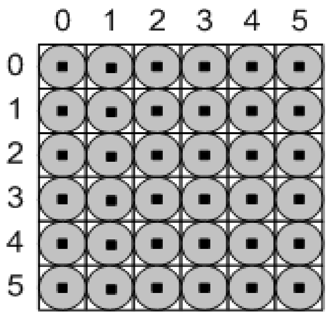

Figure 1: The wireless sensor network model.

3 PROBLEM FORMULATION

The main objective function of the coverage restoration problem is to maximize the coverage area with reduced energy consumption as stated in Equation (3). The numerator represents the total area (A_i) covered by the active deployed sensors and the denominator represents the given network area, which is the area of the given square grid.

$$Max \ \frac{\sum_{i=1}^{K} A_i}{N^2} \tag{3}$$

Here, we highlight four constraints, which are added to reduce the energy consumption during sensor mobility and restoration. The first constraint places an upper bound D on the distance moved by any of the given sensor, and it is given by $d < D$, where d be the Euclidean distance moved by a sensor from location (x_1, y_1) to location (x_2, y_2). This constraint is added to limit the movement of sensors to a far location within the network, thereby minimizing the power consumption.

The second constraint verifies the upper bound on sensing range of a sensor and it is defined as $r_i < R$ for every sensor i in the network. The terms r_i and R are the sensing range of sensor i and its upper bound on sensin range respectively. This constraint aims at balancing the power consumption between the sensor nodes with increasing sensing radius. The third constraint states a lower bound on the lifetime of the network and is given by

$$T \succ T_{\min} \text{ where } T = \sum_{i \in K} T_i$$

Where T is the sum of lifespan of the active sensors within the network and T_{min} is the minimum allowed lifespan of the network. K is the number of deployed sensors. It ensures that the restoration operation is allowed only if the lifespan of the network is sufficiently above the given lower energy bound.

In this model, it is assumed that the sensors are active for one hour daily and they are idle (sleep) for remaining 23 hours. The sensors consume 102µA in sleep mode and 77mA in active mode (Jia et al., 2009). The daily energy consumption for each active sensor is calculated as 53.5 Joules/day. The lifespan T of the network (in days) is given as in Equation (4), where E_r is the total residual energy of the network and E_c is the energy consumed till that day.

$$T = \frac{E_c}{E_r} \ days \tag{4}$$

$E_r = \sum_{i=1}^{K_a} E_i$, where E_i is the energy of the sensors present at the time of measurement and K_a represents the total active sensors at that time.

With doubling of sensing range, the energy consumption in active mode increases by certain percentage (X). The fourth constraint is added to limit the number of failing sensors at any time. The number of failing sensors should be less than the total number of deployed sensors: $M < K$, where M, K are the number of failed sensors and the total number of deployed sensors, respectively.

4 ANALYSIS OF SENSOR FAILURES

The distribution of failed sensors within the given WSN area is classified as clustered and sproadic. Our restoration algorihtm analyzes the given sensor network with multiple sensor failures, before applying the restoration algorithm. If the failed sensors are clusters by themselves as illustrated in Figure 2, then each failed node is a neighbor to at least one of the remaining failed node within the cluster. If the failed sensors are distributed randomly as shown in Figure 3, then they are sporadic.

5 COVERAGE RESTORATION ALGORITHM

We have proposed a mobility assisted restoration algorithm to restore the coverage area of the failed sensors, whereby the sensor with highest energy is allowed to move to the location of the failed clusters and double its sensing radius to restore the coverage. The resoration algorithm clusters the failed sensors before applying the resotration procedure to minimize the number of restoring sensors.

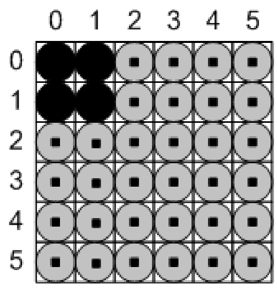

Figure 2: Clustered failure.

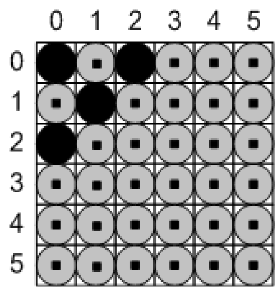

Figure 3: Sporadic failure.

Figures 4 and 5 show the series of operations on sporadic failure of four sensors as shown in Figure 3 to cluster the failed sensors and then restore the network with two active sensors. The presence of active sensors in between the failed sensors as shown in Figure 3 necessitates the movement of active sensors to nearby locations so that the failed sensors form a cluster. In this case, two sensors with doubled sensing range may be sufficient to cover the failure of the four sensors.

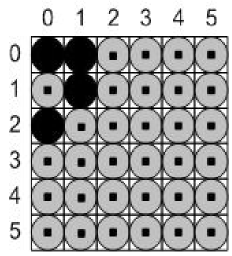

Figure 4: Swapping active and failed sensors.

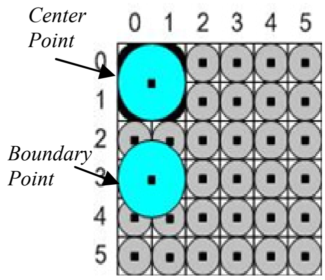

Figure 5: Restoration.

To balance the energy consumption and prevent any sensor from being drained out of energy, we have proposed a scheduling algorithm to schedule the swapping operation between the active sensors with doubled radius and with the nearby active sensors possessing higher energy at the recovery point.

6 RESULTS AND DISCUSSION

We have coded the restoration algorithm in C++. We have considered a WSN network with a grid size of 4x4, which is comprised of 16 active sensors initially. The sensing radius for each sensor is of 2m. The coverage area and energy levels are updated every day throughout the lifetime of the network for three different scenarios; without failure (normal operation), with failure but without restoration, and with failure and with restoration. Out of 16 sensors in the network, we have considered the simultaneous failure of 9 sensors generated randomly and applied the clustering and restoration algorithm to restore the coverage area. Figure 6 illustrates the area coverage against the lifespan of the network in all the three categories, where we observed that the failed sensors with restoration have showed the highest coverage in most of the days, which is even higher than the coverage achieved in normal operation. The increase in area is achieved through the additional coverage of the corner area of the squared cell, which is not covered in normal operation.

The simultaneous failure of 9 sensors decreases the coverage area from 78% to 34%. With the restoration algorithm, the coverage area has increased from 34% (failure with no restoration) to 86% (failure with restoration), which corresponds to 52% increase in the coverage area. However, with the restoration algorithm, the lifetime of the network is reduced from 296 days to 223 days, which corresponds to 24.6% reduction from the normal lifetime of the network.

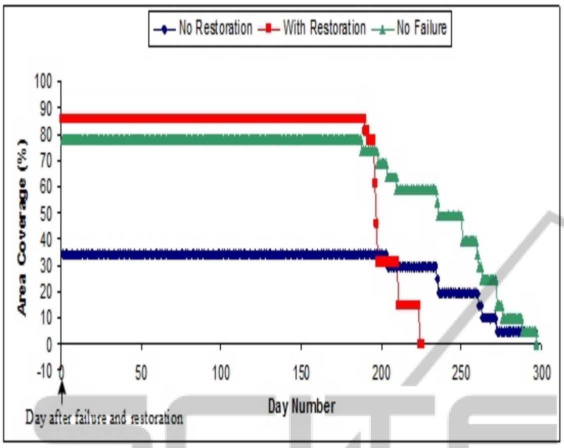

Figure 6: Comparison of coverage area.

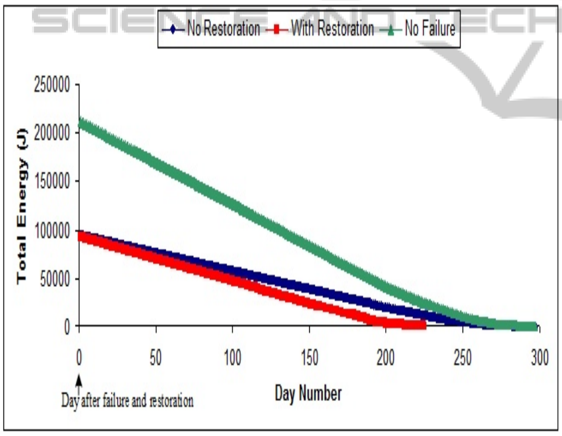

Figure 7: Network energy level.

Figure 7 shows energy of the WSN in all the three categories. The normal operation has higher energy level than the network with failed sensors (with and without restoration). The sensors failure reduces the total energy level of the network from approximately 200,000J to 100,000J. It is also observed that the energy level of the network with restoration is in-line with the energy level of the network without restoration for the first 100 days and then gap between the graph with and without restoration increases with the increased energy consumption by the doubled sensing radius.

7 CONCLUSIONS

In this paper, we have proposed a coverage restoration algorithm, whereby clustering is followed by restoration to restore the sensing area of simultaneously failed sensors. The proposed algorithm divides the failed sensors into groups of four with their proximity and the algorithm exploits the mobility of the sensor nodes to relocate and cluster the failed sensor nodes and double the sensing range of few active sensors to restore the coverage. Experimental results indicate that the proposed algorithm increases the coverage area to 86% from 34% (without restoration) at the expense of a small reduction (24%) in the life time of the network.

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