On Redundancy Identification in Randomly Deployed WSNs, Another Perspective

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Abstract—**Redundancy in Wireless Sensor Networks (WSNs) is often considered a positive development to ensure message reinforcement, increased network reliability and fault-tolerance, among many other quality of service (QoS) concerns. In certain applications of WSNs however, the negative impact of redundancy on the network could outweigh the aforementioned positive considerations . Random deployment of sensors inevitably leads to the occurrences of redundancy in the network with serious consequences (e.g., network congestion and energy wastage). In order to address the challenges posed by redundant nodes on the network, it is of prime importance to first of all, identify the redundant nodes from the network . In this paper, the concept of redundancy in wireless sensor networks and its identification are examined. Specifically, we employed the use of a modified version of Low Energy Adaptive Clustering Hierarchy (LEACH) algorithm to identify physically redundant nodes in a randomly deployed wireless sensor network. Simulation results reveal a proportional relationship between redundant nodes and the number of nodes required to keep the network functional. This relationship is equally maintained as the network's lifespan advances (i.e., some nodes begin to die out).**

Key words: redundancy; sensor; node; identification.

I. INTRODUCTION

The fact that sensors have the potential to be applied in household monitoring, military surveillance, agriculture, patients monitoring, industrial plants monitoring, oil spills detection among many other possible areas cannot be overemphasized [1],[2], [3]. To harness this huge potential however, these devices usually need to operate in consonance with other similar ones, forming a network, which could either be wired or wireless, depending on the application and the functional and non-functional requirements to be met.

Prior to the formation and subsequent operation of a network (i.e, wireless sensor network), the nodes are required to be deployed at the potential target locations [4]. In most applications, especially in disaster areas or enemy territories, the sensors are not often deployed deterministically but usually, through the use of some machinery such as an aircraft. Associated with this sensor deployment method are a number of issues that need to be highlighted thus:

a. The sensors are not smart and dynamic enough to adjust their positions, if needed, to ensure maximum coverage of the area being monitored, implying that there is little control over coverage of the target location, leading to either insufficient coverage, optimal coverage or over-coverage as the case may be.
b. Regardless of the type of coverage that is attained as a result of the deployment, redundancy could be present in a network formed by nodes deployed this way. Redundancy, is an interesting phenomenon in wireless sensor networks, because it is an attribute rather than a tangible entity. Although, the concept in wireless sensor networks parlance, has not yet been formally defined and generally accepted in all its ramifications, the term literally connotes repetition, usually in order to reduce the probability of errors in transmission (in information theory), while in other contexts, it refers to the attribute of being excessive and unneeded . In this paper, we base our consideration of the subject of redundancy in terms of the extra number of *qualified* nodes deployed within the same grid cell during the operational life of the network. In other words, we consider redundancy that arise primarily due to random deployment , which is often the case in field applications where there is little room available for the network designer to control the precise location of the nodes during deployment.

Typically, the mode of communication in a wireless sensor network is from multiple data sources to a single data fusion center (although there are propositions for multiple data sinks in some recent works [5], [6]).And quite often, the data being collected by these sensors is based on a common phenomenon, the possibility of duplication in the data being communicated is inevitable, leading to significant strain on energy resource of the network. Moreover, considering the fact that the sensor nodes do function unattended throughout the operational lifespan of the network, it becomes imperative that energy resources be carefully managed. Among the many

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approaches to energy conservation in wireless sensor networks, this paper focuses on spatial redundancy identification with the ultimate aim of reducing same to prolong the general lifespan of the network. The rest of the paper is organised as follows: In section II, we present related work on the subject area; section III highlights some approaches to redundancy identification in WSN; section IV examines the arguments for and against redundancy in WSN. We present our approach to redundancy identification using a modified version of the LEACH algorithm in section V and thereafter conclude the paper in section VI by pointing the way for further research on the subject.

II. RELATED WORK

In WSNs, the subject of redundancy is not often considered for its own sake but with respect to an identifiable objective such as: target or area network coverage maximization; maximization of network lifespan or energy conservation, among many others. Similarly, this paper seeks to examine the subject alongside sensor placement or deployment [7]. Employing an inappropriate deployment strategy for a particular application of WSN could lead to a number of possible undesirable outcomes. Some of these unpleasant outcomes include but not limited to: over-concentration of the sensors in a particular location, leading to significant energy wastage in such networks. It has been established by [8] and [9] that some form of redundancy is almost inherently unavoidable in many applications of wireless sensor networks where the nodes are densely deployed usually randomly.

The researchers in [10] used graph theory and cut sets, to define the degree of redundancy for a given sensor network. They defined the degree of redundancy as the maximum number of sensors that can be removed from the network to maintain the same level of accuracy of the measurement of a given variable. An analytical scheme has also been proposed by [11] to help in the identification of redundancy in sensor networks. The authors proposed a method, called Self Calculated Redundancy Check (SCRC), which considers the sensor field as a finite set of points and assumed that a sensor node covers a fixed subset of those points to identify any redundancy that may exist. Their scheme is aimed at extending the operational lifespan of the sensor network by eliminating any redundant energy-consuming nodes from the network. In a similar manner, other researchers such as those in [12], [13], [14], [15], [16] , [17] investigated redundant sensors detection using cover set methods iteratively in order to improve the life span of the wireless sensor networks deployed to monitor a set of targets locations. Here, the objective was not to provide area coverage but to cover the set of clearly identified points that constitute the sensor field. This problem is known as target coverage in wireless sensor networks parlance.

Sensor placement can be explored to address energy concerns in WSNs especially when redundancy is prevalent in the network [18], [19] and[20]. For example, the researchers in [21] proposed an approach to place an increased number of sensors close to the data sink and condition them to transmit at very low power levels, while keeping those far from the sink sparsely populated, allowing them to transmit at higher power levels to save energy. Similarly, reference [22] proposed duty cycle scheduling to help prolong the life span of the network. Other approaches involve the use of mobile base station(s) to collect data from the sensors as in [23].

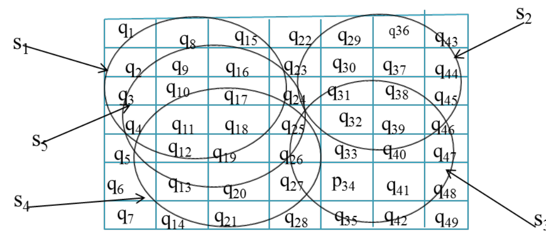

Fig. 1. Redundant Node Identification Using SCRC Technique

III. REDUNDANCY IDENTIFICATION IN WSNs

Redundancy identification is crucial when considering its applications and implications, especially if it is not deliberately included in the network by the designers. In this section therefore, we shall examine the SCRC method of redundancy identification in WSNs.

In the redundancy identification method proposed by [11], a node's redundancy is identified by checking whether it is redundantly covering an area. In other words, if the sensing region of a given sensor is completely overlapped by its neighbouring sensors, that sensor considers itself redundant. The SCRC method partitions the sensor field into distinct set of points $Q = \{q_1, q_2, \ldots, q_n\}$ to be covered by a set of sensors $S = \{s_1, s_2, \ldots, s_n\}$ and each sensor s_i has its sensing region k_i, made up of the sensing points $q_i \in Q$. The sensing region of a node is taken to be a circle represented by k_i If a point $q \in K_i$ (set of sensing points of node s_i) also belongs to K_j (set of sensing points for another node s_j), q is in the intersecting region of s_i and s_j as shown in Fig. 1. Compared to this technique for redundancy identification in wireless sensor networks, our approach extends this idea by incorporating a mechanism for identifying redundant nodes dynamically throughout the lifespan of the network. Moreover, unlike the SCRC method, our technique removes the responsibility of self-identification of redundancy from the node to a remote and centralized network controller, based on both topology information and other network dynamics.

The method defines a parameter v to signify the coverage level of any point within the sensing field. If any point $(q_i \in G)$ $i = 1, 2, \ldots, n$ in the sensor field is within the coverage range of at least v nodes, is said to be v-covered.

Therefore, any point in the sensor field that is covered by more than v nodes is said to be a redundant point. Similarly, a node s_i is said to be redundant if all the points lying within its sensing region are redundant. The reader is referred to [11] for the details of the implementation of SCRC method for identification of redundancy in sensor networks.

IV. PROs AND CONS OF REDUNDANCY IN WSNs

There is no doubting the fact that to everything that has advantages, there are always some disadvantages. In the same way, redundancy in wireless sensor networks can be viewed as a two-sided coin, with both positive and negative implications. It is also important to note that redundancy within the lifespan of a wireless sensor network is a transient concept. This is so because as time progresses from the onset of the network, nodes start to die out whenever their battery power wear out. Therefore, a redundant node at certain time say t_o, could not be considered redundant at another future time t_i, if at time t_i, all its neighbouring nodes (i.e., nodes within the same coverage area) die out. In this section, we shall briefly highlight some of the arguments for and against redundancy in WSNs.

1) **Positive Aspects of Redundancy**:

A lot of the interests shown lately in the applications of wireless sensor networks are based upon the fact that the sensing devices (i.e., sensor nodes) are becoming relatively cheap. As a result of that , it is desirable for network application designers to incorporate redundancy in order to improve network performance objectives such as robustness . In a general sense, a very low level of redundancy incorporated into a WSN design is always unfavorable for the reason that wireless sensor networks are highly error prone [9]. Therefore, incorporating redundancy into the network enables it to become more reliable. Moreover, the ability of sensor nodes to detect the event of interest is not always guaranteed but probabilistic. In view of these observations, it is proper to make room for redundancy in the network to further ensure reliability of the network. In the same vein, allowing a reasonable level of redundancy in wireless sensor networks is desired for providing fault-tolerant information, especially when individual sensor nodes are not only prone to failure, but even when they are at the risk of being physically removed by external factors such as environmental forces, or human activities, such as excavation. Redundancy is even more prevalent in those WSN applications where the nodes are deployed randomly in harsh environments or enemy territories. Furthermore, it has also been established that a higher quality result is more likely to be obtained when multiple nodes are deployed to observe the same phenomena simultaneously [24], therefore, redundancy in these scenarios is highly desirable.
Based on the foregoing, it is safe to argue that redundancy is a highly desirable design requirement to be made by any non-trivial WSN application.

2) **Negative Aspects of Redundancy**:

As already enunciated in the introductory paragraph, there is always two sides to any fair coin. In like manner, redundancy in WSNs has its other side, besides being viewed as a positive design requirement for reliable and fault-tolerant network. To highlight the negative sides of redundancy, it is pertinent to examine the concept under some QoS (Quality of Service) metrics such as energy usage. The fact that energy is a serious concern in WSNs cannot be overemphasized. More redundant nodes in the network therefore, implies more energy being consumed in the operation of the network, except if the redundant nodes are identified and carefully managed. Besides, energy concerns, other negative aspects of redundancy in WSNs include the following:

a) Increased hardware and operational costs. To make room for redundancy implies making provision for additional hardware with its accompanying cost of acquisition and operation.
b) Increased chances of data collision at the MAC layer. Whenever the event of interest occurs within the sensing area of a redundant network topology, there are increased chances of many redundant nodes transmitting the sensed information en route the fusion center at the same time, leading to increased contention for access to the communication channel.
c) Redundancy is also known to introduce additional routing costs which could result in delay in data throughput.
d) Network congestion can also result from redundancy in the network. A serious congestion can shut down the network completely making the network objectives unrealizable in the long run.

V. THE MODIFIED LEACH ALGORITHM

It has been stated earlier in the preceding section that redundancy can both be a friend and a foe, depending on the application or the objective of the wireless sensor network. The first challenge in addressing the problems arising from redundancy in WSNs is therefore, the identification of redundancy itself. The tasks of identifying redundant nodes in a randomly deployed sensor network has been shown to be a non-trivial task. In this section, we present and justify our choice of modified LEACH algorithm for redundancy identification in a randomly deployed wireless sensor network.

Just like the SCRC method mentioned earlier, our modified LEACH algorithm utilizes each node's topology information primarily to decide on a nodes suitability or otherwise for inclusion as a potential candidate for redundancy in the deployed network. Moreover, our method assumes that the sensing and communication radii of a node are not the same. This is true in practically all real sensor applications.

Although it has been shown that in wireless sensor networks, there is often no guarantee of detection of the event of interest by the nodes [25], there are applications where all the nodes can detect the event of interest simultaneously. In other words, we premised our reasoning on the assumption that the event of interest is occurring within the sensing range of each sensor (e. g., room temperature sensors), so each sensor is capable of detecting the event at the same time. This is a strong argument for LEACH algorithm which assumes all nodes have data to transmit all the time.

In addition to detectability as an important consideration in redundancy identification in WSNs, we also considered energy which plays an equally important role in most applications of wireless sensor network. To save energy, there is need for a hierarchical approach to data transmission, where the participating nodes organize themselves into dynamic clusters, and each cluster head (a role played by each sensor in turn) is responsible for onward data transmission to the sink. This feature is well supported in LEACH.

Taking into consideration these two key observations, we propose the use of modified LEACH algorithm , leveraging on the sensor field topology formed by randomly deployed nodes, for redundancy identification in the network.

It is noteworthy to state that the following assumptions in the formulation of the modified LEACH algorithm:

Assumptions:

. Each node's location in a 2-d environment (which can be extended to 3-d) is known
. Isotropic communication among the sensors is assumed
. The sensor field is assumed to be homogeneous
. Noise is neglected during signal transmission
. The sensors nodes are assumed to occupy stationary positions (i.e. mobility of the sensors is not considered)
. Each sensor in the sensor field has data to transmit to the sink throughout its life span
. Neighborhood in the sensor field is defined by a cell/grid within which two or more neighbouring nodes reside

Definitions 1:
A sensor S_i in the sensor field is said to have coverage of $cov(i) = k$, if it resides within the same grid cell as k neighbouring sensors.

Definition 2:
Two sensors S_i and S_j $(i, j = 1, 2, \ldots, n)$ are said to be neighbours if both S_i and S_j have their x, and y coordinates all resident within an identical cell defined by four grid lines (h_1, h_2) and (v_1, v_2) where h_1, h_2 are two horizontal lines, and v_1, v_2 are two vertical lines respectively.

The decision to choose any sensor with coordinates say x_i, y_i to be a redundant node is governed by the Euclidean distance between the point and a designated sink location. For a node with coordinate x_i, y_i and a sink node with coordinate, say x_j, y_j, the Euclidean distance is given by the equation :

$$d_{si,j} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}; i, j = 1, 2, \ldots, n \quad (1)$$

Given two qualified nodes S_i and S_j, $(i, j = 1, 2, \ldots, n)$ resident within the same grid cell with distances $d_{si,k}$ and $d_{sj,k}$ respectively from the sink, the node with the smallest distance is selected to represent the network in that round, while the other is considered as redundant.

For any node, to be considered as qualified for consideration as a candidate for redundancy, the node has to pass a qualifying test given by the following equation:

$$\Gamma(i) = \begin{cases} 1 & \text{if} \quad S(i).E > 0 \\ 0 & Otherwise \end{cases} \quad (2)$$

Where $S(i).E$ is the energy reserve of the node in that particular round of the LEACH cycle.

The Modified LEACH algorithm is as presented below:

```
Input: S = s_1, s_2, ..., s_n, A (an nx2 Matrix of the Coordinates of the Sensors), k
Output: Q (Set of Redundant Nodes)
Initialize Q
for (s_i ∈ S) do
   Calculate Coverage Value for Each Node s_i; i = 1, 2, ..., n
end for;
while Termination Criteria not Satisfied do
   Update the List of Qualifying Nodes(equation 2)
   Form Clusters from Qualifying Nodes
   Transmit Data to Sink
   Calculate the Coverage Value for Each Qualifying Node s_i; i = 1, 2, ..., p
   Update the Coverage for Each Qualifying Node s_i; i = 1, 2, ..., p
   if Coverage Value of Node s_i > k then
      Update Q With s_i
   end if
   Update Coverage for Non-Qualifying Node
end while
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A. Simulation Results

The following sub section outlines the simulation results obtained by implementing the modified LEACH algorithm in the identification of redundant nodes in randomly deployed wireless sensor network. One hundred

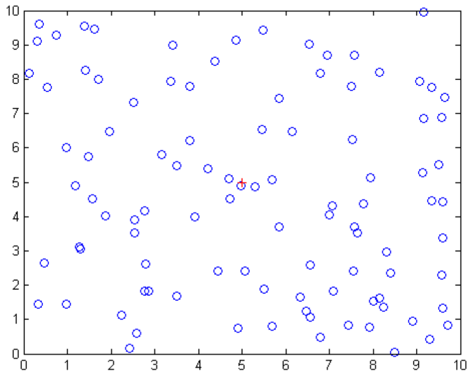

Fig. 2. Network Layout Showing Randomly Deployed Nodes

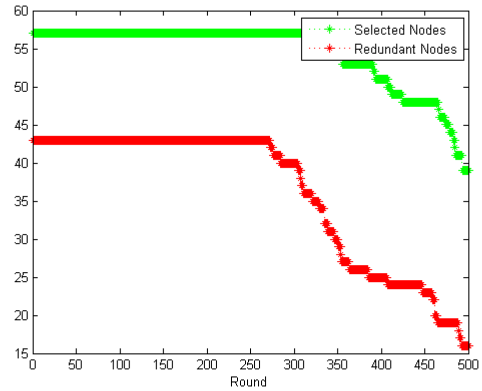

Fig. 4. Redundancy Vs. Selected Nodes

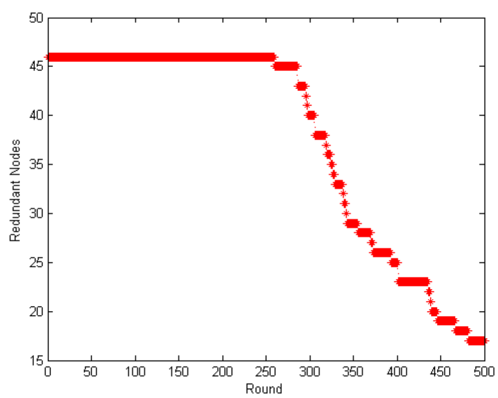

Fig. 3. Redundancy Identification Using Modified LEACH Algorithm

(100) nodes were randomly deployed in a 2D topology on a 10 x10 grid layout, as shown in Fig. 2, where node in round circles represent nodes that are potentially redundant at any particular round, while those identified by crossed circles represent those nodes that are adequate to provide the needed coverage for the network.

A careful examination of Fig.3 reveals that the modified algorithm performs to expectation. This is true because within the first 200 rounds of the algorithm, a constant number of redundant nodes is maintained, indicating that within this period,all the participating nodes are alive and active. By the time some nodes begin to die out in subsequent rounds, a fairly proportionate number of redundant nodes begin to go down correspondingly. The implication is that the sensor nodes identified to be redundant could be turned to sleep mode periodically with the potential for significant improvement in the network lifespan.

In a similar manner, the modified LEACH algorithm was used to conduct a similar experiment, using the same parameters as in the previous case. The result below shows a direct correlation between the number of nodes selected to represent the network and the corresponding nodes identified as redundant at each round. The result is presented in Fig. 4.

VI. CONCLUSION

Without loss of generality, redundancy connotes repetition or duplication. In wireless sensor networks redundancy can serve both positive and negative roles, depending on the application. If for instance, the application places more emphasis on fault-tolerance than other concerns, redundancy is highly desired. On the other hand, if the application is highly sensitive to QoS concerns (e.g., energy concerns , routing costs, network congestion , etc), then redundancy in the network cannot be ignored.

In this paper we defined redundancy as an attribute of a deployed sensor node being unneeded at a point in time, if its absence will not affect the overall performance of the network. In particular, our approach considers the redundancy that arises from duplicate physical coverage of the sensor field . Duplicate nodes covering a given area of the sensor field need to be identified and appropriate scheduling schemes implemented to better utilize the energy resources of the nodes with a view to prolonging the network's lifespan. In essence, the significant contribution of this paper is in the extension of the capabilities of LEACH algorithm by incorporating appropriate routine for the identification redundant nodes in a randomly deployed wireless sensor network. The results obtained from simulation reveal capability of the modified LEACH algorithm to effectively identify redundant nodes in the network. The redundant nodes can then be turned to sleep mode to conserve their energy for future use to help prolong the lifespan of the network.

The modified LEACH algorithm does not however, address a case where a node's coordinates lies on the demarcation of the boundary separating two adjacent grid cells. We plan to extend this work in the near future to address this shortcoming.

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