One of the most highly researched issues in wireless sensor networks is prolonging network lifetime. This is due to the limited battery capacity of a deployed node in the field of interest. It would be costly, impractical and sometimes impossible to replace their batteries once they are deployed in a remote field. When a large number of these sensor nodes are deployed (e.g. thousands) and if not properly handled, this can also lead to collisions during transmission and network congestion. This will no doubt increase latency and reduce efficiency in terms of energy consumption. We propose a practical solution called DSS (Dynamic Switching Sets) to solve the problem of network congestion as well as prolonging network lifetime. The Dynamic Switching Sets algorithm divides the scattered deployed nodes (in a non-deterministic) of the entire WSN in the field of interest into multiple DSS. An active DSS running an application would also maintain coverage of the entire sensory area while the remaining DSS are in sleeping mode waiting for their sequential turn to come alive to an active mode in a predefined sequence.

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DSS: Dynamic Switching Sets for Prolonging Network Lifetime in Sensor Nodes

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Abstract— One of the most highly researched issues in wireless sensor networks is prolonging network lifetime. This is due to the limited battery capacity of a deployed node in the field of interest. It would be costly, impractical and sometimes impossible to replace their batteries once they are deployed in a remote field. When a large number of these sensor nodes are deployed (e.g. thousands) and if not properly handled, this can also lead to collisions during transmission and network congestion. This will no doubt increase latency and reduce efficiency in terms of energy consumption. We propose a practical solution called DSS (Dynamic Switching Sets) to solve the problem of network congestion as well as prolonging network lifetime. The Dynamic Switching Sets algorithm divides the scattered deployed nodes (in a non-deterministic) of the entire WSN in the field of interest into multiple DSS. An active DSS running an application would also maintain coverage of the entire sensory area while the remaining DSS are in sleeping mode waiting for their sequential turn to come alive to an active mode in a predefined sequence.

Keywords: switching sets; prolonging network lifetime; energy efficiency

I. INTRODUCTION

The need to monitor and measure various physical phenomena (e.g. temperature, humidity, light, fluid levels, vibration etc.) is common in many areas including structural engineering, forestry, healthcare, transportation, military applications etc. Recent advances in technology have made possible the production of intelligent, autonomous sensors that can be deployed in large numbers to form self-organising, self-healing wireless sensor networks (WSN) in a geographical area [1]. A sensor node is a battery operated device capable of sensing physical quantities. In addition to sensing, it is capable of wireless communication, data storage and limited amount of computation and signal processing. A vast amount of these sensors constitute a wireless sensor network.

While these networks of sensor nodes share many commonalities with existing ad hoc network concepts, there are also a number of differences and specific challenges. One of the most important points that make WSN different is the limited amount of energy it possesses. Energy supply is scarce and hence energy consumption is a primary metric to be considered. Often the batteries of a sensor node are not rechargeable. The need to prolong the lifetime of a sensor node and hence the network has a deep impact on the system and network architecture [2]. A sensor’s radio can be in one of the following four states: transmit, receive, idle, or sleep. The idle state is when the transceiver is neither transmitting nor receiving, and the sleep mode is when the radio is turned off. Judiciously selecting the state of each sensor node’s radio is accomplished through a scheduling mechanism.

Power saving techniques can generally be classified in the following categories:

1. Schedule the wireless nodes to alternate between active and sleep mode.
2. Power control by adjusting the transmission range of wireless nodes.
3. Energy efficient routing, data gathering and reduction in the amount of data transmitted.

In this paper we address the first method as we design a mechanism of dynamic switching sets (DSS) that would dynamically switch between active and sleep modes once their energy threshold reaches the predefined set point.

II. NETWORK MODEL

We make the following assumptions about the network.

1. The transmission range (\(r_c\)) for each sensor node is fixed.
2. All the sensor nodes have identical energy.
3. Sensor nodes are densely deployed in the monitored region.
4. All sensors are randomly and uniformly deployed.
5. All the sensors and the sink are static and aware of their locations via a localization technique [9].
Our proposed algorithm implies an energy-efficient method for prolonging network life time for WSN. There are three issues that need to be addressed.

Firstly, dividing the entire sensing field FOI (Field of Interest) into a number of sets for instance three-sets. The number of sets selected represents duration of the network lifetime to be achieved and prolonged. This depends on several factors, such as size of FOI, number of nodes deployed and hence density. Now each set would be comprised of equal number of partitions of sensor nodes named Dynamic Switching Sets (DSS) as shown in Fig.1.

Basically DSS sectors of each set will run the intended application in predefined sequence. The network starts with set-one and will have all its DSS up and running in active mode while the DSS of the other two sets are in sleeping mode waiting for their priority sequence activation. The following parameters are needed for our proposed algorithm:

a) The total sensing area or filed of interest is (A)
b) Density of nodes of a uniform distribution (ρn)
c) Number of sets to run on network to achieve multiple network lifetimes is given by (m).
d) Nodes communication range (r cr) in Omni-direction

e) Node sensing range is a unit disk (r sr) such that:

\[ r_{cr} \geq 2r_{sr} \]

Secondly, we need to identify and assign an ID to each node that happened to be within each of determined DSS as well as finding total number of nodes in that particular DSS partition. For \(1 \leq i \leq k\), where \(k\) is the number of computed DSS sectors for the intended field of interest.

Finally, dealing with clustering issue and selecting a cluster head in each DSS. Our algorithm is based on a homogenous sensor network, a network in which all the nodes have identical hardware capabilities [10]. The cluster heads are responsible for collecting data from other nodes in the cluster, performing data aggregation, [10] - [12] to the remotely located sink. In order to ensure load balancing and uniform energy drainage pattern across the entire network, it is proposed to establish a rotating role of cluster heads on the nodes within each DSS.

Each cluster head CH in each DSS would store all the information related to the IDs of the nodes that reside in a particular DSS. This information will be exchanged with the base station. It is now the role of the base station to liaise with all CHs to decide on which node stays active to run the application and which goes to sleep mode.

### III. The Algorithm

1. Let \(A\) be a convex area representing the sensing field of interest (FOI)
2. Let \(K\) be the total number of partition\( s\) of \(A\) where each partition is called dynamic switching sets (DSS) such that: \(DSS_1, DSS_2, DSS_3, \ldots, DSS_K\). For a given \(K \geq 1\)
3. Assume the number of sensor nodes \(n\) is uniformly distributed in \(A\).
4. Since sensor nodes in each DSS forms a cluster, \(1 \leq i \leq k\) let \(p_1, p_2, \ldots, p_k\) be the probabilities of sensor nodes located at \(DSS_1, DSS_2, \ldots, DSS_K\) respectively [14].

The multinomial probability distributer can be used to represent the number of sensor nodes in each DSS as follows:

\[
P(n_1, n_2, \ldots, n_K) = \frac{n!}{n_1! n_2! \ldots n_K!} p_1^{n_1} p_2^{n_2} \ldots p_k^{n_k}
\]

Where, \(n = \sum_{i=1}^{K} ni\) is the total sensor of the network.

If \(N_1, N_2, \ldots, N_K\) have a multinomial distribution with parameters \(n\) and \(p_1, p_2, \ldots, p_k\), then the expected number of sensor nodes within each cluster is: \(E(N_i) = np_i\).

5. Let each sensor node has a communication range (\(r_{cr}\)) in Omni-direction

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Fig.1. Field of Interest is divided into three sets, each set is comprised of an equal number of DSS partitions. The DSSs of each set are shown in different colour.
6. Let each sensor node has a sensing range a unit disk \((r_s)\) such that: 
\[r_c \geq 2r_s\]

A new sensing range \(r_s'\) for each sensor is calculated such that an active sensor in a particular DSS would maintain coverage of neighbouring sleeping DSS partitions. This is given as follows:

\[r_s' = \frac{r_s}{m} \quad \text{for} \quad 1 \leq m\]

**Where:** 
- \(r_s'\) is the new sensing range for each node (Fig.1),
- \(m\) is the number of sets running on the network.

7. Let the perimeter of the sensing field be given by \(P_s\) in meters

Therefore the number of partitions DSS is \(K\) and is given by:

\[K = \frac{P_s}{r_s'} \quad \text{for} \quad 1 \leq m\]

Now, \(K\) represents the number of partitions based on the new sensing range calculated in equation (1). This would guarantee active running DSSs maintain coverage of areas in sleeping DSSs partitions.

8. The area of each DSS can be found as follows:

\[DSS_A = \frac{A}{K}\]

9. The approximate number of sensor nodes per each DSS can be calculated as follows (disk sensing coverage of each deployed sensor):

\[\rho_{DSS} = \frac{DSS_A}{\pi r_s'^2}\]

10. From equation (4) we can calculate approximately the total number of nodes needs to be deployed for our convex sensing field

\[n_T = \rho_{DSS} \cdot K \quad \text{for} \quad 1 \leq i \leq P_n\]

11. Let the sensor nodes at the boundary of the sensing field be \(B\).

The algorithm will now divide the sensing field area into equal partitions (DSS) by radial lines from the centre of the field area; hence the sensor nodes on the boundary of the sensing field area given by \(B\) need to be determined.

Graham’s scanning algorithm [15] is applied to find a set of the boundary sensing nodes \(B\) for the given convex polygon \(P\) of the sensing field, see Fig.2a. In this polygon each sensor node is either on the boundary or inside the polygon. The area \(A\) of \(P\) can be calculated using the locations of boundary sensor nodes:

\[(X_i, Y_i), 1 \leq i \leq P_n\]

Where: \(P_n\) is the number of boundary sensor nodes and \((X_i, Y_i)\) is the location of a boundary sensor node.
Assume the location of sensor node \((X_{p2+1}, Y_{p2+1})\) is \((X_1, Y_1)\). The area \(A_p\) (area \(A\) of convex polygon \(P\)) and the centroid location \((X_0, Y_0)\) of the polygon can be found as follows [15]:

\[
A_p = \frac{1}{2} \sum_{i=1}^{p_n} (X_i Y_{i+1} - X_{i+1} Y_i) - -(8)
\]

\[
X_0 = \frac{1}{6A_p} \sum_{i=1}^{p_n} (X_i + X_{i+1})(X_i Y_0 - X_{i+1} Y_i) - -(9)
\]

\[
Y_0 = \frac{1}{6A_p} \sum_{i=1}^{p_n} (Y_i + Y_{i+1})(X_i Y_0 - X_{i+1} Y_i) - -(10)
\]

For a given number \(K\), the sensing field area is divided into equal partition DSSs and the area of each DSS is given by equation (3).

- The procedure for finding the DSS area starts by selecting an arbitrary sensor node on the boundary \(B\) as the starting point \(P_1\) as shown in Fig.2b.
- It then selects the second sensor node \(P_2\) on the boundary in anticlockwise order.
- The area bounded by \(P_1\), \(P_2\) and \(P_0\) (the centroid) is calculated using equation (8).
- If the area is greater than the calculated DSS, this means that the required area must be bounded by \(P_0\), \(P_1\) and intermediate point (a virtual sensor node) \(P_v\) that lies on the \(P_1P_2\) line.
- Making use of DSS and the location of \(P_0\), the location of \(P_v\) is calculated as follows:

\[
Y_v = \frac{Y_1 - Y_0}{X_1 - X_0} X_0 + Y_0 - \frac{X_1 - X_0}{Y_1 - Y_0} X_0 - -(11)
\]

\[
X_v = \frac{1}{Y_0} (Y_v Y_0 - 2DSS)
\]

If the calculated area is less than the DSS area, a new sensor node on the boundary of sensing field next to \(P_2\) is selected and the area has to be recalculated.

The next stage is to identify the actual nodes that reside in each DSS partition. This is found with the following algorithm:

a) Each Dynamic Switching Set is a sector that has an angle \(\theta_{DSSi}\) calculated using the centroid and the two vertex points that make up the sector, e.g. \(\angle P_2P_0P_1\) as shown in Figure-3 below.

b) The algorithm would first calculate the angle of each particular DSS sector and identify its three points for example in a counterclockwise \(P_2, P_0, P_1\). It would then start to randomly pick a sensor node in the neighborhood. This node would become the new vertex point "\(P_z\)" such that we have \(P_zP_0P_1\). The new \(P_z\) vertex would now make a new angle (e.g. \(\Theta_z\)) with the other two fixed nodes for this sector measuring in counterclockwise direction \(\angle P_zP_0P_1\) as shown in Fig.4.
c) If the new angle resulted from the new found node is less or equal to the original sector angle then this sensor node does belong to this sector. Hence it will be identified and given an ID for this DSS by the cluster head.
d) If however the new measured angle is bigger than $\theta_{DSS}$ then it will be ignored as it resides outside that specific DSS and belongs to the adjacent sectors.
e) Then the next node is chosen and the same algorithm is applied. This node finding process continues until the number of identified nodes for a particular DSS reaches the estimated pre-calculated number of nodes that need to be residing in each DSS.
f) The next DSS sector runs the same mentioned algorithm until all the sectors in the sensing area identify their actual nodes in their jurisdictions.
g) The DSSs of set one begin in active mode and start running application while the two other sets would go to sleep mode [13] as shown in Fig. 5
h) They will continue being active until they are instructed by the BS (base station) to go to sleep mode and the next dynamic switching set comes active to begin a new second lifetime.
i) This process would continue as in Fig. 6 throughout the network life cycle which results in prolonging the network life.

![Fig. 5. DSSs of Set-One are active and running, while sets 2, 3 are in sleeping modes.](image1)

**IV. RELATED WORK**

In this section, we review some approaches for work done and researched on energy efficiency for WSN while maintaining the coverage. Various power schemes have been proposed in literature [8], not only at the hardware and architectural design, but also when designing algorithms and protocols at all layers of the network architecture.

A distributed approach for sensor scheduling in stochastic $k$-covered WSN [3] was presented. The model needs to compute the maximum size of an area that is surely $k$-covered with exactly $k$ sensors. The results show that the threshold probability increases when more sensors are needed to achieve the same degree of $k$ coverage but it is not clear how this would ultimately impact the network life time.

Another similar work is suggested in [4], the network lifetime is extended by dividing the sensor nodes into a number of sets, such that each set completely covers all the targets. The sensor sets would be activated successively, at any time instance only one set is active and all other sensors are in the sleep state. In this approach every sensor is allowed to be part of more than one set which we think is not ideal because a sensor would have already used up some of its energy while being involved in a previous set. This would create an uneven power distribution among active running sensors.

Dhawan et al [5] propose maximizing the lifetime of a target-covering sensor network. The network model consists of a large number of sensors with adjustable sensing ranges.
being deployed to monitor a set of targets. This approach adjusts a sensing range to meet application requirements and assigning a lifetime to each active sensor.

A similar approach to our proposed scheme has been suggested [6] where a node scheduling protocol is used such that some sensor nodes stay active, while others are inactive for conserving their energy. The concept of effective sensing area (ESA) is implemented as each sensor calculates its own sensing area to see it is not overlapping with other nodes’ sensing areas. The sensors would then determine whether it will be active or not. The protocol lacks to show the frequency at which each sensor needs to calculate its ESA during its lifetime to ensure proper coverage of the sensing field.

An interesting approach was developed in [7] called energy balanced chain (EBC) where energy balanced among the nodes is suggested by controlling the nodes’ hop distances. By adjusting the transmission power, nodes with higher traffic have a longer hop distances than nodes with lower traffic.

V. CONCLUSION AND FUTURE WORK

Several solutions have been reported in the literature showing the importance of wireless sensor network and the potential applications that are emerging as this technology progresses. However, one of the most important challenges facing this technology is energy limitation. Energy utilization by sensor nodes often impacts the application’s life time due to limited battery capacity. It would be costly, impractical and sometimes impossible to replace sensor nodes batteries ones they are deployed in a remote field. When a large number of these sensor nodes are deployed (e.g. thousands) and if not properly handled can also lead to collisions during transmission and network congestion. This will no doubt increase latency and reduce efficiency in terms of energy consumption.

In this paper, we have proposed an algorithm for prolonging network life time by implementing Dynamic Switching Sets (DSS) mechanism to the sensor nodes in the field of interest. Once the sensor nodes along with the BS are deployed, the algorithm uses a predetermined parameter “m” that represents number of sets to be implemented (e.g. three-sets), which means a target of three times network lifetime is aimed. As the number of sets is determined, the algorithm would then define an equal number of DSS to each set. The next step is to identify and assign nodes to each DSS and given them an ID based on their proximity and residence in each DSS.

At this stage the number of sets is determined, the number of DSS in each set is determined and finally the scattered nodes are now having identity and belonging to their specified DSS. The base station (BS), would now communicate with the cluster head in each DSS of the entire sensing field and instruct them to start the dynamic switching between active and sleep modes. The DSS of set one would start active running the application while maintaining coverage, at the same time the DSS of both sets two and three would switch to sleeping mode. The dynamic switching sequence continues among all three sets based on reaching predefined energy threshold. This mechanism proves to extend the lifetime of the network to three times the normal setting.

The future work includes implementing and evaluating the proposed algorithm, and analyzing the outcomes.

REFERENCES