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Deployment Scheme For Self Sustaining Long Term Wireless Sensor Networks

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Abstract:

The researchers have been making efforts to extend the life of Wireless Sensor Networks (WSNs) for a long time. WSN is a system made up of a group of wirelessly connected components known as Sensor Nodes (SNs) located within a target region at different geographical locations. It employs Sensor Nodes (SNs) which are battery powered elements. Battery is an exhaustible component and requires a charging or replacing after being used for certain time interval.WSNs have achieved special attention from application domains which are hazardous or away from the human reach. Deployment of SNs for such applications makes the manual maintenance of SNs an impractical task. So, here arises a need of WSN which can maintain itself in order to continue its services for long time intervals

In this article a deployment scheme for self sustaining long term WSN has been proposed. It consists of energy harvesting and distribution units (EHDs) which are aerially droppedon predetermined locations within a target region. EHD is responsible for deployment, energy harvesting, and energy supply and post deployment maintenance of the WSN. Floating SNs are ejected from EHD (in all the directions) at various altitude levels in order to scatter them uniformly though out the target region. Simulation results show that the coverage achieved by the proposed model is better than the existing models of random aerial deployment.

Keywords:

WSN, Sensor Node, Deployment, Aerial, Coverage

1. Introduction

WSN is a system formed by the group of wirelessly connected components known as Sensor Nodes (SNs) placed at different geographical locations within a target region[1][2][3][4][5][6]. It employs Sensor Nodes (SNs) which are battery driven elements. Battery is an exhaustible component and requires a charging or replacing after being used for certain time interval. WSNs have a wide spectrum of application domain which ranges from small scale WSN deployed on human body to large-scale WSN deployed in open regions to keep track of physical phenomena such as animal movement tracking, intrusion detection, forest fire detection, enemy movement monitoring in the battle field, natural calamity and weather forecasting, etc.[7][8][9]

WSNs have achieved special attention from application domains which are hazardous or away from the human reach. Deployment of SNs for such applications makes the manual maintenance of SNs an impractical task. Since long the researchers are making efforts for prolonging the life of Wireless Sensor Networks (WSNs). Several schemes have been proposed to optimize the various aspects of WSNs in order to enhance the life of SNs.

In this article a deployment scheme for self sustaining long term WSN has been proposed. It consists of energy harvesting and distribution units (EHDs) which are aerially dropped on predetermined locations within a target region. EHD is responsible for deployment, energy harvesting, and energy supply and post deployment maintenance of the WSN. Floating SNs are ejected from EHD (in all the directions) at various altitude levels in order to scatter them uniformly though out the target region. Simulation results show that the coverage achieved by the proposed model is better than the existing models of random aerial deployment.

The rest of the paper is organized as follows. Section 2 presents the related work. Section 3 presents the system model. Components and their utility are presented in Section 4. Working of EHD is explained in Section 5, followed by Simulation results and conclusion in Section 6 and 7 respectively.

2. Related work

Deployment is aessentialstage in the life of any WSN. The performance (coverage, life and connectivity) of any WSN relies on the pattern of placement of SNs within a target region. Researchers have proposed different schemes for the deployment of SNs.

Authors in[10] presented a virtual force driven scheme for evenly distributing the SNs within a target region. It exerts an attractive force between the SNs which are separated by the distance greater than the threshold whereas the repulsive force is exerted on the MSNs whose distance is less than the threshold value.

Authors in [11] presented a scheme for the homogeneous distribution of MSNs within a target region. The entire target region is divided into concentric regions centered at BS. BS instructs the MSN layer after another to move to the most appropriate locations.

Researchers in [12] proposed an energy efficient scheme to enhance the coverage achieved by the randomly scattered MSNs. All the optimal locations, which are computed by the BS are made available to each MSN. The MSNs compute their distance from each location and start moving towards the one nearest to it. This movement is supported by the regular communications that take place between the nearby MSNs in order to avoid collision.

All of the above schemes proposed by various researchers are relocation based schemes which require MSN are more bulky and costly component due to an extra module for relocation. This make the MSN based schemes less feasible for large scale implementation.

Corkeet. al. [9][13] proposed a plan for the positioning the SNs utilizing a robot helicopter. It utilizes a screw based mechanism to drop the SNs at pre-computed areas. Despite the fact that, the model effectively places the SNs in small area WSN, it can't be utilized for the deployment of SNs in large area WSN. Yoshiaki et. al. in [14], proposed a technique for airborne dissipation of SNs utilizing double state (parachutes can switch their state among "Floating" and "Falling") parachutes. The nearby SNs communicate among themselves in order to decide their densities. The state of the parachute (floating or falling) is decided on the basis of the mutually computed density. This methodology consistently disperses SNs while floating over deployment region, but the density can only be determined by the SNs flying at the same level (i.e., SNs inside correspondence run), while different SNs flying at various elevations may again prompt non-uniform dispersion of SNs within a deployment region.

Authors in [15] propose a random scattering method for SNs. It uses a sprinkler based on a centrifugal cannon (CCS) to disperse the SNs in a WSN. To randomly deploy the SNs, CCS is mounted on the helicopter that scans the entire target region following a predefined path.

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All of the above proposed models use a random deployment technique for the aerial deployment of SNs which may not yield the optimal coverage. In order to improve the coverage with the given number of SNs, more sophisticated mechanism of SN deployment need to be developed. In this article a model for the deployment of long-term WSN has been proposed.

3. System Model

Several WSNs are deployed to serve for long duration which may range up to several years. Few of the application that requires long term WSNs include Forest fire detection system, weather monitoring System, intrusion detestation system, etc. So a well defined mechanism is required to deploy the SNs for such applications.

EHDs are the self-sustainable units which are deployed in the predetermined locations within a target region

3.1 Preliminary

In this context the term "optimal number of SNs" will be used quite frequently. It refers to the minimal number of SNs which can completely cover the entire target region.

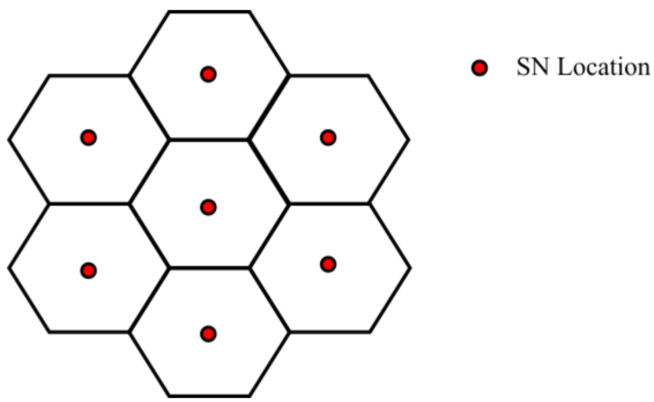

Figure 1. Hexagonal division pattern

Various researchers have proposed techniques for determining the optimal number of SNs for any region [16][12]. Among these the hexagonal division pattern for SN deployment has the best results. In this pattern the complete target region is divided into hexagonal divisions (regular hexagons with each side = sensing range (s_r)). The center point of these hexagons forms the optimal location for the placement of the SNs (see Figure 1). The relationship between s_r and communication range (c_r) is given in equation 1.

$$c_r \leftarrow \sqrt{3} * s_r \tag{1}$$

4. Components and Their Utility

Following are the prime components of EHD

- ***Aerial vehicle:*** This may be a helicopter, helium filled airship, etc. which could carry EHDs to drop them at specific predetermined locations within a target region.

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- ***Energy Harvesting Unit:***It consists of a helium filled balloon. The top surface of balloon equipped with the solar cells to harvest the solar energy during day time.
- ***Control unit:***Control unit consists of a chamber which houses three basic components
- ***Sink Node:***It is a communication unit mounted on EHD. It receives data from all the SNs located within particular HSD, aggregates the data and communicates it to the base station (BS). It is a long range transmission device with powerful transmitter.
- ***Sensor Nodes:*** These are packed inside spherical capsules. These capsules are spherical chamber made of shockproof and porous substance designed to safely hold the SNs within. The top part of these capsules contains a parachute which floats the SN to the ground once they are ejected from the main chamber.
- ***Batteries:***The solar-energy harvested by the solar cells mounted on the helium filled balloon need to be stored for future usage. The batteries installed in the bottom chamber of the control unit are used to store the harvested energy.
- ***SN Charging Platform:***It is a specially designed part of a control unit where the SNs or MSNs with low battery are recharged.

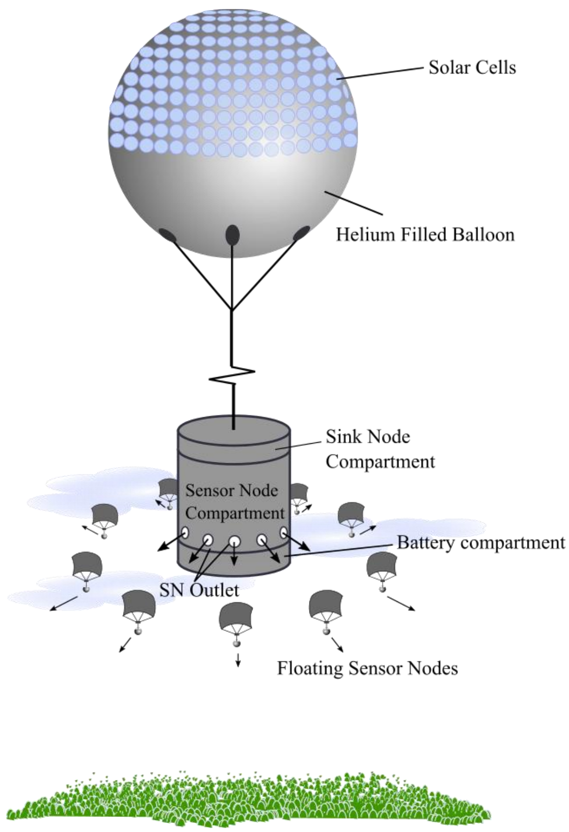

Figure 2. EHD

5. Working of EHD

Wholeof the target region is divided intohexagonal sub-divisions (HSDs). Each HSD defines the total area to be deployed and maintained by the particular EHD. EHDs are positioned on the center point of the HSD as shown in Figure 3.

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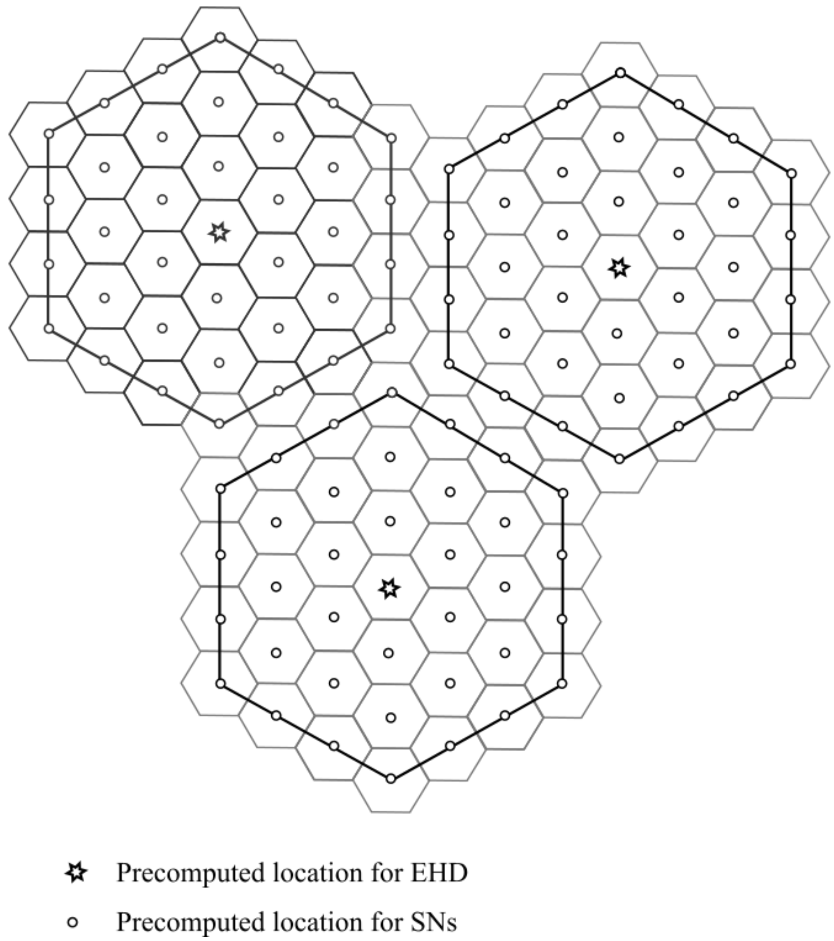

Figure 3. Formation of HSDs

The HSD is divided into number of concentric circular regions (see Figure 4) denoted by a set $C = \{C_1, C_2, C_3, \ldots, C_n\}$ each separated by distance d_s given in equation 2. The radius of each circle (starting from inner to outer) is denoted by the set $r = \{r_1, r_2, \ldots, r_n\}$. The outer boundary of these regions forms the marking for the deployment of SNs.

$$d_s = \frac{\sqrt{3} * s_r}{2} \tag{2}$$

where n is the number of concentric regions, the value of n is given in equation

$$n \leftarrow \frac{R_{HSD}}{d_s} \tag{3}$$

where R_{HSD} is the radius of the HSD. The relative density d_r is given in equation 4

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$$d_r = \rho - d_h \tag{4}$$

where ρ is the density of air (i.e., 1.255 Kg/m3) and d_h is the density of helium (i.e., 0.179 Kg/m3)

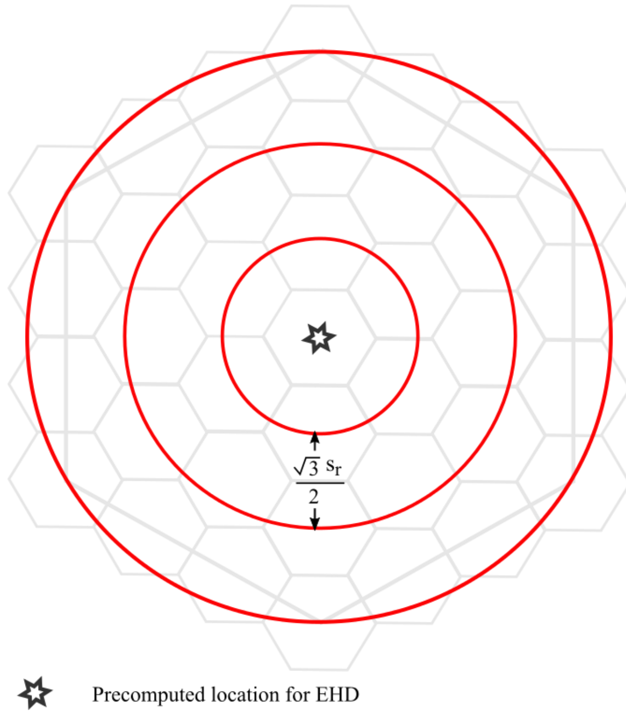

Figure 4. Circular division of HSD

The force exerted on the helium filled balloon F_h in upper direction is given in equation 5

$$F_h \leftarrow \frac{4}{3}\pi * r_h^{\,3} * d_r \tag{5}$$

where r_h is the radius of the helium balloon.

Force exerted by the gravity F_g is given by equation 6

$$F_g \leftarrow T_m * d_r \tag{6}$$

where T_m is the combined weight of balloon, control unit, string, etc. The direction of force exerted by F_h and F_g are in opposite directions, so the direction of movement of EHD will be in the direction of force with greater magnitude. In this article the EHD is supposed to land on the ground after being dropped from the aerial vehicle, so the weight of CU is determined such that the overall movement of EHD is towards the ground.So, the resultant force F_r exerted on the EHD is given in equation 7

$$F_r \leftarrow F_g - F_h \tag{7}$$

The resultant mass M_r on which the force of gravity will act upon is given by equation 8.

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$$M_r \leftarrow \frac{F_r}{g} \tag{8}$$

Every object which falls towards the ground after being dropped from certain altitude falls with constant speed termed as terminal velocity V_{tml}given in equation 9. This is due to the resistive force exerted by the air on the falling body.

$$V_{tml} \leftarrow \sqrt{\frac{2*M_r*g}{D_c*\rho*A}} \tag{9}$$

whereD_c is the coefficient of drag for sphere. A is the area of cross-section and ρ is the density of air (i.e., 1.255 Kg/m^3).

An approximate time taken by the EHD to reach the ground is given by equation 10.

$$T_{air} \leftarrow \frac{H}{V_{tml}} \tag{10}$$

where$H$ is the dropping height of the EHD.

The number of SNs to be plotted on the circumference of each region is given by equation 11.

$$Q_d = \frac{2\pi r_d}{\sum_{i=1}^{n} 2\pi r_i} * \frac{getDeploymentArea()}{\frac{3*\sqrt{3}}{2}*s_r} \tag{11}$$

The direction of dropping of SN for particular C_d is separated by an angle A_d degrees (seeFigure 5). The value of A_d is given in equation 12.

$$A_d = \frac{360}{\frac{2\pi r_d}{\sum_{i=1}^{n} 2\pi r_i} * \frac{getDeploymentArea()}{\frac{3*\sqrt{3}}{2}*s_r}} \tag{12}$$

where$0 < d \leq n$

Each EHD is assigned a certain range to cover and maintain based on which the number of SNs and dropping height of the EHD is determined.

After being released from the aerial vehicle the EHD start falling towards the ground with a fixed velocity i.e., V_{tml}. Meanwhile the control unit of EHD continuously monitors the altitude in order to release the SNs from the chamber at appropriate altitude levels.

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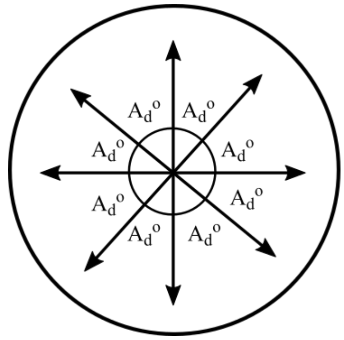

Figure 5. Angle of SN dropping.

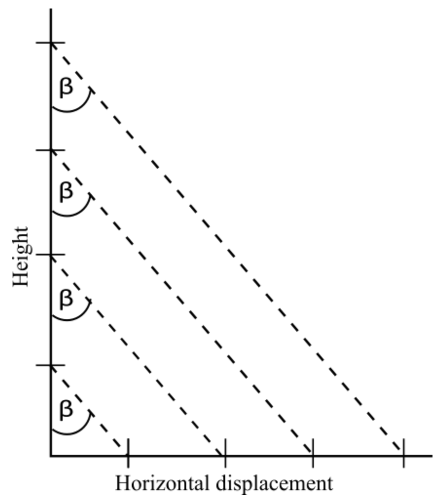

Figure 6. Horizontal distance covered by a SN while floating.

The height of dropping H_i of SNs for particular C_i is given in equation13

$$H_i \leftarrow \frac{r_i}{\tan \beta} \tag{13}$$

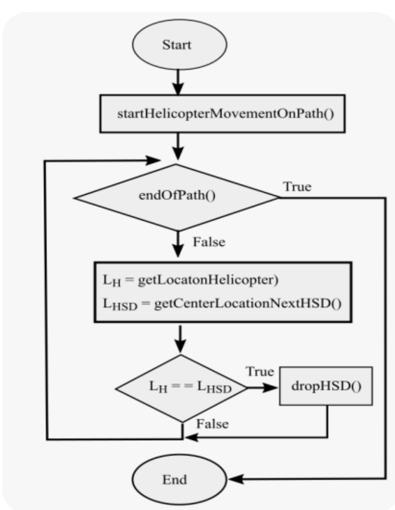

Figure 7. Flow Chart-1

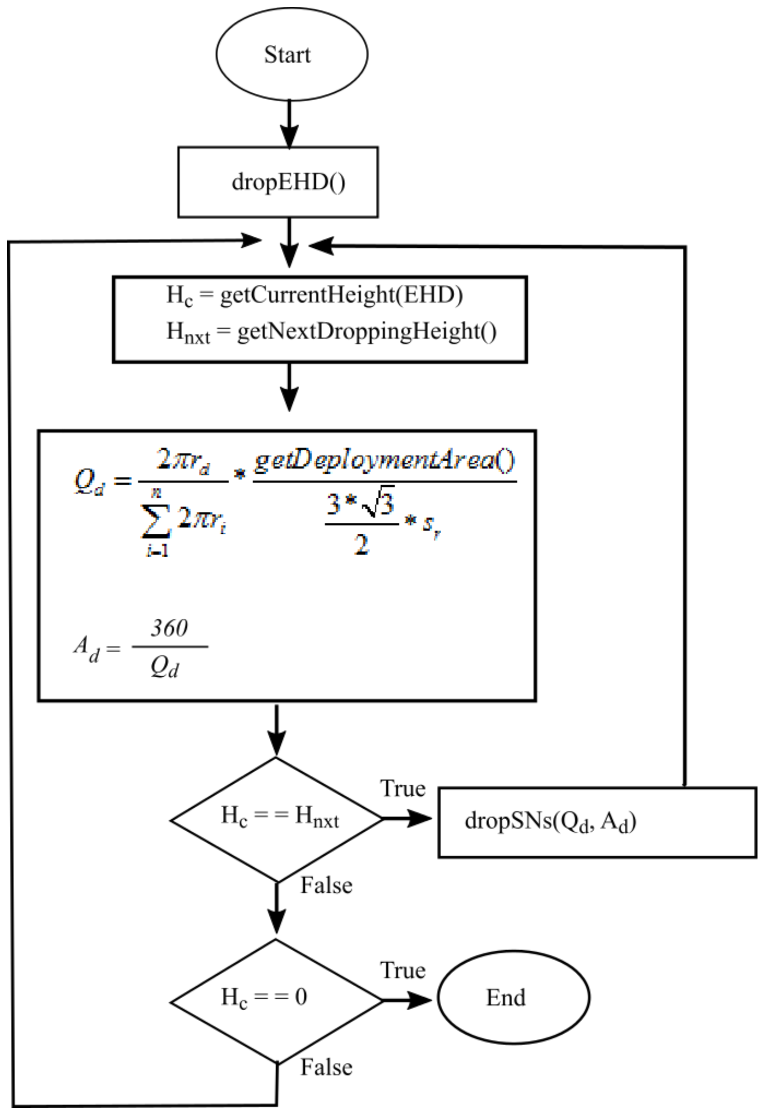

Figure 8. Flow-chart 2

Flow of operation of EHD is given in Algorithm 1 (seeFigure 7 and Figure 8)

Algorithm 1: EHD Operation
• ***getLocationHelicopter():*** *Returns the current location of the helicopter.* • ***getCenterLocNextHSD():*** *Returns the* • ***startHelicoperMovementOnPath():*** *Starts the movement of helicopter on the scan path.* • ***endOfPath():*** *Returns true if the scan-path is completed else its returns false.* • ***dropSN(Q_d, A_d):*** *drops the SNs from the EHD. Here Q_d is the number of SNs and A_d is the angle space between adjacent dropped SNs.*

- ***dropEHD():*** *drops the EHD from the helicopter.*
- ***getCurrentHeight(EHD):*** *Returns the current altitude of dropped EHD.*
- ***getNextDroppingHeight():*** *Returns the next altitude at which the SNs have to be dropped by the EHD.*

Thread 1:

Step-1: *startHelicoperMovementOnPath();*

Step-2:If *endOfPath()* ***Then***
GoTo *StepX*
Else
Step-3: L_H *= getLocationHelicopter();*
Step-4: L_{HSD} *= getCenterLocNextHSD();*
Step-5: If $L_H == L_{HSD}$ ***Then***
dropEHD();
Else
GoTo *Step-2*
End If
End If
Step-6: End

Thread 2:

Step-1: *dropEHD()*
Step-2: H_C *= getCurrentHeight(EHD);*
Step-3: *getNextDroppingHeight();*
Step-4: $Q_d = \frac{2\pi r_d}{\sum_{i=1}^{n} 2\pi r_i} * \frac{getDeploymentArea()}{\frac{3*\sqrt{3}}{2} * s_r}$
Step-5: $A_d = \frac{360}{Q_d}$
Step-6: If $H_c == H_{nxt}$ ***Then***
dropSN(Q_d, A_d*);*
GoTo: *Step-2*
Else If $H_c == 0$ ***Then***
GoTo *Step:7*
Else
GoTo: *Step-2*
Step-7: End

After the uniform deployment of the SNs and EHDs the model uses a well defined model for WSN management [17] proposed by Bindalet. al. to maintain and handle the WSN

EHDs are self sufficient units. The batteries placed in the battery compartment get charged during the daytime through the solar cells mounted on the helium filled balloon. Certain number of extra MSNs is dropped within the HSDs known as actuators of ambulance nodes which perform the task of repairing, recharging and replacing the exhausted SNs within the HSD.

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6. Simulation Result

The proposed model is simulated in java. The simulation parameters of EHD are given in Table 1. Results show that the EHD achieves about 96% percent of coverage with the optimal number of SNs.

Table 1. SimulationParamters

Variable	Value
Dropping Height	1000 m
Floating angle	30 degree
Radius of helium filled balloon	2 m
Density of air	1.25 Kg/m^3
Number of SNs	55
Radius of HSD	250 m
Area of target region	1000m X1000m
Sensing range	40 m
Communication range	70 m

Figure 10 and Figure 9 presents the coverage of CCS and EHD respectively. It is observed that SN deployment by EHD has less uncovered holes in comparison to CCS.

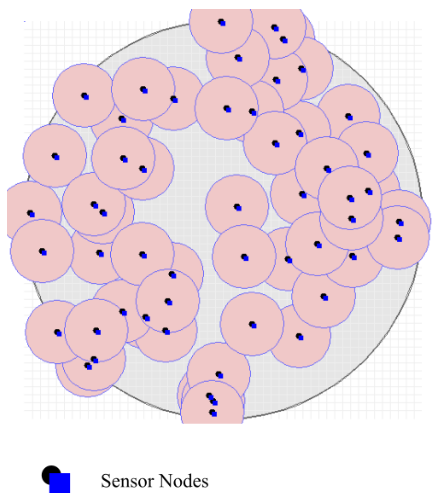

Figure 9.Coverage by CCS.

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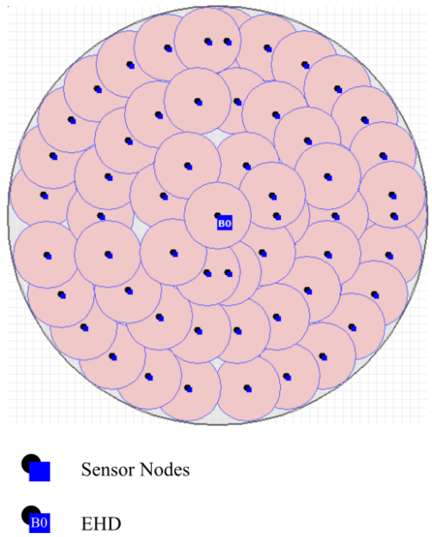

Figure 10. Coverage by EHD.

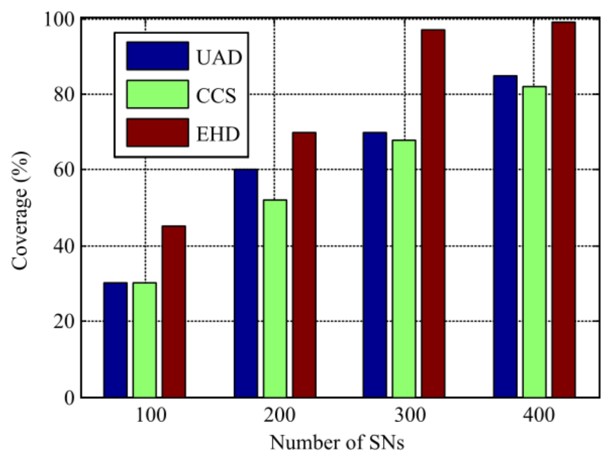

Figure 11. Relation between Number of SNs and percentage coverage.

Figure 11 represents the relation between number of SNs and percentage coverage achieved by various schemes of aerial deployment. It is observed that EHD achieves maximum coverage among all. It covers about 96% of the target region with optimal number of SNs .

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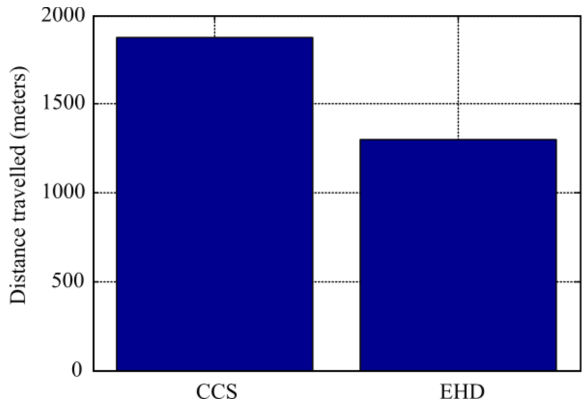

Figure 12. Length of the scan path

EHDs are dropped within a target region with the help of helicopter. Figure 12 represents the comparison of distance travelled by helicopter with CCS and EHD. It is seen that the distance travelled by helicopter with EHD is 1300 m which is far less than that of CCS for a given size of target region.

Conclusion and future work

In this article a deployment scheme for self sustaining long term WSN has been proposed. It consists of energy harvesting and distribution units (EHDs) which are aerially dropped on predetermined locations within a target region. EHD is responsible for deployment, energy harvesting, and energy supply and post deployment maintenance of the WSN. Floating SNs are ejected from EHD (in all the directions) at various altitude levels in order to scatter them uniformly though out the target region. Simulation results show that the coverage achieved by the proposed model is better than the existing models of random aerial deployment.

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