Uniform Distribution of Aerially Dropped Sensor Nodes in Large Wireless Sensor Network Area

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Abstract

Wireless sensor network (WSN) is a basic solution to the remote monitoring problems. WSN faces unique deployment and positioning challenges when the deployment region is a large sized. Aerial scattering of SNs has emerged as a practical solution to large scale deployment problem. Such types of schemes are time efficient and can be used to achieve blanket coverage over the large region. But their stochastic nature desist them from achieving the optimal coverage.In this article a uniform distribution scheme for aerially dropped SNs has been proposed. It is an enhancement on the (Centrifugal Cannon based Sprinkler) CCS, which is a basic scheme for stochastic scatting of SNs in large scale regions. The main focus of this work is to increase the coverage achieved by the CCS with optimal number of SNs. This model uses the parachutes with different dimensions to float the SNs with different floating angles in order to reach their destined locations. The simulation results shows that the proposed scheme achieves better coverage than CCS. However, the time taken by both the schemes is same.

Keywords

WSN, Sensor Nodes, Coverage, Deployment, Aerial

1. Introduction

Wireless sensor network (WSN) has emerged as an effective solution to the problemof remote monitoring, control and automation[1][2]. Sensor node (SN) is a small sized device capable of sensing the specific changes that take place in its vicinity. It is equipped with a wireless communication module to communicate the sensed information to the base station (BS). The prime performance matrices of WSN include its connectivity, coverage and life. WSN has a wide range of application domain such as house automation, agriculture, military surveillance, climate monitoring, disaster management, pollution control, etc.[3][4][5][6][7][8].

The deployment is a first phase in the life cycle of any WSN. It determines the pattern in which the SNs are to be placed in the candidate region in order to meet the requirement. Deployment can be categorized as Blanket, Barrier and point of interest (POI) type[9]. Researchers have proposed various methods to optimally deploy the SNs in various types of candidate regions such as land, water and air.

In this article a uniform distribution scheme for aerially dropped SNs has been proposed. It is an enhancement on the (Centrifugal Cannon based Sprinkler) CCS[10] , which is a basic scheme for stochastic scatting of SNs in large scale regions. The main focus of this work is to increase the coverage achieved by the CCS with optimal number of SNs. The proposed model uses two sets of SN-droppers, mounted on each side of a helicopter used for deployment. Each dropper in a set is supplied with the SNs with similar floating angle. SNs are dropped from the SN-droppers in a manner such that they scatter uniformly within a target region. In this way the UDAD covers a wide area of target region in a single scan, thereby decreasing the deployment time. The simulation results shows that the proposed scheme achieves better coverage in comparison to the existing schemes of aerial deployment.

The rest of the paper is organized as follows. Section 2 presents the literature of similar efforts made by the researchers in the recent past. preliminary and its working is defined in section-3. System model and its working is defined in section-4.Results of the simulation are presented in section-5 followed by the discussion and conclusion in section-6 and 7respectively.

II LITERATURE SURVEY

Deployment is a crucial phase in the life-cycle of any WSN. Researchers have suggested various techniques for the deployment of SNs with a sole motive to enhance the performance of the WSN. The performance (coverage, life and connectivity) of any

WSN depends on the pattern of placement of SNs within a candidate region

Authors in [11]proposed a virtual-force in order to establish uniformity in the distribution of the MSNs. The repulsive force exists between two MSNs, if the distance between them is less than the threshold; otherwise an attractive force exists if the distance is greater than the threshold.

Authorts in [12] presented a model for the deployment of Mobile Sensor Nodes (MSNs) in the most suitable locations. These locations are computed such that the minimal number of MSNs can cover the entire target region. It considers BS as the center point and divides the whole of the target area into concentric regions. BS instructs the MSNs layer after another to position them to the optimal locations within a current layer.

Auhtors in [13] presented a scalable energy efficient deployment scheme to enhance the coverage of target region using MSNs. Each MSN compute its distance from the optimal points within target region and starts moving towards the one closest to it. The movement of the MSNs is coordinated by the confined communication among the nearby MSNs in order avoid collisions and minimize the average steps moved.

Auhtors in [14] presented another MSN assisted deployment scheme for complete coverage of the target region. This scheme uses 3-stage progressive algorithm for the positioning of the MSNs within a target region. Each stage lays the foundation for the execution of the proceeding stage. This scheme dramatically decreased the average distance moved by the MSNs and enhanced the coverage with the surety of connectivity

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Corke.et.al.[11][12] proposed a scheme for the placement of SNs using a robot helicopter. It uses a screw based assembly to drop the SNs at pre-computed optimal locations. Although, the model efficiently deploys the SNs in small sized WSN, it cannot be used for the deployments in large scale candidate regions.

Yoshiaki.et.al.in [13] proposed a method for aerial scattering of SNs using dual-state parachutes (parachutes can switch their state between “Gliding” and “Falling”). The local communication is performed in the air in order to determine their densities based on which the state (gliding or falling) is selected (dense nodes glide in arbitrary directions for random time in order to scatter while the other remains Falling). This approach uniformly distributes SNs while hovering above the candidate region but densities can only be determined by the SNs flying approximately at same level (i.e., SNs within communication range), while other SNs flying at different altitudes may again lead to non-uniform deployment and mechanics of parachutes are not defined for this model.

Researchers [10] proposed a policy for random scattering of SNs. It is mounted on a helicopter which traverses the target region following a predefined scan path. It uses a set of variable sized cannons rotated at a common junction point in order to randomly scatter the SNs. using a centrifugal cannon based Sprinkler (CCS).

III PRELIMINARY

In this research article the word “optimal SNs” is often used. It refers to the minimum quantity of SNs which can fully cover the entire target region. Researchers have proposed various schemes to compute the optimal number of SNs for any region[14][15]. Among these the hexagonal division pattern for SN deployment has the best results.

This divides the whole target region into number of regular hexagons (each with side = sensing range (s_r)). The midpoint of these hexagons forms the optimal location for the placement of the SNs (see **Error! Reference source not found.**).

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

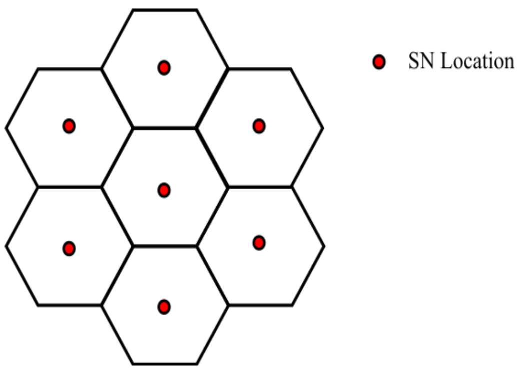

Figure 1.Hexagonal division of target region

The relation between sensing range (s_r) and communication range (c_r) is given in equation **Error! Reference source not found.**. The optimal number of SNs for any target region is given by equation 1.

$$O_{sn} \leftarrow \frac{getDeploymentArea()}{\frac{3*\sqrt{3}}{2} * s_r} \quad (1)$$

A. System model

The proposed model is an improvement on the CCS which constitute of an assembly of cannons of irregular length, which is rotated with the help of motor in order to scatter the SNs within a target region. It is somewhat similar to the water sprinkler used in the agriculture fields to irrigate the land. A SN randomly enters any cannon and get launched in a random direction. The SNs launched from different cannons of CCS have different launch velocities, depending on the length of the cannon. Say, a CCS consists of set of cannons $C= \{c_1, c_2, c_3, ..., c_n\}$ with length $l_1, l_2, l_3, ..., l_n$ then the launch velocity V_i is given by equation 2.

$$V_i = \omega * l_i \quad (2)$$

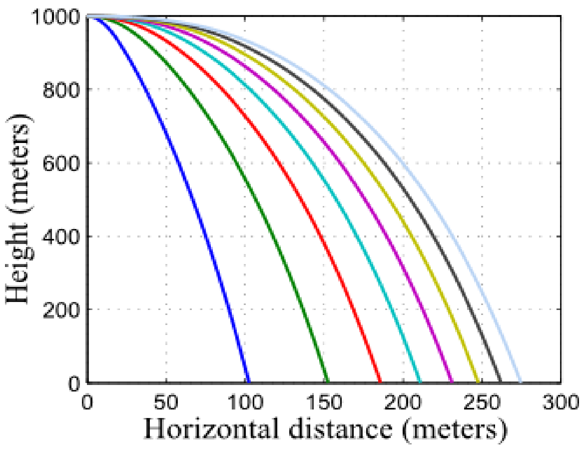

Figure 1. Trajectories of SN launched from various cannons of CCS at 100 RPM

The trajectories of SNs launched from various cannons of CCS are shown in Figure 1. It is observed that the horizontal distance travelled by the SN fired from the long cannon is more in comparison to the shorter one. This is because of the direct relation between the length of the cannon and force with which the SN is fired from it (see equation 2).

B Design of SN casing

In order to regularize the shape of SNs and protecting them from physical damage while deployment., the SNs are packed inside a spherical casing (See Figure 2) made up of porous and shock absorbing substance.

The upper compartment of capsule houses a parachute, the central compartment contains the SNs and the lower compartment contains a heavy base. The base of the SN- capsule is made heavy in order to make sure that the landing posture of all the SNs is same.

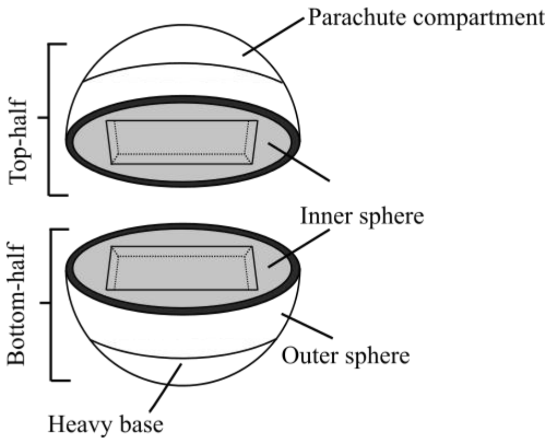

Figure 2. Encapsulation of SN

Parachute: The design of parachute is such that it can float in any particular direction in which it is released. The parachute carries the SN in that direction with constant horizontal speed S_h and floating angle (a) until the SN reaches the ground (see Figure 3).

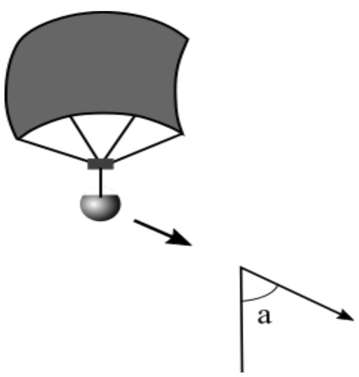

Figure 3. Floating SN.

For a particular SN with a given horizontal velocity the floating angle can be determined on the basis of the size of the canopy of the parachut

D Sensor Node Dropper (SND)

It is a prime component of a UDAD. It consists of a long threaded shaft (screw- like) as used in [11][12].The SNs are hung on this shaft at regular distance from each other as shown in

Figure 4. The shaft is rotated with the help of a motor. The thread like structure on the shaft facilitates the movement of SNs towards the dropping end from where they are released.

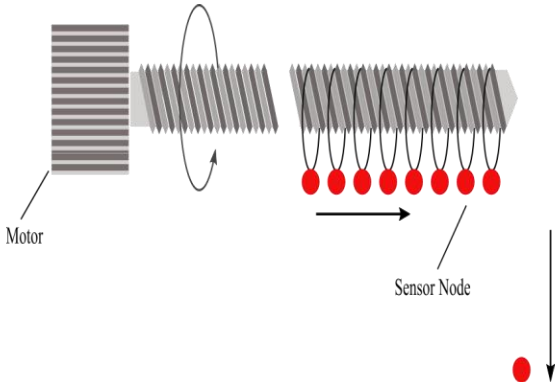

Figure 4. Sensor Node Dropper

C Working of Udsd

UDAD consists of two identical sets of SNDs one on each side of the deployment helicopter (see

Figure 5).

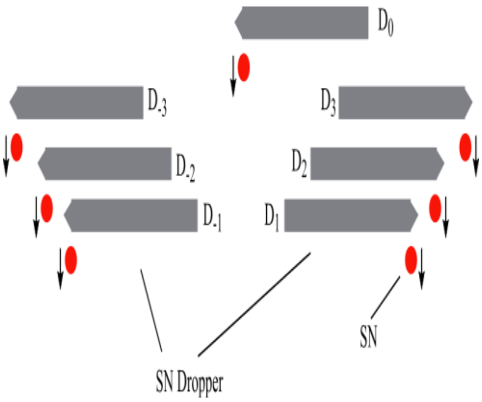

Figure 5. UDAD

Each SND in a set contains the SNs with different floating angle, however the floating angle of all the SNs contained in a SNS is same. The floating angle of the SN in the SND is adjusted such that they float to the specific horizontal lines on the ground once dropped from the SND. It is assumed that the SNs float with the constant floating angle in the direction they are released and the impact of environmental winds on the floating SNs is null.

Initially, the target-region marked by the square-grid, which consists of horizontal and vertical lines. These lines are separated by equal the distance D_{Li} as shown in *Figure 7*. The intersection point of these lines forms the preferred locations (PLs) for the deployment of the SNs. Say, a grid contains the sets of horizontal lines H_0^X to H_j^X with each set containing lines ranging from H_X^{-n} to H_X^n where n is the number of SNDs in a set. The number of horizontal lines covered by the UDAD in a single scan of target region is given by equation 3

$$ScanWidth = 2 * n + 1 \qquad (3)$$

where *n* is the number of SNDs in each set of a UDAD mounted on the deployment helicopter. The SNs released from various SNDs float at different angles, the floating angle of the SN is calibrated such that they land at their specified horizontal distance. The floating profile of SNs released from various SNDs is shown in *Figure 6*.

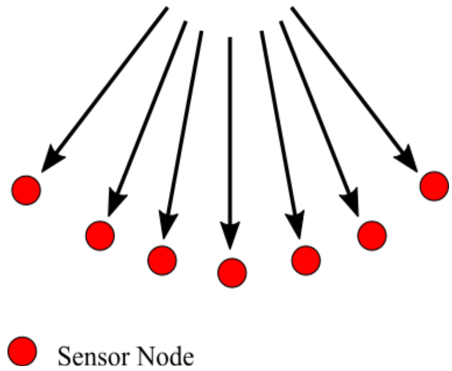

Figure 6. Floating profile of SNs

The helicopter moves on the predefined path on the grid labeled by the horizontal line H_X^0 (the line marked with red in *Figure 7*). The vertical lines of the grid are labeled as V_0 to V_m.

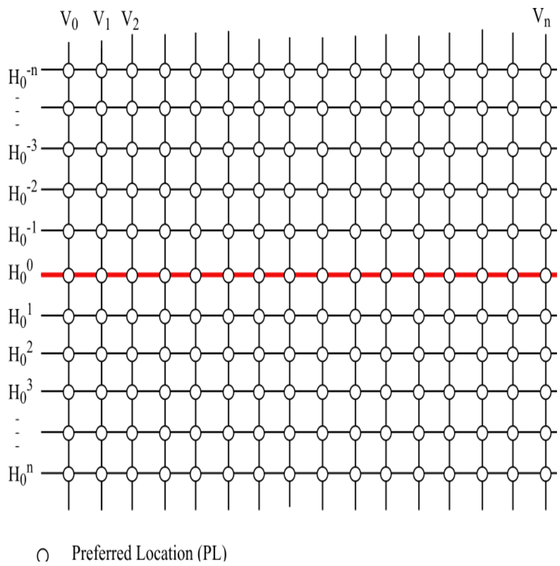

Figure 7. Grid formation

The total working of UDAD and its operational flow is shown Algorithm-1 and

Figure 8 respectively.

Algorithm 1: UDAD operation

- ***getPathDistance():*** *Returns the total distance of the scan path.*
- ***setHelicopterSpeed(V_h):*** *Sets the traversal speed of the deployment helicopter.*
- ***setDroppingHeight(H_D):*** *Sets the dropping altitude of the SN.*
- ***getDistanceTravelled():*** *Returs the total distance travelled by the deployment helicopter.*
- ***startHelicoperMovemeentOnPath():*** *Starts the movement of helicopter on the scan path.*
- ***endOfPath():*** *Returns true if the scan-path is completed else its returns false.*
- ***getX(Helicopter):*** *Returns the X-coordinate of the current position of the helicopter.*
- ***getNextVerticalLine():*** *Returns the coordinates of the next vertical line in the scal-path*
- ***dropSN():*** *turns the motor of SND to drop a SN.*

Step-1. *setHelicopterSpeed(V_h)*
Step-2. *setDroppingHeight(H_D)*
Step-3. *startHelicopterMovementOnPath()*
Step-4. ***If*** *endOfPath()* ***Then***

Goto *Step-9*

Else
Step-5. X_H = *getX(Helicopter)*
Step-6. V_i = *getNextVerticalLine()*
Step-7. X_G =*getX*(V_i)
Step-8. ***If*** $X_H == X_G$ ***Then***

dropSN()

Else

Goto *Step-4*

End-if

End-if
Step-9. ***END***

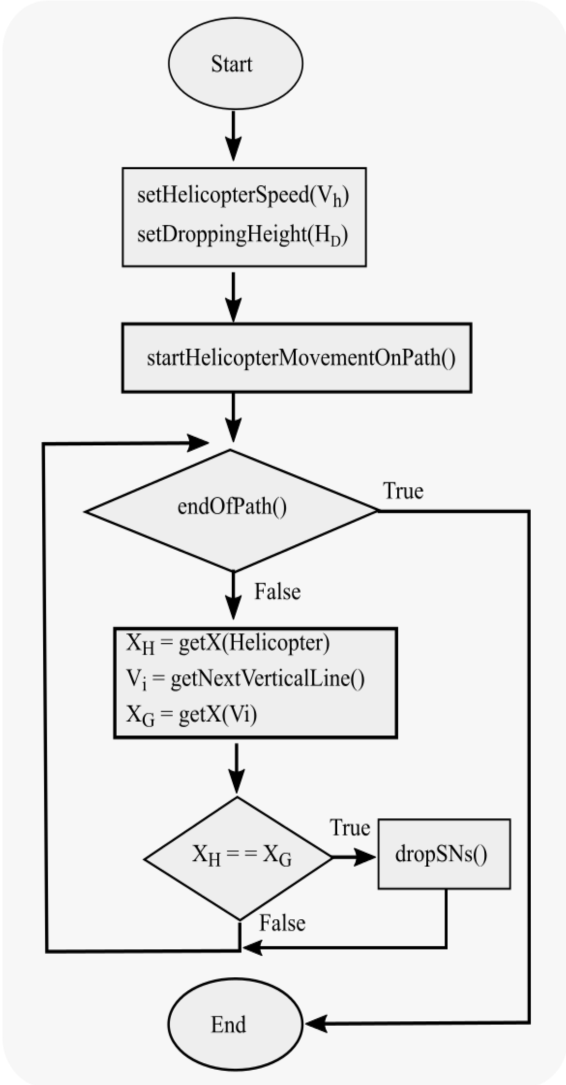

Figure 8. Flow chart

E Results

The proposed model is simulated in java and the results are compared with the existing Centrifugal Cannon Sprinkler based random deployment model. It is observed that UAD performs better than CCS in terms of coverage and connectivity. Following are the simulation parameters:

Table 1. Simulation Parameters.

Variable	**Value**
Dropping Height	1000 m
Floating angle	30 degree
Floating speed	12 m/sec
Number of SNs	200
Density of air	1.25 Kg/m^3

Weight of SN	0.150 Kg
Sensing range	40 m
Communication range	70 m
Angular velocity of CCS (ω)	100 RPM
Speed of helicopter	27.70 m/s (100 Km/h)
Shape of target region	Square
Area of target region	1000 m X 1000 m
Acceleration due to gravity (g)	9.8 m/s^2

Figure *9* and Figure *10* presents the coverage pattern of CCS and UAD with equal number of SNs respectively. It is clearly observed that the deployment pattern of UAD is more uniform than that of CCS and the size of uncovered holes are very small in case of UAD in comparison to that of CCS.

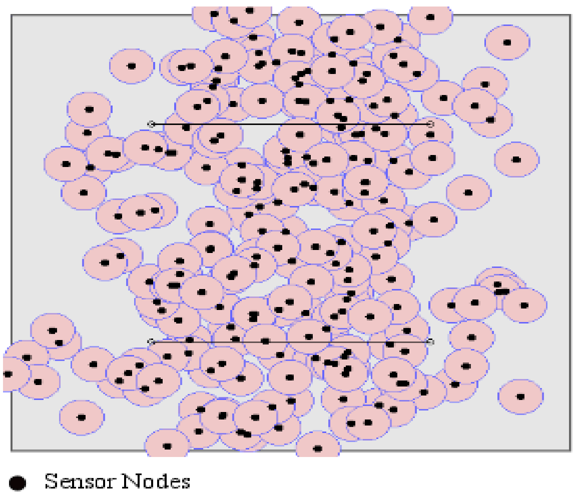

Figure 9. Coverage by CCS

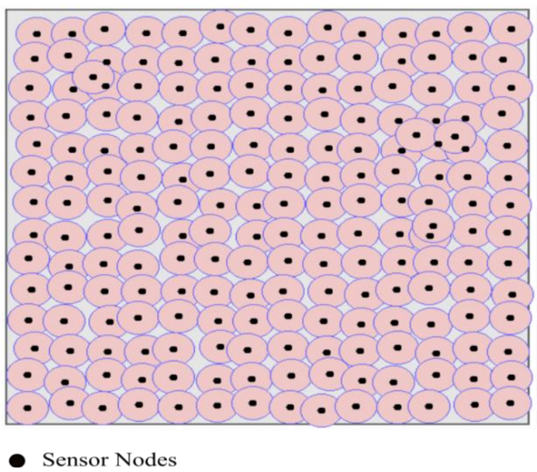

Figure 10. Coverage by UAD

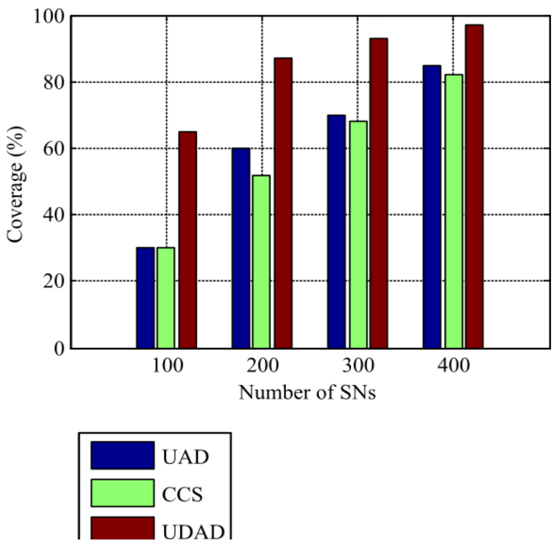

Figure 11. Relation between coverage and number of SNs

Figure *11* presents the relation between the number of SNs deployed within target region and the percentage coverage achieved by various deployment schemes. It is seen that the area covered by UDAD is far better than UAD and CCS for the same number of SNs. It achieves about 87% of coverage with optimal number of SNs.The coverage achieved by the aerial deployment may be improved by some relocation based scheme if the nature of deployed SNs is mobile. Figure 14 shows the implementation of NADS [14] (It is a relocation based scheme) with CCS and UDAD. It is seen that the average movement required by the MSNs in NADS reduces from 69m to 9 m when used with UDAD.

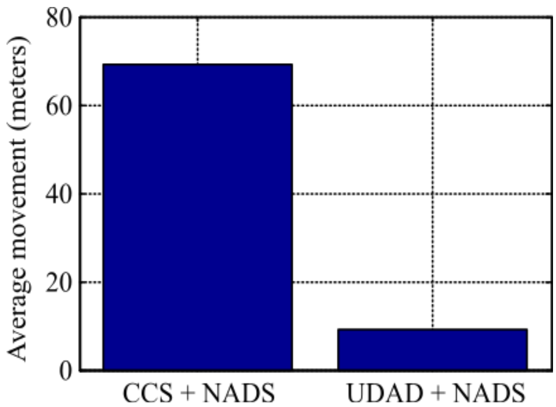

Figure 14. Performance of neighbour assisted deployment scheme(NADS) with CCS and UDAD

This reduction in the movement may reduce the power requirements of the MSNs, thereby reducing the battery size and cutting-down the cost and weight of the MSN. Figure 12 shows the movement required by the helicopter to move over the entire target while dropping the SNs. It is seen that the movement required by UDAD is 2420m where the CCS requires the movement of 1800 m only for the parameters given in Table-1

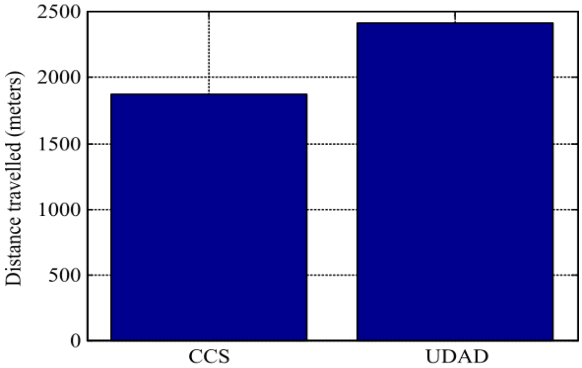

Figure 12.Distance travelled by the deployment helicopter

F. DISCUSSION

CCS may effectively be used in scenarios where the SNs are mobile in nature, i,e., Mobile Sensor Nodes (MSNs), so that the randomly scattered SNs may relocate to more optimal locations after landing. Otherwise the CCS may require a large number of SNs to effectively cover the target region, which may significantly increase the cost of a WSN. Aerial deployment mechanisms, which aim at straightly placing the SNs to the optimal positions within a target-region, are better as they may reduce the overall running and deployment cost of the WSN.

G . CONCLUSION AND FUTURE WORK

Wireless sensor network (WSN) is a basic solution to the remote monitoring problems. WSN faces unique deployment and positioning challenges when the deployment region is a large sized. Aerial scattering of SNs has emerged as a practical solution to large scale deployment problem. Such types of schemes are time efficient and can be used to achieve blanket coverage over the large region. But their stochastic nature desist them from achieving the optimal coverage.

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