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Bi-directional sensor placement for K-coverage solution

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Abstract: In wireless sensor networks (WSNs), to provide each point at least K-coverage is called K-coverage solution. We are proposing the solution for K-coverage by using bi-directional sensors so that the data transmission in all directions can be reduced. The objective of the work is to provide a coverage solution in a sensor network by reducing energy consumption. This work is addressing the issue of how to make improvement in coverage using a directional sensor model. Further, the measures of directional sensors for a given coverage rate has been estimated. The coverage probability of the region of interest (ROI) for N directional sensors is being evaluated which is further used to recognise the ratio of bi-directional to omni-directional sensors. In our simulation, the effect of offset angle on, radius for multiple rounds have been estimated and shown in a result which reflects the promising improvement over the existing proposal.

Keywords: wireless sensor network; WSN; omnidirectional sensor; bi-directional sensor; coverage; K-coverage; angle of view; boundary point deployment; boundary region deployment.

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1 Introduction

The recent advancements in the wireless sensor network (WSN) have empowered the improvement of minimal cost, multi-utilitarian, low power, little sensor nodes which is capable of recognising the encompassing condition or dispersed targets of interest within a given area, perform information preparing and communicate with each other over short separations (Kaur et al., 2018; Shaila et al., 2013). At whatever point information is collected, the sensor processes it if vital, and after that advances it towards a base station through wireless communication. Generally the base station is furnished with high computation, communication capability, and in addition adequate vitality, and it is in charge of handling all data in an incorporated way as indicated by application-particular prerequisites (Wang et al., 2009b; Arif et al., 2018a).

A basic issue getting an extended idea as of late is the issue of coverage, which centres on how well the sensors screen the physical space they deployed. Coverage in a WSN needs to ensure that the area is observed with the required level of dependability and is one of the estimations of quality of service (QoS) of WSN, and it is firmly related with energy utilisation (Zhu et al., 2012). Numerous WSN applications are required to play out specific errands whose effectiveness can be estimated as far as coverage. In this type of applications, it is important to characterise exact measures of coverage that affect the overall performance of the system. As of late, extraordinary directional sensors have ascended because of the requirements of assembling procedures, size, and cost. The limited sensing angle is the most recognising characteristic for the directional sensors. The detecting area of directional sensors is believed to be the part of a detecting circle, with the span being equivalent to the sensing range (Wang et al., 2009b). The issues of coverage can be extensively classified as the area coverage issue and the target coverage issue. The area coverage based on observing the whole area of intrigue, while the target coverage centres around checking just certain particular points in the area (Sah and Amgoth, 2018; Arif et al., 2018b, 2018c; Mini et al., 2014).

Directional sensor nodes work a predetermined way and may change their working direction in perspective of the application requirements and this ability of the sensors is called motility (Si et al., 2017). The coverage improving techniques abuse motility to restrict the obstacle and covered areas. Then again, because of the restricted battery limit of sensors, delaying the system lifetime is the optional objective of analysts who principally go for augmenting scope in DSNs. Broadening the system life can be accomplished by means of putting repetitive sensors to sleep (Guvensan and Yavuz, 2011).

The outline of the paper is as follow: in Section 1, the introduction is discussed and followed by the related work on the coverage problem in WSNs in Section 2. In Section 3, we proceeds with our system model and provide a method to measure the directional sensors for a given coverage rate and recognise the ratio of bi-directional to omni-directional sensors. Section 4 contains the proposal as linear formulation for coverage problem. With the linear formulation, the privileged of constraint such as boundary point, boundary region and combined approach has been proposed. The experimental results has been presented and discussed in Section 5. At last, the conclusion of the paper has been described in Section 6.

2 Related work

Coverage is a fundamental functionality of sensor networks. It has pulled in a lot of research consideration because of its connection to optimisation of resources in a detecting field. The coverage maximisation while keeping up a lower cost of deployment has dependably been an issue, particularly when the observing area is obscure and conceivably unsafe. A compelling methodology for energy conservation in WSNs is coverage deployment strategy. There are broad numbers of analysis about the coverage issue in omni-directional sensor networks. Since conventional sensor networks expect the omni-directional detecting model, answers for WSNs do not conquer troubles of directional sensors, for example, angle of view, directionality and LoS.

The art gallery problem (O'Rourke, 1987) figures out how to choose the number of sensors and their area critical to cover an art gallery space to such a degree, to the point that each point is anchored by no short of what one sensor. The dynamic coverage of a sensor network (Liu et al., 2005) has been studied and demonstrated that at any given time occurrence if the mean coverage stays unaltered, a greater territory will be anchored in the midst of a period interim on account of sensor movement. The authors centre on covering an arrangement of targets while utilising the movable detecting ranges to make a most extreme number of the set spreads (Cardei, 2006). The researchers accepted that an arbitrary network is deployed over a limitless area with sensors following a Poisson distribution and researches the path coverage of the network (Ram et al., 2007). They initially research the path coverage over a limitless straight line when every sensor node has an arbitrary detecting range. By then, they demonstrate that in the asymptotic circumstance, where the recognising scope of the sensors watches out for 0 and the node thickness approaches unendingness and the outcomes are extendible to limited straight and curvilinear paths.

The incremental deployment technique (Howard et al., 2002) has been defined for portable sensor networks where sensors are conveyed one at a time into an obscure domain. Every sensor makes utilisation of the data assembled by already sent sensors to decide its ideal deployment area. The algorithm ensures maximum coverage and guarantees line of sight between sensors. Layered diffusion-based coverage control (LDCC) (Wang et al., 2009a) has been proposed as a circulated and confined scope control convention. The fundamental thought of LDCC is to cover the sensor field by applying the triangular enhancement. The typical method for applying such triangular decoration thought for coverage control is to discover sensors with the areas approximating to such reliable positions to such a degree, to the point that the number of dynamic sensors can be lessened. A method has been proposed (Sahoo et al., 2007) to keep up the coverage and availability of the WSNs, where a sensor needs to ascertain the required and accessible moving separation before choosing the direction and magnitude of the portability. In light of the available portability separation of a sensor, it can move to recoup the coverage gap of the system. In Ghosh (2004), at first a settled number of static sensors are sent that deterministically discover the correct measure of coverage gap existing in the whole system utilising the structure of Voronoi diagrams, and afterward evaluate the extra number of portable sensors should have been conveyed and moved to the ideal areas of the gaps to increase general coverage. This strategy for sending a settled number of static sensors and a variable number of portable sensors can give ideal coverage under controlled cost.

The dynamic parts of coverage abusing portability are examined by Liu et al. (2005). At the point when a number of portable sensors meander around in the detecting field, revealed territories will probably get covered after some time, and gatecrashers that may never have been distinguished in stationary systems would now be able to be identified by the portable sensors. This situation is of awesome significance to applications that do not require concurrent coverage of the considerable number of areas at particular circumstances, however, require general more noteworthy coverage over some stretch of time. In Bisnik et al. (2007), it is researched how the nature of coverage relies upon parameters, for example, event dynamics, sensor speed and therefore the number of sensors conveyed. A circumstance is being considered where occasions can vanish and appear at particular known focuses, called points of interest (PoIs), inside the observing area, with the objective to identify the occasions utilising portable sensors. Moreover, ideal and heuristic way arranging calculations are displayed for the bounded event loss probability (BLEP) issue, to design sensor movement with the true objective that the probability of the occasion not being perceived is restricted from above. The main goal of Huang and Tseng (2005) is to decide if a given area satisfies the k-coverage necessity when each point in the area of intrigue is secured by in any event k-sensors. The k-coverage property has been diminished to the k-border coverage for every sensor in the system having uniform and non-uniform identifying ranges. The issue of picking a base number of sensors and allotting orientations has been talked about (Fusco and Gupta, 2009) with the ultimate objective that the given territory or the arrangement of target focus is k-covered. The creators demonstrate a straightforward greedy calculation that passes on an answer that k-covers in any event half of the target focus utilising at most $M * \log k|C|$ sensors, where $|C|$ is the best number of target focus anchored by a sensor and M is the base sensors required to k-cover all the given focuses.

Ma and Liu (2005) have exhibited the idea of the directional sensor network and have fundamentally talked about the coverage issues of DSNs. They in like manner proposed a procedure to deal with the network issue for arbitrarily conveyed sensors under the directional correspondence model. The maximum coverage with minimum sensors (MCMS) (Ai and Abouzeid, 2006) issue has been presented for DSN. Given an arrangement of targets $T = t_1, t_2, ..., t_m$ and an arrangement of n homogeneous directional sensors, all of that has p conceivable orientations, MCMS goes for expanding the number of secured targets while at the same time restricting the amount of actuated directional sensors. A subset of headings of the sensors as a cover set has been defined (Cai et al., 2007) in which the bearings cover every one of the objectives. The issue of determining a cover set in a DSN is named as the directional cover set issue. An incorporated calculation, DCS-Greedy, and a distributed calculation, DCS-Dist, have been introduced that select the operating headings of the sensors while at the same time covering the most extreme variety of targets. Two new calculations for direction optimisation namely, greedy direction adjusting (GDA) calculation and equitable direction optimising (EDO) calculation are introduced (Wen et al., 2008). GDA calculation advances the bearings as indicated by the number of secured targets, while at the same time EDO calculation alters the headings of sensors to cover the basic targets and assigns distinguishing assets among sensors the right away to limit the coverage distinction between sensors.

The directional sensor placement issue (Osais et al., 2010) diversely has been examined. The researchers display an ILP demonstrate, where both a plan of control points and a course of action of position locales for sensors are characterised ahead of time. The goal is to put sensors in the sensor field with the ultimate objective that each control point is secured by no short of what one sensor and the general cost of the sensors is slightest. The effect of the three parameters, i.e. detecting range, orientation, and FoV of a directional sensor, has been investigated completely since these parameters significantly affect the general cost of the DSN. In spite of the accompanying accessible arrangements, the sensors in this model may have unequal identifying extents and angle of perspectives. The investigation in Tao et al. (2006) is one of the pioneers takes a shot at coverage improvement in DSNs. Another procedure in view of a rotatable directional detecting model has been presented. The authors defined to isolate the directional sensor network into a few segments called sensing connected sub-graphs (SCSGs). Allotting a directional sensor network into a couple of SCSGs is separating and overcoming a unified issue into a dispersed one and diminishing the time complexity. A novel probabilistic detecting model (Akbarzadeh et al., 2013) has been build up for sensor nodes with the line of sight-based coverage to deal with the sensor arrangement issue for these sensors. The probabilistic detecting model contains enlistment capacities with respect to identifying degree and detecting angle, which mulls over detecting limit likelihood and in addition basic environmental factors, for example, territory topography. A novel model for the enhancement of sensor position has also been proposed. The oddity of this model lies in the incorporation of territory data with a probabilistic sensor model. Results are accounted for various enhancement strategies tried with this model.

3 System model

In this area, we will talk about the placement approach of the directional sensors and their properties for the rectangular region of interest (ROI).

3.1 Directional sensor model and variables

The sensing unit in WSN is commonly the omni-directional sensors and therefore the sensors set at the point P can cover the territory $\pi * R^2$, where R is equivalent to the maximum line of sight (LOS_m). Here we are displaying the directional sensors and its similarity are often found within the model given for field of view in cameras in Forsyth and Ponce (2011) as outlined in Figure 1.

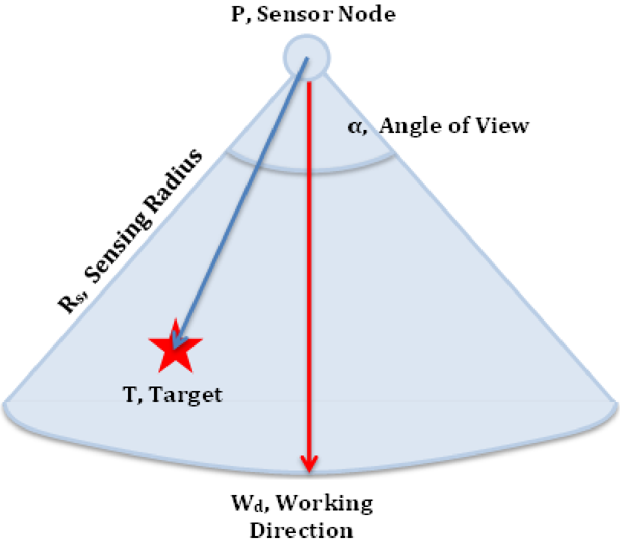
Here the 2D-model of detecting the region of sensors has considered and represented with 4-factors (LOC, R, LOS_m, α), where these factors are depicted in Table 1.

In our model as portrayed in Figure 2, the point P is secured at time occurrence t, if the accompanying conditions hold:

a $E_{dist(LOC,P)} \leq R$, wherever $E_{dist(LOC,P)}$ is a Euclidean separation between the area of any sensors S_i where $i \in N$ and point P within the AOI.

b The angle amongst LOS_m, line fragment of P, and LOC ought to be in the middle of $[-\alpha,\ \alpha]$. During this specific circumstance, the point P is secured by directional sensor accessible if the length of the line portion $|PLOC| \leq R$ and angle between line fragment $|PLOC|$ to offset LOS_m is constantly not exactly $abs(\alpha)$.

Figure 1 A directional sensor detects a unit of the area depicted with the position (P), the working direction (W_d), the detecting range (R_s) and the angle of view (α) (see online version for colours)



Note: An objective (T) might be secured in the event that it is situated inside the AOI of the node.

Source: Guvensan and Yavuz (2011)

Figure 2 The model of directional sensor (see online version for colours)

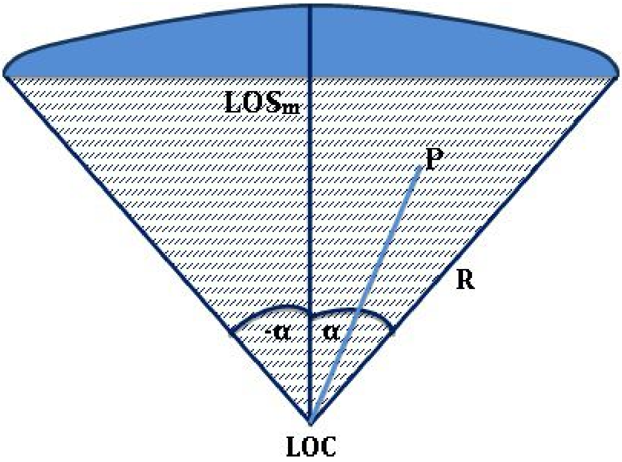
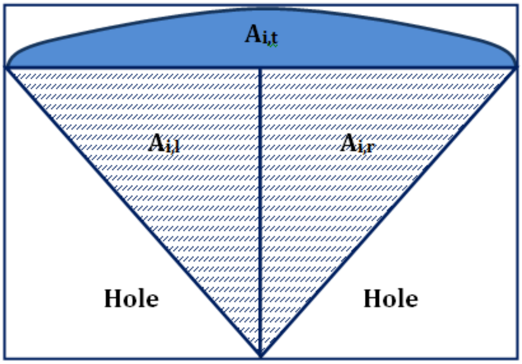


Table 1 Description of the factors used

Notations	*Description*
N	Number of sensors accessible
LOC	Sensors location
PLC	Placement
R	Sensors radius
$R_{B,O}$	Ratio of bi-directional sensors to omni-directional sensors
LOS_m	Maximum line of sight
α	Offset angle with LOS_m
S_i	Sensor with arbitrary numbering i
AOI	Area of interest or active region
$A_{i,t}$	Area covered by top notch of sensor i (Figure 3)
$A_{i,l}$	Area covered by left sensing portion of sensor i (Figure 3)
$A_{i,r}$	Area covered by right sensing portion of sensor i (Figure 3)
E_i	On initial deployment the energy of sensor i
E_{it}	At time instance t the energy of sensor i (Note: time is being calculated in unit)
$E_{dist(a,b)}$	The euclidean distance between point a and b

Figure 3 The shaded and dark region of directional sensing region (see online version for colours)



3.2 *Estimation of coverage probability for directional sensors*

The deployment of sensors in ROI of WSNs continues in two way and it is either deterministic or arbitrary (Mulligan and Ammari, 2010) and it relies on the courses of action of ROI. During this unique situation once the particular place is not effortlessly open then arbitrary arrangement with the assistance of plane or another vehicle may be used whereas within the shut region, for instance, fabricating square which may without much of a stretch available at first for the portion. In the closed site, the atomic power plant, for instance, the sensor with omni-directional is as a result of the obstacle, for example, solid divider et cetera. In addition, the directional radio wire can be savvy and furthermore the motivation behind the covering of ROI.

The detecting region is illuminated as the area which is fascinated by identifying and moreover portrayed as ROI (Huang and Tseng, 2005). The area of interest in Table 1 is indicated as AOI. Assuming that there is no precisely two sensors is settled at identical space. In like manner, every point P is by and large no under 1-coverage and the covering of the identifying range by either the left, right and top detecting segment of sensors should limit. In this specific situation, the directional sensors with offset angle α give detecting capability in the region αR^2 and for omni-directional the distinguishing area ability is πR^2. The covering probability p of ROI by each directional sensor is $\frac{\alpha R^2}{ROI}$ and $\frac{\pi R^2}{ROI}$ for omni-directional sensor. The number of sensors conveyed into the territory is identical to N as indicated in Table 1. Equation (1) depicts the probability of covering the ROI with the assistance of N directional sensors.

$$p = 1 - \left(1 - \frac{\alpha R^2}{ROI}\right)^N \tag{1}$$

The offset angle α for omni-directional sensors is $\alpha = \pi$. Equation (2) expresses the probability of coverage on the deployment of N omni-directional sensors.

$$p = 1 - \left(1 - \frac{\pi R^2}{ROI}\right)^N \tag{2}$$

So also, in an ongoing application, the system should exhibit the threshold value and a similar value can be utilised to compute the dependable nature of the system. Other than to achieve the probability p, the number of deployed directional sensors ought to be in any event N and this can basically ascertain with equation (3).

$$N \geq \frac{\ln(1-p)}{\ln(ROI - \alpha R^2) - \ln ROI} \tag{3}$$

The number of omni-directional sensors, for $\alpha = \pi$, required to accomplish the probability ought to be

$$N \geq \frac{\ln(1-p)}{\ln(ROI - \pi R^2) - \ln ROI} \tag{4}$$

As per the equations (3) and (4), the ratio of directional sensors regarding omni-directional sensors can be expressed in terms of the accompanying equation (5).

$$R_{B,O} = \frac{\ln(ROI - \pi R^2) - \ln ROI}{\ln(ROI - \alpha R^2) - \ln ROI} \tag{5}$$

4 Proposal

In this area, the computed probability assessed before is being utilised as a threshold value.

4.1 Linear formulation for coverage

In addition, the assessed probability and the other constraints are used to maximise the coverage of the area. The comparative work has been done in our past work on a translucent optical system for directing and wavelength assignment (Sah et al., 2016). In equation (6), the coverage ability of the sensors has been divided into three classes, as described in Table 1, to formulate the maximisation of area coverage. Equation (6) has been characterised to expand the shaded area and dark area fall inside the AOI thus the constraint to permit it and ensure that the demand is being satisfied by keeping the constraint. In equation (6), the accountability of the classified area of sensors is accumulating to provide the coverage. The uniqueness of the formulation is that, the contribution of all available sensors is being accounted in different category. Therefore, it helps in the improvement of coverage. Consider an example in which any two part of sensor is overlapping on any point in AOI, than it is being accounted at two different places and helps in coverage optimisation.

$$\text{maximise } \sum_{i}^{N} A_{i,t} + \sum_{i}^{N} A_{i,l} + \sum_{i}^{N} A_{i,r} \tag{6}$$

The constraints required to maximise the area coverage has given in equations (7)–(11). The limitation of the sensing range is given in equation (7) with the goal that the detecting scope of the sensors cannot surpass from a specific limit that for our scenario is ROI. The consumption of energy can be lessened by controlling the detecting range as the sensing range decrease.

$$\text{subject to, } AOI \leq ROI \tag{7}$$

As before the threshold probability has been assessed, the maximum accessible sensor is given in equation (8). Hence, to maximise the coverage, the number of sensors should be not exactly or equivalent to the number of sensors accessible.

$$N \leq N_{\text{max}} \tag{8}$$

Equation (9) guarantees that the point that lies within the AOI is secured as most extreme as could be expected under the circumstances. We have a tendency to have just examined that in directional sensors deployment, the gap in ROI is constantly conceivable. The gap is being decreased as much as could reasonably be expected by including this constraint.

$$\angle\, P\ LOC\ LOS_m \geq |PLOC| \cos\alpha \tag{9}$$

The covering angle of directional sensors is often controlled as outlined in equation (10), however at the same, on the off chance that if it increases, the consumption of energy will be quick. On the off chance that any of the outcomes are giving the π, implies those sensors can be exchanged by omni-directional sensors for better energy management and system lifetime.

$$\alpha \leq \pi \tag{10}$$

The vitality of the system has been described within equation (11) with the goal that the aggregate time of the system alive can be assessed. In our model, as we examined that, two separate layers of coverage is being utilised as a part of that either any of the one layer sensors are going to be dynamic at time t.

$$E_i \geq E_{th} \tag{11}$$

4.2 Sensor position manipulation

In the previous section, the energy minimisation has been formulated based on the availability of the sensors. The rate of coverage has been formulated in equation (4) and according to that the sensors been supplied into the optimisation formulation. We had seen in our simulation that even in 1-coverage, the overlapping of sensing range is not end and further improvement is possible. At the same, if the limited number of sensors is placed in deterministic way then specific AOI can be benefited from it and can get more coverage. To enhance the performance in terms of coverage and energy consumption, we are proposing the sensor placement which contains the voids in the ROI. Moreover, the partial determinism of sensor placement can give the better coverage. The number of partial sensors N_p will be placed partially in the ROI to provide better coverage to the AOI. In WSNs deployment, applications geographies do not allow the deterministic deployment of the sensors, therefore we are proposing the partial deterministic deployment.

The question arises is that what will be the feasible way of deterministic deployment and how to decide the initial position. To solve the issue we are proposing the following solution to keeping in mind that the geographical locality of the ROI is hard to access:

1 boundary point deployment (BPD)

2 boundary region deployment (BRD)

3 combination of BPD and BRD.

Let suppose the region in physical world contain N_{bp} boundary point and N_{br} boundary region in the ROI. The threshold probability estimated in equation (3), will now be constrained through this N_{bp} and N_{br}. The $N_{bp} + N_{br} \geq 0$ where $N_{bp} \geq 0$ and $N_{br} \geq 0$ will help in the formulation to serve its objective as random deployment or partial deterministic deployment. The objective to maximise the coverage can be formulated as follows:

$$\text{maximise} \sum_{i}^{N-(N_{bp}+N_{br})} A_{i,t} + \sum_{i}^{N-(N_{bp}+N_{br})} A_{i,l} + \sum_{i}^{N-(N_{bp}+N_{br})} A_{i,r} \tag{12}$$

$$\text{subject to, } AOI \leq ROI \tag{13}$$

$$N - (N_{bp} + N_{br}) \leq N_{\max} \tag{14}$$

$$\alpha \leq \pi \tag{15}$$

$$EW_i \geq EW_{th} \tag{16}$$

where EW represents the energy value with the deterministic placement.

To achieve the objective specified in equation (12), we have to account the constraint about the requirement which is the AOI and resources which is the number of sensors N. In equation (13), the constraint given to limit the service which is covered in AOI to the maximum of ROI. Moreover, the number of the sensor can be used to provide the service in the AOI cannot be more than the available number of sensors $N_{\max}$, which is specified in equation (14). In equation (14), the accountability of the sensors denoted in term of the sensors sparse in the region. The distribution of the sensors according to our heuristics approach can be in three-way as random, fixed BPD, BRD and combination of BPD and BRD. The description of BPD, BRD and combination of BPD and BRD can as follow:

1. Random deployment: If the sensors are being deployed randomly, then the specific number of sensor available on specific places such as boundary point or boundary region cannot be fixed prior In this case the sum of the number of sensors at boundary point which denoted as N_{bp} and boundary region denoted as N_{br} will be 0. Therefore, $N_{bp} + N_{br} = 0$.
2. Boundary point deployment: In our heuristics approach, a number of sensors fixed at boundary points should be $N_{bp} > 0$. In this way, the complexity of ILP will reduce because from the total number of available sensors, few of them is already get selected for placement at the boundary point.
3. Boundary region deployment: In the same fashion as BPD, in BRD few sensors have been placed in the region to reduce the complexity of the ILP. In this way the number of sensors reserve for BRD should be $N_{br} > 0$.
4. Combination of BPD and BRD: In our combined approach, the sensor placement at BPD and BRD being fixed prior to the optimisation simulation performed based on the ILP given in equation (12). This approach helps to reduce the running time of the simulation because of the reduction in the term of the number of variables. Therefore, in combine approach number of sensors for specific places denoted as N_{bp} and N_{br} will be $N_{bp} > 0 \in integer$ and $N_{br} > 0 \in integer$.

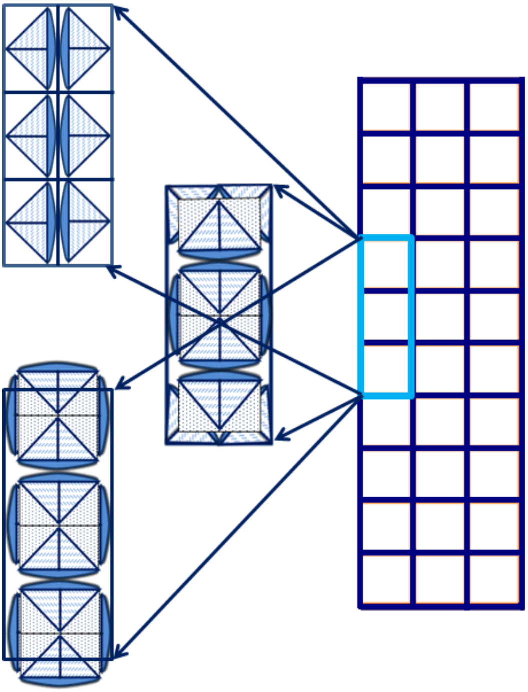
Through equation (15), the limitation of the maximum angle of the bi-directional sensors has been defined which cannot be greater than π. Moreover, equation (16) given to limit the maximum available energy at any time instance at any sensor i should be greater than or equal to the minimum threshold value. Then only any sensor can further participate in the coverage else it will be discarded and other sensors $j \neq i$ will take place of N_i.

5 Results and analysis

In this segment, the preliminary setup for the planned work has been cleared up through the parameters of the sensors and in addition ROI. The area of ROI accepted as 500 $*$ 300 unit^2, in which any of the three vertical blocks have been considered for the arrangement of the sensors. The building blocks and position for k-coverage with the orientation of the directional sensors has been given in Figure 3. In this orientation, the white part speaks to the gap if the orientation display is being outed. Besides, it is here ought to comprehend that, there may be a lot of conceivable orientation and also the orientation given in Figure 4 is only a portrayal of one of the conceivable outcomes among many.

In our investigation, the angular coverage value fluctuates from α = 30° till $\alpha = \pi$ to receive the nature from bi-directional to omni-directional sensors. Table 2 depicts the computational parameters utilised in the analysis.

Figure 4 The orientation of the directional sensing element in any of the 3-block (see online version for colours)



Assist in view of the evaluated probability, the expansion of coverage has been performed on MATLAB variant 7.10 with the machinability of 2.4 GHz and RAM limit with 4 GB. The preliminary outcome has shown up in term of the probability of coverage rate versus offset angle concerning distinctive sensor radius proportion described in Figure 5. It can be seen from the chart that as the number of the sensor is expanded, the probability of coverage is likewise expanding with a particular angle of view. Moreover, with the various angle of view, the investigation has been done and might be seen in Figure 5. Besides, as the correlation of expanding of the angle from 0 to π with the diverse estimation of a range of the sensor is displayed in Figure 6. The number of sensors in this situation is being settled in view of the information (computation parameters) introduced in Table 2.

Table 2 Computational parameters

Parameters	*Default value*	*Variations*
Rate of coverage (p)	1	0–1
No. of sensors (N)	100	0–100
Offset angle α	180	0–180
Radius of sensor	20 unit	0–25 unit
Radius of communication	40 unit	0–50 unit
Area (ROI)	$500 * 300$ unit^2	$500 * 300$ unit^2

Figure 5 The impact of the offset angle of sensors for the coverage of threshold (see online version for colours)

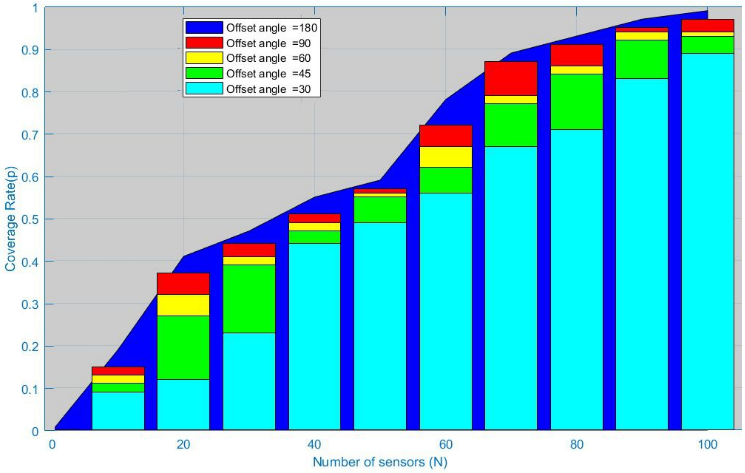
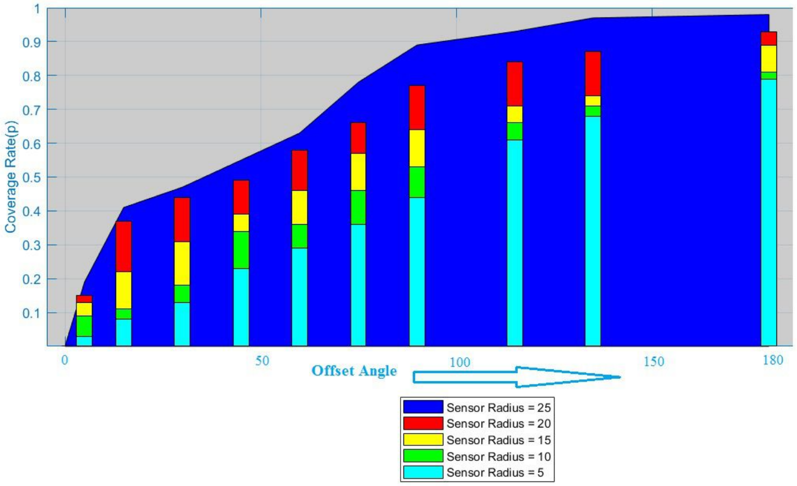


Figure 6 The impact of sensors radius on the coverage of threshold and on offset angle time line (see online version for colours)



In Figure 7, the proposed model has been compared with the existing protocol denoted as EX-1 (Tao et al., 2006) and EX-2 (Akbarzadeh et al., 2013). The number of rounds significance is that it directly connected with the network lifetime. In this context, the Tao et al. (2006) and Akbarzadeh et al. (2013) lifetime is been generalise in terms of round of communication exchange to make comparison with the proposal. As we can observe from Figure 7, our proposal is able to achieve the coverage in between 80%–90% throughout the simulation until it starts declining. The scenario is given for the random deployment of the sensors where the flexibility of coverage angle is applicable to the sensors. Moreover, for the same setup, our proposal is able to achieve better coverage with respect to the existing protocols.

Figure 7 Comparison of the effect on the coverage when the round is increases in proposed work with existing EX-1 and EX-2 (see online version for colours)

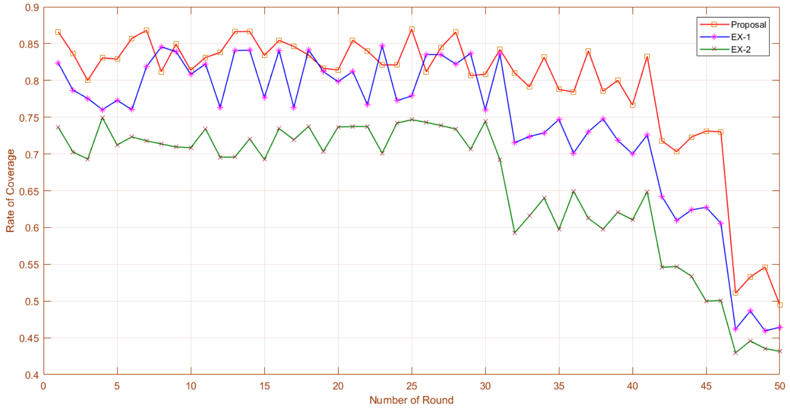
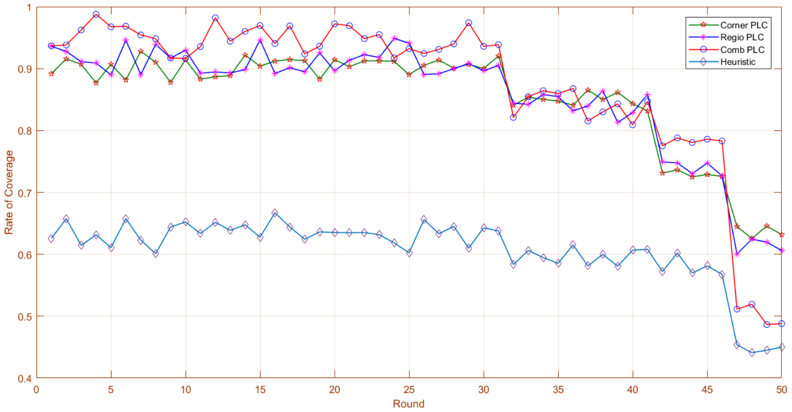


Figure 8 Comparison of the effect on the coverage when the round is increases in proposed protocol with the adaption such as heuristic, corner fixed, region fixed and combined approach (see online version for colours)



Though, our proposal varies from heuristic to fixed. We are considering the results of heuristic approach to make comparison in Figure 7. Moreover, we observed in our experiment that in know coverage scenario, if we able to fix the position of few nodes apart from heuristics consideration then coverage is being enhanced as can be observed in Figure 8 for fix corner, fix region and both. The reason by which we are able to achieve such a result is that prior to the optimisation we are placing the sensors at few places. The number of sensors in the fixed placement can be varied according to the geographical area. In our simulation, we are considering the rectangle AOI, therefore based on the available corner we are placing the sensor in BPD deployment. In BRD deployment, the placement is based on available rectangular region. In combined placement, the corner as well as region is being covered prior to the optimisation.

6 Conclusions

The detecting unit of WSNs area sensing is regularly the omni-directional and sensor set either arbitrarily or conveyed through some position calculation to take care of the area coverage issue. The issue of area coverage by directional sensors under the arbitrary deployment methodology has been talked about in this paper. A deliberate model has been produced to show the usefulness of directional sensors. With linear formulation, the coverage problem been attempted successfully. Further, the greedy approach based on boundary point/region limitation is being provided to overcome the hurdle presented through the linear approach.

In our simulation process, the observation has been made regarding the proposal. The application geographic area and accessibility play a vital role in our proposal. Though in random deployment, the placement is independent in nature for coverage, still the area for which the simulation setup is comfortable is rectangular. In our heuristics approach, the boundary point can also be applicable in a rectangular and square shape which is also not very uniform application area. Moreover, to overcome these limitations further exploration for different shapes is required in future.

In the result section, with assuming scenario our protocol has been implemented and compare with the existing solution.

References

Ai, J. and Abouzeid, A.A. (2006) ‘Coverage by directional sensors in randomly deployed wireless sensor networks’, *Journal of Combinatorial Optimization*, Vol. 11, No. 1, pp.21–41.

Akbarzadeh, V., Gagné, C., Parizeau, M., Argany, M. and Mostafavi, M.A. (2013) ‘Probabilistic sensing model for sensor placement optimization based on line-of-sight coverage’, *IEEE Transactions on Instrumentation and Measurement*, Vol. 62, No. 2, pp.293–303.

Arif, M., Wang, G. and Balas, V.E. (2018a) ‘Secure VANETs: trusted communication scheme between vehicles and infrastructure based on fog computing’, *Studies in Informatics and Control*, Vol. 27, No. 2, pp.235–246, ISSN: 1220-1766.

Arif, M., Wang, G. and Chen, S. (2018b) ‘Deep learning with non-parametric regression model for traffic flow prediction’, *Proceedings of IEEE 16th Int. Conf. on Dependable, Autonomic & Secure Comp., 16th Int. Conf. on Pervasive Intelligence & Comp., 4th Int. Conf. on Big Data Intelligence & Comp., and 3rd Cyber Sci. & Tech. Cong.*, August, pp.681–688, IEEE.

Arif, M., Wang, G. and Peng, T. (2018c) ‘Track me if you can? Query based dual location privacy in VANETs for V2V and V2I’, *2018 17th IEEE International Conference on Trust, Security and Privacy in Computing and Communications/12th IEEE International Conference on Big Data Science and Engineering (TrustCom/BigDataSE)*, pp.1091–1096, IEEE.

Bisnik, N., Abouzeid, A.A. and Isler, V. (2007) ‘Stochastic event capture using mobile sensors subject to a quality metric’, *IEEE Transactions on Robotics*, Vol. 23, No. 4, pp.676–692.

Cai, Y., Lou, W. and Li, M. (2007) ‘Cover set problem in directional sensor networks’, *Future Generation Communication and Networking (FGCN 2007)*, Vol. 1, pp.274–278, IEEE.

Cardei, I. (2006) ‘Energy-efficient target coverage in heterogeneous wireless sensor networks’, *2006 IEEE International Conference on Mobile Adhoc and Sensor Systems (MASS)*, pp.397–406, IEEE.

Forsyth, D. and Ponce, J. (2011) *Computer Vision: A Modern Approach*, Prentice Hall, Upper Saddle River, NJ; London.

Fusco, G. and Gupta, H. (2009) 'Selection and orientation of directional sensors for coverage maximization', *6th Annual IEEE Communications Society Conference on Sensor, Mesh and Ad Hoc Communications and Networks, 2009. SECon'09*, pp.1–9, IEEE.

Ghosh, A. (2004) 'Estimating coverage holes and enhancing coverage in mixed sensor networks', *29th Annual IEEE International Conference on Local Computer Networks*, pp.68–76, IEEE.

Guvensan, M.A. and Yavuz, A.G. (2011) 'On coverage issues in directional sensor networks: a survey', *Ad Hoc Networks*, Vol. 9, No. 7, pp.1238–1255.

Howard, A., Matarić, M.J. and Sukhatme, G.S. (2002) 'An incremental self-deployment algorithm for mobile sensor networks', *Autonomous Robots*, Vol. 13, No. 2, pp.113–126.

Huang, C-F. and Tseng, Y-C. (2005) 'The coverage problem in a wireless sensor network', *Mobile Networks and Applications*, Vol. 10, No. 4, pp.519–528.

Kaur, N., Khera, S. and Turk, N. (2018) 'A practical approach to energy consumption in wireless sensor networks', *International Journal of Advanced Intelligence Paradigms*, Vol. 10, No. 1, DOI: 10.1504/IJAIP.2018.10009335.

Liu, B., Brass, P., Dousse, O., Nain, P. and Towsley, D. (2005) 'Mobility improves coverage of sensor networks', *Proceedings of the 6th ACM International Symposium on Mobile Ad Hoc Networking and Computing*, pp.300–308, ACM.

Ma, H. and Liu, Y. (2005) 'On coverage problems of directional sensor networks', *International Conference on Mobile Ad-hoc and Sensor Networks*, pp.721–731, Springer.

Mini, S., Udgata, S.K. and Sabat, S.L. (2014) 'Sensor deployment and scheduling for target coverage problem in wireless sensor networks', *IEEE Sensors Journal*, March, Vol. 14, No. 3, pp.636–644, DOI: 10.1109/JSEN.2013.2286332

Mulligan, R. and Ammari, H.M. (2010) 'Coverage in wireless sensor networks: a survey', *Network Protocols and Algorithms*, Vol. 2, No. 2, pp.27–53.

O'Rourke, J. (1987) *Art Gallery Theorems and Algorithms*, Vol. 57, Oxford University Press, Oxford, New York, USA.

Osais, Y.E., St-Hilaire, M. and Fei, R.Y. (2010) 'Directional sensor placement with optimal sensing range, field of view and orientation', *Mobile Networks and Applications*, Vol. 15, No. 2, pp.216–225.

Ram, S.S., Manjunath, D., Iyer, S.K. and Yogeshwaran, D. (2007) 'On the path coverage properties of random sensor networks', *IEEE Transactions on Mobile Computing*, Vol. 6, No. 5, pp.494–506.

Sah, D.K. and Amgoth, T. (2018) 'Parametric survey on cross-layer designs for wireless sensor networks', *Computer Science Review*, Vol. 27, pp.112–134, DOI: 10.1016/j.cosrev.2017.12.002.

Sah, D.K., Ahmad, H. and Uniyal, A. (2016) 'Reliable ILP approach of Max-RWA problem for translucent optical network', *2016 Thirteenth International Conference on Wireless and Optical Communications Networks (WOCN)*, pp.1–7, IEEE.

Sahoo, P.K., Sheu, J-P. and Lin, W-S. (2007) 'Dynamic coverage and connectivity maintenance algorithms for wireless sensor networks', *2nd International Conference on Communication Systems Software and Middleware, 2007. COMSWARE 2007*, pp.1–9, IEEE.

Shaila, K., Vineet, G., Prashanth, C.R., Tejaswi, V., Venugopal, K.R. and Patnaik, L. (2013) 'LKSR: link strength keymatch secure routing in heterogeneous wireless sensor networks', *Int. J. of Computational Systems Engineering*, Vol. 1, pp.238–256, DOI: 10.1504/IJCSYSE.2013.057222.

Si, P., Wu, C., Zhang, Y. et al. (2017) 'Probabilistic coverage in directional sensor networks', *Wireless Networks* [online] https://doi.org/10.1007/s11276-017-1564-4.

Tao, D., Ma, H. and Liu, L. (2006) 'Coverage-enhancing algorithm for directional sensor networks', *International Conference on Mobile Ad-Hoc and Sensor Networks*, pp.256–267, Springer.

Wang, B., Fu, C. and Lim, H.B. (2009a) 'Layered diffusion-based coverage control in wireless sensor networks', *Computer Networks*, Vol. 53, No. 7, pp.1114–1124.

Wang, J., Niu, C. and Shen, R. (2009b) 'Priority-based target coverage in directional sensor networks using genetic algorithm', *Computers & Mathematics with Applications*, Vol. 57, pp.1915–1922, DOI: 10.1016/j.camwa.2008.10.019.

Wen, Jun and Fang, Li and Jiang, Jie and Dou, Wenhua. (2008) 'Coverage optimizing and node scheduling in directional wireless sensor networks', *4th International Conference on Wireless Communications, Networking and Mobile Computing, 2008. WiCOM'08*, pp.1–4, IEEE.

Zhu, C., Zheng, C., Shu, L. and Han, G. (2012) 'A survey on coverage and connectivity issues in wireless sensor networks', *J. Network and Computer Applications*, Vol. 35, pp.619–632, DOI: 10.1016/j.jnca.2011.11.016.