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Research Article

Voronoi, Genetic Algorithms and Their Tandem Application in Wireless Sensor Network Deployment

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Abstract: Wireless Sensor Network (WSN) had become almost an indispensible especially the demand for data acquisition from national security to disaster mitigation management, weather data to environmental changes and from many more agencies. The effectiveness and efficacy of WSN dependent on the strength and weakness of the deployment of the sensor nodes which collect and transmit the data. The success of data acquisition in any network depended upon the adequacy of coverage by the sensor nodes; which in turn depended on the method of deployment and redeployment. Since deterministic deployment of nodes could not always be done, random deployment was adopted as a compulsion rather than an option. The random deployment of sensors by nature provided poor network coverage and leading to unsatisfactory data acquisition. Therefore, a better method was sought-after to redeploy the sensors that were deployed earlier at random. Hence, the compelling need had resulted in the development of numerous algorithms for suitably moving the sensors for maximum coverage. Such algorithms were of standalone ones or hybrid/combination in nature. One such combination algorithm termed as Voronoi-Genetic Algorithm (V-GA) a combination/tandom application of Voronoi Vertex Averaging Algorithm (VVAA) and Genetic Algorithm (GA) was analyzed in this study. The displacement and coverage performance were studied, analyzed and compared with that of random deployment and redeployment by the earlier proposed algorithms namely VVAA and GA by the same researcher.

Keywords: Genetic algorithm, maximum coverage, movement assisted deployment, random deployment, voronoi diagram, wireless sensor networks

INTRODUCTION

Wireless Sensor Networks (WSN) had become a major attraction to the research community because of ever increasing data mining in almost every field. In WSN the node deployment played a most important role. Deployment may be the placement of the sensors to capture and transmit data from a designated area and on target applications. Maximizing the coverage with a given number of sensors, minimizing the energy consumption and optimizing reliability with least malfunction of a sensor were a few other constraints. As a standard practice the sensor nodes were being deployed randomly which might not cover maximum area as desired leading to some loss of data acquisition. Hence, the randomly deployed sensors must be redeployed by displacing them for optimization of coverage. The displacement must be minimum for conservation of energy. This was being achieved by appropriate algorithms. However, the Malfunction of a sensor in a WSN could happen in applications associated with forest fire, battle ground conditions, floods and other unnatural environments beyond the control of study. The ability of the sensor to move (mobility) was another factor which was taken into consideration in deployment. In this research the sensors used had the ability to move. Therefore, the WSN properties and applications determined the objectives to be met with in the deployment of sensors.. The literature in the area of deployment had concentrated on the life time, energy efficiency, coverage, number of nodes and survivability as main objectives (Younis and Akkaya, 2008). This study was based on the objective of maximizing the coverage of target area after random deployment of 100 nodes with appropriate algorithm/s. The authors had already developed Voronoi Vertex Averaging Algorithm (VVAA) and Genetic Algorithm (GA) for mobility assisted deployment for the same purpose. The newly proposed algorithm V-GA was a tandem application of algorithm VVAA with GA (Juli and Raja, 2012a, b, 2013). The proposed hybrid algorithm was simulated using MATLAB® software and compared with Random, VVAA and GA algorithms applications.

Deployment algorithms: The effect of various algorithms on sensor deployment, coverage and their results were briefly brought out for the benefit of the

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readers. Various algorithms were proposed by the authors to re-deploy the sensor nodes that were already deployed randomly. According to the method of deployment the algorithms were classified into three types namely Random Deployment, Incremental Deployment and Mobility Assisted Deployment.

Random deployment: Practical deployment in large sensor network was usually random. There the sensors were randomly dropped using aircrafts or flying robots. Clouqueur *et al*. (2002) addressed the problem of sensor deployment in a region to be monitored for target intrusion. The goal of the method was to maximize the coverage of the least exposed path in the region. The strategy consisted of deploying a limited number of sensors at a time until the desired minimum coverage was achieved. Maleki and Pedram (2005) considered the problem of energy efficient random deployment of sensor nodes with the objective of finding the sensor node density at every point inside the deployment region. In the unknown and inhospitable environments the manual deployment was not possible. The level of control in deployment of sensor nodes determined the degree of randomness in the location of nodes. Random deployment was the simplest method and easy to implement. But random deployment normally resulted in uneven distribution of sensors with in poor network coverage. This was addressed in detail in below Section.

Incremental deployment: The incremental sensor node deployment was a centralized approach in which the sensor nodes were added one by one. The information about the previously deployed node was collected by the centralized node and used for the deployment of the subsequent node. The incremental deployment was commonly dealt with by fixed sensor nodes (Howard *et al*., 2002; Li and Cassandras, 2005) dealt with the algorithms for incremental deployment of nodes in a wireless sensor network. Al-Omari and Weisong (2010) proposed an algorithm taking the deployment problem as the problem of deciding how many sensor nodes should be deployed in the sensor field over how many phases during its lifetime. In the incremental deployments, the nodes were re-positioned in optimal location during each step of deployment process. Hence, the nodes were moved to improve the coverage with minimum amount of energy consumption for sensor mobility. Here, the re-deployment time was increased. Since large number of sensors was used in the networks and several messages were being reported by the centralized node, the scalability was one of the main problems. So, the centralized node failed earlier due to energy depletion. In highly dynamic networks, the cost and the power consumption of the network were increased due to large number of messages being communicated. Such algorithms were prone to a single point failure. In such situations, the mobility assisted re-deployment algorithms would provide better solutions for solving the scalability problem.

Mobility assisted deployment: Random deployment resulted as discussed earlier in either overly clustered or uncovered areas in the target field. In incremental deployment several massages had been communicated by the centralized node. In both random and incremental deployments the actual positions of the nodes were not controlled due to existence of uncontrolled natural environment. Hence, the coverage became poor and the efficiency of the network was affected. So, there was a need or the mobile nodes to be re-deployed by moving to optimal locations to enhance the effectiveness of the network. There were three approaches in the literature studied for moving the sensors namely geometrical approach, virtual-force-based approach and molecular-diffusion theory based approach.

Geometrical approach: In geometrical approach, the sensor region was represented by grids or polygons. The deployment process would aim for placing the sensors inside the grid or polygon Guiling *et al*. (2006) suggested three deployment algorithms based on the mobility degree of sensor nodes. Pillwon *et al*. (2010) proposed a grid based scheme for sensor node deployment in which the sensors were deployed randomly and exchanged local information with the neighbors Mahboubi *et al*. (2010) proposed three algorithms namely weighted vector based, farthest point boundary and min-max point algorithms to improve coverage area. The Multiplicatively Weighted Voronoi diagram was adopted to discover the coverage holes corresponding to different sensors with unidentical sensing ranges.

Molecular diffusion theory based approach: These algorithms were inspired by equilibrium of molecules, with minimum molecular electronic energy and inter-molecular repulsion. A force was exerted between the nodes depending on the distance between them and the current local density. The force from a node that was closer was greater than that from the nodes that was farther. Rauy-Shiung and Shuo-Hung (2008) came out with an algorithm using density control by each node to concurrently deploy sensor nodes in an environment particularly in an unknown expanse. The goal of that method was to re-deploy nodes as soon as possible to get maximized coverage while keeping the network connected. The weakness of this approach was that the sensor would not select a narrow area to move if they had a better choice. The deployment was quick enabling as much areas as possible. Tariq *et al*. (2010) provided an energy efficient distributive self-deployment algorithm based on diffusion of mobile sensors in the unstable network scenario.

Virtual force based approach: Here, the virtual potential was used to represent goal constraints and the control law for the sensor's motion i.e., it was moved from a high potential state to a low potential state. These forces repelled the nodes from each other and from obstacles and hence the network was forced to spread itself throughout the environment. The approach was both distributable and scalable. Also the nodes would quickly spread out to maximize the coverage area of the network. Poduri and Sukhatme (2004) taken into account the problem of self-deployment of a mobile sensor network. They were interested in a deployment strategy that maximized the area of coverage of the network with the constraint that each of the nodes had at least K neighbors, where K was a user-specified parameter. They proposed an algorithm, based on artificial potential fields which was distributable, scalable but did not require a prior map of the environment. Guangming *et al*. (2006) followed another algorithm to deploy mobile sensor nodes in complex-shaped buildings which were inaccessible. This algorithm combined the potential field and certainty grid methods. The certainty grid method was used to represent obstacles. The network coverage was relatively good. But, the coverage rate was low. Minghua *et al*. (2008a, b, c) presented self-deployment algorithms based on the enforums-sensing performance of mobile sensor networks.

NEED FOR A TANDOM APPLICATION OF ALGORITHMS

The previous works of the authors of this study, addressed two algorithms for mobility assisted deployment of sensor nodes after their random deployment. Voronoi based algorithm called VVAA (Voronoi Vertex Averaging Algorithm) and GA (Genetic Algorithm) were recommended and for improving the sensor network coverage. While experimenting with VVAA it was observed that the network coverage was increased in initial few iterations namely 2 or 3 iterations itself. There was not much improvement when the iteration was increased further. Similarly the application of GA had also improved the coverage by re deploying the sensors. But the improvement in coverage was gradual and oscillatory The coverage was increased or decreased or oscillatory between higher and lower values. Though both algorithms improved the network coverage VVAA improved the coverage better compared to GA. Also GA consumed more time compared to VVAA and the displacement of nodes was greater than VVAA. This phenomenon was explained in the below section in detail. Hence, a combination of VVAA and GA in tandem application was attempted to as a hybrid algorithm to further improve the network performance. The displacement and coverage performance were analyzed and compared with Random, GA and VVAA based re-deployments. It was also supported that such hybridization had improved the capabilities of GA by earlier study, (Babu *et al*., 2009).

Voronoi-Genetic Algorithm (V-GA): As stated earlier V-GA was the combination of already tried Voronoi Vertex Averaging Algorithm (VVAA) and Genetic Algorithm (GA) to utilize the advantage of both. VVAA provided better coverage in lesser time. GA provided solutions for optimization problem in various applications. To overcome the limitations of VVAA and GA, a tandem application of VVAA algorithm followed by GA algorithm would be tried to optimize the network beyond the level already achieved by VVAA. The sensor network coverage of the proposed tandem algorithm application using MATLAB® simulation was studied. The V-GA model is shown as a flow chart in Fig. 1.

The present study envisaged as mentioned repeatedly an application of two already existing algorithms namely VVAA and GA for re-deployment of the sensors that had been already deployed randomly and it was termed as V-GA hybird algorithm, eventhough it was not a separate algorithm. The sequential application of algorithms was proposed for maximum coverage, Experiments for V-GA were carried out by varying the number of iterations of VVAA and GA. The combinations of VVAA and GA were called as V-GA. In V-GA VVAA was carried out for 5 iterations and GA was then applied for remaining 5 iterations.

The operational sequence was as follows:

- Nodal sensors were displayed randomly.
- They were redeployed by VVAA algorithm to its maximum efficeiency.
- Finally, the algorithm GA was applied for enhancement of courage further by fine tuning.

It could be seen that the redeployment was better and better with the application of the algorithms, in tandem-one after another as discribed. The V-GA model was explained in Fig. 1.

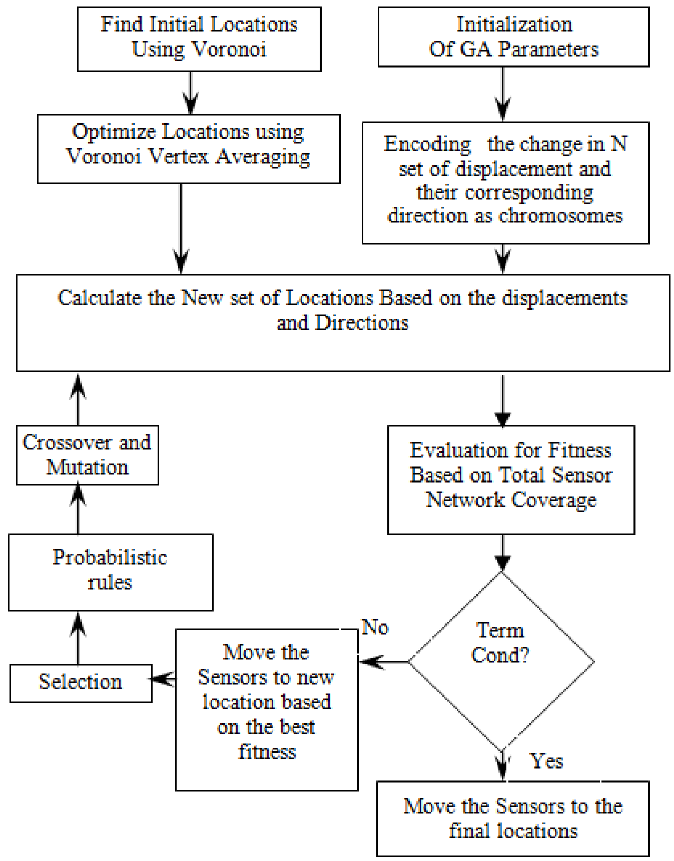


Fig. 1: V-GA model

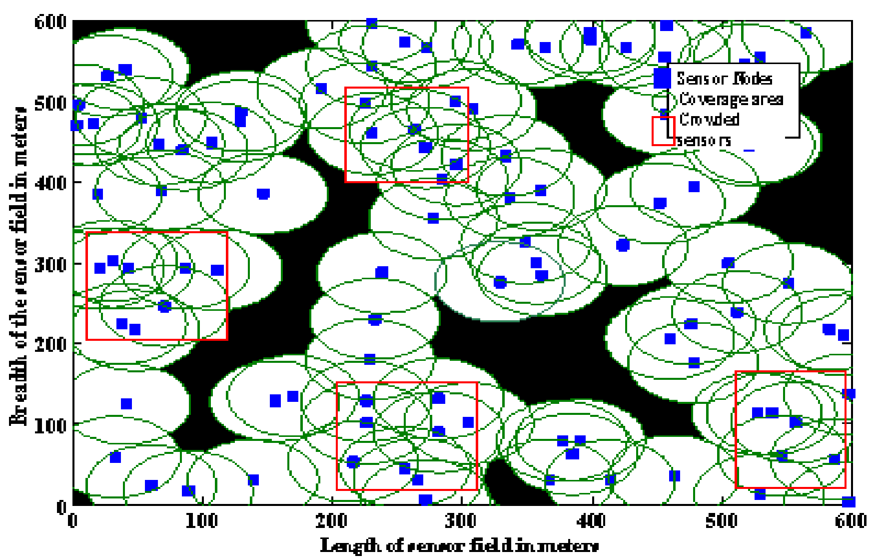


Fig. 2: Random deployment

RESULTS AND DISCUSSION

The coverage performance of random deployment of 100 number of sensor nodes was analyzed, with the application of VVAA and GA sequentially in that order, in the experiments Then the performance characteristics of previously proposed mobility assisted deployments using VVAA and GA were checked independently. Finally V-GA algorithm (the combination of VVAA and GA) was simulated using MATLAB. The performance of the algorithm V-GA in terms of coverage, total displacement of nodes and simulation time was compared with that of random, VVVV and GA based deployments individually.

Initial simulation setup: In this simulation, the initial setup was the random distribution of 100 nodes each having a sensing ranges of 50 m in the field of 600×600 m. As predicted, the coverage was not uniform throughout the field because the distribution was unequal with some crowded areas (red color rectangles) and with some unrepresented areas. The randomly deployed sensors and the coverage area of the sensors were shown in Fig. 2. The sensor nodes were represented as blue color points and coverage area of each sensor was represented as green color circles. There were plenty of coverage holes present in the target area and the uncovered areas were represented by black color filled areas. That scenario had to be changed if one had to get a meaningful and complete data from the entire field. This could be achieved by redeploying the sensors with algorithms.

Coverage performance of VVAA and GA based mobility assisted deployments: In earlier chapters the application of algorithms namely GA and VVAA were studied in detail for the improvement in the coverage with minimizing the displacement. However, they were studied as standalone algorithms that enriched the performance of the field coverage with reduction is coverage holes. Further, the number of iterations for simulating VVAA and GA was limited to 20. The

Table 1: Iteration by iteration coverage for 20 iterations of VVAA

Iteration	Coverage in percentage									
	Exp. 1	Exp. 2	Exp. 3	Exp. 4	Exp. 5	Exp. 6	Exp. 7	Exp. 8	Exp. 9	Exp. 10
0 (random)	87.64	89.42	87.71	82.69	85.88	85.47	88.55	86.49	84.79	87.91
1	92.28	97.17	94.52	94.69	96.95	94.54	97.55	95.98	92.42	94.14
2	95.26	97.24	95.60	96.70	97.73	95.75	97.78	96.92	93.72	94.85
3	96.19	98.31	95.75	96.14	98.65	96.18	98.29	96.97	94.42	96.45
4	96.80	98.40	95.89	96.68	99.12	96.34	98.42	97.31	94.72	97.50
5	97.26	98.46	96.79	96.79	99.27	96.28	98.46	97.51	94.98	97.84
6	97.55	98.47	97.00	97.30	99.22	96.15	98.51	97.62	95.22	98.00
7	97.77	98.48	97.13	97.08	99.19	96.32	98.46	97.58	95.40	98.18
8	97.98	98.65	97.20	97.73	99.17	96.42	98.48	97.57	95.54	98.36
9	98.19	98.73	97.27	97.91	99.17	96.47	98.49	97.58	95.66	98.64
10	97.73	98.77	97.33	98.08	99.21	96.50	98.51	97.57	95.87	98.73
11	98.16	98.82	97.40	98.18	99.22	97.06	98.49	97.56	96.35	98.80
12	98.34	98.82	97.43	98.29	99.23	97.18	98.49	97.56	96.84	98.86
13	98.48	98.84	97.47	98.43	99.21	97.25	98.48	97.57	97.14	98.91
14	98.50	98.86	97.51	98.51	99.22	97.39	98.46	97.58	97.32	98.95
15	98.53	98.84	97.53	98.60	99.21	97.42	98.47	97.61	97.58	98.96
16	98.54	98.88	97.54	98.65	99.21	97.40	98.47	97.59	97.67	98.97
17	98.55	98.89	97.57	98.72	99.22	97.43	98.47	97.62	97.75	98.90
18	98.56	98.89	97.60	98.77	99.21	97.45	98.49	97.64	97.78	98.81
19	98.56	98.89	97.60	98.82	99.22	97.48	98.49	97.67	97.81	98.83
20	98.57	98.89	97.60	98.86	99.22	97.48	98.49	97.67	97.86	98.88

Table 2: Iteration by iteration coverage for 20 iterations of GA

Iteration	Coverage in percentage									
	Exp. 1	Exp. 2	Exp. 3	Exp. 4	Exp. 5	Exp. 6	Exp. 7	Exp. 8	Exp. 9	Exp. 10
0 (random)	87.64	89.42	87.71	82.69	85.88	85.47	88.55	86.49	84.79	87.91
1	89.15	90.68	88.52	84.02	86.42	87.13	88.71	89.57	86.38	89.01
2	90.00	92.44	89.00	86.28	87.42	90.56	90.06	90.47	88.82	90.76
3	90.21	93.71	90.22	88.11	88.33	92.07	90.89	91.58	89.53	90.95
4	91.57	94.54	91.06	89.80	90.52	92.86	92.59	92.01	90.66	92.48
5	92.24	95.55	91.19	90.74	91.97	94.62	93.24	92.26	91.45	92.87
6	93.10	95.44	92.31	91.00	92.10	94.80	93.95	93.21	92.41	94.58
7	94.31	95.49	93.79	91.29	92.09	95.69	94.56	94.72	92.41	94.73
8	94.69	96.47	93.46	91.69	94.21	96.23	95.75	95.33	93.32	95.25
9	95.56	97.09	93.70	92.06	94.21	96.59	95.91	95.67	93.55	95.19
10	95.91	96.90	93.99	92.07	95.16	97.14	96.02	95.93	93.56	95.14
11	96.28	97.17	94.62	92.06	95.19	97.14	95.99	95.77	93.84	96.71
12	96.90	97.35	95.47	92.15	95.39	97.14	96.51	95.77	94.60	96.32
13	96.12	97.22	95.47	92.85	95.46	97.14	96.91	95.96	95.35	97.13
14	96.70	97.22	96.20	93.79	96.04	96.86	97.18	96.16	94.92	97.71
15	96.48	97.22	96.20	93.77	95.96	96.86	97.18	96.43	94.82	96.93
16	96.48	97.22	96.83	93.78	96.06	97.35	97.18	96.42	94.88	96.96
17	96.48	97.97	97.32	93.78	96.55	97.44	97.18	96.44	94.96	96.96
18	96.96	97.61	97.32	93.78	97.76	97.17	97.18	96.44	95.57	96.01
19	97.57	97.61	97.32	93.78	97.65	97.02	97.18	96.61	95.56	97.04
20	97.57	97.61	97.32	93.78	97.65	97.02	97.18	96.61	95.56	97.04

algorithms were applied and experimented for 10 random topologies and their coverage characteristics were analyzed and compared. The iteration by iteration results of coverage achieved by VVAA for 20 iterations were tabulated in Table 1 and 2, respectively.

The results of 10 experiments using VVAA were plotted (Fig. 3) for all the 20 iterations. The network coverage by VVAA was found to be initially good up to 5 iterations. When the iterations were increased from 6 to 10 the improvement in coverage percentage was marginal and not significant. During 11 to 20 iterations it was observed that there was very little or no increase in coverage. The coverage appeared to have reached the peak value or optimal value.

Similarly for 10 experiments using GA for 20 iterations, the coverage performance of GA was as shown in Fig. 4. In this case the improvement in coverage had extended up to 10 algorithms. From 11 to 20 the improvement in coverage percentage was negligible and not steady but fluctuating.

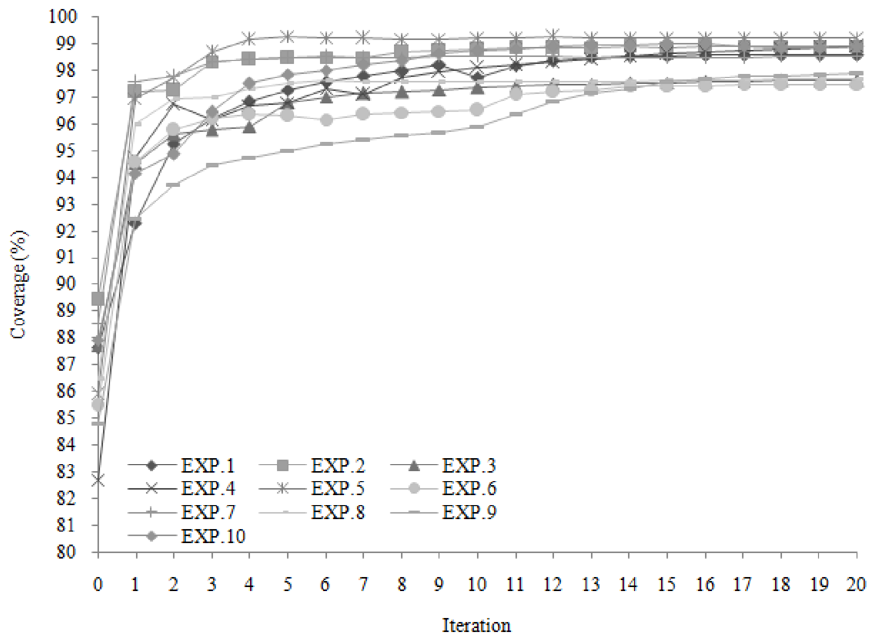


Fig. 3: Coverage vs. iteration performance of VVAA for 10 experiments

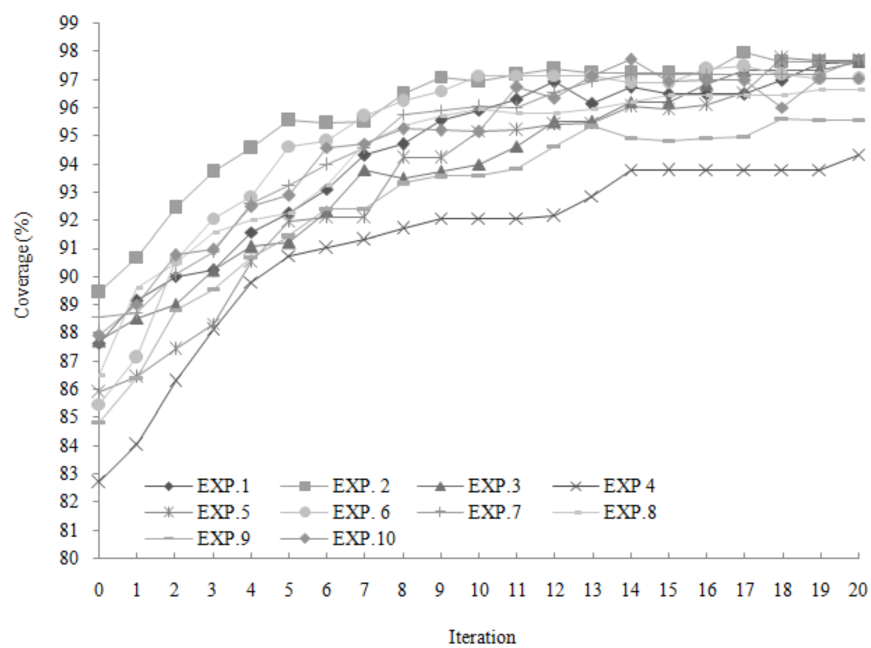


Fig. 4: Coverage vs. iteration performance of GA for 10 experiments

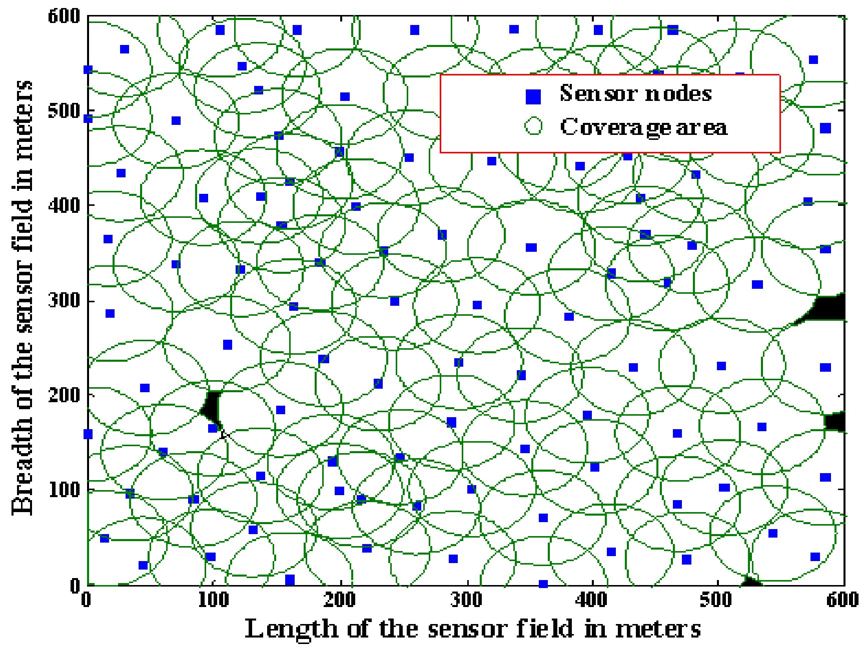


Fig. 5: Sensor field after applying V-GA

Table 3: Iteration by iteration coverage of V-GA for 10 experiments

	Coverage in percentage									
Iteration	Exp. 1	Exp. 2	Exp. 3	Exp. 4	Exp. 5	Exp. 6	Exp. 7	Exp. 8	Exp. 9	Exp. 10
0 (random)	87.64	89.42	87.71	82.69	85.88	85.47	88.55	86.49	84.79	87.91
1	92.28	97.17	94.52	94.69	96.95	94.54	97.55	95.98	92.42	94.14
2	95.26	97.24	95.60	96.70	97.73	95.75	97.78	96.92	93.72	94.85
3	96.19	98.31	95.75	96.14	98.65	96.18	98.29	96.97	94.42	96.45
4	96.80	98.40	95.89	96.68	99.12	96.34	98.42	97.31	94.72	97.50
5	97.26	98.46	96.79	96.79	99.27	96.28	98.46	97.51	94.98	97.84
6	97.54	98.78	96.55	97.20	98.88	97.37	98.87	97.72	96.02	97.62
7	97.54	98.78	96.55	97.20	98.88	97.37	98.87	97.72	95.99	97.62
8	97.54	98.78	96.55	97.20	98.88	97.37	98.87	97.72	95.99	97.62
9	97.54	98.78	96.55	97.20	98.88	97.37	98.87	98.05	95.99	97.62
10	97.54	98.78	96.55	97.20	98.88	97.37	98.87	98.05	95.99	97.62

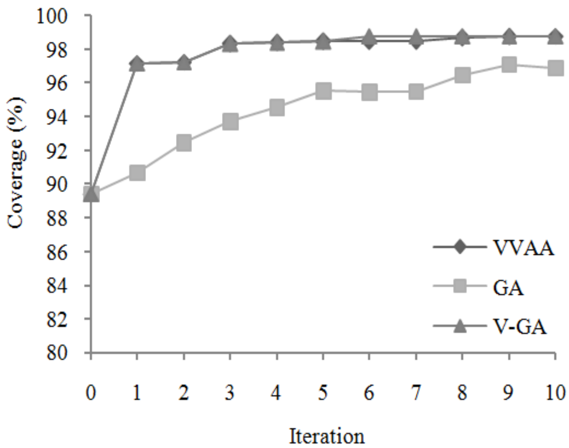
However, further increase of iterations had compounded the computational complexity and a higher level was required in computing. From the Fig. 3 and 4 it could be inferred that while performing tandem application of VVAA with GA, the increasing the number of iterations beyond 10 might not result in substantial improvement in coverage. Since, both the algorithms had shown best results between 1 to 10 iterations independently. From 10 to 20 iterations the coverage improvement was marginal and almost constant or oscillatory. Hence, to minimize or eliminate the drawbacks of independent applications of VVAA with GA, a tandem application of VVAA and GA called as V-GA was suggested.

Performance of V-GA with VVAA and GA based mobility assisted deployments: The tandem applications of VVAA with GA called V-GA were performed with a restriction of 10 iterations. In V-GA, initially VVAA was performed for 5 iterations and the sensors were relocated and first level of optimization was reached. Starting from those optimized locations considered, GA was applied for remaining 5 iterations to further enhance the coverage efficiency. Then V-GA was applied for the same 10 random topologies already adopted. The sensors were assisted by V-GA towards optimal locations. The relocated sensors were shown in Fig. 5.

By comparing the Fig. 2 and 5 one could understand that the sensors were redistributed by using V-GA and so the coverage holes and the overly covered regions were reduced. Further the V-GA performance was compared with random VVAA and GA based deployments in terms of coverage, node displacement and simulation time and energy consumption for node displacement.

Coverage performance of V-GA with VVAA and GA: The V-GA was performed for 10 iterations. The iteration by iteration coverage achieved for 10 Iterations of V-GA was tabulated in Table 3.

The percentage of coverage achieved by, V-GA was compared with VVAA and GA in the Fig. 6a to j. With V-GA it got stabilized at optimal value much earlier and hence it could be safely concluded that the application of the proposed V-GA algorithm yielded better coverage than the independent application of VVAA and GA algorithms at the 10th iterations. This also was a marginal case without much of significance.



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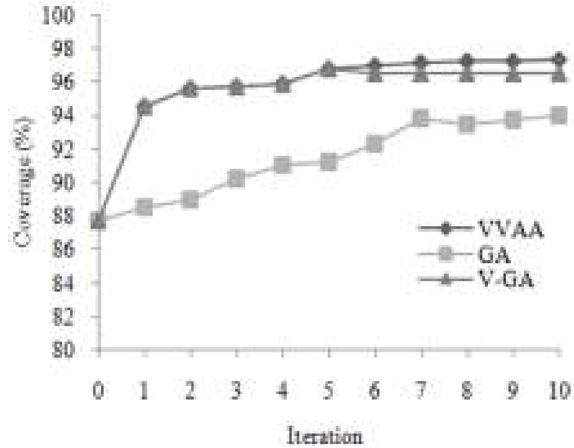

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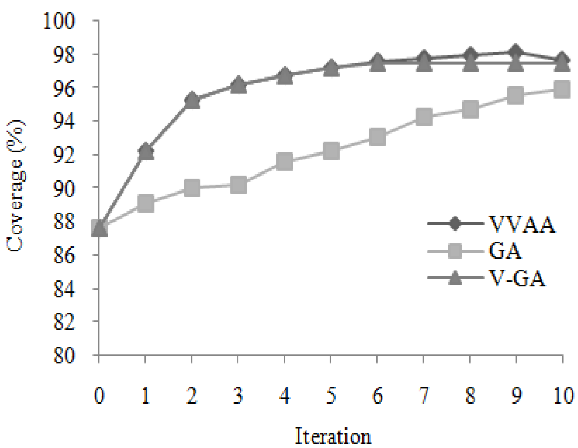

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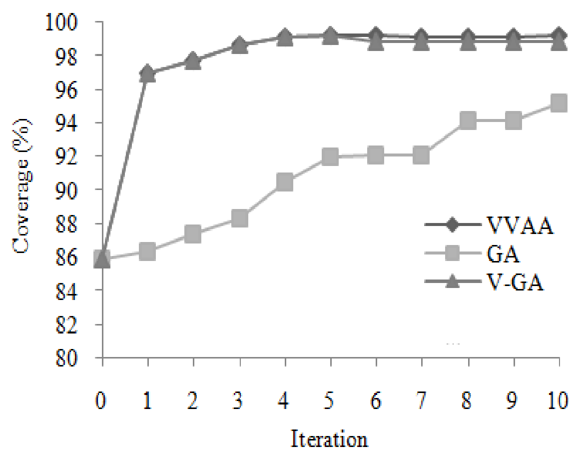

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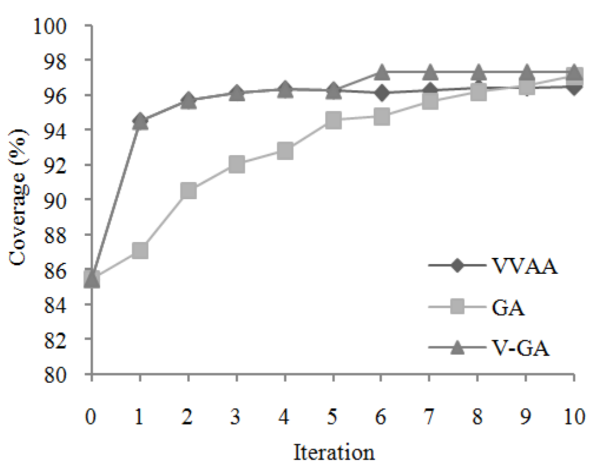

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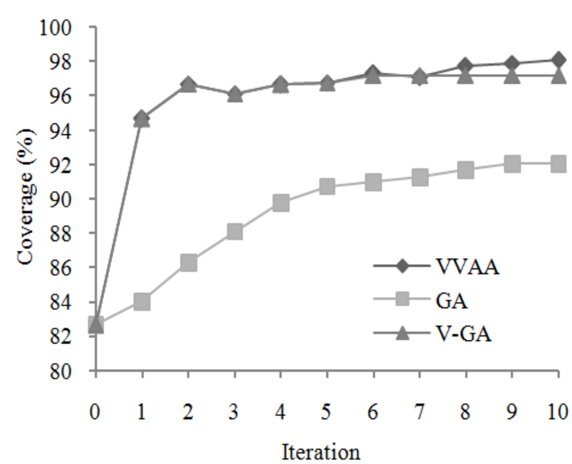

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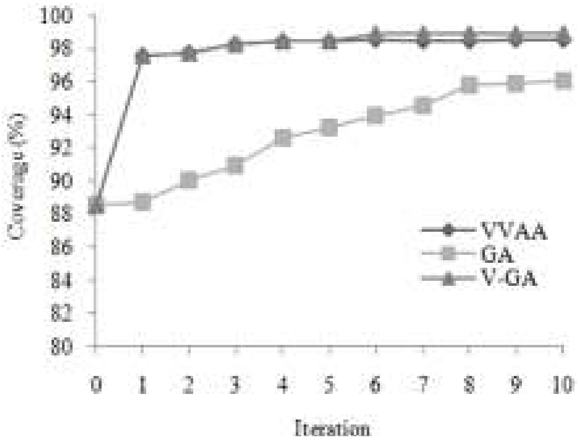

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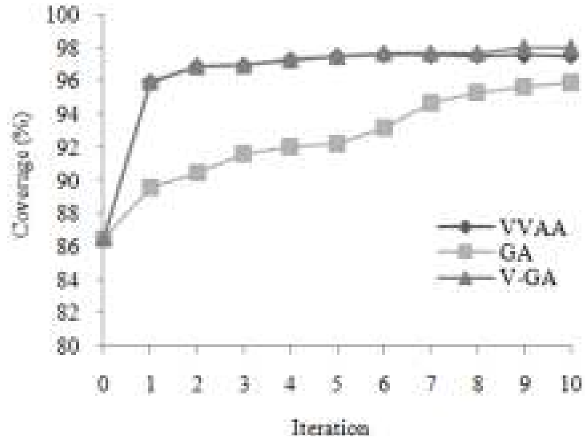

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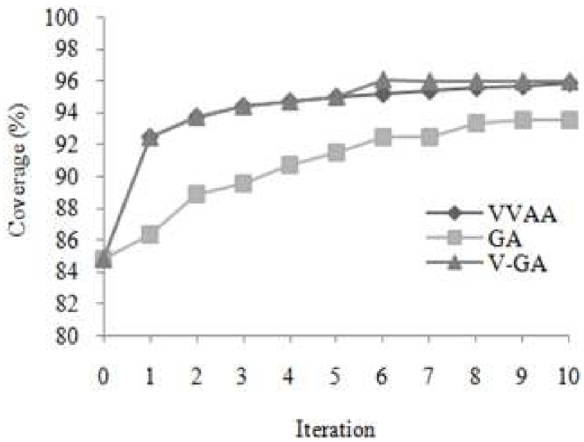

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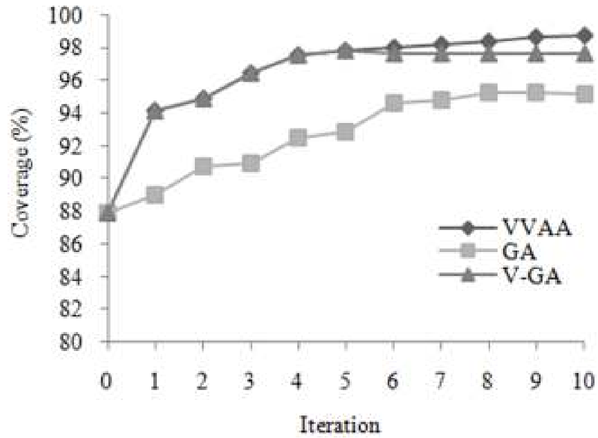


(j)

Fig. 6: (a) Experiment 1, (b) experiment 2, (c) experiment 3, (d) experiment 4, (e) experiment 5, (f) experiment 6, (g) experiment 7, (h) experiment 8, (i) experiment 9 and (j) experiment 10 coverage vs. iteration

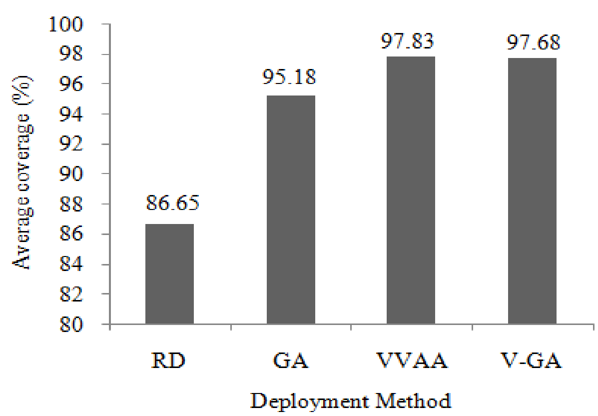


Fig. 7: Comparison of average coverage

The maximum coverage achieved by VVAA and GA and V-GA combination algorithms for 10 experiments were averaged and compared in Fig. 7. There again the combination algorithm provided an optional results than the other two parent algorithms.

Displacement performance of V-GA with VVAA and GA: Similarly, the iteration wise total displacement of sensor nodes were tabulated in Table 4 to 6, respectively for the application of VVAA, GA and V-GA.

The displacement results of V-GA was compared with VVAA and GA from Fig. 8a to j. Even though the total displacement of nodes for V-GA combination was marginally higher than that for VVAA algorithm but it was substantially less than that for GA algorithm. Here again the V-GA combination could be taken as better than the others-independent algorithms.

The maximum displacement achieved by VVAA and GA and V-GA combination were averaged and represented in Fig. 9. Here, the VVAA provided the just result of minimum displacement the V-GA combinations resulted in 2nd place. It could be due to the redeployment of more sensors and with longer movement for the best coverage with least coverage holes.

Table 4: Displacement for 10 experiments of VVAA

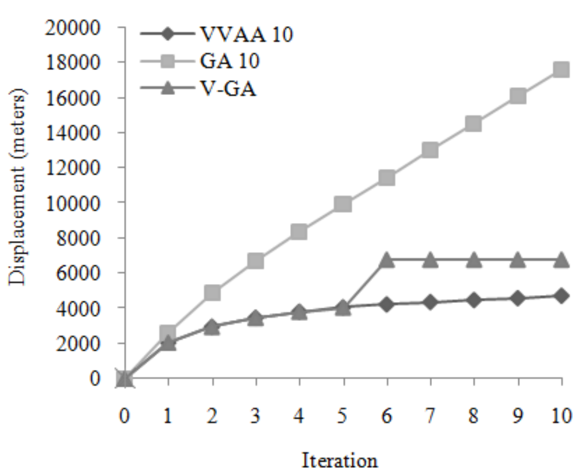
Topology	Exp. 1	Exp. 2	Exp. 3	Exp. 4	Exp. 5	Exp. 6	Exp. 7	Exp. 8	Exp. 9	Exp. 10
1	2042	2152	1866	2148	2159	2158	2219	1847	2097	2082
2	2944	3203	2859	3127	2974	2873	3067	2815	2903	3262
3	3450	3714	3202	3786	3553	3234	3456	3303	3311	3854
4	3796	3988	3859	4276	3902	3470	3678	3852	3550	4341
5	4040	4169	4224	4598	4137	3798	3896	3973	3729	4675
6	4212	4293	4405	4844	4298	3875	4168	4273	3911	4955
7	4346	4388	4519	5060	4454	3899	4405	4553	4053	5233
8	4458	4496	4606	5259	4574	4094	4554	4774	4172	5511
9	4563	4583	4674	5450	4674	4171	4684	4936	4276	5708
10	4700	4653	4793	5600	4807	4236	4839	5054	4385	5826

Table 5: Displacement for 10 experiments of GA

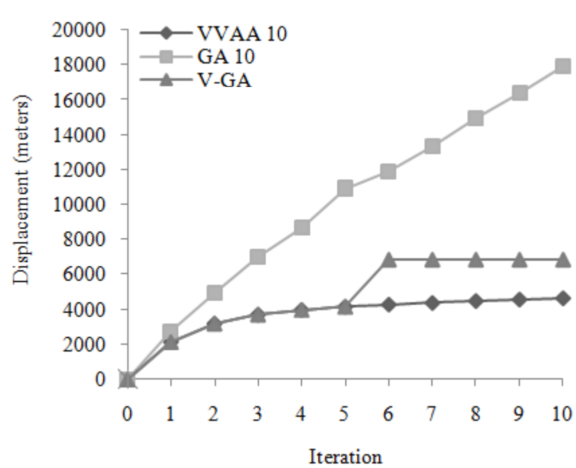
Topology	Exp. 1	Exp. 2	Exp. 3	Exp. 4	Exp. 5	Exp. 6	Exp. 7	Exp. 8	Exp. 9	Exp. 10
1	2640	2707	2547	2668	2692	2611	2606	2670	2762	2724
2	4883	4925	4733	4871	4881	4877	4691	4770	4982	4919
3	6741	6972	6545	6866	6831	7062	6552	6745	6941	6760
4	8347	8693	8233	8832	8620	8917	8251	8478	8469	6544
5	9937	10920	9785	10386	10250	10539	9990	10031	10071	10270
6	11457	11847	11373	11980	11905	12159	11538	11595	11667	11759
7	13028	13313	12822	13498	13425	13522	13047	13172	11667	13321
8	14524	14901	14365	14885	15013	14944	14565	14669	13108	14834
9	16069	16362	15887	16628	13598	16449	16098	16141	14498	16294
10	17593	17883	17370	16268	17989	17891	17636	17476	14493	17747

Table 6: Displacement for 10 experiments of V-GA

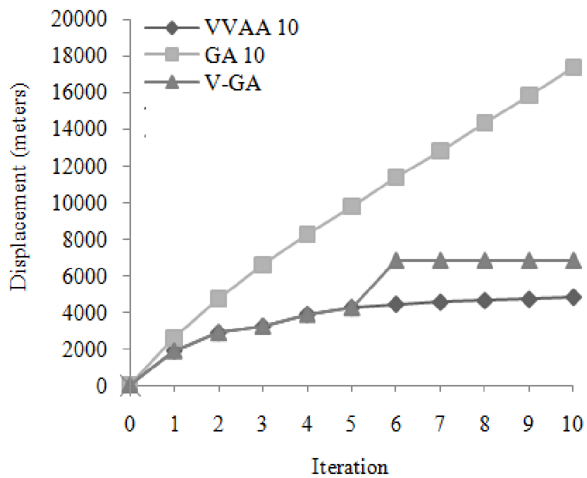
Topology	Exp. 1	Exp. 2	Exp. 3	Exp. 4	Exp. 5	Exp. 6	Exp. 7	Exp. 8	Exp. 9	Exp. 10
1	2042	2152	1866	2148	2159	2158	2219	1847	2097	2082
2	2944	3203	2859	3127	2974	2873	3067	2815	2903	3262
3	3450	3714	3202	3786	3553	3234	3456	3303	3311	3854
4	3796	3988	3859	4276	3902	3470	3678	3852	3550	4341
5	4040	4169	4224	4598	4137	3798	3896	3973	3729	4675
6	6748	6865	6794	7295	6748	6529	6343	6696	6417	7343
7	6748	6865	6794	7295	6748	6529	6343	6696	9038	7343
8	6748	6865	6794	7295	6748	6529	6343	8596	9038	7343
9	6748	6865	6794	7295	6748	6529	6343	8596	9038	7343
10	6748	6865	6794	7295	6748	6529	6349	8596	9038	7343



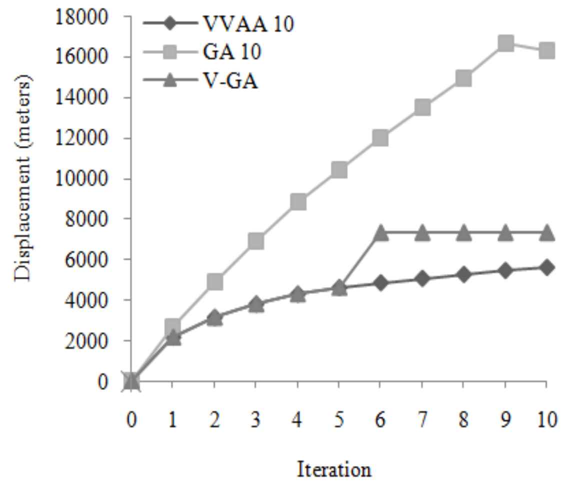
(a)



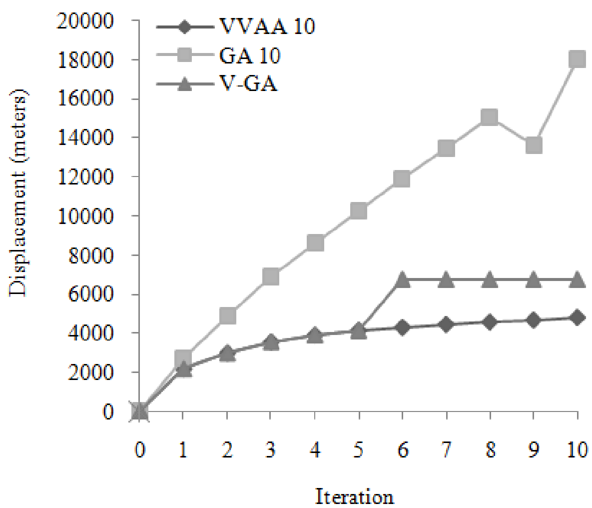
(b)


VVAA 10
GA 10
V-GA
Displacement (meters)
Iteration
0 2000 4000 6000 8000 10000 12000 14000 16000 18000 20000
0 1 2 3 4 5 6 7 8 9 10

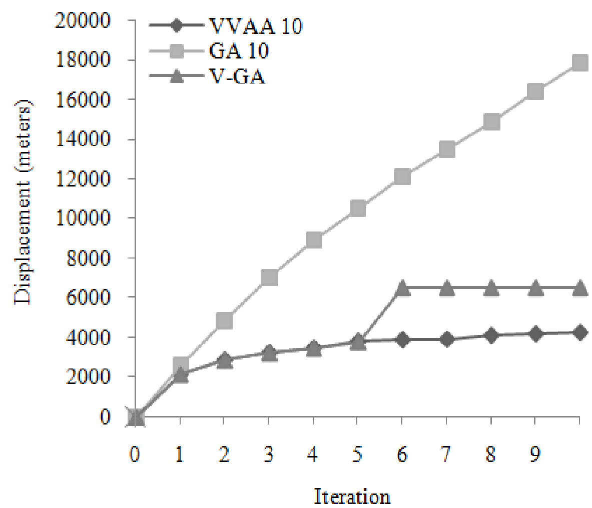
(c)


VVAA 10
GA 10
V-GA
Displacement (meters)
Iteration
0 2000 4000 6000 8000 10000 12000 14000 16000 18000
0 1 2 3 4 5 6 7 8 9 10

(d)


VVAA 10
GA 10
V-GA
Displacement (meters)
Iteration
0 2000 4000 6000 8000 10000 12000 14000 16000 18000 20000
0 1 2 3 4 5 6 7 8 9 10

(e)


VVAA 10
GA 10
V-GA
Displacement (meters)
Iteration
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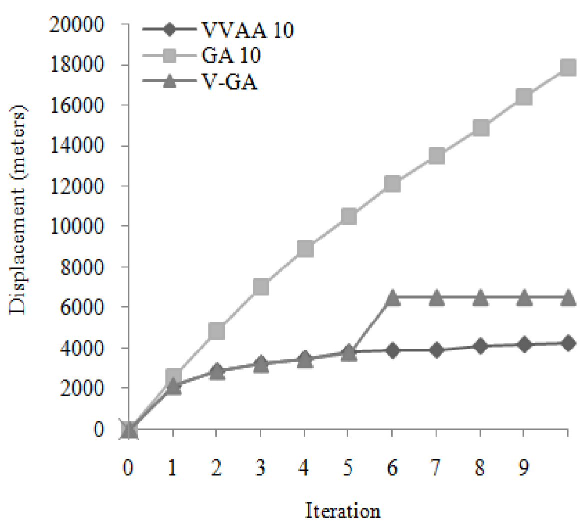
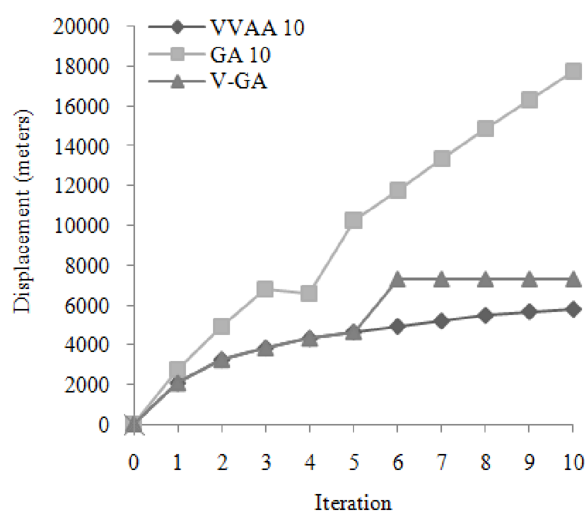
0 1 2 3 4 5 6 7 8 9

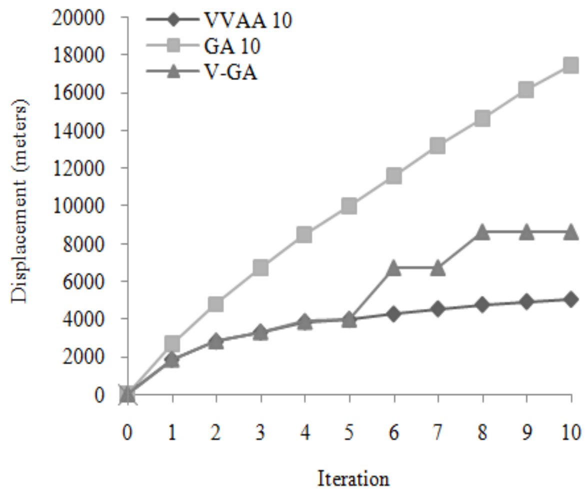
(f)


VVAA 10
GA 10
V-GA
Displacement (meters)
Iteration
0 2000 4000 6000 8000 10000 12000 14000 16000 18000 20000
0 1 2 3 4 5 6 7 8 9

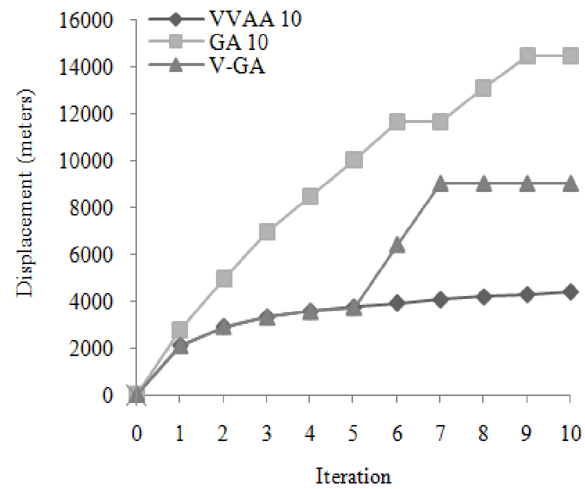
(g)


VVAA 10
GA 10
V-GA
Displacement (meters)
Iteration
0 2000 4000 6000 8000 10000 12000 14000 16000 18000 20000
0 1 2 3 4 5 6 7 8 9 10

(h)



(i)



(j)

Fig. 8: (a) Experiment 1, (b) experiment 2, (c) experiment 3, (d) experiment 4, (e) experiment 5, (f) experiment 6, (g) experiment 7, (h) experiment 8, (i) experiment 9 and (j) experiment 10 displacement vs. iteration

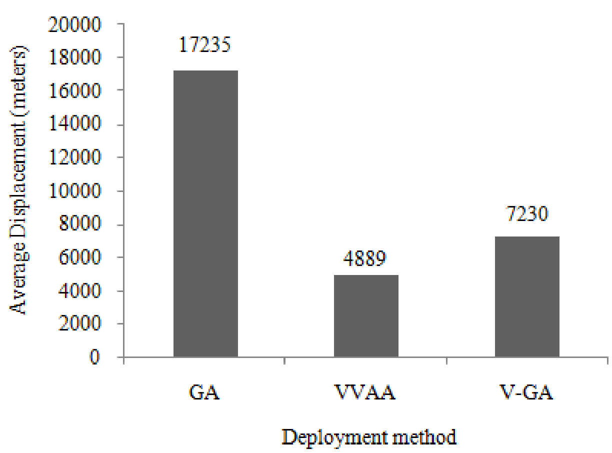


Fig. 9: Comparison of average displacement

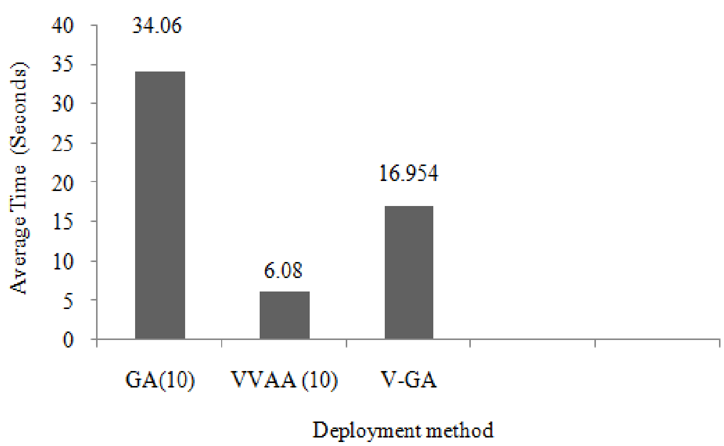


Fig. 10: Comparison of simulation time

Performance of V-GA with GA and VVAA in terms of simulation time: The simulation time for independent VVAA and GA and V-GA combination were depicted in Fig. 10. In this parameter also the V-

GA achieved second place because of the best coverage by taking more time for moving the nodes from densely populated area to sparsely located areas.

CONCLUSION

The various experiments and iterations with VVAA, GA independently and combined V-GA algorithms revealed the following:

- The proposed V-GA algorithm provided better coverage area.
- The displacement of the proposed algorithm was marginally higher than VVAA application but much less than GA application.
- The simulation time of proposed algorithm lies in between that of other two.
- From point 2 and 3 one could deduce that the energy consumption under the proposed algorithm would be reasonably less if not the least.
- Hence, the authors strongly recommend the usage of combined V-GA algorithm for redeployment of sensor nodes.

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