

## Grid and Force Based Sensor Deployment Methods in Wireless Sensor Network using Particle Swarm Optimization

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### ABSTRACT

Wireless Sensor Network (WSN) is emerging technology and has wide range of applications, such as environment monitoring, industrial automation and numerous military applications. Hence, WSN is popular among researchers. WSN has several constraints such as restricted sensing range, communication range and limited battery capacity. These limitations bring issues such as coverage, connectivity, network lifetime and scheduling & data aggregation. There are mainly three strategies for solving coverage problems namely; force, grid and computational geometry based. PSO is a multidimensional optimization method inspired from the social behavior of birds called flocking. Basic version of PSO has the drawback of sometimes getting trapped in local optima as particles learn from each other and past solutions. This issue is solved by discrete version of PSO known as Modified Discrete Binary PSO (MDBPSO) as it uses probabilistic approach. This paper discusses performance analysis of random; grid based MDBPSO (Modified Discrete Binary Particle Swarm Optimization), Force Based VFCPSO and Combination of Grid & Force Based sensor deployment algorithms based on interval and packet size. From the results of Combination of Grid & Force Based sensor deployment algorithm, it can be concluded that its performance is best for all parameters as compared to rest of the three methods when interval and packet size is varied.

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### 1. INTRODUCTION (10 PT)

Advancement in wireless communication have enabled the development of low-cost, multifunctional, small sensor nodes which can sense the environment, perform data processing and communicate with each other un-tethered over short distances [1]. Wireless sensor networks idea is envisioned and defined as self-deployed, error prone, long living inexpensive communication devices that are densely deployed to collect data from physical space. Sensor nodes communicate with each other to detect events depending on the application, to collect and process data, and to transmit the sensed information to the base station by hopping the data from node to node [2]. The sensor nodes are deployed either randomly or according to statistical distribution which is predefined, over a geographic region of interest (ROI). Wireless sensor network consists of various sensor nodes that are used to monitor any target area like forest fire detection by our army person and monitoring any industrial activity by industry manager [3]. A sensor node has resource constraints, like low battery power, limited signal processing, limited computation and

communication capabilities and a small memory; that's why it can sense only a small portion of the environment [4]. Hence, energy saving along with coverage optimization is a critical issue in the design of a WSN.

WSN issues which can be formulated as optimization problems are localization, node deployment, data aggregation and energy-aware clustering.

Limited communication and sensing range causes the problem of connectivity and coverage. To solve both problems, the sensors are positioned with respect to each other [5]. Coverage problem is regarding making sure that each of the point in the region of interest to be monitored is covered by the sensors. In order to maximize coverage the sensors are to be placed not too close so that the sensing capability of the network is fully utilized. At the same time; they must not be located too far to avoid the formation of coverage holes (area outside sensing range of sensors).

Random deployment method distributes sensor nodes stochastically and independently within the field. It is usually for dangerous or abominable such as battle field, foe military and disaster application or in hospitable areas where network size is large. Dropping sensors from a plane would be an example of random deployment. Random deployment could cause some of the sensors being deployed too close to each other while others are too far apart. In both situations coverage problem will arise, the sensing capabilities of the sensors are wasted and the coverage is not maximized in the first condition, while in the later blind spots will be formed.

Traditional analytical optimization techniques require more computational efforts, which grow exponentially as the problem size increases. An optimization method which requires moderate memory with computational resources and yet produces good results is expected, especially for implementation on an individual sensor node. Swarm optimization methods are computationally efficient alternatives to analytical methods available. Particle Swarm Optimization (PSO) is a popular multidimensional optimization technique [6]. Strengths of the PSO are ease of implementation, high quality of solutions, computational efficiency and speed of convergence [7].

The coverage optimization strategies are implemented during deployment phase and coverage is calculated based on the placement of the sensors on the region of interest (ROI). There are mainly three strategies for solving coverage problems namely; force, grid and computational geometry based [8]. To determine the optimal position of the sensors force based methods use attraction and repulsion forces. While grid based methods use grid points for the same objective. Voronoi diagram and Delaunay triangulation from the computational geometry approach are used in WSN coverage optimization method. Hence, these strategies are employed in combination with PSO to achieve better results.

Different methods implemented under Virtual Force Based method are VF (Virtual Force), PSO, VFPSO (Virtual Force Directed Particle Swarm Optimization) & VFCPSO (Virtual Force Directed Co-evolutionary Particle Swarm Optimization). VFCPSO has better performance with respect to computation time and effectiveness than the VF, PSO and VFPSO methods [9].

Different methods implemented under Grid Based method are PSO, BPSO (Binary PSO), DBPSO (Discrete Binary PSO) and MDBPSO (Modified Discrete Binary PSO). MDBPSO provides placement of sensors to increase the coverage on sensor field also it is more useful, scalable, durable, maximum coverage and minimum network cost as compared to other methods [10].

Different methods implemented under Voronoi Diagram (sub type of Computational Geometry Based method) are WSNPSO<sub>vor</sub>, WSNPSO<sub>per</sub> and WSNPSO<sub>con</sub>. In a larger ROI, WSNPSO<sub>con</sub> manages to ensure maximum distance moved to be less than threshold value [11].

As the VORonoi based method (VOR); a sensor moves to its farthest Voronoi vertex when it detects a coverage hole [12]. This consumes more amount of energy as compared to Grid & Force Based sensor deployment method.

Hence, this paper discusses performance analysis of random, Grid Based MDBPSO (Modified Discrete Binary Particle Swarm Optimization), Force Based VFCPSO and Combination of Grid & Force Based Sensor Deployment Methods based on interval and packet size.

The Network simulator helps the developer to create and simulate new models on an arbitrary network by specifying both the behavior of the network nodes and the communication channels. It provides a virtual environment for an assortment of desirable features such as modeling a network based on a specific criteria and analyzing its performance under different scenarios [13]. Network Simulator 2 is used for simulation of the methods. Section 2 discusses Random Deployment. Section 3 elaborates Grid Based MDBPSO Deployment whereas Section 4 discusses Force Based VFCPSO Deployment; Section 5 explains Combination of Grid & Force Based Deployment and Section 6 discuss simulation results. Finally the concluding remarks are given in Section 7

**2. RANDOM DEPLOYMENT**

Many scenarios adopt random deployment for practical reasons such as deployment cost and time. But it does not guarantee full coverage because it is stochastic in nature, hence often resulting in accumulation of nodes at certain areas in the sensing field but leaving other areas deprived of nodes. There are big coverage holes as the network size grows. Uneven node topology may bring about unbalanced energy consumption and lead to a short system lifetime. These limitations motivate the establishment of a planning system that optimizes the sensor reorganization process to enhance the coverage after initial random deployment

**3. GRID BASED MDBPSO DEPLOYMENT**

Modified Discrete Binary PSO (MDBPSO) is implemented for improving the coverage while deploying the sensor network. MDBPSO operates in discrete problem space for the multi-valued problems [10].

In binary PSO model,  $V_{id}$  defines the probability of value of one  $X_{id}$ . Position of each particle defines in region of one and zero (0, 1) while  $V_{id}$  is defined as probability function so it is limited in the range of one and zero (0, 1). Therefore, the particle position can be update by using equation (3). In this the new position component has to be exchanged with a value of probability obtained by applying modified sigmoid transformation to the velocity component (see equation (2)). The value of  $v_{id}$  can be high, low or zero. If the value of  $V_{id}$  is high the particle's position is unfit therefore it causes the value of  $X_{id}$  to change from 0 to 1 or vice versa. If the value of  $v_{id}$  is low for  $X_{id}$  it decreases the probability of changes in the value of  $X_{id}$ . And the value of  $X_{id}$  is unchanged if the value of  $v_{id}$  is zero according to equation (3).

Velocity of each particle can be modified by the following equation [11]:

$$v_{id}(t+1) = (w * v_{id}(t)) + (c_1 * rand() * (p_{idbest} - X_{id}(t))) + (c_2 * rand() * (g_{idbest} - X_{id}(t))) \tag{1}$$

where  $d = 1, 2, \dots, N_d$

Where,  $c_1$  &  $c_2$  are weighting factor or learning coefficients. Usually  $c_1$  is equal to  $c_2$ , and they are in the range (1, 2).  $i$  denotes the particle and  $d$  denotes the dimension search space  $w$  is weighting function or learning coefficients, usually is a number in the range (0, 1),  $rand()$  is random function in the range of (0, 1),  $x(t)$  is current position of particle,  $p_{best}$  is best of particle and  $g_{best}$  is best of the group.

The final value for velocity of each particle is limited to avoid the divergence:  $V_{id} \in [-vmax, vmax]$ . Typically, this process is iterated for a certain number of time steps, or until some acceptable solution has been found by the method.

$$\begin{aligned} \text{Sig}(V_{id}) &= 1 / (1 + e^{-V_{id}}) \\ S'(V_{id}) &= 2 * |\text{Sig}(V_{id}) - 0.5| \end{aligned} \tag{2}$$

$$\begin{aligned} \text{If } rand < s'(V_{id}(t+1)) \text{ then} \\ X_{id}(t+1) &= \text{exchange}(X_{id}) \\ \text{else } X_{id}(t+1) &= (X_{id}) \end{aligned} \tag{3}$$

The modified sigmoid also maps the values of velocities from  $(-\infty$  to  $+\infty)$  to (0 to 1) this function can be used with the sign of velocity for the direction and helps the method to converge within finite number of iterations.

Following are the steps involved in implementation of MDBPSO based deployment of sensor nodes:

1. Assume the number of nodes is  $n$ .
2. Initialize the position and velocity vectors.
3. Assign random values to position vector and assign this position to personal best position vector of particle  $p$ .
4. Evaluate the fitness of particle  $p$  and assign this fitness to personal fitness of particle  $p$ .
5. Find the particle  $p$  with minimum fitness from  $P$  and assign its position vector to global best position vector global best position and its best fitness to global best fitness.
6. Apply velocity update equation to calculate new velocity.
7. If new velocity is greater than maximum velocity then use maximum velocity as new velocity.
8. Calculate sigmoid value & new position. Evaluate the fitness function of particle  $p$ .
9. If the new fitness is less than personal best then update the personal best fitness and position & find the best particle in particle vector  $P$ .
10. If the fitness of particle  $p$  is less than global best fitness then update the global best position vector and global best fitness.

11. If the global best fitness is zero that indicates that full coverage is occupied by sensors therefore stop the iterations.
12. Create  $n$  nodes and assign  $x$  and  $y$  coordinate values from global best position vector & then stop.

#### 4. FORCE BASED VFCPSO DEPLOYMENT

Here, VF method is combined with co-evolutionary particle swarm optimization (CPSO) for improving the performance of dynamic deployment optimization. The CPSO method is an improved PSO method inspired by the co-evolution of populations [14], which uses multiple swarms to optimize different components of the solution vectors [15]. The virtual force is introduced to direct the particles flight to the optimal solutions and enhance the performance of CPSO, i.e., under the guidance of virtual force, CPSO can converge more rapidly and accurately to the optimal results [9].

Following are the steps involved in implementation of VFCPSO based deployment of sensor nodes:

1. All the SNs are randomly scattered in the ROI while initializing.
2. Sensor detection areas should be overlapped in order to compensate for potential low detection probability in the area which is far from a SN.
3. The VF method is a self organizing method which considers that the objects; including SNs, obstacles & areas of preferential coverage which need greater certainty will exert virtual attractive & repulsive forces on each other.
4. The total force exerted on  $s_i$  can be expressed as

$$\vec{F}_i = \sum_{j=1, j \neq i}^k \vec{F}_{ij} + \sum_{m=1}^M \vec{F}_{iR_m} + \sum_{n=1}^N \vec{F}_{iA_n}$$

where  $F_{ij}$  is force exerted on sensor  $s_i$  by  $s_j$ ,  $F_{iA_m}$  be the force exerted on sensor  $s_i$  due to preferential coverage area  $A_m$ ,  $F_{iR_n}$  be the repulsive force on  $s_i$  due to obstacle  $R_n$ ,  $k$  is number of SNs,  $M$  is number of obstacles &  $N$  is number of preferential coverage areas

5. The new location of SN is calculated according to the orientation & magnitude of the total force exerted on it.

$$x_{new} = x_{old} + \frac{F_x}{F_y} \times MaxStep \times e^{\frac{-1}{F_{xy}}}$$

$$y_{new} = y_{old} + \frac{F_y}{F_x} \times MaxStep \times e^{\frac{-1}{F_{xy}}}$$

where, MaxStep is the predefined single maximum distance,  $F_x$ ,  $F_y$  are  $x$ - and  $y$ - coordinate forces respectively.

6. PSO is introduced in order to calculate velocity & position of the particle. Here, velocity of each particle is updated according to not only the historical optimal solutions, but also the virtual forces of SNs in VFPSO method.

$$v_{ij}(t+1) = w(t)v_{ij}(t) + c_1r_{1i}(t)(y_{ij}(t) - x_{ij}(t)) + c_2r_{2i}(t)(\widehat{y}(t) - x_{ij}(t)) + c_3r_{3i}(t)g_{ij}(t)$$

7. For improving searching ability of PSO in high dimensional problem, the search space can be partitioned into lower dimensional subspaces by splitting the solution vectors into smaller vectors [16]. This is co-evolutionary PSO (CPSO).
8. Instead of adopting one swarm to find the optimal  $n$ -dimensional vector, in CPSO, the vector is split into its components so that each swarm attempts to optimize a single component of the solution vector, essentially a 1-D optimization problem.
9. However, the function being optimized still requires an  $n$  dimensional vector to evaluate.
10. This context vector is constructed by taking the global best particle from each of the swarms and concatenating them to form such an  $n$ -dimensional vector.
11. The fitness function of all particles in swarm is calculated.

VFCPSO method has good global searching and regional convergence abilities in the procedure of optimization, and it can implement the dynamic deployment of hybrid WSNs with mobile sensor nodes and stationary sensors nodes rapidly, effectively and robustly.

**5. COMBINATION OF GRID & FORCE BASED DEPLOYMENT**

Here, concept of Force Based VFCPSO is combined with Grid Based MDBPSO for improving the performance of the dynamic deployment optimization.

Following are the steps involved in its implementation:

1. Assume the number of nodes is  $n$ .
2. Initialize the position and velocity vectors.
3. Assign random values to position vector and assign this position to personal best position vector of particle  $p$ .
4. Evaluate the fitness of particle  $p$  using Grid Based MDBPSO method.
5. Modify the fitness function of all particles in swarm using VFCPSO method.
6. Evaluate the position & velocity of the particle.
7. If the global best fitness is zero that indicates that full coverage is occupied by sensors therefore stop the iterations.
8. Create  $n$  nodes and assign  $x$  and  $y$  coordinate values from global best position vector & then stop.

**6. RESULTS& ANALYSIS**

This paper discusses performance analysis of random; grid based MDBPSO (Modified Discrete Binary Particle Swarm Optimization), Force Based VFCPSO and Combination of Grid & Force Based sensor deployment methods based on interval & packet size.

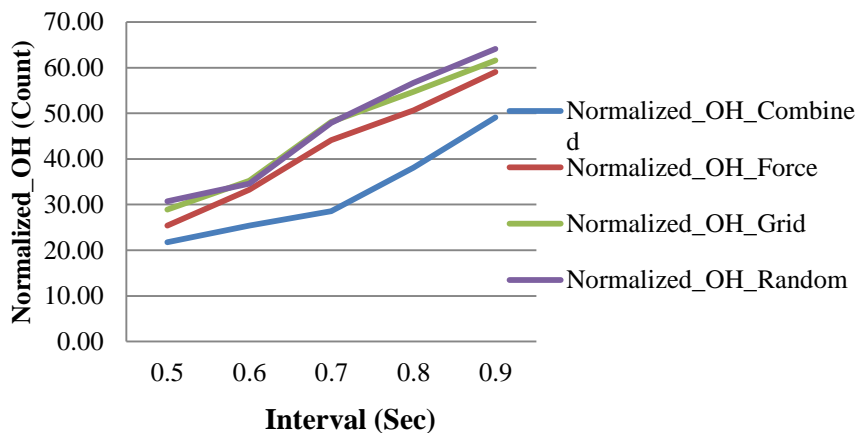


Figure 1. Comparison of 4 methods for interval vs normalized overheads

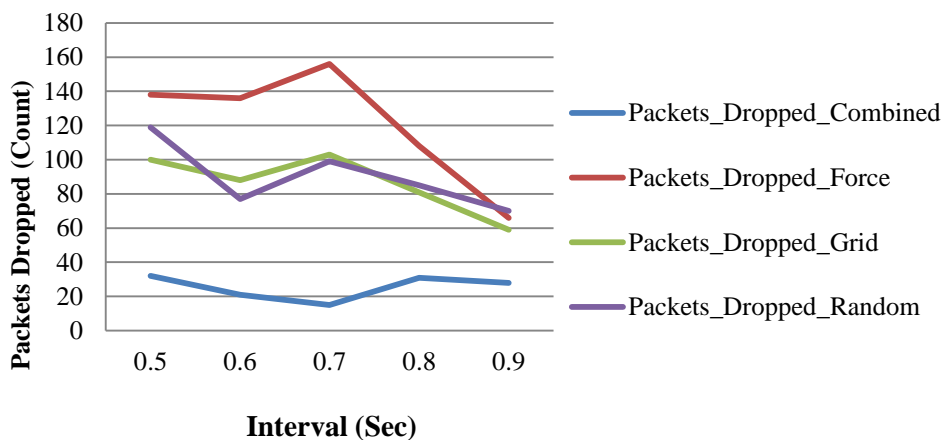


Figure 2. Comparison of 4 methods for interval vs packets dropped

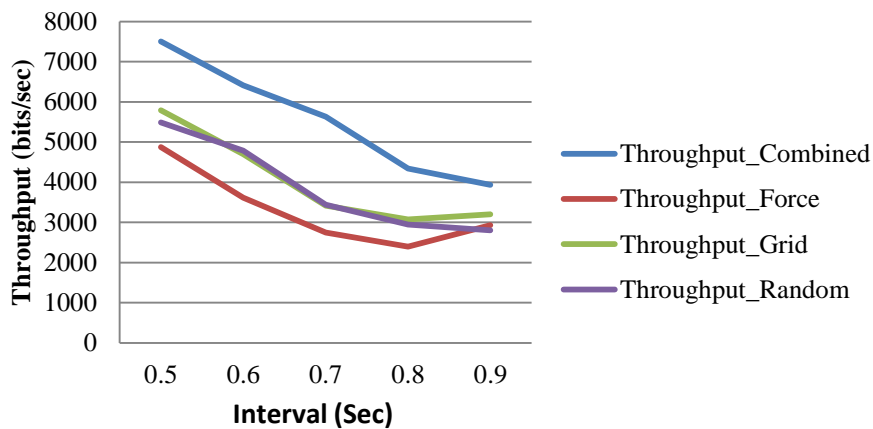


Figure 3. Comparison of 4 methods for interval vs throughput

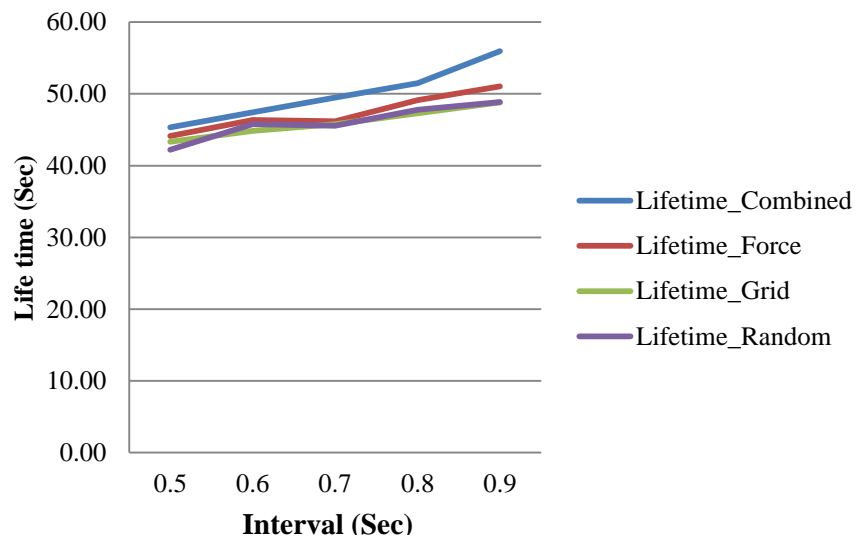


Figure 4. Comparison of 4 methods for interval vs lifetime

In Figures 1 to 4, Interval is varied against Normalized Overheads, Packets Dropped, Throughput & Lifetime and performance of all 4 methods is observed. From all above figures it can be concluded that Combination of Grid & Force Based Sensor Deployment Method performs better than Random; Grid Based MDBPSO (Modified Discrete Binary Particle Swarm Optimization), Force Based VFCSO methods.

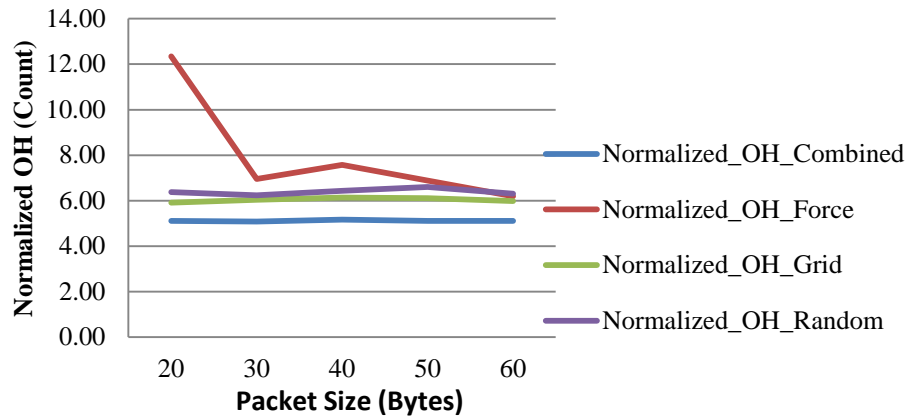


Figure 5. Comparison of 4 methods for packet size vs normalized overheads

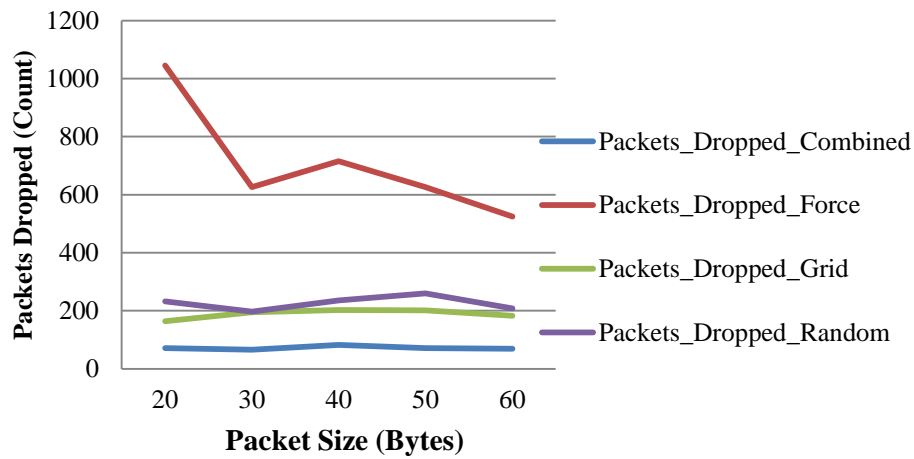


Figure 6. Comparison of 4 methods for packet size vs packets dropped

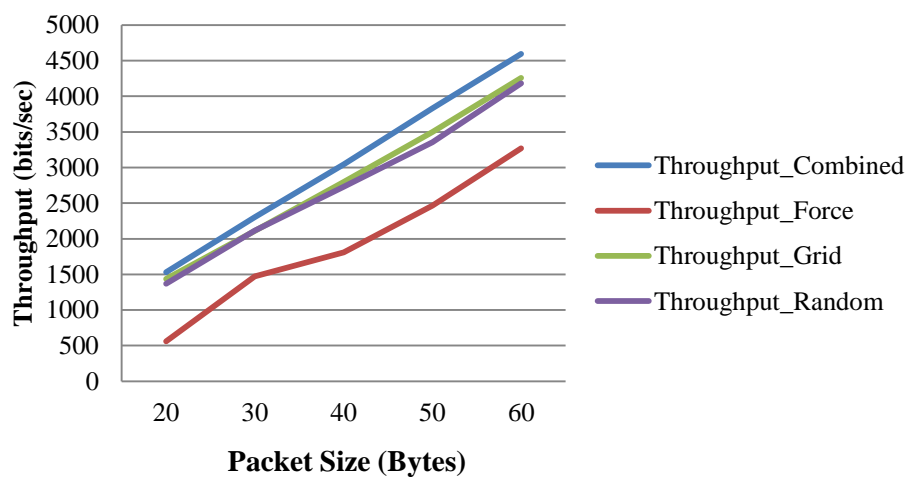


Figure 7. Comparison of 4 methods for packet size vs throughput

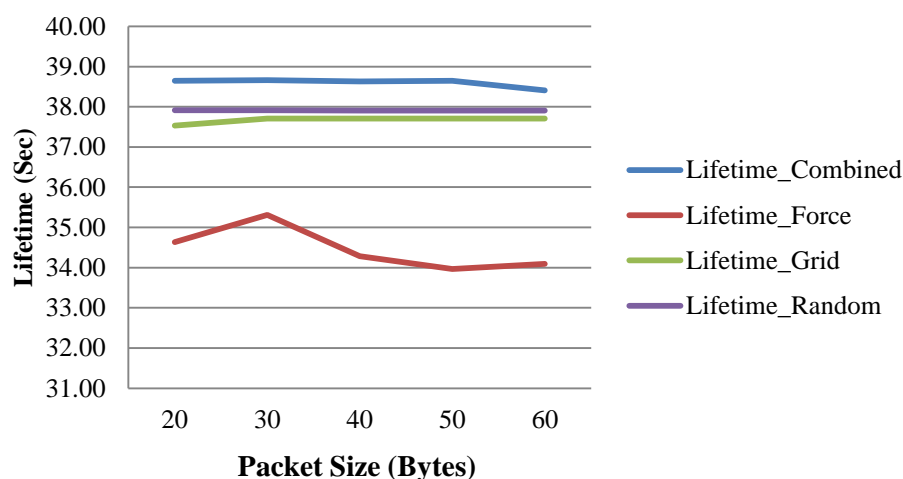


Figure 8. Comparison of 4 methods for packet size vs lifetime

In Figures 5 to 8, Packet Size is varied against Normalized Overheads, Packets Dropped, Throughput & Lifetime and performance of all 4 methods is observed. From all above figures it can be concluded that Combination of Grid & Force Based sensor deployment method performs better than Random; Grid Based MDBPSO (Modified Discrete Binary Particle Swarm Optimization), Force Based VFCPSO methods.

## 7. CONCLUSION

WSN has issues such as coverage, connectivity, network lifetime and scheduling & data aggregation. Connectivity and coverage problems are caused by the limited communication and sensing range. Coverage issue can be solved at the time of sensor deployment itself by strategically deploying sensor nodes. There are mainly three strategies for solving coverage problems namely; force, grid and computational geometry based. These strategies are employed in combination with PSO to achieve better results. Researchers have previously worked on these all techniques separately. But no one has done implementation of these techniques on common platform with same WSN parameters. In this paper, performance analysis of random; grid based MDBPSO (Modified Discrete Binary Particle Swarm Optimization), Force Based VFCPSO and Combination of Grid & Force Based sensor deployment methods based on interval and packet size and its effect is observed on parameters viz. normalized overhead, packets dropped, throughput and lifetime so as to check the robustness of each of them. From all above figures it can be concluded that Combination of Grid & Force Based Sensor Deployment method performs better than Random; Grid Based MDBPSO, Force Based VFCPSO methods.

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