POSITIONING OF RELAY STATIONS IN WIRELESS SENSOR NETWORKS

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF SCIENCE

ABSTRACT

Koganti, Nikhil, M.S., Department of Computer Science, College of Science and Mathematics, North Dakota State University, October 2011. Positioning of Relay Stations in Wireless Sensor Networks. Major Professor: Dr. Kendall Nygard.

A sensor is a device which can detect or measure a physical property and which records, indicates, or otherwise responds to the signal received. A wireless sensor in a network can communicate with the sensors located within its transmission range. In this paper, the capacity enhancement problem by adding a relay station to the sensor network was studied which can result in efficient and scalable design.

Major concerns of the wireless sensors addressed in this paper are reducing the number of hops a message needs to make from one sensor to a different sensor before it reaches the base station, restraining the number of relay stations necessary for covering the desired percentage of sensor nodes.

In this paper, the positions for the relay stations are first selected in a specific pattern such that with this initial distribution, every sensor is in reach of at least one relay station. Then priorities are given to the relay stations based on two different methods. The relay stations with low priorities are removed from the list of positions for a relay station. In this way the positions for the relay stations are eliminated until the percentage of number of sensors covered by relay stations falls beyond some number which is varied in the experiments done.

ACKNOWLEDGEMENTS

I would take this opportunity to thank my advisor, Dr. Kendall Nygard, who has given me valuable support, encouragement and advice without which this work would not have been completed. I am thankful to the members of the committee, Dr. Simone Ludwig, Dr. Saeed Salem and Dr. Chao You, for their support. I would also like to thank my parents for their valuable support and constant encouragement.

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1. INTRODUCTION

The use of sensors is increasing very rapidly in this era. There are different types of sensors and are intended for serving various purposes. Some common uses for a sensor are to measure, sense movements, transmit encrypted messages, receive messages transmitted by another sensors etc. The sensors can be used in groups spread in an area for serving variety of purposes. Recent years have witnessed an increased interest in the use of wireless sensor networks (WSNs) in numerous applications such as forest monitoring, disaster management, space exploration, factory automation, secure installation, border protection, and battlefield surveillance [4,5].

There are many problems such as low signal-to-noise-ratio, coverage holes that exist due to shadowing and non-light-of-sight connections, the access requirement of non-uniform distributed traffic in densely populated areas with the usage of sensors. Optimal node placement is a very challenging problem that has been proven to be NP-Hard for most of the formulations of sensor deployment [6–7].And to meet the growing demand and stringent design requirements for coverage extension, throughput and capacity enhancement, deploying relay stations has been considered as a promising solution to Point-to-Multi-Point (PMP) networks. A network operator always desires the most cost-effective solution with the minimal deployment expenditure to provide a satisfactory service. The RS location for sensor networks in the network planning stage is critical and will address fundamental impacts on the subsequent service provisioning scenario [1].

This paper proposes and describes four different heuristics that can be used to find positions for placing relay stations in a wireless sensor network. The main aim of these heuristics is to propose the positions for relay stations, so that using minimum number of relay stations one should be able to achieve desired amount of coverage for wireless sensors.

The relay stations are responsible for relaying data between the sensors and the base station. The relay stations considered in the study have sufficient power and are not directly connected through wire. The links between the relay stations and sensors are assumed relatively static and a deterministic TDMA/CDMA scheme can be utilized as the communication technique. This paper only considers the relay station placement problem. The application built will take the characteristics of the relay stations like its transmission range, the desired percentage of coverage for sensors by the relay stations and the positions of the sensors as the inputs and returns a list of positions for relay stations using four different methods.

The remainder of the paper is organized as follows. Section 2 describes the related work done in this area. In Section 3, the heuristics are described and the reasons for some of the decisions are also explained In Section 4, the results are shown in graphical format and the tables supporting the graphs are presented in the appendix. Section 5 concludes the paper and also talks about the future directions this research can take.

2. LITERATURE REVIEW

In [2], the authors mentioned that the technology of wireless networks can be helpful for various applications like environmental monitoring, infrastructure management, public safety, health care, home and office security, transportation, military surveillance etc. A sensor network is a group of sensors deployed together in a location to perform specific tasks. The sensors were primarily used to sense or detect or to track a target or monitor a specific location. As the technology of the sensors evolved there were several breakthroughs and achievements in this field enabling sensors to be useful in many more situations.

In [1], the authors addressed the task of Relay Station placement and relay time allocation in IEEE 802.16j Mobile Multi-hop Relay (MMR) networks. By incorporating advanced cooperative relaying technologies like Decode-Forward (D-F) and Compress-Forward (C-F), the authors aimed at finding the optimal location of a single relay station and the resource allocation for all the subscriber stations (sensors). The authors also conducted numerical analysis through some case studies and demonstrated the performance gain by using the approach proposed in the paper for relay placement and relay time allocation. The authors considered a practical deployment scenario where each subscriber station imposes some amount of traffic demand during a specific time window. In a metropolitan area the load on a particular subscriber station may vary based on the time of the day. The authors formulated the single relay station placement problem in multi subscriber station model in order to yield the optimal deployment and resource allocation for each single relay station for a given set of subscriber stations.

The major challenge in designing wireless sensor networks (WSNs) is the support of the functional, such as data latency, and the non-functional, such as data integrity, requirements while coping with the computation, energy and communication constraints [3]. Careful node placement can be a very effective optimization means for achieving the desired design goals. In [3] the authors reported the research on optimized node placement in wireless sensor networks. The authors categorized the placement strategies into static and dynamic depending on whether the optimization is performed at the time of deployment or while the network is operational, respectively. For many wireless sensor networks will consist of hundreds of nodes that operate on small batteries. Wireless sensor networks should be carefully managed in order to meet applications requirements while conserving energy. The authors aim is to help application designers identify alternative solutions and select appropriate strategies.

In [8] the authors studied the capacity enhancement problem by way of Relay Stations placement to achieve an efficient and scalable design in broadband wireless access networks. The authors developed an optimization framework to maximize the capacity as well as to meet the minimal traffic demand by each Subscriber Station. The problem of joint relay station placement and bandwidth allocation is formulated into a mixed integer nonlinear program. To avoid exponential computation time, the authors proposed a heuristic to efficiently solve the formulated problem. The authors conducted numerical analysis through case studies and demonstrated the performance gain of cooperative relaying and the comparison between the proposed algorithms against the optimal solutions. With the relay stations, the quality of wireless channels can be significantly improved not only by replacing one long distance low-rate link with multiple short-distance high rate links, but also due to the ability of circumventing any obstacles between Subscriber Stations and Base Station that may impair the channel quality.

In [9], the impact of relay station placement in IEEE 802.16j network performance is analyzed. A throughput maximization relay station placement problem is mathematically formulated as a binary integer programming problem. The authors proposed an efficient near-optimal placement solution to find the sub-optimal solution to the problem with huge input size. The throughput performance shows that with the strategy the authors proposed, the network capacity can be tremendously enhanced.

3. PROBLEM DEFINITION AND SOLUTION PROPOSED

3.1. Problem Definition

There are many problems with wireless sensor networks such as low signal-to-noise-ratio, coverage holes that exist due to shadowing and non-light-of-sight connections, the access requirement of non-uniform distributed traffic in densely populated areas with the usage of sensors. To meet the growing demand and stringent design requirements for coverage extension, throughput and capacity enhancement, deploying relay stations has been considered as a promising solution. Careful sensor placement can also result in greater efficiencies but it is not possible in all scenarios. The main problem considered in this paper is to find the optimal positions for relay stations in a wireless sensor network where the sensors are already deployed.

3.2. Initial Pattern for Relay Stations

For an area with sensors already existing in it the initial pattern chosen for the relay stations is shown in the Figure 3.2.1

The input taken by the program which gives the initial positions for the relay stations is the coordinates of the sensor networks. From the coordinates of the sensor nodes the top most, left most, right most, bottom most coordinates for the sensor nodes are calculated. By using these points the rectangle (the whole figure) shown in the Figure 3.2.1 can be formed.

After the rectangle is formed it is then divided into regular hexagonal grids as shown in the figure shown below and the length of sides of the hexagons is chosen as the transmission range of the relay station divided by square root of 3. The reason for the length of the side will be explained in Section 3.3.

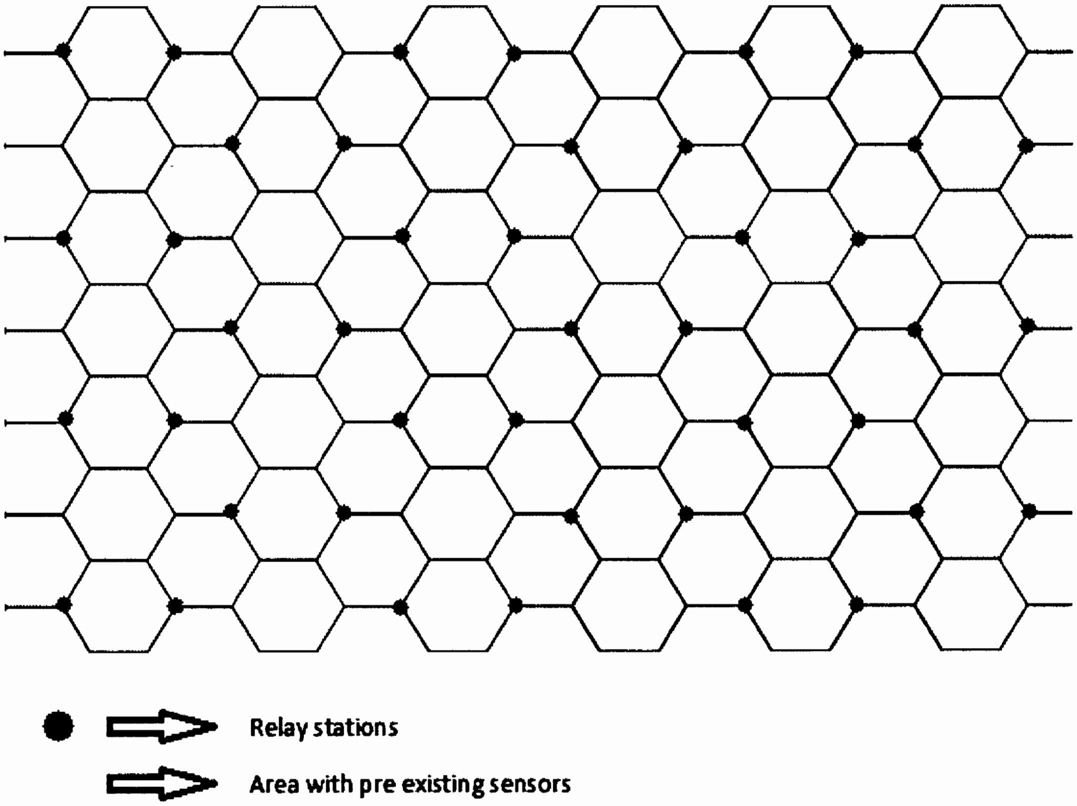


Figure 3.2.1 Initial Patterns of Relay Stations

3.3. Supporting the Pattern

With the pattern chosen almost every hexagon excluding the ones on borders have two relay stations on its corners except for the ones in green color in Figure 3.3.1.Since the length of the sides of the hexagon is designed such that the transmission range of the relay station of the relay station is the circle passing through the adjacent relay stations, it is obvious that all the hexagons except the ones in green are covered by the initial distribution of the relay stations.

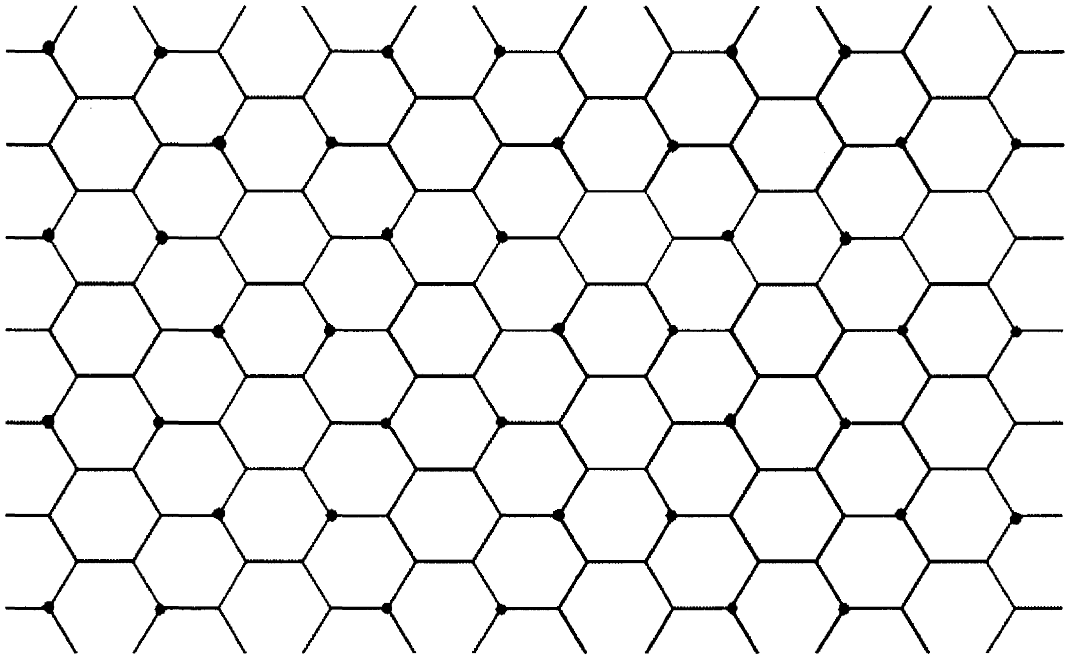


Figure 3.3.1 Supporting the Pattern

It can be proved that the green triangle shown in Figure 3.3.1is an equilateral triangle when the hexagons are regular. The red spots in Figure 3.3.1 are the initial positions for the relay stations.

The transmission range of the relay station positioned at point x is a circle passing through y and having point x as its center it will also pass through the point z. z is the center point of the hexagon it is present in. Similarly the transmission range of the other relay stations shown in Figure 3.3.2 passes through the point z as shown in Figure 3.3.3. Therefore it can be proved that all the area shown in Figure 3.2.1 including the green hexagons is covered completely with the initial distribution of the relay stations.

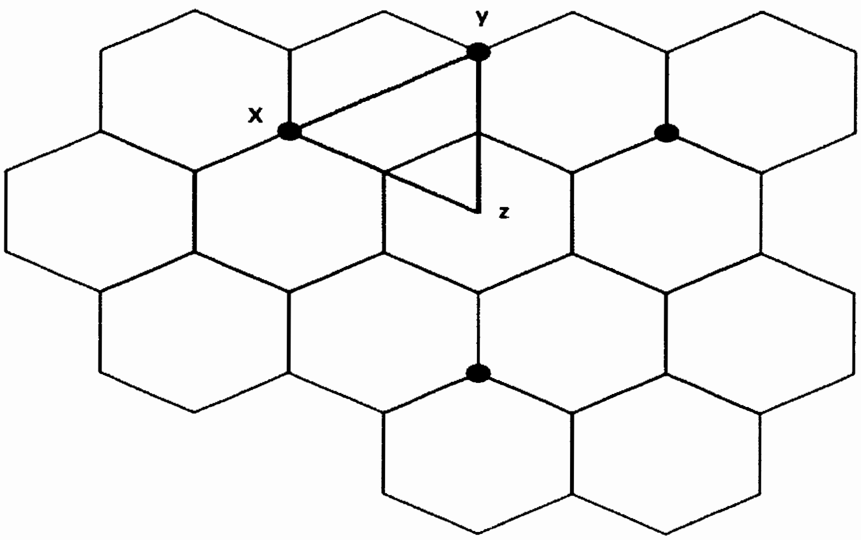


Figure 3.3.2 Equilateral Triangle

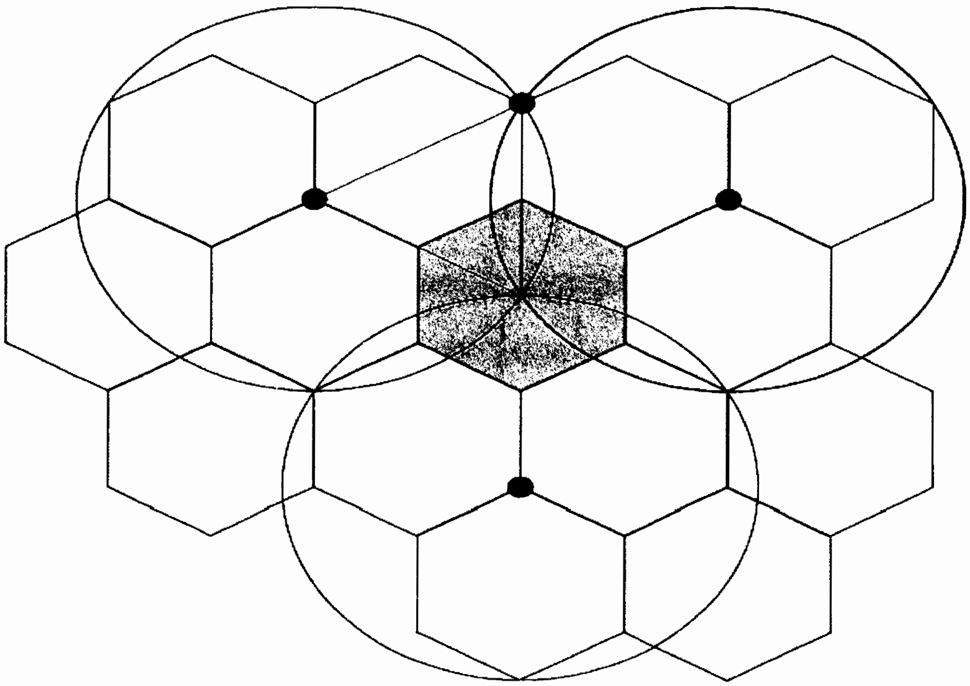


Figure 3.3.3 Proof for All Sensors Covered with Initial Pattern

3.4. Algorithms for Eliminating Relay Stations

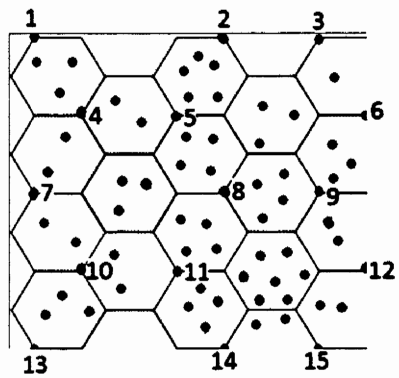
These algorithms are basically giving priorities to the relay stations from the initial pattern and eliminating each relay station at a time until the percentage of the sensor nodes covered falls beyond a desired percentage.

3.4.1. Number of sensor nodes covered by number of adjacent relay stations method

In this method the number of sensor nodes covered by each relay station is counted. And then the number of adjacent relay stations for each relay station is also counted. The relay station is adjacent to a relay station if it is on the circle of its transmission range. For example, in Figure 3.4.1 for relay station number 4 adjacent relay stations are 1, 5 and 7. Now the number of sensors covered by each relay station is divided by the number of adjacent relay stations and that is the priority number given to that relay station. The relay station with least priority number is eliminated first and the percentage of sensors covered is calculated and this process continues until the percentage falls beyond a desired coverage.

In the figure 3.4.1 the red dots are the initial positions for the relay stations and the black dots are the sensors. The number of sensors covered by each relays station is also calculated and shown in the figure.

The 3.4.1 tabulates the total number of sensor nodes covered by each relay station shown in Figure 3.4.1 and also tabulates number of adjacent relay stations for each relay station. In the fourth column the numbers shown are calculated by dividing the number in 2^{nd} row by the number in the 3^{rd} row and this is the priority number used in eliminating the positions for relay stations.



RS# - # of SS	RS# - # of SS
1 - 3	9 - 10
2 - 5	10 - 7
3 - 1	11 - 10
4 - 7	12 - 4
5 - 11	13 - 3
6 - 4	14 - 6
7 - 4	15 - 4
8 - 12	

RS# ⇨ Relay station number

# of SS ⇨ Number of sensors in the transmission range of this relay station

Figure 3.4.1 Example for Number of Sensors Covered by Each RS

3.4.1.1. Reason behind choosing this priority number

If a relay station has lot of sensors existing in its transmission range then it is evident that the relay station has a greater significance than other relay stations covering lesser number of sensors. So more number of sensors covered by a relay station indicates its importance and hence this number is in the numerator of the priority number.

Let us consider relay station number 1 and relay station number 4 from the Figure 3.4.1, relay station number 4 has three adjacent relay stations whereas relay station number 1 has only 1 adjacent relay station. Even after eliminating relay station number 4, relay stations 1, 4 and 7 can cover the area which was covered by 4. But if relay station number 1 is removed there is only one relay station that is there to cover the region relay station number 1 was previously covering. So the more number of adjacent relay stations lesser is its importance. And hence this number is in the denominator for calculating the priority number. The calculation of the priority number for the scenario in the Figure 3.4.1 is shown in the table 3.4.1. Figure 3.4.2 shows the flowchart for this method.

Table 3.4.1 Example for Priority Number Calculation

RS#	# of SN's	# of RS's surrounding	# of RS / # of RS's
1	3	1	3
2	5	2	2.5
3	1	2	0.5
4	7	3	2.3
5	11	3	3.6
6	4	2	2
7	4	2	2
8	12	3	4
9	10	3	3.3
10	7	3	2.3
11	10	3	3.3
12	4	2	2
13	3	1	3
14	6	2	3
15	4	2	2

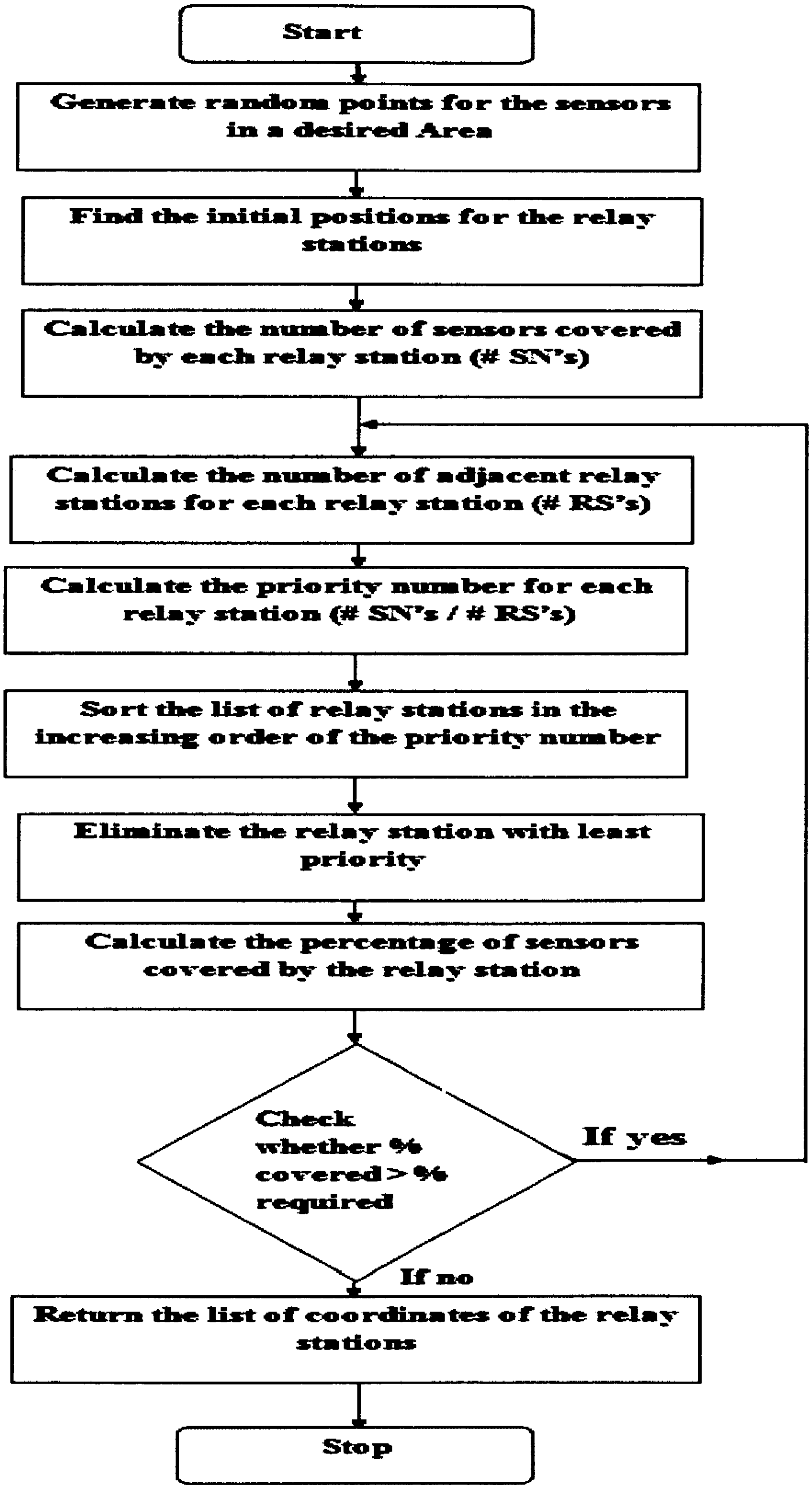


Figure 3.4.2 Flowchart for Adjacent Relay Stations Method

3.4.2. Number of sensors isolated method

The following Figure 3.4.3 demonstrates the process flow for number of isolated relay stations method.

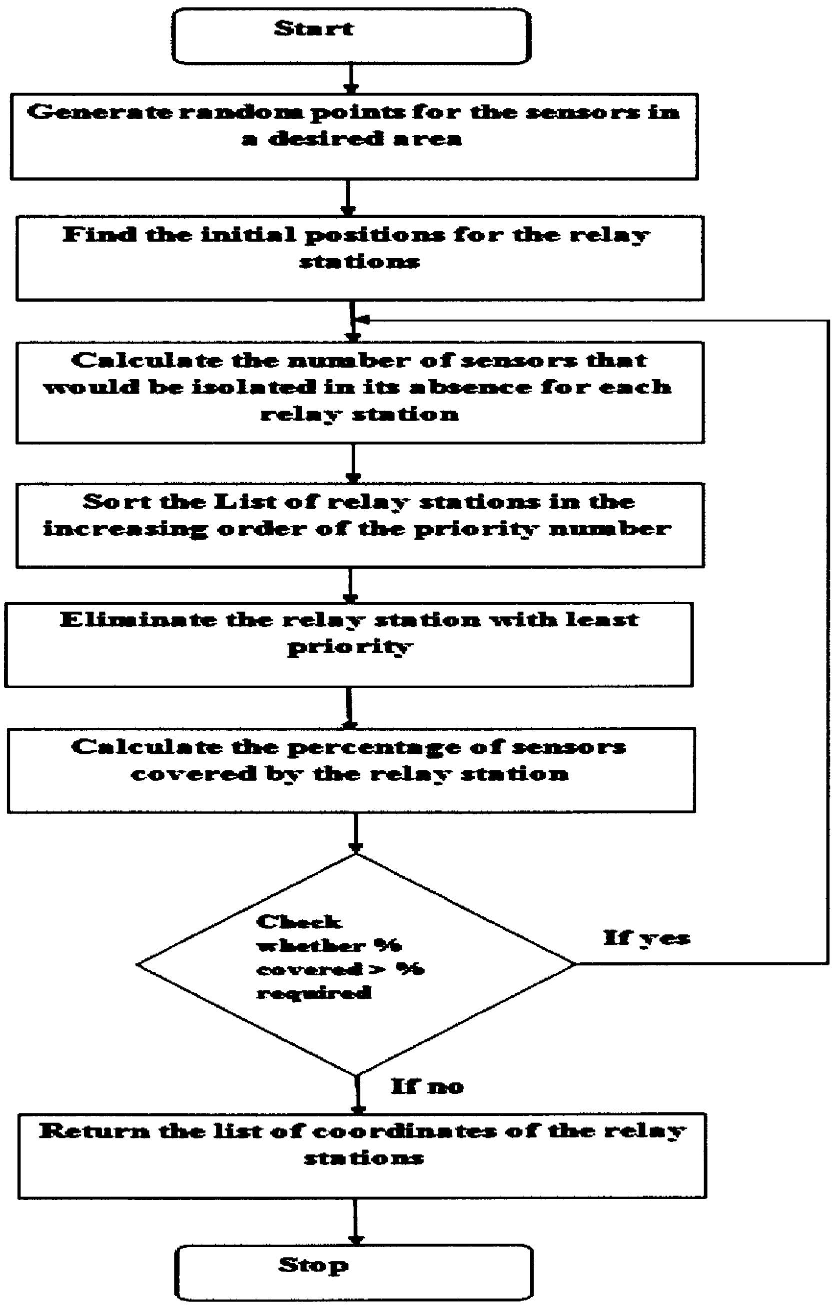


Figure 3.4.3 Flowchart for Number of Sensors Isolated Method

In this method the priority to a relay station is given based on the number of relay stations that would be isolated in the absence of itself. Isolation in this context means that the sensor will not be in reach of any other relay station. So the number of sensors that would be isolated in the absence of a relay station will be the priority number associated with the relay station and the relay station which has the least number of sensors that will be isolated in its absence will be eliminated first and then the priority numbers for each relay station are calculated again.

After eliminating each relay station the priority numbers are recalculated. It has been observed that recalculating the priority number after eliminating each relay station was resulting in lesser number of relay stations required to achieve similar percentage of coverage. And that is the reason for recalculating the priorities after eliminating each relay station.

3.4.3. The combination of first two algorithms

This method also uses the same approach for the initial positions. After finding the initial positions, the two different priorities are assigned to the relay station one calculated using the first method mentioned in Section3.4.1 and the other calculated using the second method mentioned inSection3.4.2. Then the final priority is calculated by multiplying the two priority numbers calculated by the first two methods. If one of the two initial priority numbers is a zero then it is replaced by a 1 before the two are multiplied to get the final priority number.

Then the relay station with the least priority is eliminated and then the priorities for each relay station is recalculated and the one with least priority gets eliminated, and this process repeats until we the desired percentage of coverage of sensors was acquired. And the result obtained will be the positions for the relay stations suggested by using this method.

3.4.4. Normalized combination of first two algorithms

This algorithm also depends on the results of the first two algorithms. The priority numbers for the relay stations obtained by the first two algorithms are normalized. And then let us assume that 'x' is the priority number of the first algorithm and 'y' is the priority number of the second algorithm. Now we introduce a variable lambda (λ) which varies between inclusive 0 and 1. The results obtained from the first two algorithms are combined using the formulae $\lambda*x + (1- \lambda)*y$. And using the number obtained from this expression we eliminate the relay station with least priority and then the priority for each relay station is recalculated and this process repeats. The value of λ is varied between 0 and 1 and a series of experiments are conducted to find out at which value of λ we are getting maximum efficiency.

4. RESULTS

The different parameters for conducting the experiments are number of sensors, transmission range of relay station, desired percentage of coverage, area in which the sensors are randomly distributed, lambda. In the following experiments for each set of parameters the number of relay stations required for that situation is calculated and after gathering all the twenty results the variance and standard deviations are calculated. Then one of the parameters is varied and then the mean, variance and standard deviations are calculated and this process repeated until we vary the parameter ten times. After that another parameter is chosen and the results are calculated by varying the new parameter ten times. The results gathered are by keeping all the parameters constant and varying one parameter at a time in equal intervals. The tables supporting the graphs are shown in the appendix.

4.1. Experiment One

In this experiment number of sensors is varied from 100 through 1000 in the intervals of 100, the values for other parameters are kept constant. The constant values for the parameters are, transmission range of relay station = 10 miles, percentage of coverage required = 75, bottom left most point of the area chosen = (0, 0) top right most point of the area chosen = (100,100), and lambda = 0.

Figure 4.1shows the variations in the number of relay stations required when the number of sensors distributed in the area is varied with lambda = 0. Table 4.1shows the results observed in all the experiments and Figure 4.2 shows the box plot for the standard deviations for the results in this experiment.

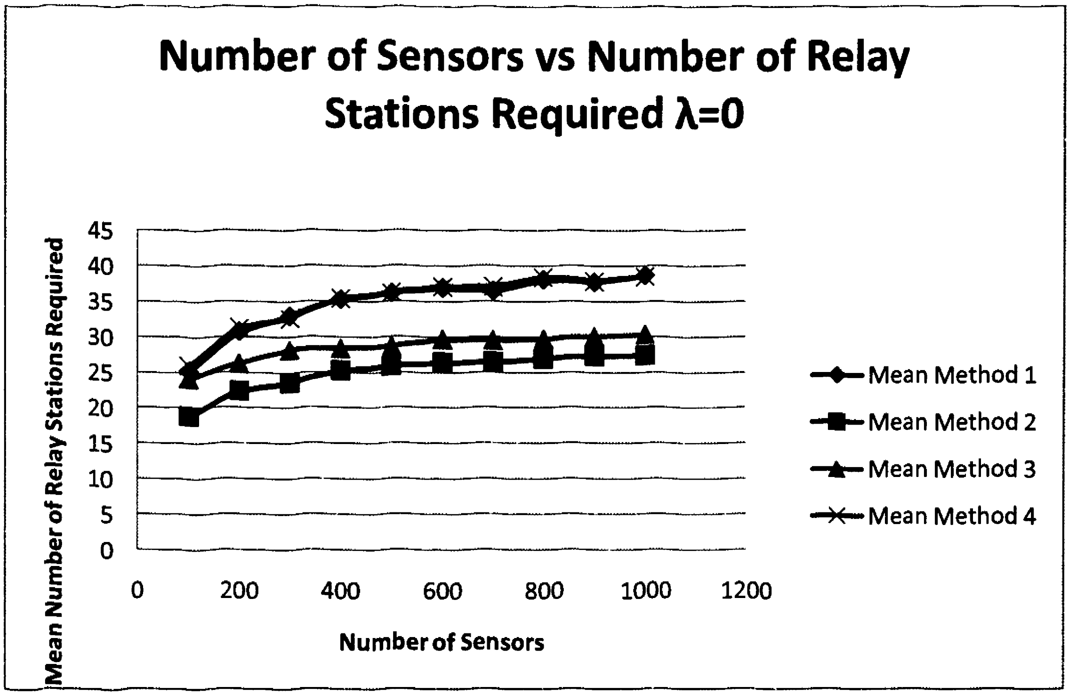


Figure 4.1 Experiment One

Table 4.1 Standard Deviation for Experiment One

Number of Sensors	Method 1	Method 2	Method 3	Method 4
100	2.06	1.32	1.55	2.58
200	2	1.38	1.51	2.38
300	1.86	1.11	1.35	2.1
400	2.17	1.02	1.01	2.39
500	1.64	0.85	1.11	1.56
600	1.92	0.96	0.96	1.85
700	1.95	0.96	1.16	1.94
800	2.33	0.7	0.9	2.19
900	2.1	0.76	1.22	1.74
1000	1.65	0.79	1	1.8

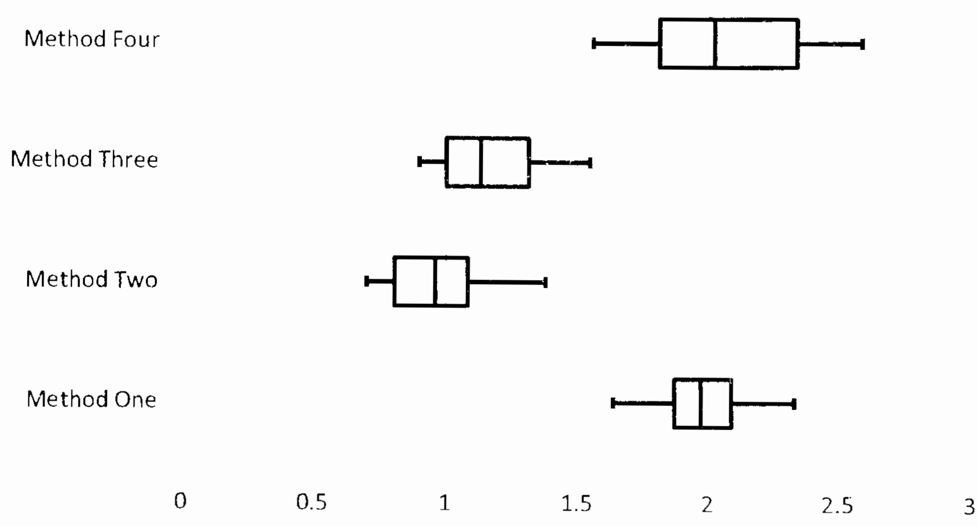


Figure 4.2 Standard Deviation Box and Whisker Plot for Experiment One

4.2. Experiment Two

In this experiment number of sensors is varied from 100 through 1000 in the intervals of 100, the values for other parameters are kept constant. The constant values for the parameters are, transmission range of relay station = 10 miles, percentage of coverage required = 75 % of all the sensors, bottom left most point of the area chosen = (0, 0) top right most point of the area chosen = (100,100), and lambda = 1.

Figure 4.3shows the variations in the number of relay stations required when the number of sensors distributed in the area is varied with lambda =1. Table 4.2 shows the results observed in all the experiments and Figure 4.4 shows the box plot for the standard deviations for the results in this experiment. The results observed in Experiment Two and Experiment Three are discussed in the Section 4.4.

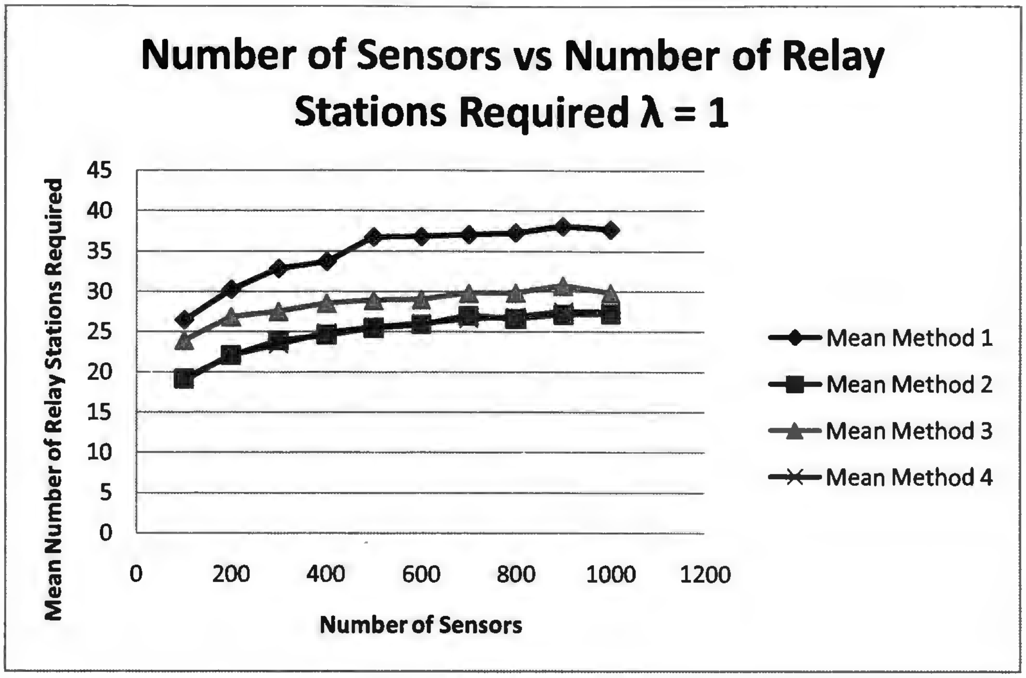


Figure 4.3 Experiment Two

Table 4.2 Standard Deviation for Experiment Two

Number of Sensors	Method 1	Method 2	Method 3	Method 4
100	2.06	1.38	1.74	1.84
200	2.68	1.2	1.62	1.33
300	2	0.88	1.02	0.73
400	2.14	1.15	1.46	1.01
500	2.32	1.02	1.13	0.73
600	2.11	0.62	1.09	0.8
700	1.8	0.83	1.28	0.73
800	1.61	0.72	1.23	0.79
900	1.75	0.67	0.69	0.66
1000	1.95	0.76	1.01	0.86

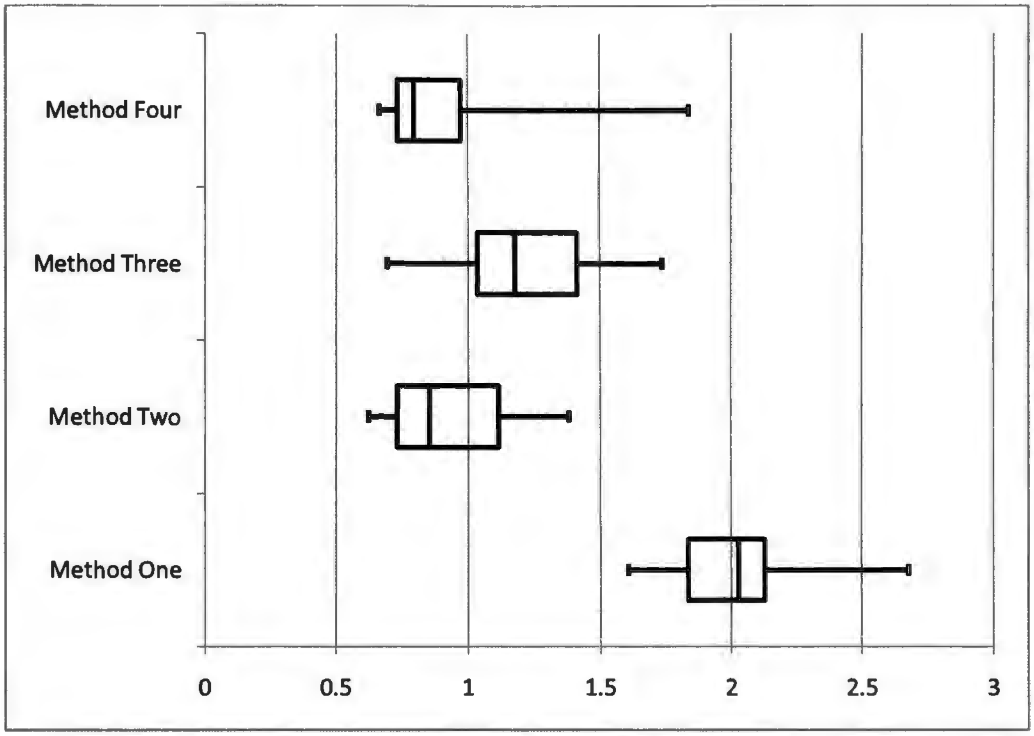


Figure 4.4 Standard Deviation Box and Whisker Plot for Experiment Two

4.3. Discussion of Sections 4.1 and 4.2

It can be observed from the graph that the number of relay stations required is increasing and the number of sensors is increasing in all the four methods (number of sensors / number of relay stations surrounding method, number of sensors isolated method, combined method, improvised combined method) in both experiments (Figures 4.1 and 4.2). The number of relay stations required by method one is very near to the number of relay stations required by using method four in Experiment One i.e., when $\lambda = 0$, whereas in experiment number 4.2 the results obtained by method four are very close to the results obtained by method two. It can also be observed that the variances and standard deviation are a little high with lower number of sensors.

4.4. Experiment Three

In this experiment transmission range of relay station is varied from 5 through 14 miles in the intervals of 1, the values for other parameters are kept constant. The constant values for the parameters are, number of sensors =500, percentage of coverage required = 75 % of all the sensors, bottom left most point of the area chosen = (0, 0) top right most point of the area chosen = (100,100), and lambda = 0.

Figure 4.5 shows the variations in the number of relay stations required when the transmission range of the relay stations is varied with lambda =0. Table 4.3 shows the results observed in all the experiments and Figure 4.6 shows the box plot for the standard deviations for the results in this experiment.

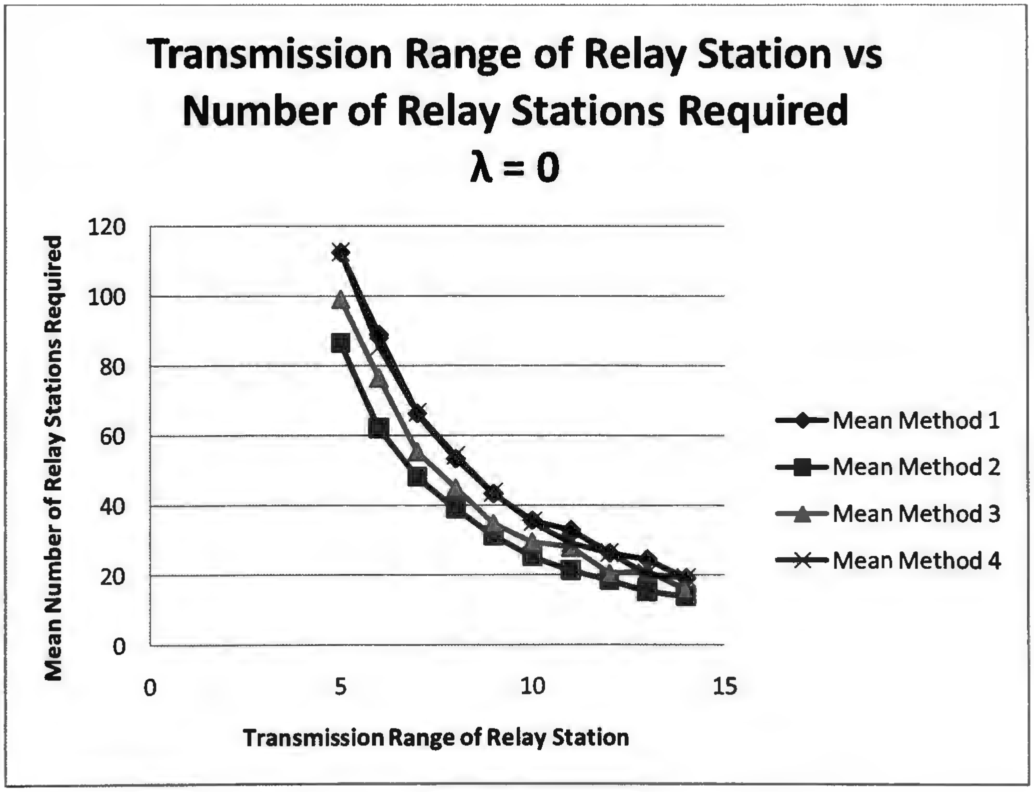


Figure 4.5 Experiment Three

Table 4.3 Standard Deviation for Experiment Three

Transmission Range of Relay station	Method 1	Method 2	Method 3	Method 4
5	4.49	2.83	2.68	4.93
6	3.99	1.75	2.35	4.01
7	2.88	1.01	1.2	3.31
8	3.49	1	1.28	3.55
9	2.39	1.34	1.16	2.51
10	2.08	0.9	0.92	2.17
11	1.62	0.72	1.09	1.93
12	1.22	0.91	1.07	1.42
13	1.2	0.58	0.76	1.11
14	1.49	0.73	0.94	1.69

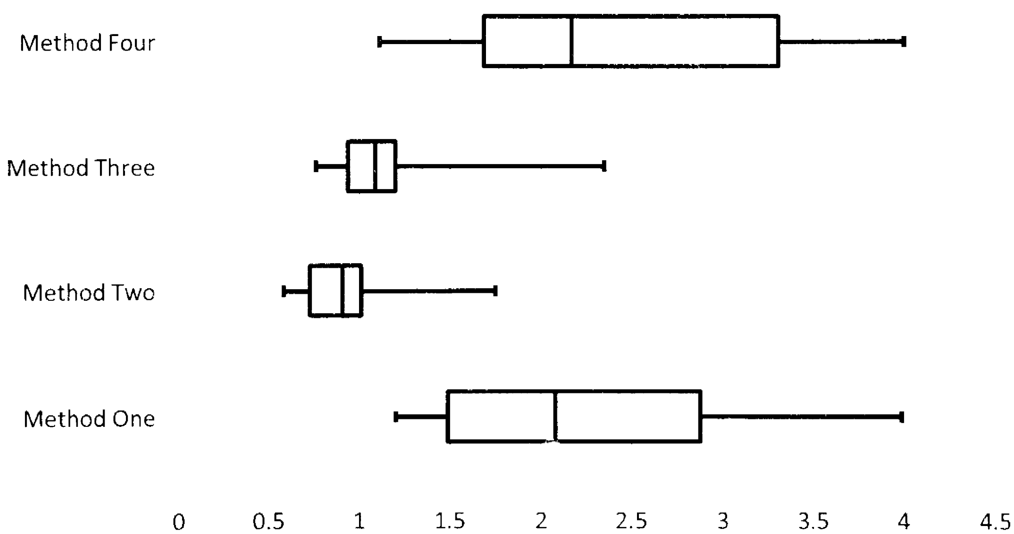


Figure 4.6 Standard Deviation Box and Whisker Plot for Experiment Three

4.5. Experiment Four

In this experiment transmission range of relay station is varied from 5 through 14 miles in the intervals of 1, the values for other parameters are kept constant. The constant values for the parameters are, number of sensors =500, percentage of coverage required = 75 % of all the sensors, bottom left most point of the area chosen = (0, 0) top right most point of the area chosen = (100,100), and lambda = 1.

Figure 4.7 shows the variations in the number of relay stations required when the transmission range of the relay stations is varied with lambda =1. Table 4.4 shows the results observed in all the experiments and Figure 4.8 shows the box plot for the standard deviations for the results in this experiment.

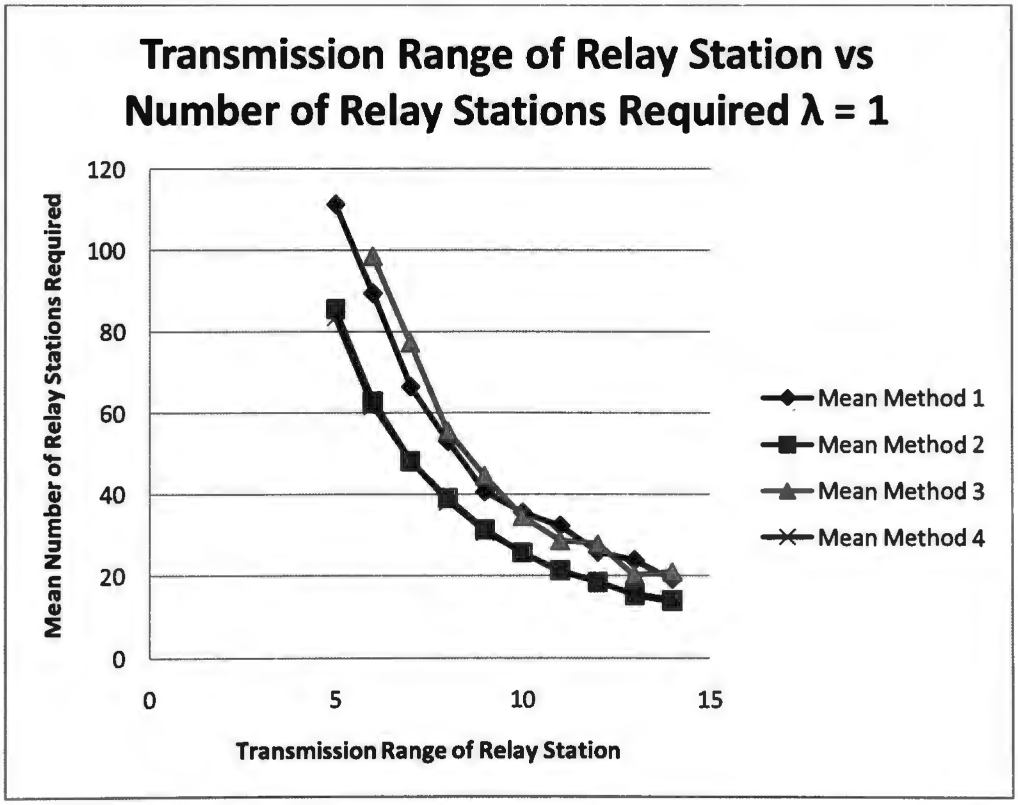


Figure 4.7 Experiment Four

4.4 Standard Deviation for Experiment Four

Transmission Range of Relay station	Method 1	Method 2	Method 3	Method 4
5	4.67	2.65	2.55	2.22
6	5.24	1.42	2.49	1.76
7	4.09	1.38	1.2	1.43
8	2.66	1.37	1.59	0.95
9	2.03	1	1.06	1.07
10	1.85	0.9	0.96	0.94
11	1.34	0.65	1.07	0.58
12	1.63	0.91	0.88	0.8
13	1.28	0.57	0.7	0.66
14	1.86	0.73	0.97	0.65

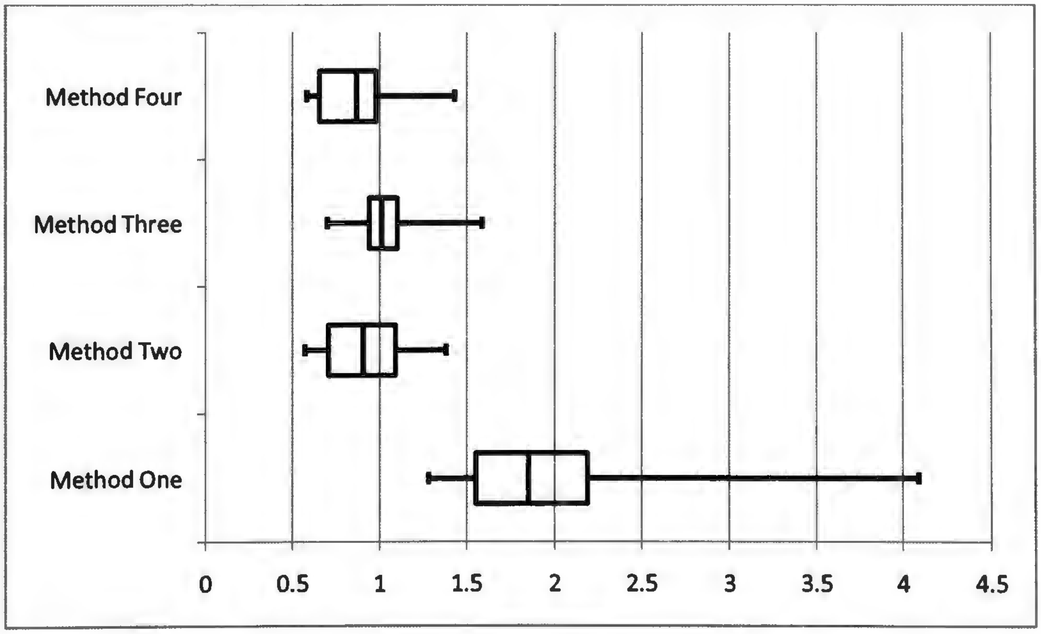


Figure 4.8 Standard Deviation Box and Whisker Plot for Experiment Four

4.6. Discussion of Sections 4.4 and 4.5

It is easy to predict that, as we increase the transmission range of the relay station keeping all other parameters constant the number of relay stations required will be required. And the results show in Figures 4.3 and 4.4 also suggest the same. The λ rule (results of method one are close to results of method four when $\lambda = 0$ and results of method two are close to results of method four when $\lambda = 1$) applies in these two experiments also. And as the graphs are suggesting the variances and the standard deviations are larger with lower transmission ranges of relay stations and smaller with less transmission ranges.

4.7. Experiment Five

In this experiment top right most point of the area chosen is varied and its values for each time are (50, 75),(75, 75), (100, 75), (125, 75), (150, 75), (175, 75), (200, 75), (225, 75), (250, 75), (275, 75) and all other parameters are kept constant at number of sensors = 500, transmission range of relay station = 10 miles, percentage of sensors covered = 75 % of all the sensors, bottom left most point of the area chosen = (0, 0), lambda = 0.

Figure 4.9 shows the variations in the number of relay stations required when the maximum x coordinate of the area is varied with lambda = 0. Table 4.5 shows the results observed in all the experiments and Figure 4.10 shows the box plot for the standard deviations for the results in this experiment. The results observed in Experiment Five and Experiment Six are discussed in the Section 4.9.

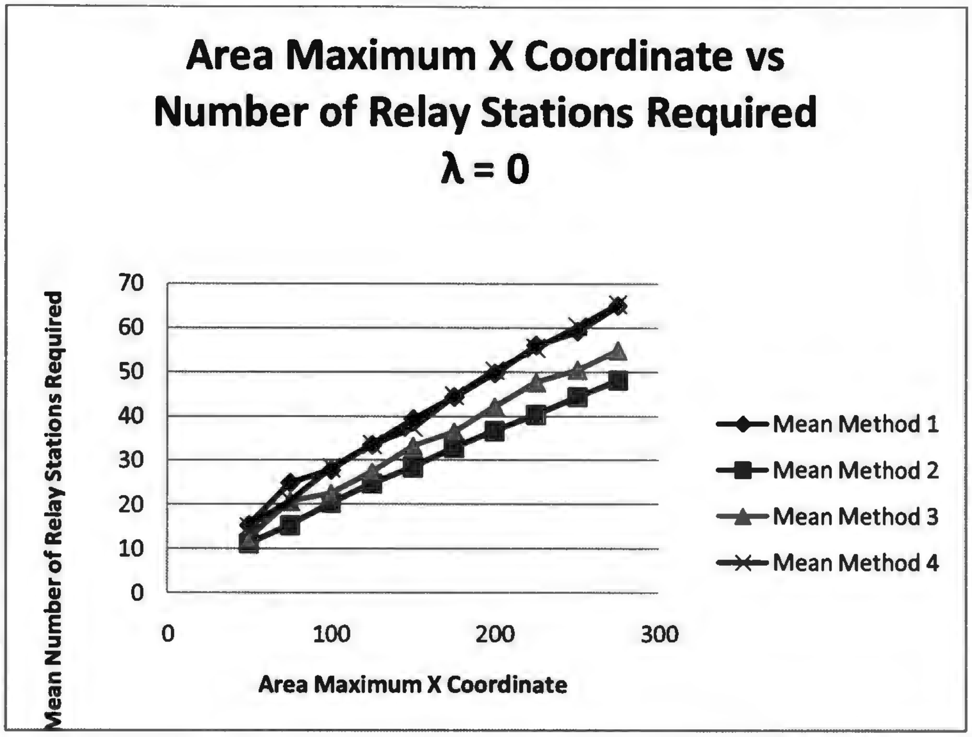


Figure 4.9 Experiment Five

Table 4.5 Standard Deviation for Experiment Five

Area X Coordinate	Method 1	Method 2	Method 3	Method 4
50	1.33	0.43	0.92	1.18
75	1.45	0.55	0.72	1.57
100	2.09	0.95	1.16	1.75
125	2.39	0.95	1.05	2.17
150	2.56	0.91	1.72	2.19
175	1.95	1.08	1.71	2.08
200	2.31	1.15	1.44	2.54
225	2.57	1.34	1.71	2.07
250	3.12	1.64	2.06	3.31
275	2.17	1.77	1.84	2.89

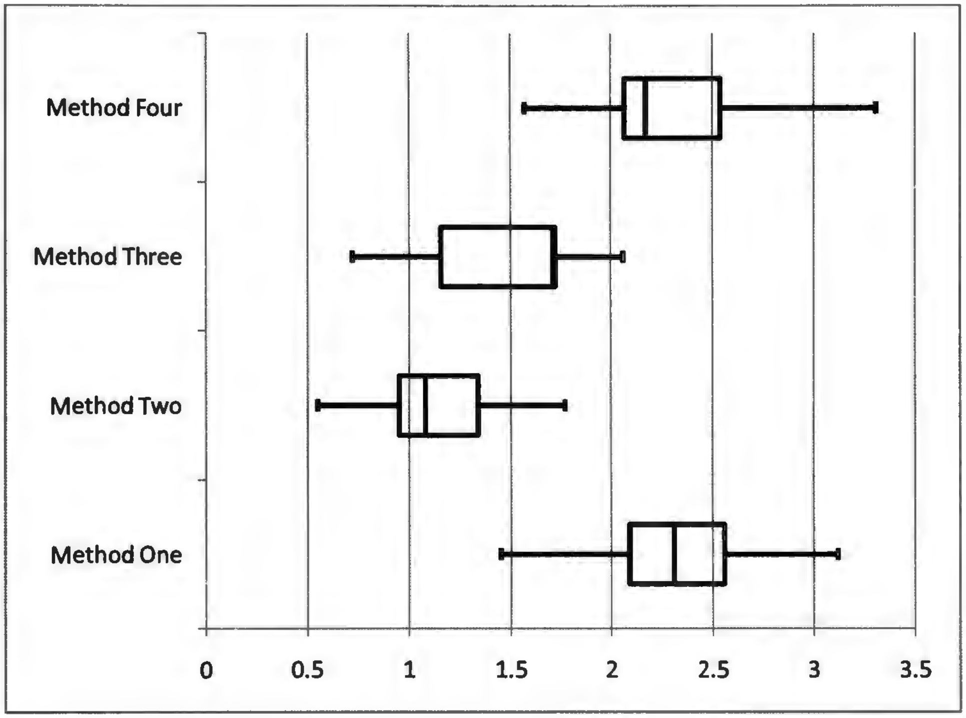


Figure 4.10 Standard Deviation Box and Whisker Plot for Experiment Five

4.8. Experiment Six

In this experiment top right most point of the area chosen is varied and its values for each time are (50, 75), (75, 75), (100, 75), (125, 75), (150, 75), (175, 75), (200, 75), (225, 75), (250, 75), (275, 75) and all other parameters are kept constant. Number of sensors = 500, transmission range of relay station = 10 miles, percentage of sensors covered = 75 % of all the sensors, bottom left most point of the area chosen = (0, 0), lambda = 1.

Figure 4.11 shows the variations in the number of relay stations required when the maximum x coordinate of the area is varied with lambda = 1. Table 4.6 shows the results observed in all the experiments and Figure 4.12 shows the box plot for the standard deviations for the results in this experiment.

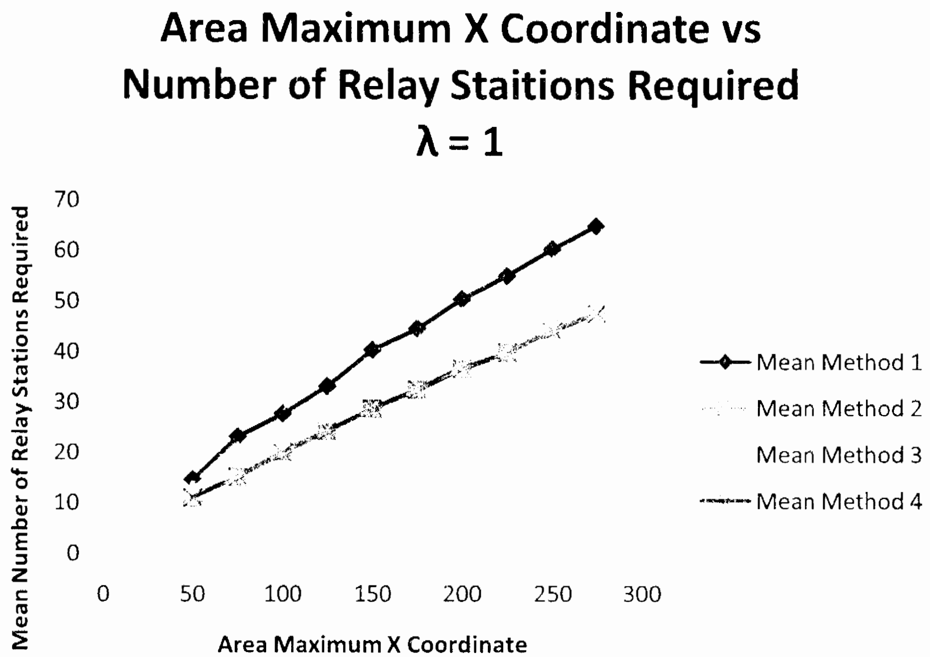


Figure 4.11 Experiment Six

Table 4.6 Standard Deviation for Experiment Six

Area X Coordinate	Method 1	Method 2	Method 3	Method 4
50	1.24	0.58	0.66	0.54
75	1.59	0.58	1.36	0.43
100	1.49	0.81	1.32	0.76
125	2.56	0.76	1.56	0.76
150	2.02	0.96	1.8	1.08
175	2.06	0.91	1.65	1.28
200	2.66	1.24	1.49	1.12
225	3.58	1.72	2	1.14
250	3.7	1.68	1.68	1.28
275	2.77	1.9	1.93	1.74

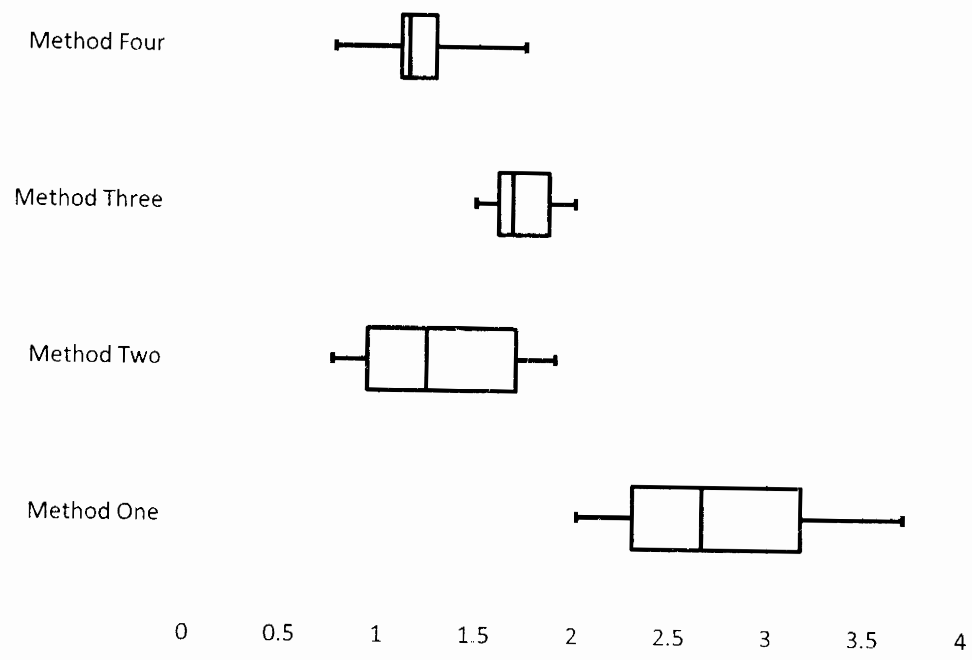


Figure 4.12 Standard Deviation Box and Whisker Plot for Experiment Six

4.9. Discussion of Sections 4.7 and 4.8

In this experiment the X coordinate of the top right most point of the area is varied by keeping all other parameters constant. It is not very hard to predict that as we are increasing the area in which the sensors are distributed, the number of relay stations required will be more when we keep all other parameters constant. The results are obeying the prediction, and are also obeying the λ rule. The variations and standard deviations have ups and downs but mostly are increasing as the area is increasing.

4.10. Experiment Seven

In this experiment top right most point of the area chosen is varied and its values for each time are (75, 50), (75, 75), (75, 100), (75, 125), (75, 150), (75, 175), (75,

Table 4.7 Standard Deviation for Experiment Seven

Area Y Coordinate	Method 1	Method 2	Method 3	Method 4
50	1.01	0.62	0.49	1.11
75	1.46	0.58	1.06	1.46
100	2.29	0.58	1.41	1.94
125	1.94	0.92	1.93	1.98
150	1.63	0.86	1.58	2.7
175	3.16	1.28	2.08	2.71
200	3.03	1.1	2.1	2.34
225	3.14	1.3	2.31	3.05
250	3.4	1.1	2.55	3.54
275	3.66	1.8	2.58	3.6

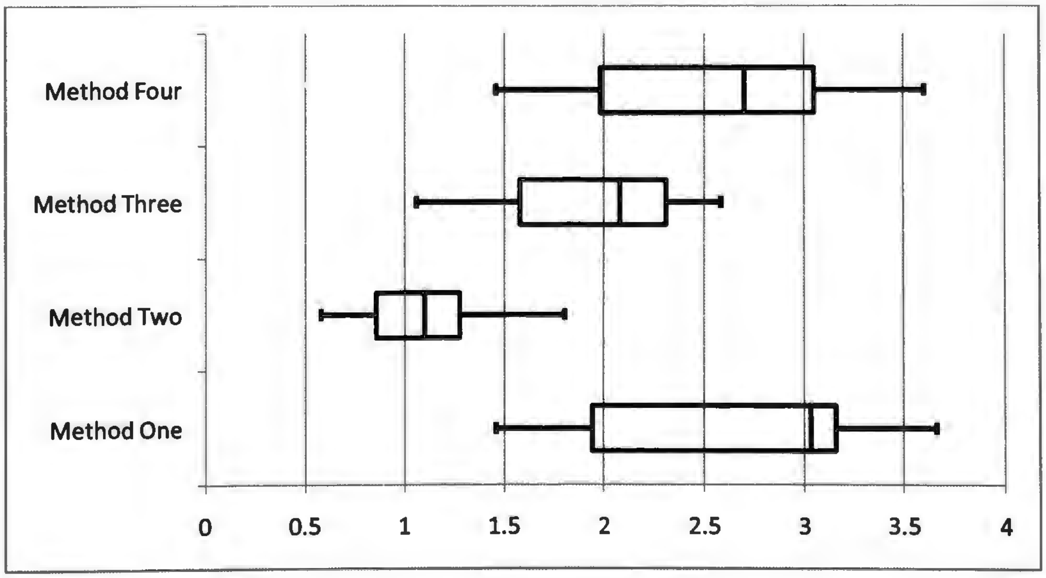


Figure 4.14 Standard Deviation Box and Whisker Plot for Experiment Seven

4.11. Experiment Eight

In this experiment top right most point of the area chosen is varied and its values for each time are (75, 50), (75, 75), (75, 100), (75, 125), (75, 150), (75, 175), (75, 200), (75, 225), (75, 250), (75, 275) and all other parameters are kept constant. Number of sensors = 500, transmission range of relay station = 10 miles, percentage of sensors covered = 75 % of all the sensors, bottom left most point of the area chosen = (0, 0), lambda = 1.

Figure 4.15 shows the variations in the number of relay stations required when the maximum y coordinate of the area is varied with lambda = 1. Table 4.8 shows the results observed in all the experiments and Figure 4.16 shows the box plot for the standard deviations for the results in this experiment.

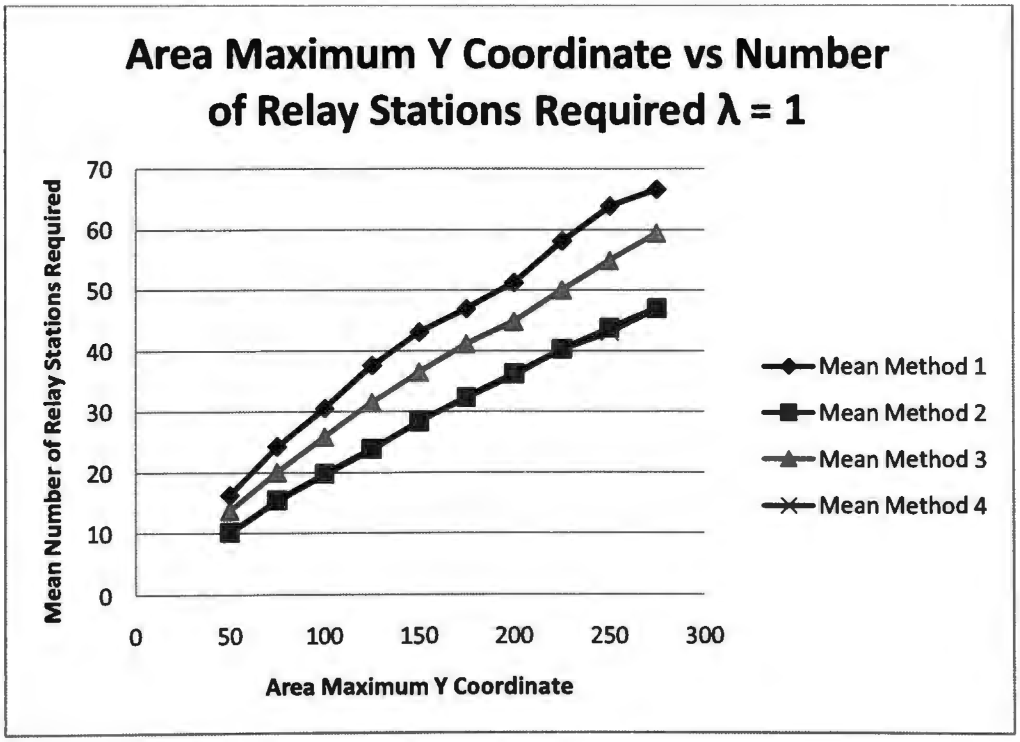


Figure 4.15 Experiment Eight

Table 4.8 Standard Deviation for Experiment Eight

Area Y Coordinate	Method 1	Method 2	Method 3	Method 4
50	1.15	0.4	0.5	0.3
75	1.45	0.49	1.17	0.47
100	1.9	0.85	1.43	0.82
125	2.3	0.76	1.32	0.92
150	3.2	0.8	2.37	0.86
175	2.8	1.11	2.22	1.22
200	2.62	1	2.36	1.6
225	3.11	1.38	1.7	1.59
250	2.89	1.42	2.61	1.4
275	3.4	1.54	2.26	1.2

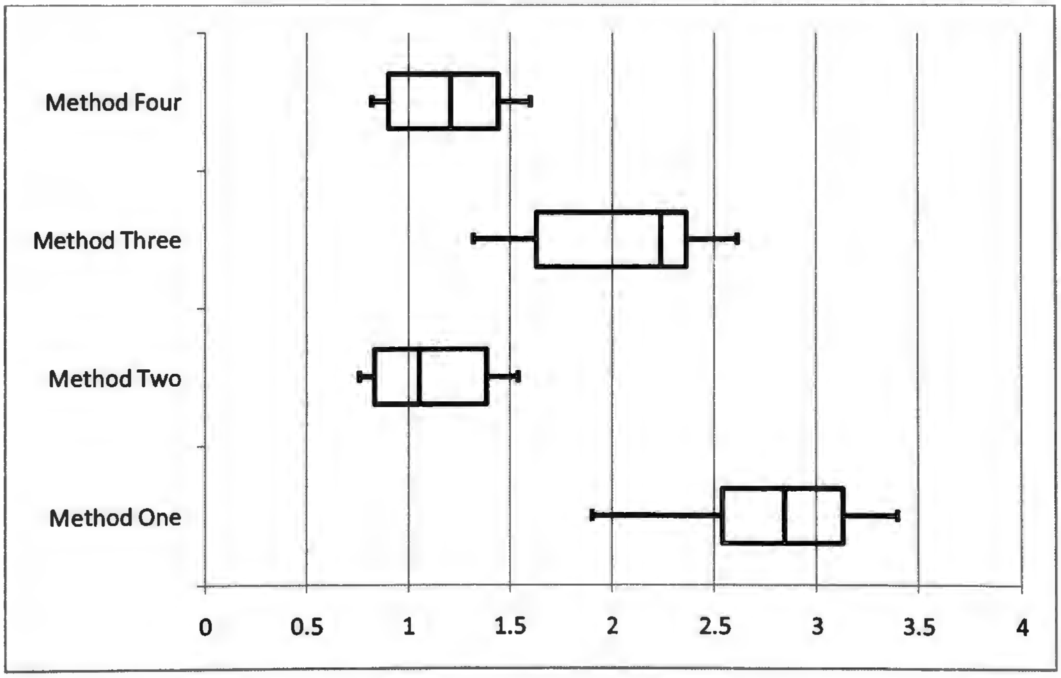


Figure 4.16 Standard Deviation Box and Whisker Plot for Experiment Eight

4.12. Discussion of Sections 4.10 and 4.11

In this experiment the Y coordinate of the top right most point of the area is varied by keeping all other parameters constant. The number of relay stations required is increasing as the area is increasing. The results also respect the conventions that as the area is increased the number of relay stations required will also increase. The results in the experiment in Section 4.10 are not obeying the λ rule as much as others are doing but the experiment in Section 4.11 is obeying the λ rule. The variations and standard deviations have ups and downs but mostly are increasing as the area is increasing.

4.13. Experiment Nine

In this experiment top right most point of the area chosen is varied and its values for each time are (100, 100), (150, 150), (200, 200), (250, 250), (300, 300), (75, 75), (125, 125), (175, 175), (225, 225), (275, 275) and all other parameters are kept constant. Number of sensors = 500, transmission range of relay station = 10 miles, percentage of sensors covered = 75, bottom left most point of the area chosen = (0, 0), lambda = 0.

Figure 4.17 shows the variations in the number of relay stations required when the area in which the sensors are distributed is varied with lambda = 0. Table 4.9 shows the results observed in all the experiments and Figure 4.18 shows the box plot for the standard deviations for the results in this experiment. And the results of Section 4.13 and 4.14 are discussed in the Section 4.15.

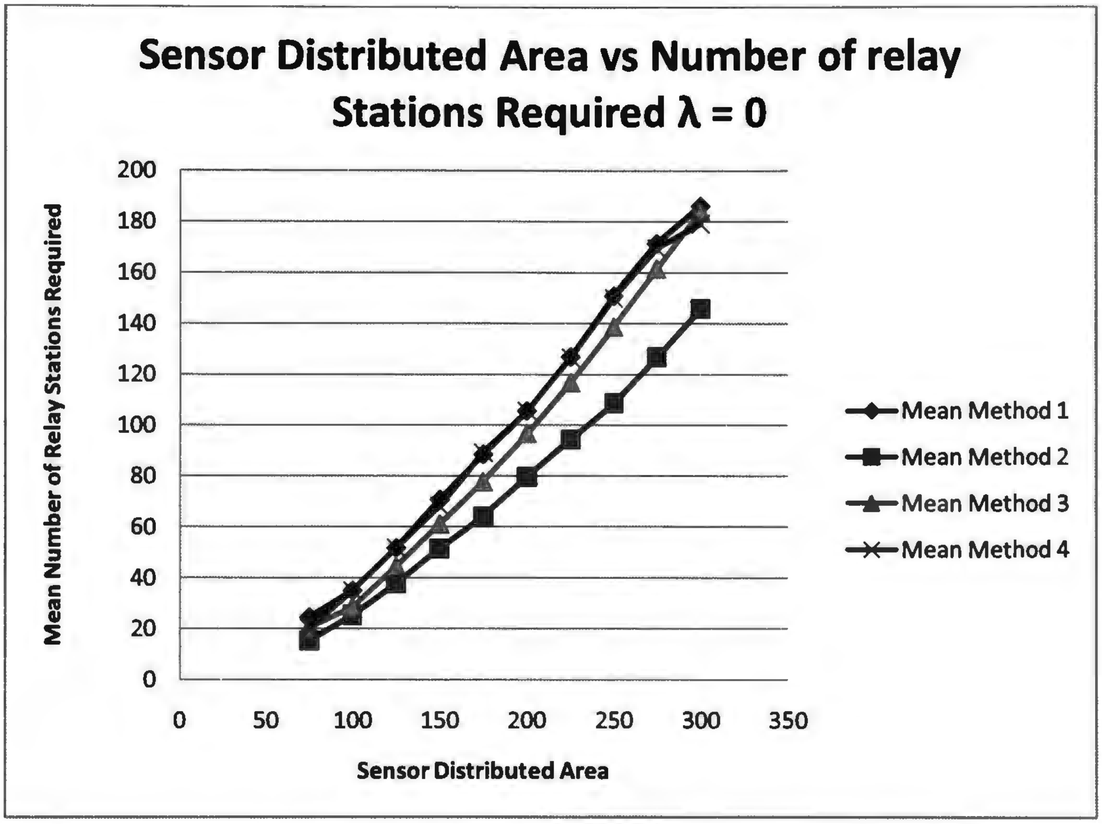


Figure 4.17 Experiment Nine

Table 4.9 Standard Deviation for Experiment Nine

Area X, Y Coordinate	Method 1	Method 2	Method 3	Method 4
75	1.3	0.71	0.96	0.9
100	2.18	1.18	0.92	2.03
125	3.03	1.14	1.88	3.08
150	2.84	1.65	3.19	3.23
175	4.93	1.46	2.6	5.21
200	4.7	2.16	2.58	5.39
225	6.16	2.95	3.32	5.38
250	6.07	3.18	2.11	9.51
275	6.72	4.2	5.68	8.43
300	8.63	4.84	5.47	13.15

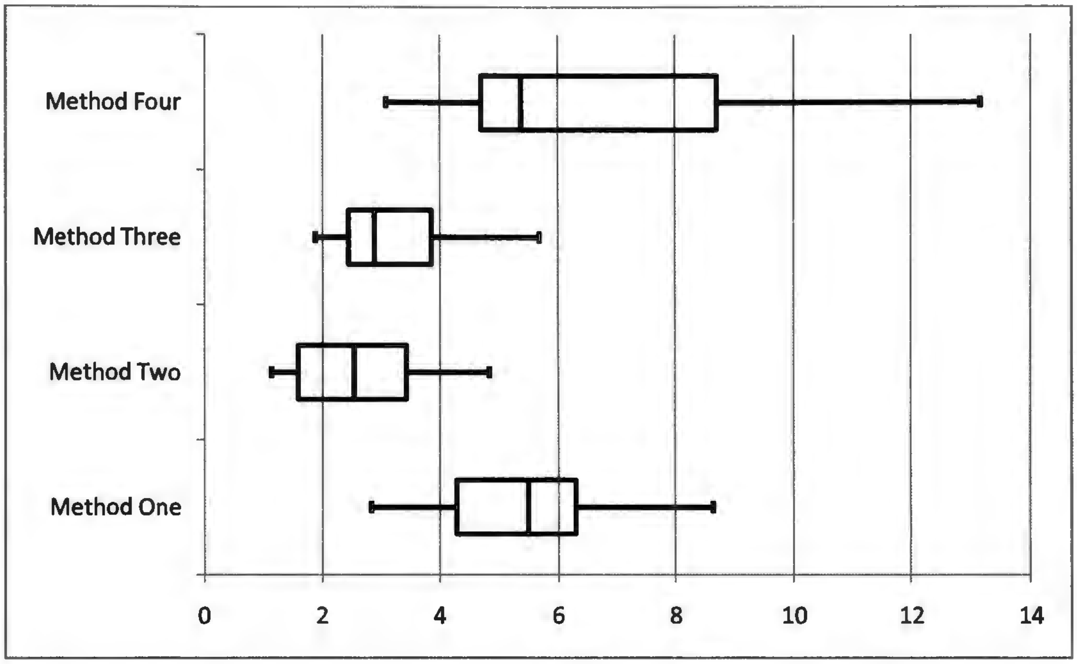


Figure 4.18 Standard Deviation Box and Whisker Plot for Experiment Nine

4.14. Experiment Ten

In this experiment top right most point of the area chosen is varied and its values for each time are (100, 100), (150, 150), (200, 200), (250, 250), (300, 300), (75, 75), (125, 125), (175, 175), (225, 225), (275, 275) and all other parameters are kept constant. Number of sensors = 500, transmission range of relay station = 10 miles, percentage of sensors covered = 75, bottom left most point of the area chosen = (0, 0), lambda = 1.

Figure 4.19 shows the variations in the number of relay stations required when the area in which the sensors are distributed is varied with lambda = 1. Table 4.10 shows the results observed in all the experiments and Figure 4.20 shows the box plot for the standard deviations for the results in this experiment.

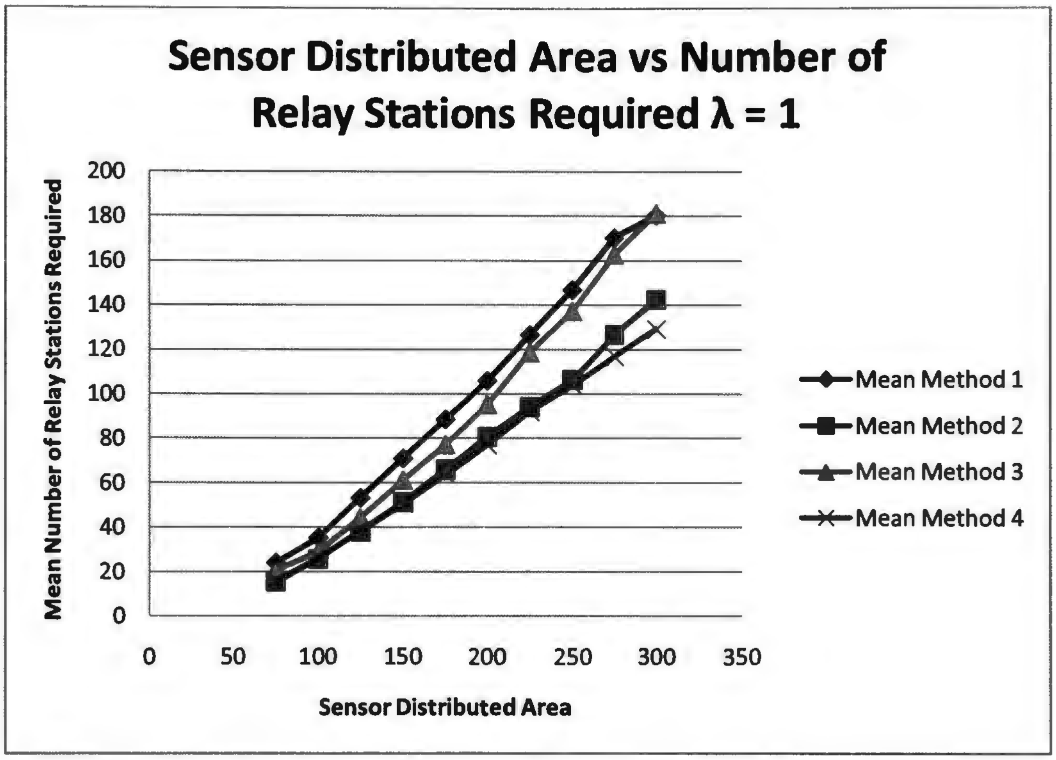


Figure 4.19 Experiment Ten

4.10 Standard Deviation for Experiment Ten

Area X, Y Coordinate	Method 1	Method 2	Method 3	Method 4
75	1.94	0.57	1.28	0.54
100	1.95	0.74	1.57	1.15
125	2.62	1.22	1.38	1.1
150	2.94	1.69	2.27	1.22
175	3.59	2.16	2.55	1.98
200	4.35	1.68	2.89	2.98
225	5.78	3.21	3.78	2.82
250	6.38	3.69	3.43	3.07
275	5.94	4.9	3.19	3.71
300	7.06	5.72	4.96	4.42

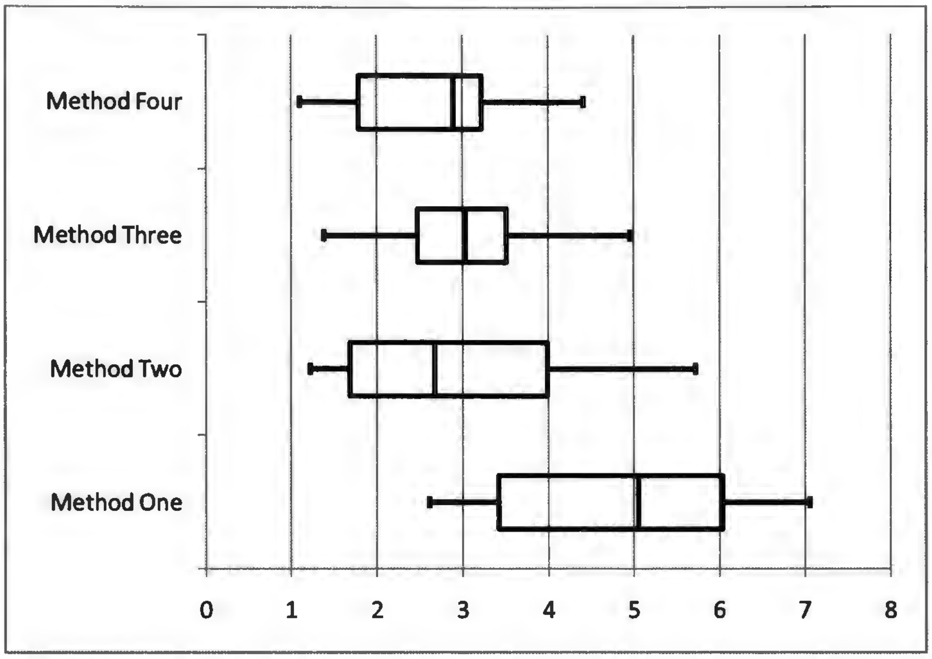


Figure 4.20 Standard Deviation Box and Whisker Plot for Experiment Ten

4.15. Discussion of Sections 4.13 and 4.14

In this experiment the X and Y coordinates of the top right most point of the area is varied by keeping all other parameters constant. The number of relay stations required is increasing as the area is increasing, and the results are obeying the λ rule. The variations and standard deviations are increasing as the area is increasing.

5. CONCLUSION AND FUTURE WORK

Deployment of sensors in a wireless sensor network is one of the key areas that affect the overall performance of the network. It is not always feasible to deploy sensors in a controlled fashion. The concern of coverage area is of more value in a network where sensors are deployed randomly. And because of the limitations of the transmission capabilities of the sensors a data packet needs to make many hops before it actually reaches the base station. So introduction of the relay stations has been considered as a promising approach to solve these limited capacities of the network.

Now as we know that introducing the relay stations is one of the good solution and the optimal relay station placement problem arises. The work done in this paper suggests that the method Two (number of sensors isolated method) is very promising in finding the optimal positions for the relay stations when compared to the other methods proposed in this paper. Method Four (improvised combined method) also gives us results as efficient as Method Two when the value of $\lambda = 1$. Method One (Number of Sensors by number of relay stations method) is one method of finding the optimal positions for the relay stations and when compared with the results of the Method Two proves that latter is better than former for almost all occasions. The results also prove that Method Two is better than the Method Three which is the Method One and Method Two combined together.

Future research can be done on this topic by finding the best possible solution using the linear programming and then compare the results obtained with the results of the methods proposed in this paper. The solutions proposed in this paper can be applied to some real time situation to see the results and develop some intuition on how much better the performance will be after the introduction of the relay stations. More heuristics can be formulated to solve the optimal relay station placement problem and the results can be compared.

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