

*Greedy Algorithms for
Target Coverage Problem
in Wireless Sensor Networks*

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by

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Certificate

This is to certify that the project entitled, “**Greedy Algorithms for Target Coverage Problem in Wireless Sensor Networks**” submitted by **Saptarshi Chaudhuri** is an authentic work carried out by him under my supervision and guidance for the partial fulfillment of the requirements for the award of **Bachelor of Technology Degree in Computer Science and Engineering** at **National Institute of Technology, Rourkela**.

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Date - 9/5/2011

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Abstract

Wireless Sensor Networks have seen tremendous advancement in design and applications in the recent years. Wireless Sensor Networks (WSNs) involve deployment of huge number of wireless sensor nodes essentially for monitoring a certain area and collecting data. These collected data are then sent to the base station which acts like a control room and there further processing is done as per requirements. The rapid advancement of digital electronics and wireless communications has resulted in more rapid development of WSN technology. This rapid growth has resulted in focus being given into solving the challenges that this field has to face. One such challenge is to maximise the network lifetime of the network while the target nodes remain monitored constantly. This problem of maximizing the network lifetime while satisfying the coverage and also energy constraints (sensors are equipped with battery as the only power source and hence the energy constraint) is known as the Target Coverage Problem in Wireless Sensor Networks. In this paper a simulation of an existing technique is simulated. Then a modified version of the algorithm is simulated which is found to give better performance over the existing one.

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Chapter 1

Introduction

Sensors and wireless sensor networks have seen tremendous advances and utilisation in the past two decades. Starting from petroleum exploration, mining, weather and even battlefield operations, all of these require sensor applications. One reason behind the growing popularity of wireless sensors is that they can work in remote areas without manual intervention. All the user needs to do is to gather the data sent by the sensors, and with certain analysis extract meaningful information from them. Usually sensor applications involve many sensors deployed together. These sensors form a network and collaborate with each other to gather data and send it to the base station. The base station acts as the control centre where the data from the sensors are gathered for further analysis and processing.

Sensors are hardware devices[1]. The main functions that a sensor is normally involved with are monitoring, routing data and little amount of processing in some cases. Sensors in most cases measure and gather physical data like temperature, pressure and speed. This is done through the sensing system equipped within every sensor[1]. Now the data available in the physical world is analog in nature. So the sensing unit is equipped with an Analog to Digital converter that converts the analog data into digital information[1]. Once the sensing unit gathers the data, they are stored in the memory placed within the sensor. Normally memory sizes in sensors varies because it can actually be an overhead. Smaller the sensor we want, lesser should be its memory size. Plus there are cases where the memory can be split into memory for permanent storage (supposedly that part which stores the program that the sensor follows throughout its functional period), and temporary storage.

Temporary storage is required to save the sensed data. Now the memory resides within the processing unit which comprises a microcontroller. Now then when a sensor is a part of an entire network then there are a lot of activities or tasks that it has to perform, for example send network discovery packets like "Hello" messages, acknowledge an incoming message, etc. Plus some applications might require local processing of data (sensed data being processed at the site itself) before being passed onto the base station. Plus like any other hardware device, a processing unit has to perform the responsibility of controlling the other functional components of the sensor node. But then again just like memory processor is also an overhead. This is because sensors are equipped with a battery as their only source of power and hence has a limited source of power. More processing would mean more energy being consumed and so sensor lifetime would decrease. Apart from collecting, storing and processing the data, the sensors are also required to relay the data/information to the neighbouring nodes so that it can be conveyed to the Base Station. Of course the relaying of information is done by following a certain communication protocol. But this functionality is achieved by the communication unit of the sensor. Normally it has a transceiver that can act as both transmitter and a receiver. The transmitter and the receiver hardware is not kept separate in order to save space and energy. Most of the modern day sensors can communicate through transmission media ranging from radio frequency to optical lasers and infrared.

The first phase in implementing a Wireless Sensor Network, as has been given in reference[2] is Deployment. One of the parameters that is measured for correct deployment is extent of coverage, that is how perfectly the target locations are being covered by the sensor network.[2] Normally if one goes for a larger number of sensors then the extent of coverage improves. But sometimes deployment with huge number of sensors is not feasible because of cost and other constraints. In such a situation sensor placement becomes the major issue. With a lesser number of sensors, each sensor has to be placed in such a manner that one gets a satisfiable extent of coverage.

A totally contrasting scenario provided in reference[2] might be when cost is not much of a constraint(say for example low cost sensors can be used). In this case, a huge number of sensors are deployed and that too densely and hence density control becomes a major issue[2].

The second phase is the activation and maintenance of the network. How to assign/activate and even schedule the role of active sensors among the sensors so that the network lifetime is maximised [3]. This problem of maximising the Network Lifetime while satisfying the coverage and energy constraints is known as the Target Coverage Problem in Wireless Sensor Networks[4]. As wireless sensor nodes are battery driven so they have energy constraints too and in this regard the main challenge becomes coverage of the entire area and also ensuring a prolonged network lifetime. Though work has been done to resolve this issue but mainly as the problem inherently involves time issues, so the problem formulation is time dependent[4], and which in turn makes the problem non-polynomial in nature[4]. Now even non-linear problems belong to the NP-Hard class[4] and thus till date only heuristic algorithms to solve the Target Coverage Problem has been discussed which have been successful in providing if not optimal, near optimal or sub-optimal solutions to this problem. Some of these algorithms are discussed duly in references [5][6][7][8][9][10]. In this paper we look into a proposed heuristic algorithm given in [13] that attempts to compute the set of sensors that should remain active at any iteration. Then the proposed algorithm[13] is modified which gives better performance over the existing one. The other work that has been done in this paper is to introduce a new quality of service parameter that gives an indication of the amount utilisation of every sensor by the algorithm. This is necessary because buying the sensors requires more expenses and hence an algorithm that can meet the required network lifetime and also use less number of sensors is preferable.

1.1 Wireless Sensor Networks and QOS

The quality of any network can be measured based on certain parameters. These are the Quality Of Service (QOS) parameters. Also different networks emphasize on different QOS parameters. For example in a certain application the network might be required to deliver data quickly in which the network should focus on minimising delay, whereas in certain other applications demand might be for providing an accepted level performance in any situations in which the robustness gets emphasized. Similarly for Wireless Sensor Networks also certain QOS parameters exist. A detailed

discussion of the QOS parameters can be found in reference[14] and here only some of them will be mentioned which are Reliability, timeliness, delay, security, availability, security etc., among many. One of the most fundamental QOS parameter for WSNS is:

Network Lifetime: Network lifetime is defined as the total amount of time the network was active and could successfully monitor the interested terrain, gather data and relay them back to the base station or the users concerned. Now the biggest challenge hindering a high Network lifetime is mainly the limited battery power with which every wireless sensor node is equipped. Obviously cost is also a constraint to some extent. For example having sensors with higher ranges do the monitoring works might lead to increase in the network lifetime substantially.

1.2 Unutilised Sensors

A nobility introduced in this paper is the quality of service parameter that measures the extent of utilisation of the sensors by the algorithm employed. This parameter called Unutilised Sensors is the count of the sensors left with energy at the end of the network lifetime but cannot be deployed as coverage constraints are not satisfied. Once the functioning of the wireless sensor network ceases and the Network Lifetime is reached most of the sensors enter into dead state that is with no remaining battery power. But there always remains some sensors that still have energy left with them but together cannot cover the entire set of target nodes. These sensors thus remain unutilised. An algorithm that results in more number of unutilised sensors is a cost inefficient one as in most of the cases the demand for the network to monitor the target location is fixed. If an algorithm A_1 uses N sensors to monitor the location and have N_1 sensors unutilised at the end, then it is obviously inferior to an algorithm A_2 which will have less number of unutilised sensors. This is because as A_2 can utilise the sensors more effectively than A_1 and hence can reach the network lifetime deadline by employing less number of sensors than A_1 . In chapter 5, this parameter is discussed in detail and an existing algorithm plus the algorithm proposed in this paper are checked on the basis of this parameter.

1.3 Motivation

The last decade has seen the demand for Wireless Sensor Networks based applications rise heavily. Given their widespread demand and utility a lot of research is now being invested in these areas. But this relatively young field still faces some fundamental problems. First of all is the challenge from the limited energy source equipped with every sensor that is from the battery source. Added to this is the problem of covering an uneven target area in most of the cases. Then cost minimisation becomes a major issue. It has already been discussed about the various qualities of service parameters in the earlier section and so it would not be out of place to mention that meeting even a single QOS parameter poses a challenge and requires proper analysis and observation to find out a solution.

If the functioning of a wireless sensor network is considered, then initially comes the question of deployment so that the target nodes are fully covered[2]. Once this challenge is dealt with comes the question of monitoring and functioning of the network in a way so that the energy consumption is minimum and also the network can meet certain quality of service standards. Usually the situation is that there a number of sensors with a fixed and limited energy that are required to monitor a number of target nodes. In such a case one thing that is to be taken into account is the time for which the application, or should it be put in another way, the time span for which the user wants the targets to be monitored. One such scenario would be where the army wants to monitor the movement of the enemy troops for the next two weeks before deciding on a cease fire. In such a case it is imperative that the sensor network functions up to the two weeks mark, otherwise the total point of deploying the sensors becomes meaningless. So the problem is not just full coverage of the target nodes but also that the sensor network be able to monitor the target nodes for a longer period of time, that is the network lifetime should be maximised.

This very challenge of optimising the network lifetime while monitoring the target nodes is known as the Target Coverage Problem. In chapter 2 it will be established that the problem is non-polynomial in nature. Now even non-linear problems are NP-Hard in general[4]. So being a non-polynomial problem, no known algorithm has existed till now that can provide an optimal solution to this problem in polynomial time. This is the main motivation behind this work as work has been done to modify

a heuristic algorithm (proposed in [13]) that can provide better performance over the existing heuristic one [13].

1.4 Objective

The present work deals with the Target Coverage Problem in wireless sensor networks which asks to optimise the network lifetime under energy and coverage constraints [4]. The problem is formulated first and the mathematical model for the problem is made. After that the conventional heuristic algorithm used for scheduling the sensors is simulated. The main objective of this work is to modify the existing technique that can be used to tackle the problem. The second objective is to provide a new parameter for comparing the quality of service of the algorithms.

1.5 Related Work

Ad-hoc applications and wireless communication capabilities are becoming increasingly available for commercial and military applications [2]. Reference [2] gives a comprehensive treatment of the Coverage Problem in WSNs. Specifically they provide fundamental properties of coverage and corresponding algorithms that will realise them.

The issue of building long-lived sensor networks and maintaining robust operations through low cost sensor devices having lesser lifetime is discussed in [3]. The authors suggest a protocol PEAS that involves two different algorithms. First is Probing Environment (it decides which sensors should work and on what basis an active sensor will go to sleep) and the second is Adaptive Sleeping (dynamic adjustment of the sleep times of sensor to maintain a relatively constant wakeup rate).

Reference [8] addresses the issue of maximising the network lifetime through scheduling for K to 1 sensor-target surveillance networks. The constraint here is that any sensor can watch only one target at a time and a target is required to be watched by minimum K sensors.

A detailed account of the energy consumption by the activities of a sensor can be found out in [8] whereas [14] gives a detailed account of the various QOS parameters

involved in WSNs.

1.6 Organization of the thesis

This thesis is divided into six chapters. The first chapter gives an account of Wireless Sensor Nodes and Networks, the QOS parameters and the challenges involved. The second chapter starts by providing an account of the assumptions on which this work has been based and goes onto forming a mathematical model for the problem. It also introduces an energy consumption model based on which the algorithms are to be compared. The third chapter starts with a simple algorithm that can be used for solving the target coverage problem. The main objective behind including this algorithm is to increase the understandability of the strategies that are normally used to solve the problem. A detailed account of the flaws of the algorithm is given to help with the matter further. Then an existing algorithm is taken and simulated[13]. After that in chapter 4 we make some modification of the algorithm given in [13]. Then in chapter five, a new parameter is introduced in order to measure the relative performance of the algorithms and also provide a different angle of observation which might be useful in tackling the problem. The paper is concluded in chapter 6 where the results are summarised and areas for future work are discussed.

Chapter 2

System Model

The present work deals with the Target Coverage Problem in wireless sensor networks which asks to optimise the network lifetime under energy and coverage constraints. The problem is formulated first. Then the mathematical model for the problem is made. After that the conventional heuristic algorithm proposed in reference[13] is simulated. The main objective of this work is to modify the algorithm which can be used to tackle the problem. The second objective is to provide a new parameter for comparing the quality of service of the algorithms.

2.1 Assumptions

In this work certain assumptions have been made. Firstly we consider that the sensors are statically deployed. This means that once the sensors are deployed in a certain fashion, these sensors cannot change their coordinates that is they are not mobile and their positions are fixed. The next assumption is that we consider the area to be monitored as planar. So the sensors deployed all lie on a single plane and a two dimensional analysis can be used. This assumption doesn't really cost much. This is because a hierarchically deployed network can also be treated as a collection of a number of planar ones and then treated in the same fashion. Another assumption is regarding the states in which a sensor generally resides. We consider that there are two different states for a sensor. One is the active state in which it is working for the network and the other is the sleep or the idle state where the sensor is not active but in a kind of hibernating mode. In the active node the sensor is involved in

Table 2.1: Energy Consumption States

Activities	Cost(μ W.sec/byte)
Point to Point send	1.9
Broadcast Send	1.9
Point to Point Receive	0.42
Broadcast Receive	0.50
Processing	Major Consumption

(i)Sensing,(ii)Routing which involves receiving and transmitting,(iii)Packet Generation. The first activity sensing involves monitoring the target and collecting data from it. The third activity of packet generation usually involves in assembling the collected data from sensing in a certain standard packet format. It might also involve generating packets for control packets, acknowledgement packets, route discovery packets such as Hello Packets, etc. The second activity Routing is a complex one. Normally a sensor needs to save as much energy as possible plus keep the performance level above the accepted standard. Now for reducing energy consumptions these sensors go for implementing a variety of routing protocols and most of such protocols involve a path formation by the sensors itself so that one sensor can send the data to the next and so on. Thus a sensor is required to transmit the packets to their neighboring sensor nodes and also receive the packets transmitted from those nodes stationed earlier to it. Both these transmitting and receiving activities consume some percentage of battery power. Finally we present the various energy consumption activities the sensors are involved and the relative energy lost in a tabular form. Energy loss due to sensing and processing is directly proportional to the number of targets being monitored by that sensor [12][13].It consumes the maximum amount of energy, at least 35 percent of the whole[12]. The energy consumption for the top four activities concerning Point to Point traffic and Broadcast traffic have been adopted directly from reference [11]. The broadcast service doesn't support for any acknowledgement and retransmissions. The sender listens to the channel for some time. If the channel is free it transmits otherwise it retries later[11]. [11]In point to point traffic, the source sends an RTS(Request To Send) control message, identifying the destination. The destination replies with a CTS (Clear To Send) response message. Upon receiving the CTS the source sends

the data and waits for an ACK from destination.

2.2 Target Coverage Problem

We consider a scenario where a large number of target nodes are to be continuously observed and a number of sensors are deployed randomly around the target locations close to these targets. There is a data collector node central to the sensors called the Base Station. This base station is responsible for processing of the sensed data which is then transmitted forward to the users concerned. In such a scenario the Target coverage Problem asks to schedule the sensor nodes placed in the vicinity of the target nodes in such a fashion so that the network lifetime is maximum given that all targets are covered throughout the network lifetime and also that the total energy consumption by a sensor doesn't exceed its initial energy.

By network lifetime we mean the time from the point the sensors had started observation to the point in time where a target node cannot be assigned a sensor for its coverage (which happens because the sensors in its vicinity are all dried out).

The model has been based on reference[6]. $S = \{S_1, \dots, S_n\}$ is the set of Sensors and $T = \{T_1, \dots, T_m\}$ are the set of target nodes. Every sensor $S_i \in S$ covers a subset of T , where $i \in [1, m]$. Let the set of target nodes covered by a sensor S_i be U_i . Then we define a set cover $C_k = \{S_1, \dots, S_n\}$, where $(U_i \cup \dots \cup U_j) \equiv T$, that is the elements of the set cover can cover the entire network. If every set cover C_k is associated with an active time then the total network lifetime will be the summation of the active time of all the set covers.

So the TCG problem asks to MAX(\mathbf{T}) where the energy constraint is that the total energy dissipated doesn't exceed the initial energy of the sensor[4] and the coverage constraint is that at any point during the network lifetime a target is covered by at least one sensor[4].

For a sensor if the initial energy is E and the energy consumptions due to

- (1) Sensing is $E_s(t)$,
- (2) Routing(Receiving and Forwarding) is $E_r(t)$,
- (3) Packet generation is $E_p(t)$

Then the energy constraint becomes:

Energy Constraint

$$\int (E_s(t) + E_r(t) + E_p(t)) \leq E \quad (2.1)$$

Coverage Constraint The Coverage constraints is that any time during the functioning of the network, all the target nodes must be covered by atleast one sensor, that is no target node must remain uncovered while the network is monitoring.

Given the coverage constraints and 2.2, we have the objective function as

Objective Function

$$Max(T) \quad (2.2)$$

2.3 Conclusions

The Target Coverage Problem is non-polynomial in nature. It is known that even non linear problems fall into NP-Hard category[4]. So obviously the above problem which is non polynomial also is NP-Hard[4] for which no known algorithm exists which can give a polynomial time solution. So in this work only heuristic algorithms are considered.

2.4 Summary

This work considers the case where the sensors are statically deployed and the target area to be covered is two dimensional. We consider two different states for a sensor, either active or in sleep state. In the active state, the sensor can be involved in a number of sub states visibly sensing, routing and packet generation. Considering these three states we argue that the energy constraint for any sensor should be that the net energy consumption over the network lifetime should not exceed the initial energy that it is having. Modelling the problem mathematically it is found out that the problem is non-polynomial in nature. Now as even non linear problems fall into the NP-Hard category, we can say that no known algorithm exists that can give an optimal solution to this problem in polynomial time. Plus an effort has also been made into finding out the various energy consumptions involved while the sensors are active and the conclusion drawn was that the energy required in maintaining the

network far exceeds the other consumption activities.

Chapter 3

Greedy Algorithms

Wireless Sensor Networks have found popularity in a variety of applications ranging from warfare tactics to medical sciences to oil pipelining in recent years. And such wide variety of applications has resulted in a lot of research into finding better ways of implementing these networks and maintaining them with minimal loss of energy. Problems involved with deployment, communication and routing and many more are being considered and attempts to find better solutions made. Target Coverage Problem is another such problem that discusses about the activation and scheduling of the sensors in such a way so that the network lifetime is maximised.

Now in the last chapter a conclusion was drawn regarding the nature of this problem which was found to be NP-Hard. The implications of this are that no known algorithm thus exists that can solve the problem in polynomial time and also proving us with the optimal solution. That is why most of the research has been performed for finding out better heuristic algorithms that can provide if not optimal, at least a sub optimal or near optimal solution to this problem.

In this chapter, first we see at a simple greedy based strategy which at any point selects that sensor which is covering the maximum number of target nodes. This step is required to understand the flaws with the normal approach and in which direction one needs to think in order to define new heuristics. Then we look at the algorithm in reference[13] and simulate that existing algorithm which aims to provide a near optimal solution to the Target Coverage Problem in polynomial time.

3.1 A Simple Strategy

In a Wireless Sensor Network, a sensor can either be in a sleep state or in active state. Activities in active state involve routing data packets, packet generation, monitoring etc.

According to [6] power saving techniques involves scheduling the sensors between sleep mode and active mode, or through energy aware routing schemes and by cutting down useless activities. The authors have provided an energy efficient mechanism for scheduling

Now the simple algorithm aims at generating a Maximum Set Cover (MSC), where the elements of the set cover are nothing but sensors that are to be activated. In any cycle, only those sensors included in the set cover are activated and rest are kept in sleep mode. The set cover is constructed so that the members of the set cover can cover all the targets and monitor them with their available energy. If there is at least one target which cannot be covered by the members of the set cover then that set cover is discarded and the operational time of that set cover is noted which is added to the total network running time, which is called the Network Lifetime of the network.

Question now arises as to when a target node might become uncovered. Initially when the set cover is constructed and activated all the target nodes remain covered. Now as time progresses these active sensors lose energy. Now as some of the active sensors might have been members of earlier set covers so they have lesser energy as compared to the recently activated ones and so these sensors run out of energy faster. In any case if there is at least one such sensor that has run out of energy then the corresponding targets that this sensor was covering get uncovered and so the above situation arises.

Another situation arises when there is not enough sensors left with which a set cover can be constructed. This situation arises at the last cycle when almost all sensors are used up and left with no energy. Then not enough sensors are available with which the entire network can be monitored. The algorithm terminates in this position and the total network running time is the Network Lifetime at this stage.

The above simple algorithm was given purely for understanding and so was not simulated. Understanding the flaws of the above strategy would give a better understanding of the challenge involved with finding better heuristics and in which direction

we should think for devising new ones.

In the next section, we discuss the issues with a simple algorithm as above and then discuss the algorithm given in reference[13].

3.2 An Advanced Greedy Based Heuristic Algorithm

The last section introduced a conventional algorithm which would provide a solution to this Target Coverage Problem that asks to maximise the network lifetime under energy and coverage constraints. The main step in the algorithm involved finding out which sensor could cover the maximum number of target nodes and assigning them until all the target nodes are covered. Once the feasibility of that assignment finished (which would happen when one of the sensors run out of energy and so the coverage constraint is not yet satisfied), then the algorithm selected another set of assignments among the existing sensors. This was done until the sensors with remaining energy could not cover the target nodes fully. When such a case arose, the network had ceased its feasibility and the network lifetime was recorded.

The primary problem with the initial algorithm is that it blindly goes on selecting those sensors which can cover the maximum number of target nodes. The flaw behind such a strategy can be immediately visible with a simple observation. Suppose there are two exactly alike sensors which also happen to be deployed at small distances to one another (such a scenario can happen when the number of sensors are large and a random deployment is carried out). In this case it is likely that both these sensors are covering exactly the same targets. And if it so happens that these sensors are covering a maximum number of targets, then surely the conventional scheme will select both the sensors in the same cycle thus resulting in two sensors monitoring the same target nodes and generating redundant data at the same time. Now although we don't know about a polynomial time optimal algorithm for this problem, but we can guess that it is highly unlikely that an optimal algorithm would follow a similar behaviour as the above conventional one. It is more likely that an optimal algorithm will activate one of the two similar sensors in one cycle and let it run till its energy finishes and then activate the other one. Or else it can alternate the activity of both the sensors every

cycle.

But the above observation provides a clue with what one useful heuristic can be. A simple modification of the above technique would be that rather than selecting the sensor that covers the maximum number of target nodes in each iteration, we go on selecting the sensor that covers the maximum number of uncovered target nodes. This would require an additional checking after each assignment to check which are the nodes that are not yet covered and then finding out the sensors that can cover maximum of those uncovered target nodes.

Usually the scenario is that there are a lot of sensors which are deployed in each other's vicinity and so the intersection of the set of target nodes that each of them cover can be large that is two sensors might be covering a similar set of target nodes. If S_1 and S_2 are two sensors having lifetime T_1 and T_2 respectively, and are covering almost similar targets then our aim should be to activate these two sensors at different cycles so that the effective time that we get is (T_1+T_2) . On the other hand it is easy to notice that if both the sensors get activated at the same cycle then the time for which their mutual targets are getting covered is $\text{maximum}(T_1, T_2)$. This need can be satisfied by using the modified heuristic of selecting that sensor that covers the maximum number of uncovered target nodes at each iteration to construct the set cover.

The authors in reference[13] uses this same technique to select the sensors for their set cover. But the above technique cannot give a full proof guarantee that two nearby sensors won't get activated at the same time. Realising this, the authors devised an additional strategy to filter out all those sensors that are monitoring the same set of target nodes and activate only one of them.

The situation is something like this. After running the main algorithm which decides the sensors that are to be a part of a set cover, an additional procedure is run. They have called it the Responsible Sensor Scheduling Algorithm(RSSA). Normally there are a lot of sensors who usually get deployed in each other's vicinity. In that case the set of target nodes that they might be monitoring would have some common targets. Similarly, it is highly likely that once a set cover is created, then some of the sensors assigned might be covering a similar type of target nodes. The RSSA algorithm does the work of finding such overlapped targets, and by overlapped

targets we mean a target that is getting covered by more than one sensor. Such a scenario would then lead to formation of redundant data. The RSSA algorithm avoids this situation by then selecting a responsible sensor from the overlapped sensors and deactivating the rest.

The algorithm is given in reference[13] and in the next section we simulate the algorithm.

3.3 Simulation

A stationary network with a fixed number of targets and sensors randomly deployed around the targets is simulated. The range of each sensor is considered fixed and so is the initial energy of the sensor which is kept equal for all sensors without any loss of generality.

After each iteration we increase the number of sensors and run the algorithm to note the new Network Lifetime. So the number of sensors is the variable parameter here.

The main objective of is to record the increase in network lifetime as we increase the number of sensors. The number of sensors is increased and for every new number of sensors the network lifetime is noted. Then a graph is plotted. The formal procedure is as follows:

- (1) The minimum number of sensors is taken to be 20.
- (2) Then we assigned the sensors using the MSC heuristic algorithm and noted the network lifetime.
- (3) The number of sensors was varied from 20 to 100.

3.4 Inferences

The inferences drawn from the above simulation are

- (1)The slope of the curve decides the degree of optimization of the network lifetime.
- (2)As the number of sensors increase, sensors available for participating in a set cover increases and so the total network lifetime increases.

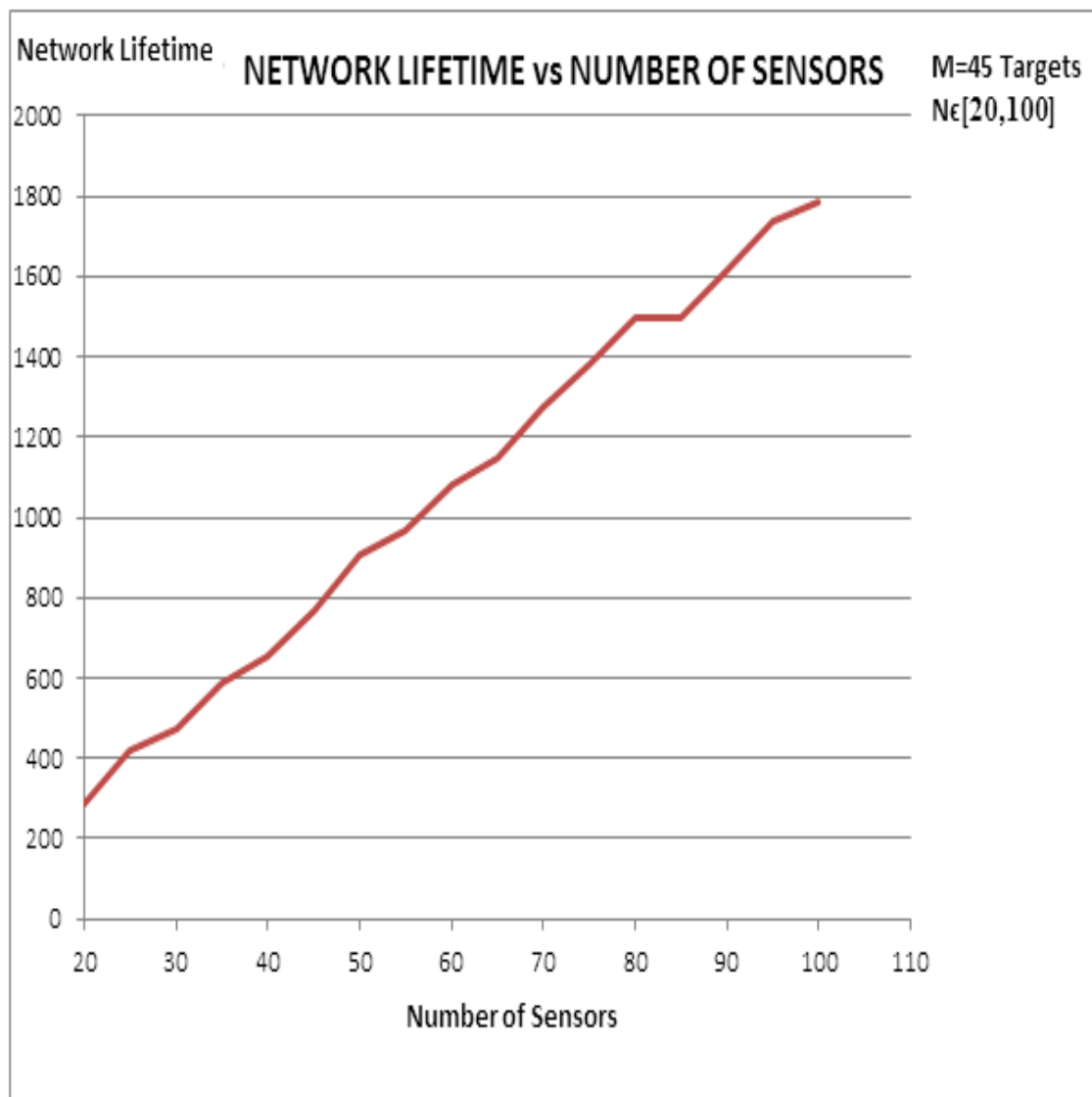


Figure 3.1: Performance of Existing Algorithm

(3) Also as the number of sensors are increased then with more number of sensors covering a target node the number of overlapped target nodes also increases and so the performance gain that results from the RSSA which eliminates the overlapped sensors, also increases.

(4) A better algorithm will have a greater slope than the present one.

3.5 Conclusion

This chapter proves through analysis and observation that a simple technique of selecting that sensor which can cover the maximum number of target nodes at any iteration cannot maximise the network lifetime. Then the strategy given in reference[13] is discussed and simulation results show that with increase in the number of sensors the network lifetime increases. In the next chapter a detailed analysis of the existing technique is done to uncover the inherent flaws of the algorithm and then a new algorithm is proposed.

Chapter 4

Proposed Algorithm

In this paper a new algorithm to solve the target coverage problem have been proposed and introduced. But before introducing the new algorithm we look at an analysis of the algorithm simulated in the previous chapter.

4.1 Analysis of the Existing Algorithm

The previous chapter introduced an existing algorithm[13] that provided a near optimal solution to the Target Coverage Problem which asks to maximise the network lifetime under energy and coverage constraints. The main step in the algorithm involved in selecting a critical sensor and then finding out which sensor could cover the maximum number of uncovered target nodes and assigning them until all the target nodes are covered. Once the feasibility of a set cover finished (which would happen when one of the sensors run out of energy and so the coverage constraint is not yet satisfied), then the algorithm selected another set of assignments among the existing sensors. This was done until the sensors with remaining energy could not cover the target nodes fully. When such a case arose, the network had ceased its feasibility and the network lifetime was recorded.

There is one observation that we need to make about the previous algorithm. This is about employing the Responsible Sensor Scheduling Algorithm(RSSA) which selects a responsible sensor from a group of sensors. Although there are performance benefits from employing this additional procedure but even then one can prove that it would be impossible to select a responsible sensor for each and every overlapped

target node. The situation is straightforward. If there is an overlapped target node that is covered by a set of sensors then there can be two extreme possibilities for this situation. Number one, all these sensors are covering only this target node alone, and in which case RSSA will select only one of them and rest of them returns to the sleep state. Number two is when these sensors are covering other target nodes also. Then one can't simply deactivate all of them but one because in that case, the set of target nodes other than the overlapped target that these sensors were covering will get uncovered. In the extreme case it might be possible that there are more than two critical targets, and one of these overlapped sensors is covering that critical target. Add to this the possibility that there can be more than one overlapped target nodes and having totally unique set of overlapped sensors covering them, or similar sets and the situation gets more complicated. Thus there is now way that all the overlapped sensors can be removed by the RSSA. Rather, after a certain point, RSSA will not do much work but only add to the computational overhead.

Another important observation is the formation of the set covers by this algorithm. One needs to follow the flow of this algorithm from the start in order to realise the issue here.

At first the algorithm forms a set cover and it is employed to monitor the target nodes. But once the set cover cannot work anymore another set cover is employed. Normally a set cover cannot work anymore because one or more of its constituent sensors run out of energy. And if we consider that RSSA has reduced the number of overlapped sensors, then if one sensor runs out of energy then there will be no more sensor that can cover all the target nodes that the died out sensor was covering. In this case the coverage constraint fails and the set cover has to be discarded. But this had happened because of only one sensor running out of energy. Now given that the creation of a set cover requires the entire algorithm to run once (along with the RSSA), we find that it is very costly. On the other hand one could have simply replaced that died out sensor with a new sensor and reemploy the set cover and that would require a lot less computational overhead.

4.2 Enhancement of the Existing Algorithm

In this paper the heuristic algorithm give in [13] is modified, and the modified algorithm is found to be superior than the previous algorithm both in terms of performance and efficiency. This present section discusses about the algorithm and the heuristics employed.

The first step is the selection of the critical target. The technique followed is the one suggested in reference [6]. The modified algorithm selects that target node as the critical target which is covered by the least number of sensors. The rationale behind this decision can be understood from the following example. Suppose there are two target nodes which are covered by 3 and 6 sensors. Then the target node getting covered by three sensors has the higher probability of running out of any sensors to cover it than the other. And whenever we have even one target node which is not getting covered then the coverage constraint fails and either a new set cover is activated or the network lifetime ends. That is why the target node which is covered by the least number of target nodes is kept as the critical target.

Once we have the critical target, we select the critical sensor. But unlike the previous algorithm which selects the sensor on the basis of the number of uncovered target nodes it is covering, the present algorithm decides that sensor that has the highest value of the product of the energy available and the number of uncovered targets it is covering. This way if there is a choice to be made between two sensors, one covering large number of uncovered target nodes but having very less energy, and other having sufficient energy but covering almost equal number of target nodes, then the latter will be selected.

Thirdly the RSSA is not employed here. This is in order to have a mix of redundant sensors and unique ones. The number of redundant sensors will be very less because of the heuristic of selecting that sensor which covers the maximum uncovered target nodes and having high energy and so is more computationally efficient than the earlier one.

Finally unlike the algorithm in reference [13], this algorithm doesn't discard a set cover once it has lived out its tenure. Rather it checks to see which sensor has run out of energy and then replaces it, thus being computationally more efficient than the previous.

The pseudocode is adopted directly from reference[13]. The only change is in line number 6 and from line number 14 to 19. In line number 6 where the critical sensor is selected, rather than selecting the sensor that covers the maximum number of uncovered target nodes, the selected sensor is one having the maximum value of the product of the energy available and the number of uncovered target nodes. Line number 14 to 19 is pretty much self explanatory where the sensors that have dried out is found out, then these are replaced by other sensors in the set cover, thus not discarding the entire set cover. clearpage

Algorithm: Enhanced Heuristic Algorithm

1. Set initial lifetime of sensors, $S_s=S$, $j=0$
2. While each target is covered by at least one sensor in S_s
3. $j=j+1$, $C_j=\emptyset$, $S_T=T$
4. While $S_T \neq \emptyset$
5. Find a critical target $k_{critical} \in S_T$
6. Select critical sensor $S_{critical} \in S$
7. $C_j = C_j \cup S_{critical}$
8. For all targets
9. If k_i is covered by $S_{critical}$
10. $S_T = S_T - k_i$
11. End For
12. End While
13. Update Lifetime
14. For all sensors S_i in C_j
15. If energy of $S_i \leq 0$
16. $S_T = U_i$
17. GOTO 4
18. Exit For
19. End For
20. End While

4.3 Simulation

The simulation is based on the exact same network as the earlier one. A stationary network with a fixed number of targets and sensors randomly deployed around the targets is simulated. The range of each sensor is considered fixed and so is the initial energy of the sensor which is kept equal for all sensors without any loss of generality.

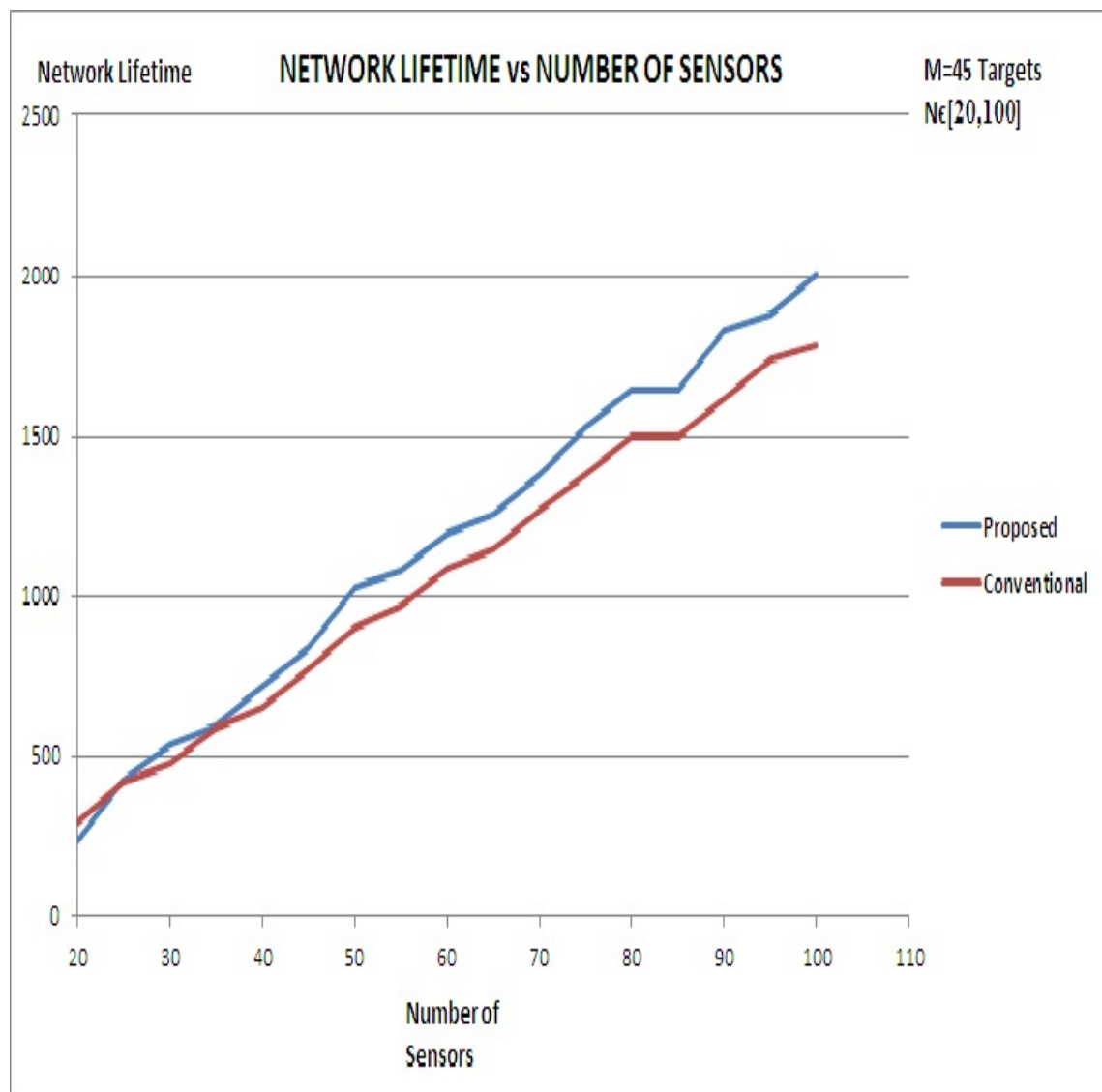


Figure 4.1: Performance of Proposed versus Existing Algorithm

4.4 Inferences

From the simulation we infer the following:

(1) The network lifetime increases with the increase in the number of sensors. This

proves the soundness of the algorithm.

(2) The slope of the graph for the new heuristic algorithm has a greater value than the older one. Thus it can be said that the rate of increase of network lifetime with the increase in the number of sensors is also higher than the previous one.

(3) For the same number of sensors, if scheduling is done according to the proposed algorithm than the network lifetime achieved will be higher than the one achieved if scheduling is done with the older algorithm.

4.5 Conclusion

In this chapter a detailed analysis of the existing technique proposed in [13] is made. Based on this observation and analysis idea for a new algorithm was developed. It is argued that the new algorithm is both computationally efficient and also outperforms the existing algorithm in maximizing the network lifetime. The reason for computational efficiency is the fact that unlike the existing technique, the present algorithm doesn't execute an extra method that selects a responsible sensor among the group of overlapped sensors monitoring a single target. Other reason is that unlike the existing algorithm, it doesn't discard the set cover that has got exhausted. rather it simply replaces those sensor which has run out of battery power by new ones.

Chapter 5

Quality of Service in terms Sensor Utilisation

In the earlier section, the issues involved with heuristic algorithms that attempt to solve the Target Coverage Problem were dealt with. Initially a simple algorithm was presented which would help in throwing more light into the actual challenges involved with solving the problem. Then an existing algorithm proposed in [13] was taken into consideration and simulated. Then the algorithm in reference [13] was modified and the modified algorithm proved to perform better and also computationally more efficient than its former counterpart.

5.1 Sensor Utilisation and Network Lifetime

In this section the work is extended further by the introduction of a new parameter that can be used to measure the overall utilisation of the network. To the best of my knowledge no such parameter has been introduced or used to measure the quality of the sensor network. Earlier the parameter used to measure the quality was Network Lifetime which was defined as the time from the initiation of the operation of the sensor network to the point in time when no other sensors are present that can be used to cover the entire set of target nodes.

Although it is agreeable that a plot of Network Lifetime versus the number of sensors gives a very reasonable account of the performance of the algorithms being employed. But no information is achieved regarding the sensor utilisation. The con-

cept of sensor utilisation will be clear soon. But firstly consider the example of a factory housing hundred machines that are run together to perform certain amount of task. The task is sub divided into a number of sub tasks and are performed by each machine. In this case, optimal performance is not the only issue. There are costs involved in buying the machines also, and hence the factory would like to employ an algorithm that can give a fairly optimum performance but also with less number of machines. If the algorithm is such that it employs a lot of machine to give an optimal performance, but some of the machines are utilised only for a small proportion of the total time and also for small proportion of the task then the costs incurred will increase thus resulting in reduced profit.

A similar case exists with the wireless sensor networks. Normally quite a large number of sensors are deployed to monitor the network. Now the network outlives its importance at the point when no other sensor can be employed to get full coverage of the target nodes. But that doesn't mean that all the sensors are exhausted. For example the network might start with say ten sensors and employing some algorithm go on forming and assigning set covers. At a certain point of time, the algorithm will find that not all but most of the sensors have run out of energy and so can't be included in a set cover. But there are still some sensors remaining that can monitor the target nodes. But together they cannot cover the entire set of target nodes and hence can't contribute to form a set cover. In this scenario we find that these sensors were not fully utilised. But procurement of these sensors from market did require extra expenses. Thus it becomes imperative that the algorithm that is employed doesn't just maximises the network lifetime but also minimises the number of sensors that remain unutilised at the end. And as we see, doing this ensuring one doesn't ensure the other, that is an algorithm that might maximise network lifetime won't minimise the number of unutilised sensors that and vice versa, that is they are quite different.

5.2 Unutilised Sensors

The new parameter introduced in this paper is Number of Unutilised Sensors. Normally the number of unutilised sensors is quite low for any algorithm and so to avoid

additional computations the parameter has been kept as the number of sensors that remained unutilised rather than percentage of unutilisation, etc. Simply put, this parameter is nothing but the count of the total number of sensors that were not used up fully before the network has lived its total working span. For the x-axis the battery power of the sensor has been taken. This is to check the sensor unutilisation of the algorithms when sensors with increasing battery power is used. And by increasing battery power we generally mean increasing cost (sensors with higher battery power are costlier than sensors with lower battery power). Two different simulations were carried out because both the simulations helped in drawing two different conclusions. In the second simulation the x-axis was kept as the number of sensors and the behaviour was noted, that is in this case the battery power was fixed.

5.3 Simulation

For the simulations we took into account the same two algorithms from the earlier chapter. The first algorithm was the conventional one and the second was the proposed one. In the first simulation we keep the number of sensors as the x-axis and vary it while recording the number of unutilised sensors. The graph is given in the next page.

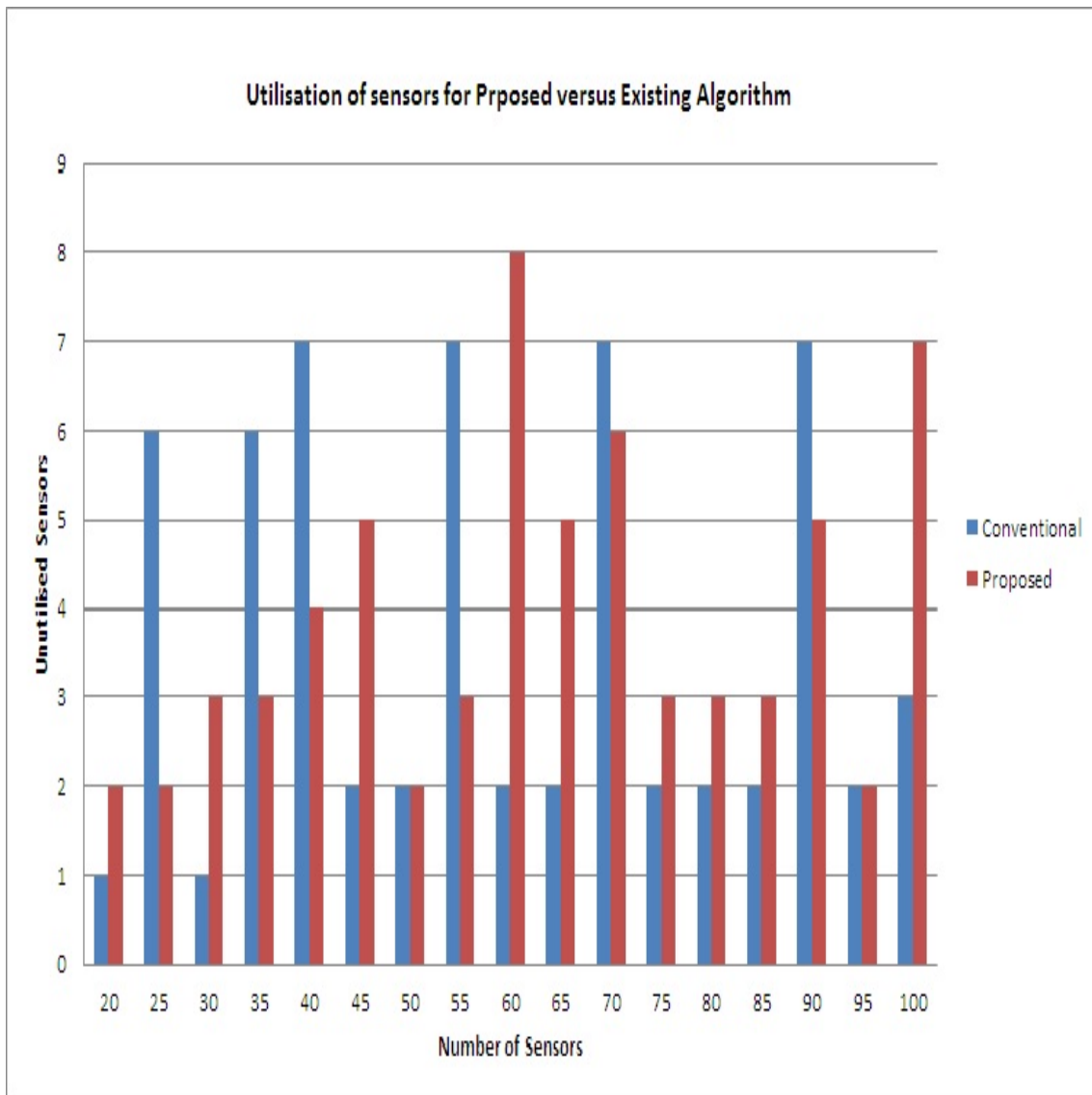


Figure 5.1: Utilisation of Sensors in Proposed versus Existing Algorithm

The second simulation uses battery power as the x-axis. We can say that the battery power is directly proportional to the cost of the sensors and hence can be said that we check the values of the unutilised sensor as we vary the cost of the sensors involved.

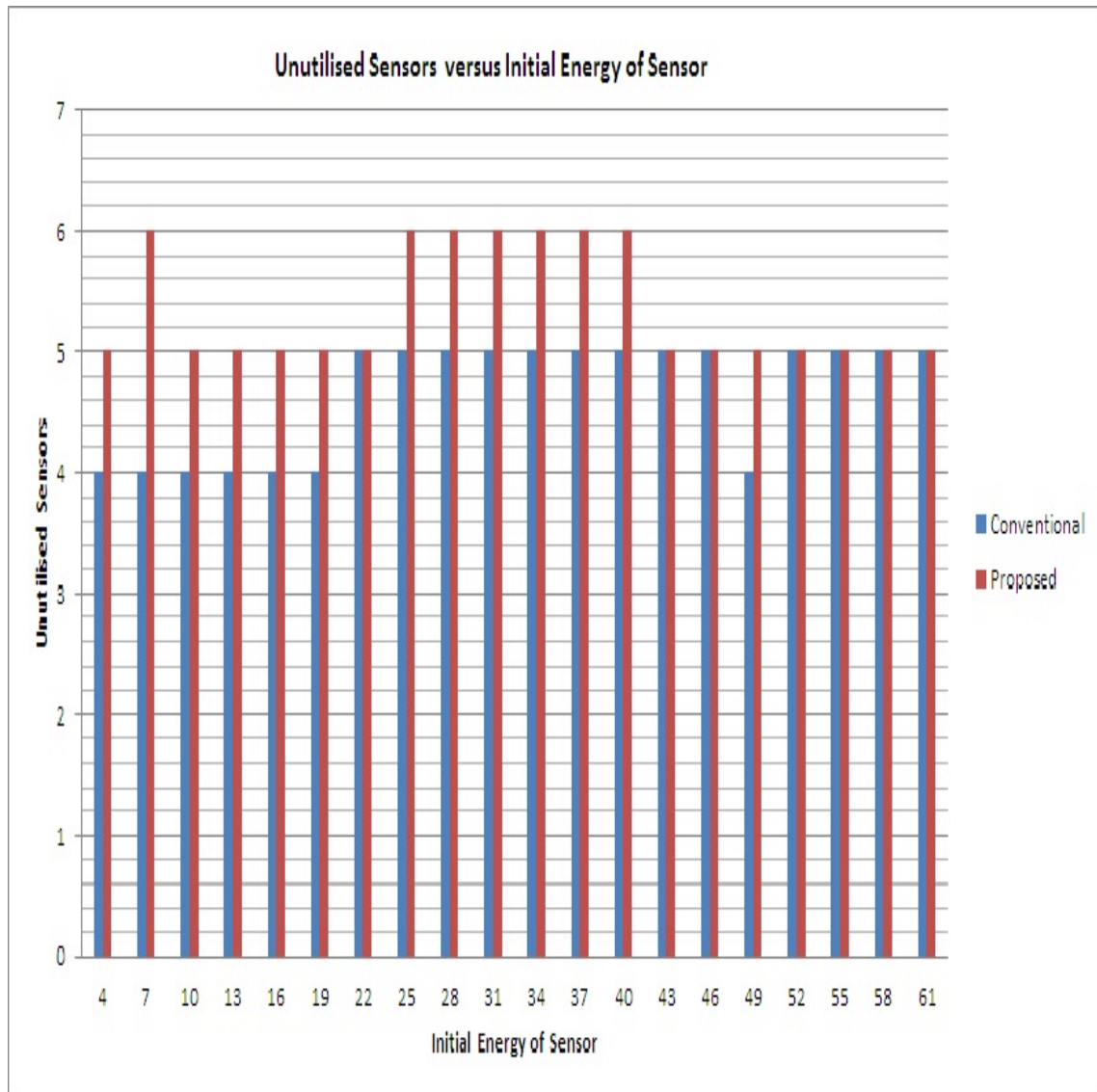


Figure 5.2: Utilisation versus Battery Power

5.4 Inferences

From the first graph it is clear that the number of sensors unutilised is more or less same for both the new heuristic algorithm proposed and the conventional one. In fact a careful observation reveals that in majority of the cases, the new heuristic algorithm provided better sensor utilisation than the conventional one.

The second graph shows that the number of unutilised sensors is almost same for both the proposed algorithm and the conventional algorithm.

So we conclude that in terms sensor utilisation, the new heuristic is as good as the conventional algorithm.

But that is not all. The second graph can be used for much more. We can see that the second graph gives the behaviour of the algorithm with the change in battery power that is the cost of the sensors. Now there can be cases where the network lifetime required is not that high but the cost is more important. In the extreme case, there might arise a scenario say, where the network lifetime achieved by two different algorithms are different but acceptable, but the number of sensors unutilised for the algorithm giving higher network lifetime is more than the other algorithm that provides with acceptable amount of network lifetime. In real life cases such scenarios are more likely than cases where the network lifetime is the only parameter to be maximised. This is because it is more likely that the information received from monitoring is required for a fixed period of time and not for infinite time. Thus it is advisable that we select that algorithm that can give an acceptable amount of network lifetime but at lesser costs, and it is obvious that the algorithm with the lesser number of unutilised sensors at the end of the network lifetime will incur lesser costs than the one having high amount of unutilised sensors.

5.5 Conclusion

In this chapter the work has been extended to formulate a totally new parameter for measuring or comparing the algorithms targeted at solving the target coverage problem. This parameter, which is nothing but the count of the number of sensors unutilised at the end of network lifetime can depict a picture of the sensor utilisation carried out by the algorithms. This parameter is important because normally even

after the network lifetime finishes, there might be sensors left with energy, which can operate but cannot actually form a set cover together. Now an algorithm that maximises the network lifetime but at the cost of large number of unutilised sensors means that it is wasting money in terms of the large number of sensors unutilised, where as another algorithm can be employed which can give almost equal performance but at lesser cost. The two conventional and the new heuristic algorithms were then simulated and we arrived at the conclusion that the new heuristic is as good as the conventional one in terms of sensor utilisation.

Chapter 6

Conclusion

Wireless Sensor Networks have found tremendous applications in various areas in the last decade or so. With such increase in demand for wireless sensor applications, there has been a rise in the research involved with solving the challenges confronting this arena. The function of a wireless sensor network is to monitor a particular area and record certain characteristics and then relay them back to a base station. And so comes the challenge of effective coverage of the target area, also called as the target nodes. Then there is also the issue of limited energy that the sensors are equipped with. Normally they are equipped with a battery and so these sensors are subjected to energy constraints. In such a case, as energy source is limited, there is a need to maximise the effective time for which a collected number of sensors can monitor the target nodes, which we call as the Network Lifetime. So the effective question is to maximise the network lifetime while subjected to energy and coverage constraints. This is known as the Target Coverage Problem in Wireless Sensor Networks. This thesis is focussed on modifying an existing greedy based technique to tackle the Target Coverage Problem which is an NP-Hard problem[4], and hence only heuristic polynomial time algorithms are known. A comparison has been made among the existing conventional algorithm[13] and the modified greedy algorithm to arrive at the conclusion that the modified algorithm performs better than the existing algorithm. Another work that has been done includes defining a new parameter that measures the utilisation of the sensors while a specific algorithm is being run.

In the remaining sections of this chapter we briefly summarise the original contributions of this study.

6.1 Conventional Algorithm

In this paper after simulating an already existing greedy based algorithm proposed in reference[13] (which in any iteration selects that sensor that covers the critical target and the largest number of uncovered target nodes), detailed analysis was made.

6.2 Enhanced Greedy Algorithm

Then the algorithm in [13] is modified, and that gives performance benefits over the conventional algorithm. The approach to modifying this algorithm has been to analyse the conventional scheme and then to find alternate techniques.

The first step is the selection of the critical target. The modified algorithm selects that target node as the critical target which is covered by the least number of sensors. The idea is taken from reference[6].The rationale behind this decision can be understood from the following example. Suppose there are two target nodes which are covered by 3 and 6 sensors. Then the target node getting covered by three sensors has the higher probability of running out of any sensors to cover it than the other. And whenever we have even one target node which is not getting covered then the coverage constraint fails and either a new set cover is activated or the network lifetime ends. That is why the target node which is covered by the least number of target nodes is kept as the critical target.

Once we have the critical target, we select the critical sensor. But unlike the previous algorithm which selects the sensor on the basis of the number of uncovered target nodes it is covering, the present algorithm decides that sensor that has the highest value of the product of the energy available and the number of uncovered targets it is covering. This way if there is a choice to be made between two sensors, one covering large number of uncovered target nodes but having very less energy, and other having sufficient energy but covering almost equal number of target nodes, then the latter will be selected.

Then the RSSA is not employed here. This is in order to have a mix of redundant sensors and unique ones. The number of redundant sensors will be very less because of the heuristic of selecting that sensor which covers the maximum uncovered target nodes and having high energy and so is more computationally efficient than the earlier

one.

Finally unlike the algorithm in [13], the modified algorithm doesn't discard a set cover once it has lived out its tenure. Rather it checks to see which sensor has run out of energy and then replaces it, thus being computationally more efficient than the previous.

The simulation result shows that the modified version performs better than the one given in reference[13].

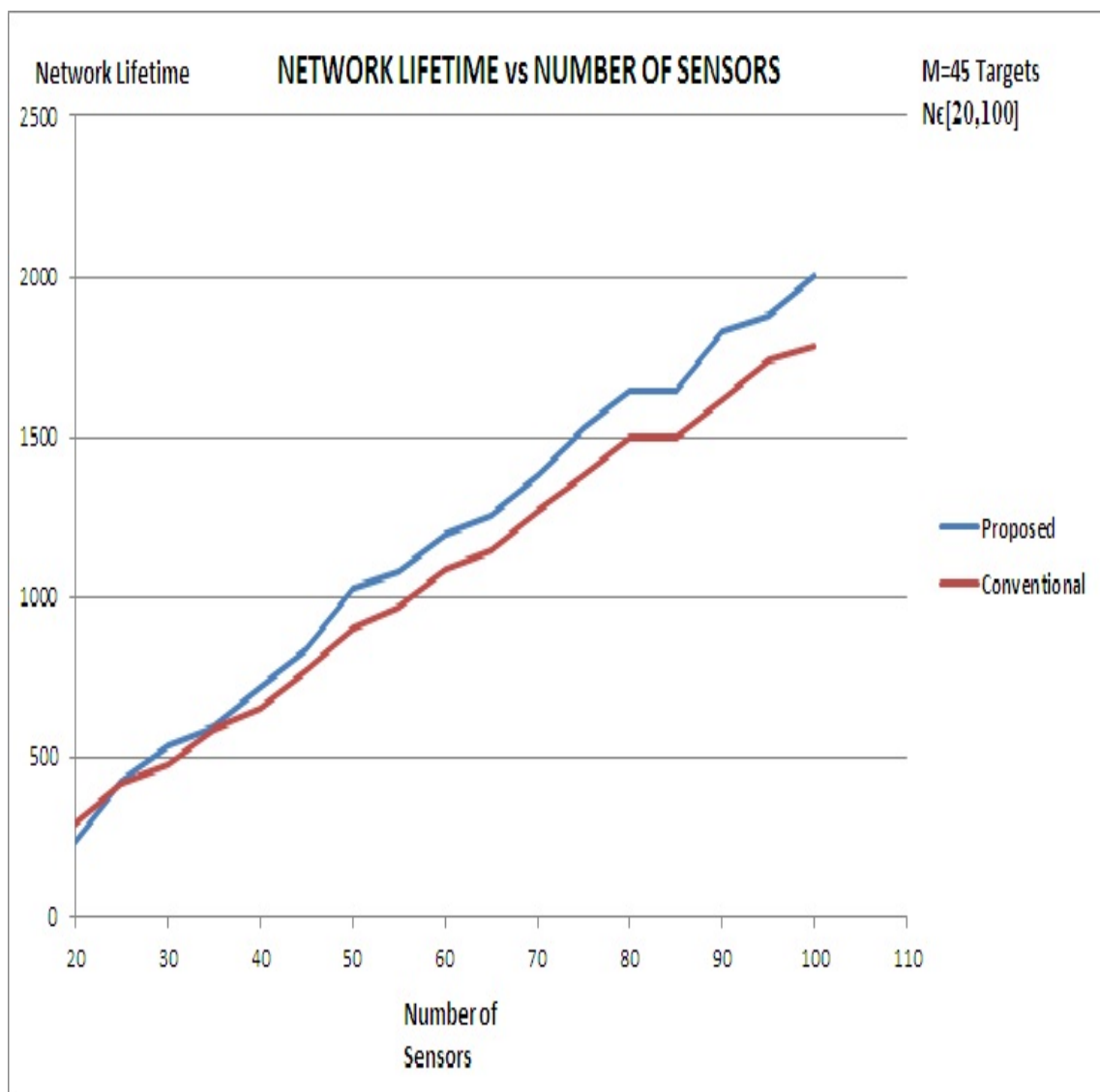


Figure 6.1: Performance of Proposed versus Existing Algorithm

6.3 A New Parameter

Another work that has been done in this thesis is the introduction of a new parameter to measure the quality of service for the Wireless Sensor Networks. This parameter is simply the count of the number of sensors that still has energy but yet cannot be deployed as they cannot together form a set cover that is simply put, together they cannot monitor the entire set of target nodes.

Usually procurement of every sensor incurs some cost, and so it is required that the algorithm uses up all the sensors possible so that the value of this parameter is as low as possible. It was found just as predicted that the new heuristic would provide better results in terms of utilisation than the conventional one. The argument provided if recapped was that the conventional algorithm is finding out a critical target and then selecting a critical sensor that can cover the critical target. Now with one simple observation we can find that the above step is not computationally efficient. The algorithm that they have given is having a complexity of the order of $O(n^4)$. Now suppose, again there are two sensors S_1 and S_2 , but with energy available as E_1 and E_2 , and where $E_1 \ll E_2$, that is S_1 is having very little energy left. Now say that for a critical target T_1 , the sensor S_1 is the best choice as it is covering T_1 and also the maximum number of uncovered target nodes and S_2 is the second best choice. In such a scenario, the algorithm will select S_1 as the critical sensor and go on forming the set cover. But once the set cover is formed and activated, it will remain operational for a very short period of time, that is the time until S_1 runs out of energy. Then once again the algorithm will run for $O(n^4)$ time until returning the next set cover which will be having S_2 as the critical sensor now. But some may argue that in any case, to increase the network lifetime S_1 will have to be activated at some point to get even the minute increase whatsoever. But even then as will was discussed in chapter 4, at the end of the network lifetime, there will always be some sensors that would still have energy left with them but cannot contribute to the construction of a set cover as they together can't cover the entire set of target nodes.

Thinking in this light we find that there is a possibility that at the end of network lifetime for the above case, there is a possibility of S_2 remaining unutilised but still having more energy than S_1 . Certainly in that case it is a loss of performance for the algorithm as if the algorithm could have just assigned S_2 before S_1 then this situation

won't have arisen and we could have seen better performance. Regardless to say, if the heuristic is designed with the motive of simply maximising the number of set covers then the network is under performing and the performance received can be improved. In the next section we will see a better suited heuristic for avoiding this problem.

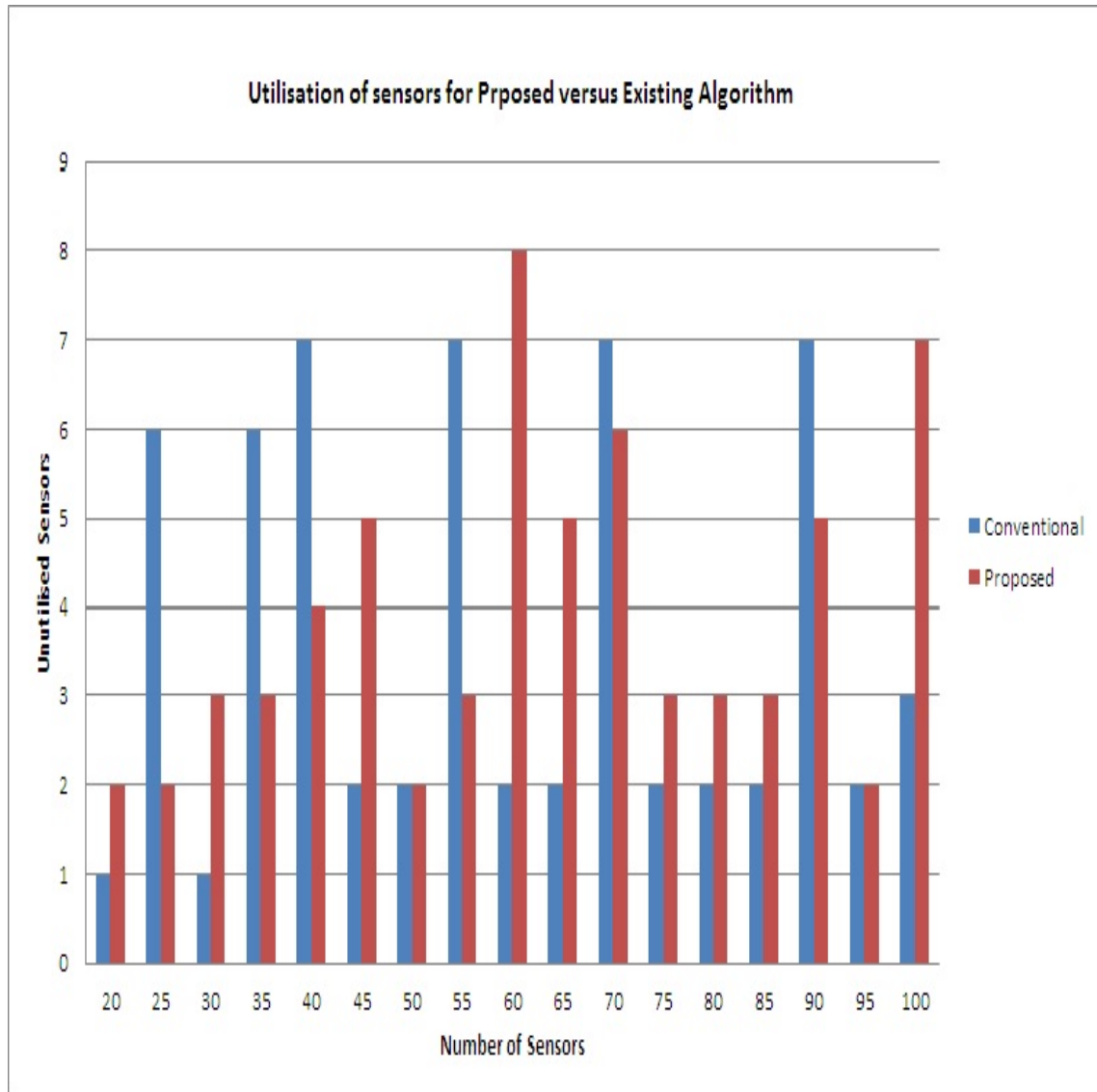


Figure 6.2: Utilisation of Sensors in Proposed versus Existing Algorithm

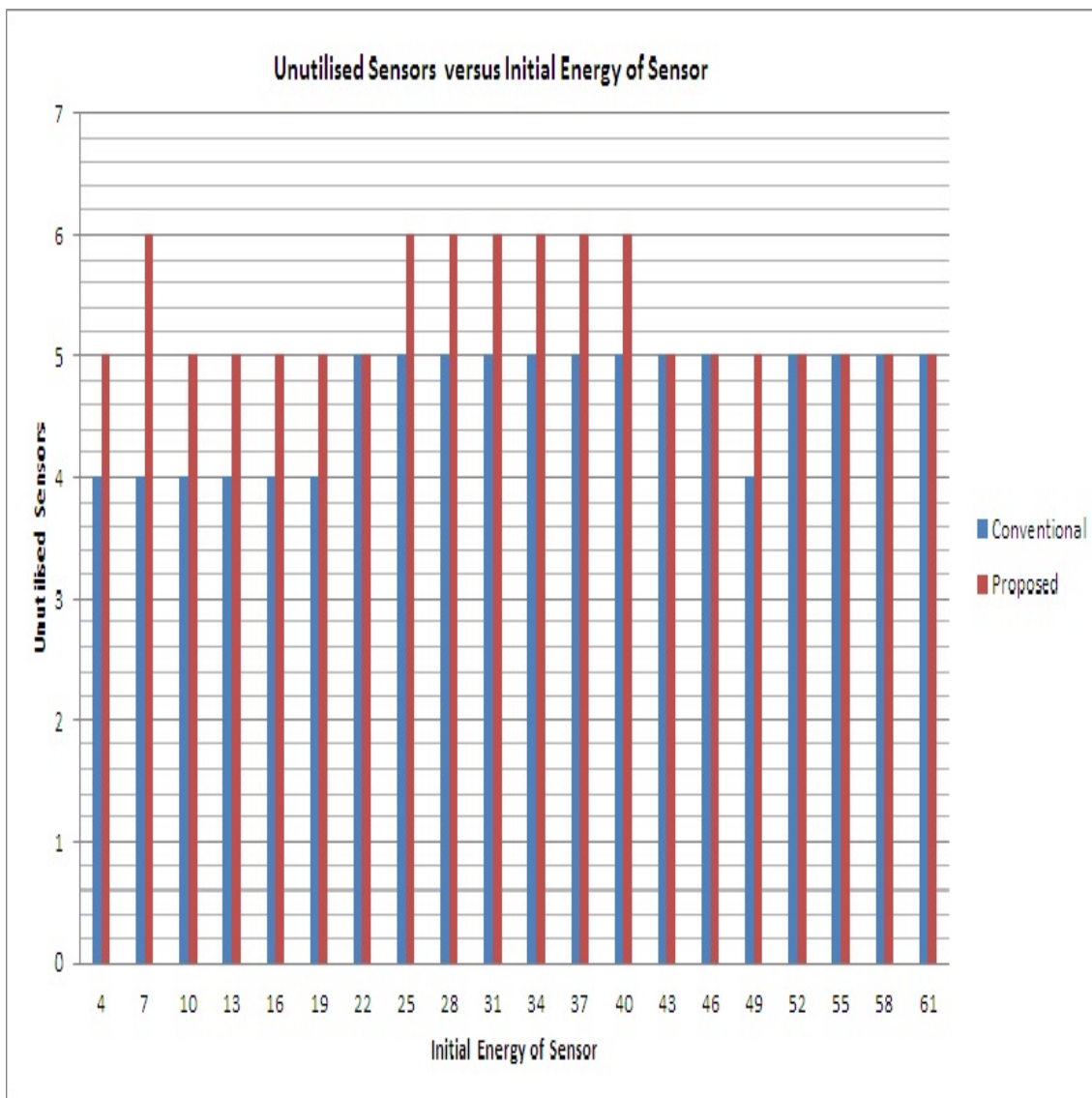


Figure 6.3: Utilisation versus Battery Power

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