ENERGY EFFICIENT MULTI-TARGET TRACKING IN HETEROGENEOUS WIRELESS SENSOR NETWORKS

A THESIS IN
Computer Science

Presented to the Faculty of the University
of Missouri-Kansas City in partial fulfillment of
the requirements for the degree

MASTER OF SCIENCE

By
Kaustubh Dhondge
B.E. Computer Science, RTM Nagpur University, 2008

Kansas City, Missouri
2011

ENERGY EFFICIENT MULTI TARGET TRACKING IN HETEROGENEOUS WIRELESS SENSOR NETWORKS

Kaustubh Dhondge, Candidate for the Master of Science Degree

University of Missouri-Kansas City, 2011

ABSTRACT

Tracking multiple targets in an energy efficient way is an important challenge in wireless sensor networks (WSNs). While most of the prior work consider tracking multiple targets as execution of single target tracking algorithms multiple times and utilize only single parameters for efficient energy consumption, we identify multiple parameters that can influence the energy efficiency of sensors in the WSN. We observe that there are several impacting parameters that can affect the energy efficiency of the sensors in the WSN which are: the relative location of the sensor with respect to the target's motion, multiple targets tracked by the sensor, and the remaining energy in the sensor. These impacting parameters are used to decide the tracking state of the sensors and further, our observations reveal the implications of combining these parameters and we identify that the optimal energy consumption is governed by their usage in particular network conditions. Based on these observations we proceed to propose our Adaptive Multi-Target Tracking (AMTT) algorithm that can identify the local network conditions for individual sensors in distributed environment without any centralized co-ordination, and uses required combination of impacting parameters to achieve energy efficiency.

The faculty listed below, appointed by the Dean of the School of Computing and Engineering, have examined a thesis titled “A Layered Mobile Target Tracking System”, presented by Kaustubh Dhondge, candidate for the Master of Science degree, and certify that in their opinion it is worthy of acceptance.

Supervisory Committee

Baek-Young Choi, Ph.D., Committee Chairperson
CSEE Department
School of Computing and Engineering

Cory Beard, Ph.D.
CSEE Department
School of Computing and Engineering

Praveen Rao, Ph.D.
CSEE Department
School of Computing and Engineering

CONTENTS

ILLUSTRATIONS

Figure

Chapter 1

Introduction

Wireless Sensor Networks (WSNs) are being used increasingly to track targets in battlefields, wildlife or habitat monitoring, and monitoring of hazardous chemicals while they are in transit. When the sensors have targets within their sensing range, the sensors collect target signatures and relay them back to the base station. At the base stations, target signatures from all the sensors are collected and processed to identify the next location the target might move to. Because of the nature of deployment environment involved, these sensors cannot have a fixed or permanent source of power and hence, are equipped with batteries to run on. While this increases the sensor's versatility, it also introduces energy limitations. This problem can be alleviated by using the sensors responsibly, i.e. the sensors are scheduled to operate in different operational modes depending on local network conditions to save their energy.

The targets typically move about in the environment, and might move off to a location in the WSN which is not monitored by desired number of sensors. In conditions like these it is attractive to have mobility capability among the sensors. Recent advances in the field have made it possible to have mobility capability among the sensor nodes. Even then, such mobile sensors tend to be costly and having a combination of mobile and static sensors reduces the deployment cost. We define such a WSN with heterogeneous mix of static and mobile sensors to be a Heterogeneous WSN. Mobility of sensors is still an expensive activity in terms of energy, and thus it becomes important to decide carefully which mobile sensors should be moved to track targets while keeping in mind the future requirements of the WSN.

1.1 Problem Statement

In many practical scenarios, there are multiple targets in the environment which have to be tracked by at least n sensors ($n \geq 1$) for better accuracy in target localization by corroborating the results. One of the well-known instance is the use of $n = 3$ in the trilateration method used for target localization. The rest of the sensors that cannot sense any target within their range should not be kept on. We consider different operating modes for sensors in form of SLEEP, READY, ON and MOVE to save their energy. The goal of this work is to determine the operational status of individual sensors based on their local environment to optimize the overall energy consumption.

1.2 Components of Wireless Sensor Networks

A typical Wireless Sensor Network is shown in Figure 1.1. The three distinct elements that make up of most Sensor Networks are: Base Station(s), Sensor Nodes and Targets

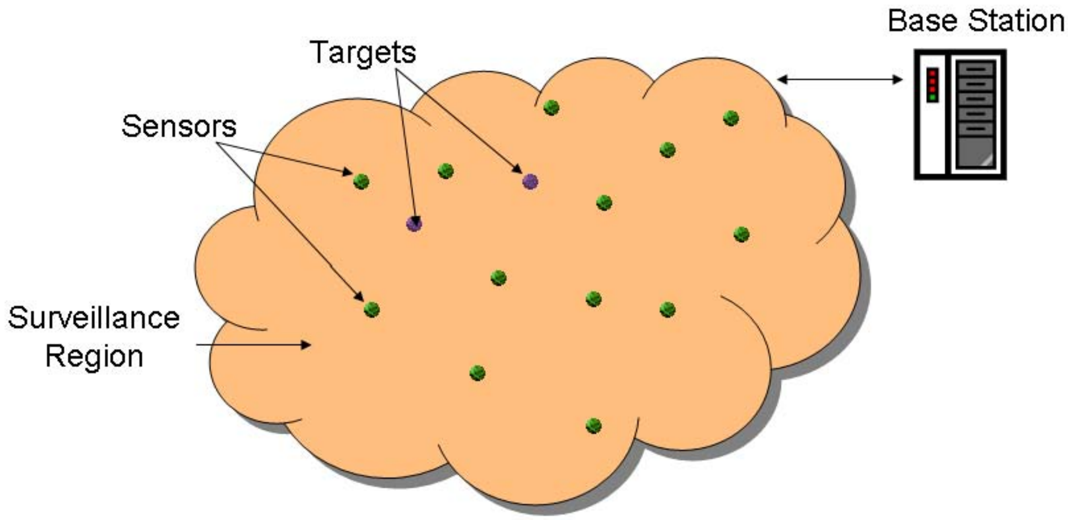

Figure 1.1: A basic Sensor Network composed of a Base Station, multiple Sensor Nodes and multiple Targets.

The Sensor Nodes, often called just as Sensors are scattered across a uniform or non-uniform Surveillance Region. These Sensors track the Targets that are within their surveillance range and report the gathered data to the Base Station. The Targets could be mobile and roaming in within the Surveillance Region in a known or a random pattern. In this work, we consider the targets to start at random locations and follow a linear path of motion.

1.3 Characteristics of Wireless Sensor Networks

The wireless sensor networks have a distinct set of characteristics that have a huge impact on their functioning and capabilities. The major area of concern is the limited battery power of the sensor nodes. A naïve way of using the available sensor nodes can seriously reduce the efficiency of sensor network by reducing the lifetime and can also affect the coverage of the surveillance region during the lifetime of the network. Some of the sensors can be turned off to conserve their energy. These nodes are then made available for future use and thus it helps in increasing the network lifetime and ensuring a better coverage of the network. The networks are also characterized by low bandwidths and the sensors lack high computation capabilities.

1.4 Our Approach to Target-Tracking in Heterogeneous WSNs

Most of the related studies until this point have considered multi-target tracking as an extension of single target tracking algorithm multiple times. Also, to achieve energy efficiency they use single or few parameters. Whereas, we have identified a set of parameters that can influence the energy efficiency of the WSN based on local environment conditions around individual sensor in a distributed environment. These impacting parameters include: the relative location of the sensor with respect to the target's motion, multiple targets tracked by the sensor, and the remaining energy in the sensor. We carry out extensive simulations to observe their effect on the energy efficiency of the WSN individually and in a combined manner. We observe that their effectiveness is governed by the different network conditions. Based on these observations, we propose the Adaptive Multi-Target Tracking (AMTT) algorithm. This algorithm is capable of identifying the correct set of parameters for individual sensor to determine its tracking state based on its local network conditions in a distributed environment which renders any centralized coordination unnecessary.

1.5 Outline

The rest of the thesis is sectored into four chapters. In Chapter 2, we cover the other notable work done in this field along with their shortcomings. Chapter 3 discusses in detail about our approach to solve the above mentioned problem and explains the algorithm developed using examples. In Chapter 4 we explain the simulation set up, the results obtained and their interpretation. Chapter 5 deals with the conclusions that can be made from this study and the scope of further research is this area.

Chapter 2

Related Work

A lot of research has being carried out in the field of target tracking using WSNs. Some of the significant works that deal with target tracking are [2], [3], [4], [5] and [6]. Many recent works aim at exploiting network heterogeneity in the wireless sensor network by introducing both static and mobile sensors in the network [7], [8], [9], [10], [11]. In accordance with these works we introduce mobility in some of the sensors in our environment to facilitate better target tracking and focus on making this activity as energy efficient as possible. A new trend is also developing in using game theory approaches for solving and strategizing mobility problems of sensors in the WSNs [12], [13], [14]. In [13] and [14], the sensors move actively to improve surveillance quality but the power consumption of locomotion is not explicitly considered [12].

In this chapter we discuss some of the above mentioned works in brief. This involves the contributions of these approaches, their shortcomings and how our work helps in overcoming them.

In the work done by Xing, et al. [7], the authors explore efficient use of mobile sensors to address limitations of static WSNs for target detection. Their proposed data-fusion-based detection model allows static and mobile sensors to collaborate in target detection. They also propose an optimal sensor movement scheduling algorithm to minimize the total moving distance of sensors while achieving a set of spatiotemporal performance requirements that include a high detection probability, low system false alarm rates and a bounded detection delay. While scheduling their sensors for moving to a new location their complete focus is on minimizing the total distance travelled by the sensors. Because of this a node that lies in the path of the target's motion and that can potentially track a target in near future is moved to a new location. It's necessary to avoid such scenarios. Our proposed algorithm specifically tries to avoid moving a sensor that can possibly track a target at later stage.

Chin, et al. [14], propose a coordinating protocol for sensors to collaboratively track targets in sensor networks. The sensors form a cohort opportunistically to limit the target's degree of freedom in escaping detection. They also minimize the overlap in the spatial coverage of this cohort's members. Though this technique is effective, it fails to extend to a heterogeneous type of sensor network. Having all sensors with mobility can be expensive and a heterogeneous model can solve that problem. Also the authors fail to consider the cost of these operations in terms of energy consumed which is an important factor in such networks.

In the work done by Abdelkader, et al. [2], a multi-target tracking framework is proposed which is based on use of Voronoi tessellations. Two mobility models are proposed to control the coverage degree according to target presence [2]. Their goal is to allow the detection of targets using multiple sensors and to discover redundant sensors. Their approach helps them in determining the locations where the probability of the occurrence of target is more as compared to rest of the area. They also propose a way to discover redundancies in the network to improve the cost effectiveness of the overall wireless sensor network. Simulations carried out by them are in favor of their approach. The main drawback of this study is that it does not extend to multiple targets and it fails to consider a very important criterion while carrying out sensor motion – the battery power. It is essential to consider this factor while moving sensors because it consumes a lot of battery power and can lead to leaving the sensors in a depleted energy state.

Kim, Mechitov, et al. [3], study the feasibility in using binary proximity sensors for tracking targets. They propose a system in which the sensor output is used estimate individual positions in the path of the target in the near past and find a line that gives an estimate that best fits the path points. This is in turn used to find out the current location of the target. Though the approach used is novel and effective for single target tracking, the main drawback of this work is its inability to track multiple targets. The ability to track multiple targets by a single sensor goes a long way in the efficient use of the network resources and helps to a great extent in increasing the network lifetime and robustness.

In [5], the authors propose two sleep-awake protocols that help in achieving a high quality of surveillance and reducing the overall power consumption in the components of the network. They also suggest a set of pointers to efficiently deploy sensors in target tracking applications. Their approach of having the sensors operate in different working modes is exploited by us in deciding on which nodes need to be in ready state to track a target. Again, the major drawback of this study is that it does not take into consideration target tracking for multiple targets.

In our study we try to solve the problem of multiple targets tracking in WSNs considering significant factors like using multiple sensors to track a single target, using a single sensor node to track multiple targets if possible and all this in a setting where the targets and some of the sensors are mobile in nature. The parameters that are used in deciding which sensor nodes to turn on, which sensor nodes to turn off, which sensor nodes to be kept in ready state and which ready state sensors to be moved to watch sensors are: the number of targets the sensor can watch, the location of the sensor with respect to the path of motion of the target, the battery power of the sensor node and the number of targets the ready state sensor node can watch if it is moved. The sensors have to dynamically decide which set of parameters are to be used depending on their neighbor network densities so that optimal performance is obtained in terms of sensing and saving the battery power.

In the next chapter we discuss the approach formulated by us in detail and explain the algorithm developed using examples.

Chapter 3

Proposed Multi-Target Tracking System

In this chapter we explain the approach designed by us to solve the problem of tracking multiple mobile targets in wireless sensor network In a step wise manner we will cover the problem that needs to be addressed, the environment that is consider for the system, the significant factors that contribute in decision making, the algorithm we design to solve the problem and a set of examples to help understand the working of the algorithm.

3.1 Problem Definition

In this section we formulate the target tracking problem that we address in the wireless sensor networks. Also we explain why it is necessary to address this issue.

Our goal is to decide which sensor nodes should be turned ON to track a target, which should be kept READY and which ones should be turned off. In case the number of sensors tracking a target is less than the minimum required value, we need to decide which mobile sensors from a READY pool of sensors should be moved in to watch the target. These cases need to be addressed in a distributed system of sensor nodes in a prioritized as well as a weighted model for deciding factors.

Multiple target tracking is an important aspect of WSNs and if the above problem is not tackled in an intelligent way, it can lead to a reduced system performance in terms of its lifetime as well as the coverage offered. Proper scheduling of sensor nodes and correct movement of sensor nodes to track multiple targets can help in attaining efficiency in the battery consumption of the sensor nodes. This is turn helps in increasing the overall system performance by increasing the lifetime of the sensor network and offering a better coverage.

In the next section we discuss the environment that we consider for the wireless sensor network system. It is important to understand the environment as it has some unique conditions which the proposed algorithm exploits to offer an efficient solution.

3.2 System Environment

In this section we list the various components of the system and the entire setup of the system environment.

The wireless sensor network has a defined area and the set of sensors with mobility heterogeneity are randomly scattered within this area at the beginning of the network lifetime. The targets are mobile in nature and keep moving throughout the lifetime of the network and need to be tracked by a minimum number of sensor nodes till they are within the boundaries of the wireless sensor network. All the targets have an uncorrelated movement pattern i.e. the targets are randomly scattered and they have different directions of motion. The mobile sensors move to the required new position only when they are elected to move to track target(s). The sensor may be elected to move or it might make the decision itself based on the nature of the system i.e. weather it is a centralized system or a distributed one. The sensors can be in track mode and turned ON if the target(s) are within their sensing range. If the target is outside their sensing range, but within a certain distance, the sensors can be in READY mode for that target(s).

In the next section we discuss which factors play an important role in deciding which sensors nodes should be turned ON or OFF and if needed, which sensor nodes should be moved to track the target(s).

3.3 Significant factors in ON/OFF/MOVE decision making

In this section we discuss the factors that help us in deciding which nodes should be turned ON to track particular target(s), the nodes that need to be turned OFF, which should be kept READY and in case if needed which mobile sensors from the READY pool should be moved and turned ON to track the target(s).

The first criteria in deciding which sensor nodes should be turned ON is the number of targets that the particular sensor node can track if turned ON. If a sensor node can track multiple targets then some other redundant sensors nodes can be turned off and their power can be conserved for use at some later time during the lifetime of the sensor network.

Next in line is the position of the sensor with respect to the movement of the target. It is more useful to keep those sensor nodes turned ON that have the maximum proximity to the path of the motion of the target as these nodes can still be useful in near future when the target moves. In case of sensor nodes that don't lie in the path of the motion of the target, the target might move out of their sensing range in near future and hence they should have a lower priority over those sensor nodes that lie in the path of the motion of the targets.

Lastly, the nodes with higher battery power get preference over the nodes with lower battery power. Choosing the nodes with higher battery power can help in maximizing the time that the minimum number of required nodes should watch the target. If some node looses all its battery power then the target needs to be allocated with a new set of sensor nodes to track it.

While deciding on which mobile nodes to MOVE to watch a target if needed, the same set of parameters that are mentioned above are used. The only difference is that for moving, the sensor nodes that do not lie in the path of motion of the target and are in READY state for that target are given a higher preference over those sensors that lie in the path of the motion of the target and are in READY state for that target.

In the following two sections we describe the algorithms for the centralized system and the distributed system

3.4 Algorithm for a centralized system

In this section we describe the algorithm for the Centralized Layered Mobile Target Tracking System.

Input: Set of Sensor Nodes and Targets randomly located in the Surveillance Region.

Output: Sensor Nodes to be turned ON and for which Target(s), Sensor Nodes to be turned OFF and Sensor Nodes that needs to be MOVED and for which Target(s).

Step1: Sensor Nodes are randomly scattered in the Surveillance Region.

Step 2: Base Station gathers information on which Sensors can track which Targets, which Sensors can be ready for which Targets, the location of Sensor with respect to Target's path of motion, the battery power of the Sensors and their corresponding Sensor ID.

Step 3: The Base Station sorts this information in the descending order of triplets – Number of Targets the Sensor can watch, the location of the Sensor and the Battery power of the Sensor or combines them by assigned weights

Step 4: For each Target, if there are more than or equal to 'n' Sensors in a position to track it the Base Station picks the 'n' best Sensors to turn ON based to criteria mentioned above. All the Sensors in position to be in ready mode for the target are turned to READY. Rest all other Sensors are turned OFF. Here 'n' is the minimum number of Sensor that should watch the target at any given time and 'n' is greater than one.

Step 5: For each Target where 'n' Sensors are not available to track it, selects the deficit number of Sensors from that particular Target's READY state Sensor pool. Decision is made in a made based on maximum Targets the Sensor can track if moved, least proximity to the path of motion of Target and highest battery power available.

Step 6: GOTO Step 2 for next iteration when the Targets move.

3.5 Adaptive Multi-Target Tracking Algorithm (AMTT)

In this section we describe the proposed Adaptive Multi-Target Tracking Algorithm (AMTT) using pseudo code.

Input: Set of Sensor Nodes and Targets randomly located in the Surveillance Region.

Output: Sensor Nodes to be turned ON and for which Target(s), Sensor Nodes to be turned OFF, Sensor Nodes to be kept READY and Sensor Nodes that needs to be MOVED and for which Target(s).

For each sensor(i)

TargetDistance=sqrt((sensor(i).x-target(j).x)*(sensor(i).x-target(j).x) + (sensor(i).y-target(j).y)*(sensor(i).y-target(j).y))

Check Number of Neighbors

if below Threshold

sensor(i) acts in sparse network mode

else sensor(i) acts in dense network mode

if TargetDistance<=SurveillanceRange

sensor(i) can track target

else if TargetDistance<=ReadyRange

sensor(i) turns READY

else sensor(i) turns OFF

if sensor(i) can track target j

get info of each sensor that can track target j

[((WeightPriority(k)*sensor(k).w)/5)+(DirectionPriority(k)*(SensorVector(k)* TargetVector(j)*cos((target(j).angle-sensor(k).angle))/abs(SensorVector(k)-TargetVector(j))))+((PowerPriority(k)*sensor(k).p)/100) k]

if sensor(i) in top ‘n’

sensor(i) turns ON

else sensor(i) turns READY

if sensor(i) READY and MOBILE

if Target tracked by < n sensors

get info from each sensor that is READY and MOBILE

[((WeightPriority(l)*sensor(l).rw)/5) (DirectionPriority(l)*(SensorVectorLength(l)* TargetVectorLength(j) *cos((target(j).angle-sensor(l).angle))/abs(SensorVector(l)-TargetVector(j))))+((PowerPriority(l)*sensor(l).p)/100) l]

if sensor(i) in top ‘m’ sensors

sensor(i) MOVES and turns ON

3.6 Examples

In this section we explain some examples that help in understanding the proposed approach to solve the multi target tracking problem in wireless sensor networks.

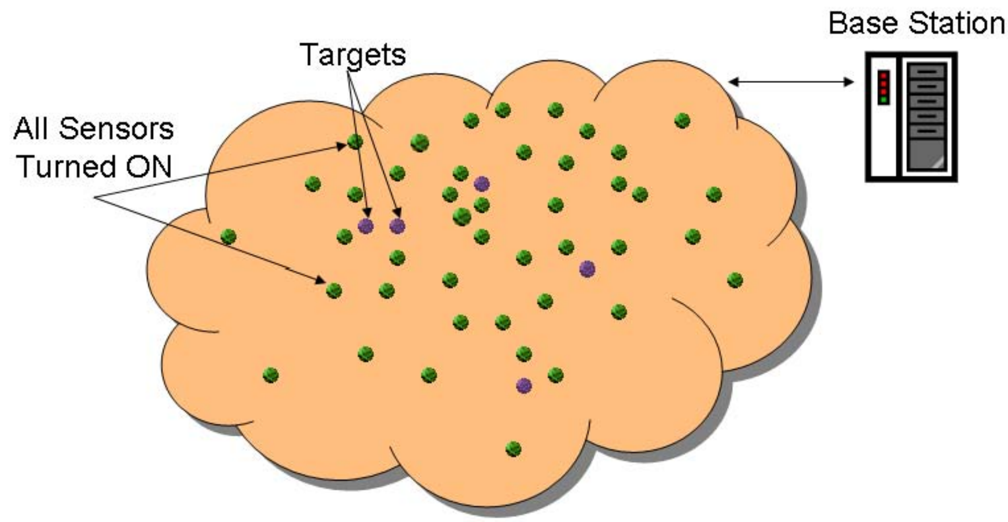

Figure 3.1: A naïve target tracking system in which all the Sensors are ON

Figure 3.1 represents a very naïve approach to tracking multiple targets in a WSN. Here all the Sensors are turned ON to track the targets irrespective of weather they can track a target or not. This approach leads to a reduced system performance as the network lifetime is reduced. This occurs because the Sensors keep loosing battery power even if they are not tracking a target.

Hence the next step is to determine the sensor nodes that can track the target and turn them ON, determine the sensor nodes that can be in READY state and if the sensor nodes do not satisfy this condition, we turn them OFF.

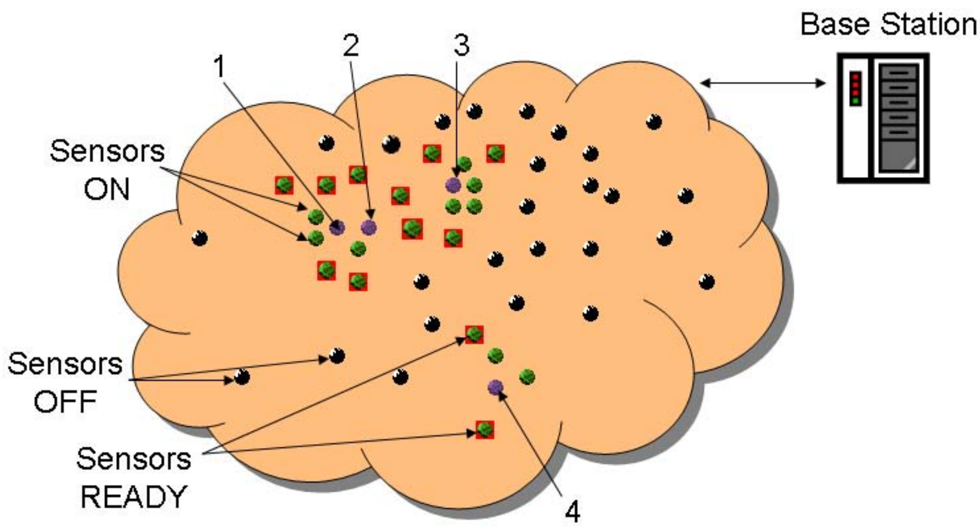

Figure 3.2: Intermediate step of Sensor allocation

In Figure 3.2 we can see that the sensors that can track a target are turned ON, the sensors that can be in READY state are turned READY and rest of the NODES are turned OFF. This helps us in saving the power of the sensor nodes. Now if each target needs to be tracked by three sensors at any given time, we can observe that Target 1 is being tracked by exactly three sensors. Target 2 is being tracked by only one sensor but it has sensors that are in READY state for it. Hence we move sensors for Target 2 from its READY pool considering the criteria mentioned in the above algorithm. In case of Target

3, there are more sensors turned ON than what is required. Hence we need to pick the three best sensors based on criteria above and turn OFF the rest of them. Target 4 has only two sensors tracking it so we move in one sensor from its READY pool.

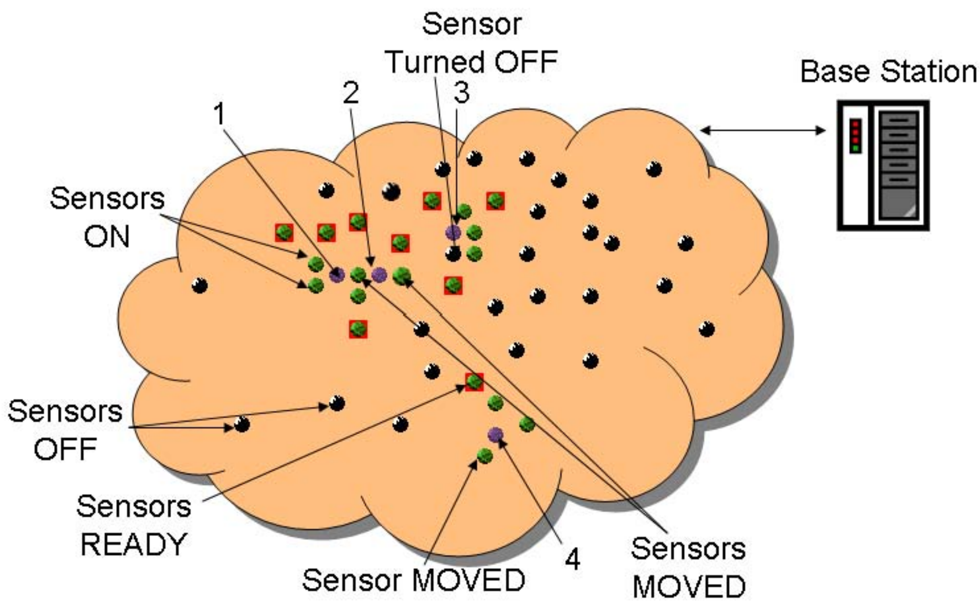

Figure 3.3: Final stage of Sensor allocation

In Figure 3.3 it can be observed that once we implement our algorithm more unnecessary Sensors can be turned OFF and better coverage can be obtained.

In the next chapter we discuss the Simulation set up and interpret the results obtained from the simulation.

Chapter 4

Simulation Setup and Results

In this chapter we discuss the simulation setup in details and next we provide the interpretation of the results obtained from them.

All the simulations are carried out in Matlab Version 7.5.0. The network is of 100 * 100 square units in area. The number of sensors is varied form 50 to 400 with increments of 25. If a sensor can contact 3 or more neighbor sensors, it perceives the network as dense network or else it perceives it as a sparse mode network. The number of targets is 5. All the targets start at a random location in the WSN and have no correlation in their movement patterns. The WSNs heterogeneity is set at 75%. This means that 75% of the sensor nodes can be mobile. Depending on weather it is a dense mode or a sparse mode network, the sensors exchange the following information with their neighbor sensors: maximum number of targets the sensor can track, sensors location and its remaining battery power.

For comparison purposes, we consider a Base Line Algorithm. This Base Line Algorithm also consists of a distributed system approach where each target is tracked by n sensors. The main difference from our proposed algorithm is that random sensors choose to track the targets. In case n sensors are not available to track the targets, the required numbers of mobile READY sensors move in to track the targets in a random fashion.

In the following sections we will explain how the optimal combinations of impacting parameters are recognized and used in the AMTT depending on the local network conditions of the sensor.

4.1 Impact of Basic Parameters

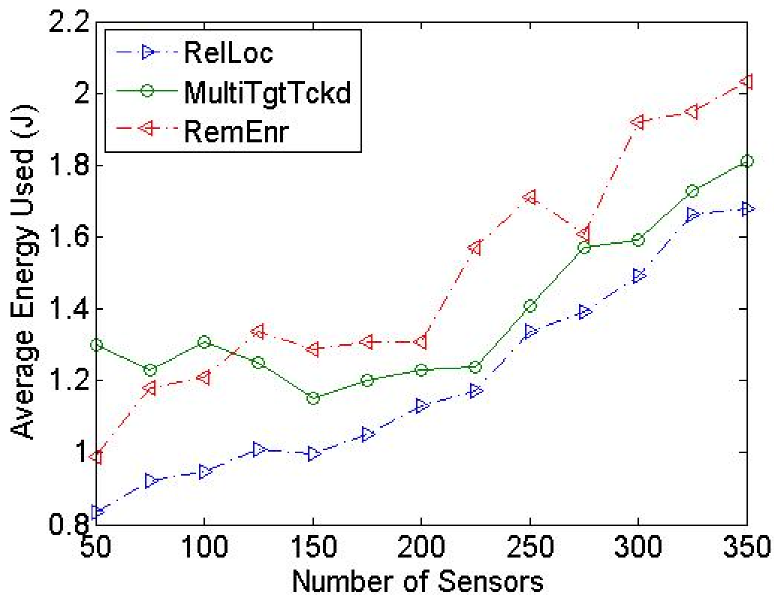

Figure 4.1: Evaluating Basic Parameters

In this section we explore the impact of individual parameters on energy efficiency of the WSN. In Figure 4.1 it can be observed that using only Remaining Energy as impacting parameter leads to worst performance in terms of overall energy savings. Multiple-targets tracked by sensor gives an improved performance in the mid to high sensor densities. The parameter Relative Location of Sensor wrt to targets motion performs best individually. However the factor Remaining Energy cannot be ignored as it is an important factor in improving the network lifetime especially at low network densities as can be seen from Figure 4.2.

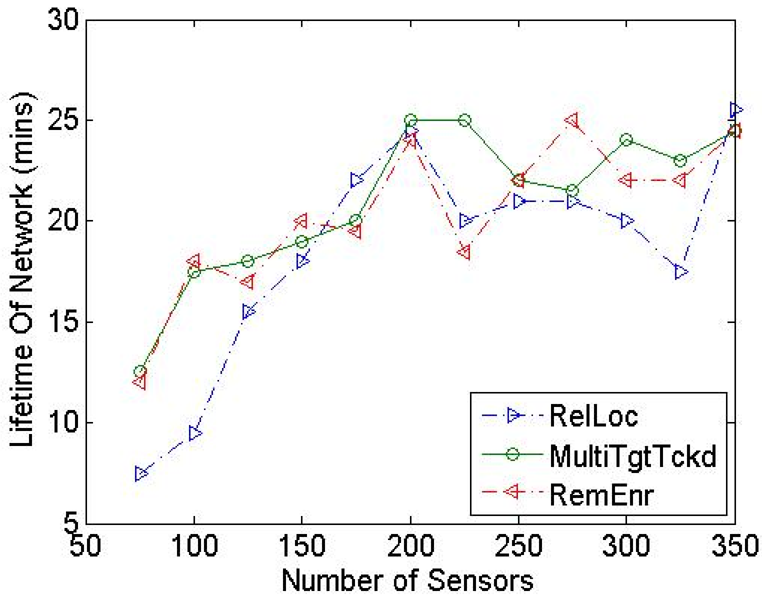

Figure 4.2: Evaluating Basic Parameters for Lifetime

4.2 Impact of Combining the Parameters

We have observed that combining the impacting parameters is useful and the performance actually improves in terms of energy savings. Even if it doesn't improve, it is at least as good as the individual parameter that performs the best.

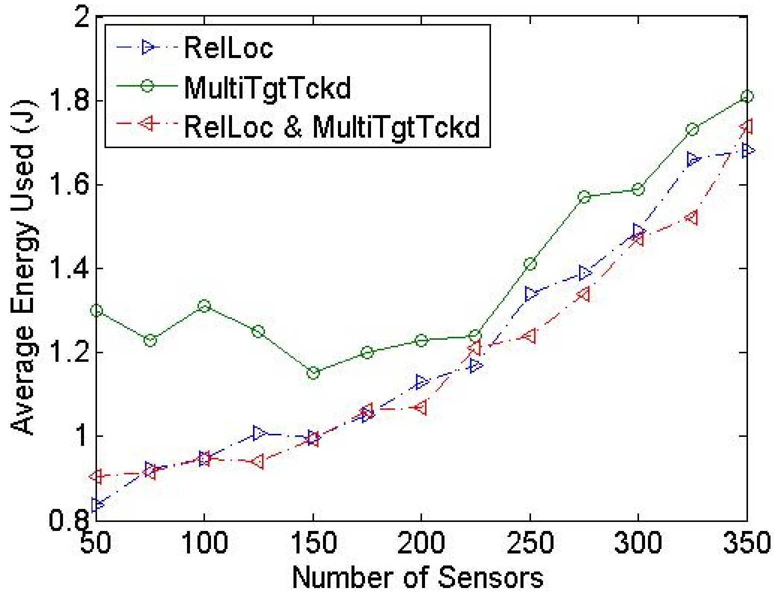

Figure 4.3: Combining Relative Location & Multi-Targets Tracked

From Figure 4.3 it can be seen that combining Relative Location and Multiple-targets tracked by sensor gives optimal performance in mid to high network densities. From Figure 4.4 it can be seen that Relative Location and Remaining Energy gives optimal performance in low to mid network densities.

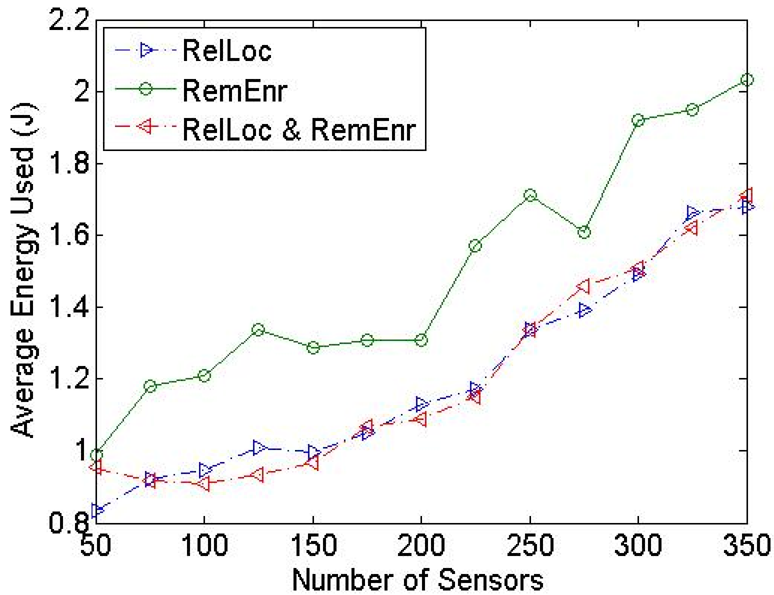

Figure 4.4: Combining Relative Location and Remaining Energy

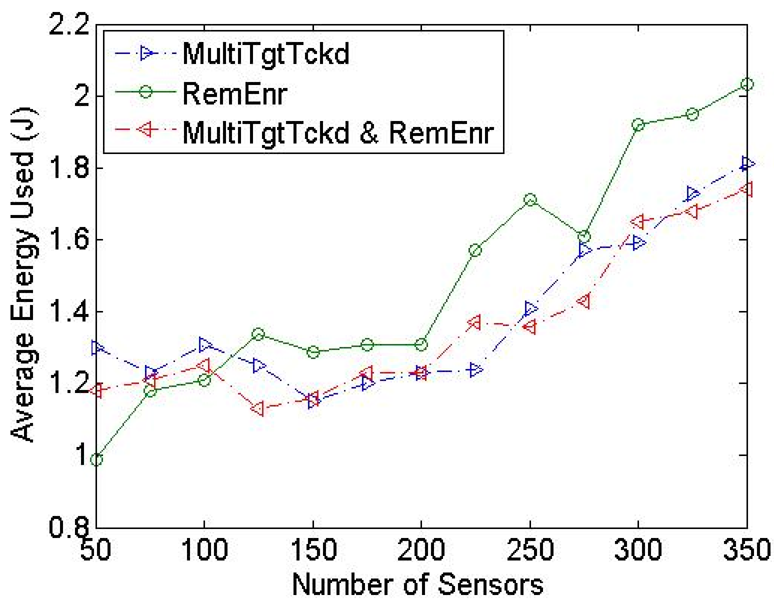

Figure 4.5: Combining Remaining Energy and Multi Targets Tracked

4.3 Required Parameters for AMTT

In this section we identify the combination of parameters that are most effective in minimizing energy consumption based on specific network conditions. From Figure

4.6 it can be seen that Relative location and Remaining Energy perform the best for low to mid network densities and Relative Location and Multiple-targets tracked by sensor performs the best for mid to high network densities. So to achieve optimal performance across all network densities, we have to bridge this transition.

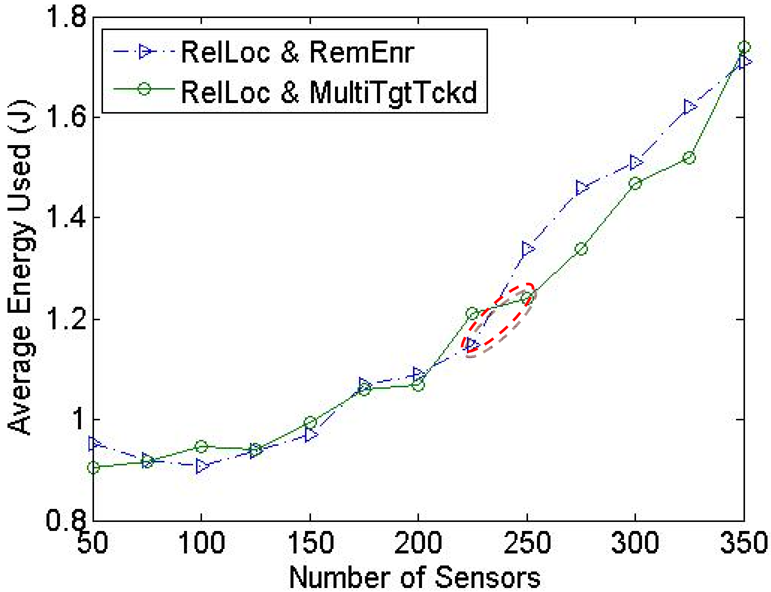

Figure 4.6: Required Parameter Combinations

So while designing the AMTT algorithm, the intuition is to have the sensors select their set of impacting parameters based on local network conditions. The sensors choose their operational mode – either dense or sparse based on the number of neighbor sensors they can contact. In a sparse mode, AMTT chooses Relative location and Remaining Energy and in a dense mode AMTT chooses Relative Location and Multiple-targets tracked by sensor. As can be seen from Figure 4.7, AMMT achieves its desired performance pattern.

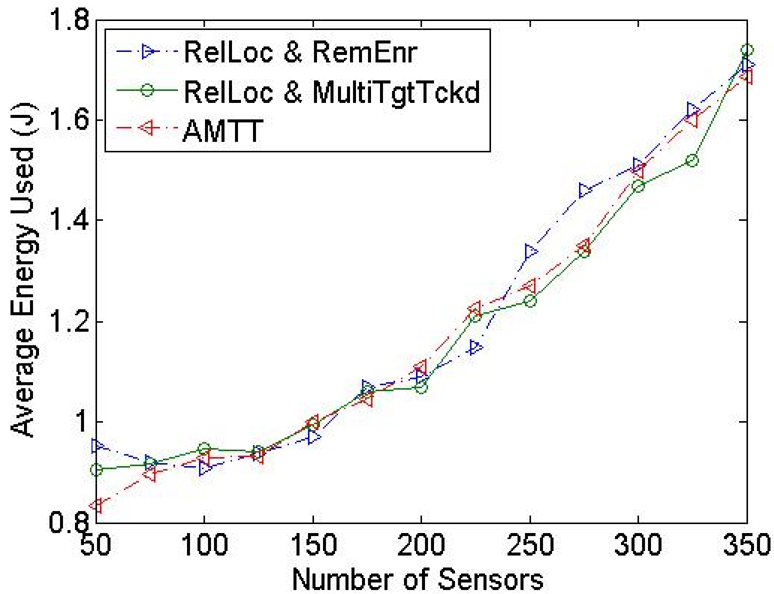

Figure 4.7: Evaluating AMTT

4.4 Evaluating AMTT's performance

In this section we compare the performance of AMTT with the Base Line Algorithm and find that the proposed AMTT algorithm has significant energy savings and longer lifetime as compared to the Base Line Algorithm.

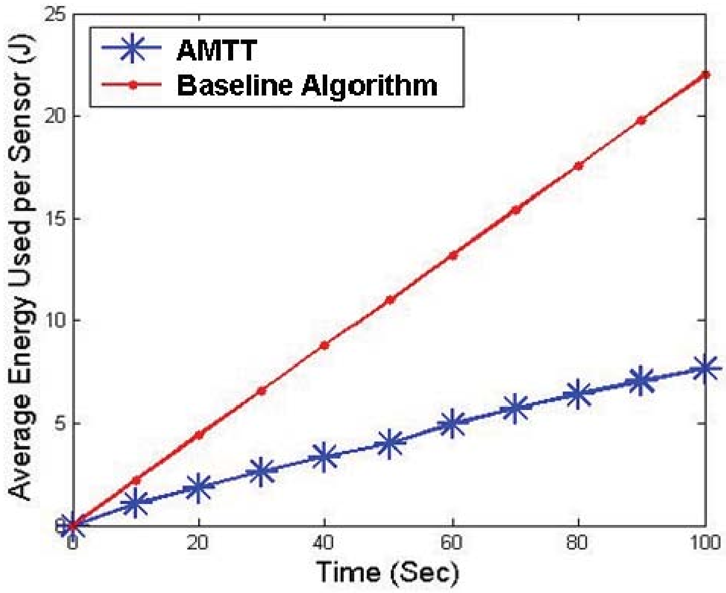

Figure 4.8: Evaluating AMTT & Base Line Algorithm

From Figure 4.8 it can be seen that the AMTT performs better than Vanilla System significantly. Also as the execution time increases, the performance of AMTT gets comparatively better.

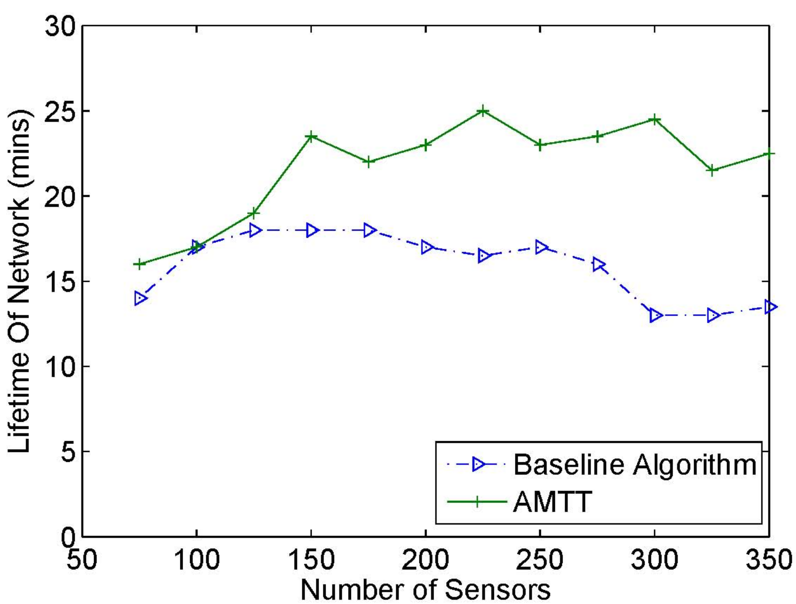

Figure 4.9: Evaluating AMTT and Base Line Algorithm for Lifetime

From Figure 4.9 it can be observed that the AMTT has a better network lifetime as compared to the Vanilla System. The definition that we consider for network lifetime is as follows: It is the first instance from start time when any of the targets is not monitored by *n* sensors. There are various definitions for network lifetime in the reviewed literature but our consideration for the above definition is based on the need for the target to be at least tracked during the lifetime of the network.

4.5 Analysis of Results

In this section we analyze the obtained results and explain their significance. The first parameter that we consider is the max number of targets that a sensor can track. This parameter helps in using same sensor to track multiple targets and reduces the number of sensors that are ON. When this factor is used to MOVE sensors, they can be moved to track multiple targets at the same time. It works best in WSNs with high sensor density.

The next parameter that we consider is the location of sensor with respect to targets motion. In this sensor closest to the path of target turned ON. This reduces the overhead of turning sensors ON/OFF as the sensor that lies nearest to path of motion of target can track it for longest duration. While moving a READY sensor to track a target, READY sensor farthest to the path of target is MOVED to track a target. This helps avoid moving potential READY sensors that can track target in future. This parameter works best in WSNs with low sensor density.

Finally using sensors with maximum energy helps avoid the usage of same sensors throughout the lifetime of the network. Using the same sensors can lead to a set of sensors that are very much depleted in energy.

CHAPTER 5

Conclusions and Future Work

In this chapter we discuss the conclusions we draw form this thesis and discuss the scope for future work in this area.

In this thesis we have proposed an energy efficient algorithm to track multiple targets in a heterogeneous wireless sensor network. We identify the different factors that affect the performance and energy consumptions in WSNs based on different network conditions like its density and the presence of multiple targets. These factors are the Multiple-targets tracked by the sensor which is significant in high network densities, the Remaining Energy in the sensor which is significant in the low network densities and the Relative Location of the sensor which is significant across all network densities. Also the combination of these parameters can give us better performance or is at least as good as the best performing individual parameter. The proposed AMTT algorithm can identify the optimal combination of impacting parameters based on the local network conditions of the sensor and result in significant energy savings and longer network lifetime.

For future work we plan to include existing predictions models for target's movement in our algorithm and have more realistic constraints on sensor's movements. We plan to explore more thorough metrics to identify the correct network threshold and find the optimal percentage of sensor heterogeneity required. Also the proposed AMTT algorithm can then be compared with some existing target tracking systems that have been evaluated for metrics similar to our consideration.

REFERENCES

[1] W. Wang, V. Srinivasan and K.C. Chua, “Trade-offs between mobility and density for coverage in wireless sensor networks”, Proceedings of the 13th Annual International Conference on Mobile Computing and Networking, Mobicom’07, Montreal, Quebec, Canada, September 2007, pp. 39–50.

[2] M. Abdelkader, M. Hamdi and N. Boudriga, “Multi-target Tracking Using Wireless Sensor Networks Based on Higher-Order Voronoi Diagrams”, Journal of Networks, Volume 4, No 7, September 2009, pp. 589-597.

[3] W. Kim, K. Mechitov, J.-Y. Choi, S. Ham, “On target tracking with binary proximity sensors”, Information Processing in Sensor Networks, April 2005, pp. 301-308.

[4] Y. Gu; D. Bozdag, E. Ekici, F. Ozguner and L. Chang-Gun, "Partitioning based mobile element scheduling in wireless sensor networks," Sensor and Ad Hoc Communications and Networks, 2005. IEEE SECON 2005. 2005 Second Annual IEEE Communications Society Conference, pp. 386-395.

[5] G. Gui and P. Mohapatra, “Power conservation and quality of surveillance in target tracking sensor networks,” in Proc. ACM MobiCom, 2004, pp. 129–143.

[6] B. Jiang, B. Ravindran and H. Cho, “Energy Efficient Sleep Scheduling in Sensor Networks for Multiple Target Tracking”, DCOSS, 2008, pp.498-509.

[7] G. Xing, J. Wang, Z. Yuan, R. Tan, L. Sun, Q. Huang, Z. Jia, H. So, “Mobile Scheduling for Spatiotemporal Detection in Wireless Sensor Networks”, IEE Transaction On Parallel And Distributed Systems, Vol. 21, No. 12, December 2010

[8] W.-P. Chen, J.C. Hou and L. Sha, “Dynamic Clustering for Acoustic Target Tracking in Wireless Sensor Networks”, IEEE Trans. Mobile Computing, Vol. 3, No. 3, pp. 258-271, July 2004.

[9] T. He, S. Krishnamurthy, J.A. Stankovic, T. Abdelzaher, L. Luo, R. Stoleru, T. Yan, L. Gu, J. Hui and B. Krogh, “Energy-Efficient Surveillance System Using Wireless Sensor Networks”, Proc. ACM Mobisys, 2004.

[10] J. Liu, J. Liu, J. Reich, P. Cheung and F. Zhao, “Distributed Group Management for Track Initiation and Maintenance in Target Localization Applications,” Proc. Int’l Conf. Information Processing in Sensor Networks (IPSN), 2003.

[11] Y. Zou and K. Chakrabarty, “Distributed Mobility Management for Target Tracking in Mobile Sensor Networks,” IEEE Trans. Mobile Computing, vol. 6, no. 8, pp. 872-887, Aug. 2007.

[12] Cao, H.; Ertin, E.; Kulathumani, V.; Sridharan, M.; Arora, A.; , "Differential games in large-scale sensor-actuator networks," Information Processing in Sensor Networks, 2006. IPSN 2006.

[13] L. Schenato, S. Oh, S. Sastry, and P. Bose, “Swarm Coordination for Pursuit Evasion Games Using Sensor Networks,” Proc. Int’l Conf. Robotics and Automation, 2005.

[14] J.-C. Chin, Y. Dong, W.-K. Hon, and D. Yau, “On Intelligent Mobile Target Detection in a Mobile Sensor Network,” Proc. Int’l Conf. Mobile Ad-Hoc and Sensor Systems (MASS), 2007.

[15] K. T. Soe, “Increasing lifetime of target tracking wireless sensor networks,” World Academy of Science Engineering and Technology, Aug. 2008, 32(32): 440-446

VITA

Kaustubh Dhondge was born on 21st February 1987 in Nagpur, India. After finishing his schooling in 2004, he enrolled for the Bachelor of Engineering program in Computer Science at GHRCE which is affiliated to RTM Nagpur University, Nagpur, India. He graduated and got his degree for the same in June 2008. He then began his Master of Science program in Computer Science at University of Missouri – Kansas City, USA in August 2008.