ACTOR REPOSITIONING
IN
WIRELESS SENSOR AND ACTOR NETWORKS

MCS

By

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A Thesis submitted to the Faculty of Computer Science Department, Military College of Signals, National University of Sciences and Technology, Rawalpindi in partial fulfillment of the requirements of an MS Degree in Computer Software Engineering

AUGUST 2010

ABSTRACT

In Wireless Sensor and Actor Networks (WSANs), the phenomena`s of sensing and acting are performed by sensor and actor nodes, respectively. The number of sensor nodes deployed in a target area may be in the order of hundreds or thousands. Actor nodes are generally few in number because actors have higher capabilities and can act on larger area. In WSANs, actors are responsible for taking a localized decision which may require strong co-ordination with neighboring actors. One of the major problems in WSANs is to place the actors within the monitored region so that certain goals, such as maximizing actor coverage, minimizing data collection delay, balancing the acting load etc., can be achieved. However it may not be possible in many applications as sensor networks are deployed on a fly. As a result precise deployment is difficult at network establishment time. Upon the occurrence of an event the nodes report the event to their nearby actor which can be at a substantial hop distance from event region. In order to decrease the energy consumption of nodes and to increase the network lifetime actors can be repositioned near to event region. In existing literature, very little work has been done in the field of actor placement/ positioning in WSANs. This work has been focused on the development of an Efficient Actor Repositioning (EAR) algorithm that is aimed to extend the network life time by reducing the energy consumption of the network. An actor using EAR algorithm can find the appropriate co-ordinates to reposition/ relocate itself or some other actor based on Euclidean distance, energy of the region and number of nodes.

DEDICATION

To My Wonderful Family...

ACKNOWLEDGEMENT

I thank Allah who provided me with strength and caliber to bring this thesis work to its successful completion.

I am deeply obliged to my supervisor, Dr. Faisal Bashir, for his guidance, unwavering support and confidence in me throughout the course of this thesis work. His time and efforts were very valuable. He contributed much to not only the thesis work but also imparted significant amount of knowledge to me. I am also grateful to my Guidance and Evaluation Committee, Maj. Dr. Asif Masood, Maj. Athar Mohsin, Dr. Awais Majeed, for dedicating their time and making contributions to this thesis work.

I offer my regards and blessings to all of those who supported me in any respect during the completion of this work. Alongside that, I thank the university administration, for facilitating the progress of work at different phases, faculty members of MCS for polishing my knowledgebase, my university mates

Last but not the least; I am grateful to those people without whom I could never have accomplished my aim; my family, especially my parents, my husband, my sisters and brothers. I thank them all for their constant prayers and unfaltering support throughout this journey.

May Allah bless them all with eternal happiness!

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INTRODUCTION

1.1 Overview

A sensor network is a group of specialized transducers with a communications infrastructure intended to monitor and record conditions at diverse locations. Commonly monitored parameters are temperature, humidity, pressure, wind direction and speed, illumination intensity, vibration intensity, sound intensity, power-line voltage, chemical concentrations, pollutant levels and vital body functions. There are three main capabilities of sensor networks i.e. sensing, communication, and computing. Modern research on sensor networks started around 1980 with the Distributed Sensor Networks (DSN) program at the Defense Advanced Research Projects Agency (DARPA). Technology components for a DSN were identified in a Distributed Sensor Nets workshop in 1978. These included sensors (acoustic), communication (high-level protocols that link processes working on a common application in a resource-sharing network), processing techniques and algorithms (including self-location algorithms for sensors), and distributed software (dynamically modifiable distributed systems and language design) [1].

Recent technological advances have lead to the emergence of distributed wireless sensor and actor networks which are capable of observing the physical world, processing the data, making decisions based on the observations and performing appropriate actions. These networks can be an integral part of systems such as battlefield surveillance and microclimate control in buildings, nuclear, biological and chemical attack detection [3], home automation [13] and environmental monitoring. The unique characteristics of WSANs are: real-time requirements and coordination. Many protocols and algorithms have been proposed for Wireless Sensor Networks (WSNs) in recent years. However, the above listed requirements impose strict constraints; certain existing solutions may not be well-suited to cater for these unique features and application-specific requirements of WSANs. Although there have been a number of research efforts related to WSANs, still many issues relating to real time communication and co-ordination in WSAN are open to research [1].

1.2 Motivation

The wireless sensor network (WSN) has emerged as a promising platform to monitor an area with minimal human intervention. Initially, the WSN applications were dominated and funded by the military for applications such as monitoring the activity in a battle field. Now, many civilian applications, such as environmental and habitat monitoring [34], have emerged to benefit from the usage of WSN.

A typical wireless sensor network (WSN) is formed by a large number of tiny sensors together with a static sink. The sensors usually have limited and non-renewable energy reserve [1]. Therefore, the lifetime of WSNs is a key issue that should be considered before practical applications of such networks become possible. Recently, there has been a lot of interest towards introducing sink mobility into WSNs for lifetime improvement. The nodes near the sink are more likely to use up their energy because they have to forward all the data generated by the nodes farther away. With a mobile sink, the nodes around the sink always change, balancing out the energy consumption in the network and improving the network lifetime. However, each time the mobile sink moves, it has to inform all the nodes about the topological or location change, so that the data of the sensors could be successfully routed to the sink. Previous studies either assume the availability of some global information of the network (e.g., location of the mobile sink) ([20], [21], [22]) or let the sink spread the global information through repeated broadcasts across the network ([23], [24], [25]). The lifetime improvement of WSNs from sink mobility could be canceled out by the high energy loss in the frequent network-wide broadcasting.

The additional requirement for intelligent interaction with the environment has lead to the emergence of distributed wireless sensor and actor networks (WSANs). WSANs refer to a group of sensors and actors linked by wireless medium to perform distributed sensing and acting tasks. Sensors are low-cost, low power devices with limited sensing, computation and wireless communication capabilities. While actors are resource rich nodes equipped with better processing capabilities, higher transmission powers and longer battery life. Moreover, the number of sensor nodes deployed in a target area may be in the order of hundreds or thousands, where such a dense deployment is usually not necessary for actor nodes. For actors to take an appropriate actions strong actor-to-actor co-ordination might be required in many applications such as target tracking. Moreover, with a number of available actors energy of the network is conserved by reporting event to closest actor. Since actors are generally thrown or scattered just like the sensors, it is more useful to move actors close to event regions upon event occurrence. By moving the actor closer to the event region substantial energy conservation and delay in event reporting can be reduced.

1.3 Problem Statement

WSAN is comparatively a new area of research as compared to WSN. Actor positioning in WSANs is the least explored area where much work is needed. Existing study in this domain has shown the following:

- Sensors are low energy devices. In order to increase the lifetime of the network, sensor energy conservation should be the key focus.
- Actor positioning is vital to take decisions about the event in time.
- Actor positioning and repositioning has been studied in the clustered environment. A generalize algorithm is required that can handle these issues in any environment.
- Euclidian distance is used for the calculation of distance for movement.

In this research focus is on **the development of an efficient actor repositioning algorithm for WSAN to increase network lifetime and reduce the energy consumption**.

Following are the goals of this work.

- To study the existing mechanism of sink and actor placement in WSN and WSAN.
- To identify the constraints and limitations of techniques for actor positioning.
- To devise an algorithm for optimal and energy efficient actor positioning in WSAN.
- In the end, comparative analysis of proposed scheme in terms of energy gain, with and without relocation.

1.4 Research Objective

WSAN comprises of a number of sensors and actors. Upon an event occurrence, sensors will report to the actor. Actors are placed at a considerable amount of distance from the event region. Existing literature shows that actor positioning has been the least studied area. Appropriate actor relocation at the event region is needed to reduce the energy consumption of the sensor field. Hence, this work will contribute in the efficient re-tasking and re-location of the actor in case of any event in WSANs field.

1.5 Thesis Organization

In Chapter 1 introduction and motivation of the research has been discussed. Chapter 2 will cover the background and related work in the field of actor relocation in WSAN. Chapter 3 will cover the new methodology proposed to solve the problem. Validation of the newly designed algorithm will be tested using test cases and the results achieved will be discussed in Chapter 4. Chapter 5 will contain the conclusion and limitations.

C h a p t e r 2

BACKGROUND AND RELATED WORK

2.1 Introduction

In this chapter brief introduction of Wireless sensor network (WSN), Wireless Sensor and Actor Networks (WSAN), related work and problems in the field of actor positioning/repositioning have been discussed.

2.2 Wireless Sensor Networks (WSN)

A wireless sensor network consists of a number of sensor nodes gathering information about the environment and physical world. These sensors are low cost and have limited computation, communication and sensing power. The need to monitor and measure various physical phenomena is common to many areas including structural engineering, agriculture and forestry, healthcare, logistics and transportation, and military applications [2]. Advancement in technology has helped in making intelligent, autonomous and energy efficient sensors that can be deployed in large numbers to form self organizing and self healing WSNs in a geographical area [2]. The sensors that comprise WSNs include:

- Cameras as vision sensors
- Microphones as audio sensors
- Sensors capable of sensing ultrasound, infrared, temperature, humidity, noise, pressure and vibration.

WSN covers a large space and gathers data through the sensors as shown in Figure 2.1. It is still a challenge to realize a distributed WSN, comprising of small and cost effective sensor modules with high speed, low latency and reliable networking infrastructure, software platforms that support easy and efficient installation of the WSN, and sensor information processing technologies [2].

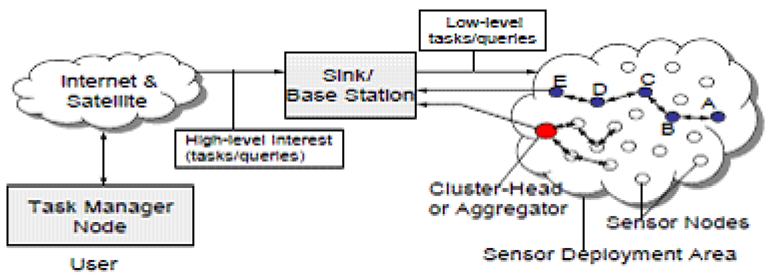

Figure 2-1. WSN Overview [2]

Real-world deployment usually consists of stationary sensor nodes. WSNs are more intelligent as compared to the traditional sensors, and some WSNs are designed to use in-network processing, where sensed data can be gathered and transformed in to more abstract and aggregated high-level data before transmission. The combination of processing power, storage and wireless communication also means that data can be assimilated and disseminated using smart algorithms. The vast number of sensor nodes planned for many applications also implies that a major portion of these networks would have to acquire self-organization capability. A denser infrastructure would create a more effective sensor network. It can provide higher accuracy and has more energy available for aggregation. However, denser network has to be configured properly to avoid collisions during transmission and network congestion because it can increase latency and reduce efficiency in terms of energy consumption. One distinguishing characteristic of WSNs is their lack of strong boundaries between sensing, communication and computation. Unlike the Internet, where data generation is mostly the province of end points, in sensor networks every node is both a router and a data source.

2.3 Wireless Sensor and Actor Networks (WSANs)

WSAN is the extension of WSN. In WSANs, the phenomena of sensing and acting are performed by sensor and actor nodes, respectively. **Sensors** are low-cost, low power devices with limited sensing, computation, and wireless communication capabilities. **Actors** are resource rich nodes equipped with better processing capabilities, higher transmission powers and longer battery life. The number of sensor nodes deployed in a target area may be in the order of hundreds or thousands, where as actor nodes deployment is very few, since actors have higher capabilities and can act on large areas. WSANs have the following unique characteristics [12].

• **Real-time requirement:** In WSANs, depending on the application, there may be a need to rapidly respond to sensor input. For instance, in a fire application, actions should be initiated on the event area as soon as possible. Moreover, the collected and delivered sensor data must still be valid at the time of acting. For example, if sensors detect a malicious person in an area and transmit this information to the disposer of tranquilizing gas actors, that person must then still be in the same area when actors carry out the task. Therefore, the issue of real-time communication is very important in WSANs [12].

• **Coordination:** Unlike WSNs where the central entity (i.e., sink) performs the functions of data collection and coordination, in WSANs, new networking phenomena called sensor-actor and actor–actor coordination may occur. In particular, sensor-actor coordination provides the transmission of event features from sensors to actors. After receiving event information, actors need to coordinate with each other in order to make decisions on the most appropriate way to perform the action. Many protocols and algorithms have been proposed for WSNs in recent years [3]. However, since the above listed requirements impose stricter constraints, they may not be well-suited for the unique features and application requirements of WSANs [12].

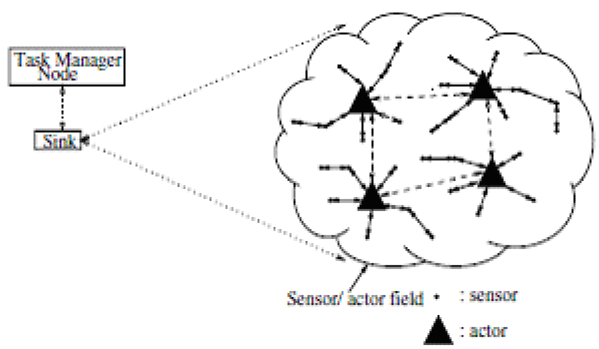

Figure 2-2. The Physical architecture of WSANs [3]

In WSANs, sensors and actors are placed in the field to gather the required data and perform appropriate actions on the data. In Figure 2.2 Sensor nodes are deployed in the field and they are linked with their nearby actors. Sink is monitoring the network communication with the task manager node and sensor/actor nodes [12].

2.3.1 WSANs Architectures:

There are two types of architecture: automated and semi-automated as shown in Figure 2.3. Depending on the types of applications; one of these architectures may be used.

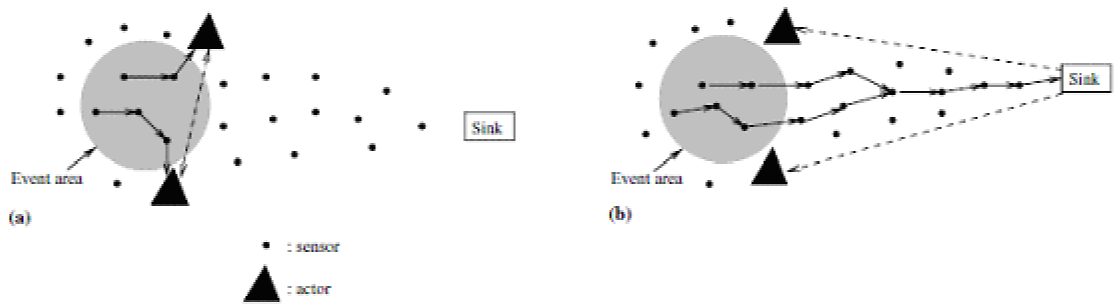

Figure 2-3. Automated vs. (b) Semi-Automated Architecture [3]

a. **Automated Architecture:** Sensors, after detecting an event, transmit their readings to the actor nodes which process all incoming data and initiate appropriate actions

b. **Semi-Automated Architecture:** Sensor, after detecting an event, route data back to the sink which may issue action commands to actors.

The advantage of the Semi-Automated Architecture is that it is similar to the architecture already used in wireless sensor network (WSN) applications [3]. Thus, there is no need to develop new algorithms and protocols to perform communication and coordination.

2.3.2 WSANs Components:

WSANs consist of a number of sensors and few actors. Sensor and actor components are explained below:

a. Sensor Component:

Sensor is low cost, low power device having following parts.

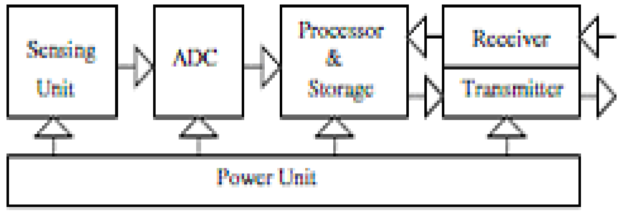

Figure 2-4. Sensor Component

Sensor nodes are equipped with power unit, communication subsystems (receiver and transmitter), storage and processing resources, Analog to Digital Converter (ADC) and sensing unit, as shown in Fig 2.4. The sensing unit observes phenomena such as thermal, optic or acoustic event. The collected analog data are converted to digital data by ADC and are then analyzed by a processor and finally transmitted to nearby actors [1].

b. Actor Components:

Actor nodes are equipped with power unit, communication subsystems (receiver and transmitter), storage and processing resources.

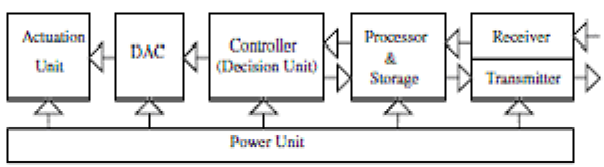

Figure 2-5. Actor Components in WSAN

The decision unit (controller) functions as an entity that takes sensor readings as input and generates action commands as output. These action commands are then converted to analog signals by the Digital to Analog Converter (DAC) and are transformed into actions via the actuation unit as shown in Fig 2.5.

2.3.3 Example of Sensor and Actor Nodes:

Sensor and actor nodes are shown in the figure below:

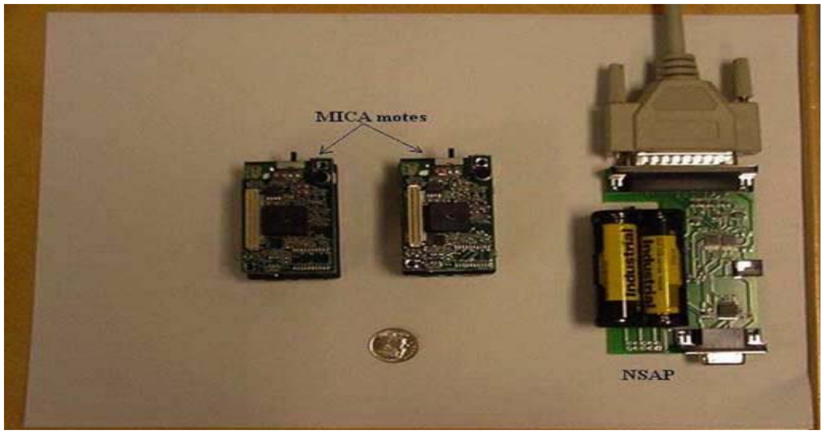

Figure 2-6. Sensor and actor nodes

MICA, shown in Figure 2.6, is an open-source hardware and software platform that combines sensing, communications, and computing into a complete architecture to form an integrated wireless smart sensor. In addition to sensor-actor communication, in most situations, actor–actor communication is also required to achieve the overall application objective in WSANs. Since actors are resource-rich nodes with high transmission power, actor–actor communication can be long-range unlike sensor-actor communication. Furthermore, actor–actor communication is similar to the communication paradigm of ad-hoc networks due to the small number of (mobile) resource-rich actor nodes being loosely deployed. Therefore, WSAN can be considered as the union of wireless sensor and ad-hoc networks. In addition to both sensor and ad-hoc network challenges, there exist challenges due to the real-time properties and nature of ‘‘acting’’ phenomenon [12].

2.3.4 Protocol Stack for WSAN

Protocol stack for WSAN is shown below:

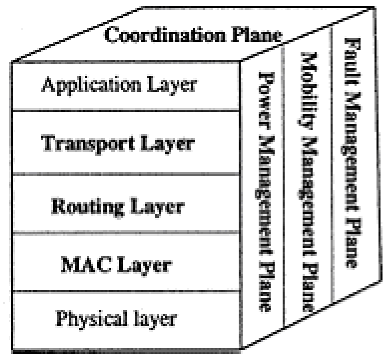

Figure 2-7. WSAN Protocol Stack

The protocol stack for sensor and actor nodes may consist of three planes, (i.e., communication plane, coordination plane, and management plane) as shown in Figure. 2.7.

2.3.4.1 Management Plane:

The functions performed by the management layer can be categorized into the following three areas:

a. Power management plane manages how a node uses its power. For example, when the power level of a node is low, this plane informs the coordination plane so that the node will not participate in sensing, relaying, or acting activities.

b. Mobility management plane detects and registers the movements of nodes so that network connectivity is always maintained.

c. Fault management plane refers to the detection and resolution of node problems. For example, when the sensitivity of sensing unit or the accuracy of the actuation unit degrades, fault management plane informs the coordination plane about this situation.

2.3.4.2 Coordination plane:

Coordination plane determines how a node behaves according to the data received from communication plane and management plane. After sensing an event, sensors communicate their readings to each other. At each sensor node, these exchanged data are submitted to the coordination plane to make decisions. This way, sensors are able to coordinate among themselves on a higher-level sensing task. Moreover, sensor–sensor coordination may also be required to determine nodes which will not transmit data (due to low power or applied MAC protocol) to perform multi-hop routing and data aggregation, and most importantly to select actor(s) to which sensor data will be transmitted.

The existence of coordination plane may be much more critical for actors than for sensors, since actors may need to collaborate with each other in order to perform appropriate actions. When an event occurs, the common goal of all actors is to provide required action on that event. Thus, social abilities, i.e., sophisticated coordination and negotiation capabilities, are necessary in WSANs to ensure coherent behavior in the community of actors [12].

2.3.4.3 Communication plane

Communication plane receives commands from coordination plane (regarding the decision as to how the node will behave) and according to that information provides the link relation between nodes by using communication protocols. Specifically, the communication plane deals with the construction of physical channels, the access of the node into the medium (MAC), the selection of routing paths through which the node transmits its data and the transport of packets from one node to another [12].

2.4 Actor Positioning in WSAN:

In most of the wireless sensor and actor network (WSAN) applications, the locations for the actors are determined autonomously by the collaboration of actors and/or sensors in order to eliminate human intervention as much as possible. Particularly, sensors can collaborate in a distributed manner and elect cluster-heads (CHs) among them based on certain criteria. The actors can then move to such CH locations by talking to nearby sensors/actors. Such movement, however, should be done wisely in order to minimize the movement distance of actors so that their lifetimes can be improved. Nevertheless, this may not be possible since not all the actor and CH locations will be known by each actor. In addition, the actors may not be reachable to each other and thus conflicts in assignments can easily occur [4].

One of the major problems in WSANs is to place the actors within the monitored region so that certain goals can be achieved. The actors can be placed within the region with various goals such as maximizing actor coverage, minimizing data collection delay, balancing the acting load, etc. While the placement can be done manually in some applications (e.g., urban search and rescue) where the region is accessible and the number of sensors/actors is not very high, such deployment should be done in a distributed manner in applications where a large number of sensors and actors are employed (e.g., forest or ocean monitoring). Specifically, in such applications, the sensors and actors will be dropped randomly from an aircraft and later the sensors will collaboratively cluster the network in a distributed manner based on the goal of the application.

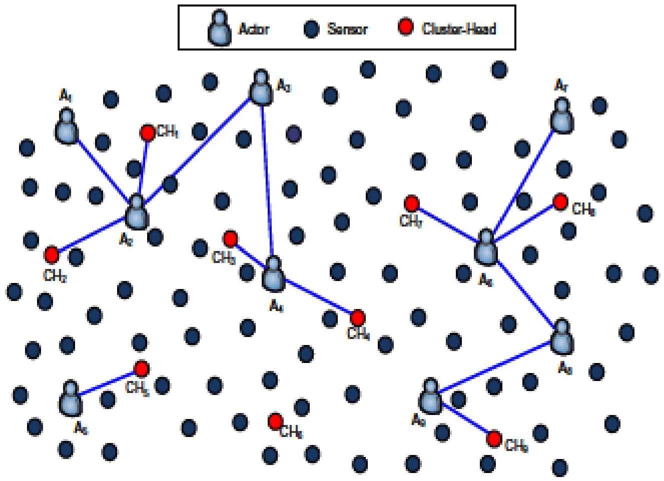

Figure 2-8. An example of WSAN with CHs

Figure 2.8 shows the example of WSAN with CHs. Note that distributed computation of actor locations is more feasible and cheaper as opposed to a central solution where the locations are computed at a base-station with the assumption that all the sensor information can be collected. Once the cluster-heads (CHs) and their locations are determined, the actors can be placed at such locations (i.e., moved to those locations from their initial locations) [4].

2.5 Related Work:

The problem of actor placement and repositioning in WSANs has been studied in the past. Actor-to-actor interaction algorithms, placement of actors in the field and repositioning of the actor in case of other actor failure have been studied widely. However, the least explored domain is the energy efficient actor positioning after event occurrence and movement of actor to the most appropriate region. Existing research dealing with actor positioning are as follows:

In [5], the actors are placed uniformly within the monitored area and then relocated based on vertex1-center of the sensors within each cluster in order to cater for delays. Each sensor picks the closest actor as its cluster-head. The algorithm is further extended to maintain connectivity.

In [6], authors have proposed two actor placement mechanisms for WSANs, namely COLA and COCOLA that consider both the delay requirements of data collection and the coverage of the area. COLA evenly distributes the actors in the region for maximized initial coverage. Actors then collaboratively form clusters. Each individual actor repositions itself at a new location that enables minimal latency in collecting data in its cluster. COCOLA is an extension to COLA which additionally enforces connectivity among the actors by assigning appropriate locations to each actor for improved coverage and reduced latency.

Similarly, in [7] the initial coverage of randomly placed actors is improved through the application of repulsion forces.

The goal of [8] is to locate the actors based on sensor distribution, as opposed to previous work, using independent dominating set of the sensor network. In all of these works, the placement of actors is done in a centralized manner. In other words, the actors are either placed to certain exact locations or programmed to go to those locations.

Minimization of travel distance has also been studied for different problems in WSNs or WSANs. For instance, in [9] [10], the goal is to restore inter-actor connectivity with minimized actor travel distance in response to the failure of an actor.

Similarly, in [11] the goal is to minimize the sensor travel distance while coverage holes are fixed.

As in [15], a distributed actor positioning and clustering algorithm is used that employs actors as cluster-heads and places them in such a way that the coverage of actors is maximized and the data gathering and acting times are minimized. Such placement of actors is done by determining the *k*-hop Independent Dominating Set (IDS) of the underlying sensor network. Basically, before the actors are placed, the sensors pick the cluster-heads based on IDS. The actors are then placed at the locations of such cluster-heads. If inter-connectivity does not exist, the actors coordinate through the underlying sensors in their clusters to adjust their locations so that connectivity can be established.

In [16], the goal is to maximize connected coverage via controlled actor relocation in wireless sensor and actor networks. Researchers have proposed a distributed actor deployment algorithm that strives to maximize the coverage of actors without violating the connectivity requirement. The approach applies repelling forces between neighboring actors and from the sensors that sit on the boundaries in order to spread them in the region. The spreading of the nodes is done using a tree of actors which can provide more freedom for the movement of the nodes but at the same time maintain the required connectivity among the nodes. Researchers have presented two techniques for creation of such an actor tree which are based on local pruning of the actor links and spanning tree of the inter-actor network.

In [17], the authors have adapted the Gale-Shapley (GS) stable matching algorithm from stable matching theory. In this matching algorithm, actors are regarded as men and CHs are regarded as women. For distributed execution of the algorithm, sub-networks of actors and CHs are determined. Each sub-network elects a leader that performs the matching in the sub-network based on GS algorithm. If there are unmatched actors after this process, either a separate search is used to detect such nodes, or leaders talk to each other to share this information so that further matching can be performed

In [18], authors discuss that federating disjoint segments may be necessary in some applications of wireless sensor networks (WSNs). The segments can be simply distinct WSNs that operate autonomously or partitions of a single WSN that has suffered a significant damage. Linking these segments is subject to varying distances among segments which may be longer than twice the communication range of a relay node. In this work, researchers have focused on designing an effective approach for federating these segments by populating the least number of relay nodes. The deployment area is modeled as a grid with equal-sized cells. The optimization problem is then mapped to selecting the fewest count of cells to populate relay nodes such that all segments are connected. Finding the optimal number and positions of relay nodes with respect to length between segments is NP-hard and heuristics are thus pursued. Researchers have proposed a distributed Cell-based Optimized Relay node Placement (CORP) algorithm and explain the beneficial aspects of the resulting topology with respect to connectivity, and traffic balance. The performance of CORP is validated through extensive simulation experiments.

In [26] authors have addresses the problem of *sensor relocation*, i.e., moving previously deployed sensors to overcome the failure of other nodes, or to respond to an occurring event that requires that a sensor be moved to its location. This sensor relocation is different from existing work on mobile sensors which concentrate on sensor deployment; i.e., moving sensors to provide certain initial coverage [27], [28], [29], [30], [31]. Compared with sensor deployment, sensor relocation has many special difficulties. First, sensor relocation may have a strict response time requirement. Authors have proposed a framework for relocating mobile sensors in a timely, efficient, and balanced manner, and at the same time, maintaining the original sensing topology as much as possible. In this framework, sensor relocation consists of two phases: the first is to find the redundant sensors in the sensor network; the other is to relocate them to the target location. For the first phase, authors propose a Grid-Quorum based solution to quickly locate the redundant sensors with low message overhead. For the second phase, authors propose efficient heuristics to achieve good balance between energy efficiency and relocation time when determining the sensor relocation path. Simulation results show that the proposed heuristics are very effective in reducing the relocation time and the energy consumption.

In [32] authors explores the idea of exploiting the mobility of data collection points (sinks) for the purpose of increasing the lifetime of a wireless sensor network with energy-constrained nodes. Authors have given a novel linear programming formulation for the joint problems of determining the movement of the sink and the sojourn time at different points in the network that induce the maximum network lifetime. Differently from previous solutions, their objective function maximizes the overall network lifetime (here defined as the time till the first node "dies" because of energy depletion) rather than minimizing the energy consumption at the nodes. For wireless sensor networks with up to 256 nodes, model produces sink movement patterns and sojourn times leading to a network lifetime up to almost five times that obtained with a static sink. Simulation results are performed to determine the distribution of the residual energy at the nodes over time. These results confirm that energy consumption varies with the current sink location, those nodes being more drained that lie in the proximity of the sink. Furthermore, the proposed solution for computing the sink movement results in a fair balancing of the energy depletion among the network nodes. In this paper authors are concerned with the joint problems of determining the movements of the sink and the times the sink sojourns at certain network nodes so that network lifetime is maximized. They consider WSNs where the $n = L2$, homogeneous nodes are arranged in a bi-dimensional grid and one mobile sink travels through them. For this model, Authors have presented a novel linear programming formulation for the network lifetime maximization problem which is elegantly simple, yet capable of expressing network lifetime in terms of sink sojourn time at the nodes. Differently from the ILP formulation in [33], their objective function concerns the overall network lifetime (here defined as the time till the first node "dies" for energy depletion) directly, instead of indirectly deducing it from the greedy minimization of the energy consumptions at the nodes. The model is solved for WSNs with up to 256 nodes. Improvements are obtained which are almost five-fold when the sink sojourns at the four corner areas and at the central area of the grid. Simulation results demonstrate that by moving the sink according to the pattern determined by solving the linear programming formulation, they obtain an even distribution of the nodes' residual energy, which leads to a significant increase in network lifetime.

2.6 Summary:

This chapter has discussed the existing literature in the field of actor positioning/ repositioning of WSAN. Research has shown that actor to actor co-ordination and placement of actor to the most appropriate region is needed for better co-ordination and meeting the real time requirements of WSAN.

Chapter 3

METHODOLOGY

3.1 Introduction

In this chapter, the methodology of Efficient Actor Repositioning (EAR) Algorithm is proposed and designed to enhance the network lifetime and reduce the energy consumption of the network. Moreover, the basic assumptions and network model has been discussed.

3.2 Network Model

WSAN consists of a set of sensor and actors which are linked through wireless medium. Sensors sense the events from the environment and actors collect the data from the sensors and take decisions about the events. Two types of actors are placed in the field:

- Static Actor (SA): Collects event data, takes decision, and performs action if needed.
- Mobile Actor (MA): Moves to the desired location specified by SA collects data and takes action if required.

It is considered that a number of sensors and few actors are placed in the field. These actors are placed at considerable distance to cover the maximum region of the field. Sensors and actors are linked through wireless medium for communication.

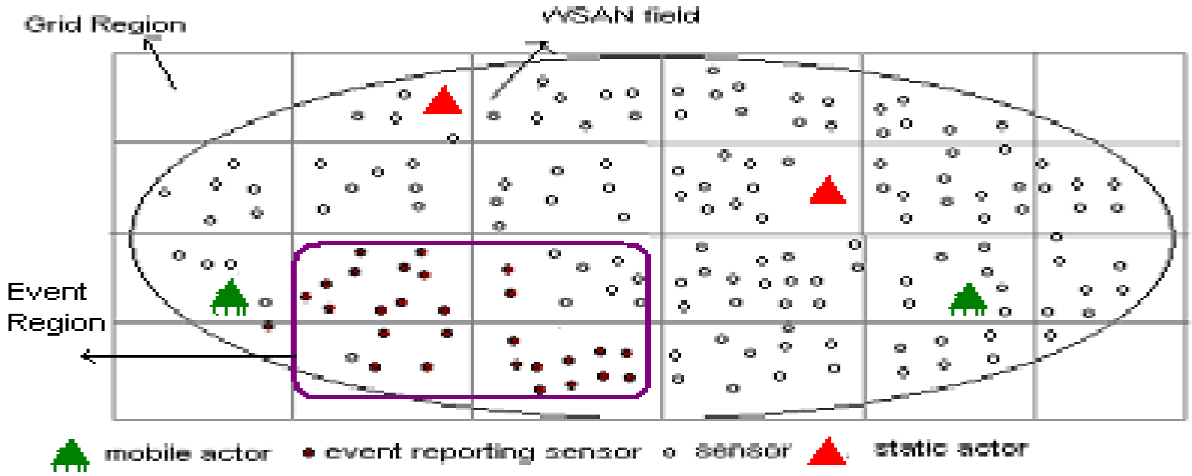

Figure 3-1. Communication among actors: field sensors report to the static actors and static actors, after finding best location, redirect mobile actors to the location

The network model is shown in Figure 3.1, consisting of a set of sensors and actors.

The grid is a logical grid established at actors for dividing the sensor field into small sensing units as explained in section 3.3 of this chapter.

Each sensor is associated with a static actor for event reporting. This association is done during the actor discovery phase as explained in the next subsection.

The purpose of this research is to design and develop an algorithm that can find the appropriate co-ordinates near/ in the event region. As a result, a MA can be informed to move and collect event information from the region. Thus, reducing the energy cost, delay, packet drop ratio, while on the other hand extending the lifetime of the network.

Efficient Actor Repositioning (EAR) algorithm is developed for this purpose which takes into consideration to increase network lifetime and reducing energy consumption, while finding the appropriate position to relocate an actor. Before elaborating the operation of EAR algorithm, it is essential that nodes must have information about neighboring actors.

Therefore, actor discovery is required to inform presence of actor in the field and to associate actor with the sensors.

3.2.1 Actor Discovery

An actor selection procedure is required to select an appropriate actor for a node. Actor selection can be done on the basis of metrics like latency, efficiency, load etc. However, in this study a node selects the actor on the basis of minimum hop distance. As a result, minimum number of transmissions will be required for sending or receiving information, resulting in energy conservation. The nodes sending/receiving information to/from a specific actor are termed as *members* of the actor.

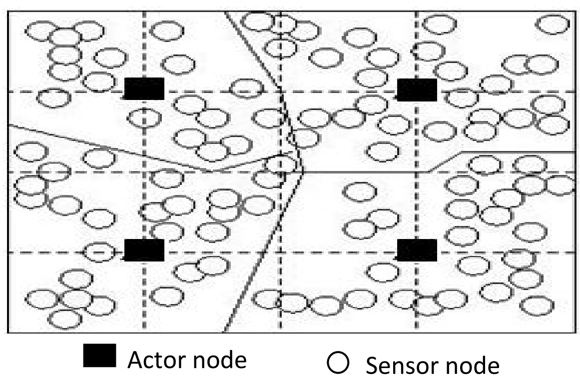

Figure 3-2. Membership of nodes after actor selection procedure, in 100x100m sensor field with 150 sensor nodes and 4 actor nodes.

During the network configuration, actors broadcast *presence beacon* to their neighboring nodes. The beacon contains actor's address, hop count and a time-stamp. The beacon is broadcasted in the network using controlled flooding. Nodes, after receiving the first beacon packet, become the members of the actor from which the packet has been received. After incrementing the packet, the nodes wait for a small random amount of time before further broadcasting this packet to their neighbor nodes. If during this time nodes receive the same packet more than three times then they cancel their broadcast.

This ensures controlled flooding and maximum coverage. In [35] authors have observed that in broadcast environment, broadcasting the same packet more than three times gives either no or very less coverage.

After receiving a packet with a hop count greater or equal to the already accepted actor, member nodes will discard the packet. If member nodes receive a packet with hop count smaller than the one they have previously accepted, then they will discard the previous membership and will take up a new membership (even if it is from the same actor). Moreover, they will further broadcast this packet after incrementing the hop count. The result of actor selection procedure is shown in Figure 4.2, with 150 sensor nodes and 4 actor nodes in a 100x100m sensor field.

3.3 Operation of EAR Algorithm

In WSANs, after establishment of the field, static sensors are placed in the field along with the few actor placements. Actor and sensors form wireless links through some wireless medium. SA will broadcast its presence at a location and sensors in the field will form links with the actors. It will also broadcast with high transmission range to connect with the other MA in the network. Hence sensor to actor and actor to actor communication is established. When SA is placed in the field, it will form a gird according to the field size specified by application.

Grid consists of multiple gird regions/cells, set up in accordance with the defined radio range of the sensors. For instance, if radio range of sensors is 20 meter, grid region/cell will also be of 20 meters. Sensors will monitor their environment according to the application requirement and when an event occurs, actor will record event information in the event table explained in next section. This event table will help the actor to take decision. Decision will be taken when a certain threshold is achieved. Here threshold is the number of packets received per second and is again application dependent. Most appropriate location that will give the best coverage for the event is selected. This decision will be based on the energy of the reporting sensors. Once the selection for the coverage has been done, if SA is already in the region of event and it is covering the best area, then it will keep on observing and will take action according to the application requirement. If the SA is at a hop distance from the event region then SA will co-ordinate with the available MA in the field and this MA will move to the location. After reaching at the location, MA will now broadcast, so that all reporting event sensors will stop sending their information to the SA and start reporting to MA. This will reduce the transmission required to send data to SA and will make-up for the energy consumed in the movement of the actor.

When SA is placed in the field it will form a virtual grid on the field. Grid is divided into small cells. Grid establishment is explained in the next subsection.

When an event will occur, sensors located at the event region will listen the event and send event information to the associated actor. Event reporting will be stored in the actor to take some decision. Event reporting is explained in the next subsection.

When received event packets will reach certain threshold, actor will start taking decision. This decision will be according to certain conditions; these conditions will be explained in next subsection.

Once decision has made, if actor is not at the appropriate event location it will co-ordinate with other actor. This actor –to-actor co-ordination will be explained in the next subsection.

Mobile actor will move to the appropriate location and then it will inform sensors in the event region about its presence. Sensor nodes will associate themselves with this actor inside the region of event. This is explained in the next subsection.

3.3.1 Grid Establishment

Sensors are placed in the field to monitor the environment for a particular event and actors are meant to take decisions based on the sensed data. Actors, when placed in the field, will set-up a grid. Grid size will depend on the size of the field transmission range of node or as specified by the application. It is established only once at the time when actor is placed in the field and will need further modification only when the field size varies. Assume that the field of WSAN is 90 x 95 meter. The actor will then create a grid of size 100 x 100 meter. Grid will be divided into multiple cells or regions known as grid cell/region. Size of these grid regions will be same as the radio range of the sensor. As in this algorithm, the radio range of the sensor is about 20 meters; the grid region will also be of size 20 x 20 meter. In a grid of 100 x 100 meter, 25 grid cells will be formed, as shown in figure 3.3.

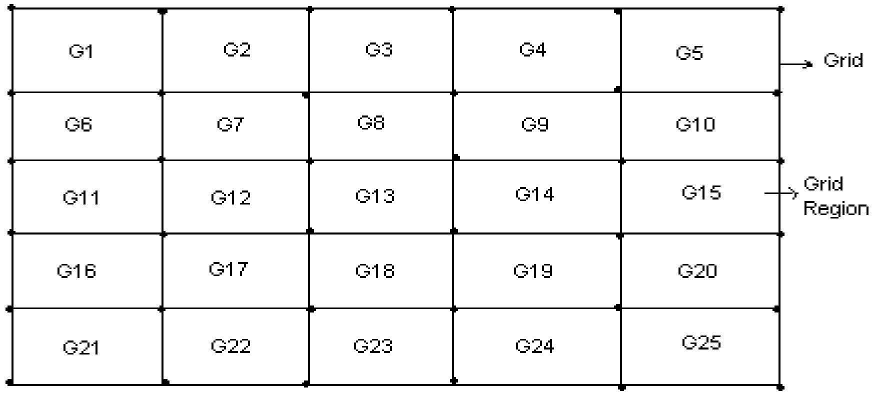

Figure 3-3. Grid and Grid IDs of the grid region

Grid regions have four "x" and "y" coordinates whose information will be stored in the Grid Table. Grid Table is stored at the actor and it will be used for the decision of sensor location in the field.

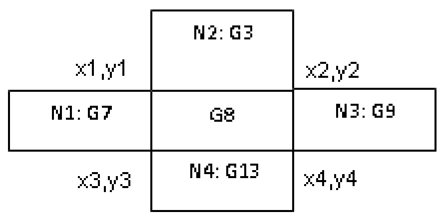

Figure 3-4. Grid ID 8, location coordinates and neighbors

Figure 3.4 shows that Grid ID G8 has four corners and corresponding location coordinate values; it has four neighbors G7, G3, G9, and G13. This information will be stored at SA according to every grid region and surrounding neighbors. At event occurrence, these values will be used to find location of sensors from the SA.

Table 3-1. Grid table containing Grid ID, location coordinates for the region and neighbors of Grid ID

Grid ID	x1	y1	X2	y2	X3	Y3	x4	y4	N1	N2	N3	N4
G1	0	0	20	0	0	20	20	20	--	--	G2	G6
..	..	..	..	..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..	..	..	..	..
G25	80	80	100	80	80	100	100	100	G24	G20	..	..

Every grid region is assigned a unique ID and its location coordinates are stored in the "Grid Table". Information of neighbors of specific Grid Regions will also be stored as shown in Table 3.1. Corner grid regions like G1, G5, G21 and G25 have 2 neighbors. Information according to the neighbors and location is saved in grid table.

3.3.2 Event Reporting

Event is the desired activity to be sensed or monitor in WSAN application. At event occurrence, the sensors in the region of event will sense and inform its linked SA. Sensor will send their location information and energy status along with the event information to the SA. Threshold is the minimum number of packets received before the decision. As threshold is reached, SA will take localized action. It will check whether SA is present at the desired location. If SA is at the desired location, then it will take the application defined action. If SA is away from the event region, it will coordinate with the free available MA near the event region to move to the desired location. Desired location will be calculated when the threshold is reached, at which time the SA will start computation for decision making. Threshold will be defined according to application. SA will also create and maintain an event table.

Table 3-2. Event table containing reporting sensor's information with associated grid region

Packet Number	SA	Sensor ID	X	y	Energy	Grid ID
Pi	Ai	Si	xi	yi	Ei	GID
..	..	..	..	..	..	..
Pn	Ai	Sn	xn	yn	En	GID

Event table will include the following information as shown in Table 3.2. $Pi...Pn$ are the packet numbers, Ai is the SA receiving all the information, $Si...Sn$ will be the reporting sensors' ids, x and y are sensors' location in the field, $Ei...En$ correspond to the energy of the sensor at the time of reporting. GID is the Grid region selected from the Grid table on the basis of sensors location.

By using this Event table, SA will count C, the number of sensors reporting from the same Grid Region and take the average of the energy E in the region. This C and E will be stored in "Energy Count Ratio Table". This table will show the values of the grid cell. This table will help in to identify that which region should be selected.

Count Ci= Total number of sensors nodes reporting from a particular grid region

Energy Ei= Total average energy of all the nodes reporting from the grid region.

Energy / Count is the ration between total average energy of the region and total number of sensors reporting from the region.

By increasing Energy Ei value of the ratio will increase showing that the region has large energy and by increasing Count Ci value of the ratio will be decreased to show that amount of sensor reporting is high. Preferred region will be the one having low E/C value. As count of sensor reporting is high and these sensors have low energy. To increase network life time these sensors should be focused.

Table 3-3. Energy count ratio table with grid region and neighbors

Grid ID	GC	GE	GE/GC	N1E/N1C	N2E/N2C	N3E/N3C	N4E/N4C	Total Count
GID	Ci	Ei	GRi	$N1Ri$	$N2Ri$	$N3Ri$	$N4Ri$	$TiCi$

Table 3.3 shows "Energy Count Ratio" of the reporting sensors grid region. E/C is Energy/Count ratio. Count Ci is the number of reporting sensors of a particular Grid region and Energy Ei is the average energy of the sensor nodes reporting. If neighbor 1 of grid region is also reporting for the same event, its Count $N1Ci$ and Energy $N1Ei$ will also be calculated and ratio $N1Ei/N1Ci$ computed to be used later. Same calculation for other neighbors will also be done if they are reporting for the same event. Total count $TiCi$ is the count of all the sensors reporting for the grid region including reporting neighbor count. Grid ID having Maximum Total Count and lowest E/C ratio value in the table will be selected. If multiple grids have same Total Count then lowest GRi value will be the criteria to select the Grid Region. If there are multiple girds having same

maximum count and lowest GRi value then selection will be based on the nearest Grid ID from the SA.

3.3.3 Actor Decision

SA will select the lowest value of E/C ratio for the selection of grid. There will be 5 cases to select the final destination on the basis of neighbors. Assume that energy count ratio at the following grid region is as listed below. These values are used to explain the different cases for decision making:

G8 has $E/C = 0.69$

G7 has $E/C = 0.81$

G3 has $E/C = 0.91$

G9 has $E/C = 0.92$

G13 has $E/C = 0.71$.

Case 1: Isolated Grid Reporting

If selected Grid region has maximum count and lowest E/C ratio, it is considered isolated grid region reporting an event. The coordinates for MA within the grid region will be selected in such a way that MA covers the maximum event region.

Figure 3-5. Isolated Grid region reporting selects the centre of the grid region

Assuming the values defined above G8 has the lowest E/C value. If grid has no neighbor reporting for the event, covering location will be the centre of the Grid region. As shown in the figure 3.5., fx, fy are the final x and y coordinates selected for the MA.

Case 2: Event Region has One Neighbor

This is the case when selected grid region has one neighbor which is also reporting for the same event. Grid region having lowest E/C ratio will be selected for computing the location for MA placement.

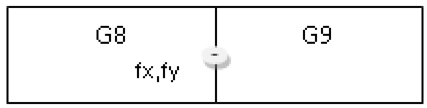

Figure 3-6. Two Grid regions reporting: select centre of the consecutive neighbors

Assuming that G8 is the Grid ID having lowest E/C value but total count of G8 and G9 is maximum in all events reporting region. The best coverage of MA will be at the centre of G8 and G9 grid region. Final x and y co-ordinates selected in the figure 3.6.

Case 3: Event Region has Two Neighbors

This is the case when selected grid region has two neighbors reporting.

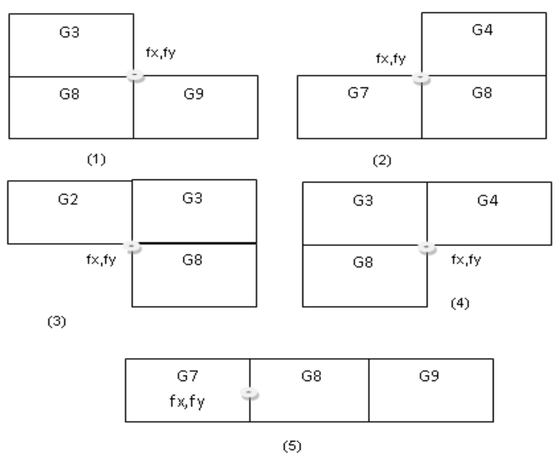

Figure 3-7. Three Grid regions reporting: select centre of the consecutive neighbors. Maximum coordinate occurring will be selected for the MA location.

Grid region having lowest E/C ratio will be selected for finding the location for MA placement.

Assuming that G8 is the Grid ID having lowest E/C value but total count of G8 with other two neighbors are maximum. In (1),(2),(3) and (4) of Figure 3.7, maximum occurring corner is selected for the best coverage of actor. In (5) E/C between G7 and G9 will be compared. As G7 has lower E/C value as compare to G9. Hence, center of the G7 and G8 will be selected.

Case 4: Event Region has Three Neighbors

This will be the case when selected grid region has three neighbors reporting. Grid region having lowest E/C ratio will be selected for finding the location.

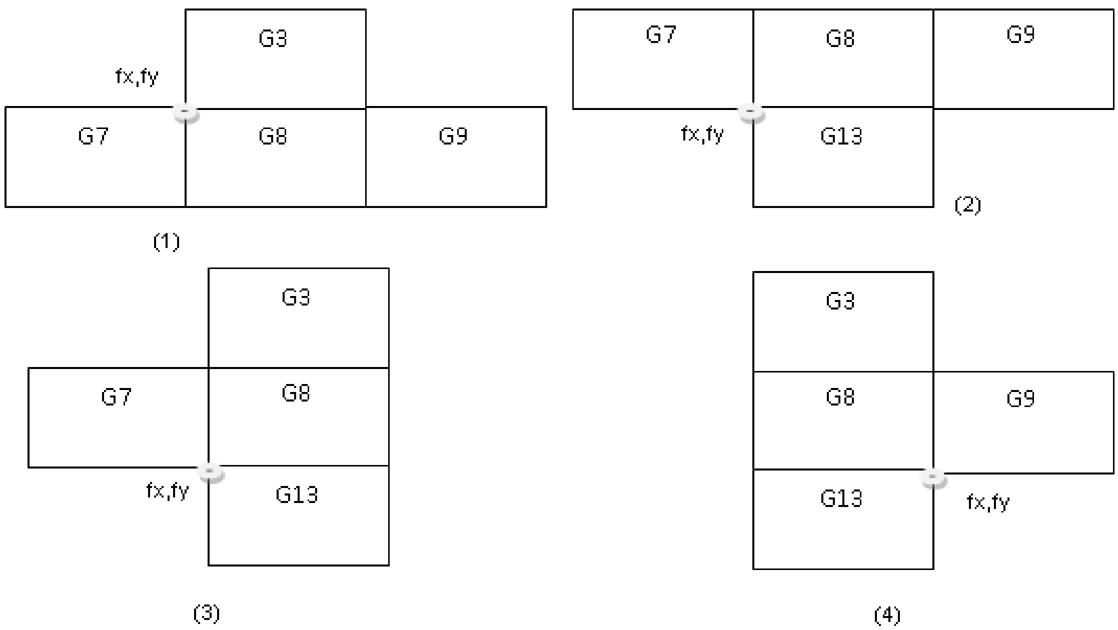

Figure 3-8. Four Grid regions reporting: select coordinates according to the lowest E/C after Grid region.

In the figure 3.8, four different scenarios for selection are presented. In (1) corner of G7 and G3 is selected as G7 has lower E/C as compared to G9. In (2) corner of G7 and G13 is selected as G7 and G13 have lower E/C as compared to G9. In (3) corner of G7 and G13 is selected as G7 and G13 have lower E/C as compared to G3. In (4) corner of G9 and G13 is selected as G9 and G13 combined have lower E/C as compared to combined G3 and G9.

Case 5: Event Region has Four Neighbors

This will be the case if selected grid region has four neighbors reporting. Grid region having lowest E/C ratio will be selected for finding the location for MA placement.

As in Figure 3.9 shown below, all the neighbors are reporting and selection will be on the basis of other lower E/C value grids. Best location coverage will be at the corner of G7 and G13.

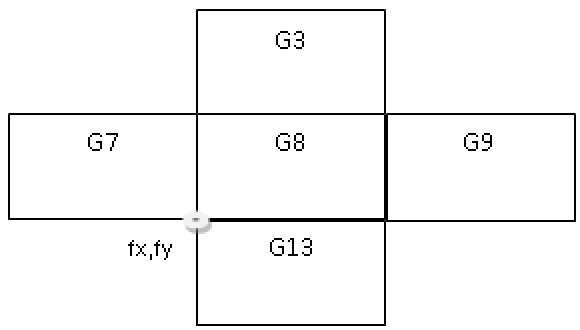

Figure 3-9. Five grid regions are reporting: the decision will be on the basis of lowest E/C of other neighbors reporting

3.3.4 Static Actor (SA) -Mobile Actor (MA) Coordination:

SA, after taking the decision regarding the desired location, will match its current location with the desired location.

Required Destination is the selected co-ordinates from EAR with Tolerance factor

Tolerance factor is specific to the application. Assuming tolerance factor is 5 meters. It is the range which is acceptable for the desired location. If SA is already at the desired location then it will take action according to the application. However, if SA is away from the event region, it will send message to the free available MA to reach at the desired location. MA will move to the new location in the event region.

3.3.5 Mobile Actor (MA) Repositioning

Final x and y co-ordinates will be computed at SA. SA also contains the information of free available MA in the field. SA will send MA the destination location coordinates and MA will move to that location and broadcast a presence beacon in the network. Sensors listen the beacon and will remove their link with SA and will now start sending information to the MA, hence reducing the energy consumption of the network by reducing number of transmissions. Sensors that were reporting to the SA will now report the event to the MA. As hop distance is reduced, this will result in reducing the number of transmissions from the sensor to the actor.

3.4 Summary

This chapter has covered the methodology defined and implemented for the problem of actor repositioning in WSAN. The designed algorithm has achieved the desired goal of reducing the energy consumption of the network. As hop distance is reduced, this will subsequently decrease the number of transmissions from the sensor to the actor. Sensors utilize most of their energy during data transmission and as transmissions decrease, network lifetime is enhanced.

Chapter 4

ANALYSIS AND RESULTS

4.1 Introduction

An EAR algorithm is proposed to reduce the energy consumption of sensors in the network, by considering the energy and count of reporting sensors for relocation. This chapter will cover the analysis and results of the developed approach using test cases. A test case shows how fairly results are matched with the desired results.

4.2 Analysis

It is assumed that all the sensor and actor nodes are of same type. As a result, each sensor and actor nodes consumes same amount of energy for transmission, reception and in idle state. Specifications used to develop the test cases for the EAR algorithm are discussed in Table 4.1 below:

Two types of actors are used in the field:

Static Actor (SA): Purpose is to collect data from the sensors and take decisions regarding the events. It will send messages to other mobile actors only if it is not at an appropriate position within the event region.

Mobile Actor (MA): The purpose of mobile actors is to reduce the energy consumption of the network by moving them closer to event region. Moreover, an appropriate action can only be taken by an actor if it is within or close to event regions this will decrease the delay of event information.

Sensors in the field are static and numerous. These sensors will sense the event and then report to the linked SA. These sensors are location aware. The initial energy of the sensor, specified for the analysis, is 2 Joules. Sensors will subsequently lose energy during transmission. Sensors can transmit within a range of 20 meters.

Table 4-1. Specified parameter for the analysis and testing of the algorithm

Grid Field Size	100X100 meters
Grid Region Size	20 meters
No of Grid Region/ Cells	25 Regions
Number of Sensors	150 nodes
Network Layer	AODV
Radio Range of Sensor	20 Meters
Transmitting power	0.00066 mWatt
Receiving power	0.000395 mWatt
Sense power	0.00000175 mWatt
Energy of Sensor	2 Joules
Packet Size	52 Bytes
SA Listening Interval	5 Seconds
Threshold	100 packets

SA will contain the grid table. Grid regions depend on the field size and they are application specific. As mentioned in Table 4.1, a grid region or cell size is 20x20m. Nodes upon the detection of an event will report the information to their closest SA. The reason for selecting non-mobile actors for initial event reporting is that nodes can discover, SA once and after this can use this information. If mobile actors are used to initial event reporting then nodes will have to discover the closest MA each time on event occurrence.

SA will listen for the event information till the defined threshold is reached. Threshold is the minimum number of packets received for successful event detection by application. As the threshold is reached, SA will start calculating the desired or optimum position of actor field within the event region. If the current actor is not at proper position then it will move the nearest MA to the desired location. MA will move to the location and then broadcast its presence in the event region. Thereafter, sensors will stop reporting to the SA and will start reporting the event to MA. This will reduce the energy consumption of the sensors.

4.2.1 Test Cases

Analyses of the EAR Algorithm will be carried out through test cases for different scenarios and will be matched with the desired results. These test cases are developed using the specification defined in the Table 4.1. These results will be compared with the proposed algorithm explained in chapter 3. When sensors start reporting for the event, SA maintains tables for storing the reporting sensors information. SA computes the count of the nodes reporting from the same region and then calculates the average energy of the grid region nodes. Using this energy and count, it will calculate E/C. The grid having maximum Count and lowest E/C ratio will be selected. Test cases are developed when lowest E/C grid is already selected and algorithm has to find the best possible location for the actor so that maximum region of the event is covered.

4.2.1.1 TestCase1: Event Reporting Sensors lies in Isolated Grid Region:

If the event reporting nodes lye in the same grid region then the maximum count region having lowest E/C ratio is isolated, as there is no other region to compete with.

Table 4-2. Event Reporting nodes information from same Region

Grid Region	Sensor ID	Node X axis	Node Y axis	Energy (J)
GID 9	NID 5	60	26	1.999291
GID 9	NID 6	78	26	1.999296
GID 9	NID 2	73	20	1.999296
GID 9	NID 3	72	20	1.999296

Table 4-3. Grid Region information for sensor reporting from 1 Grid Region

Grid Region	X1	Y1	X2	Y2	X3	Y3	X4	Y4
GID 9	60	20	80	20	60	40	80	40

Table 4.2 show the reporting nodes information from the same region. Energy and location of the sensors are used to take decision. Table 4.3 shows that corner co-ordinate of the event grid region, according to the methodology explained in chapter 3, if all sensors are reporting from the single grid region then selection will be the center of the grid region’s and from Table 4.3 center coordinates will be (70,30).

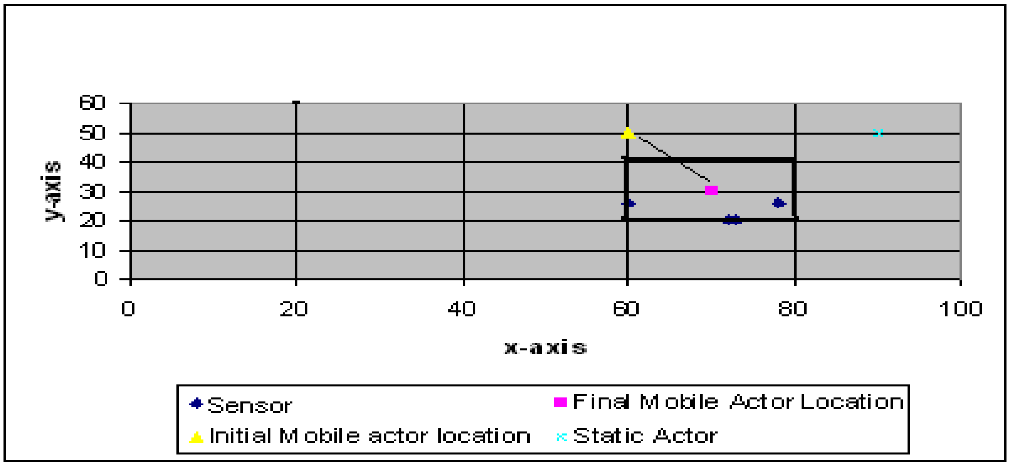

Figure 4-1. MA destination selection in Isolated Grid Region

The isolated grid region, old and new position of MA is shown in figure 4.1.

4.2.1.2 Test Case 2: Event Reporting Region Nodes from 2 Grid Regions:

If the event reporting nodes lye in different grid regions then the selection for the location depends on the linked neighbor and the E/C ratio of the neighbor regions. Test case for the Grid region having one linked neighbor is as follow:

Table 4-4. Event Reporting sensors information from 2 Grid Regions

Grid Region	Sensor ID	Node X axis	Node Y axis	Energy (J)
GID 9	NID 3	72	20	1.999116
GID 9	NID 5	60	20	1.999103
GID 9	NID 6	78	26	1.999117
GID 9	NID 2	73	20	1.999122
GID 8	NID 1	57	20	1.998770

Table 4.4 shows the Event reporting sensors information.

Table 4-5. Grid Regions information for Grid ID 8 and 9

Grid Region	X1	Y1	X2	Y2	X3	Y3	X4	Y4
GID 9	60	20	80	20	60	40	80	40
GID 8	40	20	60	20	40	40	60	40

Table 4.5 shows the Grid region co-ordinate information. Computing E/C values of consecutive grid regions will help in the selection of the best possible location for the actor to cover the entire event region.

Table 4-6. Grid Regions Count and Energy and E/C ratio for the selection of best location for sensor reporting from 2 Grid Regions

GID	Count (C)	Average Energy (E)	E/C
GID 8	1	1.998770	1.998770
GID 9	4	1.999114	0.499779

Table 4.6 shows the Grid region count energy table, according to the methodology explained in chapter 3, if all sensors are reporting from the two consecutive grid regions then selection will be the center of the two linked grid region's and from Table 4.5 center coordinates will be (60,30).

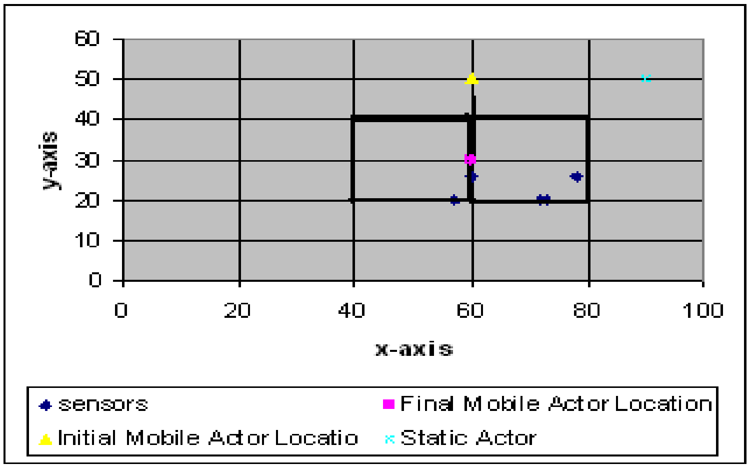

Figure 4-2. MA destination selection in two consecutive neighbors

The two consecutive grid regions, old and new position of MA are shown in Figure 4.2.

4.2.1.3 Test Case 3: Event Reporting Region Nodes from 3 Grid Regions:

If the event reporting nodes lye in different grid regions and these regions are consecutive with the grid having lowest E/C then selection for the best location will be according to the other two grid neighbors' E/C value.

Table 4-7. Reporting nodes information for sensors reporting from 3 Grid Regions

Grid Region	Sensor Node ID	Node X axis	Node Y axis	Energy (J)
GID 9	NID 6	78	26	1.999126
GID 9	NID 3	72	20	1.999203
GID 9	NID 5	60	26	1.999109
GID 9	NID 2	73	20	1.999121
GID 10	NID 7	81	26	1.999126
GID 8	NID 1	57	20	1.998687

Table 4.7 shows the event reporting nodes information from different grid regions**.**

Table 4-8. Grid Regions information for sensor reporting from 3 Grid Regions

Grid Region	X1	Y1	X2	Y2	X3	Y3	X4	Y4
GID 9	60	20	80	20	60	40	80	40
GID 8	40	20	60	20	40	40	60	40
GID 10	80	20	100	20	80	40	100	40

Table 4.8 shows the event reporting grid region and their co-ordinates information.

Table 4-9. Grid Regions Count and Energy and E/C ratio for the selection of best location for sensor reporting from 3 Grid Regions

GID	Count (C)	Average Energy (E)	E/C
GID 8	1	1.998687	1.998687
GID 9	4	1.999139	0.499785
GID 10	1	1.999126	1.999126

Table 4.9 shows the Energy count table of the current grid regions reporting. When the two grid regions are at the opposite ends of the grid region having lowest E/C then selection will be done according to the lowest E/C value of the neighbors. In this test case GID 8 has lower E/C values as compare to GID 10. Consequently, the selection of the location will be the centre of the GID 9 and GID 8 which is 60, 30.

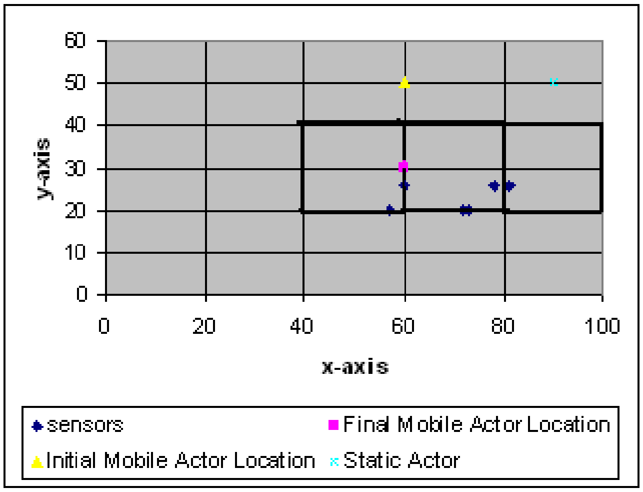

Figure 4-3. MA destination selection in three consecutive neighbors

The three consecutive neighbors, old and new position of MA are shown in Figure 4.3.

4.2.1.4 Test Case 4: Event Reporting Region Nodes from 4 Grid Regions:

If event reporting sensors lye in different grid regions but these regions are consecutive with the grid having lowest E/C then selection for the best location will be according to the other three grid neighbors' E/C value.

Table 4-10. Event reporting nodes information from 4 Grid Regions

Grid Region	Sensor Node ID	Node X axis	Node Y axis	Energy (J)
GID 14	NID 4	60	58	1.999117
GID 10	NID 7	81	26	1.999114
GID 9	NID 2	73	20	1.999114
GID 9	NID 5	60	26	1.999106
GID 9	NID 3	72	20	1.999115
GID 9	NID 6	78	26	1.998120
GID 8	NID 1	57	20	1.998658

Table 4.10 shows the information of all regions and the information about the region.

Table 4-11. Grid Regions information for sensor reporting from 4 Grid Regions

Grid Region	X1	Y1	X2	Y2	X3	Y3	X4	Y4
GID 9	60	20	80	20	60	40	80	40
GID 8	40	20	60	20	40	40	60	40
GID 10	80	20	100	20	80	40	100	40
GID 14	60	40	80	40	60	60	80	60

Table 4.11 shows the location co-ordinates of the event grid regions. Table 4.12 shows the E/C ratio of the every event reporting regions. It will help to select the other grid regions for the selection of desired co-ordinates.

Table 4-12. Grid Regions Count and Energy and E/C ratio for the selection of best location from 4 Grid Regions

GID	Count (C)	Average Energy (E)	E/C
GID 8	1	1.998658	1.998658
GID 9	4	1.999114	0.499778
GID 10	1	1.999114	1.999114
GID 14	1	1.999117	1.999117

If three consecutive neighbors are also reporting for the same event, with the lowest E/C value grid region, then algorithm should select according to the E/C values of the neighbors. Table 4.12 shows the E/C values of the reporting grid regions. GID 9 has lowest E/C value. Now compare between GID8 and GID 10: GID 8 has lower E/C value as compared to GID 10. Therefore the common location between GID 9, GID

8 and GID 14 will be selected with coordinates 60, 40. This location will cover the maximum event region.

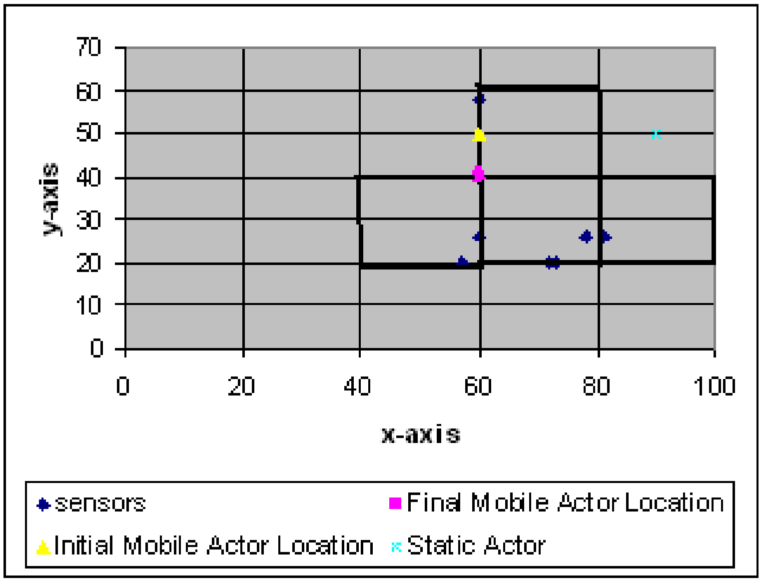

Figure 4-4. MA destination selection in four neighbors

The three event reporting neighbors with lowest E/C value, old and new position of MA are shown in Figure 4.4.

4.2.1.5 Test Case 5: Event Reporting Region Nodes from 5 Grid Regions:

If event reporting sensors lye in different grid regions but these regions are consecutive with the grid having lowest E/C then selection for the best location will be according to the other four grid neighbors' E/C value.

Table 4.13 shows the Event reporting sensors information from 5 different consecutive grid regions.

Table 4-13. Reporting nodes information for sensor reporting from 5 Grid Regions

Grid Region	Sensor Node ID	Node X axis	Node Y axis	Energy (J)

GID 9	NID 5	60	26	1.999108
GID 10	NID 7	81	26	1.999130
GID 14	NID 4	60	58	1.999126
GID 9	NID 6	78	26	1.999130
GID 9	NID 2	73	20	1.999129
GID 9	NID 3	72	20	1.998129
GID 4	NID 8	60	11	1.998129
GID 8	NID 1	57	20	1.998563

Table 4-14. Grid Regions information for sensor reporting from 5 Grid Regions

Grid Region	X1	Y1	X2	Y2	X3	Y3	X4	Y4
GID 4	60	0	80	0	60	20	80	20
GID 8	40	20	60	20	40	40	60	40
GID 9	60	20	80	20	60	40	80	40
GID 10	80	20	100	20	80	40	100	40
GID 14	60	40	80	40	60	60	80	60

Table 4.14 shows the location information about the event reporting grid regions. It will help to identify for the selection of the desired co-ordinates in EAR algorithm.

Table 4-15. Grid Regions Count and Energy and E/C ratio for the selection of best location for sensor reporting from 5 Grid Regions

GID	Count (C)	Average Energy (E)	E/C

GID 4	1	1.999129	1.999129
GID 8	1	1.998563	1.998563
GID 9	4	1.999124	0.499781
GID 10	1	1.999130	1.999130
GID 14	1	1.999126	1.999126

According to the algorithm, the selection of the best location for 5 reporting girds regions consecutive with the grid region having lowest E/C value, will be according to other neighbors' E/C value. As in the above case GID 9 has lowest E/C value, GID 8 has lower E/C as compare to GID 10 and GID 4, GID 14 has lower E/C as compare to GID 4. Table 4.15 shows the E/C ratio of all the reporting regions for the event.

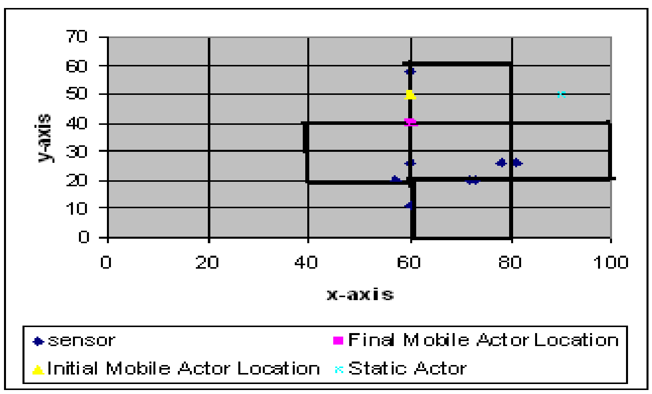

Figure 4-5. MA destination selection in five neighbors

Figure 4.5 shows the visual picture of the event regions. Therefore, the common coordinate between GID 9,GID 8, GID 14 will be selected which is 60,40.

4.3 Results

Results of EAR algorithm are evaluated through throughput, residual energy of the network, packet delay, and packet delivery ratio and convergence time.

4.3.1 Throughput

Throughput of the network is the number of data packets received per second.

Table 4-16. Specifications for finding throughput

Grid Region Size	20 meters
Number of Sensors	150 nodes
Network Layer	AODV
Radio Range	20 Meters
Energy of Sensor	2 Joules
Packet Size	52 Bytes or 416 bits

Throughput is calculated in bits per second. Table 4.16 shows the specifications to find throughput. Grid Region is 20x20 meters. Numbers of sensors in the region are 150 nodes distributed inside the field. Network layer uses AODV, as EAR algorithm is running on application layer, any adhoc or wireless routing protocol can be used. Radio range of the sensor is 20 meters. Energy of the sensors is 2 Joules and packet size is 52 Bytes.

Throughput can be calculated through different data rate. Data rate used are 6,8,12 packets/seconds. Field size used is 100x100 meters with 10 sensors reporting for the event, specifications are shown in table 4.17. By increasing the field to 500x500 meters is also used with data rate of 2 packets/seconds.

Table 4 -17. Specifications of field 100x100 with 6 Data Rate

Grid Field Size	100x100 meters
Grid Region/Cells	25 Regions
Event Reporting Sensors	10
Data Rate	6 Pkt/sec
Data Packet Size	0.374400 Megabits/Interval
SA Listening Interval	15 Seconds
Hop Distance	3 Hops
Threshold	200

Table 4.17 shows 10 sensors reporting with data rate of 6 per seconds i.e. 60 packets/Seconds are received with the interval of 15 seconds showing that 900 packets are originated every interval (60x15=900).

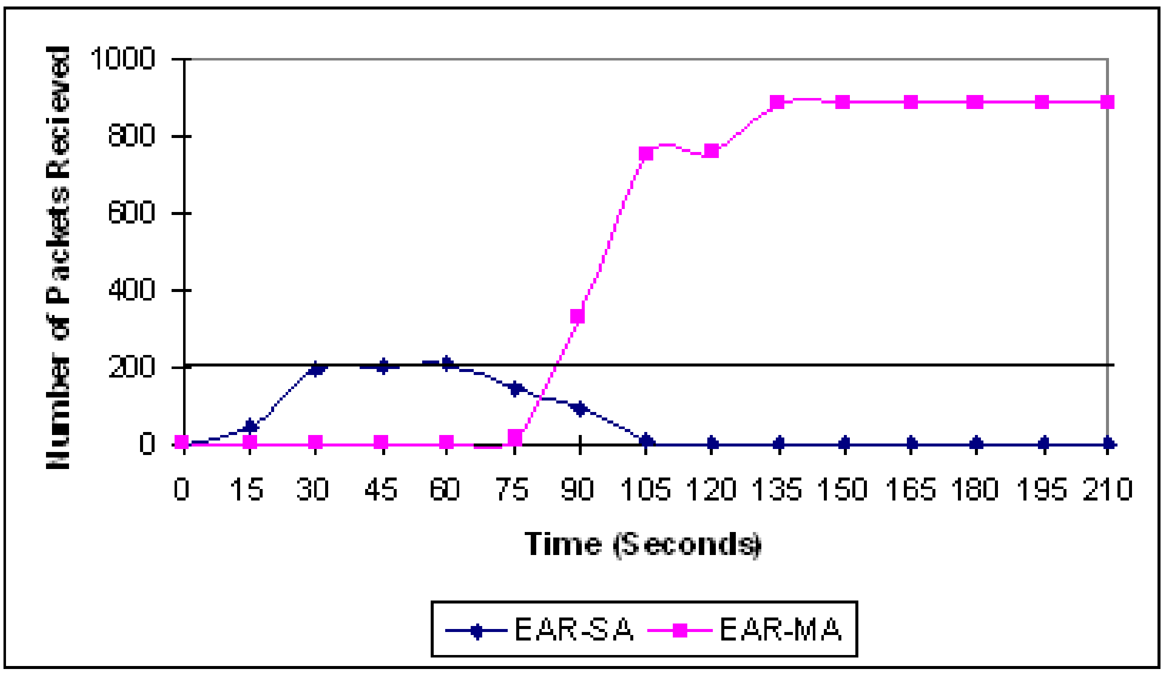

Figure 4-6. Throughput of 10 nodes in 100x100 meters with data rate 6

Figure 4.6 shows that Static actor starts getting packets on 15 seconds and at 45 seconds threshold is reached and decision has been made on the basis of EAR algorithm. At 55 seconds Mobile Actor (MA) has moved to the new location and it broadcasts its location to the sensors in the region. At 75 seconds MA starts getting packets and increases with time and stable at 889 packets/ Interval at 180 seconds. SA at 105 reduces to zero as it is not getting and more packets. Hence it shows that MA is placed to the best possible coverage location where it can get 889 packets / 900 originated packets from different sensors in the region

Table 4-18. Specifications of field 100x100 with 8 Data Rate

Grid Field Size	100x100 meters
Grid Region/Cells	25 Regions
Event Reporting Sensors	10
Data Rate	8 Pkt/sec
Data Packet Size	0.499200 Megabits/Interval
SA Listening Interval	15 Seconds
Hop Distance	3 Hops

Table 4.18 shows 10 sensors reporting with data rate of 8 per seconds i.e. 80 packets/Seconds are received with the interval of 15 seconds showing that 1200 packets are originated every interval (80x15=1200).

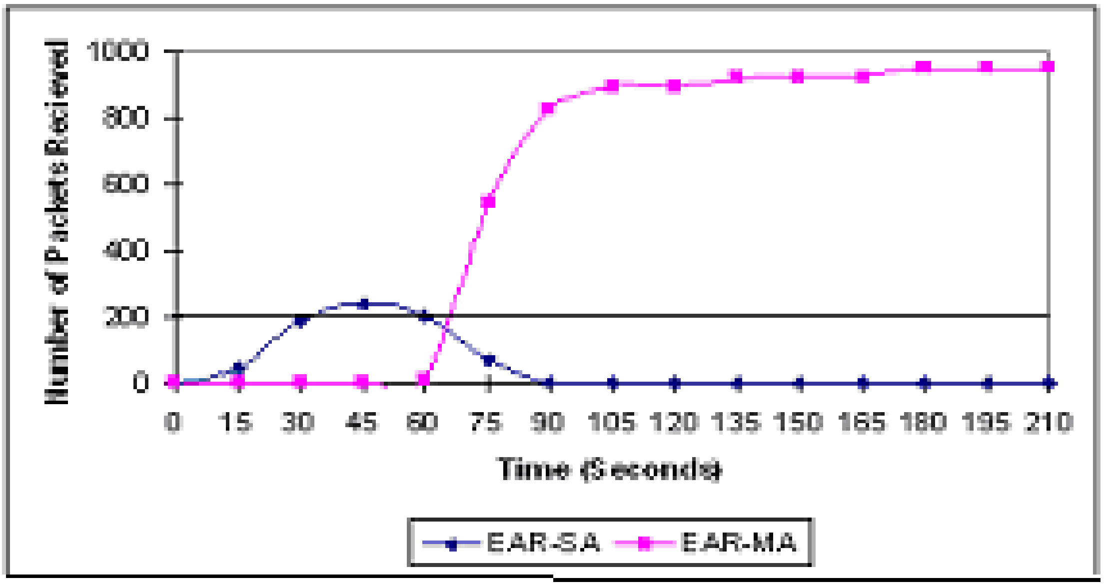

Figure 4-7. Throughput of 10 nodes in 100x100 meters with data rate 8

Figure 4.7 shows that Static actor starts getting packets on 15 seconds and at 40 seconds threshold is reached and decision has been made on the basis of EAR algorithm. At 50 seconds Mobile Actor (MA) has moved to the new location and it broadcasts its location to the sensors in the region. At 60 seconds MA starts getting packets and increases with time and stable at 950 packets/ Interval at 180 seconds. SA at 90 reduces to zero as it is not getting and more packets. Hence it shows that MA is placed to the best possible coverage location where it can get 950 packets / 1200 originated packets from different sensors in the region.

Table 4-19. Specifications of field 100x100 with 12 Data Rate

Grid Field Size	100x100 meters
Grid Region/Cells	25 Regions
Event Reporting Sensors	10
Data Rate	12 Pkt/sec
Data Packet Size	0.748800 Megabits/Interval
SA Listening Interval	15 Seconds
Hop Distance	3 Hops
Threshold	200

Table 4.19 shows that 10 sensors reporting with data rate of 12 per seconds i.e. 120 packets/Seconds are received with the interval of 15 seconds showing that 1800 packets are originated every interval (120x15=1800).

Figure 4.8 shows that Static actor starts getting packets on 15 seconds and at 90 seconds threshold is reached and decision has been made on the basis of EAR algorithm. At 100 seconds Mobile Actor (MA) has moved to the new location and it broadcasts its location to the sensors in the region.

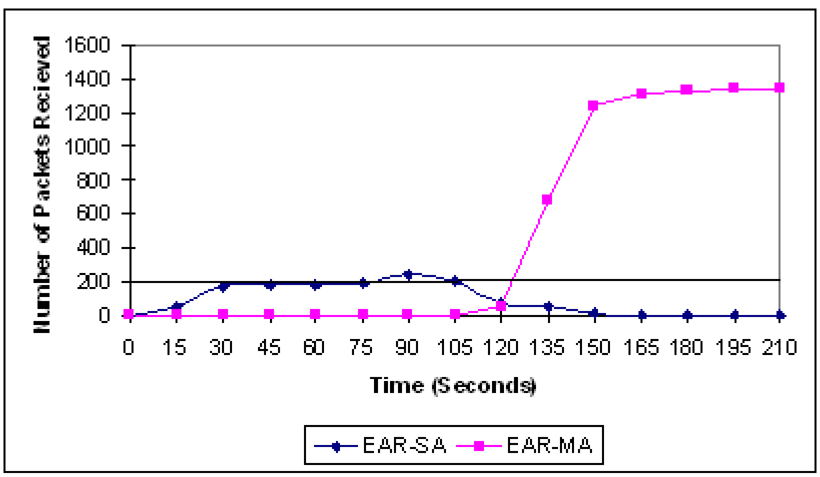

Figure 4-8. Throughput of 10 nodes in 100x100 meters with data rate 12

At 105 seconds MA starts getting packets and increases with time and stable at 1336 packets/ Interval at 180 seconds. SA at 150 reduces to zero as it is not getting and more packets. Hence it shows that MA is placed to the best possible coverage location where it can get 1336 packets / 1800 originated packets from different sensors in the region.

Table 4-20. Specifications of field 500x500 with 2 Data Rate

Grid Field Size	500x500 meters
Grid Region/Cells	625 Regions
Event Reporting Sensors	30
Data Rate	2 Pkt/sec
Data Packet Size	0.374400 Megabits/Interval
SA Listening Interval	15 Seconds
Hop Distance	11 Hops
Threshold	200

Table 4.20 shows that 30 sensors reporting with data rate of 2 per seconds i.e. 60 packets/Seconds are received with the interval of 15 seconds showing that 900 packets are originated every interval (60x15=900).

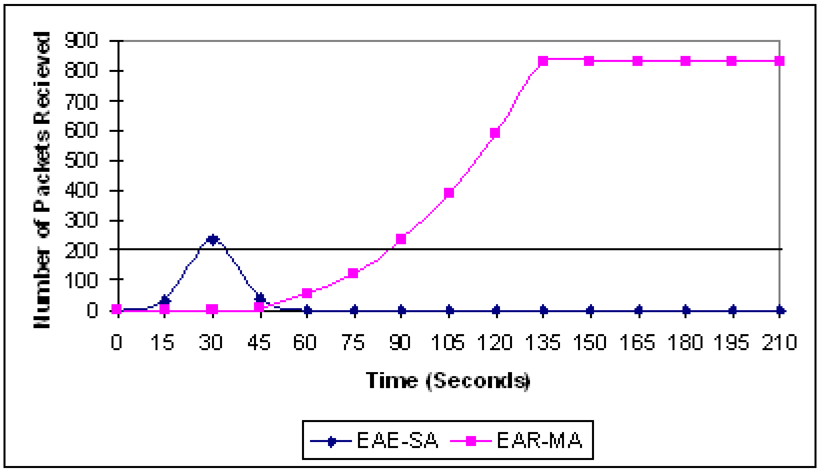

Figure 4-9. Number of packets received/second for static and mobile actor in the field with 2 Data Rate

The graph shown in the above figure 4.9 plots the relation between the numbers of packets received per second by two different actors. SA records the event and as the threshold reaches at 30 seconds, computation is performed and new location is calculated. New location is sent to MA. It will move to the event region and started broadcasting around 35 seconds. At 45 seconds, sensors will start sending packet to the MA instead of SA. Number of packets being received at SA is reduced to zero at 60 seconds while MA will keep on getting the packets till it takes any action.

Literature work has widely one of the following factors for the selection of appropriate location in the event region. Factors are as follow: Euclidian distance, Energy of the event region or Maximum number of sensors in the event region.

Using the specification of Table 4.20 throughput between different factors like energy, distance, energy and EAR Algorithm can be computed.

Table 4-21. Information of Reporting Regions

Grid ID	No of sensors	Energy
G-336	1	1.9935
G-311	10	1.9975
G-338	1	1.9926
G-312	5	1.9961
G-337	3	1.9955
G-313	8	1.9972
G-314	2	1.9993

Table 4.21 shows the reporting region information. Information contains number of reporting sensors from the region and the average energy of the region.

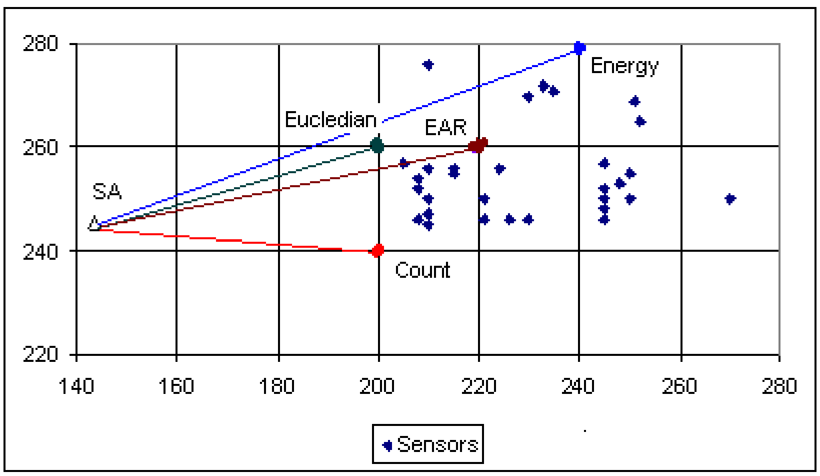

Figure 4-10. Information of Reporting Sensors

Figure 4.10 shows the graphical information of the region and the selection criteria for all the factors including Euclidean distance, Energy, count and EAR algorithm. This figure shows that EAR has covered the maximum region of the reporting nodes.

Table 4-22. Final Selected Location from different selection factors

	Grid ID	Location X	Location Y	Reporting Count
Count-MA	G-311	200	240	10
Energy-MA	G-338	240	280	1
Euclidean-MA	G-336	200	260	1
EAR-MA	G-311	220	260	10

Table 4.22 shows different factors for the selection of the appropriate location, Count-MA is the mobile actor used to move at the location calculated through maximum count factor. Energy-MA is the mobile actor used to move at the location calculated through lowest energy of the region. Euclidian-MA is the mobile actor used to move through the smallest distance between SA and the event region. EAR-MA is the mobile actor used to select the location on the basis of E/C of the region. Region having lowest energy and maximum count, E/C will give the ratio of energy and count in the region and hence will move to the best appropriate location to cover the most event region.

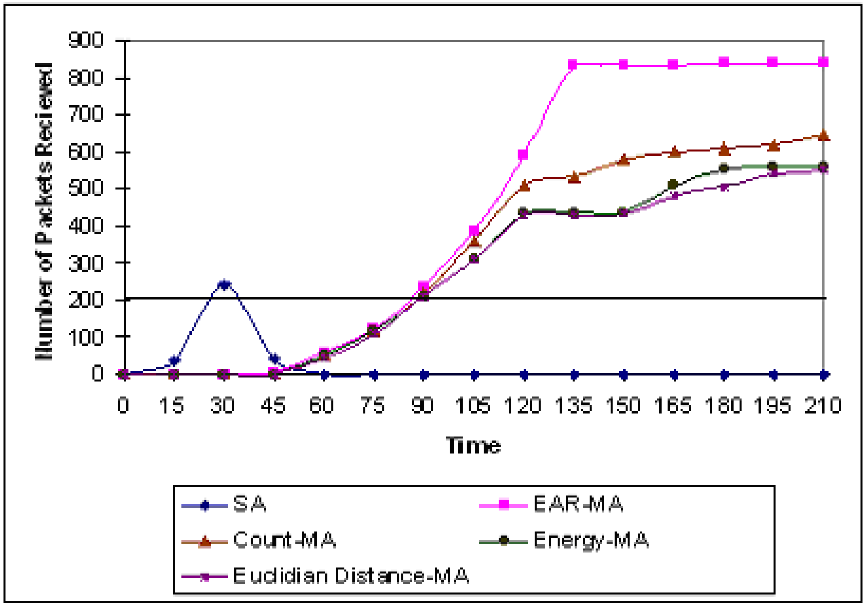

Figure 4-11. Comparison between count, energy, Euclidian distance and EAR algorithm throughput

Figure 4.11 shows that SA has started reporting at 15 seconds and at 30 seconds it has reached the threshold. Threshold defined is 500 and SA will start computation for the appropriate location. When using Euclidean distance as a factor for selection, it will select Grid ID 336, for Low energy of the region Grid ID 338 is selected. In case of Maximum sensors reporting Grid ID 311 is selected. EAR algorithm calculates E/C of all the region, 312 is the region having maximum count including all the neighbors and lowest E/C of the region. It is shown that EAR algorithm is getting the maximum number of reporting packets as it is covering the best appropriate location, Euclidean distance is also selected on the basis of lowest distance from event to actor.

It has increased the throughput like EAR algorithm but will give different selection regions in different scenarios on the basis of SA placement. Count factor is also considering the maximum count reporting from any region and hence neighbors are not been considered in this scenario, hence its throughput is lower then EAR algorithm throughput. Lowest energy of the region is used to select and reduce energy of the network but it is not the best appropriate location as in this scenario, region having lowest energy has only 1 sensor node reporting, i-e it is not the best possible region to cover all the event regions.

4.3.2 Residual Energy of Network

The purpose of the mobility of the actor in the WSAN field is to reduce the energy consumption in the network. Network energy can be reduced if the actor itself moves to the location of event and establishes new links with the reporting sensors to reduce the number of sensor transmissions. The graph below shows this relation using specifications of Table 4.16.

Figure 4.12 shows that residual energy of the network is conserved by reducing the number of transmissions of the sensors by virtue of the mobility of the actor. Initially, all sensors are reporting to the SA at a distance of 3 hops

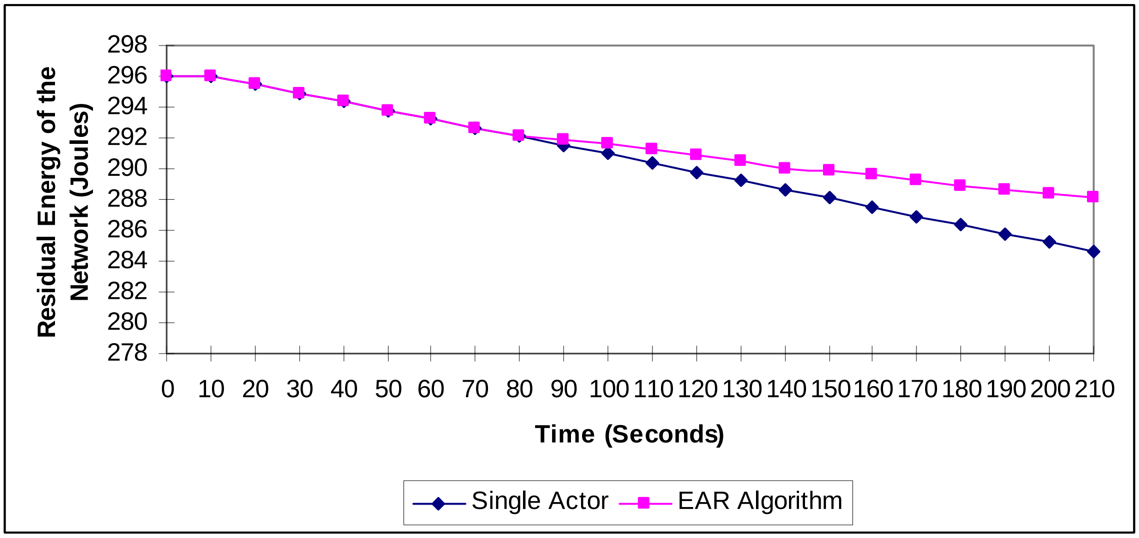

Figure 4-12. Residual energy of the network with 100mX100m field

. Field size is 100x100m and data rate is 8 packets /seconds using specification of Table 4.18.

When an event occurs, MA will move to the event region. Data transmission will be now between MA and the sensors. Hence transmissions are reduced with the developed approach as shown in Figure 4.12.

Table 4-23. Specification to find residual energy with 300x300 field size

Grid Field Size	300X300 meters
Hop Distance	5 Hops
Event Reporting Sensors	10
Data Rate	8 Pkt/sec
Data Packet Size	0.332800 Megabits/Interval
SA Listening Interval	10 Seconds

Table 4.23 is used to find the residual energy of the field 300mx300m with increased hop distance from the SA to event region and using other specification defined in table 4.16.

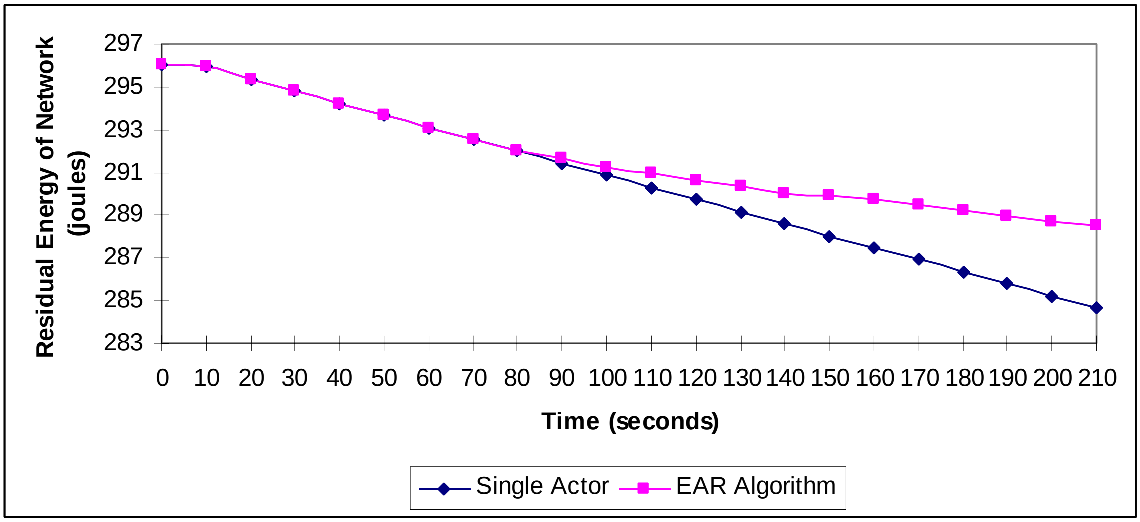

Figure 4-13. Residual energy of the network with 300mx300m field

With the variation of field size and increased number of hops between SA and event location, it is observed that by exploiting the mobility of MA, energy consumption is reduced by a greater factor in comparison with the SA as shown in Figure 4.13.

Figure 4.13 shows that relocation of the actor to the event region consumes energy and increases the network lifetime.

Table 4-24. Specification to find residual energy with 500x500 field size

Grid Field Size	500X500 meters
Hop Distance	11 Hops
Event Reporting Sensors	10
Data Rate	8 Pkt/sec
Data Packet Size	0.332800 Megabits/Interval
SA Listening Interval	10 Seconds

Figure 4.14 shows the residual energy of the network in 500x500m and 30 nodes are reporting and it is clearly observed that more energy can be consumed through repositioning.

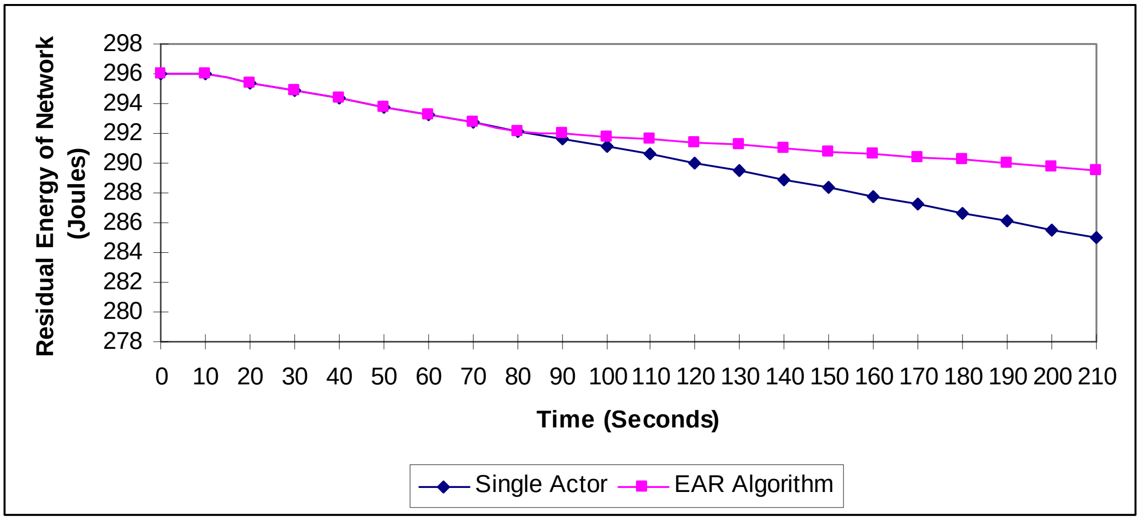

Figure 4-14. Residual energy of the network with 500mx500m field

In existing literature, SA is used for the communication of event. EAR algorithm is using both SA for collection and decision making and MA for action. Hence it is observed that there are significant improvements in terms of energy consumption when using SA-with-mobility (MA) as opposed to using only SA, as evident from the Figures 4.11, 4.12, 4.13. With the increasing hop distance, the improvement in terms of reduced number of transmission between sensors reporting to SA is even greater. Till the threshold is reached, more energy is consumed. However, once the MA moves to the event region, all event reporting nodes will start communicating with the MA which, after entering the event region, will be at 2 hop distance. Hence developed algorithm has reduced the energy consumption through decreasing the number of transmissions.

4.3.3 Packet Delay

Packet delay is the delay of the packet reception from the sensors to the actor. Using the specification of Table 4.16 and Table 4.20, delay with the time is calculated.

Delay = Time at which data has reached the destination – Time at which data has been originated

Total Delay= Total Delay + Delay (each Packet)

Average Packet Delay= Total Delay/ Number of Packets

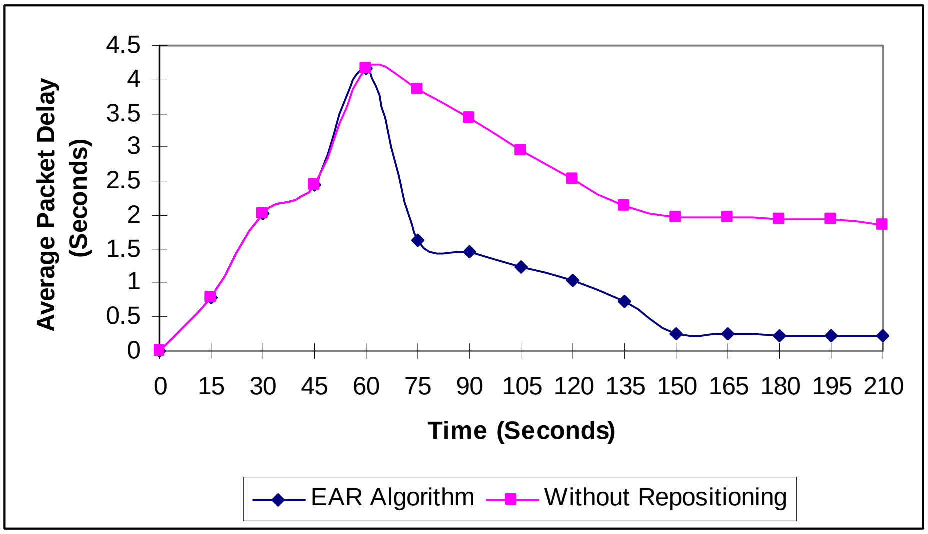

Figure 4-15. Packet delay for 500mx 500m field with data rate 2

Figure 4.15 shows the delay in the data transmission from sensor to actor. At 10 seconds, data is originated and reaches the SA of EAR Algorithm. Delay increases since all the sensors start reporting almost simultaneously at 30 seconds and congestion can be experienced. At 75 seconds SA reduces to zero and MA of EAR Algorithm starts getting packets at new location and reduces the delay in the network.. At 150 seconds EAR Algorithm delay reduces to 0.23453 as it is inside the event region.

In without repositioning at 60 seconds delay is maximum It is observed that as relocation has not taken place in the region Static actor continues getting packets and drop ratio is very high. Delay is reduced to 2.13244 and it becomes stable at 150 seconds.

4.3.4 Packet Delivery Ratio

Packet Delivery Ratio is the number of packets received to the number of packets originated.

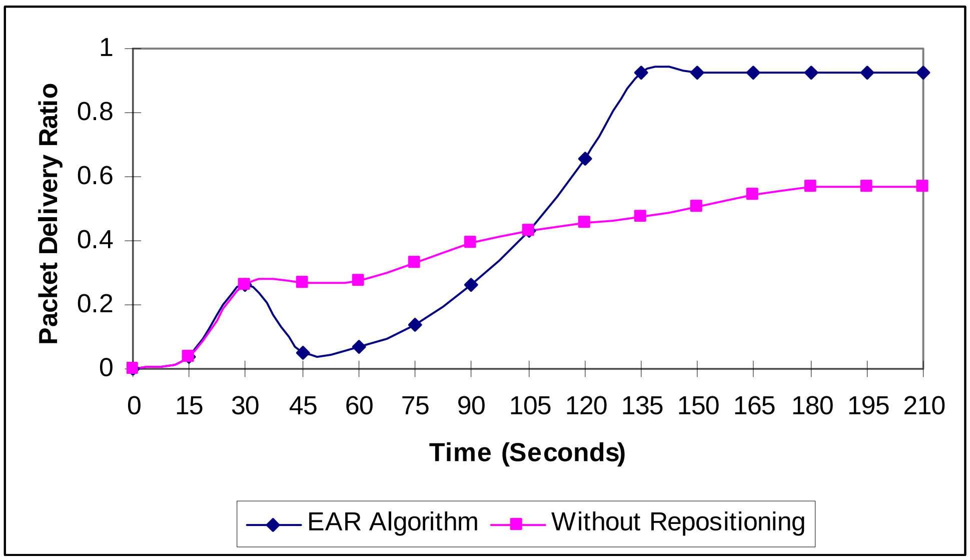

Figure 4-16. Packet delivery ratio for 500mx500m field with 2 packets/sec

Figure 4.16 shows the packet delivery ratio with time in the field of 500x500m and with the hop distance of 11 and data rate of 2 packets per second. Before an event occurs and reporting to SA begins, the initial packet delivery is zero.

At 30 seconds, threshold is reached and due to the network congestion, packets start to drop. At 60 seconds, packet delivery ratio is again increased at EAR algorithm as MA is reached in the event region. In the case of without repositioning SA kept on getting packets but around 0.5 Packet delivery ratio it will become stable at 180 seconds, EAR on the other hand is getting packets and packet drop ratio is very low and at 135 seconds it is getting packets with the packet delivery ratio of 0.95.

4.3.5 Convergence Time

It is the time MA takes to reach to the desired destination. By increasing the speed of the MA we can reduce the delay it takes to reach the destination.

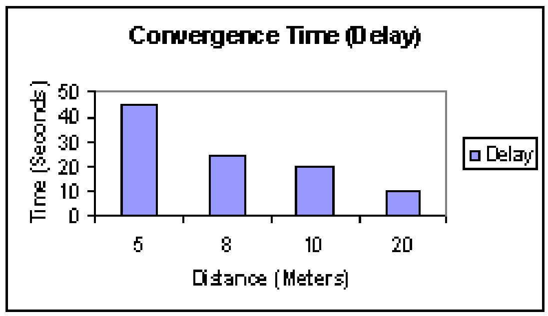

Figure 4-17. Convergence Time using the EAR Algorithm

Figure 4.17. shown below shows that by increasing the speed of the MA we can reduce the delay of the MA to reach the destination. As with speed of 5 meters/sec MA takes 45 seconds to reach when it is away from event region at 11 hops.

With 8 meters/sec speed MA takes 25 seconds to reach the destination. With the speed of 10 meters/sec MA takes 20 seconds to reach the destination and with the speed of 20 meters/sec MA reaches to the destination within 10 seconds. Hence by increasing the speed of the MA we can reduce the delay to reach to the destination.

4.4 Summary

In this chapter, a detailed analysis of the performance of the EAR algorithm is carried out in terms of throughput, residual energy of the network, packet delays and packet delivery ratio. The results are obtained through various carefully designed test cases. It is demonstrated that the EAR algorithm, proposed and implemented as part of this thesis, is an energy efficient algorithm for actor repositioning in WSANs.

Chapter 5

LIMITATIONS AND CONCLUSION

5.1 Introduction

This chapter will illustrate the advantages and limitations for the proposed algorithm. Finally a conclusion to the thesis is presented.

5.2 Advantages

The proposed algorithm has several advantages:

- Algorithm is specific to actors and their positioning in WSANs; they have high power and computational capabilities; sensor energy will only be used during the transmission of data.
- Actor will setup a grid only once, at the time when it is placed inside the field. However, if the field size changes, actor will again setup the grid according to the new field size.
- Algorithm is implemented at the application layer therefore it is independent of underlying routing protocols. It also doesn't apply any modifications or enhancements to the lower layers. This placement increases the utilization of the algorithm for various applications.
- Algorithm is equally useful for clustered as well as non-clustered approaches.
- Algorithm makes use of additional parameters, such as energy, to find the destination for MA placement.

- Algorithm has significantly reduced the network energy consumption and packet delay ratio by incorporating the use of mobile actor.

5.3 Limitations

Algorithm has a few limitations as listed below.

- Algorithm assumes the availability of static and mobile actors.
- Sensors should be location aware.
- Sensors will send their location and energy information when they report an event to the actor.

5.4 Conclusion

Wireless sensor and actor networks (WSANs) have attracted a lot of attention in recent years due to their potential relevance in many applications. A number of applications employ such mobile actors which can move towards the direction of an event region in order to minimize the number of transmissions and cover the maximum area for the event reporting sensor nodes. Mobile actors could be relocated to the monitored region to minimize energy consumption of the sensors in the network. As sensors are low power devices, this algorithm has focused to reduce the energy consumed by the sensors in reporting events to actors over multiple hops. To increase the network lifetime and the residual energy of the network, a new approach has been proposed and developed. The number of packet transmissions in the network has been reduced which has resulted in improved network lifetime. Results have shown that the new approach has reduced the energy consumption of the network by use of mobile actors in the field. Energy has also been considered in the decision making phase of the algorithm regarding mobile actor placement. The decreased number of packet transmissions and improved network lifetime achieved with the use of EAR algorithm makes it a suitable candidate to be used extensively in applications that require relocation of actor in the field in the presence of an event.

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