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# Increasing Lifetime of Target Tracking Wireless Sensor Networks

Khin Thanda Soe

***Abstract*—**A model to identify the lifetime of target tracking wireless sensor network is proposed. The model is a static cluster-based architecture and aims to provide two factors. First, it is to increase the lifetime of target tracking wireless sensor network. Secondly, it is to enable good localization result with low energy consumption for each sensor in the network. The model consists of heterogeneous sensors and each sensing member node in a cluster uses two operation modes—active mode and sleep mode. The performance results illustrate that the proposed architecture consumes less energy and increases lifetime than centralized and dynamic clustering architectures, for target tracking sensor network.

***Keywords*—**Network lifetime, Target Localization, Target Tracking, Wireless Sensor Networks.

## I. Introduction

Wireless Sensor Networks (WSNs) are distributed embedded systems composed of a large number of low-cost, low-power, multifunctional sensor nodes. The sensor nodes are small in size and communicate wirelessly in short distances. These tiny sensor nodes can perform sensing, data processing and communicating. They are densely deployed in the desired environment.

A sensor uses one type of energy, a signal of some sort, and converts it into a reading for the purpose of information transfer. Each sensor node has multiple modalities for sensing the environment such as acoustic, seismic, light, temperature, etc. However, each sensor can sense only one modality at a time.

Sensor networks apply the cooperating ability of sensor nodes. Collaborative detection and tracking requires data exchange between sensor nodes over an ad hoc wireless network with no central coordination medium.

Our environment can be instrumented with sensor nodes. There are many application areas offered by WSNs. Examples include enemy detection and tracking for military purpose, machine monitoring and inventory control system, remote sensing and environmental monitoring. The sensors are typically battery-powered and have limited wireless communication bandwidth. Therefore, energy efficient target tracking systems are needed for less consumption of important energy from sensors.

One of the key advantages of WSNs is the ability to gather certain useful information from the physical world and communicate that information to more powerful devices that can process it. If the ability of the WSNs is suitably harnessed, it is envisioned that WSNs can reduce or eliminate the need for human involvement in information gathering in event detection and tracking applications.

The energy constraints are more fundamental than the limited processor bandwidth and memory in sensor networks. Energy constraints are unlikely to be solved in the near future with the slow progress in battery capacity and energy scavenging. Moreover, the unattended nature of sensor nodes and the hazardous sensing environment prevents manual battery replacement. For these reasons, energy awareness becomes the key research challenge for sensor network protocol design. Several researchers [6], [10], [12] have addressed energy conservation recently.

In this paper, the system design and implementation architecture is proposed to increase sensor network lifetime for target tracking. The purpose of the system is to support the ability to track the position of moving targets in an energy efficient manner with low energy consumption for the sensing nodes in the network and to extend the life time of a sensor network.

Our system is the designed architecture of an energy efficient target tracking system using acoustic sensors and photoelectric sensors. It also uses sleep mode and active mode for each acoustic sensor to make these acoustic sensor nodes save their important energy.

The rest of the paper is organized as follows: Section II discusses the target tracking in a WSNs and some related works. Section III presents the proposed target tracking system. In Section IV, performance evaluation results are presented. Finally, Section V concludes the paper.

## II. Related Work

### *A. Target Tracking*

Target detection, classification and tracking are the important applications in WSNs. In a target tracking system such as in [1], [2], a moving target such as a vehicle or a person which passes through wireless sensor network can be tracked using multiple modalities, acoustic, light, seismic, etc. of the sensors.

There are centralized and distributed approaches for target tracking in WSN. In a centralized target tracking system, sensors in the sensing network detect the target and send the target signatures to the Base Station (BS) that is also a sensor connecting to a laptop or a processing unit. BS determines whether there is a target or not by using the target signatures sent from the sensing nodes and tracks if there is the target. There may be many sensor nodes transporting the target

Khin Thanda Soe is with the Wireless Sensor Network Lab, University of Computer Studies, Yangon, Myanmar (e-mail: ktdsoe@gmail.com).

information to BS at the same time. Therefore, this centralized approach causes the data receiving sensor at BS to die easily because of the information overload.

For a distributed approach [3], [8], the whole sensor network is divided into regions. There is one manager node in each region. The processing tasks are performed at the manager nodes, not only at base station.

To facilitate collaborative data processing for target tracking in sensor networks, the cluster architecture is usually used in which sensors are organized into clusters. Within each cluster, there consists of a cluster head (CH) and several neighboring member sensors. In the conventional cluster architecture, clusters are formed statically at the time of network deployment. The attributes of each cluster, such as the size of a cluster, the area it covers, and the members it possesses, are static. The static clustering architecture offers the sensor networks to save the important energy of the sensors for finding cluster heads.

Dynamic cluster architectures [11] offer several desirable features. Formation of a cluster is triggered by certain events such as detection of an approaching target with acoustic sounds. Specifically, when a sensor with sufficient battery and computational power, detects with a high signal-to-noise ratio (SNR), certain signals of interest, it volunteers to act as a CH. On the other hand, a decentralized approach has to be used to ensure that for most of the time only one CH is active in the neighborhood of a target to be tracked. Sensors in the vicinity of the active CH are "invited" to become members of the cluster and will report their sensor data to the CH. In this manner, a cluster is only formed in the area of high event concentration. Sensors do not statically belong to a cluster, and may support different clusters at different times. Moreover, as only one cluster is active in the locality of a target, redundant data is suppressed.

Although dynamic clustering offers many benefits, it consumes the sensor's essential energy for choosing the next cluster head and trying to form cluster with its neighbors until the target leaves the sensor networks. By focusing on energy conservation and tracking quality, static clustering architecture and distributed approach are used for our system.

For instance, in a simple Leader-based Approach [5], there is only one leader at any time instant where a new measurement is taken. Belief is updated based on Bayesian filtering. The leader selects the new leader node from its neighborhood to handoff the tracking responsibility. Then the current leader communicates the current belief to the new leader. The benefits of this approach are minimum communication of measurements and good scalability with number of targets if the targets are well separated.

However, there are also many potential issues with many redundant tracks without proper track initiation and management, difficulties in handling ambiguity with track collisions resulting from redundant tracks or target crossovers. And it uses minimum collaborative signal processing to improve localization and tracking performance.

### *B. Localization Measurement Techniques*

Most localization measurement techniques depend on three types of physical variables measured at the sensors for localization. These are Direction Of Arrival (DOA), Time Delay Of Arrival (TDOA) and Received Signal Strength (RSS) or Energy. DOA is suitable for narrow band signals but requires either arrays at each sensor or synchronization across sensors. It also has less quality to compare with the other two approaches. Time Delay of Arrival (TDOA) [7] is suitable for broadband signals and requires accurate measurement of relative time delays between sensor nodes. In contrast, Received Signal Strength or Energy (RSS) technique requires only appropriate signal attenuation model. It is much easier and less costly to obtain from the time series recordings from each sensor.

Acoustic energy for source localization is used by many researchers. Energy based acoustic source localization presented in [13] calculates average energy in the time period and performs energy-based constant false alarm rate (CFAR) detector for detection node and performs simple voting algorithm and decision fusion algorithm for manager node. They showed that the performance of localization and region detection is related to the sensor deployment. The optimum sensor deployment is very important for sensor network communication.

In [14], sequential acoustic energy based source localization using particle filter was presented. The algorithm represents the required probability density function as a set of random samples. Using the prior likelihood function and post likelihood function, the particle filter propagates and updates the set of random samples, eliminates the requirement of a comprehensive search over the whole location space and filters out the spurious location. Hence, the system is more robust to parameter perturbations and more computationally efficient.

RARE [4] presented energy-efficient target tracking protocol and weighs the sensor readings for quality of data. Target position is estimated using trilateration. E-MAC [9] proposed the efficient protocol design for wireless sensor networks. The protocol uses four states: sleep, idle, transmit, and receive. For a sensor, checking for state changes and switching from one state to another consumes energy.

In this paper, RSS (energy) measurements are considered for acoustic sources localization using trilateration method in WSN and acoustic sensors use two states for target tracking. Energy-based source localization is motivated by a simple observation that the sound level decreases between the sound source and the listener becomes large. By modeling the relation between sound level (energy) and distance from the sound source, one may estimate the source location using multiple energy reading at different, known sensor locations.

As sensors have limited battery power and limited wireless communication, energy efficient collaborative signal processing algorithms are needed. Source localization using acoustic signal need little data to be transmitted via wireless communication channel. Acoustic signal intensity measurement is more efficient to detect the presence of a target and track this target than using other modalities such as seismic or radar. Centralized tracking approach is not effective for WSN. Dynamic clustering reduces the lifetime of sensors by using the sensor's important energy. In simple leader based approach, performance results are not good. These factors contribute to the development of our acoustic target tracking system.

## III. System Architecture

In this section, the proposed wireless sensor network architecture is presented. The architecture aims to design and implement a wireless sensor network that enables energy efficient detection and tracking of events.

### *A. Assumptions*

Initially, we assume that each sensor has it own localization and stationary awareness. The sensing area of a sensor is shaped as a circle with a radius R centered at the location of the sensor. We also assume that sensors can directly communicate with the neighboring sensors within a radius at least 2R because the communication range is twice more than the sensing range. The sensing range for the photoelectric sensors and acoustic sensors is about 10 m.

The system uses uniform distribution for sensor placement. By using this approach, the sensor network area is equally divided into a number of regions based on the number of sensors. It is assumed that multiple targets can be detected if they are far enough apart and there is only one target at a time in each cell. However, there can be many targets at the same time in the sensing area.

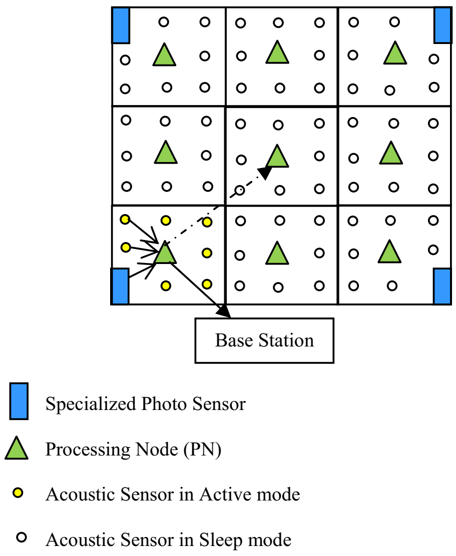


Fig. 1 Architecture for target detection and tracking system

### *B. Target Tracking Architecture*

The proposed sensor network architecture is a static cluster-based architecture as shown in Fig. 1. The system uses heterogeneous sensors that are specialized photo detecting sensors, acoustic sensors and processing nodes. There are two processing modes for sensors as described in Table I.

Here we assume that a target may enter the sensing area via one of the four corners of the sensing range. The specialized photo detecting sensors are placed like guards at the four corners of the sensing area. These are shown in Fig. 1 with four rectangles. They are set at active mode all the time so that they can detect whether a target enters the sensor network.

The acoustic sensors are also described with small circles in Fig. 1. They are not active if the target is not in their corresponding region. They are initially set at the sleep modes and turned to active modes only when there is a target. Therefore, they can save their energy and make their life time long.

TABLE I
Two Processing Modes for Acoustic Sensors

| Processing Mode | Tasks perform in the corresponding mode |
|---|---|
| Active Mode | All parts of the sensor are fully powered. Sensor performs sensing the environment, processing, receiving packet from cluster head, and transmitting RSS value to cluster head. |
| Sleep Mode | It is energy saving mode. Sensor only listens an interrupt to go active mode. |

By using uniform distribution of sensor placement, we divide the whole sensor network into the equal regions. The system uses decentralized target tracking so there is only one cluster head in each region. The cluster head that we also call the processing node (PN), the triangles in Fig. 1, collects the sensing data from the acoustic and photo detecting sensors in their region. Then it processes the receiving data and sends the target signature to the Base Station.

Base Station is a sensor, which can take appropriate actions such as sending a message on the internet or to the satellite, connecting to the processing unit with a cable and it is also wirelessly connected with the sensor network. The Base Station in our system predicts the next region that the target may go and also reports the target signature to the user.

In our system, the whole sensor network does not need to use the energy for sensing the target all the time. Only the sensors in the region where a target arrives need to be active states. Otherwise, they go to the sleep states for energy efficiency. The active sensors with color and other sleep sensors are shown in Fig. 1. Sensor nodes in active states consume more energy than nodes in sleep states. Compared with the number of sleeping nodes, there are a small number of active nodes at any time in our network. Therefore, our proposed system is an energy efficient target tracking system what increases the sensors and network lifetime.

The proposed target tracking system consists of three main procedures as shown in Fig. 2. They are

- Target detection
- Acoustic source localization
- Target state estimation and tracking

### *C. Target Detection*

When the photo sensor at one of the four corners detects a target, it tells the processing node that there is a target. At that time the acoustic sensors go to active states and sense the acoustic signals from the target. If the Received Signal Strength (RSS) value from the target at a particular acoustic sensor exceeds the predetermined threshold, this sensor determines that a target is in the network. Then the detected sensor sends its RSS value with the corresponding target signatures such as receiving time to the processing node.

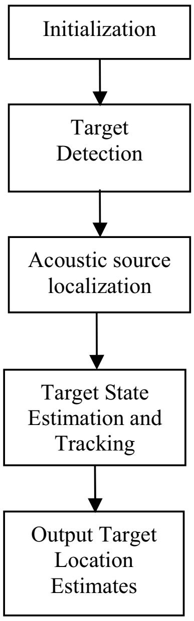


Fig. 2 Processing steps of the target tracking system

### *D. Acoustic Source Localization*

The target location at successive time instants is determined by integrating with target tracking. Localization performs at the processing node (PN) in the region where the target currently arrives by using the RSS values sending from the neighboring acoustic sensors in that region. During this step, the processing node performs the energy based acoustic source localization using trilateration method.

The processing node firstly chooses three highest RSS values among the sensing RSS values. The localization process computes by trilateration at PN and then it reports the target signatures to the base station until the target leaves the sensing network. If the target is stationary or moves around within a small area, the PN may not change the target localization estimation. When the target has left the current region, the current target information is propagated to the next processing node of the other region where the target currently arrives.

### *E. Target State Estimation and Tracking*

At the last stage of our system, the processing node reports target information such as location, time and velocity of the target, which information are processed at step 2 to the base station. Base station estimates the next active region that the target will go by using the information from the processing node and track the moving path of the target. Finally, the base station reports the target tracking information to the user via the internet.

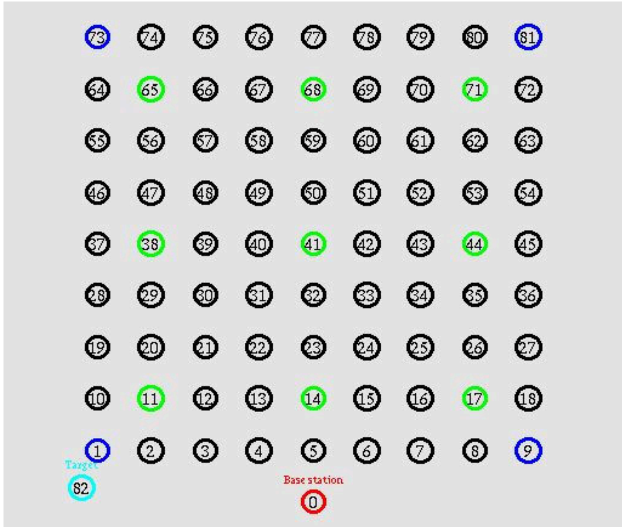


Fig. 3 Simulated sensor network with 83 sensors

## IV. Performance Evaluation

This section compares the energy efficiency of the proposed system with centralized and dynamic clustering architectures. For the experiment, the sensor network is deployed with 83 sensors: 4 specialized photo sensors, 9 cluster head and 68 acoustic sensors, as shown in Fig. 3. Node number 0 is base station and the mobile node, 82, serves as target. In Fig.3, photo sensors are 1, 9, 73, and 81. The cluster heads, processing nodes (PN), are 11, 14, 17, 38, 41, 44, 65, 68, 71 and the rest are acoustic sensors. We focus on the energy consumption of both sensor nodes and sensor network.

Each acoustic sensor had the parameters as follows: the initial energy 500 J, transmitting power 0.036 Watt, receiving power 0.024 Watt, processing power 0.024 Watt, sensing power 0.015 Watt, sending data every 10 s. Within simulation time 300 s, the energy consumption for an acoustic sensor in active node is 6.348 J.

For cluster head, the parameters are set as follows: the initial energy 1000 J, transmitting power 0.6 Watt, receiving power 0.3 Watt, processing power 0.36 Watt, sending data every 10s. So at simulation time 300s, the energy consumption is 75.9 J

For centralized tracking, we define the same for both cluster head and member nodes; the initial energy 1000 J, transmitting power 0.036 Watt, processing power 0.024 Watt, sensing power 0.015 Watt, sending data every 10 s. Thus, at simulation time 300 s, the energy consumption for each sensing node is 5.22 J.

The performance comparison of energy consumption for the whole sensor network is illustrated in Table II. In the analysis, the target enters the sensor network from the lower left corner in which cluster head is 11 and goes to the region with cluster head 41 and then goes out from upper right corner of the sensor network. The spending time in each region for the target is 300s. The processing nodes consume more energy than other sensing nodes as shown in Figs. 4, 5 and 6.

TABLE II
COMPARISON OF ENERGY CONSUMPTION FOR THE WHOLE SENSOR NETWORK

| Simulation Time (second) | Number of Nodes | Centralized Architecture (Joule) | Distributed Architecture (Joule) | |
|---|---|---|---|---|
| | | | Dynamic | Proposed |
| 200 | 81 | 288.36 | 107.244 | 87.684 |
| 300 | 81 | 432.54 | 148.644 | 129.084 |
| 600 | 81 | 442.26 | 272.988 | 255.468 |
| 900 | 81 | 442.26 | 397.332 | 381.852 |
| 300 | 54 | 291.6 | 140.544 | 128.184 |
| 600 | 54 | 301.32 | 264.888 | 254.568 |

In Table II, the proposed system is compared with centralized architecture and dynamic clustering architecture by changing simulation time and number of nodes. At simulation 200s with total 81 nodes, the centralized architecture and dynamic clustering architecture consume 288.36 J and 107.244 J respectively while the proposed system consumes only 87.684 J for the whole sensor network. We can see that the proposed system is the most energy efficient system that enables to increase the network lifetime. The dynamic clustering architecture is the second most energy efficient system and the centralized architecture consumes more energy than the other two approaches

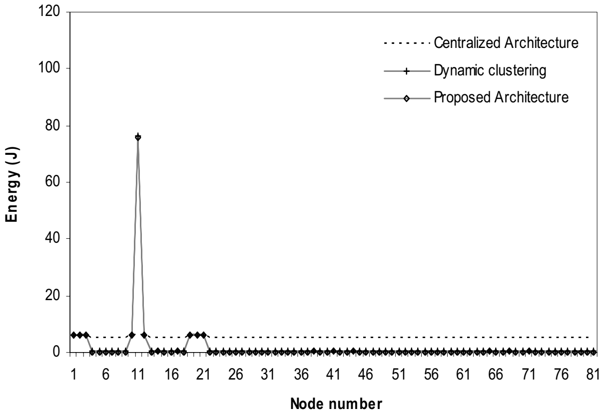


Fig. 4 Energy consumption per node at 300 seconds

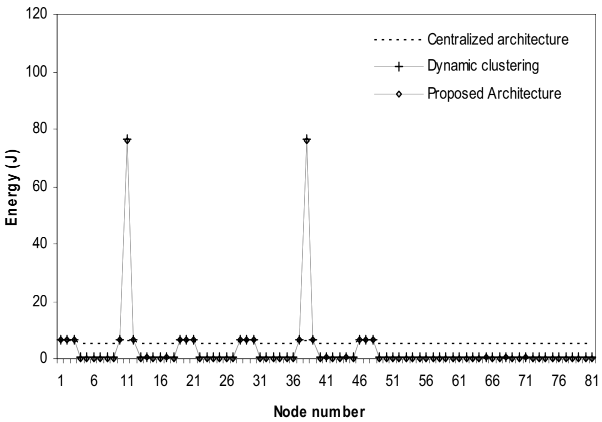


Fig. 5 Energy consumption per node at 600 seconds

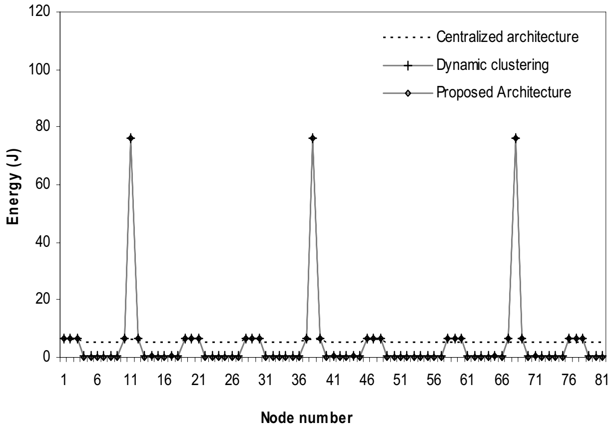


Fig. 6 Energy consumption per node at 900 seconds

Fig. 4, Fig. 5 and Fig. 6 show the energy consumption for 81 sensors at 300 s, 600s and 900 s. As shown in the figures, cluster head 11, 41, and 71 consumes 76.26 J and 75.9 J for dynamic and static cluster architectures and each active cluster member consumes 6.348 J. In centralized architecture, all sensors consume 5.22 J if there is a target or not in the sensor network. Therefore, the static cluster architecture is the most energy efficient system that increases the lifetime for the whole sensor network.

## V. CONCLUSION

In this paper, the energy efficient heterogeneous wireless sensor network for target tracking is presented. The performance results show that the energy consumption for the whole sensor network is significantly reduced by static cluster architecture as compared to dynamic clustering and centralized architectures. This provides the wireless sensor network to improve lifetime for tracking the target.

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