Energy Efficient Target Coverage using Energy Harvesting Wireless Sensor Network (EH-WSNs)

Dissertation

A thesis Submitted in partial fulfillment of the requirements
For the degree of

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in Distributed And Mobile Computing

Submitted By

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This is to certify that the thesis entitled **“Energy Efficient Target Coverage using Energy Harvesting Wireless Sensor Networks(EH-WSNs)”** is a bona fide work carried out by **Rituparna Maji** (**Registration No- 141107 of 2017-18**) under my supervision and guidance for partial fulfillment of the requirement of Master of Technology (Distributed and Mobile Computing) in School of Mobile Computing and Communication ,during the academic session 2017-2019.

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All information in this document have been obtained and presented in accordance with academic rules and ethical conduct.

I also declare that, as required by these rules and conduct, I have fully cited and reference all material and results that are not original to this work.

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Abstract

Recently, Wireless Sensor Networks (WSNs) have attracted lot of attention due to their pervasive nature in Internet of Things, Cyber Physical Systems, battle field surveillance, home application, smart space, inventory tracking and other emerging areas. Wireless Sensor Networks (WSN) comprises of smart sensor nodes capable of collecting, processing, storing and communicating information from one node to another. A basic and important function of WSNs is to monitor areas or targets for a long period, such as battlefield, fire monitoring and environment detection. Then, collect the useful data in the monitor areas, and then send the data to the base station or the sink. Wireless sensors usually use batteries as their power supply. A sensor becomes useless in the absence of energy and becomes unable to contribute to the utility of the network as a group. To overcome this major limitation, the design and development of efficient energy harvesting systems for WSN environments are being explored. A comprehensive taxonomy of the various energy harvesting sources is presented here. As sensor nodes operate on limited battery power, energy usage is a very important concern in a WSN and there has been significant research that focuses on harvesting and minimizing energy.

Coverage problem is an important issue in wireless sensor networks, which has a great impact on the performance of wireless sensor networks. Given a sensor network, the coverage problem is to determine how well the sensing field is monitored or tracked by sensors. In this paper, we classify the coverage problem into three categories: area coverage, target coverage, and barrier coverage.Target coverage is a typical application in wireless sensor networks. Target coverage requires a set of specified targets or a region of interest (ROI) to be within the sensing range of operative sensors. Target coverage problem has been well investigated in traditional WSNs with battery-powered nodes. Due to the limited battery capacity, battery-operated sensors can remain active (and be sensing) only for a limited amount of time, until they run out of energy. Saving energy often sacrifices tracking performance, while enhancing tracking performance needs to consume more energy This motivates the deployment of energy harvesting sensors to cover the area of interest, and to schedule the sensors carefully in order to prolong the network lifetime. Here an efficient sleep scheduling algorithm is put forward to tackle the above problem in energy harvesting sensor networks.

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I gratefully acknowledge for the assistance, cooperation, guidance and clarifications provided by my project guide during the development of this project.

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I would like to thank the members of Distributed Mobile Computing department who contributed, without any discrimination,to make this environment an excellent place for academic purposes .

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Finally, I thank my parents who have always supported me with deep love and sacrifice throughout my life.I dedicate my work to them in the most sincere way I can think of.

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Chapter 1

Introduction: WSN with Energy Harvesting

1.1Introduction

A collection of tiny nodes capable of sensing the environment, performing simple computations and supporting wireless communications to accomplish a monitoring task can be referred to as **Wireless Sensor Network (WSN) [1]**. Wireless Sensor Networks (WSNs) have played a major role in the research field of multi-hop wireless networks as enablers of applications ranging from environmental and structural monitoring to border security and human health control. Research within this field has covered a wide spectrum of topics, leading to advances in node hardware, protocol stack design, localization and tracking techniques and energy management.

Research on WSNs has been driven (and somewhat limited) by a common focus: Energy efficiency. Nodes of a WSN are typically powered by batteries. Once their energy is depleted, the node is "dead." Only in very particular applications batteries can be replaced or recharged. Many problems are associated with batteries. First, the current leakages that consumes the battery even if not in use. Second, extreme weather conditions may break down the batteries, resulting in chemical leakages that can cause various environmental problems. There are many WSN application scenarios where the lifetime of the sensor node ranges from months to several years based on the application requirements. Therefore, the lifetime of the sensor nodes must end several years before their batteries drain and they become idle due to the lack of power supply. Therefore when the energy of a sensor node is depleted, it will no longer fulfill its role in the network unless either the source of energy is replaced or some **harvesting mechanism** is introduced to fill the energy gap.

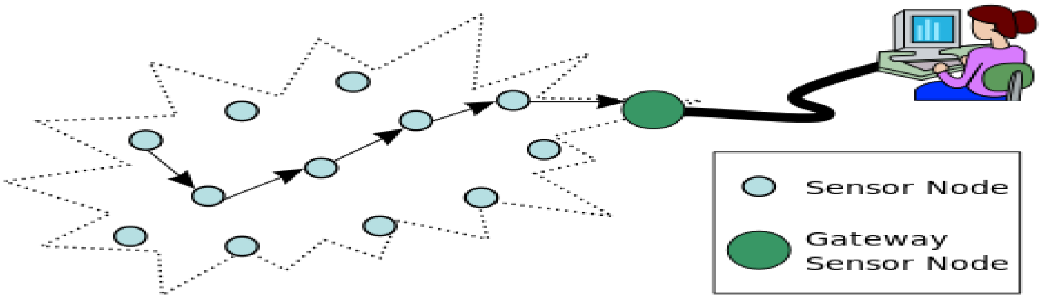


Fig 1.1 WSN

1.2 **Wireless Sensor Network**

Wireless sensor network consists of large number of distributed nodes which are used for monitoring or surveillance of physical area [2]. The information thus gathered is relayed back to a base station or main server. Wireless network has many applications and depending upon the type of use, the quality of service differs. For one application, the quality of service depends upon how information is transferred from one node to another while for others the delay in transmission has to be minimized. The quality of service parameter here is that the target points in the area under surveillance are to be maximized while taking in account the limited energy supply of the sensor. Basically, it is ensured that every sensor monitors at least one target and that they operate in covers. Each cover is scheduled to work in turns while other sensors remain in sleep mode. Thus when a particular cover runs out of energy, other cover is activated which monitors the area and hence the network lifetime is maximized.
WSN is currently used for real-world unattended physical environment to measure numerous parameters. So, the characteristics of WSN must be considered for efficient deployment of the network. The significant characteristics of WSN are described as follows.

1.2.1Network Lifetime

Network lifetime[3] is the amount of time each target is covered by at least one sensor, obtain data and transmit them back to the base station. The main concern or the bottleneck is the limited amount of battery available since there are various situations in which the sensors are deployed in hostile situation where it is very difficult to replace the battery. The objective is to maximize the number of targets monitored before the sensors consume their energy. The second factor can be assigned to cost which might not be as great constraint as that of energy. But as the sensing range increase the number of targets monitored will also increase.

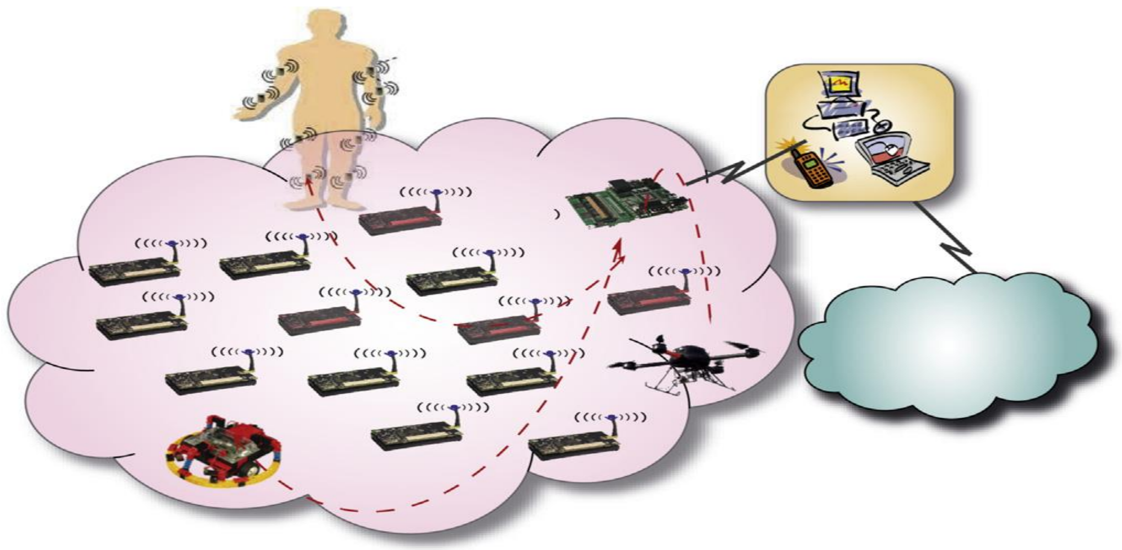


Fig 1.2 A Typical WSN Scenario

1.2.2 Low cost:

In the WSN normally hundreds or thousands of sensor nodes are deployed to measure any physical environment. In order to reduce the overall cost of the whole network the cost of the sensor node must be kept as low as possible.

1.2.3 Communication Capabilities

WSN typically communicate using radio waves over a wireless channel. It has the property of communicating in short range, with narrow and dynamic bandwidth. The communication channel can be either bidirectional or unidirectional. With the unattended and hostile operational environment it is difficult to run WSN smoothly. So, the hardware and software for communication must have to consider the robustness, security and resiliency.

1.2.4 Security and Privacy

Each sensor node should have sufficient security mechanisms in order to prevent unauthorized access, attacks, and unintentional damage of the information inside of the sensor node. Furthermore, additional privacy mechanisms must also be included.

1.2.5 Distributed sensing and processing

The large number of sensor node is distributed uniformly or randomly. WSNs each node is capable of collecting, sorting, processing, aggregating and sending the data to the sink. Therefore the distributed sensing provides the robustness of the system.

1.2.6 Dynamic network topology

In general WSN are dynamic network. The sensor node can fail for battery exhaustion or other circumstances, communication channel can be disrupted as well as the additional sensor node may be added to the network that result the frequent changes in the network topology. Thus, the WSN nodes have to be embedded with the function of reconfiguration, self-adjustment.

1.2.7 Self-organization

The sensor nodes in the network must have the capability of organizing themselves as the sensor nodes are deployed in a unknown fashion in an unattended and hostile environment. The sensor nodes have work in collaboration to adjust themselves to the distributed algorithm and form the network automatically.

1.2.8 Multi-hop communication

A large number of sensor nodes are deployed in WSN. So, the feasible way to communicate with the sinker or base station is to take the help of a intermediate node through routing path. If one need to communicate with the other node or base station which is beyond its radio frequency it must me through the multi-hop route by intermediate node.

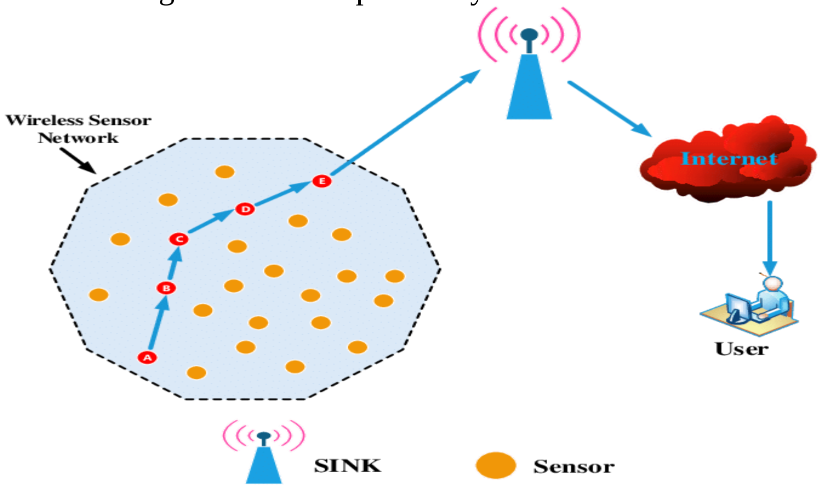


Fig 1.3 Hop to Hop Communication of WSN

1.2.9 Application oriented

WSN is different from the conventional network due to its nature. It is highly dependent on the application ranges from military, environmental as well as health sector. The nodes are deployed randomly and spanned depending on the type of use.

1.2.10 Robust Operations

Since the sensors are going to be deployed over a large and sometimes hostile environment. So,the sensor nodes have to be fault and error tolerant. Therefore, sensor nodes need the ability to self-test, self-calibrate, and self-repair.

1.3 Wireless Sensor Node Architecture

A sensor node typically consist of three basic subsystems [4]:(i) a sensing subsystem to acquire data,(ii)a processing subsystem for processing data locally,and(iii)a wireless communication subsystem for communicating data. Also,a powersource (usually a battery with a limited energy budget)is used to power the sensor nodes subsystems. Furthermore,for most of the applications,it is very difficult, if not impossible,to recharge the batteries due to the deployment of the nodes in difficult and hostile terrain or due to the large number o fnodes deployed in the environment. Despite these constraints,the applications running on WSNs require the sensor nodes to be functional and to fulfill their requirements for several months or even years. These requirements highlight the need to extend the lifetime of WSNs by prolonging the life of their sensor nodes either by applying different energy minimizing techniques or providing energy harvesting mechanisms for the sensor nodes. In this section we will focus on the mandatory subsystems power consumption and management which are processing unit, Transceiver, Sensing unit, power supply.

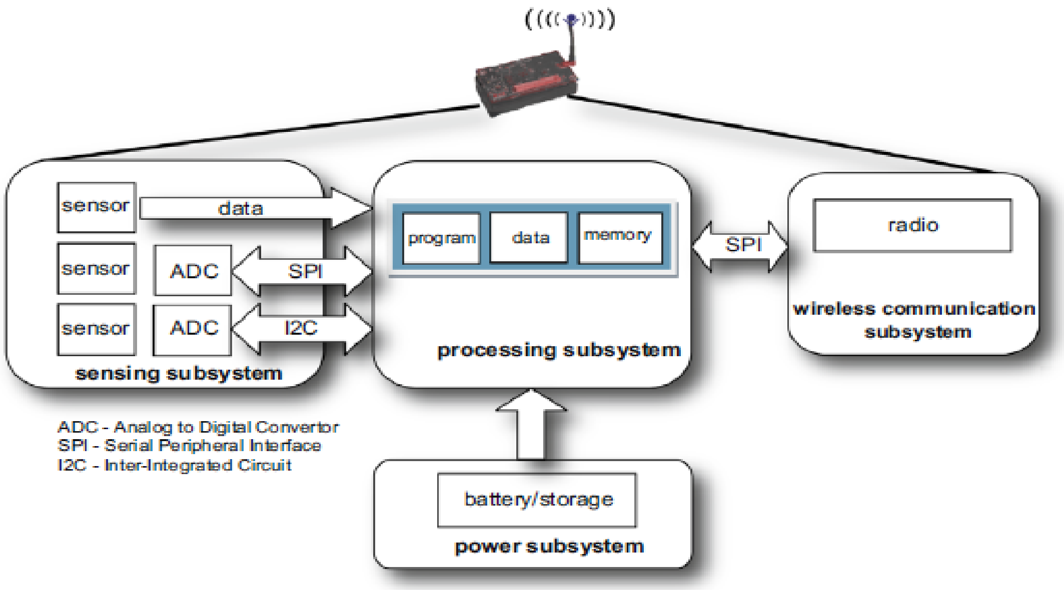


Fig 1.4 Wireless Sensor Node Architecture

A.Processing unit:
The processing unit is another word for our micro-controlling unit (MCU); When that micro-controlling "Processor + Memory" is running continuously is not sufficient for multiyear battery life, so the MCU has two main modes which are active mode and the power saving modes, but the MCU should be putted into power saving modes which are Idle, Sleep, and Stop mode whenever it's possible.

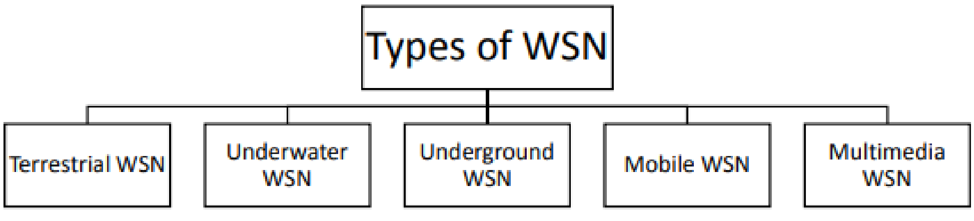
B. Communication device "Transceiver":
The Transceiver is the Sensor node radio device which provide wireless communication with the neighboring nodes; The power consumption of that communication device is depending on many parameters such as (1) Modulation types "M-PSK, M-FSK, MSK", (2) Data transfer rate usually in Kbytes, (3) The transmission power which is depending on the routing protocol to determine the least power needed to exchange data with the neighbor nodes, And finally (4) The Duty Cycle ; Like the power saving modes in MCU,The transceiver also got modes which are (1) Off -Stop in MCU power saving modes- in which the power consumption only from the leakage current, (2) Sleep/Standby mode that is waiting for internal timer to be triggered to be switched to another mode which is (3) Listen mode that is in attention to any intruder that want to make communication, if no intruder is detected then go back to the Sleep/Standby mode, but if intruder is detected the communication devices go to (4) The Active Receiving mode that is receiving data and either buffering it or processing it, the final mode is (5) Active Transmitting mode where most power is consumed by the RF power Amplifier circuit; The following table 2 discuss the power consumption of the Transceivers sorted according to their Receiving power.

C. Sensing units:
The sensing units main job is translating quantities from non-electrical domain into electrical domain; The two sources of power consumption are signal sampling and conversion to electrical signal and A/D conversion.

D. Power supply:
Giving power to all the Sensor nodes modules in order to make a task, as we mentioned above that batteries stores only limited amount of energy which state the upper bound of our network life time, so we can use harvesting sources to increase our life time, but harvesting without batteries can't stand alone as it may be not available all the time which means energy may be interrupted.

1.4 Types of WSN

WSN has many types of sensors[5] depending on the situation such as underground WSN, underwater WSN, terrestrial WSN, multimedia WSN, and mobile WSN. Figure 1.5, represents the classifications of WSN.



1.4.1 Terrestrial Wireless Sensor Network

Terrestrial WSNs consist of numerous tiny sensor nodes. These nodes are randomly deployed in a specific area from where an ad hoc network is used for communication between the nodes. These nodes can be organized by optimal placement, grid placement, or 2D and 3Dplacement models **.**

1.4.2 Underground Wireless Sensor Network

An underground WSN is a sensor node which is placed under the ground for collecting information on underground conditions. The drawback of WSN is its limited battery power because this is very difficult to recharge or change. The wireless communication's main limitation is the loss of signal at high potential. Therefore, in order to enhance the reliability of WSN, efficient routing algorithms have been carried out for solving the limitation of the WSN's accuracy during the routing process.

1.4.3 Underwater Wireless Sensor Network

An underwater WSN includes very expensive sensor nodes, which are placed under the water for collecting data and information about underground ambiance. Some limitations or challenges of wireless communication underground include the delay of the network, limited bandwidth, and poor network signal. . The aforesaid problem has been recognized by investigators, and in order to o increase the efficiency of the system, the authors designed a user interface for managing the optical Physical (PHY) layer implementation on a Digilent Spartan 3 Board [19]. Nithin et al. (2017) have assembled a review for prevalent approaches and issues relating to a certain parameter of research**.**

1.4.4 Mobile Wireless Sensor Network

A mobile WSN has the advantage that power changes its position and automatically connects to the environment. Mobile sensors connect with computers and communicate. Mobile sensors are used for collecting data from a wide area or information from other nodes or sensors. The main limitations of mobile WSNs are the present status, coverage area, navigation, reposition, and maintenance **.**

1.4.5 Multimedia Wireless Sensor Network

A multimedia WSN consists of tiny sensor nodes that can sense, compute, actuate, and communicate. A variety of applications of the WSN include habitation monitoring, traffic management systems, and ecological monitoring. The multimedia WSN is a network of wirelessly interconnected devices that are able to ubiquitously retrieve video and audio transmission, still images, and scalar sensor data from the environment .

Some Key Requirements of Wireless Sensor Networks-

- **Scalability:** It will expand this network to add nodes as required. Its expansions should be easy to conduct.
- **Reliability:** Many methods are there for reducing the power usage of (WSN) nodes, which are resulting in an increase in the lifetime of the network and their consistency.
- **Responsiveness:** The response time is very quick because of its limitations.
- **Mobility:** Mobility is the basic feature of WSN. It is a wireless network so no wire is used for this network. That is why mobility is a key requirement of WSN.
- **Power efficiency**: It uses a sensor that results in low power consumption.

1.5 Applications of WSN

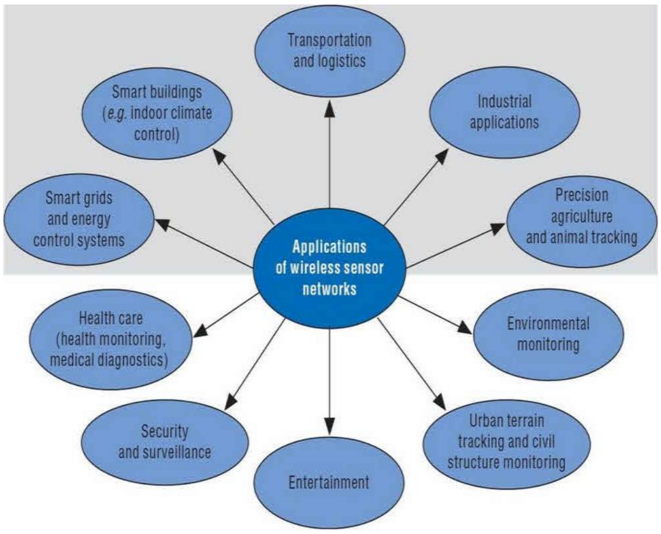


Fig 1.5 Applications of WSN

Wireless Sensor Network finds in a wide variety of application[6] in several fields –

1. **Military Applications** -Monitoring Friendly Forces, Equipments and Ammunition, Battlefield Surveillance, Targeting, Battle Damage Assessment, Nuclear, Biological and Chemical Attack Detection . One of the most important characteristics of WSNs that make them prominent for military applications is their ability to autonomously reorganize themselves to form a network capable of routing measurement data to the commanders. From defense's perspective, WSNs represent an important technology necessary for maintaining soldiers safe in the battlefield.

2. **Environmental Applications** - Environmental control in office building, Forest Fire Detection, Flood Detection, Monitoring Biodiversity.

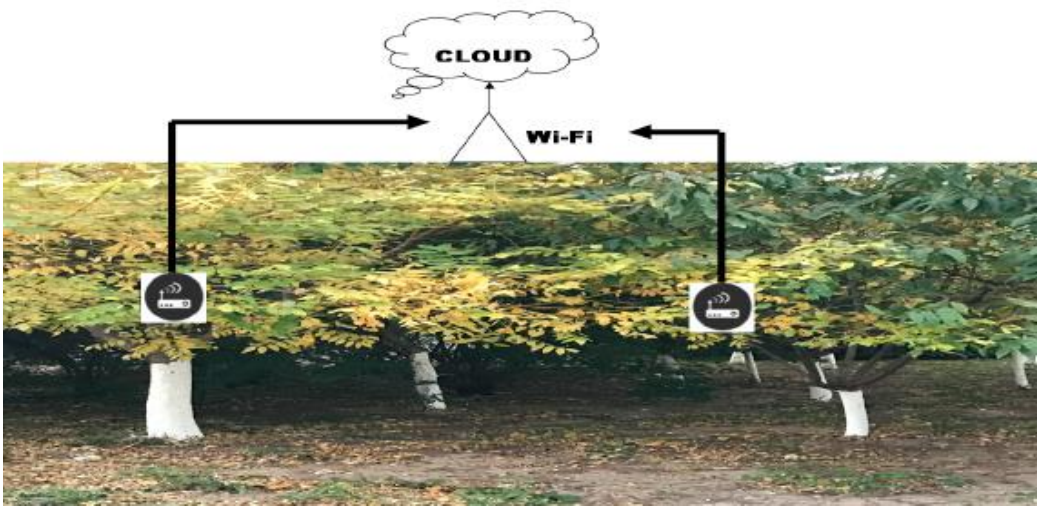


Fig 1.6 Sensor deployment for forest monitoring

WSNs can facilitate the measurement of a large variety of environmental data for a huge number of applications such as agriculture, meteorology, geology, zoology, etc. The advantage of using WSNs in such applications is mainly due to the need for acquiring large amounts of data in each region that would be difficult to obtain using existing technologies

3. **Industrial applications-** Several organiz ations, such as CISCO , are excited about the possibilities of using WSNs to monitor and enhance each step of product including production, delivery and consumption. Sensor nodes can offer real- time access to information about eq uipment or plants, and prevent disruption of infrastructures . Unlike wired networks, W SNs are excellent candidates for monitoring of the entire life of a product, step by step from raw material provision used for its fabrication to its final assembling. The equipment to be monitored by WSNs can include assembly machines , product parts, logistics and transportation (containers or vehicles) , warehouses palettes localisation , and end-user assets.

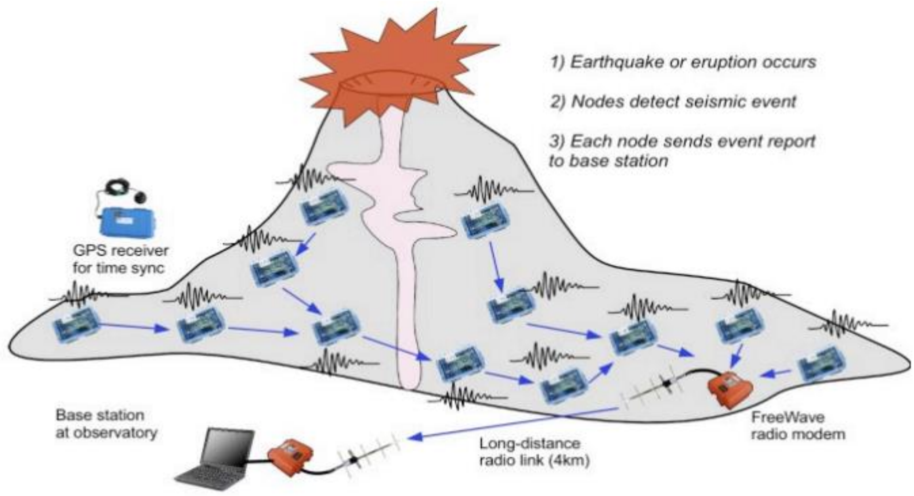


Fig 1.7 Earthquake Detection

4. **Habitat Monitoring Applications** – It includes monitoring of wild animals,

5. **Health Applications**- It includes Tele-monitoring of Physical Data, Tracking and Monitoring Doctors and Patients in a Hospital, Drug Administration in Hospitals. The medical domain has produced many implementations of sensor nodes ranging from equipment and patient health monitoring to wireless medicine injection and control . There are many health monitoring products implementing WSNs such as SmartVest [7], AMON, Wealthy. These systems transmit wirelessly and continuously physiological parameters about the health of the patient (e.g. monitoring of vital signs, blood glucose, organ monitor, cancer detector , etc.) so that the health care professionals can diagnose and assure timely interventions.

Fig 1.8 Future Applications of WSN

6. **Home and Office Applications** – It includes Smart Homes, Home automation, Inventory Control. Sensor nodes can transform a traditional home into a "smart home" that is aware of its occupants' special needs and respond accordingly. A future smart home will be able to regulate the rooms' temperature, control air quality, adjust lighting, and even play music that fits with a particular resident. This automation would obviously minimize the building's energy consumption as-well. Sensor networks can also improve the security of the house by sending an alarm message to the resident when it detects intruders, gas leakage, fire occurrence or other security incidents.

7. **Other Applications** like- Target Tracking, Monitoring Nuclear Reactor, Suspicious Individual detection, Fire Fighting etc and many more.

1.6 SWOT (Strength, Weakness, Opportunities, and Threat) Analysis of WSNs

The acronym of SWOT is Strength, Weakness, Opportunities, and Threat. SWOT [8]is applied in this study to diagnose the merits and demerits of the real time application of the WSN. A WSN is ubiquitously applied in every aspect of daily life for its convenience in terms of intelligence and wireless networking such as smart and improved transportation systems. An attempt has been made in this paper to recognize the SWOT analysis for the real time application of the WSN. Furthermore, this kind of approach has not yet been performed by any researchers of this field. We have incorporated the analysis of SWOT in this study. Figure 1.8, presents an illustration of SWOT depicting the explanations.

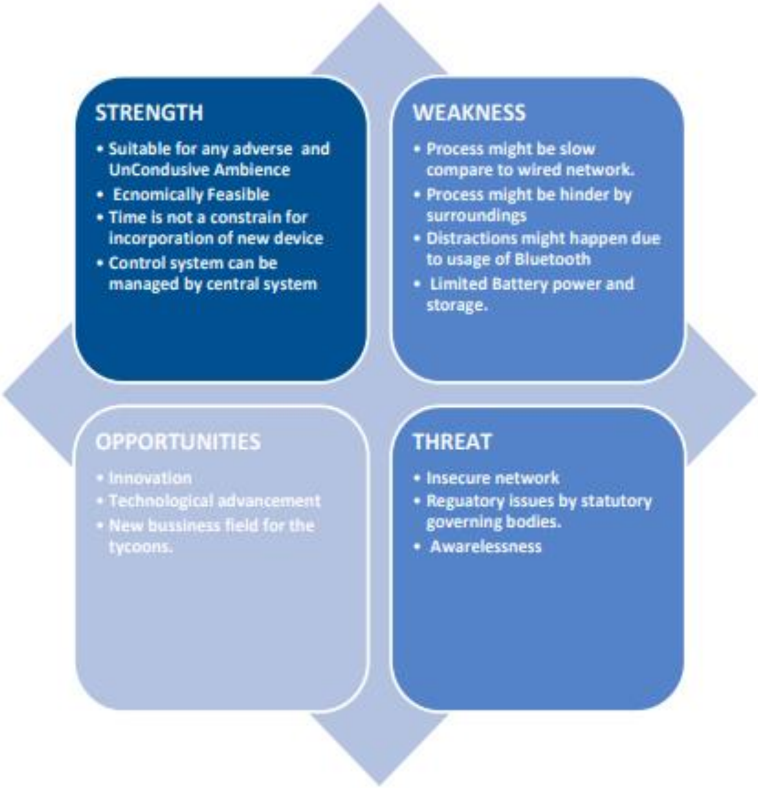


Fig 1.9 SWOT Analysis of WSN

1.7 WSN with Energy Harvesting

There are many WSN application scenarios where the lifetime of the sensor node ranges from months to several years based on the application requirements. Therefore, the lifetime of the sensor nodes must end several years before their batteries drain and they become idle due to the lack of power supply. To work uninterrupted in most cases, sensor nodes require a continuous power supply, whether that supply is in an active mode to transmit and process data or an inactive mode when sensor nodes go to sleep. A WSN should be self-powering, long lasting, and almost maintenance free. Accordingly, energy harvesting can be described as a mechanism used to generate energy from a networks ambient surroundings to provide an uninterrupted power supply for a specific sensor node and for the overall WSN.

Energy Harvesting-based WSNs (EHWSNs) [9] are the result of endowing WSN nodes with the capability of extracting energy from the surrounding environment. Energy harvesting can exploit different sources of energy, such as solar power, wind, mechanical vibrations, temperature variations, magnetic fields, etc. Continuously providing energy, and storing it for future use, energy harvesting subsystems enable WSN nodes to last potentially forever.

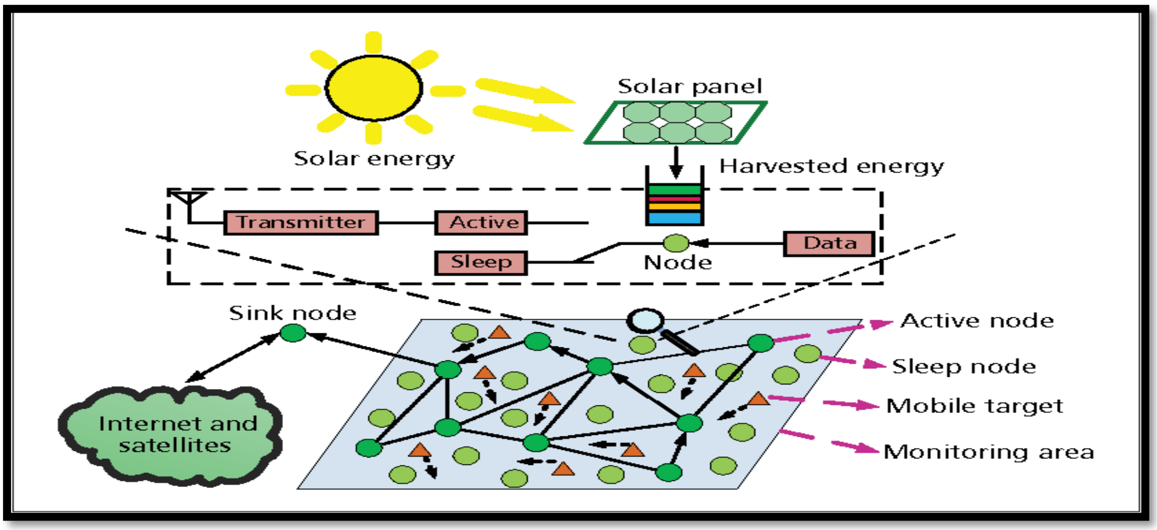


Fig 1.10 Energy Harvesting in WSN scenario

1.8 ENERGY HARVESTING

A. Nodes Enhancements:

Nodes are – in addition to sensing unit, Transceiver, MCU, and battery – capable to extract energy from multiple sources and convert it into usable electrical power.

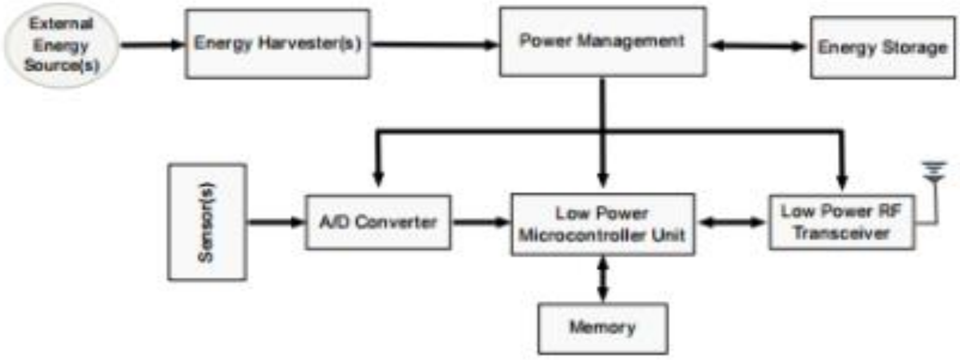


Fig 1.11 Enhancements on ordinary SN

B. Architecture with added Energy Harvester modules:

Added modules are needed to enable energy harvesting,[10] Three more parts are added for efficient energy harvesting as shown in figure 1.6,

(1) The Energy Harvesters "can be more than one" which is responsible to convert external ambient energy into electrical energy, then

(2) Power Management collects electric energy from harvesters and either storing it or delivering it to other subsystem to use it directly, if the energy will be stored for future use then here come the job of

(3) The Energy Storage that accumulates, and preserving that harvested energy

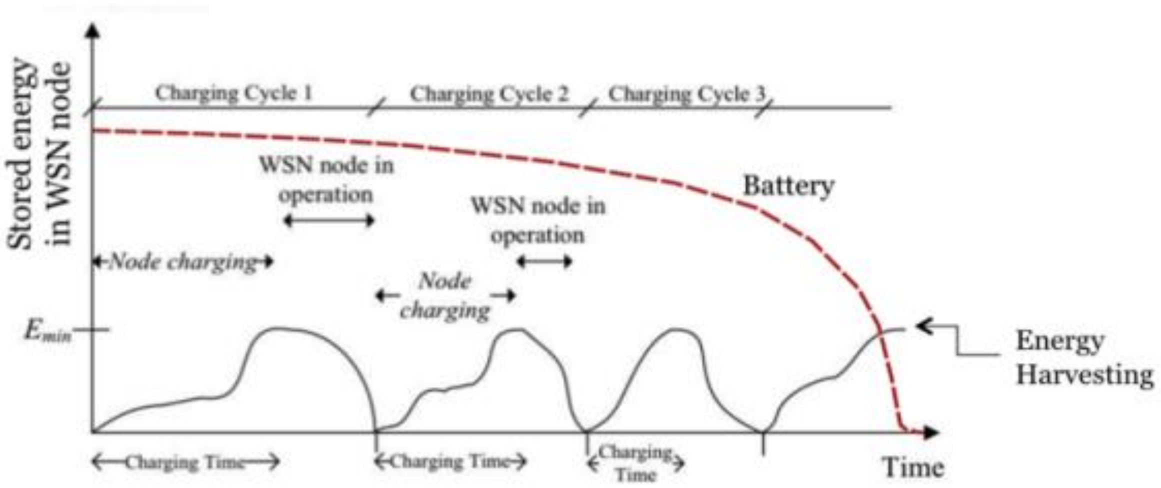


Fig 1.12 EH-WSN vs Battery-powered WSN

As shown in Fig 1.7 if we can have access to unlimited power, we can have infinite lifetime in network. This unlimited power can be provide by environment such as light, vibration and heat. Then it stores the harvested energy in a storage device. When the device uses energy harvested instead of battery, the residual energy is no more an useful quantity to preserve. In EH-WSN, if the rate of harvesting power is lesser than the power used by the node, the sensor node should go to sleep to charge up.

1.9 Applications of EHWSNs

Energy harvesting is ideal for applications that need to survive for longer time periods, i.e., those that are deployed once and then always available, such as environmental monitoring applications. Other applications that can benefit from energy harvesting are those that require the transportation of large amounts of data to the sink, as is the case in multimedia applications [11] WSNs , structural monitoring data etc. Essentially, all types of WSN applications can benefit from energy harvesting mechanisms to prolong the lifetime of the networks.

Fig 1.13 Energy Harvesting Wireless Standard for Building Automation

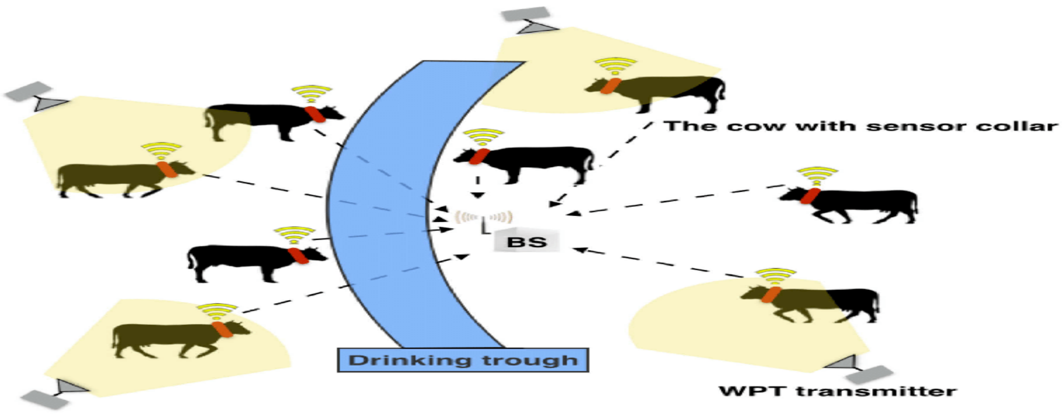


Fig 1.14 Energy Harvesting mobile sensor network for cattle monitoring

1.10 Energy Harvesting Architecture

Energy harvesting architecture[12] can be referred as the combination through which various components in an energy harvesting system may combine and interact together to achieve an optimal performance level . Fig.1.9 shows the overall architecture depicting various components of the energy harvesting system and their interactions.

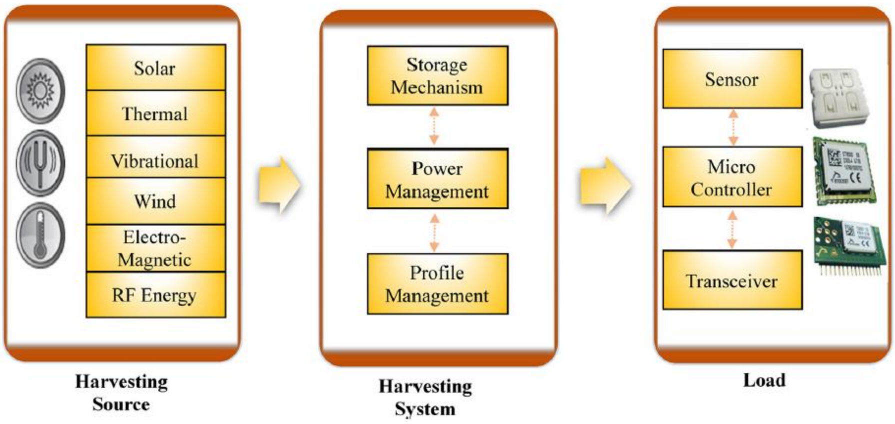


Fig 1.15 Energy Harvesting Architecture

Energy harvesting architecture can be seen as the combination of three fundamental components**; Load, harvesting source** and, **harvesting system**

A. Load

It can be seen as an energy consuming process in the system such as a sensor node in the WSN. A node generally consumes energy in the following activities:

√ Sensing (when a shared medium is used, the sender senses the channel before transmitting to reduce the probability of generating a collision)

√ Contention (when multiple nodes simultaneously have data to transmit on the shared medium, a contention stage is entered to limit the impact of collisions)

√ Transmission (Similarly, after the successful contention, nodes undergo actual transmission of data to their intended nodes)

√ Collision (e.g., Hidden or Exposed Terminal Problem)

√ Idle Listening (Listening the channel with no packet)

B. Source

Source can be seen as any harvesting technology being used such as solar, wind, vibrational or thermal or other alike technologies capable of extracting ambient energy from the natural sources. The amount of harvested energy at the source side plays a vital part in the overall system design because it can exhibit unpredictable and time-varying dynamics that strongly affect the life- time of a WSN.

C. Harvesting system

This is the most crucial and significant part of the architecture. It serves as a mediator between the source and load, keeping in view energy consumption/generation profiles and application re- quirements. As inbound and outbound energy flows cannot be de- terministically known in advance, the harvesting system should be designed based on worst case conditions. It can also be seen as an energy management module that stores excessive energy when the inbound flow is larger than the outbound one to face under- provisioning periods. It is also capable of tuning the load profiles (e.g., altering the data rate) to achieve optimal performance level.

1.10.1 Harvesting Hardware Model

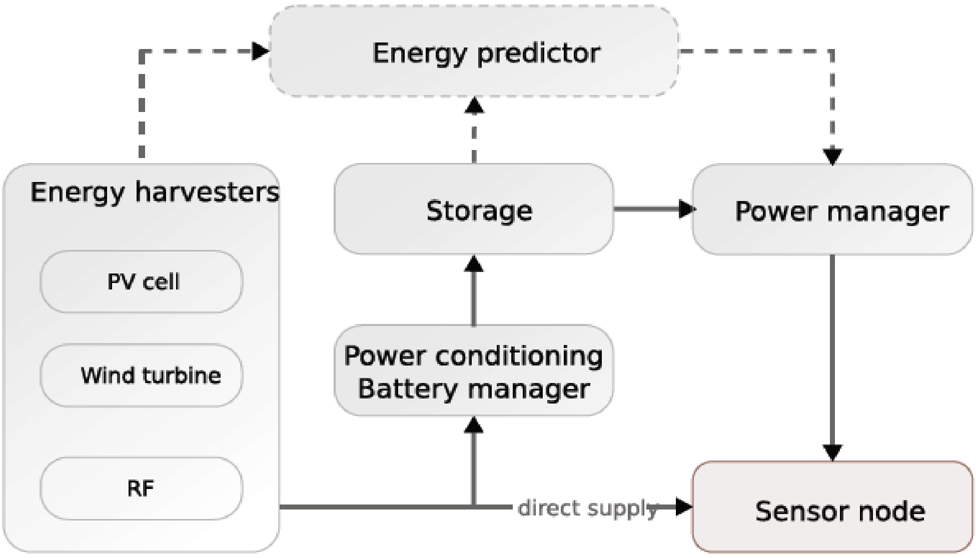


Fig 1.16 The general architecture of the energy subsystem of a wireless sensor node with energy harvesting capabilities

The energy subsystem [13] includes one or multiple harvesters that convert energy available from the environment to electrical energy. The energy obtained by the harvester may be used to directly supply energy to the node or it may be stored for later use. Although in some application it is possible to directly power the sensor node using the harvested energy, with no energy storage, in general this is not a viable solution. A more reasonable architecture enables the node to directly use the harvested energy, but also includes a storage component that acts as an energy buffer for the system, with the main purpose of accumulating and preserving the harvested energy. When the harvesting rate is greater than the current usage, the buffer component can store excess energy for later use (e.g., when harvesting opportunities do not exist), thus supporting variations in the power level emitted by the environmental source.

1.11 Classification of Energy Harvesting Techniques in WSNs

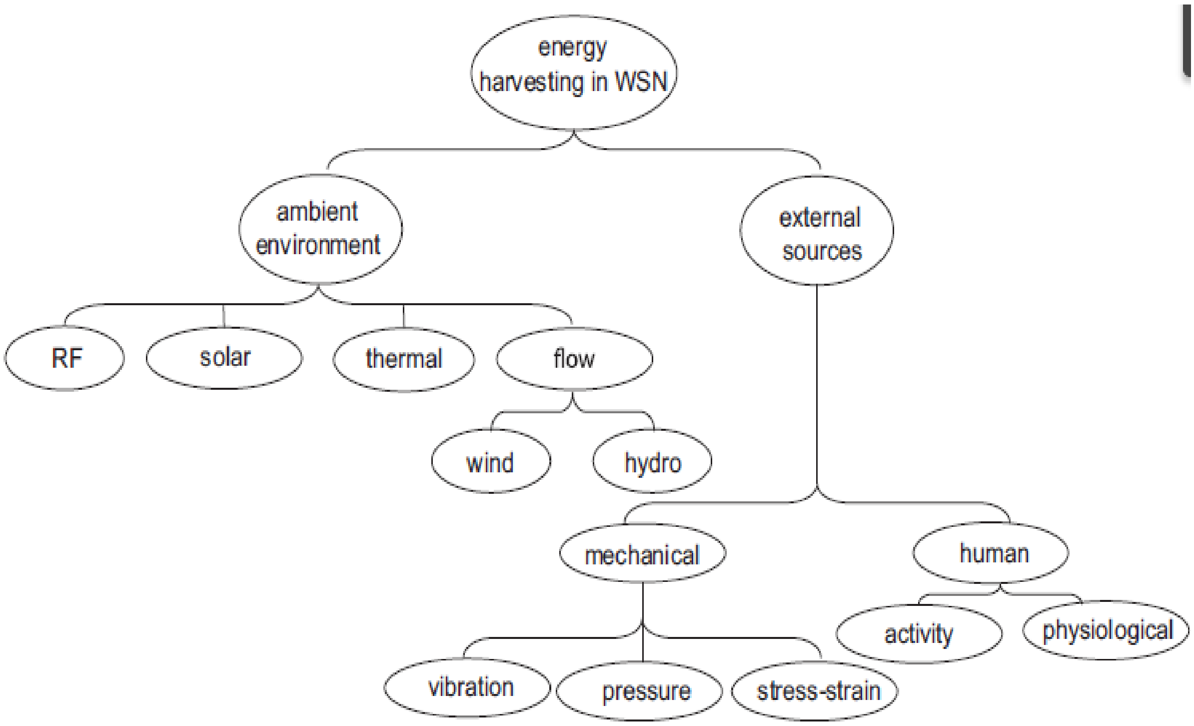


Fig 1.17 Energy Harvesting Sources

We classify the energy harvesting sources [14] into two broad categories: ambient sources and external sources(as shown in Fig-1.7) Ambient sources are readily available in the environment at almost no cost. On the other hand, external sources are deployed explicitly in the environments for energy harvesting purposes.

1.11.1 Ambient Sources:

I. **Radio Frequency-based Energy Harvesting** : For RF-based energy harvesting, received radio waves are converted to DC power after conditioning . Converting the RF signals into DC power can be achieved through several approaches, such as single-stage vs. multistage, depending on the desired application requirements (i.e., power, efficiency, or voltage).

II. **Solar-based Energy Harvesting :** Solar energy is an affordable and clean energy source that could eliminate the impending energy problem in WSNs. The photovoltaic effect can be observed when certain semiconductor materials are exposed to sunlight and convert solar rays into DC power. Due to the limitations of solar energy harvesting systems during the night, developers must ensure the highest possible efficiency during daylight hours to guarantee the viability of solar power. There are several implementations of solar energy harvesting sensor nodes that are different from each other based on the type of solar panels, battery type, and complexity of the circuit for recharging.

III. **Thermal-based Energy Harvesting :**Thermal energy harvesting is implemented by thermoelectric energy harvesting and pyroelectric energy harvesting. Thermoelectric energy harvesting is the process of creating electric energy from temperature difference (thermal gradients) using thermoelectric power generators (TEGs).Pyroelectric energy harvesting is the process of generating voltage by heating or cooling pyroelectric materials.

- **Thermoelectric Energy Harvesting: It** is the process of creating electric energy from temperature difference (thermal gradients) using thermoelectric power generators (TEGs). The core element of a TEG is a thermopile formed by arrays of two dissimilar conductors, i.e., a p-type and n-type semiconductor (thermocouple), placed between a hot and a cold plate and connected in series.

A thermoelectric harvester scavenges the energy based on the Seebeck effect, which states that electrical voltage is produced when two dissimilar metals joined at two junctions are kept at different temperatures. This is because the metals respond differently to the temperature difference, creating heat flow through the thermoelectric generator. This produces a voltage difference that is proportional to the temperature difference between the hot and cold plates. The thermal energy is converted into electrical power when a thermal gradient is created. Energy is harvested as long as the temperature difference is maintained.

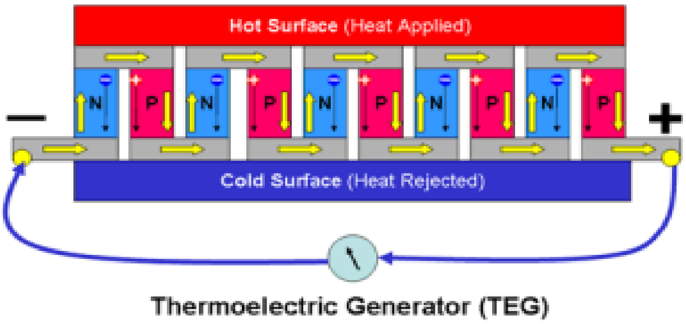


Fig 1.18 A Thermoelectric Generator

- **Pyroelectric Energy Harvesting**: It is the process of generating voltage by heating or cooling pyroelectric materials. These materials do not need a temperature gradient similar to a thermocouple. Instead, they need time-varying temperature changes. Changes in temperature modify the locations of the atoms in the crystal structure of the pyroelectric material, which produces voltage. To keep generating power, the whole crystal should be continuously subject to temperature change. Otherwise, the produced pyroelectric voltage gradually disappears due to leakage current. Pyroelectric energy harvesting achieves greater efficiency compared to thermoelectric harvesting. It supports harvesting from high temperature sources, and is much easier to get to work using limited surface heat exchange. On the other hand, thermoelectric energy harvesting provides higher harvested energy levels. Because of the various sizes of thermal harvesters, they can be placed on the human body, on structures and equipment.

IV. **Flow-based Energy Harvesting_:** Flow based energy harvesting generally use turbines and rotors that convert rotational movement into electrical energy using electromagnetic induction principal .Wind energy harvesting is the process of converting air flow (e.g., wind) energy into electrical energy. Hydropower (waterpower) harnesses the energy of moving or falling water.

- **Wind Energy Harvesting:** It is the process of converting air flow (e.g., wind) energy into electrical energy. A properly sized wind turbine is used to exploit linear motion coming from wind for generating electrical energy. A miniature wind turbine exists that are capable of producing enough energy to power WSN nodes. However, efficient design of small-scale wind energy harvesting is still an ongoing research, challenged by very low flow rates, fluctuations in wind strength, the unpredictability of flow sources, etc. Furthermore, even though the performance of large-scale wind turbines is highly efficient.

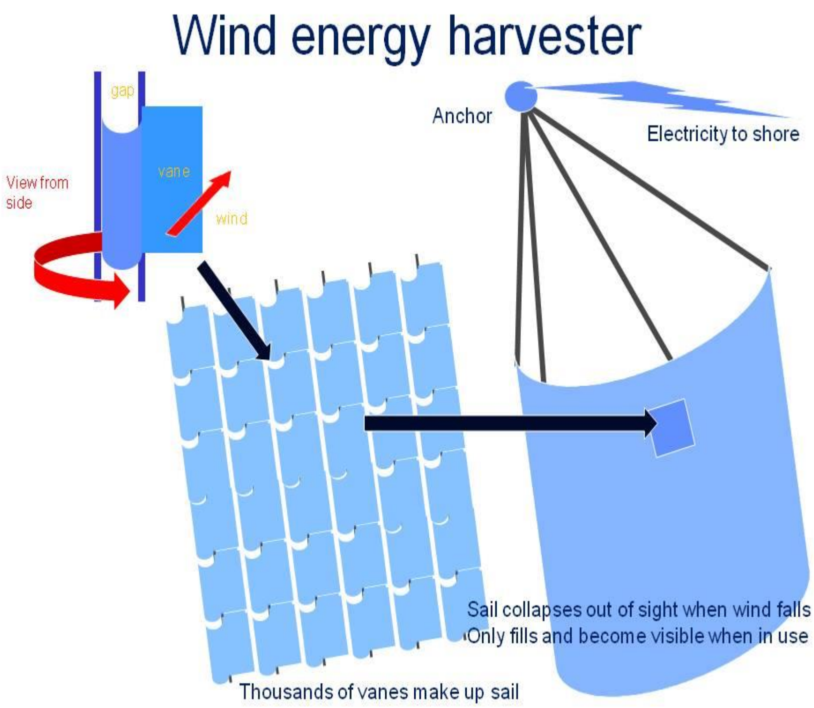


Fig 1.19 Wind Energy Harvester

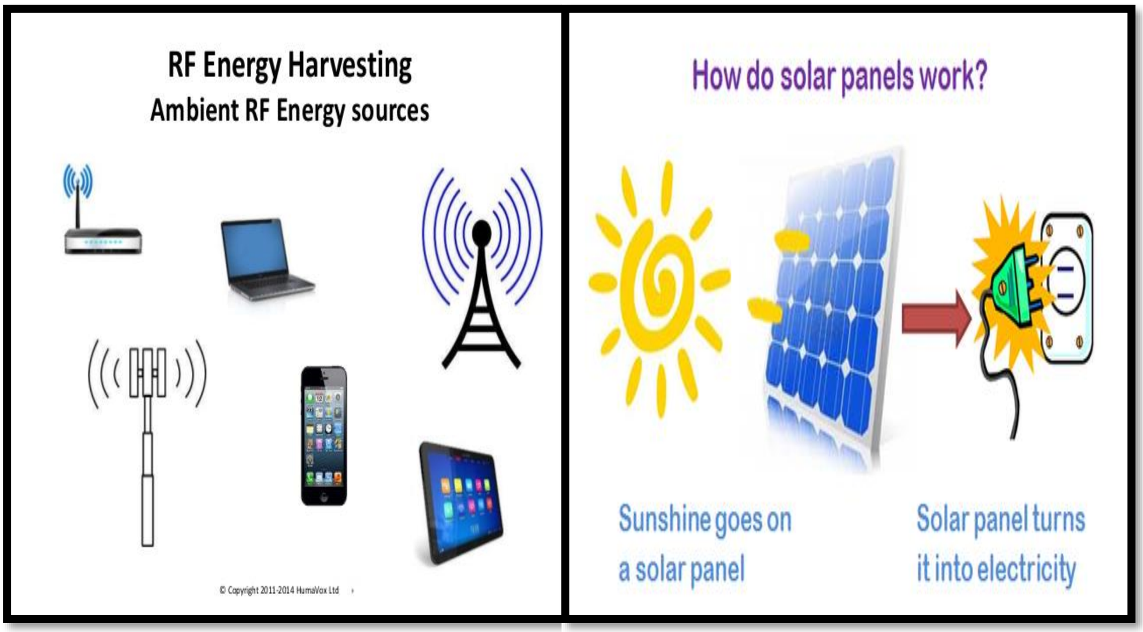


Fig 1.20 RF based and SOLAR Based Energy Harvesting

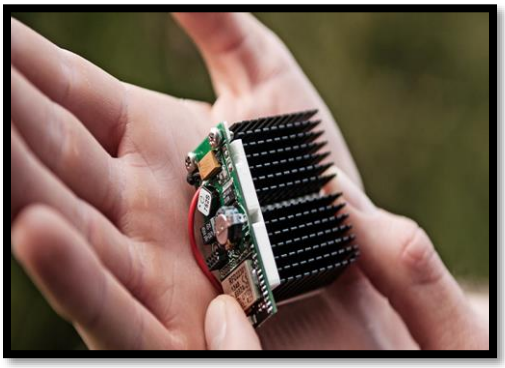


Fig 1.21 Thermal based Energy Harvesting

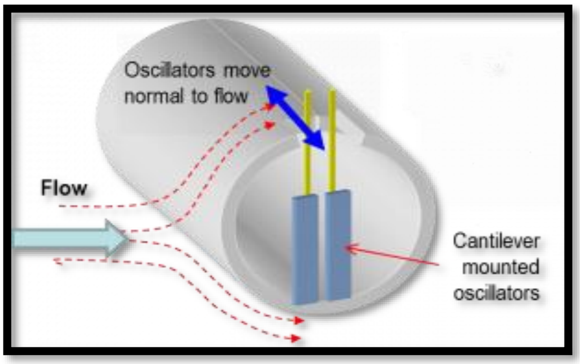


Fig 1.22 Energy Harvesting System Using flow induced vibrations

1.11.2 External Sources

I. **Mechanical-based Energy Harvesting :** To harvest energy from vibrations,pressure,and stress–strain, one needs to use a suitable Mechanical-to-Electrical Energy Generator(MEEG). Generally,a MEEG uses either electromagnetic, electrostatic,or piezoelectric mechanisms to harvest energy**.** The pressure variations can be converted to energy using either piezoelectric or electrostatic generators, which provide the highest density of power.

1) **Piezoelectric Energy Harvesting:** It is based on the piezoelectric effect for which mechanical energy from pressure, force or vibrations is transformed into electrical power by straining a piezoelectric material, In particular, strains in the piezoelectric material produce charge separation across the harvester, creating an electric field, and hence voltage,

proportional to the stress generated . Voltage varies depending on the strain and time, and an irregular AC signal is produced. Piezoelectric energy conversion has the advantage that it generates the desired voltage directly, without need for a separate voltage source. However, piezoelectric materials are breakable and can suffer from charge leakage

2) **Electrostatic Energy Harvesting:** The principle of electrostatic energy harvesting is based on changing the capacitance of a vibration dependent variable capacitor. In order to harvest the mechanical energy a variable capacitor is created by opposing two plates, one fixed and one moving, and is initially charged. When vibrations separate the plates, mechanical energy is transformed into electrical energy from the capacitance change. This kind of harvesters can be incorporated into microelectronic-devices due to their integrated circuit compatible nature . However, an additional voltage source is required to initially charge the capacitor. Recent efforts to prototype sensor-size electrostatic energy harvesters can be found in.

3) **Electromagnetic Energy Harvesting:** Electromagnetic energy harvesting [15] is based on Faraday's law of electromagnetic induction. An electromagnetic harvester uses an inductive spring mass system for converting mechanical energy to electrical. It induces voltage by moving a mass of magnetic material through a magnetic field created by a stationary magnet. Specifically, vibration of the magnet attached to the spring inside a coil changes the flux and produces an induced voltage. The advantages of this method include the absence of mechanical contact between parts and of a separate voltage source, which improves the reliability and reduce the mechanical damping in this type of harvesters. However, it is difficult to integrate them in sensor nodes because of the large size of electromagnetic materials

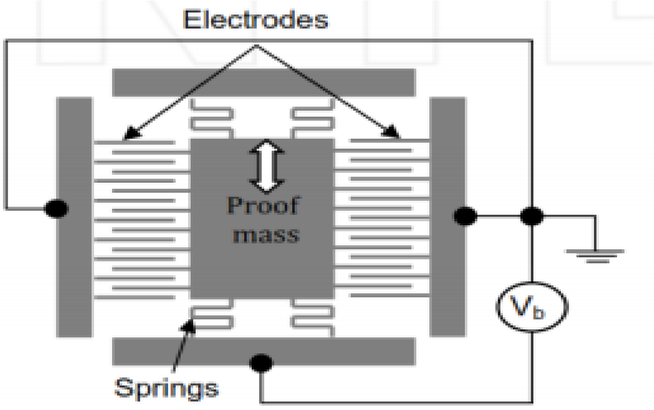


Fig 1.23 Electrostatic Energy harvesting concept

II. **Human-based Energy Harvesting :** Harvesting energy from the human [16] is preferable to alternative sources of power. Fortunately energy can be harvested from humans in a variety of ways,

a. A small turbine located inside a millimeters-wide human artery can harvest enough energy from blood flow to power implanted medical devices.

b. Electroactive polymers, to convert human movement into power.

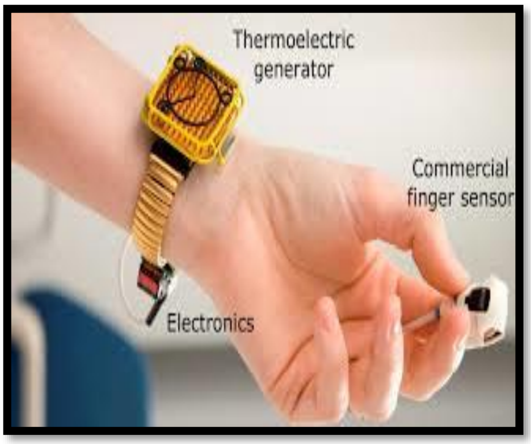


Fig 1.24 The shoe-powered RF tag system By piezoelectric energy harvesting

Fig 1.25 Human based Energy Harvesting using body heat

Energy Efficient Target Coverage using EHWSN

CHAPTER-2

Coverage Problems in Energy Harvesting Wireless Sensor Networks

Chapter 2

Coverage Problems in Energy Harvesting Wireless Sensor Networks

2.1 Introduction

Coverage problem[17] is an important issue in energy harvesting wireless sensor networks, which has a great impact on the performance of wireless sensor networks. Given a sensor network, the coverage problem is to determine how well the sensing field is monitored or tracked by sensors A fundamental problem in energy harvesting Wireless Sensor Networks (WSNs) is to maximize coverage, whereby the goal is to capture events of interest that occur in one or more target areas. Target tracking is a typical application in wireless sensor networks. Both energy efficiency and tracking performance are important issues that need to be considered. They are a pair of contradictions most of the time. Saving energy often sacrifices tracking performance, while enhancing tracking performance needs to consume more energy.Target coverage requires a set of specified targets or a region of interest (ROI) to be within the sensing range of operative sensors. Target coverage is a fundamental performance requirement for various wireless sensor network (WSN) applications.Target coverage problem has been well investigated in traditional WSNs with battery-powered nodes. Due to the limited battery capacity, battery-operated sensors can remain active (and be sensing) only for a limited amount of time, until they run out of energy. This motivates the redundant deployment of sensors to cover the area of interest, and to schedule the sensors carefully in order to prolong the coverage time after deployment.

2.2 Classification of Coverage Problems

The coverage algorithms[44] often based on the subject to be covered (area versus discrete points), sensor deployment mechanism (random versus deterministic) as well as other wireless sensor network properties (e.g. minimum energy consumption and network connectivity). In this thesis, we survey recent works into three types[18]: area coverage, point coverage and barrier coverage.

2.2.1 Area Coverage

Area coverage problem is the popular coverage problem in WSNs, and is widely studied for many years, where the main objective of the sensor network is to cover or monitor an area or sometimes referred as region. Under the condition that any sensor node can be covered in the monitoring area, area coverage aims at how to schedule the sensor nodes in the network, so as to maximize the network lifetime. Fig. 2.1 shows an example of a random deployment of sensors to cover a given rectangular-shaped area.

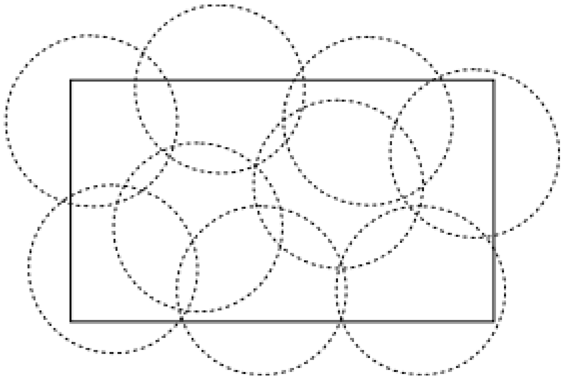


Fig 2.1 Area Coverage

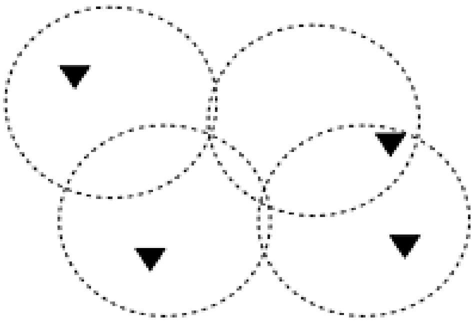


Fig 2.2 Point Coverage

2.2.2 Point Coverage

In the point coverage problem, the objective is to cover a set of points (targets). Under the condition that all the targets can be covered in the monitoring area, point coverage aims at how to schedule the sensor nodes in the network, so as to maximize the network lifetime. Fig. 2.2 shows an example of monitoring the discrete targets in a wireless sensor network. The black nodes form the set of active sensors, the result of a scheduling mechanism.

2.2.3 Barrier Coverage

Barrier coverage problem[43] is to detect the probability of a moving object be found when crossing the deployment region of wireless sensor networks. We consider the barrier coverage as the coverage with the goal of minimizing the probability of undetected penetration through the barrier (sensor network). Fig.2.3 shows an example of a general barrier coverage problem where start and end points of the path are selected from bottom and top boundary lines of the area. The selection of the path depends on the objective.

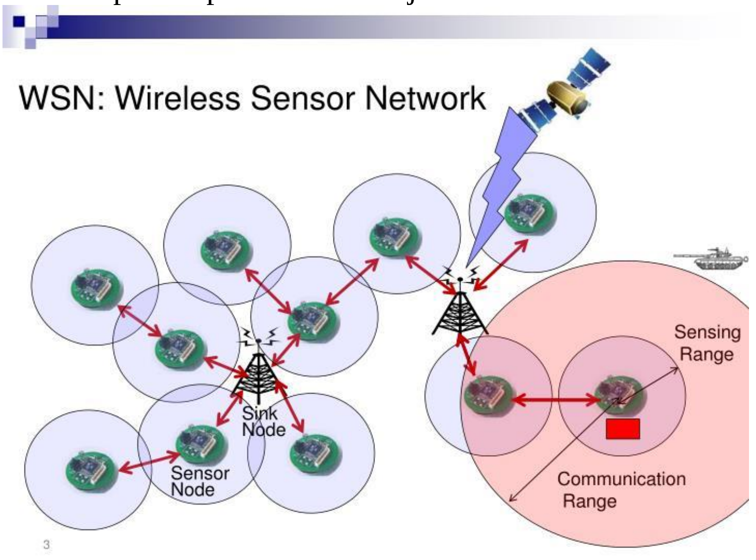


Fig 2.3 Sink Connected Barrier Coverage

2.3 Target Coverage

In the target coverage problem, the objective is to cover a set of points. The point coverage problem considers how to maximize the network lifetime on the condition that all the objectives in the monitoring area are covered. In many practical applications of wireless sensor networks, such as the monitoring in forest fires and nuclear leakage, we can abstract them into the target coverage problem in wireless sensor networks, so the research on target coverage problem is very important.
A sensor si is said to cover a point q if and only if the distance d(q, si) ≤ ri. The distance function d can be the Euclidean distance function[19].

Let s_1, s_2... and s_n are randomly deployed n sensors and t_1, t_2... and t_m be m targets. A sensor s covers a target t_j iff t_i lies within the sensing range of s_i .

In the fig 2.1 below we can see a set of sensors Si deployed in a region to be monitored and a set of targets Tj so that all the targets are covered by atleast one sensor. The circles denote the sensing range of each sensor individually that cover the targets.

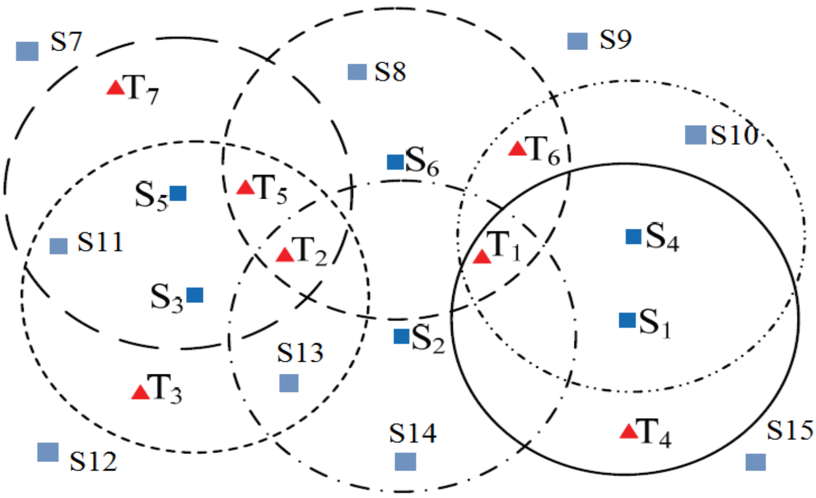


Fig 2.4 Target Coverage

One important application of target coverage[20] is forest fire detection. Fig 2.5 briefly illustrates how forest fire is detected by utilising sensor network and timely managed. The sensor nodes deployed detect the fire through a rise in temperature in the environment. The data is collected and reported to the sink or base station. The monitoring tool collects the precipitation, wind speed data from the meteorological service besides the data collected from the sink. Accordingly an alarm is triggered and the fire workers are sent to the affected area.

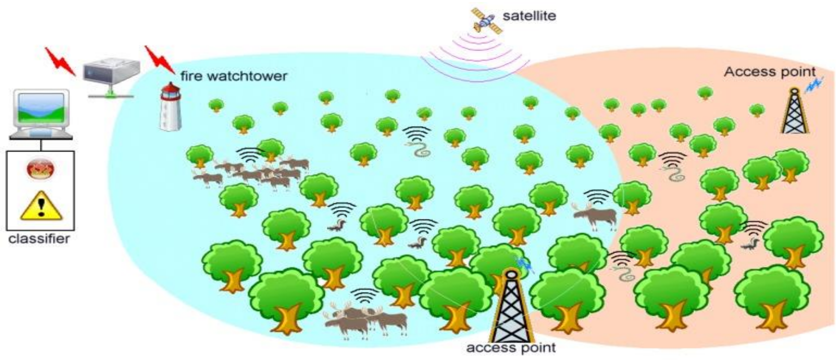


Fig 2.5 Forest Fire Detection

To cover only the interested targets instead of the whole area, researchers have defined target-based coverage problems. Some sensor applications are only interested in stationary target points, such as buildings, doors, flags, and boxes, whereas other applications aim at tracking mobile targets like intruders. Stationary targets can be located anywhere in the observed area. In some studies, researchers name the target coverage approach as point coverage. Unlike the area coverage, this issue puts emphasis on how to cover the maximum number of targets. In target coverage, each target is monitored continuously by at least one sensor. However, some DSN (Distributed Sensor Network) applications may require at least k sensors for each target in order to increase the reliability of the network. K-coverage problem[42] has been formulated based on this requirement.

A sensor cover S is a set of sensors that jointly cover all the targets. Formally,
S= {s_i | for each t_i there is a $s_i \in S$ such that s_i covers t_j }.

2.4 Factors Involving Target Coverage

The coverage problem is based on a fundamental question: ―How well do the sensors observe the physical space? The main objective is to cover each target location of the sensor communication range by at least one sensor. There are several factors that must be considered when dealing with target coverage problem in a WSN [21]. Many of these will be dependent upon the particular application that is being addressed. The capabilities of the sensor nodes that are being used must also be considered. Following are some factors related with sensor target coverage.

2.4.1 Node Deployment: Deployment can usually be categorized as **random** or **deterministic.** A deterministic deployment[41] (such as grid deployment) is where and how many of sensor nodes placed can be predetermined. Deterministic sensor placement can be applied to a small to medium sensor network in a friend environment. The exact positions and number of sensor nodes cannot be engineered or predetermined due to

(a) various area like remote or inhospitable areas.

(b) Military and disaster related applications, and

(c) where the network size is large.

Therefore, random deployment, where sensor nodes are distributed within the field stochastically and independently (e.g., air-dropped, scattered from an aircraft or launched via artillery), is required exclusively.

2.4.2 Node Types: The set of nodes that are selected for a sensor network can be either a **homogeneous** or **heterogeneous** group of nodes. A homogeneous group is a group of sensor nodes having same capabilities /configuration. A heterogeneous group comprises of sensor motes having different configurations. For example some nodes may have more powerful sensing range/transmission range than other nodes. Usually there would be a smaller group of more powerful nodes known as cluster heads which would gather data from the less powerful nodes .In the following figure a group of homogeneous(Fig 2.6(a)) and heterogeneous (Fig-2.6(b)) sensors are showed, where circles represent sensor nodes' sensing/transmission range. Homogeneous architecture is easy to model and resilient to individual sensor failures. However, the presence of a few more powerful sensors can improve the network reliability and stability with increase in the cost of network deployment.

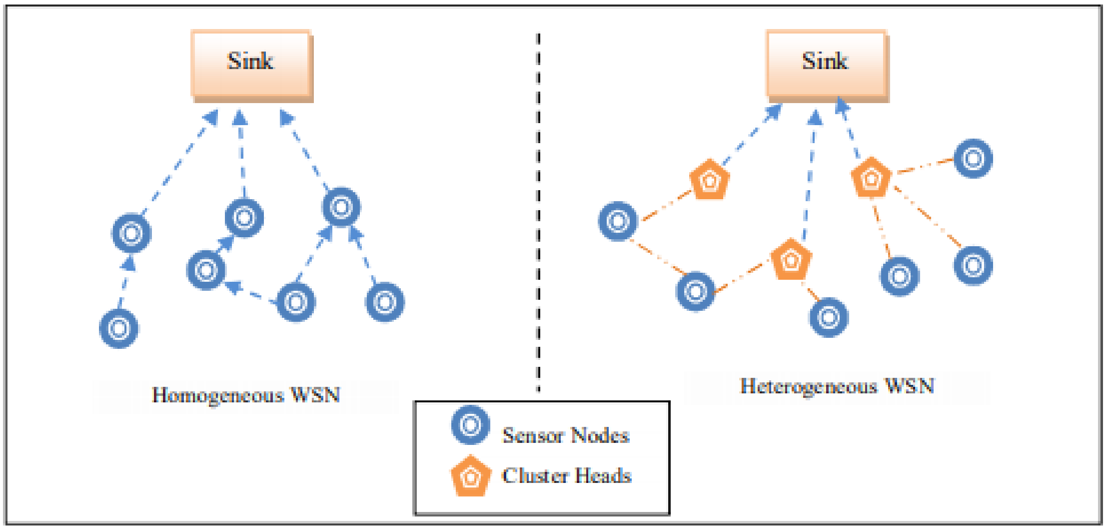


Fig 2.6(a) Fig 2.6(b)

2.4.3 Energy Constraints: Perhaps the most important factor to consider in the development of a target coverage scheme[22] is that of energy constraints. Sensing, processing and communication of the sensed information require energy. Sensor nodes usually depend upon a battery for their energy source and in most deployments battery replacement or recharging is not feasible. It therefore becomes very important to conserve energy and prolong network lifetime. There are several methods available to do this. Placing unneeded sensors into a low energy sleep mode is a popular method to conserve energy. Another method is to adjust the transmission range so that the sensor nodes only use enough energy to transmit to a neighbour node. When sensors are arranged in a hierarchical network then cluster heads can be used to aggregate data and reduce the amount of information sent up to the sink. Improving the efficiency of data gathering and routing is also used to conserve energy.

2.4.4 Sensing area and Communication Ranges: Sensor having invariable transmission range, some sensor's radio transceiver is capable for changing its transmission power in continuous steps to achieve different communication ranges. Practically, the actual communication ranges may also be affected by many external factors such as the height of the sensor and its surrounding objects. WSNs have sensor nodes having different or same sensing range. A factor that relates to connectivity is the communication range that can or not be equal to sensing area. The sensors should be within each other's communication range for transmission of sensed data to base station.

2.4.5Algorithm Characteristics: A target coverage scheme can operate in either a centralized or distributed. In the former case, the coverage algorithm is executed in a central node. In this case, information from all nodes needs to be transferred to the central node. In distributed (localized) scheme, the coverage algorithm is executed based on information from only some nodes (e.g., neighbouring node within a constant number of hops) in WSN, and the decision is made locally. Although the approach of centralization can provide more accurate information for coverage scheme, it incurs more communication overhead and energy consumption.

2.4.6 Sensor Mobility: The coverage performance of stationary sensor network can be determined by the initial network configuration, and it remains unchanged over time after deployment. On the contrary, sensors mounted on mobile platform (such as mobile robot) result in a dynamic sensor network where the topology of the network changes over time. Mobile sensor network can improve or maintain coverage performance by sensor mobility. It is extremely valuable in situations where deployment mechanisms fail or coverage maintenance. The coverage of mobile network depends not only on the initial configurations, but also on the mobility behaviour of the sensors.

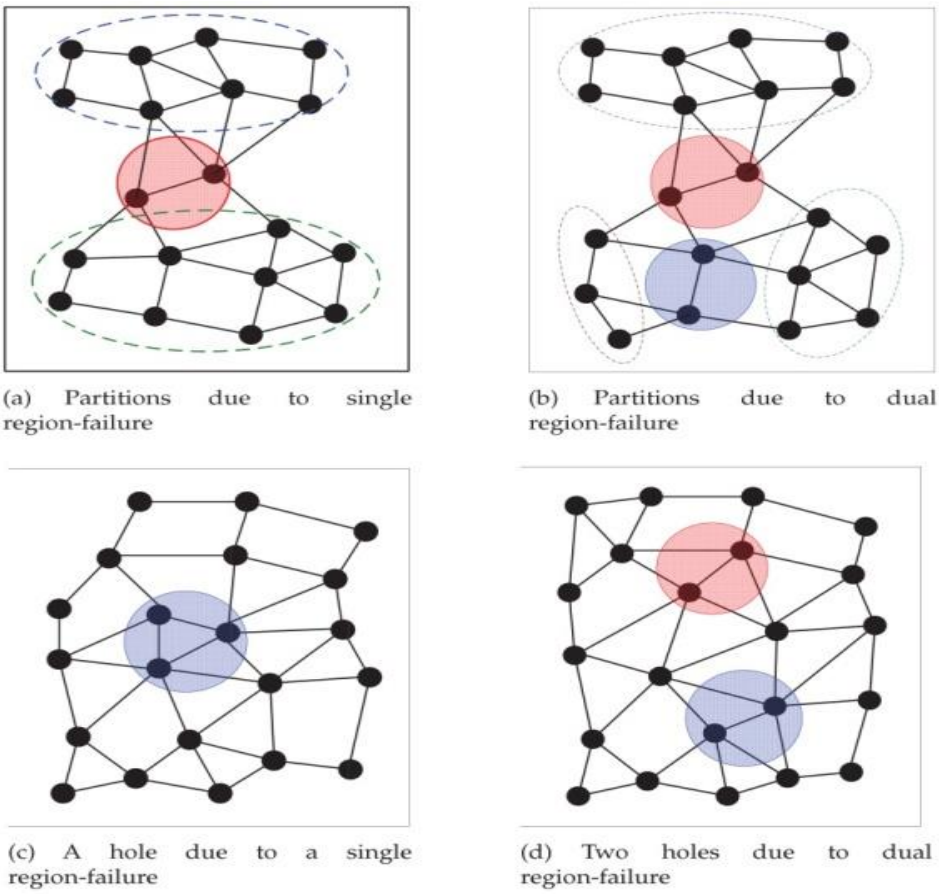
2.4.7 Coverage Topology: Coverage problem is a sign of how well a wireless sensor communication area is monitored or Traced by sensors. The coverage and connectivity problems in sensor networks have received considerable attention in research community in the recent year. This problem can be formulated as a decision problem, whose goal is to determine the every point in the service area of the sensor network which is covered by at least k sensors, where k is a given parameter.

In addition, failure model, location information, time synchronization, scalability, robustness, adaptability and so on, are also factors affected for coverage schemes in wireless sensor networks.

2.5 Coverage and Connectivity

- **(i)** **Coverage**: the area that can be monitored is not smaller than that which can be monitored by a full set of sensors.
- **(ii)** **Connectivity**: the sensor network remains connected so that information collected by sensor nodes can be relayed back to data sinks or controllers. Under the assumption that an signal can be detected with certain minimal signal to noise ratio by a sensor node only if the sensor is within a certain range of the signal source, the first issue essentially broils down to a coverage problem: assuming that each node can monitor a disk (the radius of which is called the sensing range of the sensor node) centered at itself on a two dimensional surface, what is the minimum set of nodes that can cover the whole area? On the other hand, the second (connectivity) issue can be studied, in conjunction with the first, if the relationship between coverage and connectivity can be well characterized (e.g., under what condition coverage may imply connectivity and vice versa).

Connectivity[23] only requires that the location of any active node be within the communication range of one or more active nodes such that all active nodes can form a connected communication backbone, while target coverage requires all targets in the coverage region be within the sensing range of at least one active node. Once sensor configuration is finished, nodes shall be comprised of connected networks[40] to send information collected back to the control centre. Hence, how to combine consideration of target coverage and connectivity maintenance in a single activity scheduling is essential. The target of research on relationship between coverage and connectivity is to select the least number of active nodes, while preserve target coverage and maintain connectivity. Under the condition that **Rc ≥ 2Rs**, a sensor network only needs to be configured to guarantee target coverage in order to satisfy both coverage and connectivity where Rc denotes the communication range and Rs denotes the sensing range. Fig 2.7 clearly depicts the relationship between coverage and connectivity.



(a) Partitions due to single region-failure

(b) Partitions due to dual region-failure

(c) A hole due to a single region-failure

(d) Two holes due to dual region-failure

Fig 2.7 Coverage and Connectivity

2.6 Taxonomy of Tracking Methods

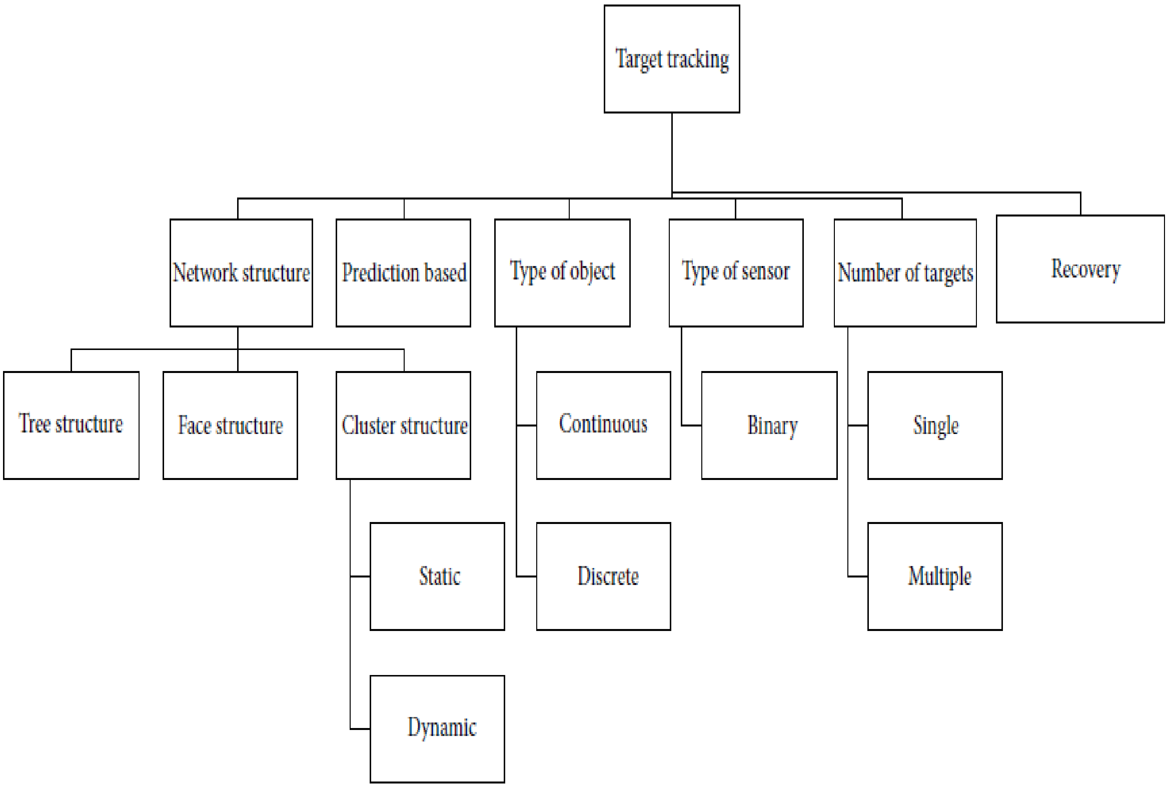


Fig 2.8 Target tracking possible metrics.

Target tracking algorithms [24]were studied in the literature from several angles, so there is no standardized classification. Target tracking can be classified according to different aspects: security, energy efficiency, network structure, accuracy, mobility of the target, fault tolerance, and so on. As shown in Figure 2.8, there are six metrics: network structure, prediction-based mechanisms, type of chased object, type of sensor, number of targets, and recovery strategies.

2.6.1 Network Structure

the network structure is classified into three categories: tree structure [25], cluster structure, and face structure.

Tree Structure: In the tree structure, sensor nodes are organized in a hierarchical tree or represented as a graph in which vertices represent sensor nodes and edges are links between nodes that can directly communicate with each other.

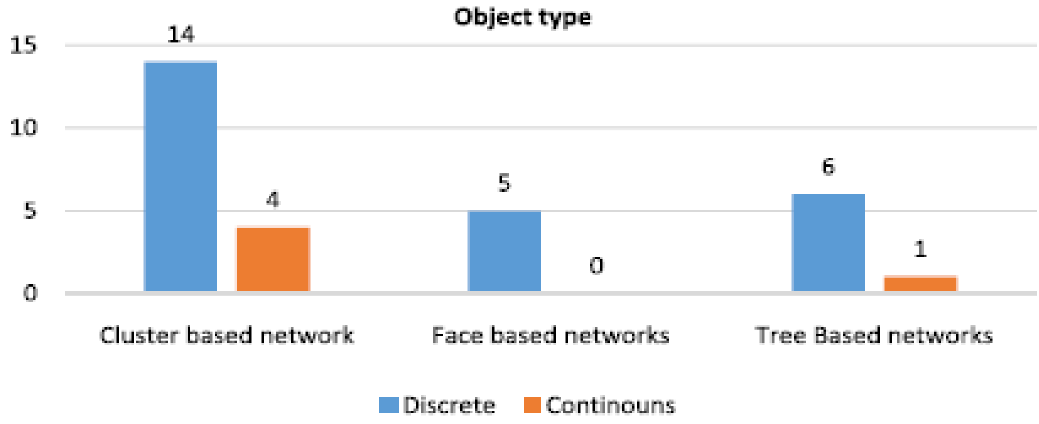


Fig 2.9 Object Type in Object Tracking Sensor Network

Face Structure: It is wherethe sensor network is divided into faces. Each face contains a set of sensor nodes organized in a ring model. In a face, each member node knows its spatial neighbors and their locations.The face structure is built using the Relative Neighborhood Graph (RNG) algorithm [26].

Cluster Structure **:**The cluster architecture is used to facilitate the target tracking. It provides a significant impact on the implementation of the object tracking systems. Sensors are organized into clusters, where each cluster contains a cluster head and member nodes.
We can distinguish two types of clustering:

(i) Static clustering: in static clustering, clusters are formed at the time of network deployment and remain unchanged until the end of network lifetime. Despite its simplicity, the static clustering [27] has several negative sides: in case a cluster head dies due to its power depletion, the whole cluster becomes useless. Furthermore, sensor nodes from different static clusters do not have the possibility to collaborate or exchange information.

(ii) Dynamic clustering: the clusters are formed dynamically as the target moves. The use of dynamic clustering has many benefits.This is due to its flexibility; that is, new clusters are established as the need arises. Furthermore, only one cluster is activated when the mobile target passes by, which implies the mitigation of data redundancy and interference issues.

2.6.2 Prediction-Based Tracking

Prediction methods are used to predict the future position of the mobile object. Only sensor nodes located near this position are turned on to detect the target, while the other nodes remain in sleep mode to conserve energy. Prediction techniques are often integrated with face, cluster, or tree structure. Different techniques are used to predict the next position of the target such as kinematics, Kalman filter (KF) , extended Kalman filter (EKF) , and particle filter (PF)

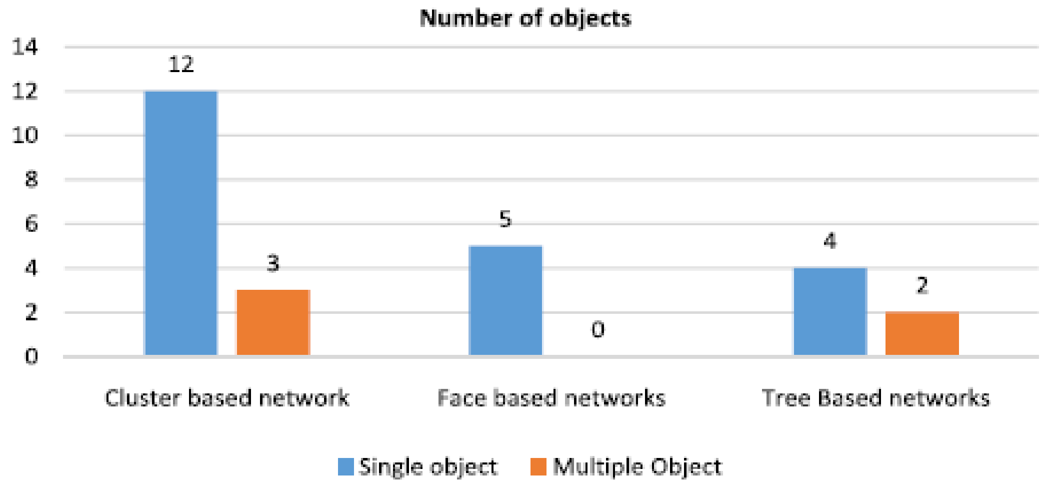


Fig 2.10 Number of Objects in Object Tracking Sensor Network

2.6.3 ***Type of Object***.

Most of the proposed approaches in target tracking aim to track individual (called also discrete) objects such as vehicles, people, and animals. However, few research efforts have been done on tracking continuous objects such as forest fires, gas leakage, biochemical material diffusion, and oil spills. In contrast to discrete objects, the continuous ones occupy a large area, tend to diffuse, change in shape, increase in size, and even split into smaller objects.

2.6.4 ***Type of Sensors.***

Sensor node can be either binary or ordinary. Binary sensors detect the presence or absence of the target in its sensing range by generating one-bit information (0 or 1).They are low-cost and consume less energy. By using binary outputs, the size of data sent to the base station is reduced.

2.6.5 ***Number of Targets***.

Target tracking approaches are divided into two types: single and multiple target tracking.

- Single target: in general, tracking[39] a single object is energy efficient and consumes less power. This is because only a low traffic load is generated in the network while chasing the target.
- Multiple targets: tracking multiple objects is a very challenging task, especially when the number of targets arises. It becomes more complex because of the different directions and speed variations of the tracked objects. In cluttered environment, and in the presence of multiple targets, a sensor node can obtain more than one measurement. It is difficult to knowwhich observation belongs to which target.This uncertainty in measurements results in data association problem.

2.6.6 ***Recovery***.

Prediction algorithms may suffer from localization errors. This is why a recovery mechanism should be included while designing target tracking approaches in order to relocate the missing object.

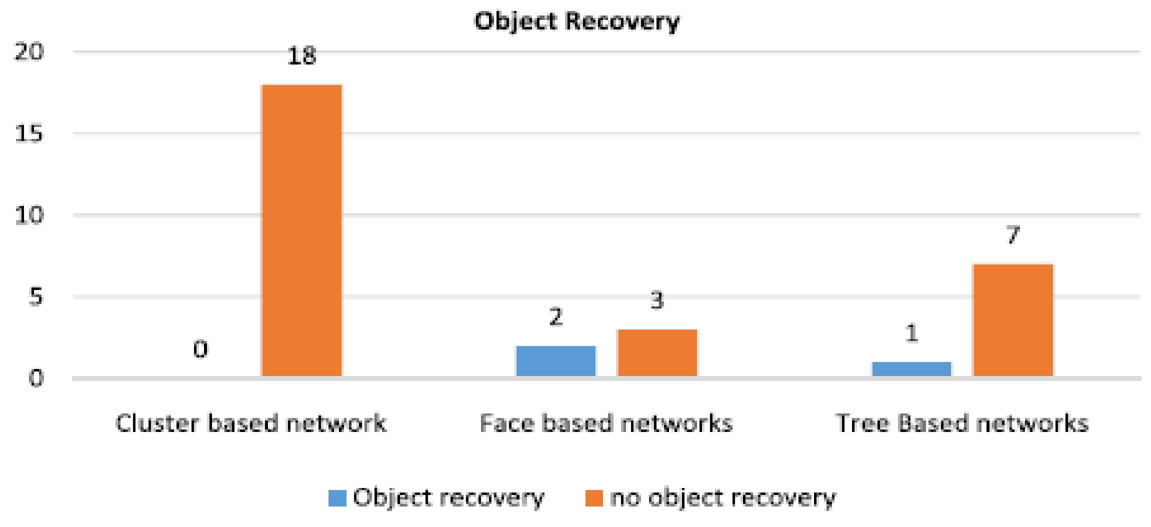


Fig 2.11 Object Recovery in Object Tracking Sensor Network

2.6.7 Other Metrics

Target tracking can also be studied from the network architecture aspect. We can distinguish two types of architecture.

Centralized: When sensor nodes detect the target, they send the information to the base station. This latter analyzes and processes the received data and then takes the appropriate decisions. In the centralized approaches , more messages are exchanged in the network with the base station which consumes large bandwidth and communication overhead.
Distributed: Distributed systems are more robust than the centralized one; this is because sensor nodes are autonomous in decision and collaborate between each other to track the target. Therefore, the traffic overload is reduced and the network lifetime is enhanced.

2.7 Classification of target tracking protocols

Target tracking protocols [28] may be classified into following major categories-

2.7.1 Tree-based target tracking protocols

Nodes in a network may be organized in a hierarchical tree or represented as a graph in which vertices represent sensor nodes and edges are links between nodes that can directly communicate with each other.

2.7.2 Cluster based architecture

Clusters are formed statistically at the time of network deployment and the properties of each cluster are fixed such as number of members, area covered, etc. Clusterbased methods provide scalability and better usage of bandwidth than other types of methods. If cluster head is formed via local network processing, extra messages are reduced and fewer messages are transmitted towards base station thus providing security as well as less usage of bandwidth. Clustering may be static or dynamic

2.7.3 Prediction-based tracking protocols

Rely on tree-based and cluster-based tracking[29] in addition to prediction. These models assume that moving object will continue the current speed and direction for the next few moments and process historical data to deduce subsequent movement of a mobile object. These methods allow limited number of sensors to track the moving object.

2.7.4 Mobicast message-based tracking protocols

It is a spatiotemporal multicast method in which message is delivered to a group of nodes that change with time according to estimated velocity of moving entity.

2.8 Applications Of Target Coverage

Applications of target tracking [30] are found in diverse civilian and military fields. Civilian applications include **air traffic control, navigation, fault tolerant systems and decision problems**. In the military field, applications include **surveillance[31],target identification**, **command and control**, **sensor management and weapon guidance.**

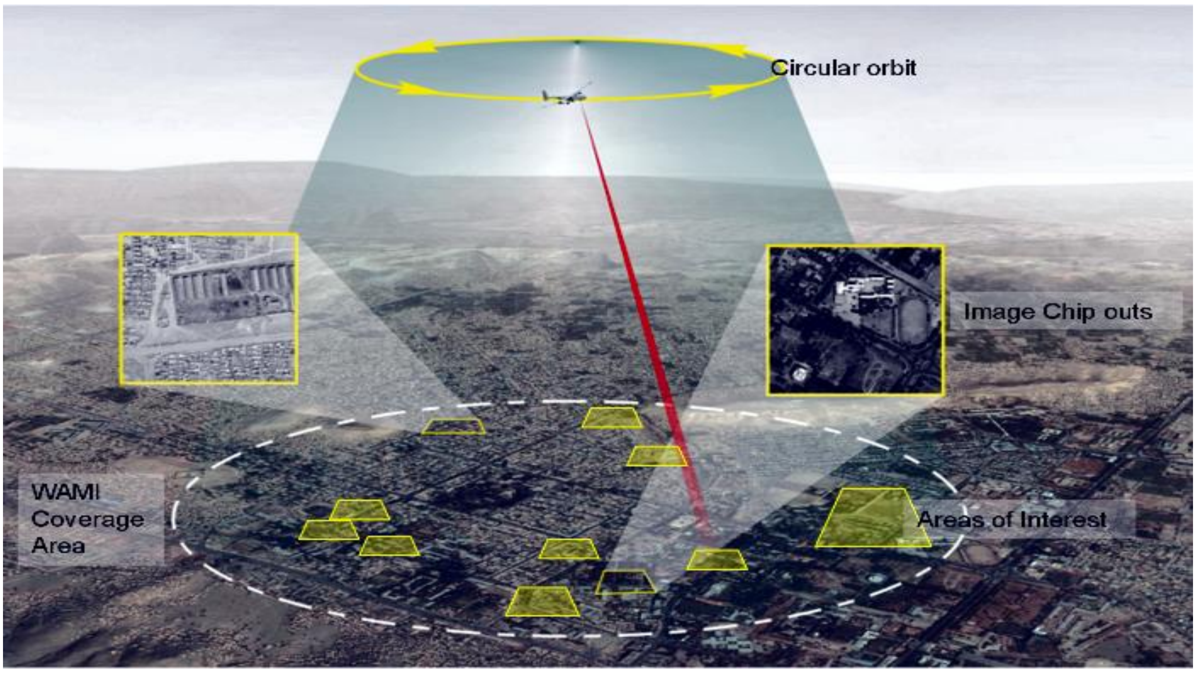


Fig 2.12 spy plane in the sky — a wide area surveillance

The target tracking problem is widely researched due to its increasing applications in security industry due to heightened concerns about the safety of men and material in present day world. In order to keep a check on movements of suspicious people and their activities, we have to employ video monitoring and surveillance and tracking systems.
Tracking [32]is useful in keeping check on movements of individuals whether pedestrians or mobile in heavily congested areas such as business district of cities, government buildings, nuclear facilities, borders, seaports, airports and national monuments. We have to be able to do this in an efficient manner optimizing utilization of all our resources and must look at low cost techniques of doing so. Tracking basically assists the first responders in taking immediate corrective actions such as deny and destroy of individuals who may pose a threat.

While tracking, a couple of things have to be kept in mind such as
1) what objects need to be tracked
2) what is the setting, i.e. urban or rural
3) what are the capabilities of the system i.e. how accurately does the system track and
4) what are the acceptable levels of tracking.

The target tracking applications employ a simple and effective technique to track objects. This technique is efficient and the errors associated with the tracking results are very acceptable in nature. The tracking system can be deployed to keep a check on movements of individuals in business districts or can be used in conjunction with video surveillance systems for safeguarding government buildings, monuments, airports, seaports and borders.
The tracking scheme[33] can also be deployed to study the behavioral pattern of animals and the effect of various emotions on their movements. Animals are left in open fields and sensors deployed all over the area. The track followed by an animal can be tracked to know about its movements when it is sad, happy or excited. Such data is quite helpful to zoologists to conclude for certain that emotions are an integral part of not only human beings but also animals. Since they cannot speak, their actions and movements definitely tell us about their emotional well being.

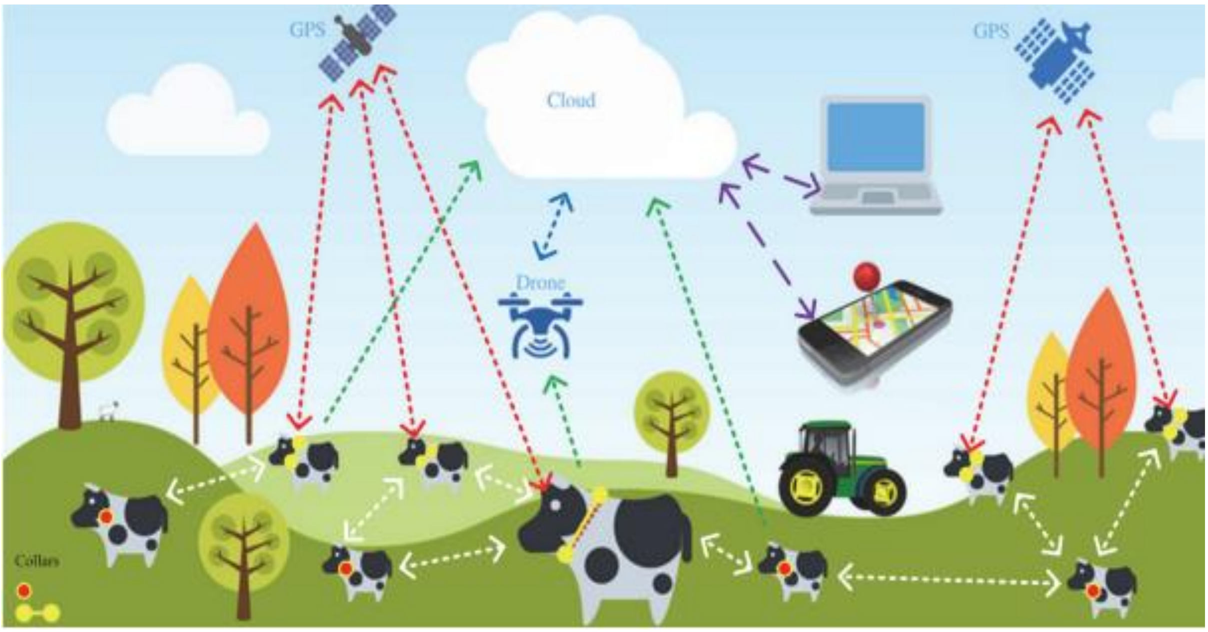


Fig 2.13 Animal Movement Tracking

In addition to this, such a study also helps the aviation industry. They can get information on bird activity in the closer vicinity of airports and hence are able to accordingly schedule arrival and departure times of various flights as well as decide the path to take and the flying altitude.

2.9 Research Motivation

Earlier generations of wireless sensor networks [34]used nonrechargeable batteries to supply electrical power, which has limited energy storage. When the power of the battery in a sensor node is run out, that sensor node cannot work anymore. Therefore, researchers have made great effort to reduce energy consumption and to prolong network lifetime in various application fields. Consequently,each sensor node,in the resulting energy harvesting WSN,is able to harvest energy and recharge its battery from its environment. Target tracking is a typical application in wireless sensor networks. Many target tracking algorithms have been proposed, such as Kalman filter , Bayesian tracking, Bernoulli filter , probability-based prediction, and sleep scheduling (PPSS) .There are many requirements in the tracking procedure that need to be considered and energy efficiency is one of the key aspects.

A fundamental problem in energy harvesting[35] Wireless Sensor Networks (WSNs) is to maximize coverage,whereby the goal is to capture events of interest that occur in one or more target areas. We address the problem of maximizing network lifetime of rechargeable wireless sensor network whilst ensuring all targets are monitored continuously by at least one sensor node.

Two key problems are considered here,1:Duty cycling sensor nodes such that they provide complete target coverage, 2:placing minimal no of nodes in a manner that achieves **Energy neutral coverage[36]** as well as **Complete Target Coverage.** To address these problems ,different solutions have been proposed in literature such as distributed solutions like Maximum Energy Protection algorithm ,linear programming (LP)based solutions as well as other solutions like variable power scheduling, event driven mechanism coverage control etc.The results show that these solutions achieve greater performance in terms of network lifetime in energy harvesting wireless sensor network than conventional WSNs.

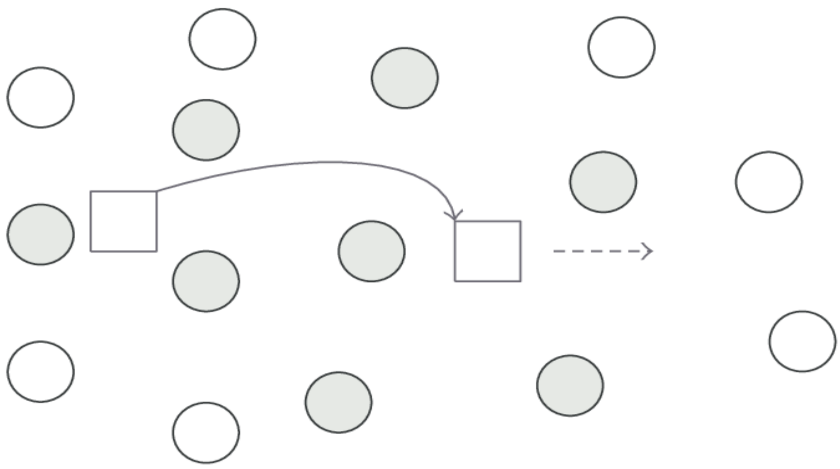


Fig 2.14 Target Tracking in Energy Harvesting Sensor nodes

Energy Efficient Target Coverage using EHWSN

CHAPTER-3

Literature Survey

Chapter 3

Literature Survey

3.1 Introduction

Energy Harvesting Wireless sensor networks can be used to monitor targets continuously. This assumes sensor nodes have *energy neutral* operation[37], whereby the energy consumed to monitor targets is less than their harvested energy. Target coverage problems in energy harvesting sensor networks have been extensively investigated in different proposed algorithms[38]. This chapter reviews on prior works on target coverage in energy harvesting WSN.

3.2 Related Work

3.2.1 Maximum Energy Protection Algorithm (MEP)

Changlin Yang and **Kwan-Wu Chin** in [45] have proposed a distributed algorithm called **Maximum Energy Protection Algorithm** that allows sensor nodes to form a minimal set cover using local information whilst minimizing missed recharging opportunities**.** The algorithm places an on-duty node with low energy to sleep while maintaining complete targets coverage. It is based on off duty rule which states that: If all targets within the sensing range of sensor node si are covered by a sub-set of its neighbours N(si), then si can turn itself off without reducing the overall targets coverage. Otherwise, si goes into the active state. This solution addressed the Distributed Maximum Lifetime Coverage with Energy Harvesting node (DMLC-EH) to maximize a WSN’s lifetime by balancing usage/demand and harvested energy. It works as follows-(1).all sensor nodes enter a global reshuffle phase and decide their status based on the off-duty rule.(2) If a sensor node si decides to go into the sleep state, broadcasts a ’TURN OFF’ message.(3) Sensor nodes deciding to be active will set their epoch to their current battery lifetime.

Advantages: (1) It considers the recharging rate of different sensor nodes and does not need global synchronization.(2) MEP increases network lifetime by at least 30% and reduces network redundancy by 10%

3.2.2 LP-MLCEH (Maximum Lifetime Coverage With Energy Harvesting)

Changlin Yang and Kwan-Wu Chin in [46] proposed a Linear Programming (LP) based solution to determine the activation schedule of sensor nodes whilst affording them recharging opportunities and at the same time ensures complete target coverage. In LP-MLCEH (Maximum Lifetime Coverage with Energy Harvesting) solution, It aims to minimize the energy consumption of each sensor node whilst maintaining complete targets coverage. It ensures that all targets are watched. The main objective is to determine the set covers and their corresponding active time such that all targets are monitored continuously. That is, determine the maximum coverage time t, where $t \in [0, \infty]$, that satisfies the following constraints: (i) $E(Ct) = 1$, and (ii) $\varphi(Ct , Z) = 1$. Constraint (i) ensures all sensor nodes in cover Ct have sufficient energy. Moreover, as per constraint (ii), Ct provides complete coverage. Each sensor node does not exceed its energy in one time slot t. It ensures energy neutral operation i.e the total energy spent is less than the sum of a node's battery and harvested energy.
Advantages: (1) LPMLCEH doubles the network lifetime as compared to a similar algorithm proposed for finite WSNs.
Drawback: It is computationally expensive to solve.

3.2.3 MUA (Maximum Utility Algorithm)

MUA (Maximum Utility Algorithm) proposed by Changlin Yang and Kwan-Wu Chin in [47] is Fast algorithm compared to LP-MLCEH. It minimizes energy wastage due to lost recharging opportunities. Utility is defined as the number of recharging nodes over the number of nodes with full battery.
Advantages: MUA achieves 3/4 of the network lifetime of LP-MLCEH using only a fraction of the computation time of LP-MLCEH.

3.2.4 Variable-Power Scheduling for Perpetual Target Coverage

Qianqian Yang and Deniz G¨und¨uz in [48] studied perpetual target coverage with an energy harvesting wireless sensor network (WSN) assuming that each sensor can modulate its sensing range by dynamically varying its operating power, e.g., radar sensors. In this variable-power scheduling scenario, they first solved the maximum network lifetime problem for battery-powered WSNs for perpetual target coverage. The goal is to provide continuous coverage of all the targets perpetually in the most energy efficient manner. To obtain an approximation to the maximal lifetime, we consider successive time slots, and at each time slot, a minimum weight sensor cover (MWSC) is activated to prolong the network lifetime for a battery powered sensor network. In this variable-power transmission model, they first solve the maximum lifetime problem with batterypowered sensors. They then show that the solution to the battery-limited target coverage problem can be used to decide if an energy harvesting WSN is capable of perpetual coverage while satisfying energy neutrality. They formulate the energy efficient perpetual target coverage problem and prove its NP-completeness. A greedy polynomial time approximation algorithm is proposed, and its effectiveness is validated by extensive numerical simulations..
Advantages:(1) A low-complexity greedy algorithm is proposed to approximate the optimal variable-power schedule.(2) the capability of the sensors to modulate power levels

significantly improves the performance of the WSN in terms of coverage lifetime and energy efficiency.

3.2.5 Quality-Aware Target Coverage in EHWSN

XIAOJIANG REN1, (Student Member, IEEE), WEIFA LIANG1, (Senior Member, IEEE),And WENZHENG XU1,2 in [49] introduced a new coverage quality metric to measure the coverage quality within two different time scales modeled by a sub-modular function. The system model states that a set of heterogeneous sensors powered by renewable energy and operated in duty cycle mode and a base station used to monitor the set of targets for a specified period in a monitoring region. Sensors transmit their sensing data to the base station in a real time manner. They focused on devising efficient centralized and distributed algorithms in which sensors are powered by time-varying harvesting energy sources for a novel coverage maximization problem that takes both sensing coverage quality and network connectivity into consideration.
Advantages: An adaptive framework is proposed to deal with energy prediction fluctuations.

3.2.6 Event-driven mechanism Coverage Control Protocol (ECCP)

In [50] the authors proposed Event-driven-mechanism Coverage Control Protocol (ECCP) which is Energy-efficient Multi-target Coverage Control Protocol. The algorithm uses the correlation between the nodes and dynamic grouping to adjust the coverage area. Algorithm makes full use of the association between sensor nodes and target nodes and a wake-up mechanism to achieve the coverage of the target nodes in the monitoring area. In order to obtain data exactly and comprehensively, a large number of sensor nodes should be deployed in the monitoring area to multiple cover the target. To ensure the energy balance in the wireless sensor network and extend its lifetime, they only wake partial nodes to work in a cycle, so that they can work in turn. In terms of extending the network lifetime, wireless sensor network lifetime problem is designed to search for the maximization of the coverage set under conditions of constrained energy.
Advantages: The proposed algorithm effectively prolongs the wireless sensor network lifetime

3.2.7 Stochastic program (SP) based Uncertain Maximum Lifetime Coverage (SP-UMLC)

Changlin Yang and Kwan-Wu Chin in [51] proposed a Stochastic Programming (SP) based uncertain maximum lifetime coverage (SP-UMLC) approach that considers on complete target coverage with random battery levels. In the first stage, a decision is made based on the “current” battery level of nodes. In the second stage, actual battery levels become available, which require recourse actions to be carried out if the decision made in the first stage is inadequate .Problem seeks the minimum activation time for sensor nodes such that all targets are covered, whilst affording them ample time to recharge.
Advantages: (1) It is a promising solution that addresses the tradeoff between uncertainties and energy consuming, frequent updates conducted to obtain accurate battery level information from all nodes.(2)This SP approach achieves 80% of the theoretically achievable coverage lifetime.

3.2.8 Green Energy Optimization

In [52] the authors studied sensor activation control for the optimization of green energy utilization in an EH-WSN, where both energy generation and target distribution exhibit temporal and spatial diversities. 1. Temporal diversity: Target distribution varies with time due to moving characteristics of targets. 2. Spatial diversity: sensors at different locations may experience different target distribution intensities. It involves two sub problems: the dynamic mode adaptation problem in the temporal dimension and the energy balancing problem in the spatial dimension. Due to the interactions among autonomous distributed sensors, game theory is applied to the local information based decentralized optimization for the spatial energy balancing problem.Fig 3.2 shows the schematic diagram of green energy optimization.
Advantages: Through green energy optimization, not only is the energy consumption minimized, but the green energy collection is also maximized
Drawback: (1) More Efficient Game Models should be designed (2) the green energy optimization performance can be improved at the cost of convergence speed, computational complexity, signaling overhead, and so on.

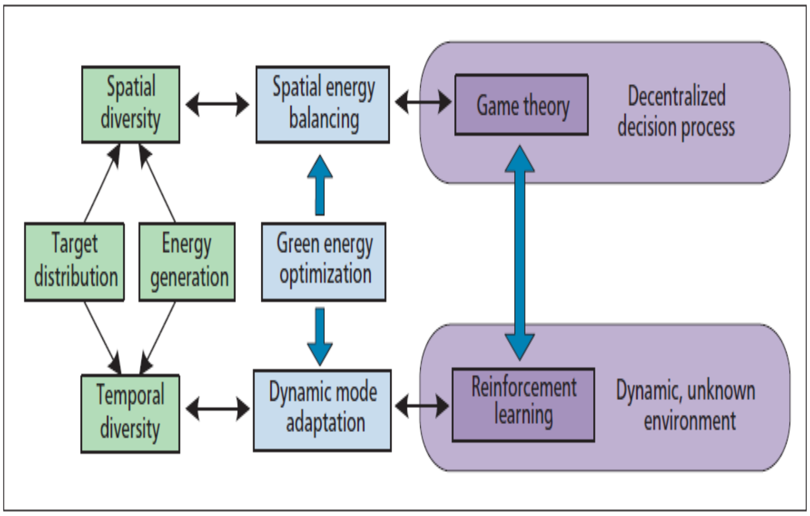


Fig 3.1 Green Energy Optimization

3.3 COMPARISON OF DIFFERENT APPROACHES FOR TARGET COVERAGE IN EHWSN

APPROACH REFERENCE	TYPE OF SOLUTI-ON	ENERGY SAVING STRATEGY	CONNECTIVITY	MOBILITY	ALGORIT-HM TYPE	K-COVERAGE	SENSOR TYPE	SENSOR DEPLOYMEN-T STRATEGY
Changlin Yang et al in [45]	Distributed	Based on off-duty rule between sensors	No	No	Maximum Energy protection algorithm	No	Homogeneous	Random
Changlin Yang et al in [46]	LP based	Energy Neutral operation by finding set covers	No	No	MaximumLifetime Coverage With Energy Harvesting	No	Homogeneous	Random

Changlin Yang et al in [47]	Greedy selection policy	Based on utility	No	No	Maximum Utility Algorithm	No	Homogeneous	Random
Qianqian Yang et al in [48]	Variable power scheduling	Dynamically varying operating power of sensors	No	No	Variable Power Scheduling algorithm for perpetual target coverage	No	Homogeneous	Random
XIAOJIANG REN1, et al in [49]	Distributed and centralized	Sensors operating in duty cycle mode	Yes	No	Coverage quality maximization algorithm	Yes	Heterogeneous	Random/Deterministic
Zeyu Sun et al in [50]	Greedy algorithm	multiple-cover the target node only and allow the others remain	No	No	Event-driven-mechanism Coverage Control Protocol	Yes	Homogeneous	Random
Changlin Yang et al in [51]	Stochastic Programming (SP)based	Sensors with random recharging rates	No	No	Uncertain Maximum Lifetime Coverage	Yes	Heterogeneous	Random
Jianchao Zheng Et al in [52]	Decentralized Optimization Using GAME THEORY	Dynamic mode adaptation and Spatial energy balancing	No	No	Green Energy Optimization	No	Homogeneous	Random

Energy Efficient Target Coverage using EHWSN

CHAPTER-4

Proposed Work

Chapter 4

Proposed Work

4.1 Introduction

The main objective of this thesis is to introduce an efficient sleep scheduling algorithm to enhance the target tracking performance, while the energy harvesting nodes make the sensor network work longer. There are many requirements in the tracking procedure that need to be considered and energy efficiency is one of the key aspects . Different methods were utilized to enhance energy efficiency of target tracking.In this thesis, our proposed algorithm is put forward to achieve better tracking accuracy and energy efficiency. Compared to other algorithms and the proposed algorithm without energy harvesting, the proposed sleep scheduling algorithm can improve the target tracking efficiency and increase the nodes' residual energy.

4.2 Efficient Sleep Scheduling Algorithm for Target Tracking in Energy Harvesting Sensor Networks

4.2.1 Algorithm Description:

In this section, a sleep scheduling algorithm in the energy harvesting sensor network is derived. We consider a wireless sensor network which is composed of static, uniformly distributed sensor nodes in a planar area. The nodes are equipped with energy harvesting components. The node's working time is divided in to sleep state and awake state. The awaking state occupying the percentage of each TP is called a duty cycle (DC). They can harvest energy in both sleep and awake state. The awaking nodes can detect the target and transmit and receive messages.At first, connected dominating sets of sensors are formed using some algorithms to organize them in a better way and to ensure full coverage of the network. A connected dominating set(CDS) can be shown as a backbone which is a subset of nodes that are able to perform especial tasks and serve nodes which are not in the backbone. We have formed CDS following some algorithm as described in [58]. The awake nodes sense one or more targets , generate the detected messages and broadcast the messages to their immediate neighbours.At the first step of target detection,the nodes also awake the immediate sleeping nodes to track the target. The immediate neighbour nodes acknowledge the reception of message and start sensing targets. If any node tracks the target ,it will update the message and broadcast its immediate neighbours without awakening the sleep nodes. The nodes goes to sleep mode after a limited amount of time. Finally the target detected messages are forwarded to the sink by lowest hop count.

Nowadays, few sleep scheduling algorithms for target tracking in sensor networks considered energy harvesting. In the tracking procedure, sleep scheduling means that only the sensors which are near to the target keep awake [53], while other sensors which are far away from the target stay in the sleepmode. In[54], a sleep strategy was proposed that each node autonomously determines the sleeping time. It also can make one subset of nodes active while others enter the sleep state to conserve energy and ensure that the target is tracked . Besides, in [55] a PPSS algorithm was proposed to proactively wake tracking nodes. A heuristic sleep scheduling algorithm is proposed in [56] where the algorithm takes the target speed and the amount of harvested energy in the target tracking region into account, which tries to put the nodes with more residual energy to work without modeling of the energy harvesting process.

When nodes operate in a duty cycling mode, tracking performance can be improved if the target motion can be predicted and nodes along the trajectory can be proactively awakened. However, this will negatively influence the energy efficiency and constrain the benefits of duty cycling. In , we present a[57] Probability-based Prediction and Sleep Scheduling protocol (PPSS) was presented to improve energy efficiency of proactive wake up. Based on the prediction results, PPSS then precisely selects the nodes to awaken and reduces their active time, so as to enhance energy efficiency with limited tracking performance loss.

4.2.2 System Model:

- We consider a wireless sensor network which is composed of static, uniformly distributed homogeneous sensor nodes in a planar area.
- The nodes are equipped with energy harvesting capabilities
- There is a sink in the sensor network.
- Nodes are assumed to know their locations through GPS or other techniques
- Nodes are also locally time synchronized and have the ability to detect target's movement status(position, velocity,magnitude,direction etc)
- The nodes are assumed to operate in two states- **Sleep** and **Active**
- The nodes in the sleep state have the lowest power consumption.
- The nodes can harvest energy in both states whenever energy is available to harvest.
- The awaking nodes can detect the target and transmit and receive messages.
- If a target appears, the awaking nodes will detect the target and begin to track it
- All nodes have sensing radius r and communication radius R.

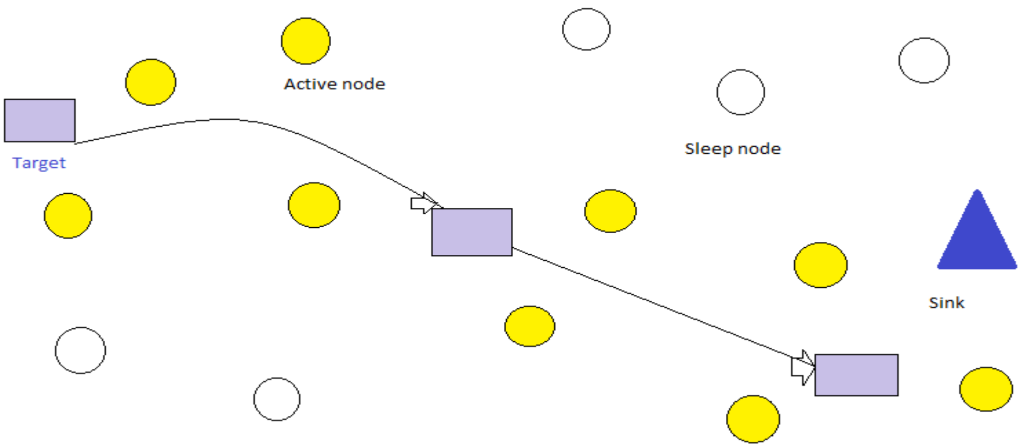


Fig 4.1 Target Tracking procedure in proposed algorithm

4.2.3 Proposed Sleep Scheduling Algorithm

For the actual implementation,we list flowchart of the algorithm. Sleep scheduling algorithm is described as follows:

1. Homogeneous sensor nodes with energy harvesting ability and same initial energy are deployed uniformly in a planar area.
2. CDS are formed using some algorithm to cover entire region
3. At each time interval any one set will stay awake assuring full coverage and rest of the sets stay in sleep mode
4. In both sleep and awake mode,
   if (solar energy available) & e<ethreshold
      harvest energy and store
5. If an awake node detects target in its sensing region,
      generates detection message(Md) containing target id and velocity , broadcasts to immediate neighbours since the target is found.
6. If any immediate neighbour is in sleep mode,
      Processor awakens the node getting Md
7. Upon receiving Md from awake node, neighbour node acknowledge the awake node
      detects the target
      Regenerate Md if target detected
      Broadcasts the message without awaking the sleep node.
8. If no target is detected within a limited amount of time
      Awake node goes to sleep mode.
9. Detection messages are forwarded to the sink with lowest hop count by the sensors.

Energy Efficient Target Coverage using EHWSN

CHAPTER-5

Simulations & Result

Chapter 5

Simulations & Result

5.1 Introduction

According to the system model, we conduct a simulation by Using JAVA to evaluate the performance of the proposed algorithm.We have implemented the proposed algorithm using following platform-

- **Java SE 12** (12.0.1) 2019-04-16

5.1.1 Why JAVA?

Java is a general-purpose programming language that follows the object-oriented programming paradigm and the Write Once Run Anywhere approach. Java is used for desktop, web, mobile, and enterprise applications.
Java is not only a language but an ecosystem of tools covering almost everything you may need for Java development. This includes:

Java Development Kit (JDK) – with that and a standard Notebook app you can write and run/compile Java code

Java Runtime Environment (JRE) – software distribution tool containing a stand-alone Java Virtual Machine, the Java standard library (Java Class Library), and a configuration tool

Integrated Development Environment (IDE) – tools that help you run, edit, and compile your code. IntelliJ IDEA, Eclipse, and NetBeans are the most popular ones.

Java can be found anywhere you look. It's a primary language for Android development. You will find it in web applications, governmental websites, and big data technologies such as Hadoop and Apache Storm. And it's also a classic choice for scientific projects, especially natural language processing. Java was dominating mobile even in pre-smartphone days – first mobile games in the early 2000s were mostly made in Java. So, it's fair to say that Java, thanks to its long history, has earned its place in the Programming Hall of Fame. TIOBE index, one of the most reputable programming rankings in the world, uses search engine results for calculation. Despite the growing popularity of Go and Python, Java has remained at the top of the list for more than a decade.

5.1.2 Benefits of programming in Java

- **Object-oriented programming**

  Java embraces **object-oriented programming** (OOP) – a coding concept in which you not only define the type of data and its structure, but also the set of functions applied to it. This way, your data structure becomes an object that can now be manipulated to create relationships between different objects. It prevents errors by having objects hide some information that shouldn't be easily accessed. It offers simple maintenance and legacy code modernization.

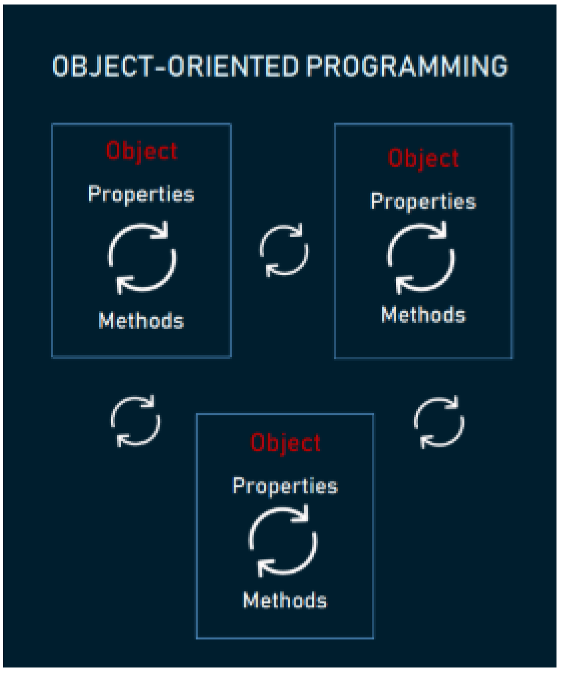


Fig 5.1 Object Oriented Programming

- **High-level language with simple syntax and a mild learning curve**

  Java is a high-level language, meaning that it closely resembles human language. In contrast to low-level languages that resemble machine code, high-level languages have to be converted using compilers or interpreters. This simplifies development, making a language easier to write, read, and maintain.

- **Standard for enterprise computing**

  Enterprise applications are Java's greatest asset. It started back in the 90s when organizations began looking for robust programming tools that weren't C. Java supports a plethora of libraries – building blocks of any enterprise system – that help developers create any function a company may need.

- **Platform-independency**

  Write Once Run Anywhere (WORA) is a popular programming catchphrase introduced by Sun Microsystems to describe Java's cross-platform capabilities. It meant you could create a Java program on, let's say, Windows, compile it to bytecode, and run the application on any other platform that supports a Java Virtual Machine (JVM). In this case, a JVM serves as an abstraction level between the code and the hardware. All major operating systems including Windows, Mac OS, and Linux support JVM. And unless you're writing a program that relies mostly on platform-specific features and UI, you can share – maybe not all – but a big chunk of bytecode.

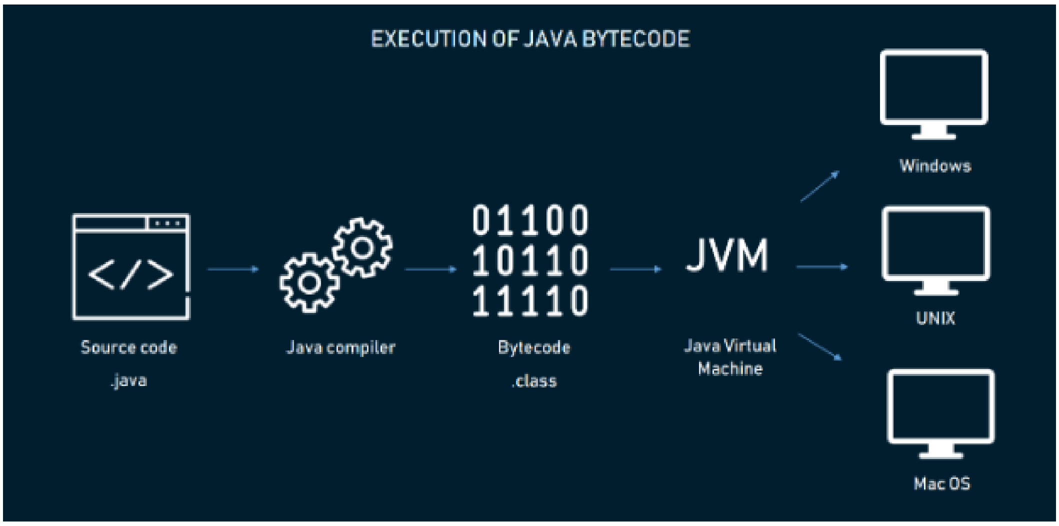


Fig 5.2 JAVA VIRTUAL MACHINE

- **Distributed language for easy remote collaboration**

  Java was designed as a distributed language meaning that it has an integrated mechanism for sharing data and programs among multiple computers for improved performance and efficiency. Unlike other languages, where you have to use external APIs for distribution, Java offers this technology at its core. Java-specific methodology for distributed computing is called **Remote Method Invocation** (RMI). Using RMI allows you to bring all Java benefits, such as security, platform-independency and object-oriented programming, to distributed computing.

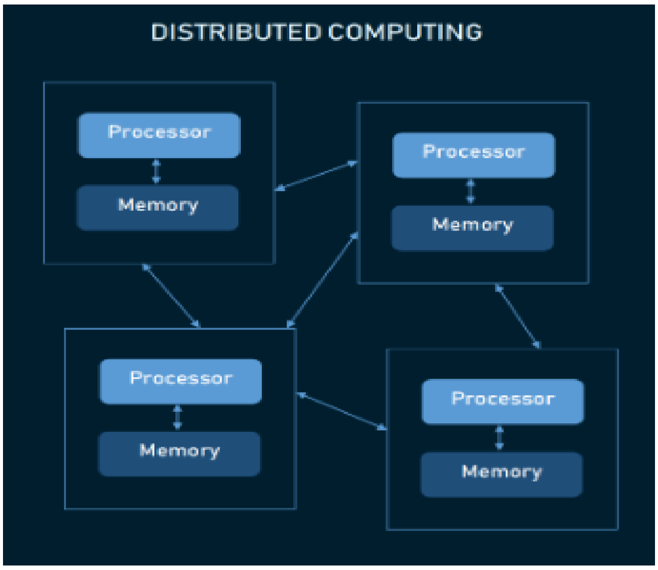


Fig 5.3 Distributed computing in java

- **Automatic memory management**

Automatic memory management (AMM), also used in the Swift programming language, and garbage collection, an application that automatically handles allocation and deallocation of memory. A **garbage collector** can locate objects that are no longer referenced by your program and remove them. Despite the fact that it affects your program's CPU, you can reduce or prevent it with smart optimization and tuning.

- **Multithreading**

In programming, a thread is the smallest unit of processing. To maximize utilization of CPU time, Java allows you to run these threads simultaneously – in a process called multithreading. Threads share the same memory area so switching between them takes little time. They are also independent, so if one thread faces exception, it doesn't affect other threads.

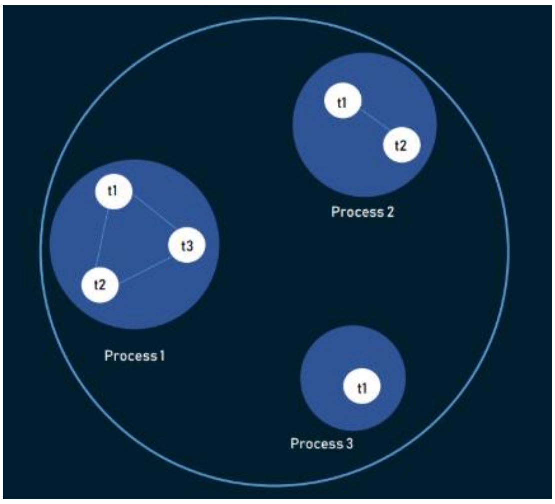


Fig 5.4 Multithreading

- **Stability and massive community**

  Java has survived to a respectable age thanks to the community, Oracle's support, and the cornucopia of applications and languages that keep running on JVM. Besides, new versions of Java are regularly released with fresh, interesting features.

5.2 Parameter Settings

- The tracking region is a 150 × 150m2 square
- Nodes are uniformly deployed in it assuring full coverage.
- The density of nodes is changed from 1.5 nodes/100m2 to 5.5 nodes/100m2
- The initial energy of each battery is 2 J..
- Energy harvesting rate 0.96 J/hour
- The network has mobile targets with linear motion.
- The results are obtained by averaging.

5.3 Performance Metrics

The performance metrics are target loss ratio and Network lifetime.

- **Target Loss Ratio**

Target loss ratio is defined as the ratio of the times of target missed detection and the times of target detection by the nodes. High target loss ration means low network efficiency and low target loss ration means better network performance and efficiency.

- **Network Lifetime (NL)**

  Generally defined as the time during which the **network** is operational. This is the time duration from which a network starts operation to when a target is not watched by any sensor nodes. In other words the **lifetime** of **network** is defined as the operational time of the **network** during which it is able to perform the dedicated task(s).The network lifetime of a sensor network means the time whilst ensuring all the targets are monitored by atleast one sensor at all times. More available energy in the sensors means increase in network lifetime.

5.4 Discussions of SimulationS

5.4.1. Target Loss Ratio versus Number of Nodes

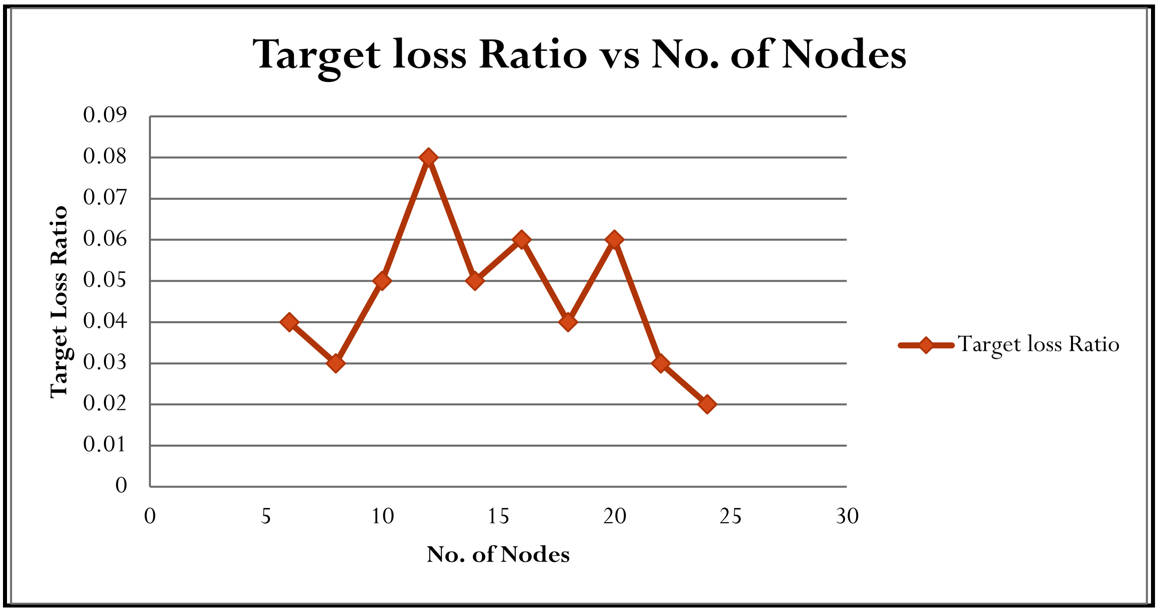


Fig 5.5 Target Loss Ratio vs No. of Nodes

The influence of number of nodes on the target loss ratio is shown in Figure 5.5,where number of targets is fixed ie. 2. There is no linear relation or correlation between target loss ratio and number of nodes. When the awaking nodes' number increases, it just increases the number of nodes in the same range but does not increase the target tracking area. As a result, the target loss ratio does not increase.

5.4.2 Target loss ratio versus nodes density

Figures 5.6 illustrates the target loss ratio versus the node density where number of targets is fixed. The figures illustrates that the proposed algorithm reduces the target loss ratio. The target loss ratio does not change regardless of energy harvesting or no energy harvesting. As the increase of node density makes the increase of tracking nodes' number, the target loss ratio obviously drops.So with the increase of node density, the tracking nodes' number increases and the target loss ratio decreases.

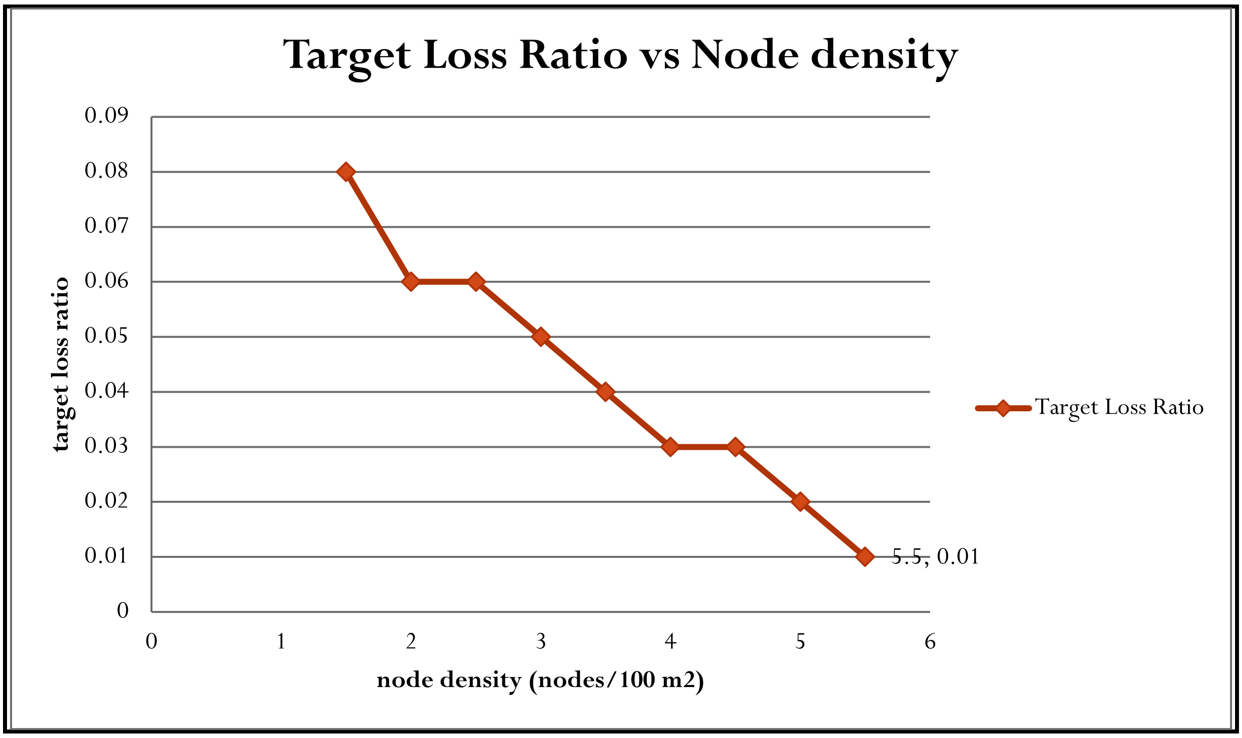


Fig 5.6 Target loss ratio versus nodes density

5.4.3 Network Lifetime versus No. of Targets

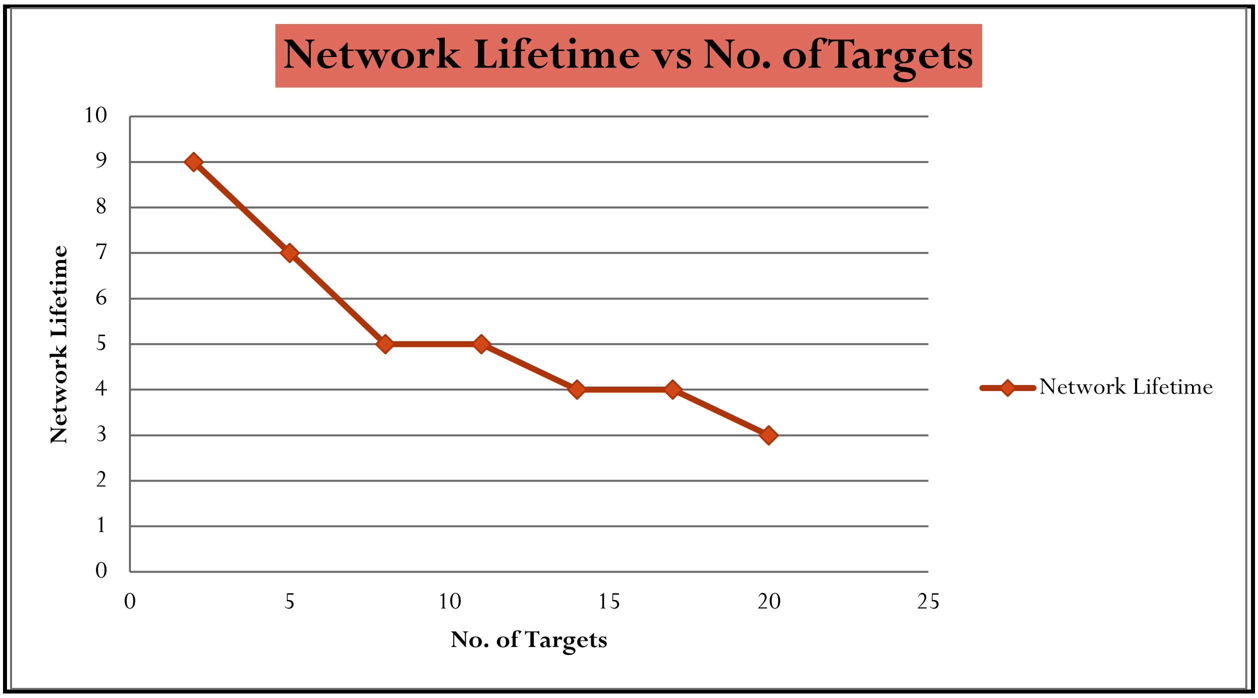


Fig 5.7 Network Lifetime versus No. of Targets

Figures 5.7 illustrates the network lifetime versus no. of targets where number of nodes is fixed.Assume that twenty sensor nodes are deployed within a 150 × 150m2 field,each has a uniform sensing range of 10 meters. The number of targets is increased from 3 to 20.It can be seen that network lifetime decreases when there are more targets. The reason is that as the number of target increases,each sensor node covers more targets within its sensing range. As a result it has fewer opportunities to recharge itself,which compromises network lifetime. But overall network lifetime increases if we compare it with other algorithms.

5.4.4 Network Lifetime versus No. of Nodes

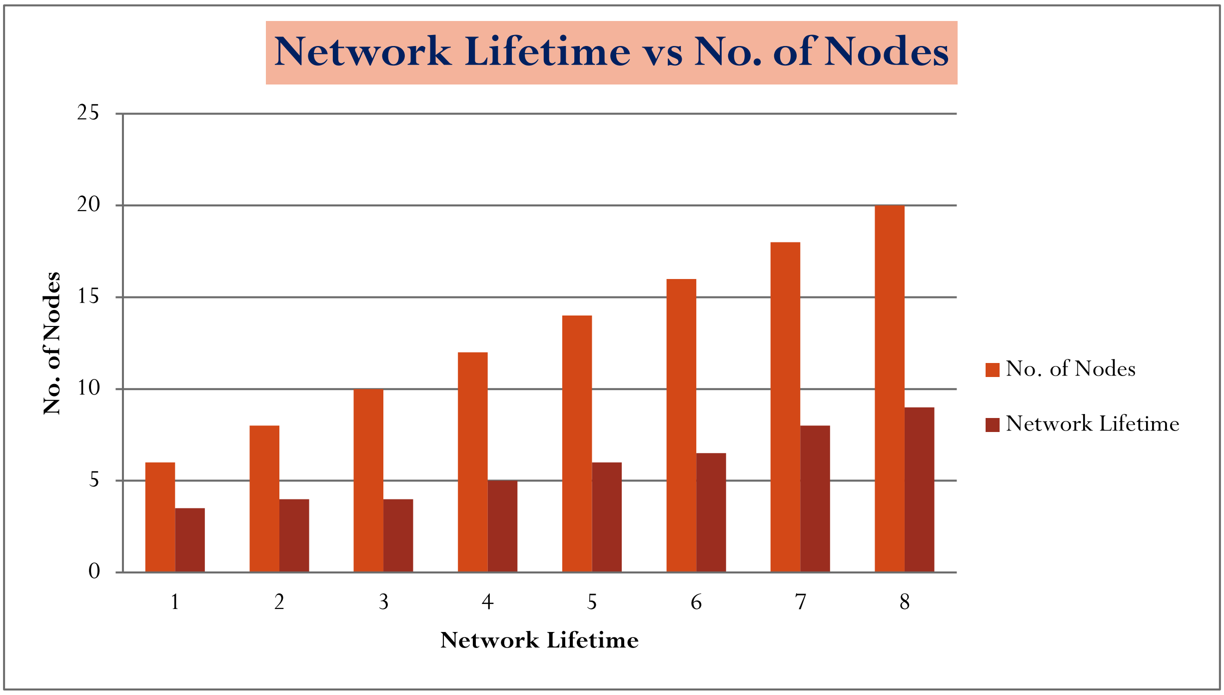


Fig 5.8 Network Lifetime versus No. of Nodes

Figure 5.8 illustrates the comparison of network lifetime with number of nodes when number of targets is fixed. In this experiment the number of targets is fixed to five and the number of sensor nodes are varied from 6 to 20.Allsensor nodes have uniform sensing range. The figure shows that when the number of nodes increases ,the network lifetime also increases.The reason is that the sensor nodes have more opportunities to harvest energy . So the total energy available in the sensor network also increases. As a result,It prolongs the lifetime of the network.

5.4.5 No. of Sensor Nodes versus No. of Targets

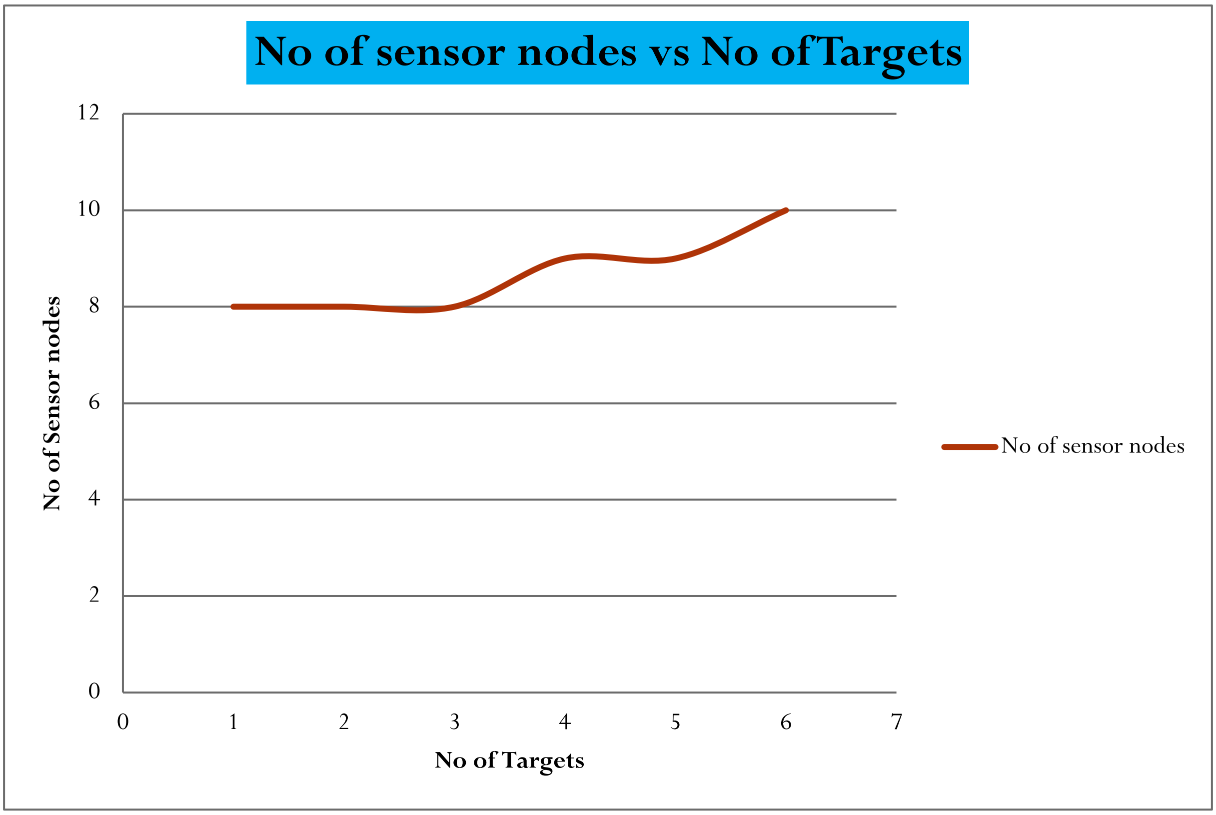


Fig 5.9 No. of Sensor Nodes versus No. of Targets

From Fig. 5.9 , we see that the required number of sensor nodes for this algorithms to ensure energy neutral complete target coverage increases with the addition of targets. This is because a higher number of targets require sensor nodes to expend more energy to monitor targets and forward data.Here the increase in sensor nodes is very less with compare to other algorithms as connecting dominating sets of sensors are formed here to assure full coverage and also energy harvesting is available to extend the lifetime of sensors.

5.5 Improvements with comparison of other algorithms

With the use of energy harvesting nodes, energy usage is no longer deficit. So the nodes can consume more energy in every tracking procedure. But due to the randomness of available energy harvesting time and the limit of solar panel conversion efficiency, the tracking procedure still needs to adapt to the energy harvesting situation. In the target tracking process, the first concern is to ensure the target is tracked, and the second concern is to optimize the energy utilization.

We use sleep scheduling algorithm to track the target, and we also add some communication processes of awake nodes with their neighbor nodes. After awake nodes send target detected messages to neighbor nodes, awake nodes immediately turn into the receiving status to wait for neighbor nodes'replying messages. In the first step the awake nodes broadcast the message to all the immediate neighbours and also make the immediate sleep nodes awake.From the next step the awake nodes only broadcast the detected message without activating the immediate sleep nodes.In this way the target is tracked and target tracking information is sent to the sink with lowest hop count.Thus larger tracking coverage is made to find the target. Target tracking performance is enhanced.

Energy Efficient Target Coverage using EHWSN

CHAPTER-6

Conclusion & Future Work

Chapter 6

Conclusion & Future Work

6.1 Conclusion

Target tracking has been an area that received a considerable amount of attention by researcher because of the importance of its application in different fields such as military, environmental, habitat monitoring, home or office application and others. The massive research in this field has inspired us to present this work. In this paper, we proposed an efficient sleep scheduling algorithm to decrease the target loss rate in energy harvesting sensor networks. Whenever there is a chance to harvest energy from ambient sources nodes can harvest and store energy in both sleep and active mode.This efficient energy management technique is used to prolong the network lifetime We analyzed the proposed work from different angles. It is clear that all experiments presented in this paper share one common objective, which is ensuring a high target tracking accuracy while maintaining the energy..Simulation results show that the proposed sleep scheduling algorithm can enhance the target tracking performance, while the energy harvesting nodes make the sensor network work longer, compared with other algorithms and the proposed algorithm without energy harvesting.

6.2 Future Work

Nevertheless, the proposed approach has some limitations.

- The technique developed is theoretical in nature and has to be implemented on ground.
- The nodes can be heterogenous with different recharging rates of harvested energy.
- The initial energy of the sensors can be different.
- The other improvement could be made if we consider that different sensor nodes have different sensing radii. In this case, all sensor nodes have been considered to have the

same sensing radii which may not be the case. It can be extended in this regard..

- Data aggregation technique can be applied to enhance the network performance.
- The main improvement in the algorithm can be brought about by removing the Constraints which are assumed in the proposed algorithm.

Much additional research effort will be needed-

- to handle the problem of data association in multiple target tracking,
- to treat the problem of inaccurate measurements that may occur in the network,
- since sensor nodes are prone to failures due to energy depletion, communication errors, and malicious attacks. More research efforts should be done to deal with fault tolerance issue in target tracking.
- to track mobile objects in presence of obstacles.
- Message transmission consumes more energy than local processing, thus, work may be done for designing target tracking method with the consideration for well organized computing and nominal transmission of messages without degradation of performance.
- Work may be done to reduce cost of infrastructure still maintaining the efficiency by reducing the number of sensors or considering sparse deployment of sensors or by using low cost binary sensors.
- Protocols need to be developed to address higher topology changes and higher scalability. New internetworking schemes should be developed to allow easy communication between the sensor networks and external networks. One of the unexplored domains is error control in sensor networks

Future work will proceed in several directions. First, to increase the utility of the proposed algorithm, we will conduct more experiments on various scenarios. Further, other constraints as mentioned above are interesting and worthy of investigation, especially for verification of the proposed algorithm's performance in many directions.

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Appendix

```
import java.util.*;
class Point{
    protected int x, y;
    Point()
    {}
    Point(int p, int q)
    {
        x = p;
        y = q;
    }
}

class CheckBounds{
    public static boolean onSegment(Point p, Point q, Point r){
        if (q.x <= Math.max(p.x, r.x) && q.x >= Math.min(p.x, r.x)
                && q.y <= Math.max(p.y, r.y) && q.y >= Math.min(p.y, r.y))
            return true;
        return false;
    }
    public static int orientation(Point p, Point q, Point r){
        int val = (q.y - p.y) * (r.x - q.x) - (q.x - p.x) * (r.y - q.y);
        if (val == 0)
            return 0;
        return (val > 0) ? 1 : 2;
    }
    public static boolean doIntersect(Point p1, Point q1, Point p2, Point q2){
        int o1 = orientation(p1, q1, p2);
        int o2 = orientation(p1, q1, q2);
        int o3 = orientation(p2, q2, p1);
        int o4 = orientation(p2, q2, q1);
        if (o1 != o2 && o3 != o4)
            return true;
        if (o1 == 0 && onSegment(p1, p2, q1))
            return true;
        if (o2 == 0 && onSegment(p1, q2, q1))
            return true;
        if (o3 == 0 && onSegment(p2, p1, q2))
            return true;
        if (o4 == 0 && onSegment(p2, q1, q2))
            return true;
```

```
        return false;
    }
public static boolean isInside(Point polygon[], int n, Point p){
        int INF = 10000;
        if (n < 3)
            return false;
        Point extreme = new Point(INF, p.y);
        int count = 0, i = 0;
        do
        {
            int next = (i + 1) % n;
            if (doIntersect(polygon[i], polygon[next], p, extreme)){
                if (orientation(polygon[i], p, polygon[next]) == 0)
                    return onSegment(polygon[i], p, polygon[next]);
                count++;
            }
            i = next;
        } while (i != 0);
        return (count%2==0);
    }
}
public class CoverageAndTarget{
    private int pn;
    private Point Areas[];
    private int sn, sr;
    private Point Sensor[];
    private float sel, sec, SensorEL[];
    Scanner sc = new Scanner(System.in);
    int mn;
    private Point movement[];

    public static void main(String args[]){
        CoverageAndTarget cnt = new CoverageAndTarget();
        HashMap<Integer, Set<Point>> points = new HashMap<Integer, Set<Point>>();
        cnt.inputArea();
        cnt.inputSensorData();
        cnt.inputMovement();
        for(int i=0;i<cnt.sn;i++){
            Set<Point> res=cnt.getArea(cnt.Sensor[i]);
            points.put(i+1,res);
        }
        for(int i=0;i<cnt.sn;i++){
            Set res=points.get(i+1);
            System.out.println("Area of sensor number " + (i+1));
            for(Object ob:res){
                Point object=(Point)ob;
                System.out.println(object.x+" "+object.y);
            }
        }
        cnt.detectMovement(points);
```

```
    }
public void inputArea(){
        System.out.print("Number of sides of polygon: ");
        pn=sc.nextInt();
        Areas=new Point[pn];
        System.out.println("Enter the x y coordinates of the polygon");
        for (int i=0;i<pn;i++){
            Areas[i]=new Point();
            Areas[i].x=sc.nextInt();
            Areas[i].y=sc.nextInt();
        }
    }
    public void inputSensorData(){
        System.out.print("Number of sensors: ");
        sn=sc.nextInt();
        System.out.print("Sensor Radius: ");
        sr=sc.nextInt();
        System.out.print("Initial Energy Level of Sensors ");
        sel=sc.nextFloat();
        System.out.print("Energy Consumption of Sensors ");
        sec=sc.nextFloat();
        Sensor=new Point[sn];
        SensorEL = new float[sn];
        System.out.println("Enter the x y coordinates of the sensors");
        for (int i=0;i<sn;i++){
            Sensor[i]=new Point();
            Sensor[i].x=sc.nextInt();
            Sensor[i].y=sc.nextInt();
            SensorEL[i]=sel;
        }
    }
    public void inputMovement(){
        System.out.print("Number of movement points: ");
        mn=sc.nextInt();
        movement=new Point[mn];
        System.out.println("Enter the x y coordinates of the movement");
        for (int i=0;i<mn;i++){
            movement[i]=new Point();
            movement[i].x=sc.nextInt();
            movement[i].y=sc.nextInt();
        }
    }
public double distance(Point p1, Point p2){
        int x1=p1.x, y1=p1.y, x2=p2.x, y2=p2.y;
        return Math.sqrt(Math.pow(y1-y2,2)+Math.pow(x1-x2,2));
    }
    public Set<Point> getArea(Point p){
        CheckBounds cb = new CheckBounds();
        Set<Point> points = new HashSet<Point>(){
            @Override
```

```
            public boolean contains(Object obj) {
            Point p = (Point) obj;
            for (Point p1 : this) {
                if (p1.x==p.x && p1.y==p.y) {
                    return true;
                }
            }
            return false;
        }
    };
    points.add(p);
    int b, c;
    b=p.x;
    c=p.y;
    for (int t=1;t<=sr;t++){
        for(int i=b-t;i<=b+t;i++){
            for(int j=c-t;j<=c+t;j++){
                Point p1 = new Point(i,j);
                if (distance(p,p1)<=sr && !points.contains(p1) && cb.isInside(Areas,pn,p1))
                    points.add(p1);
            }
        }
    }
    return points;
  }
  public void detectMovement(HashMap<Integer, Set<Point>> points){
    for(int i=0;i<sn;i++){
        Set res=points.get(i+1);
        for(int j=0;j<mn;j++){
            if (res.contains(movement[j])){
                System.out.print("Movement detected by sensor "+(i+1));
                System.out.println(" at "+movement[j].x+" "+movement[j].y);
            }
        }
    }
  }
}
```