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Toward Sustainable Smart Cities: Thermal Monitoring for Solar Panel Based WSN Leach Protocol

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A B S T R A C T

Currently, numerous cities are moving toward becoming smarter and more sustainable. Therefore, wireless sensor networks (WSNs) have become essential due to their high capacity for real-time data collection and monitoring, as well as increased environmental awareness. There are two major challenges that many large-scale applications will face: energy efficiency and network lifetime. Therefore, we propose an integrated system in this approach to harvest solar energy and optimize renewable energy sources using the low-energy adaptive clustering hierarchy (LEACH) protocol. This will be used to distribute power evenly among sensors to reduce electricity consumption and thus increase network stability. Therefore, this system will help monitor the temperature of solar panels. The effectiveness and efficiency of this proposed system were tested using MATLAB. The simulation results demonstrated efficient data transmission with high reliability and reduced power loss, thus extending the network's lifetime.

Keywords: WSN, LEACH Protocol, Solar Energy Harvesting, Thermal Monitoring, MATLAB.

1. Introduction

As the world becomes increasingly urbanized, the concept of smart cities has become a pioneering solution for energy efficiency, resource management, and sustainability issues [1]. Such an outcome is achieved by integrating solar panels and other renewable energy sources into urban structures, where high temperatures negatively impact their efficiency despite their being considered a clean and renewable resource [2].

For this reason, it has become necessary to monitor the temperature of these solar panels in smart cities, as the increasing energy consumption has led to the need to improve the efficiency of managing their resources to ensure the efficiency of the system's performance and also the quality of energy production [3]. In 2004, Younis and Fahmy proposed a hybrid energy-efficient distributed energy (HEED) system by selecting the most efficient collector head based on the amount of remaining energy and communication costs [5]. Scoblai and Palivos (2009) examined various aspects of how temperature affects the efficiency of solar panels within the framework of solar energy & thermal monitoring. The significance of efficient heat management systems was emphasized in this context [6]. Tiwari et al. (2011) examined the function of wireless sensor networks, also called WSNs, in continuous surveillance of solar energy systems, emphasizing the significance of precise information accessibility and efficiency of energy [7]. As cities increasingly strive to develop environmentally sustainable smart cities that facilitate real-time monitoring and data collection, WSNs, or wireless sensor networks, are gaining prominence. The primary challenges are energy economy and network longevity, particularly when implemented on a wide scale. The the LEACH algorithm (Low Energy Adaptive Clustering Hierarchy) method has been refined to enhance the effectiveness of renewable energy utilization. This research shows a cohesive energy harvesting system utilizing solar panels as the principal power source. As cities increasingly endeavor toward creating environmentally sustainable smart cities that facilitate real time monitoring and data collection, WSNs, or wireless sensor networks, are gaining prominence. The primary obstacles are energy economy and network longevity, particularly when implemented on a wide scale. The the LEACH algorithm (Low Energy Adaptive Clustering Hierarchy) method has been refined to enhance the efficacy of renewable energy utilization. This research illustrates a cohesive energy harvesting system utilizing solar panels as the principal power source.The device monitors the solar panel's temperature to ensure optimal performance under various weather conditions. The Voronoi algorithm facilitates the equal sharing of power among sensors, thereby diminishing electrical consumption and enhancing network stability. Simulation results conducted with MATLAB illustrate the efficacy of this methodology in diminishing power loss, enhancing transmission of data reliability, and prolonging network longevity. Furthermore, the implementation of renewable energy-efficient systems and sources demonstrates the feasibility of constructing smart cities with environmentally sustainable and durable infrastructure.

Recent improvements have significantly facilitated the utilization of wireless sensor networks powered by solar energy. Al-Tarjuman and Abu Jubbah (2019) discussed the Internet of Things (IoT) and its potential to enhance smart grid development. They emphasized the importance of efficient in terms of energy monitoring systems [8]. Kumar et al. (2020) recently presented a hybrid strategy to these systems. They demonstrated that the amalgamation of solar energy harvesting plus energy-efficient routing techniques enhanced the network's longevity and reduced energy consumption [9]. Khan et al. (2020) developed a framework for the surveillance of solar power plants utilizing a WSN. They demonstrated its efficacy in enhancing energy management [10].Lee et al. (2021) established (IoT) or an Internet of Things -based thermal surveillance system, which continually tracks the temperature of solar panels, could enhance energy production efficiency. Raza et al. (2022) demonstrated the efficacy of incorporating machine learning approaches into thermal monitoring, enhancing the adaptability and effectiveness of solar energy systems for management [12]. This essay emphasizes the significance of integrating temperature surveillance with energy-saving protocols such as LEACH to enhance the sustainability of powered by solar energy WSN in intelligent enhances the system by diminishing energy usage in the WSN. LEACH groups sensor nodes into clusters, and each cluster is assigned a leader (called a cluster head) who is responsible for collecting and transmitting data to the base station. This structure reduces energy consumption and increases the network's lifetime by reducing the distance data must travel.

1.1 Thermal Monitoring of Solar Panels:

Initially, solar panel monitoring was primitive, requiring manual intervention and limited data collection methods due to limited remote access. Therefore, connected systems and data loggers were added to transmit data locally [13]. With advances in communication technology, wireless monitoring using IoT and AI emerged. Modern systems rely on Wireless Sensor Networks (WSNs), composed of sensor nodes for data sensing and storage [14]. This paper focuses on monitoring solar panel temperature using Resistance Temperature Detectors (RTDs), as temperature significantly affects panel efficiency and lifespan. To extend node battery life in harsh environments, the energy-efficient LEACH protocol is employed.

1.2 Wireless Sensor Networks (WSNs)

Wireless sensor network contains by gathering numerous numbers of nodes that connected to each other to collect and transmit data to do some process. WSN has wide rang benefits, its ability to collect, process, and transmit data from everywhere in a specific area. Also, WSN provide a good cost-effective compare to wire establish (it reduces the need for cable and its infrastructure). WSN gives a good real time data monitoring its collect and transmit data remotely. Although harsh environment WSN can work in this area such as in gas or oil exploring or any extreme area where cable cannot work in these environments [15].

The more famous protocol in WSN called LEACH that able to manage energy consuming in efficiently way. It plays a great role to improve the lifetime of the network by arrange nodes to clusters; each cluster has a leader named cluster head (CH) with number of nodes. The basic principle behind LEACH is to rotate the role of cluster heads among nodes to evenly distribute energy consumption. [16]. Fig. 1 shows leach protocol where network contains number of CH with its nodes, each CH connected to all nodes in its cluster and gather the data from nodes and transmitted it to base station (BS). Cluster head selected randomly and each node in a cluster become a cluster head in other rotating time this method guarantee that energy consuming equally in all node in the cluster as a result the network lifetime improved [17].

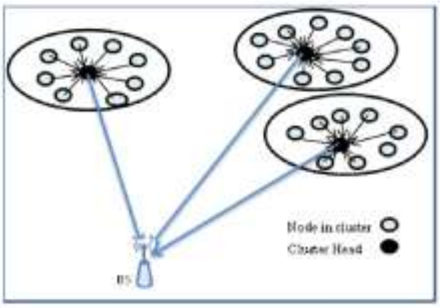

Fig. 1 Leach protocol where network contains number of cluster [17]

Minimizing energy consumption is an important role in leach protocol there are widely research for energy efficiency in WSNs. Enhancement LEACH have been extended to further eliminate the energy consumption for example using multi-hop leach, this process uses multi-hop contact to bring data from the cluster head to the base station. Also, using Sleep Scheduling that enable nodes to save energy when they are not active for transmitting data. solar panel have been monitored using leach protocol in WSN technique, this real time monitoring has been proposed in this paper.

1.3 Solar panel monitoring

The earlier stage of solar monitoring is basic and required human intervention, this monitoring system has drawbacks its needs manual monitor and no remote access in addition its limited data collection. Rising the solar monitoring appearing as automatic monitoring such as using data logger (device used to record the performance of solar panel like current, voltage and track the energy). Also wired monitoring system that used to transmuted data to the local computer [18]. The advance in communication system entered in solar monitoring that used wireless networks for transmitted data. The modern monitoring system used new technique such as internet of things or artificial intelligent. Fig. 2 show the timeline of the Adoption Stages of Solar Panel Monitoring Technologies (1980–2020) [19]

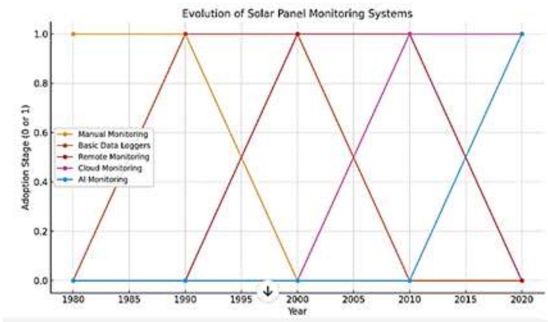

Fig. 2 Evolution of Solar Panel Monitoring (1980–2020)

1.4 Leach protocol

As denoted in the introduction section LEACH arrange nodes as a cluster, each led by a cluster head (CH). These CH are responsible for collect information from nodes within their cluster and then sent it to the base station, so as to eliminate the need for direct communication between each sensor node and the base station. The node become a CH depend on probabilistic model as (1): [20]

$$T(n) = \begin{cases} \frac{P}{1-P*(r \, mod \frac{1}{P})} & if \ n \in G \\ 0 & otherwise \end{cases} \quad (1)$$

Where G sets of nodes that may be elected to be CH in the round r, P desire percentage to be a CH=0.05. During round 0 (r = 0), each node has a probability P of becoming a cluster-head. The nodes that are cluster-heads in round 0 cannot be cluster-heads for the next rounds. Thus, The probability of the remaining nodes becoming cluster heads should be increased, because there are fewer nodes suitable to become cluster heads.

2. LEACH Protocol Simulation in MATLAB

The flowchart illustrates the sequence of operations in simulating the LEACH protocol in MATLAB as shown in Fig..3 . Here's a step-by-step breakdown:

Start Simulation

Begin the simulation process.

Initialize Network Parameters

Define the size of network, nodes numbers, location of base station , and starting energy for each node.

Random Node Deployment

Randomly distribute the sensor nodes within the defined field area.

Start Round Loop

Begin the loop that runs for a defined number of rounds.

Reset Cluster Head Flags

Clear previous CH selections before the new round begins.

Select Cluster Heads (CHs)

Use a probabilistic method to select a certain percentage of nodes as CHs (e.g., 5%).

Form Clusters

Non-CH nodes choose the nearest CH to join, forming clusters.

Data Transmission from Nodes to CHs

Cluster members send their sensed information to their CH using short-range communication.

Data Aggregation and Transmission from CHs to Base Station

CHs aggregate received data and send it to the base station using long-range transmission.

Update Node Energies

Deduct energy based on data sent and received, using an energy model.

Check for Dead Nodes

Identify nodes with zero or negative energy and mark them as dead.

Repeat for Next Round

Continue the loop until the maximum number of rounds is reached or all nodes are dead.

Display Simulation Results

Plot graphs such as the number of alive nodes per round, residual energy, and CH distribution.

End Simulation

Finalize the simulation and analyze performance metrics.

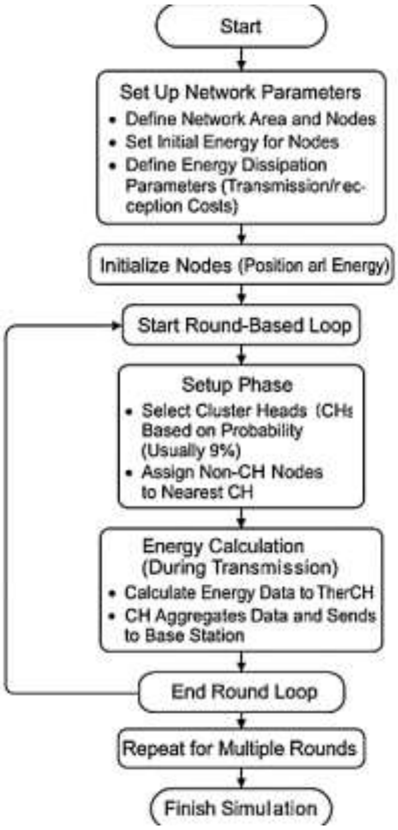

Fig. 3 LEACH Protocol Simulation in MATLAB

3. The mathematical model for LEACH

To model and simulate the LEACH protocol, the following assumptions are made

3.1 Assumptions

A sensor network consists of N sensor nodes distributed randomly over a field of area A.

The nodes are homogeneous with initial energy E_0.

Nodes communicate with a Base Station (BS) located within or outside the field.

3.2 CH Selection

The probability T(n) for a node n to become a CH in round r is given I equation (1).

3.3 Energy Model

The energy consumption for transmission are given as equations (2)(3)(4): [21]

$E_{T_x}(l,d) = l.E_{elec} + l.\varepsilon_{fs}.d^2\ (if\ d < d_0)$ (2)

$E_{T_x}(l,d) = l.E_{elec} + l.\varepsilon_{mp}.d^4\ (if\ d \geq d_0)$ (3)

$E_{R_x}(l,d) = l.E_{elec}$ (4)

Where:

l: Number of bits transmitted or received.

E_{elec}: Energy dissipated per bit for transmission or reception.

ε_{fs}, ε_{mp}: Amplifier constants for free space and multipath models.

$d_0=\sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}}$: Threshold distance.

3.4 Energy Consumption Per Round

Consuming energy for each round in the LEACH protocol depends on the actions of both Cluster Heads (CHs)as in (5) and non-Cluster Head (non-CH) nodes as in (6). Each round contains of two steps, the first one called Setup Phase and the other called Steady-State Phase, but most energy is shrinking in the Steady-State Phase, where actual data transmission takes place. [21]

$E_{CH} = E_{DA}\,.n_{cluster} + E_{T_x}\,(l\,.n_{cluster}, d_{BS})$ (5)

Where: $n_{cluster}$ is the numbers of nodes in the cluster.

$E_{non-CH} = E_{T_x}\,(l\,, d_{CH}) + E_{R_x}(l)$ (6)

Where d_{CH} is the distance to the CH

3.5 Total Energy Dissipation in One Round

The total energy dissipation per round in LEACH can be calculated by summing the energy consumed as in (7) :

$E_{round} = \sum_{j\in CHs} E_{CH} + \sum_{jCHs} E_{non-CH}$ (7)

3.6 Lifetime Estimation

The network lifetime L is the total number of rounds until the first node depletes its energy as (8):

$L = \frac{\sum_{i=1}^{N} E_i}{E_{round}}$ (8)

This model provides a basis for analyzing and simulating LEACH in WSNs. You can adapt it for specific variations or energy optimization strategies.

4. Notations

E_i: Residual energy of node i.

E_{CH} Energy consumption for a cluster head (CH).

E_{non-CH}: Energy consumption for a non-cluster head.

p: Probability of a node being a CH.

k: Number of CHs in a round.

r: Current round number.

d_{ij}: Distance between node i and j.

d_{BS}: Distance between a node and the base station.

E_{T_x}: Energy for transmitting data.

E_{R_x} : Energy for receiving data.

E_{DA}: Energy for data aggregation at CH.

5. Simulation Results

This section presents the simulation results of using the LEACH protocol for thermal monitoring in a solar panel-based Wireless Sensor Network (WSN). The goal is to evaluate energy efficiency and network lifetime in a smart city context. The result initially calculated without using leach protocol it uses direct transmission (each node send data to base station without clustering) that deployment of a Wireless Sensor Network (WSN) in a 100m × 100m area, with number of node is 100 and each node have an initial energy of 0.5 joules which represent in Fig. 4.

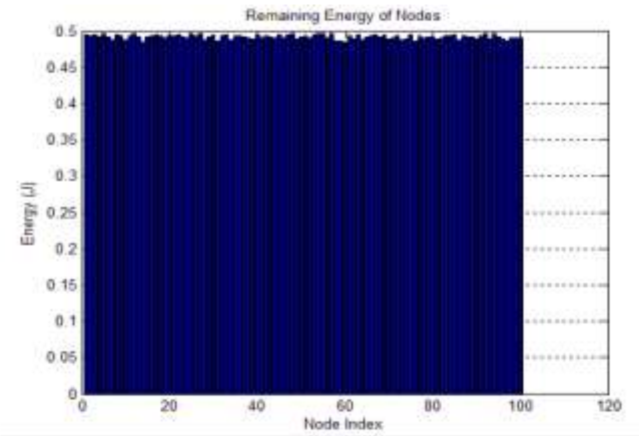

Fig. 4 Initial energy for 100 nodes

The direct transmission method shows that the network lifetime and performance depend on energy consumption due to communication and sensing tasks. Therefor this method consumes energy of node and want to improve Fig. 5 illustrate 100 nodes communicate in direct transmission, the X and Y-axis represents the distance in meters, ranging from 0 to 100 meters. To optimize energy consumption and network longevity, alternative methods clustering could be considered such as Leach protocol, where nodes relay data through intermediate nodes to reach the base station, thereby reducing the transmission distance and energy usage for individual nodes.

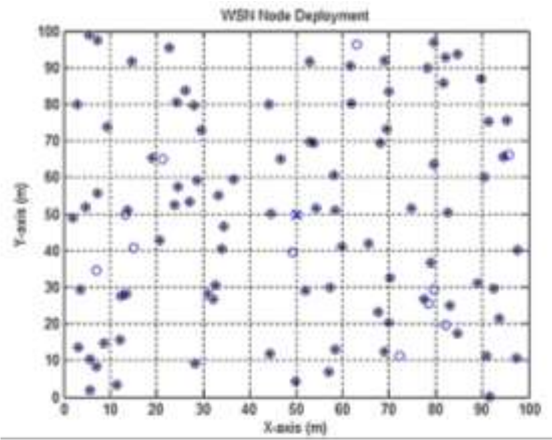

Fig. 5 100 node communication in direct transmission

Leach protocol is used with clustering (area is divided to small spots called cluster. Fig. 6 shows the initial rounds, here each node is in life state with 0.5J energy, no dead node in these rounds.

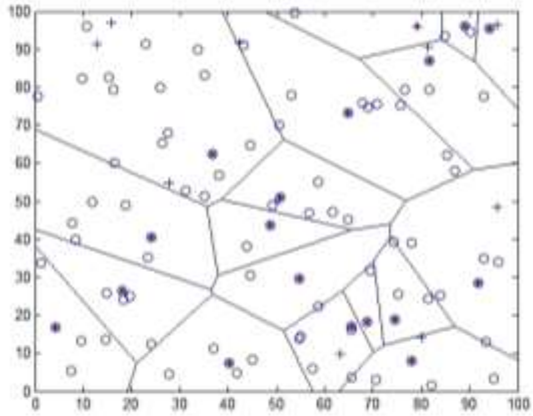

Fig. 6 clustering in leach protocol

Fig. 7 illustrate residual energy of nodes over time the decrease in energy levels for 100 nodes over a series of rounds. The x-axis represents the number of rounds, ranging from 0 to 500, while the y-axis represents the residual energy in joules (J), starting from 0 J up to 2 J. The data points on the graph show a gradual decline in residual energy as the number of rounds increases. This trend indicates that the nodes are consuming energy over time, which is expected in network operations where nodes perform tasks such as data transmission, reception, and processing. The number of dead decreased when the rounds number increased Fig. 8 shows that the number of nodes is 100 in round 3600 and this number will decline in the next rounds where in round 4600 the number of life node recorded 90 (10 nodes enter to dead state). In the final round the number of dead node increased, Fig. 9 illustrate dead nodes in each cluster.

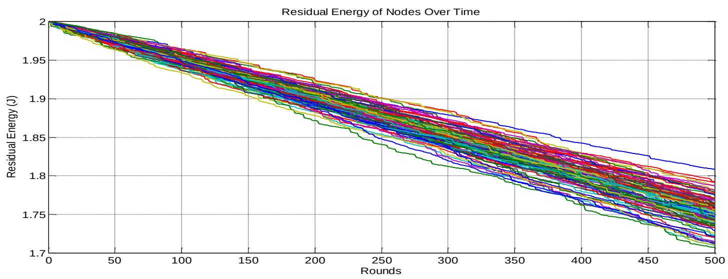

Fig. 7 - The node life span in leach protocol

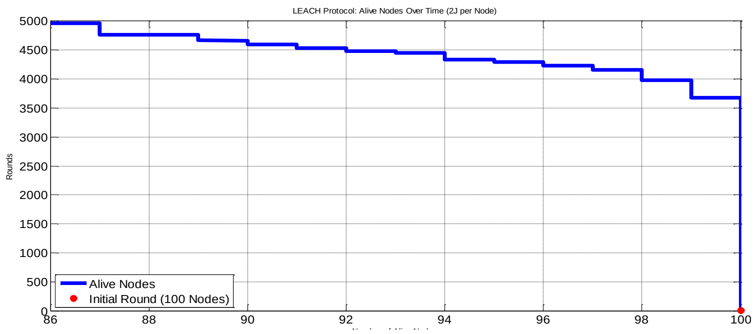

Fig. 8 - alive node overtime

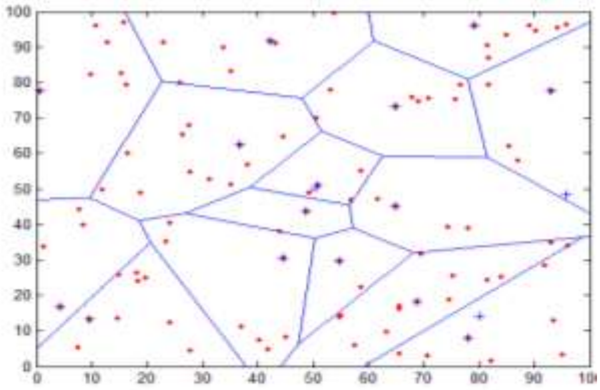

Fig. 9 Dead nodes in leach protocol method

6. Conclusion

The LEACH protocol's clustering mechanism plays a great role in balancing energy consuming through sensor nodes, thereby prolonging the operational life of the entire network. By circling the role of Cluster Head (CH) among nodes and enabling local data aggregation, LEACH minimizes the energy burden on individual sensors. This efficient use of energy resources is critical in solar panel monitoring applications, where sensor nodes are often deployed in remote, elevated, or otherwise inaccessible locations. In such scenarios, replacing or recharging batteries frequently is not feasible, making energy-aware communication protocols essential. LEACH not only reduces the number of long-range transmissions to the base station but also optimizes data flow, which results in lower energy depletion rates and enhanced network reliability. This contributes directly to the sustainability of smart city infrastructure, particularly in the context of renewable energy systems like solar farms.

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