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ENERGY EFFICIENT PV BASED WIRELESS SENSOR NETWORK MODEL WITH ANALYSIS OF COST

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ABSTRACT

Wireless Sensor Networks are used widely in today's world due to their large applications in almost every field such as military applications, weather forecasting, irrigation, commercial applications, scientific research, etc. But challenge in WSN is that it consumes high power and is operated by batteries that need regular replacement which makes maintenance of WSN costly and difficult. This also poses high environmental risks due to disposal of billion of batteries every year. Therefore, the best option is to utilize the renewable energy to power the WSN and as the solar energy is the renewable energy which is widely available as compared to others. So we have powered WSN through solar energy. Simulation results are carried out on MATLAB and concludes that energy efficient solar based WSN are cost effective as compare to regular battery powered WSN.

***Keywords: Wireless Sensor Networks (WSN), Photovoltaic** (PV)*

I. INTRODUCTION

Energy has become an indispensable and inevitable form for determining the economic development of a country. The oil and petroleum crisis of 1973 and great concern for environment has forced the public to think about some alternative source of energy. The renewable sources of energy such as the sun, wind, biomass, geothermal, hydro, ocean are very eco-friendly and everlasting in nature. These energy resources are also well suited for the grid connected power generation and supplying energy to those remote and rural areas which are not or could not connected to the grid. Thus, the programs and policies which are apt for the optimization of these available resources with new technologies should be promoted and adopted. Due to the finite and limited stock of conventional energy sources and their harmful effect on the environment has forced private and govt. sector to put more and more emphasis on renewable resources for the benefits and betterment of human mankind.

SENSORS

A sensor is a device which is used to measure a measurable quantity and convert it into a signal which can be read by an observer or by an instrument. Some commonly used examples of sensor are thermistors or thermocouples used to measure temperature, pressure gauges or barometers used to measure pressure, anemometers or wind meter used for measuring wind speed, strain gauges used to measure mechanical strain and so many others.

SENSOR NODE

It is a node in WSN that processes and gathers information and communicates with other connected nodes in the network. Due to the vast advancement in fields of wireless communication and electronics, there is a great need for the development of low cost, low power, multifunctional sensor nodes. The main components of a sensor node are microcontroller, transceiver, external memory, power source and sensors which is shown in fig 1.

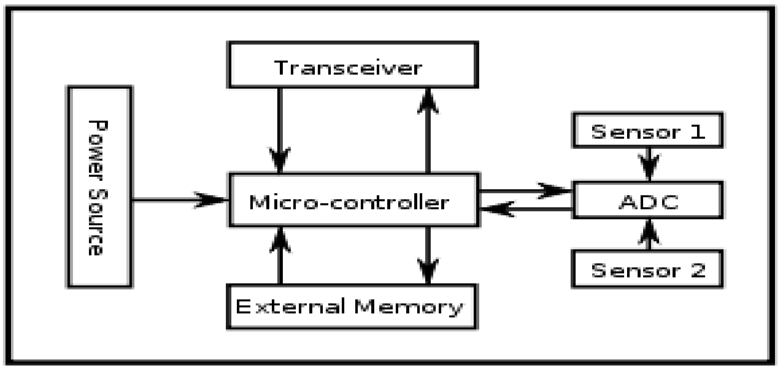

Figure 1 Sensor Node

1.1 Wireless Sensor Networks (Wsn)

A Wireless Sensor Network(WSN) is a collection of nodes organized into a cooperative network. Each node consists of processing capability (one or more microcontrollers), may contain multiple types of memory (program, data and flash memories), have a RF transceiver (usually with a single omnidirectional antenna), have a power source (e.g., batteries or renewable energy), and accommodate various sensors and actuators. The nodes communicate wirelessly and often self-organize after being deployed in an ad hoc fashion. Systems of 1000s or even 10,000 nodes are anticipated.

WSN consists of a large number of tiny sensor nodes and few powerful control nodes also called as a base station, which are small, low-cost, low-performance, battery powered wireless computing devices equipped with various sensors. It also consists of number of sensor nodes which are connected wirelessly to each other and a base station that connects the sensor nodes with another network. Fig. 2 shows the wireless sensor network model.

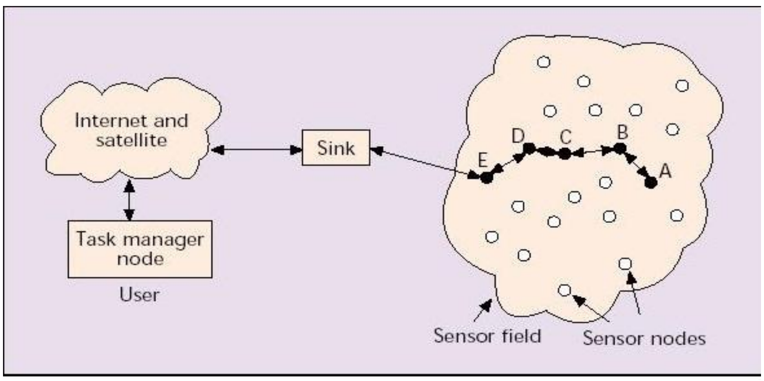

Figure 2 Wireless Sensor Networks (WSN)

II. CONSTRAINTS AND CHALLENGES OF WSNs

WSNs suffer from various constraints and challenges related to the design, protocols, algorithms some of which are explained below: -

Energy: - Sensor nodes operate with the limited energy budgets. Typically, they are powered through batteries, which must be either replaced or recharged when exhausted.

Random Topology: - Usually the sensors are deployed randomly from the airplane and hence it is difficult to know the exact topology of the sensor networks a priori.

Hostile Environment: - Sensor networks are usually placed at remote or hostile environment such as battlefields and their nodes are very much prone to physical attacks, since anyone could have access to the location where they are deployed and can introduce his own malicious nodes inside the network.

Power Restrictions: - This is very important constraint as this is raised due to the smaller physical size and lack of wires. Sensors need constant power supply for its operation and usually battery-driven. So, it is very difficult to replace or recharge the batteries as mostly WSNs are deployed in remote or hostile environment.

Storage Restrictions: - The limited capability for storage affects the storage of information. Each sensor node need to know a number of keys for each other node in the network to secure communication and thus store the keys in the nodes storage space.

Fault Tolerance and Adaptability: - If any sensor node4s fails due to technical problem or consumption of battery, the rest of the network must continue its operation without a problem.

Self-Management: - Sensor nodes usually deployed in harsh environment must be capable of self-managing in the sense that they configure themselves, operate and collaborate with the other nodes themselves and adapt to failures and change in the environment without any human support.

Decentralized Management: - Most of the WSNs are rely on centralized algorithms to implement network management solutions such as topology management. But in actual, sensor nodes must be collaborating with their neighbors to make localized decisions. Though the result of these decentralized algorithms will not be optimal but may be more energy-efficient than centralized solutions.

Security: - Many wireless sensor networks collect sensitive information. The unattended operation of sensor nodes increases their exposure to malicious intrusions and attacks.

Design Constraints: - The primary goal of wireless sensor design is to create smaller, cheaper and more efficient devices. The need for small form factor and low energy consumption also prohibits the integration of many desirable components such as GPS receivers. These constraints have very significant impact on the software design at various levels.

Scalability: - As the sensor nodes are placed in large number over very large physical areas, protocols for the sensor networks must be able to scale; The performance of the network must not deteriorate even if the number of nodes in the network is increased.

Tasking and Querying: - A sensor field is like a database, Data is required from environment, and distributed across nodes which are connected by unreliable links.

Therefore, it is important that user have a interactively task and query the sensor networks. One challenge is to develop a language for queuing and tasking, as well as a database that can be readily queried.

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Security Algorithms: - Security and integration of data is most important, hence we need to select networking technology as well as security algorithm accordingly.

Data Processing: - Sensor nodes have low computing power and hence not able to perform complex processing. However, if each sensor node is able to do some simple data processing such as data aggregation before passing this sensed data to the sinks, this may improve the overall network performance and improves the packet delivery ratio.

Transmission Media: - Sensor nodes typically communicate over a shared wireless transmission medium because the sensors are usually deployed in such environment where there is no possibility of setting up infrastructure such as centralized base stations or wires. Depending on the environment that the sensor nodes operate in, different transmission media may be used like terrestrial sensor networks make use of radio links, underwater sensor networks used acoustic links for communication etc.

III. SIMULATION OF PV MODULE

The I– V characteristic of the PV module are

$$I = IL - I0\ (e\hat{\ }q(V + IRS)/nkT - 1) \qquad (3.1)$$

Where IL = photo current, I0 = diode saturation current, RS = series current, q = charge of electron, k = constant, T = temperature , N = number of PV module.

The I-V curve for a PV module depends upon the type of PV module we are using. Now plotting the curve for different values of G (irradiance (wm^2). PV curve for different value of G=.25, .50, .75, 1

$$IL\ (T1) = Isc\ (T1nom)*G/G\ (nom) \qquad (3.2)$$

Where Isc = short circuit current, G = ambient irradiation

EVALUATION PARAMETERS

There are many metrics which would determine strength of clustering algorithm for WSNs. After the detailed study, it can be inferred that below mentioned six metrics decide the extent of adaptability in the clustering algorithm in case of failure of cluster head. These metrics are selected and are defined as follows:

Power Consumption for all systems, process and communication protocols in sensor nodes and sensor networks should be minimum as sensor nodes run on batteries and recharging them is very difficult since large number of nodes are generally not attended after the deployment. Nodes in clustered Wireless Sensor Network communicate via CHs. If the clusters are not properly formed, then the communication cost might increase. Therefore, clustering technique should be properly selected. The various parameters of wireless sensor network are given in table 1

Table 1. WSN Parameters

PARAMETER	VALUE
SIMULATION TIME	2000 rounds
1 round	1 day
Number of Nodes	100
Network Grid	100m * 100m
Initial Energy	1730 Joules
Packet Size	1000 bytes
$E_{electrical}$	50 nJ/bits
E_{amp}	.0013 $\mu J/bit/m^4$
E_{fs}	10 $\mu J/bit/m^2$
Battery Size	3.7 V, 130 mAh

By using the battery of 3.7 V, 130 mAh, WSN network runs for approximately 71 days, which means network is totally dead after this time period. We need to replace the batteries of all the nodes.

Table 2 Evaluation of Dead Nodes

PARAMETER	VALUE
Half Nodes Dead	15 days
All Nodes Dead (Network Lifetime)	71 days

Total energy is consumed after 71 days which will lead to the network dead state

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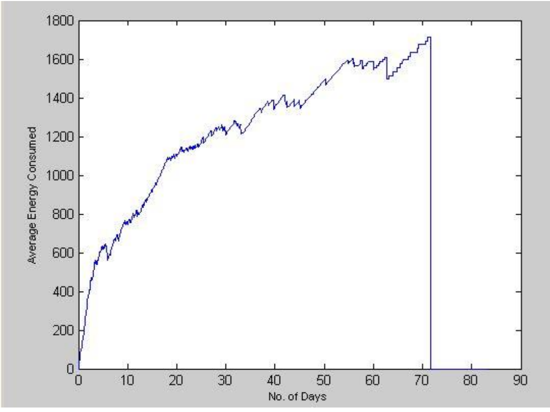


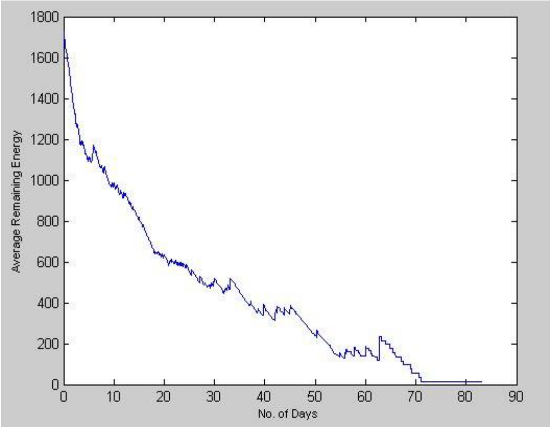
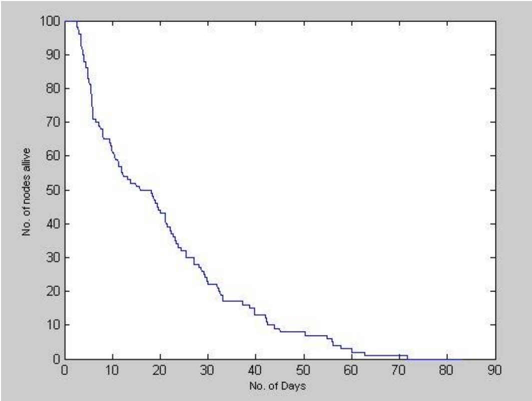


Figure 3 Average Energy Consumed **Figure 4 Average Remaining Energy**

The average remaining energy of the network has been calculated and is demonstrated in the figure below. It is clear from the bar chart that the network consumes all the available energy by approximately 70 days and will be dead afterwards.

Number of Alive Nodes

In this subsection, the number of alive nodes in wireless sensor network are shown below. The evaluated results are shown below in the figure 5.



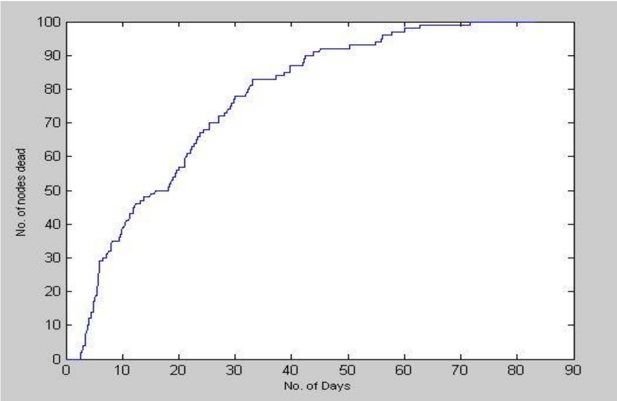


Figure 5 Alive Nodes **Figure 6 Dead Nodes in the network**

All nodes are dead in the network. It would be difficult to keep on changing the batteries after the gap of 71 days.

Solar Cell Configuration

In the table 3, we have specified the different properties of solar cell like voltage, current and the current wattage.

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Table 3 Different Parameters of a solar cell

SOLAR CELL PROPERTIES	
Voltage at Maximum Power	3V
Current at Maximum Power	20 Ma
Dimensions	40 * 35 * 2 mm
Operating Temperature	-40^{o}C to 85^{o}C
LifeTime	20 years
Watt	0.06
Sunshine in a day	9.32 hours
Solar Cell Efficiency	30%

The research work will further find out the economic impact of implementing the wireless solar sensor network of 100 nodes. The solar sensor nodes should be implemented in the area where there is abundant of solar energy available. Various factors like rainy days, natural disasters are not taken into an account while carrying out the cost analysis

Table 4 Rechargeable Battery Properties

PARAMETER	VALUE
Rated Capacity	130 mAh
Nominal Voltage	3.7 V
Dimensions	3 * 20 * 30 mm
Self-Discharge Rate	< 10% per month
Cycles	Maintains 80% Capacity after 500 cycles
LifeTime	5 months

In the table 5, we have evaluated the cost of rechargeable batteries for the 100 nodes.

Table 5 Cost of Rechargeable Batteries

PARAMETER	VALUE
Total Nodes	100
Total Batteries Required	100
Cost of 1 Rechargeable Battery	$ 12.99
Cost of 100 Rechargeable Batteries	$ 7.94 * 100 = $ 1299 = 86,513.40 Rs.
Lifetime of Battery	5 months
Total Annual Cost of Batteries	2,07,632.16 Rs.

In the table 6, the overall cost of implementing the solar panels has been evaluated. It includes the capital cost as well as the maintenance cost of the solar panel per year.

Table 6 Cost of Solar Cell

PARAMETER	VALUE
Total Nodes	100
Total Solar Cells Required	100
Capital Cost of 1Solar Panel	60 INR
Capital Cost of 100 Solar Panels	60 * 100 = 6000 INR.
Operation and Maintenance Cost	1 % of Capital Cost for 1 year

The overall cost of the solar cell for 20 years and the cost of the rechargeable batteries has been computed and is specified in the table 7

Table 7 Overall Cost of Solar cell for 20 years

PARAMETER	VALUE
Solar Panel Capitation Cost	6000 INR
Solar Panel Maintenance Cost for 20 years	1200 INR
Rechargeable Batteries Replacement Cost for 20 years	41,52,643.20 INR
Overall Cost	41,59,843.20 INR

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COST OF SOLAR WIRELESS SENSOR MODEL

The table 8 specifies the overall cost of solar cell and battery for the lifetime of 20 years. The operation and maintenance cost can be estimated as either a fixed amount per year or a percentage of the cost of the turbine. This could also include a service contract with the piezo tile manufacturer which is 1% of the capital costs.

Table 8 Solar Wireless Sensor Model

PARAMETER	VALUE
Solar Panels Required	100
Capital Cost(In Rs)	6000 Rs.
Annual Maintenance Cost(1% of Solar Capital Cost + Battery Replacement Cost)	2, 07,692.16 Rs.
Lifetime(Years)	20
Interest Rate (%)	12.75

The annual cost of owning an asset over its entire life. Equivalent annual cost is often used by firms for capital budgeting decisions. Equivalent annual cost is calculated as:

$$= \frac{\text{Asset Price} \times \text{Discount Rate}}{1-(1+\text{Discount Rate})^{-\text{Number of Periods}}} \quad (5.3)$$

where Asset Price = Capital Cost of the Component, Discount Rate = The Rate at which bank provides the loan, Number of Periods = Lifetime of Component.

Annualized Cost of the Component = Equivalent Annual Cost + Maintenance Cost

Table 9 Annualized Cost

MODEL	COST IN RUPEES
Annualized Capital Cost	841.30 INR
Maintenance Cost	2,07,692.16 Rs.
Total Annual Cost	2,08,533.46 Rs.

In this table, the total cost for the non-rechargeable batteries in the same network.

PARAMETER	VALUE
Total Nodes	100
Total Batteries Required	100
Cost of 1 Battery	$ 6.72
Cost of 100 Batteries	$ 6.72 * 100 = $ 672 = 44,755.20 Rs.
Battery Replacement Period	24 days
Annual Replacement Cost on Batteries	2,30,080 Rs.

Table 10 Annualized Cost Comparison

	Existing Model (Non-rechargeable Batteries)	Proposed Model (Solar WSN With Rechargeable Batteries)
Annual Cost Comparison	2,30,080 Rs.	2,08,533.46 Rs.

It is clear from the above comparison that the wsn installed with solar panels will be more cost-efficient and are cleaner to the environment. It will increase the overall lifespan of the network as they are dead after few months by using non-rechargeable batteries.

IV. CONCLUSION

The research detailed in this paper has increased the autonomy of wireless smart sensor networks used for different applications like structural health monitoring (SHM) purposes. The solar energy harvesting system developed for this research has been experimentally analyzed and can increase the lifetime of an entire network to reach that of its individual hardware components. The result of this research is a system that can operate as an autonomous entity for extended periods of time. A wireless smart sensor (WSS) platform comparison has been given with the non-rechargeable batteries, ultimately revealing why the solar powered wireless sensor network is best suited for most high-demanding applications. The high-performing battery, the higher lifetime of the node, and the scalability of the processor on the wireless node equipped with solar cell make it the top choice for various applications. Its superior performance, however, causes the wireless node to demand more energy than other platforms, suggesting a need for a smart power management strategy.

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