

MODEL FOR SOLAR ENERGY HARVESTING AND OPTIMIZATION IN WIRELESS SENSOR NETWORKS

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ABSTRACT: Presented in this thesis is the energy harvesting and management model concerning wireless sensor network. Wireless sensor network, bears resemblance as routers. However, wireless sensor network cannot afford large batteries because of their small size. Continuous operation of these devices result in rapid consumption of available energy. It is difficult to replace and recharge the battery due to limited accessibility. Sometime these devices are installed in remote areas or areas with uneven terrain such as hilly areas. One approach to counter this problem is to harness the ambient energy which is unevenly distributed in our environment. Availability of this energy is random and uncertain. Ambient energy has been successfully harnessed by solar energy harvesting technique. We present a feasible approach of management model with appropriate energy management for wireless sensor network. The proposed solar energy harvesting and management model not only saves energy, it also assures the connection and communication within the network by optimum consumption of energy along with the management of the harvested and battery energy.

Key words: Energy harvesting, IoT, Sensor, Wireless Network

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INTRODUCTION

In order to sense the environment, a Wireless Sensor Network (WSN) is a network of detecting sensor nodes spread out across an unsupervised region. However, wireless sensor networks cannot afford large batteries because of their small size. Continuous usage of these devices swiftly depletes the available energy. Recharging or replacing the WSN battery may be challenging or impossible in some monitoring situations. In a WSN, sensor nodes are spread out geographically. In a WSN, each sensor node has the ability to process and perceive data independently. To relay what they have discovered, sensor nodes also communicate with one another. Several sensor nodes that can perceive, connect wirelessly, compute, and are often battery-operated make form a wireless sensor network (WSN) [1]. These sensor nodes are scattered across an unattended space to sense the physical environment. The sensed data may be collected by a few sink nodes, also known as base stations.

These days, wireless sensor networks are extensively used in commercial and industrial settings, such as surveillance, healthcare, and environmental monitoring. Through communication with other nodes, these sensor nodes gather information about their surroundings and transmit it to the base station, also known as the sink.

Wireless sensor networks are becoming more and more popular every day. In terms of battery limitations, it also faces the issue of energy limits. This has grown to be a significant problem in WSN as every node requires on energy for its operations. A single node failure has the potential to disrupt the system as a whole. For both receiving and transmitting operations, all sensing nodes should always be operational. Nodes in active mode use energy while sending or receiving data. Because of its limited capacity, the battery has to be changed or recharged on a regular basis. It seems that carrying out these duties during operating hours or during any emergency is challenging. Occasionally, the network is located in a hard-to-reach position, making battery replacement or recharging impossible. In some monitoring environments, it may be difficult or impossible to recharge or replace the WSN battery. Utilizing the ambient energy found in the environment is one potential way to address this issue. The process of using energy, such as the solar energy harvesting model, is called energy harvesting.

LITERATURE REVIEW

WSNs are used extensively in environmental monitoring nowadays. By interacting with other nodes, these sensor nodes gather information about their surroundings and transmit it to the base station. Wireless sensor networks are becoming more and more popular

every day. In terms of battery limitations, it also confronts the significant issue of energy limits. Small batteries in WSNs rapidly deplete due to constant node connection [1].

There are several methods for gathering ambient energy from the surroundings. The process of gathering and using energy from the environment around the devices, such as mechanical [3], thermal [4], radio frequency (RF), and solar [2], is known as energy harvesting. The ambient energy sources are classified as totally controlled, moderately controllable, uncontrollable but predictable, and uncontrollable and unexpected owing to their stochastic character [5]. Table 1 describes the many sources of ambient energy. Every network node has energy harvesting equipment that allows it to draw energy from the surrounding environment.

Table 1: Energy source and corresponding Harvester

Energy source	Nature of source	Transducer
RF	Partially controllable	Antenna
Thermal	Fully controllable	Thermoelectric element
Mechanical	Uncontrollable	Piezoelectric
Solar	Uncontrollable	Photovoltaic cell

This project uses solar energy as a source for energy harvesting. Because solar energy is unavailable at night and environmental energy is random, the utilization of captured energy is optimized to stockpile it. The load's characteristics have a significant impact on how an energy harvesting structure is modelled. The part of any device (load) that uses the most energy is often the transceiver. Sometimes the energy needed for the WSN load should be equal to or more than the energy that is available. The equation defines this fact.

$$E_{harvested(t)} + E_{stored(t)} \geq E_{load(t)} + E_{loss(t)} \quad (1)$$

Three different kinds of energy collecting techniques are available. The fundamental method, known as the native approach, is based on the energy neutral operation hypothesis [6]. The second strategy is used with an optimal energy buffer, meaning that no internal loss occurs when the energy held after harvesting is used [7]. The buffer's capacity is unlimited as well. The third, and most realistic, strategy is that energy captured and held in a buffer with a limited capacity is always more than the energy used [8].

Three different kinds of energy collecting techniques are available. The fundamental method, known as the native approach, is based on the energy neutral operation hypothesis, which states that the total energy utilised should be less than or equal to the energy gathered [6]. The second strategy is used with an optimal energy

buffer, meaning that no internal loss occurs when the energy held after harvesting is used [7]. The buffer's capacity is unlimited as well. The third, and most realistic, strategy is that energy captured and held in a buffer with a limited capacity is always more than the energy used [8]. Inside diagram 2.1 the different system components are described.

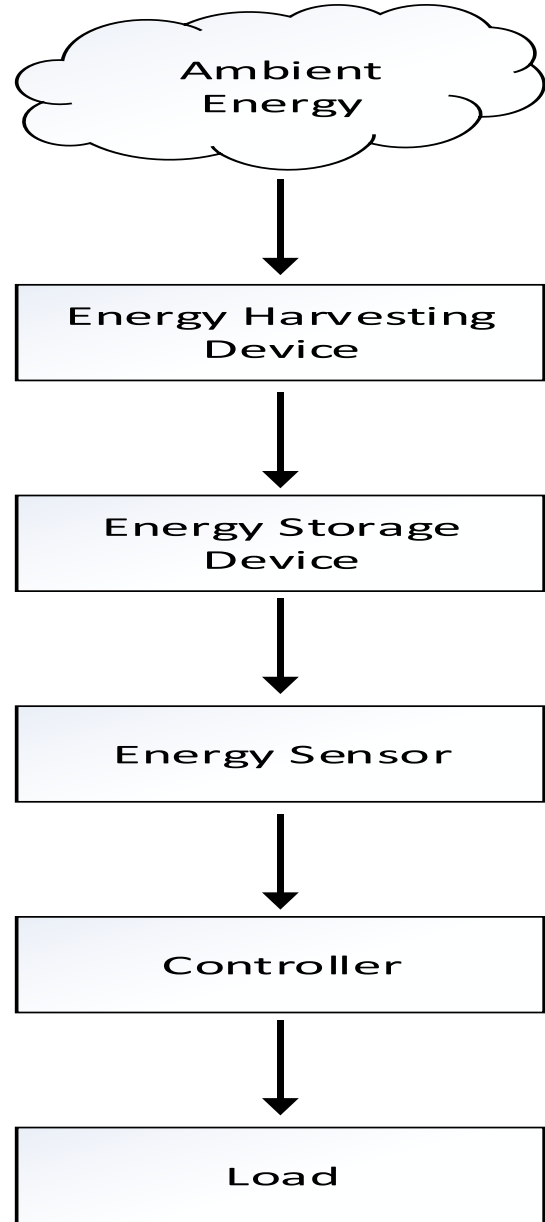


Figure 2.1: Ambient energy harvesting model.

However, super capacitors and two-storage-device batteries are used. The main buffer/storage device is a super capacitor, and the secondary buffer/storage device is a battery [12]. A switch uses a battery to regulate how the load operates. This concept effectively addresses the network's lifetime and connectivity

problems. This proposed model ignores changes in the amount of ambient energy that is accessible and completely parasitizes the storage devices. On the other hand, a different energy harvesting paradigm combines ambient energy with battery storage devices. Every device has a DC-DC converter allocated to it for regulation. The accumulator charges the battery connected in parallel and provides the node with direct energy for operation. Every device is linked to a power management, which regulates the node's functionality [13]. This model has many states, including turnoff, overpower, battery aid, soft start, and battery charge. This architecture is complex and must manage storage devices on limited energy resources, even if it guarantees connection. A power manager is absolutely necessary for this architecture, which is referred to as an autonomous hybrid energy storage concept [14].

Proposed Methodology: Because sunlight is erratic, the best way to describe harvesting nodes in a solar natural environment is as a stochastic process. Every node uses ambient energy to function, and the battery is kept in reserve for use only in situations when ambient energy is insufficient or unavailable to run the transceiver. Until the ambient energy falls below a certain threshold, this process keeps going. By this point the energy that was previously used to charge the storage device is now supplied to the transceiver of the node. In addition, the relay constrains the transceiver to the battery-stored energy as soon as the ambient energy drop below the operational voltage of the device, and switch it back to ambient energy when the voltage exceeds the threshold level. This allows the node to function even in the absence of ambient energy. The technology fixes the connection issue and extends the network's lifespan.

Harvesting analytical model as follow, harvesting device (solar cell) is attached with every node. Available harvesting power during time interval (t_i, t_f) is given below.

$$P_h(t_i, t_f) = P_{pv}(t_i, t_f) - P_c(t_i, t_f) \quad (15)$$

where

P_h = Harvested power

P_{pv} = Panel power

P_c = Consumed power

Now, power required for transceiver operation

$$P_{transceiver} = P_t + P_r \quad (16)$$

P_t = Transmission power

P_r = Received power

$$E_h(t_i, t_f) = \int_{t_i}^{t_f} P_h(t) dt \quad (17)$$

$$E_{transceiver}(t_i, t_f) = \int_{t_i}^{t_f} P_t(t) dt \quad (18)$$

There are three cases, first

$$E_h > E_{transceiver} \quad (19)$$

Then ambient energy directly operates for transceiver and also ambient energy is use for purpose of battery charging. Energy at charging time is given bellow

$$E_{charge} = E_h - E_{transceiver}$$

If

$$E_h = E_{transceiver} \quad (20)$$

Then total actual harvested energy use for purpose of transmission operation of node.

When

$$E_h < E_{transceiver} \quad (21)$$

The amount of solar electricity you get at your location is measured by solar irradiance. The seasons have an impact on this irradiance throughout the year [15]. Additionally, it fluctuates during the day based on the weather and the sun's location in the sky. Direct irradiance ($E_{e,dir}$) and diffuse irradiance ($E_{e,diff}$) make up the global irradiance on a horizontal surface of the planet. $E_{e,refl}$, the component that is reflected from the ground, is an additional irradiance component on a slanted plane. About 20% of the total irradiance is reflected by the ground on average. As a result, there are three parts to the irradiance E_e on a slanted plane.

$$E_e = E_{e,dir} + E_{e,diff} + E_{e,refl} \quad (22)$$

$$I_{sc}(G) = I_{sc(standard)} \frac{G}{G_{standard}} \quad (23)$$

where $G_{standard}$ is the irradiance value in peak hour, which is 1000 watts/m². Short circuit current I_{sc} increase from 3.2 Ampere to 4 Ampere as G varies from 800 watts/m² to 1000 watts/m². The value of open circuit voltage V_{oc} also increase with different value of G . The value of power increase with increase in irradiance levels [16]. For each irradiance level, we can achieve a certain amount of power, but as the power depends upon the irradiance, so as shown in the figure (3.1) the maximum power is harvested for irradiance of 1000 watts/m².

Here, $G_{standard}$ represents the peak irradiance value of a solar day, which is 1000 watts/m². As the irradiance G increases from 800 watts/m² to 1000 watts/m², the short-circuit current I_{sc} increases from 3.2 A to 4 A. Similarly, the open-circuit voltage V_{oc} also rises with varying irradiance levels. Power output increases as irradiance levels rise. According to Figure 3.1, the highest power is achieved under irradiance of 1000 watts/m², the highest power generation value found in the literature) [19].

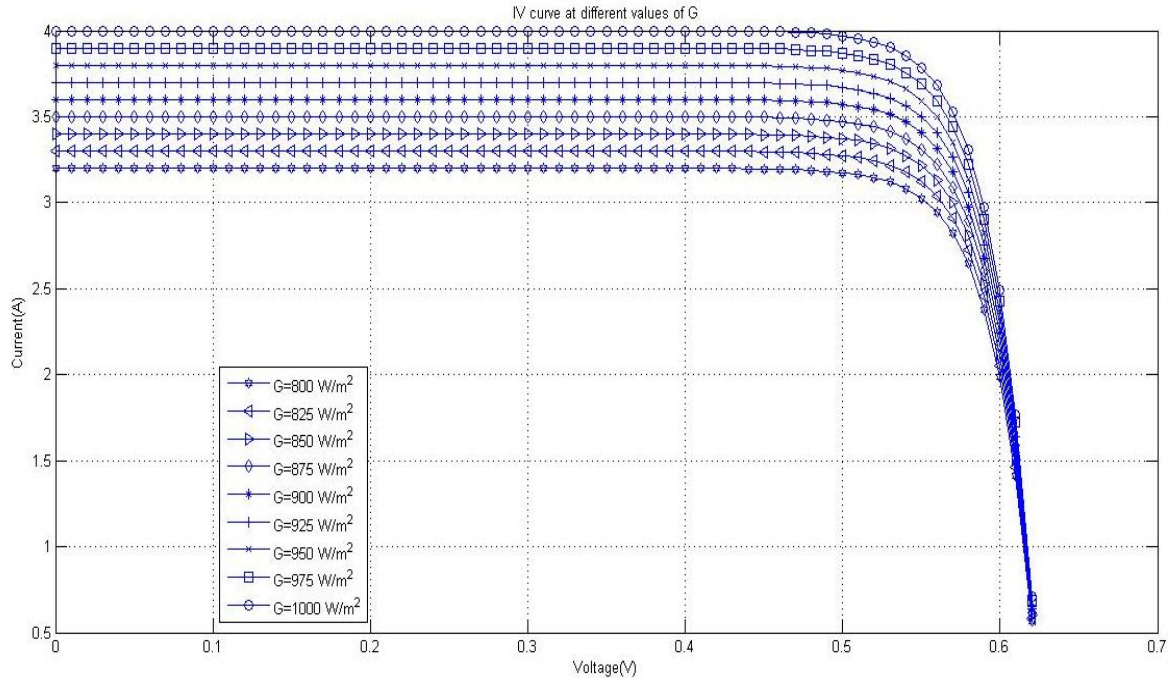


Figure 3.1: IV Curves at Different value of G

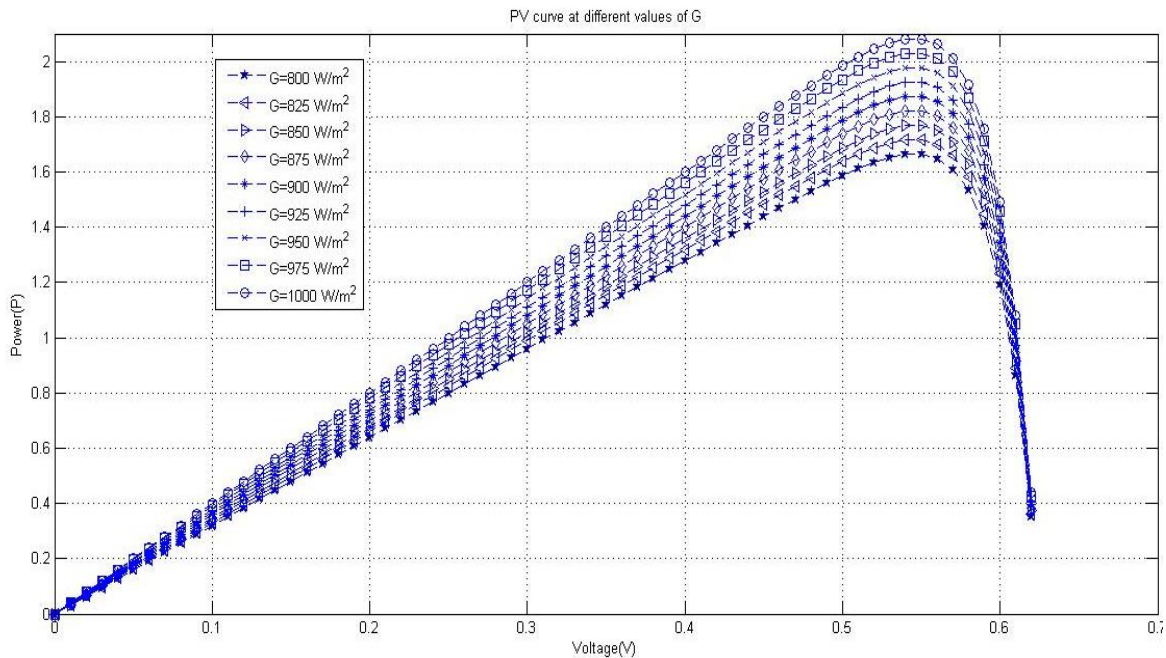


Figure 3.2: PV Curves at Different value of G

As the sun moves closer to its zenith, the amount of irradiance rises. The amount of irradiance is lower in the morning and continues to climb as the sun rises higher. The irradiance level keeps rising until about 12:00 p.m., at which point it achieves its maximum value, which is equivalent to a standard value [17]. The irradiance level begins to decline around 12:00 p.m. and

reaches a very low level as the day goes on. The maximum power, which rises as the irradiance level does, may be used to determine this.

A node is consisting of solar energy harvesting device [19, 21], battery and decision device which can be MPPT as shown in figure 3.3 given below.

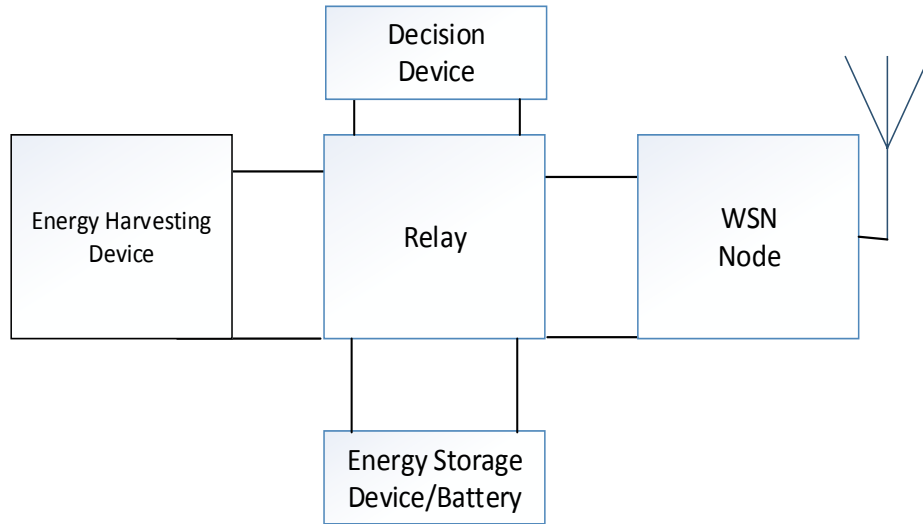


Figure 3.3: Node Block Diagram

In Figure 3.4 Deploy the 250 nodes randomly in space

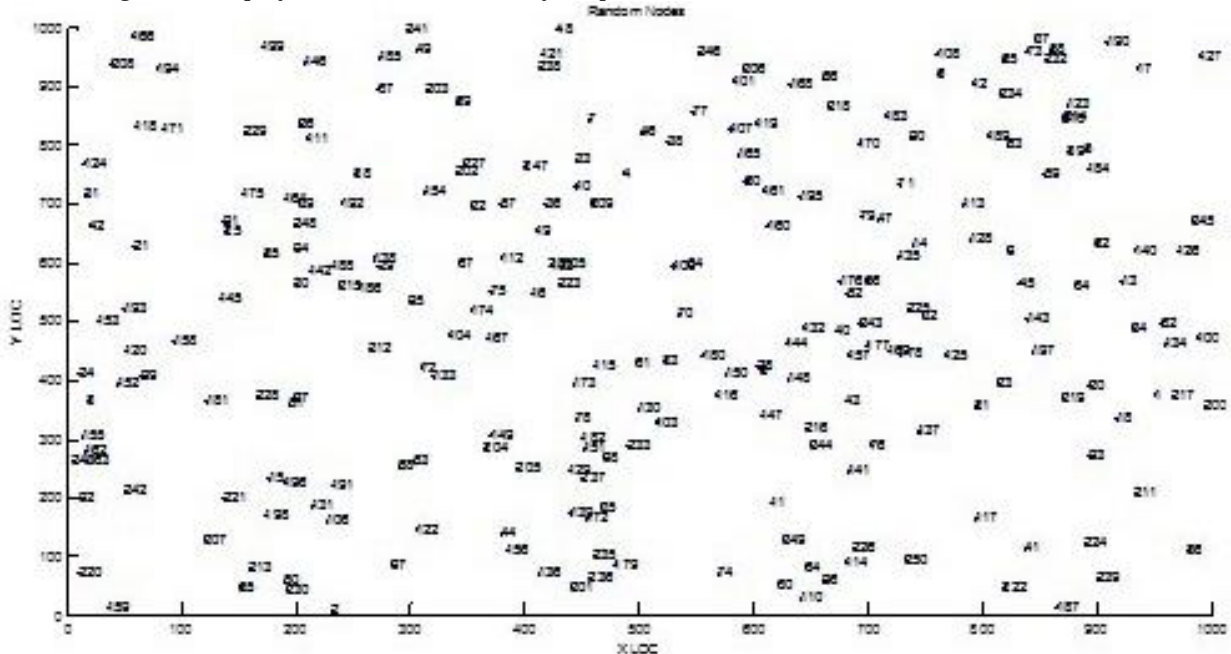


Figure 3.4: Random Nodes

In this proposed study, attached the battery with node and then make a path with greater energy of battery power. Now attached the solar energy harvesting device, and find the path where greater received. Between 00:00 a.m. and 8:00 a.m., irradiance levels are lower and results in decreased battery power. This is due to the battery regenerating energy to the load whilst concurrently generating energy from the solar source (but the energy produced is limited by the lower irradiance level) (i.e., incident irradiation on degrees of freedom of an electric circuit), as well.

Harvested energy at this stage is less than transceiver threshold value to send the data [23]. This scenario is same as the first condition discussed section 3.1.1, so as we have smaller amount of harvesting energy therefore, battery power is used for transmission of data. Irradiance level increase continually till about noon 12 o'clock, that's "when the irradiance level reaches its peak. The harvested energy as depending upon the irradiance level will also increase, greater than transceiver threshold value. As second condition is satisfied, the harvested energy will be used for the transmission of the data and the remaining energy will be

used for charging the battery connected. Also after 4 o'clock amount of irradiance decrease and smaller amount of energy received battery power is decrease again first condition is fulfilled [24].

The deployment of nodes leave us with a problem to calculate the distances between them as it is necessary to find the neighboring nodes and to calculate the transmission power required by each node. This is illustrated using a flowchart shown below.

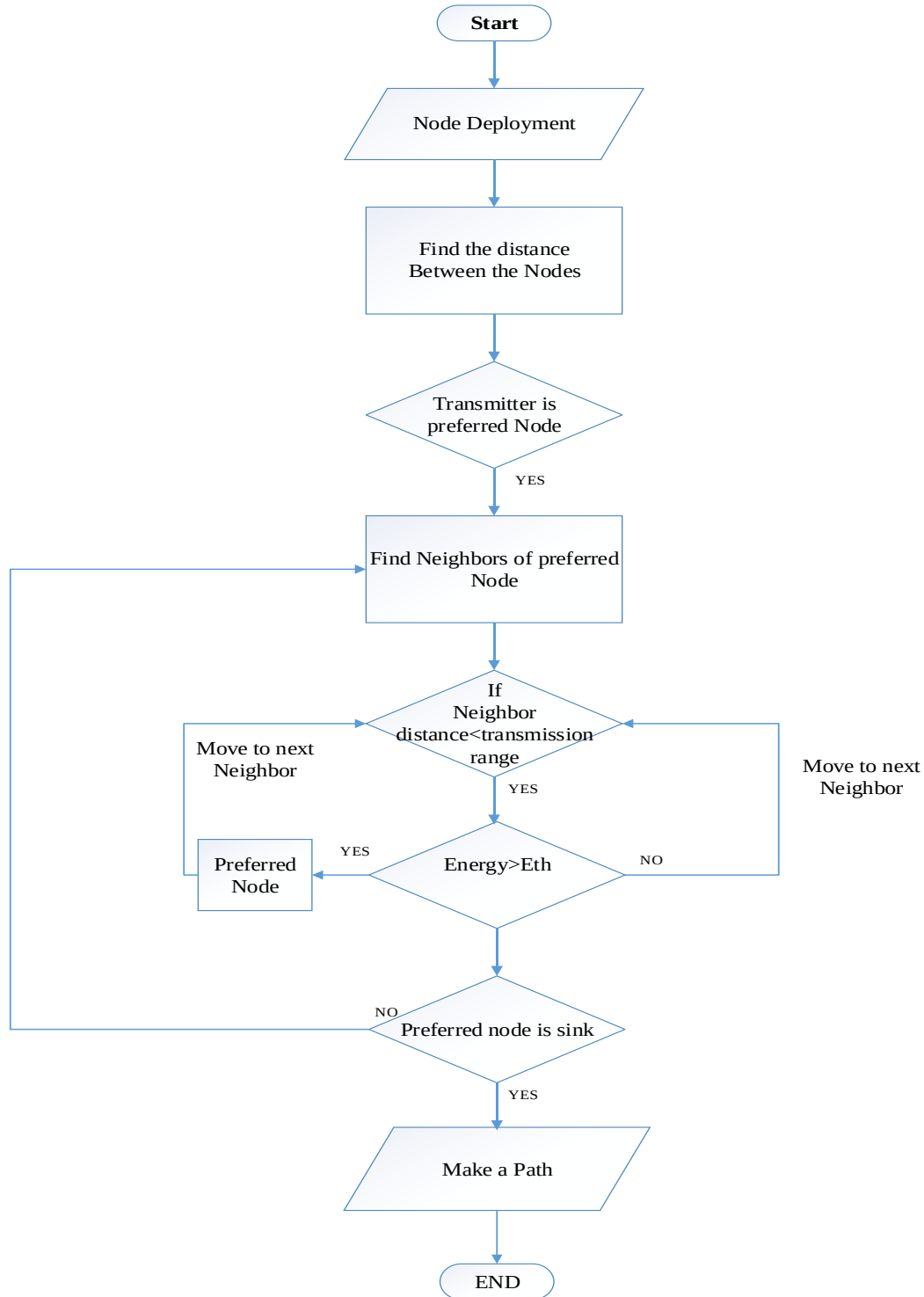


Figure 3.5: Flow Chart

RESULTS

The use of wireless sensor networks [20] is increasing day by day. At same the time it face the major problem of energy constraints in term of limiting battery. As each node depends on energy for its activities, this has become a major issue in WSN.

Figure 4.1 Different irradiance levels are displayed by showing various PV Curves. With increasing irradiance values, the power generation value increases in turn. For each irradiance level, we optimize

maximum power at $G = 1000 \text{ Watts/m}^2$ that will be greater from other gains.

In Figure 4.2, A solar day's duration is shown against the irradiance. As the Sun moves closer to its zenith, the amount of irradiance rises. The irradiance level keeps rising until about 12:00 p.m., at which point it achieves its maximum value, which is equivalent to the standard value $G = 1000 \text{ Watts/m}^2$. past 12:00 p.m. As the Sun sets with the passage of the day, the irradiance level decreases to the minimum value.

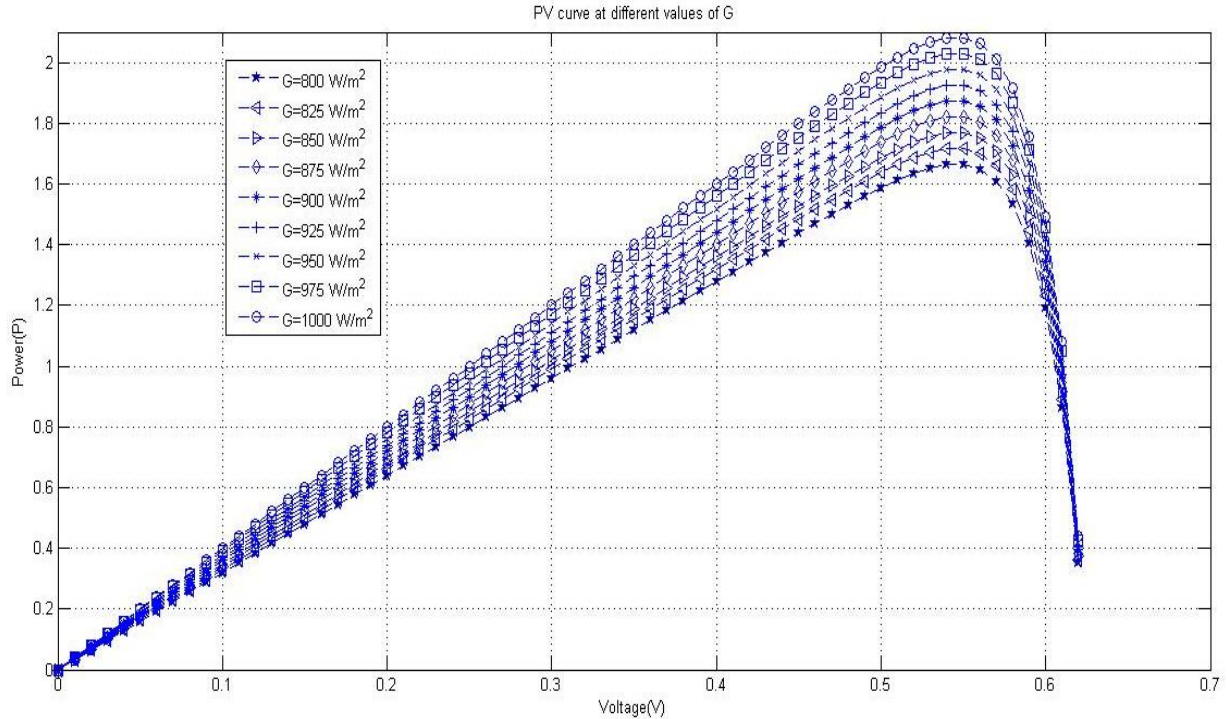


Figure 4.1: PV curve on values of G.

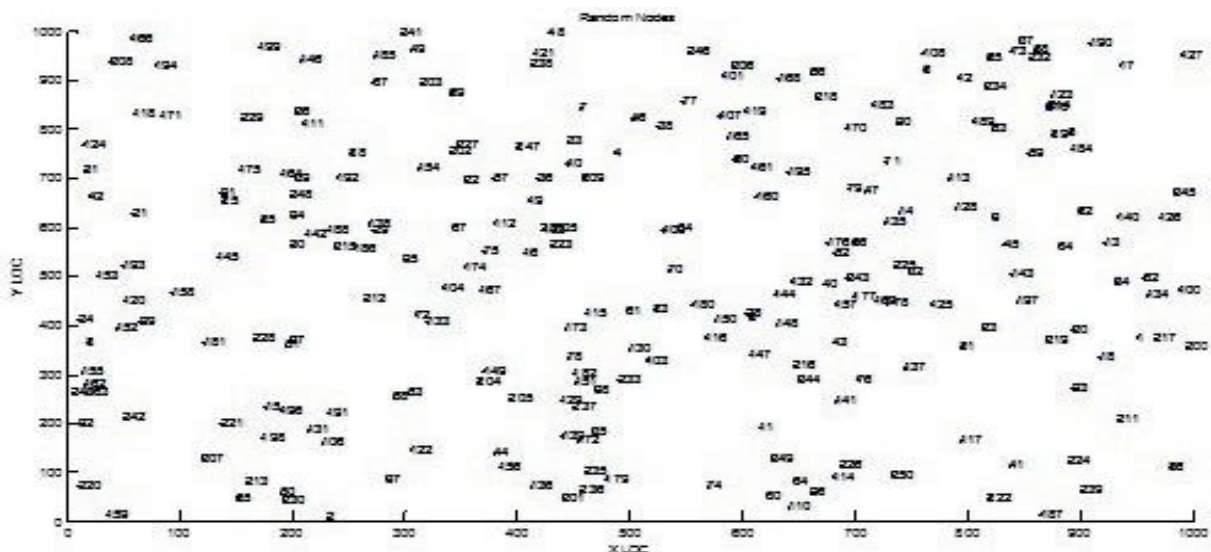


Figure 4.2: Irradiance against time of a solar day

The Figure 4.3 shows the irradiance level throughout a solar day and corresponding maximum current gain. This shows that maximum current is

achieved when the irradiance level reaches its standard value.

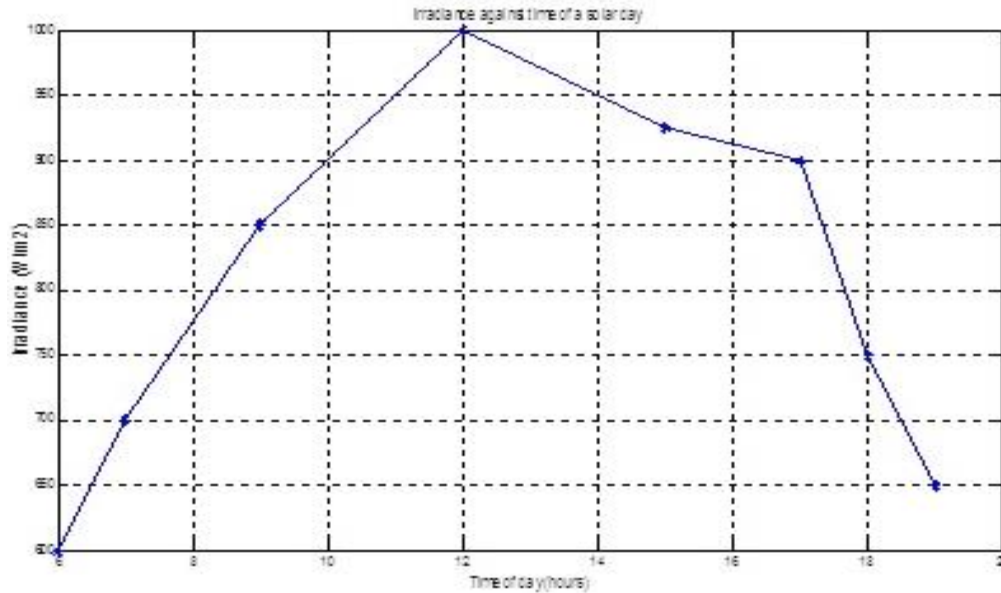


Figure 4.3: Maximum current vs values of G .

The Figure 4.4 displays the SD power levels in relation to the hours of the day. The battery power decreases between 6:00 and 8:00 in the morning since it is used to power the load in addition to gathered energy. The value of gathered electricity grows as the Sun rises, which eventually causes the battery power to climb as well. According to the plots, this power surge lasts until almost 4:00 p.m. At the end of the day, the value reduces again as on Figure 4.4.

The relay switches the node's transceiver to the battery-stored energy when the ambient energy drops below the load's operational voltage and back to the ambient energy when the ambient energy level rises over the threshold. This allows the node to function even in the absence of ambient energy. The technology fixes the connection issue and extends the network's lifespan.

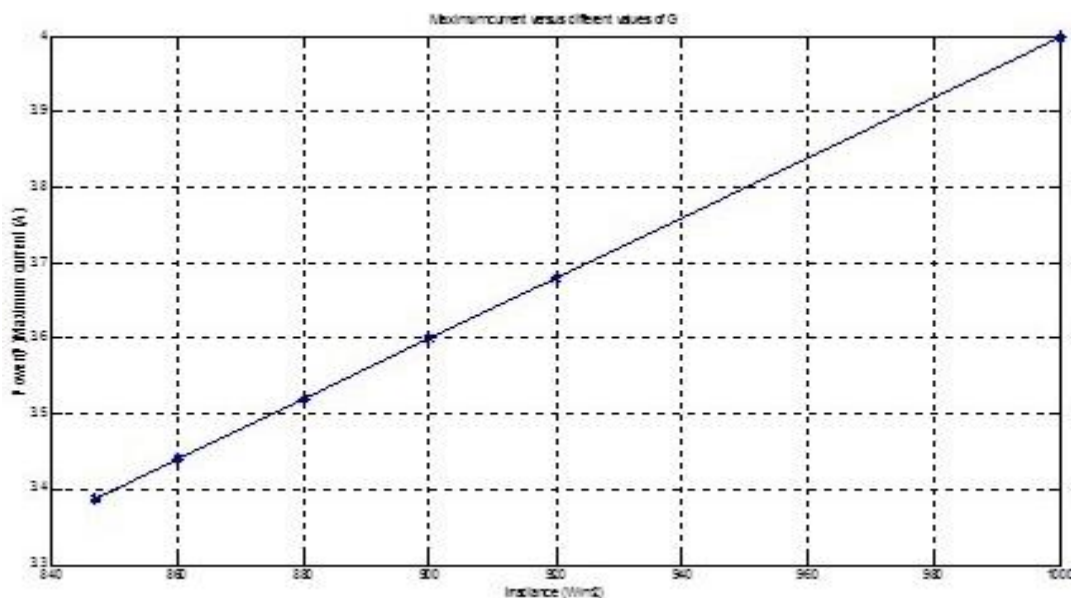


Figure 4.4: Battery Power against Solar Day

In Figure (4.5), 250 nodes are deployed randomly in 1000m – by - 1000m coverage area. There are three nominated lines shown in this figure. Red dashed shortest path from starting node to ending node is optimized by using Dijkstra algorithm [18]. Black dotted line is a modified path of Red dashed shortest path which includes maximum battery power gain. Yellow dotted line is a modified path of Red dashed shortest path which includes harvested energy.

In Figure (4.6), Dead nodes are increasing continuously because such WSN nodes uses only battery power. In case of using harvesting energy, Dead nodes increases till 7am as in battery powering nodes, But after that Dead nodes decreases gradually due to have solar harvesting energy till 8pm. Then after 8pm, it starts increasing gradually.

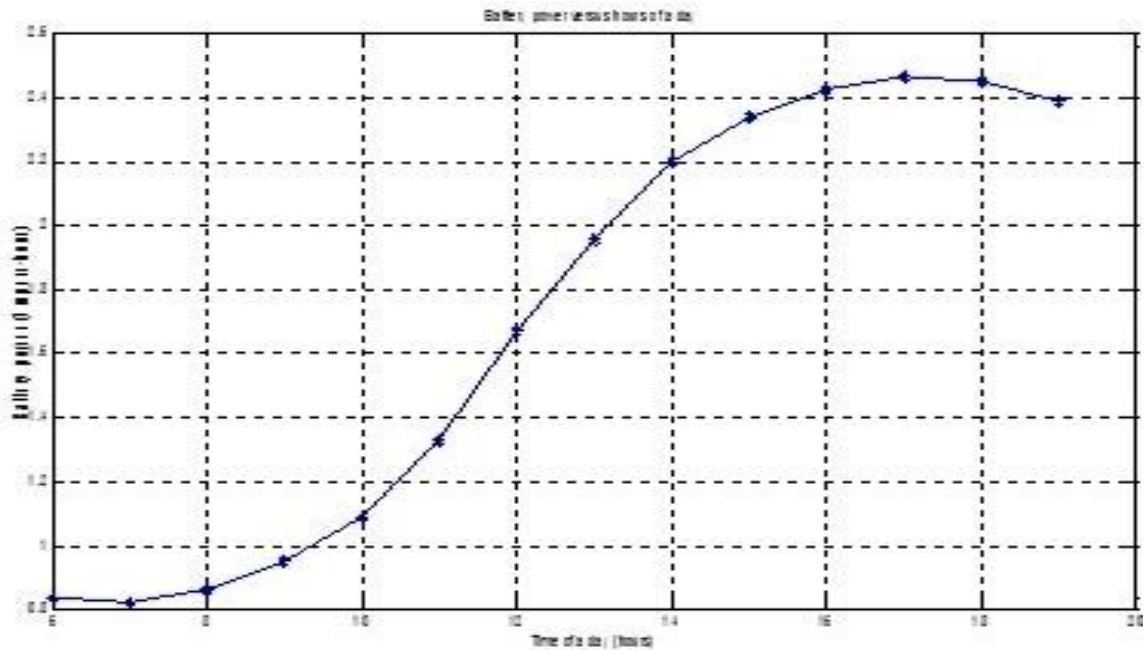


Figure 4.5 Random Nodes

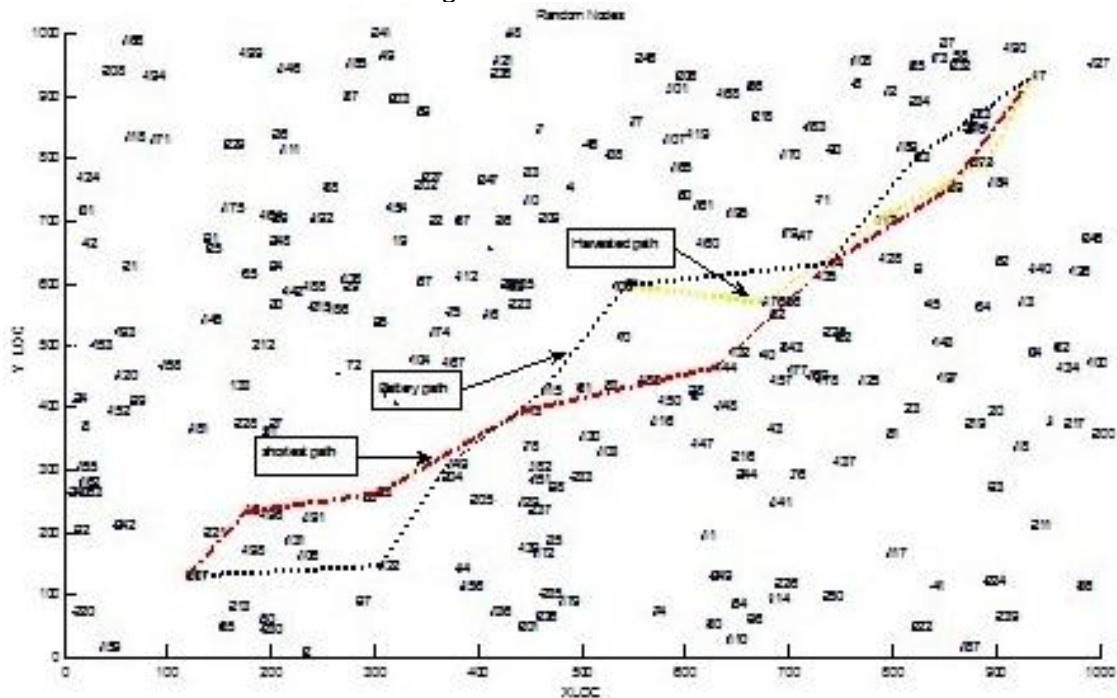


Figure 4.6: Network Life

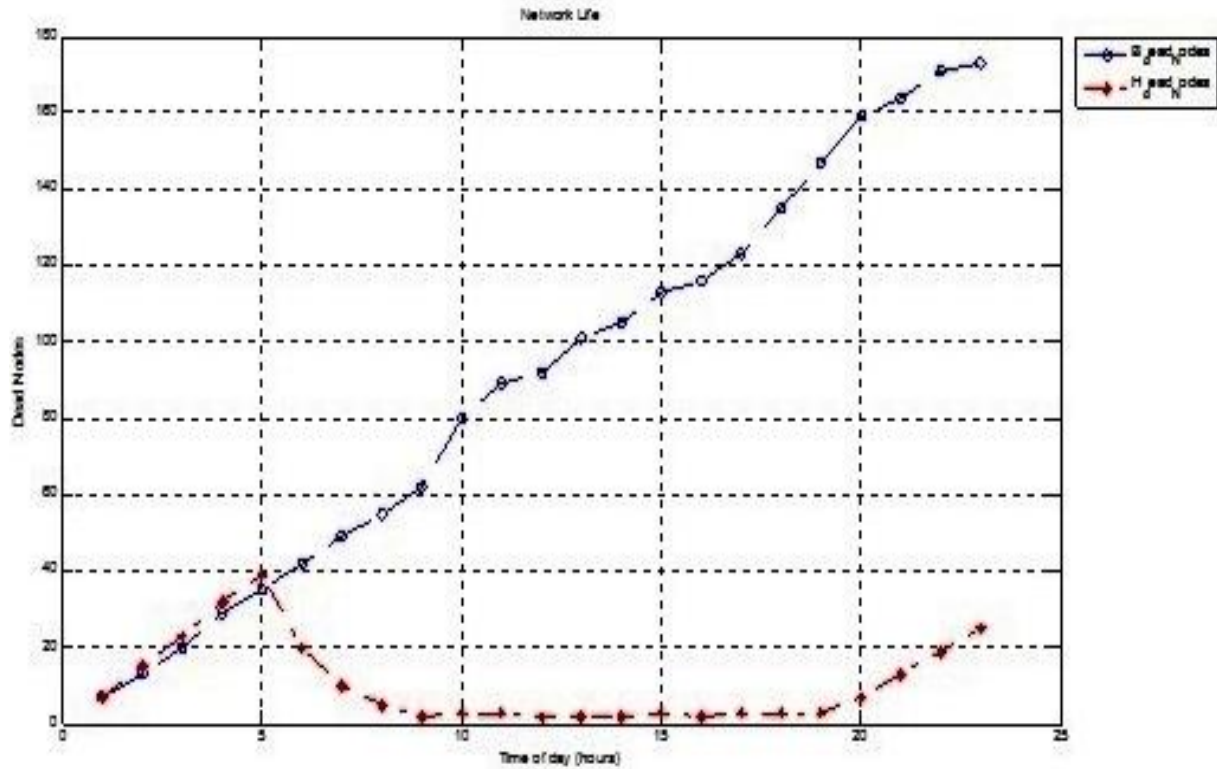
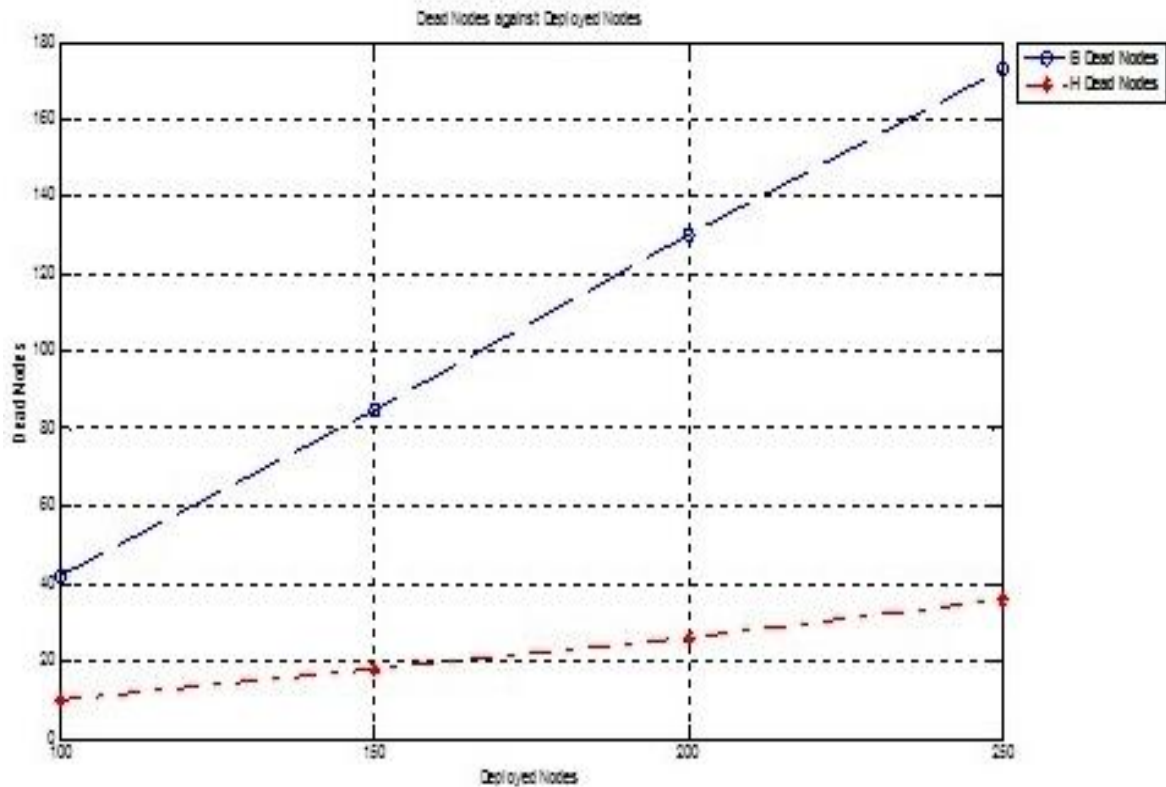


Figure 4.7: Dead Nodes against no of Nodes

In figure 4.7, as the deploying nodes increases, the dead nodes also increases with the deploying nodes.



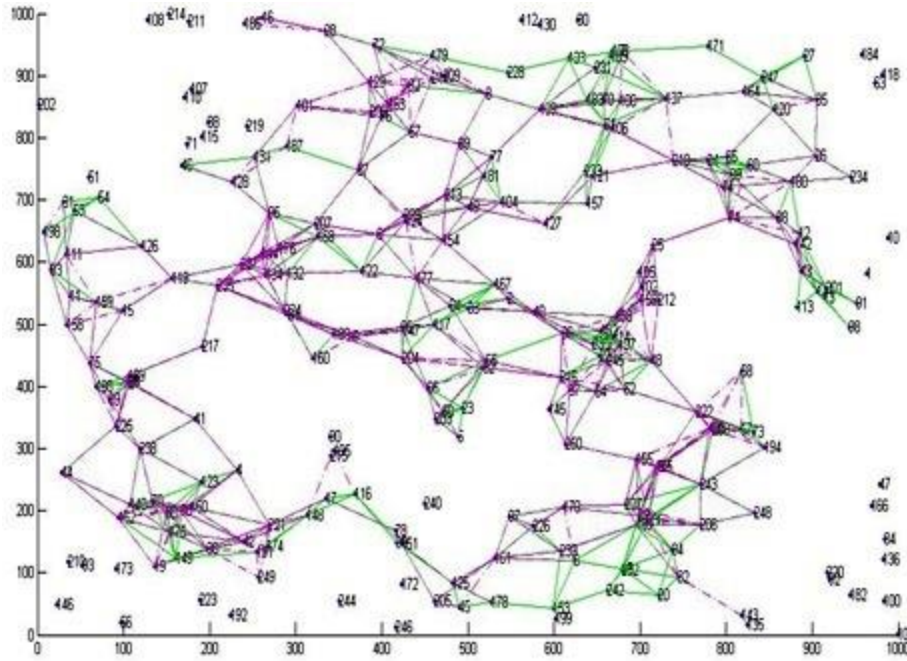


Figure 4.8: Transmission Paths

In figure 4.8 represent the all harvested and battery paths after transmission of packet.

Conclusion: This research use the energy harvesting technique to control the dead nodes. A node will be dead if its battery cannot provide the desired transmission power. The solution to this problem is energy harvesting. Since solar energy holds a lot of promise mainly in respect to reliability, cost-effectiveness, ease of distribution, and effortless integration with existing electrical grids, it is efficient. Thus, an energy harvesting model coupled with an energy management system is proposed in this study. The ad-hoc network with WSN is simulated in Matlab. Behavior of IV and PV curve increases with increase of irradiance level. The characteristics of network life show that dead nodes are increasing continuously because such WSN nodes uses only battery power. In case of using harvesting energy, dead nodes increase 6am to 8am, But after 8am. Dead nodes decreases gradually due to have solar harvesting energy. The proposed model is geared towards efficient management such that sustainability of network performance through time is assured. It also guarantees reliable connectivity and extended lifespan of the network.

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