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Green IoT Based on Tropical Weather: The Impact of Energy Harvesting in Wireless Sensor Network

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ABSTRACT

Wireless Sensor Networks (WSNs) are a key component of Green IoT, as they play a critical role in many applications. However, a major challenge faced by WSNs is their limited energy capacity, which can impede their effectiveness. To address this issue, energy harvesting techniques are used to harness ambient energy and power the nodes, eliminating the need for frequent battery replacements or recharging. This study proposes a solar energy harvesting technique to prolong the lifespan of each wireless sensor node in a network. The aim of the research is to assess the impact of energy harvesting on wireless sensor networks with a focus on solar ambient light energy, as it is a critical component of achieving a Green Internet of Things (IoT). The study is adapted to the tropical weather of Malaysia and its forecasted conditions. Through the use of NetSim simulations, the energy efficiency and reliability of the network are evaluated using solar energy harvesting. The recharge rate for energy harvesting in a wireless sensor network is calculated to be 2.34W per day using a 55x70mm solar photovoltaic panel based on Malaysia weather forecasts and sun hours. This proposed method is successfully executed using NetSim, which utilizes real device parameters for a WSN in a simulated agriculture environment. The results show an overall improvement of 22.4 percent in performance parameters in all areas, including energy consumption, network layer, routing performance, and IEEE 802.15.4 metrics, representing a significant improvement. With the implementation of solar energy harvesting, traditional energy of WSNs can benefit from developing smart agricultural monitoring systems. This efficient method and calculation for solar energy harvesting can help to sustain the infinite lifetime of WSN by optimizing the operational time to 18% of the duty cycle. Results demonstrate that the proposed method can effectively increase the energy efficiency and reliability of the network, making it a promising solution for WSNs operating in tropical regions. This research contributes to the development of sustainable and energy-efficient WSNs, promoting the Green IoT concept.

Keywords:
Green IoT; energy harvesting; wireless sensor network

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1. Introduction

Green Internet of Things (IoT) is a concept that combines the principles of sustainability and environmental responsibility with the deployment of IoT technology. It utilizes IoT devices, sensors, and related technologies to reduce the negative impact of human activities on the environment and promote sustainability [1-4]. Green IoT can be found in various domains, including agriculture, transportation, energy, water management, and waste management [5]. In transportation, IoT-enabled vehicles can optimize routes and reduce fuel consumption [6]. Smart grids can apply to manage energy consumption and optimize the use of renewable energy sources [5,6]. Thus, Green IoT has the potential to adapt for more sustainable and efficient use of resources, reducing waste and emissions.

Wireless Sensor Networks (WSNs) have become growly popular due to their capability to provide real-time data acquisition and monitoring of various physical parameters. WSNs have been applied in various domains, such as healthcare, agriculture, and environment monitoring [7-10]. There are several challenges faced by WSNs, and significant challenge can vary depending on the specific application or context such as energy efficiency, scalability, security, data management and fault tolerance. However, the fundamental limitations of these networks stem from their energy constraints, which can result in the frequent need for battery replacements or recharging [11,12]. As a consequence, maintenance costs and environmental waste can also increase. To address this issue, energy harvesting techniques have been proposed to power the nodes using ambient energy. The integration of energy harvesting and wireless sensor networks (WSNs) is well-aligned with the principles of Green IoT as it promotes efficient resource management and sustainability.

Numerous studies have focused on the integration of WSNs and energy harvesting for Green IoT applications. For example, a study proposed a hybrid energy harvesting system for WSNs using solar and kinetic energy sources, achieving better energy efficiency, and reducing the network's carbon footprint [13-15]. Another study proposed a WSN-based monitoring system for precision agriculture, which used solar energy harvesting to power the nodes and optimize water usage, reducing the environmental impact and increasing crop yields. The integration of WSNs and energy harvesting has shown promising results in various domains, contributing to the development of sustainable and energy-efficient systems for Green IoT.

This research aims to investigate the impact of energy harvesting on the WSN to achieve Green IoT by increasing the battery capability and lifetime. The focus is on reviewing the recent literature on energy harvesting for wireless sensor networks, especially solar ambient light energy, and proposing a method for solar energy harvesting to enhance the battery capability lifetime of Wireless Sensor Network [16]. NETSIM is used to simulate an agriculture environment to implement the proposed method for Wireless Sensor Network. The study investigates how energy harvesting could impact the wireless sensor network lifetime and longevity of the wireless sensor node with energy harvesting and without energy harvesting. The contributions of this research can increase the longevity of each node in a WSNs environment. By reusing or recharging the battery of a wireless sensor, the cost of battery replacement can be lowered, and the long-term sustainability of Green IoT can be achieved. This approach can reduce maintenance costs and environmental waste caused by frequent battery replacements or recharging. The proposed solution could help achieve a more sustainable and efficient use of resources in various domains such as agriculture, transportation, energy, water management, and waste management.

The primary objective of this research is to investigate the impact of solar ambient light energy on wireless sensor networks, which is crucial for achieving a sustainable Green Internet of Things (IoT). The study is focused on the tropical climate of Malaysia, taking into account its unique weather conditions. To evaluate the energy efficiency and reliability of the network, NetSim simulations are employed, utilizing a standard small solar panel for WSNs with dimensions of 55x70 mm. To conduct the simulation, each sensor's initial battery of 1000 mAH is drained.

2. Methodology

The system design for this study is based on the solar energy harvesting (SEH)-WSN model, which is designed for smart agriculture applications. This model is relied on the principle of using solar energy harvesting to power the wireless sensor nodes and enable them to collect environmental data from the sensor nodes in the field. Therefore, the system can provide efficient solution that reduces frequent battery replacements and maintenance costs. Figure 1 illustrates the proposed WSN nodes equipped with solar energy harvesting for smart agricultural monitoring. The system comprises 20 WSN nodes with solar panels, a sink node, a WSN gateway, and a computer for user monitoring.

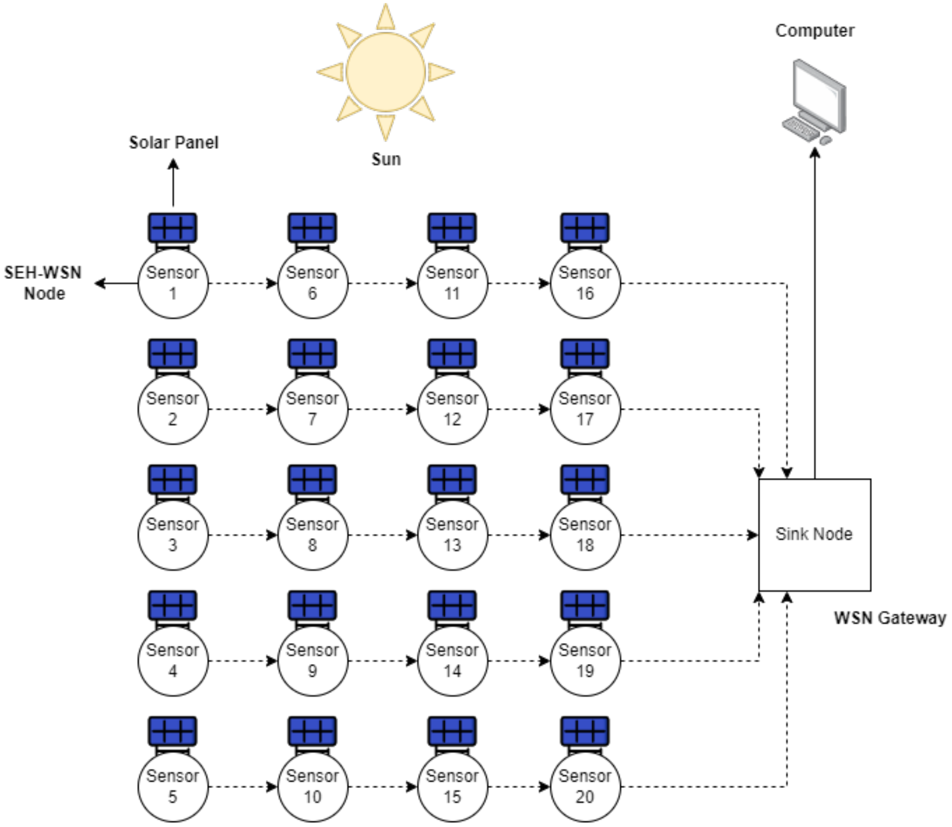


Fig. 1. Proposed WSN nodes with solar energy harvesting for smart agricultural monitoring

The topology arrangement for this study includes 20 wireless sensor nodes, 1 ad hoc link, and 1 sink node, which are essential for conducting the simulation in NetSim as shown in Figure 2. The ad-hoc link is responsible for connecting all the sensor nodes in the network, while the sink node stores all the information and data collected by the sensor nodes. Each sensor node has been equipped with an application that transfers the data to the sink node, enabling the data to be accurate collected, effectively gathered, and analysed.

Fig. 2. WSN Topology arrangement in NetSim

The operation of environmental data collection begins with the sensors send the collected data such as humidity and temperature to the sink node, enabling remote monitoring of the agricultural conditions. The system will also include the control of relay switches or motor pumps to manage the agricultural process from time to time. To determine the fixed parameters for the topology and testing of the system, parameters such as "Transmitting Current," "Idle Mode Current," "Receiving Current," and "Sleep Mode Current" are referenced from Kamalinejad *et al.,* [16], Zonouz *et al.,* [17], and NetSim [18], as shown in Table 1.

Table 1
Simulation parameters

Performance parameters	Values
No. of Sensor Nodes	20
No. of Sink Node	1
Physical and MAC Layer	IEEE 802.15.4
Network Layer Protocol	DSR
Initial battery (mAH)	1000
Transmitting Current (mA)	17.4
Idle Mode Current (mA)	0.02
Receiving Current (mA)	19.7
Voltage (V)	3
Sleep Mode Current (mA)	0.015
Mobility model	No mobility
Simulation time (s)	3600
No. of packet generated	3600
Recharging Current (mA) (SEH-WSN)	0.00905625

In this research, a small-sized solar panel with the dimensions of 55x70 mm is used for the WSN. During this investigation, two simulations are carried out: one with energy harvesting enabled, and another with energy harvesting disabled. The simulations are configured with a 100% duty cycle for each operating sensor. In the simulation where energy harvesting is enabled, a recharging current, RR_n of 9.05625 μA is set for each node, which is determined using the Eq. (1) [18].

$$RR_n = (RR_m/V)/SD_s \tag{1}$$

Where V is the voltage, SD_s is simulation duration, and RR_m is the recharge rate based on the number of sun hours per day in Malaysia, as determined by Eq. (2).

$$RR_m = \left(RR_a \times SPV_f\right) \times SH_d \tag{2}$$

Where SPV_f size of the solar photovoltaic panel in square feet, SH_d is the median of average sun hours in Malaysia obtained Figure 3, and RR_a is average recharge rate, as determined by Eq. (3).

$$RR_a = \left(P_o/\,SPV_f\right) \times (1hr/3600\ s) \tag{3}$$

Where P_o is the total power output.

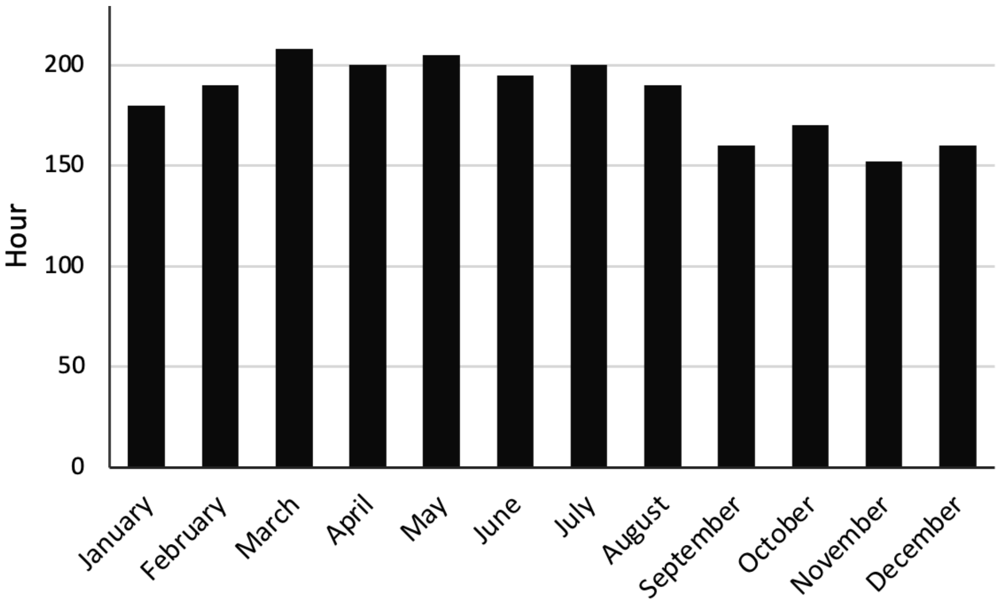


Fig. 3. The monthly total of sun-hours over the year in Kuala Lumpur, Malaysia

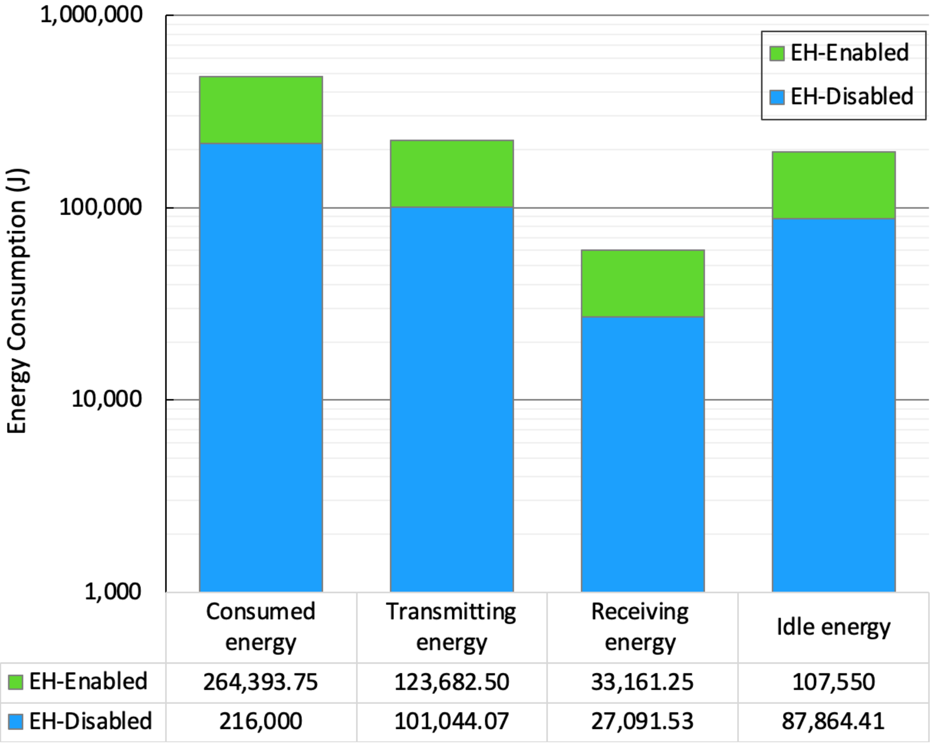
Next section will discuss the performance analysis of the system with energy harvesting enabled versus energy harvesting disabled, considering energy consumption performance, network layer performance, routing performance, and IEEE 802.15.4 metrics performance.

3. Results

The energy harvesting is made possible by a recharging current, RR_n of 9.05625 µA obtained from Eq. (1). The study evaluates the performance of energy consumption, network layer, and routing using dynamic source routing (DSR), as well as relevant IEEE 802.15.4 metrics performance for the physical and medium access control (MAC) layers of wireless sensor networks (WSNs).

3.1 Energy Consumption Performance

The length of the simulation is set to 73,220,339 seconds in order to drain the initial battery of 1000 mAH that is configured in each sensor for this simulation, which translates to approximately 847 days. During the simulation, the sensor nodes are set up with a static route directly to the sink node. When energy harvesting is enabled, the sensors receive more energy, resulting in a higher overall energy consumption compared to the simulation with energy harvesting disabled. The simulations are run with a 100% duty cycle to ensure that the energy is depleted. Figure 4 illustrates the increase in energy consumption from 216,000J to 264,393.75J for the simulation with energy harvesting. The simulation with energy harvesting shows a 22.4% averaged increase in performance for transmitting, receiving, and idle energy.



	Consumed energy	Transmitting energy	Receiving energy	Idle energy
🟩 EH-Enabled	264,393.75	123,682.50	33,161.25	107,550
🟦 EH-Disabled	216,000	101,044.07	27,091.53	87,864.41

Fig. 4. WSN energy consumption parameter results

3.2 Network Layer Performance

To evaluate the network layer performance, the implementation of Energy Harvesting (EH) in sensor nodes results in an increase in all metrics related to network performance. To evaluate the network performance, various parameters are analysed, including the number of data packets transmitted, the number of control packets transmitted, the number of data packets collided, the number of control packets collided, the total number of bytes transmitted, and the number of payloads transmitted. These metrics are used to assess the impact of energy harvesting on network performance.

Figure 5 presents the estimated number of data packets transmitted increased from around 380 million to approximately 465 million, and the number of control packets transmitted rose from around 5.6 billion to approximately 6.8 billion. However, the number of collided data packets and control packets increased from approximately 31 million to about 38 million and from approximately 1 billion to around 1.3 billion, respectively. As previously mentioned, this is expected as more data packets transmitted result in more data packets collisions. Moreover, the total number of bytes transmitted, payloads transmitted, and overheads transmitted all increased by a factor of 22.4 when energy harvesting is enabled.

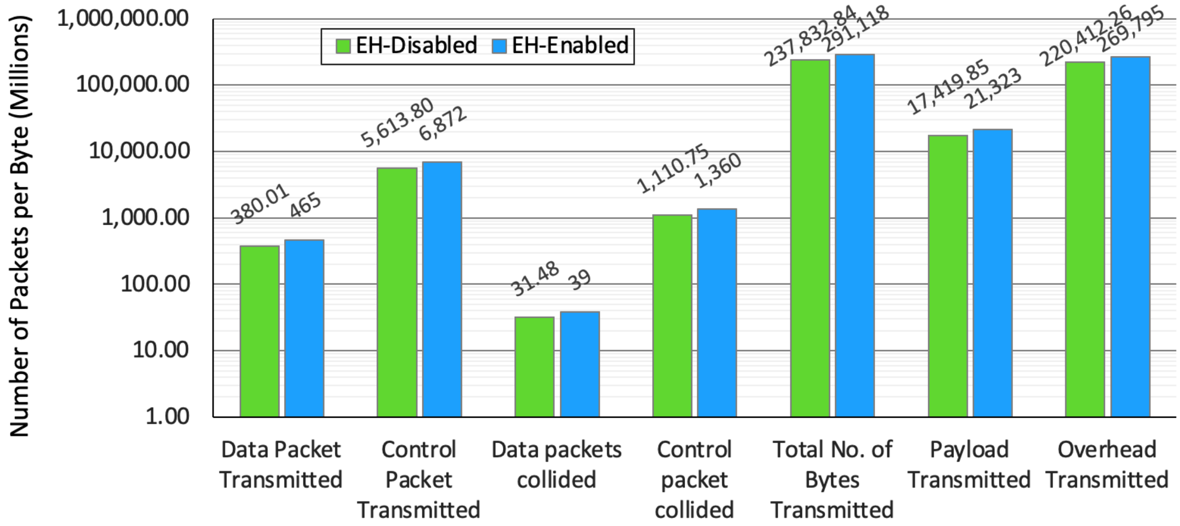


Fig. 5. Results of network layer performance parameters

3.3 Routing Performance

In a wireless sensor network (WSN), when a source node needs to transmit a message to a destination node that is not within its routing, it broadcasts a Route Request (RREQ) to the entire network. This allows the network to determine the most efficient path for transmitting the message. Once the destination node receives the RREQ, it sends a response message back to the source node, known as the Route Reply (RREP).

The total number of RREQ, RREP, RRER, route break, packet originated, packet transmitted, packet received, and packet dropped increases by 22.4 percent with the use of energy harvesting as shown in Figure 6. This increase in the number of packets transmitted and received can impact the packet delivery ratio and end-to-end delay. The number of dropped packets increased due to the higher transmission rate. This is because the 802.15.4 protocol has a built-in mechanism that causes more packets to be dropped as the number of transmitted packets increases.

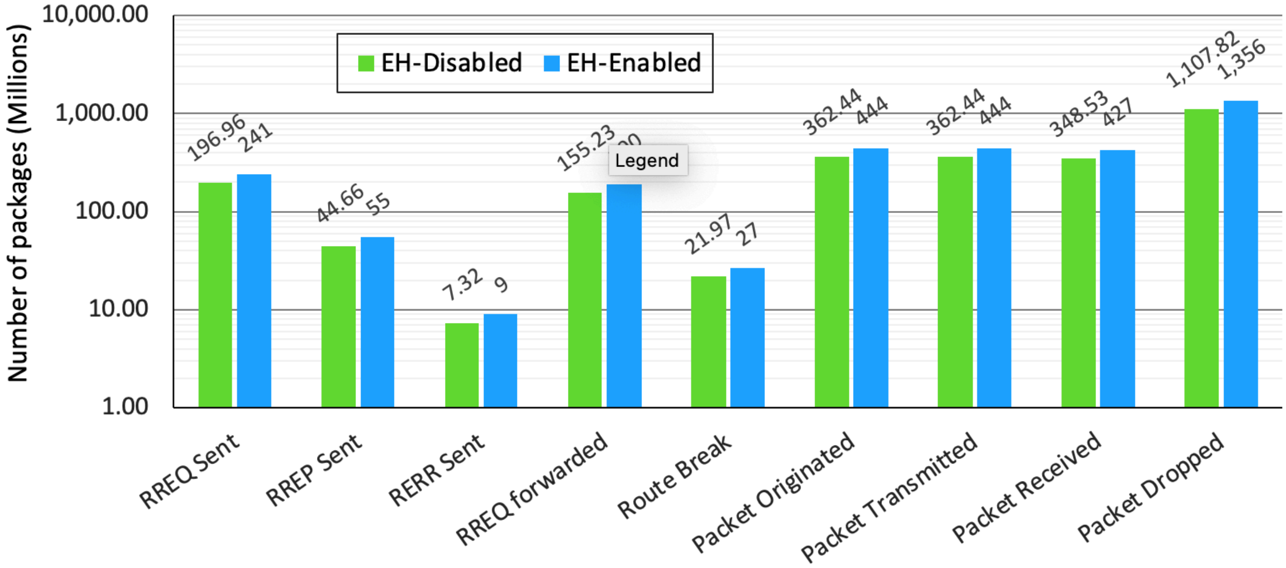


Fig. 6. Routing performance evaluations based on DSR protocol

3.4 IEEE 802.15.4 Metrics Performance

The IEEE 802.15.4 standard outlines the settings for the Physical and Medium Access Control (MAC) layers used in Wireless Sensor Networks (WSNs). The simulation scenario in Figure 2 with 20 SEH-WSN nodes, the performance improvements are summarized and depicted in Figure 7.

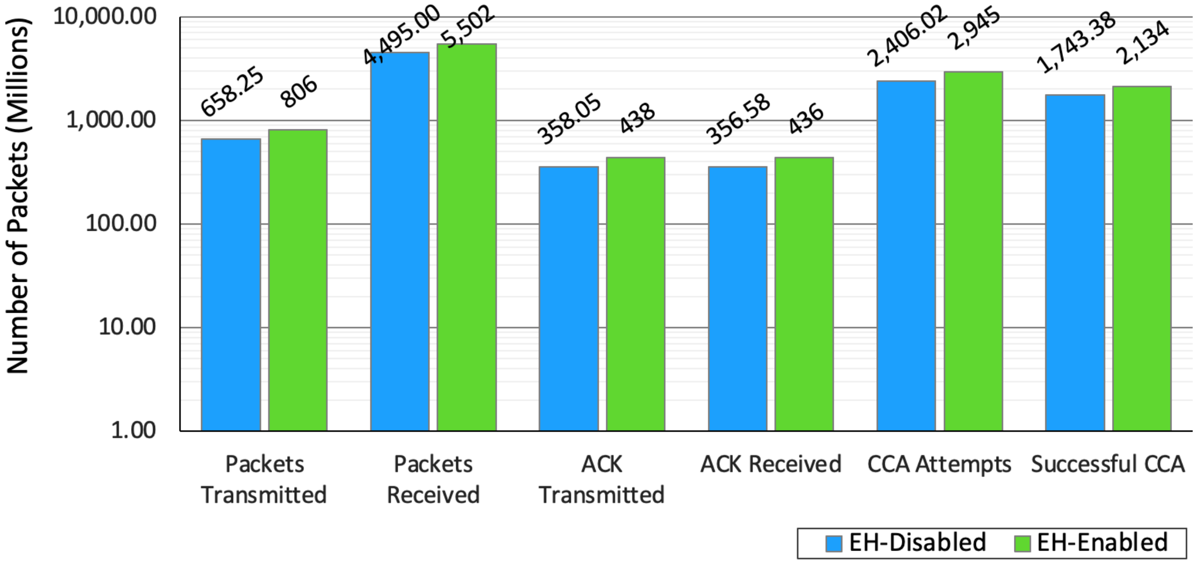


Fig. 7. Evaluation of IEEE 802.15.4 metric performance for 6 parameters

It observes that energy harvesting significant increases in the number of data packets sent and received. The number of acknowledgments (ACKs) receive by neighbour nodes rise from around 356 million packets to 436 million packets with energy harvesting. Furthermore, the number of successful clear channel assessment (CCA) attempts also increase from approximately 1.7 billion packets to 2.1 billion packets. These results indicate a significant improvement in the network's overall performance, which average increase by up to 22.4 percent.

4. Conclusions

One of the most significant challenges encountered by WSNs is their limited energy capacity. In order to address this issue, solar energy harvesting has been proposed as a potential solution for smart agriculture applications. Ambient energy using energy harvesting techniques for WSNs can prolong the lifespan of the sensor nodes in a network. In this context, the calculation of the energy harvesting recharge rate for WSNs based on Malaysian weather forecast is determined using NetSim and a 55x70mm dimension solar photovoltaic panel. The results showed an overall improvement of 22.4 percent in various performance parameters, including energy consumption, network layer, routing performance, IEEE 802.15.4 metrics, and network lifetime analysis with a 100% duty cycle. This highlights the effectiveness of energy harvesting techniques in enhancing the performance of WSNs and extending their lifespan.

Therefore, incorporating energy harvesting can greatly improve their performance, as demonstrated by the increase in various performance metrics. However, the increase of packet collisions and dropped packets may be due to the IEEE 802.15.4 protocol. This highlights the potential benefits of energy harvesting in the field of wireless sensor network communication, which could pave the way for future research and development in low voltage systems.

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