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Impact of Nodes on Energy Consumption of IoT Devices

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Abstract

The rapid growth of the Internet of Things (IoT) has raised concerns about energy consumption in IoT devices, significantly influenced by the number of network nodes. This research investigates the impact of nodes contributing to the highest and lowest energy consumption of IoT devices and analyze energy consumption based on battery model in IoT devices. A simulation model is created using Network Simulator Tool (NetSim) with four types of lithium-ion batteries and 3 nodes configuration: 5, 10 and 15 nodes. Results show that, for a 5-node setup with a 3000mAh 3.7V design, the lowest energy consumption value is 2.6634 kJ and the highest remaining energy value is 93.33% occur after 12 hours. For 10 nodes, energy consumption is 5.3497kJ with remaining energy is 86.61%. While for 15 nodes, the highest energy consumption is 8.0542kJ and the remaining energy is 79.84%. The study concludes that more nodes lead to higher energy consumption due to increased computing load, network traffic, and resource utilization. It is also highlighting that prolonged activation of nodes leads to higher batter consumption, emphasizing the need for efficient power management in IoT devices.

1. Introduction

Energy is the ability to perform work in physics. It may exist in different forms, including potential, kinetic, thermal, electrical, chemical, radioactive, and others. The use of goods and services in an economy, or the volume of products and services utilised, is referred to as consumption. The term "energy consumption" refers to all energy consumed to carry out an action, create something, or just occupy a space. Energy needs are not always met by a single energy source. The example of energy consumption that can be seen is in the household. Energy use in a home comprises the use of electricity, gas, water, and any other fuel required to maintain a comfortable standard of living [1-2]. IoT devices, which include the numerous devices on the internet of things, are nonstandard computing devices that may connect wirelessly to a network and transmit data [3]. An IoT deployment typically includes embedded devices (sensors), communication over an IP network (between the devices and to/from cloud servers), cloud services, big data. IoT devices can be watched over and managed from a distance. The examples of IoT devices are smart mobiles, smart refrigerators, smartwatches, smart fire alarms, smart door locks, smart bicycles, medical sensors, fitness tracker and smart security system.

Every IoT devices have different power requirement which they use different type of batteries depending on the complexity of the device. A basic sensor node will only need a little amount of current and can run on an AA battery or even a coin cell with an output voltage of 3V. However, an IOT gadget that needs to power a motor will require more. It will need a battery with a maximum current output of 2 Amperes [4-5]. There are many factors that affects the consumption of energy in IoT devices. Nowadays, sensors are widely used in various field such as in homes, feeding rising service demands and service appetites. Therefore, there are a few factors that can be listed out which that has been contributing to the energy consumption of the nodes after the analyzation of data such as device functionality, data transmission, processor power, display size and brightness, power management, network connectivity and battery capacity. Different IoT systems contribute to the different types of factors. For smart home system, IoT devices are commonly used for automating and controlling varieties of home systems such as lighting, heating, and security meanwhile for industrial application, IoT device is used in manufacturing and industrial processes to help boost productivity, keep an eye on performance and reliability, and improve supply chain management [4-5].

Energy consumption is very important to be monitored as it can help an organization to minimize their spending on the energy. It can also help to reduce the risk to the emission of carbon and help to ease the process of controlling the energy consumption. However, there are a few problems encountered when researching about the investigation of energy consumption. Firstly, lack of energy consumption investigation based on battery model specifically using simulator tools. Most researchers used actual equipment to investigate the energy consumption of IoT devices. By doing so, it consumes a lot of energy and uses a lot of devices that contribute to high costing to make it work [6-7]. Next, some of the IoT systems are connected to a lot of nodes. This project is proposed with the idea of proving that when the more nodes for the IoT devices used, more energy will be consumed. In terms of technology, the increase in energy consumption is affected by the increasing number of sensors due the high number devices that are connected to the internet. Since there are so many nodes connected to one IoT device, it is difficult to find out which of the nodes contribute to the most and least to the consumption of energy on the battery. Therefore, this research will investigate the impact of nodes in energy consumption [4]. Lastly, lack of testing on the performance of energy consumption of battery models in IoT devices. The lack of testing could cause many things to happen such as short battery life, inefficient use of resources, unhappy customers, safety issues and ecological effect. An IoT device using more energy than necessary might lead to inefficient resource utilization and higher expenditures. A gadget with excessive energy use can contribute to environmental degradation by raising greenhouse gas emissions and depleting natural resources. This conclude that testing on the performance of energy consumption of battery models in IoT devices is necessary [4],[8].

The objectives of this research are firstly to design the structure of battery model in IoT applications for measuring the energy consumption using simulation tool by setting the parameters which are voltage, current and power. Next, to investigate the impact of nodes that contribute to the highest and lowest of energy consumption in IoT devices and lastly to analyze the performance of energy consumption based on battery model in IoT devices.

To analyze the energy consumed by the IoT devices, this project will be highlighting the energy consumption of IoT devices on the battery and the correlation between the number of nodes used and the energy consumption of the system. The system that is chosen to be used as the investigation material is the smart home system. This project will be done using software which is on NetSim IoT simulator with different parameters of power, current and voltage depending on the type of batteries researched. The lithium-ion packet 18650 batteries will be connected to varies range of nodes of the system and the battery level will be monitored until the battery is worn out. The research will continuously be done with different types of batteries and with different number of nodes connected. There were a few limitations encountered when using the NETSIM software. Firstly, the range of battery capacity values that can be inserted into the software is limited to 3250mAh. Meanwhile, for the voltage, the maximum value that can be used is up to 10V. These limitations restrict the range of battery variations that can be used for the simulation.

In this paper, Section 1 provides an overview of the background of the study, the objectives, the scope of work, and the limitations of the project. Section 2 presents previous work related to the researched topic. Section 3 describes the methods used, including simulation parameters, simulation scenarios, and formulas used to obtain the results. Section 4 displays the results obtained from the simulation and presents the analysis based on those results. Finally, Section 5 presents the conclusion of this study.

2. Literature Review

2.1 IoT devices

The usage of IoT has gained so much recognition in recent years with the multiple of concepts in various fields due to the continuation of the evolvement of the internet that offers aid in intelligence to the humans [4]. IoT stands for Internet of Things and which it can also be called as Internet of objects. It is a technology that makes it convenient for people to access data and information through any items or gadgets, making life easier and more efficient in many ways [9].

IoT also consists of four main layers which are the sensing layer, the network layer, the data processing layer, and the application layer. The sensors in the sensing layer take measurements of the desirable environmental physical, chemical, or biological data. The system layer uses established communication networks such the Internet, LoRa, NB-IoT, or 4G to send the information it has acquired from the sensing layer to any specific information processing system. The data processing layer retains the information gathered by the sensing layer and processes it so that automatic actions can be taken [5]. There was not much data to gather in the past because there were few devices connected to the Internet, such as laptops and mobile phones. With IoT, a variety of previously unconnected objects are now connected to the Internet, including household appliances, medical equipment, agricultural equipment, vehicles, and additionally construction machinery, agricultural machinery, and die casting in manufacturing industries. By utilizing sensing technology, it is also possible to gather a wide range of high-quality data [8].

2.1.1 Cloud Server and Open Channels

The Internet of Things (IOT) is a system of connected sensors, processors, and digital devices that are dispersed around the world over the internet and may interact with one another to share and transmit information using unique identifiers (UIDs) that are assigned to each and every device [10]. IoT devices can be very convenient, helping to manage energy consumption as the data that was collected are all stored in the cloud server. Since the data is all collected and stored, they can be monitored anywhere and at any time whenever the internet is accessible. A virtual server that is hosted on a cloud computing platform is referred to as a cloud server. It offers scalable computing resources like CPU, RAM, and storage that customers can access and utilize as needed. It is delivered over the internet. Compared to conventional physical servers, this kind of server has numerous advantages, including cheaper costs, improved dependability, and greater scalability [18].

The implementation of numerous specialized and generalist IoT solutions is attained by the IoT's popularity. Back in the old days, the information gained was all kept within the company. With the existence of the cloud server and the implementation of it, data can be collected in a huge amount from all kinds of devices, and they can be stored. Cloud server also allows the analyzation of big data. An open-source cloud platform called MCS lite and affordable application development boards called LinkIt 7697 are part of a solution offered by MediaTek Inc. It is more convenient if open source allows the field of the data to be displayed simultaneously. However, MediaTek open-source solution only allows one data to be conveyed at a time [9],[11]. An example of the application of cloud server is that it can be used to monitor the battery health conditions and optimal battery power management [12].

In order to deliver the to the data to the cloud server, an open channel is necessary in the system. An open channel is a communication line that enables two entities to share data or information. This can be a logical connection or a physical connection (such a cable or wireless link) (such as a software-defined network or network protocol). Open channels are made to be transparent, which means they don't change or tamper with the data being conveyed, enabling an impartial exchange of information. In other words, an open channel is necessary for a cloud server to operate properly since it allows data to be transferred to and from the server [11]. A society that employs IoT uses vast volumes of data, therefore connections that cross borders between industries can be expected. In the past, there was a propensity to use dedicated lines that could only be utilized within firms and were not connected to other fields or enterprises [18].

2.1.2 Wireless Sensor Network (WSN)

WSNs can be categorized as a group of sensor nodes tasked with detecting a paranormal event that occurs naturally and reporting their results to a sink node on the opposite side of the network. The foundation of IoT is wireless sensor networks. Wireless sensor networks could be used to encourage the increase of lifespan of the network. The majority of wireless sensor applications are battery-based and have a lifetime limit imposed by the battery's power or capacity. As a result, the wireless sensor's battery cannot be changed while the network is active or while processing data [13].

On the basis of constrained resources, wireless sensor networks (WSNs) offer application-specific networking strategies. Due to these factors, WSN-based routing algorithms can be created for applications in a variety of ways. The advancement of wireless communication technology has altered lifestyles and given people the chance to monitor the intense environment. A WSN is made up of numerous fast wireless detector nodes that are effective at gathering, storing, transforming, and transmitting information about the environment to other nodes. The sensors are the first cable-connected for specific communication. The recent advancement of ad hoc networking technologies has made it possible for the advanced small sensors to communicate across wireless links in a more relaxed manner [14].

Even if two separate WSN applications coexist in the same network (for example, target tracking and temperature monitoring), each application may utilize a different routing strategy while simultaneously operating on the same sensor nodes and network. However, until both algorithms can run simultaneously, the sensor nodes can effectively use their limited resources (such as battery power) [15]. The development of WSNs has made it feasible to multiply the number of sensing nodes, expanding the scope of the conventional system. Since the acquisition frequency should be as often as one per hour, the needed computing effort is relatively low. One of the network topologies in Wireless Sensor Network is tree (cluster tree). Recent years, Zigbee has been know of its advanced technology for WSN's. Zigbee is a distinctive communication standard that is primarily intended to be used for low-rate wireless personal area networks. Since it facilitates power rescue operations, Zigbee cluster-tree topologies are well-known Zigbee topologies that are particularly ideal for WSN's consuming low strength and sustaining cut rate. Due to insufficient bandwidth usage, the performance of the Zigbee cluster network tends to suffer as traffic volume increases. Depending on how much traffic is required by such a system, the nodes collecting the sensed data are assigned appropriately. When used, network bandwidth is enhanced, which upgrades the network's overall performance [16].

2.1.3 Nodes in Energy Consumption

Energy is associated with sustainable evolution of national economy and society [2]. Due to the evolvement of the internet and high utilization of IoT, it has contributed to the high consumption of energy. At the collection stage of process side, an observation has been made and it can be seen that there is an increase in energy consumption as the sensors increase due to the increasing number of things with sensors connected [18]. Although IoT has successfully managed the energy savings to reach up to 50%, it also has escalated the number of sensors and affect the national grid's power requirements due to their control system [5]. In Bangladesh, the most contributed sector on energy consumption is the domestic sector which has causes the IoT smart meter to be used to track the electricity flow between several smart grid nodes [17]. It is now possible to reliably monitor and control a variety of information and managed applications thanks to wireless sensor networks (WSNs). However, randomly placed low-powered sensors are used to observe the contour, resulting in a dense number of nodes [13].

Each sensor node needs to be capable of effectively harvesting, buffering, and consuming the energy available for this notion to be implemented in a practical way [7]. To appraise the influence of IoT devices to energy consumption, it must be looked in various views. As an example, in a manufacturing plant, the distribution methods and service configuration should not be outlook. The changes of the IoT devices implementation in a field should be looked comprehensively without neglecting minimal changes such as optimizing manufacturing processes and enhancing customer service [18].

Because batteries are lightweight, dependable, and simple to install, they are frequently used in IoT devices. Furthermore, batteries are perfect for IoT devices that must function in remote areas without access to an electrical outlet. Sensors, wearable tech, smart home tech, and many other IoT gadgets utilize batteries. These gadgets frequently use low-power components and enter a low-power mode when not in use in order to save energy consumption and assure long battery life. Given their high-power density, high energy density, minimal maintenance requirements, low self-discharge, and lack of memory effect, lithium-ion (Li-ion) batteries are excellent power sources and energy storage devices. Li-ion batteries have thus become increasingly used in a variety of applications, ranging from mobile electronics to grid-level energy storage systems for solar and wind farms [12].

The working concept of a battery is quite simple in its most basic form. Two electrodes that are individually connected to an electrical circuit and separated by an electrolyte that can hold charged species that make up the cell. The electrodes are frequently separated by a barrier material to prevent the electrodes from coming into direct touch with one another and short circuiting the battery. An oxidation process at the negative electrode results in electrons travelling from the electrode via the circuit when the battery is used to generate electric current in the discharge mode. Similar reduction occurs on the positive electrode (cathode), and electrons from the circuit are used to refill it. The entire process is spontaneous, and the potential difference between the electrodes mostly determines the cell voltage. Rechargeable (secondary) batteries can reverse the process, and external voltage can be used to trigger complementary redox processes at the electrodes. This procedure requires energy and is not spontaneous. A rechargeable battery is simply one that has the ability to charge and discharge under load. This gives it the advantage of being able to be recharged more times than an opposable battery, which must be disposed of once it has been fully charged. Rechargeable batteries exist in a variety of sizes and shapes, from button cells to megawatt systems, and everything is integrated to maintain a reliable electrical supply chain. Electrolytes and electrode materials come in a variety of forms [19].

The application of lithium battery can be seen on electric bicycles. Businesses that rent out batteries and share electric bicycles have an increased need for real-time access to battery information as a result of the growth of the sharing economy. However, the ability to transmit internal data in real-time or to monitor power battery health in real-time is not present in 2019 advanced battery management systems. The Internet of Things and the conventional battery management system can be combined to meet the needs of managing Shared electric bicycle businesses and some battery rental businesses for real-time monitoring of battery information, as well as the needs of operating businesses for man-machine interaction while the equipment is in operation, particularly the needs for battery fault diagnosis and safety protection [20].

The Li-ion batteries suffer from several problems, including increased battery impedance with ageing, which reduces the battery's power density, and shorter battery life due to overvoltage and overheating. The battery's state of charge (SOC) and state of health (SOH) are two critical components. To evaluate the behavior of a battery that has a huge capacitor, the electrical equivalent model of the battery can be created [21].

3. Methodology

3.1 System Development

Fig. 1 shows the process flow of the system. The system starts with the discoveries of the batteries that are used by IoT devices. Then, the battery structure is designed based on the identified parameters. The system then is simulated by using NetSim tool and all the energy consumption of each devices is obtained.

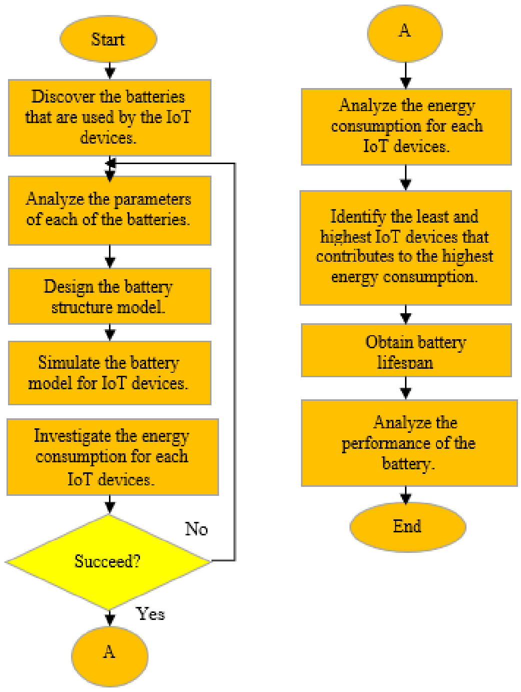

Fig. 1 *Process flow of executing of project study*

3.2 Design of the Battery Structure Mode

The simulations were conducted using four types of lithium-ion 18650 packet batteries. Specifically, the batteries used were 3.7V and 7.4V lithium-ion 18650 packet batteries, each with two different capacities: 1500mAh and 3000mAh. Table 1 present the values employed during the simulations for the 3.7V and 7.4V lithium-ion 18650 pack batteries [13].The battery designs were categorized as follows: Design 1 represents a 3.7V battery with a capacity of 1500mAh, Design 2 corresponds to a 3.7V battery with a capacity of 3000mAh, Design 3 represents a 7.4V battery with a capacity of 1500mAh, and finally, Design 4 is a 7.4V battery with an initial energy of 3000mAh. Despite differences in initial and voltage, all battery structures maintain the same values for transmitting current, idle mode current, receiving current, and sleep mode current, which were set at 8.8mA, 3.3mA, 9.6mA, and 0.237mA, respectively.

The energy consumption for each of the nodes was calculated individually. There were 4 modes of energy that were calculated by the software which are transmit energy, receive energy, idle mode energy and sleep mode energy [13]. Transmit energy refers to the energy consumed by the IoT node when it is actively sending data packets over the network. Receive energy is the energy consumed by the IoT node when it is receiving data from other nodes or the network. Idle mode energy represents the energy consumed by the IoT node when it is powered on but not actively transmitting or receiving data. The node is in a standby state, ready to respond to incoming data or commands. Sleep mode energy is the energy consumed by the IoT node when it is in a low-power state, effectively minimizing energy usage while maintaining the ability to wake up and respond to stimuli.

Table 1 *Structure of battery model*

	Design			
	1	2	3	4
Initial Energy(mAH)	1500	3000	1500	3000
Transmitting Current(mA)	8.8	8.8	8.8	8.8
Idle Mode Current(mA)	3.3	3.3	3.3	3.3
Voltage(V)	3.7	3.7	7.4	7.4
Receiving Current(mA)	9.6	9.6	9.6	9.6
Sleep Mode Current(mA)	0.237	0.237	0.237	0.237

The initial energy represents the total energy capacity of the battery when fully charged, measured in milliampere-hours (mAH). It indicates how long the IoT device can operate before needing a recharge. Devices with higher initial energy capacities can sustain longer operational periods, making them suitable for applications where recharging is not feasible.

Transmit current refers to the amount of current the IoT node draws when it is actively transmitting data over the network, measured in milliamperes (mA). The receive current is the current drawn by the IoT node when it is receiving data from other nodes or the network, measured in milliamperes (mA). The idle mode current represents the current consumed by the IoT device when it is in an idle state, meaning it is powered on but not actively transmitting or receiving data, also measured in milliamperes (mA). The refers to the current consumed by the IoT device when it is in a sleep mode, which is a low-power state designed to conserve energy, measured in milliamperes (mA). Voltage is the potential difference that drives the current through the device's components. It is typically measured in volts (V).

For Transmit energy (for which node transmits packets) as expressed in Eq. (1),

$$\text{Transmit energy} = \text{Transit current} * \text{Voltage} * \text{Time} \tag{1}$$

For Receive energy (for which node receives packets), as expressed in Eq. (2),

$$\text{Receive energy} = \text{Receive current} * \text{Voltage} * \text{Time} \tag{2}$$

For Idle Mode energy (in idle mode), as expressed in Eq. (3),

$$\text{Idle mode energy} = \text{Idle mode current} * \text{Voltage} * \text{Time} \tag{3}$$

For Sleep Mode energy (in sleep mode), as expressed in Eq. (4),

$$\text{Sleep mode energy} = \text{Sleep mode current} * \text{Voltage} * \text{Time} \tag{4}$$

For initial battery energy, as expressed in Eq. (5),

$$\text{Initial battery energy(J)} = \text{initial energy (Ah)} * \text{Voltage} * 3600 \tag{5}$$

For total consumed energy, as expressed in Eq. (6),

$$\text{Total consumed energy(J)} = \text{energy device1} + \text{energy device2} + \text{energy device3} + \ldots\ldots + \text{energy device } n \tag{6}$$

where n is the number of nodes.

For consumed energy, as expressed in Eq. (7),

$$Consumed\ energy(J) = Transmit\ energy + Receive\ energy + Idle\ mode\ energy + Sleep\ mode\ energy \quad (7)$$

For remaining energy, as expressed in Eq. (8),

$$Remaining\ energy(J) = Initial\ energy(J) - Total\ consumed\ energy(J) \quad (8)$$

To estimate the battery lifespan of the system, as expressed in Eq. (9),

$$Battery\ lifespan(h) = \frac{Total\ consumed\ energy + remaining\ energy}{Concumed\ energy\ per\ hour} \quad (9)$$

For Percentage of Remaining Energy, as expressed in Eq. (10),

$$Remaining\ energy\ (\%) = \frac{Initial\ energy - Consumed\ energy}{Initial\ energy} \times 100 \quad (10)$$

3.3 IoT Application Scenario

Figs. 2-4 shows the NetSim topology configuration for the analysis simulation. The simulation is run using three different number of nodes (wireless sensor network) which are 5, 10 and 15. The rationale for choosing these specific node counts is to assess the network's performance and energy consumption across varying scales, from small to moderately large configurations, while maintaining manageable complexity. Each setup consists of a sink node and an ad hoc link. A sink node is a device that stores all the data and information gathered by the sensor nodes in a network, whereas an ad hoc link is a device that connects all the sensor nodes in a network. Additionally, the system configuration includes one router, one server, and one gateway, which facilitate the routing, data processing, and interconnection with other network types. Each design was simulated with three different times which are 1 hour, 12 hour and 24 hours to evaluate the system's performance and energy consumption over short and extended durations.

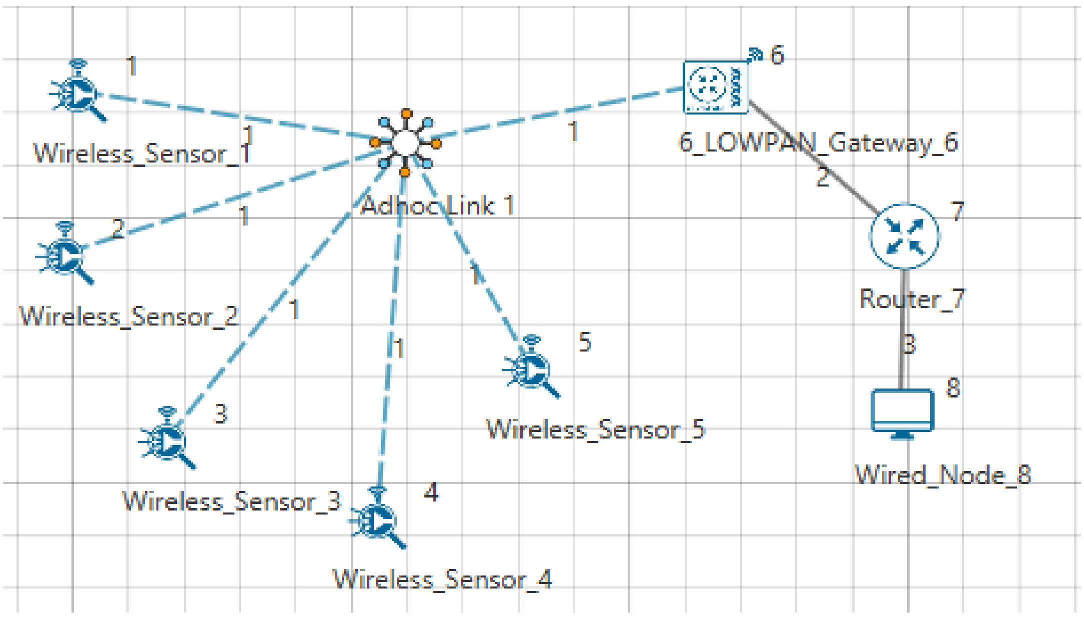

Fig. 2 *5 nodes design architecture*

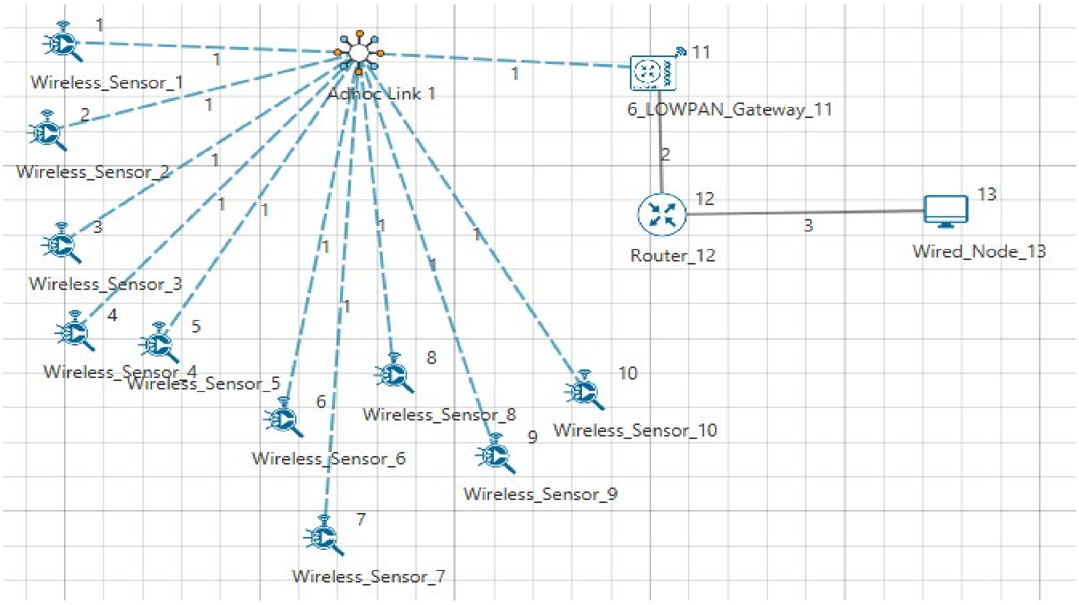

Fig. 3 *10 nodes design architecture*

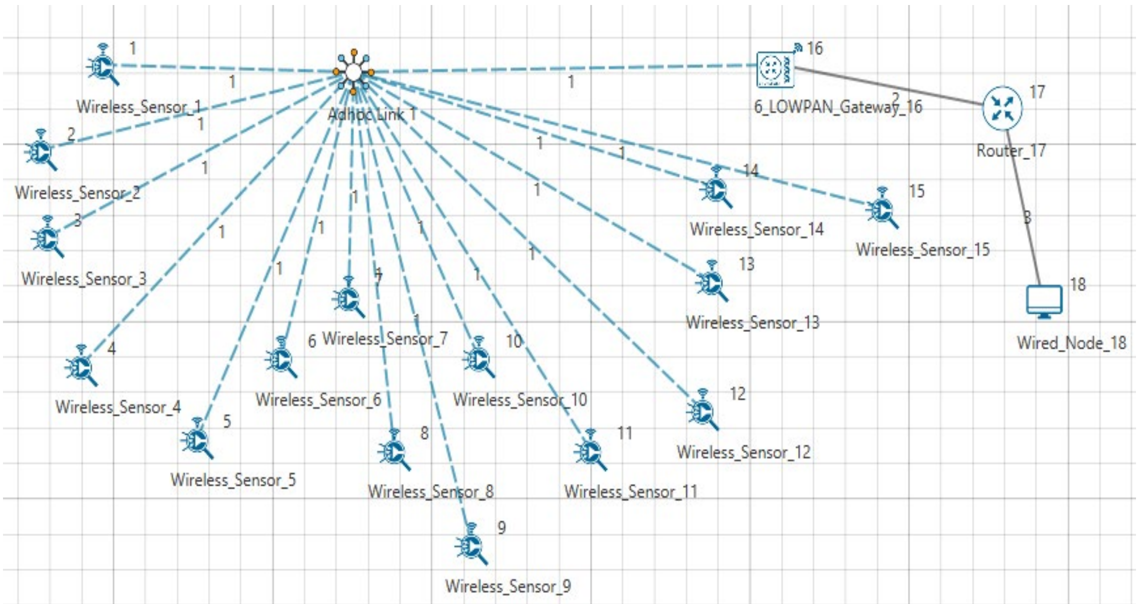

Fig. 4 *15 nodes design architecture*

4. Results and Discussion

For the 5-node configuration, it is simulated with two different numbers of applications: 1 and 3. Meanwhile, for the 10-node configuration, it is simulated with 2 and 6 applications. All configurations were simulated for three different durations: 3600s (1 hour), 43200s (12 hours), and 86400s (24 hours), except for the 15-node configuration. The 15-node configuration is simulated with only one application at 43200s due to the limitation of the NetSim software itself. A sample of the 5-node configuration with 1 application is shown in Fig. 5 below.

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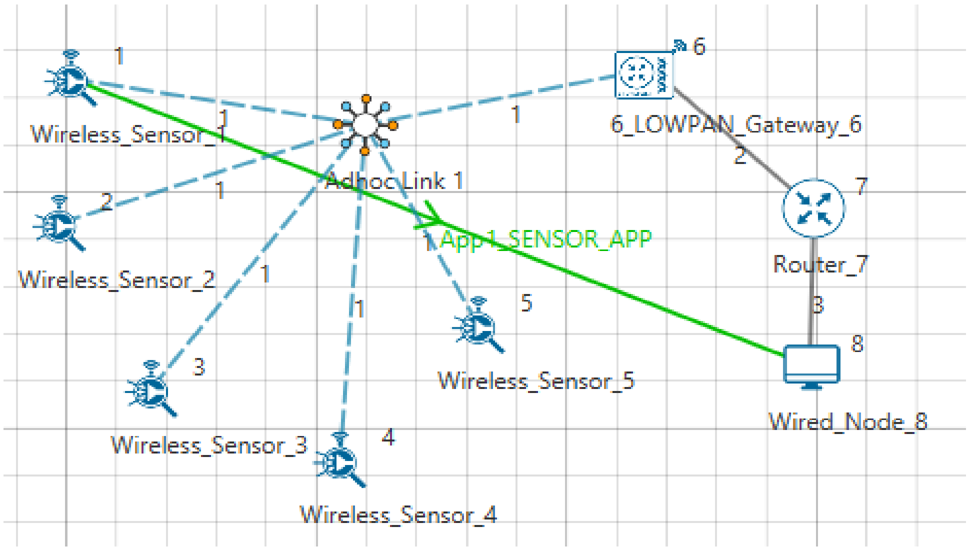

Fig. 5 *5 nodes with 1 application*

Based on the results obtained from Table 2, 3, and the graph plotted in Fig. 6, we can observe that using different values of battery capacity, it significantly affects the energy consumption of the battery. Battery capacity, which determines the duration a device can run before requiring recharging, directly impacts the energy usage of a battery-powered device. A larger battery with higher energy storage capacity enables the device to run for longer periods before needing to be recharged, but it does not increase the energy consumption of the battery. The energy consumption remains the same regardless of the difference in capacity values. As shown in the Table 2 and 3, the energy consumed for both 3.7V, 1500mAh and 3.7V, 3000mAh batteries is the same for each number of nodes. The same pattern can be observed for the 7.4V battery. However, the percentage of remaining energy differs among the designs. The battery with a capacity of 3000mAh has a higher percentage of remaining energy compared to the 1500mAh battery.

Next, the value of the remaining energy of the battery used decreases as time passes by which indicates that the energy consumed by the nodes also increases if simulation time is increased. When the simulation is simulated at 1 hour, it has the lowest value of energy consumed compared to when it is simulated at 12 and 24 hours, and when it is simulated at 24 hours, it has the highest value of energy consumed for each of the configurations. The cause of the increasing value of energy consumed over time might be due to the increased workload. A device is probably carrying out more tasks or running more demanding applications when it is utilized for a longer period of time. Due to the increased workload, the CPU, display, and network connectivity of the device must run for longer periods of time, which increases energy consumption.

Table 2 presents the results of the configuration when the application is set to 60%, while Table 3 shows the results of the configuration when the application is set to 20%. Different application loads can lead to varying energy consumption patterns across nodes. By introducing this variability, we can study the impact of different workloads on individual node energy usage, leading to more comprehensive insights into energy efficiency and optimization strategies. Upon analyzing the results, it is evident that the 60% application exhibits a higher energy consumption compared to the 20% application. This difference can be attributed to network traffic and communication. In NetSim, programs generate network traffic by engaging in communication with other programs or network nodes to exchange data and messages. The quantity of network traffic increases as more applications become active, resulting in a higher energy requirement for transmitting, receiving, and processing additional data packets. Consequently, 60% of applications consume more energy in comparison to the 20% application due to the elevated network traffic and associated communication demands.

Table 2 *Result for 60% applications*

Battery Level (v)	Initial Energy (mAH)	Number of nodes	Time (h)	Energy Consumed (kJ)	Remaining Energy (kJ)	Remaining Energy (%)
3.7	Design 1 1500 (19.98kJ)	5	1	0.2219	19.7581	98.89
			12	2.6634	17.3166	86.67
			24	5.3269	14.6531	73.34
		10	1	0.4463	19.5337	97.77
			12	5.3569	14.6231	73.19
			24	10.7140	9.2660	46.38
	Design 2 3000 (39.96kJ)	5	1	0.2219	39.7381	99.44
			12	2.6634	37.2966	93.33
			24	5.3269	34.6331	86.67
		10	1	0.4463	39.5137	98.88
			12	5.3569	34.6031	86.59
			24	10.7140	29.2460	73.19
7.4	Design 3 1500 (39.96kJ)	5	1	0.4438	39.5162	98.89
			12	5.3268	34.6332	86.67
			24	10.6538	29.3062	73.34
		10	1	0.8927	39.0673	97.77
			12	10.7138	29.2462	73.19
			24	21.4280	18.5320	46.38
	Design 4 3000 (79.92kJ)	5	1	0.4438	79.4762	99.44
			12	5.3268	74.5932	93.33
			24	10.6538	69.2662	86.67
		10	1	0.8927	79.0273	98.88
			12	10.7138	69.2062	86.59
			24	21.4280	58.4920	73.19

Table 3 *Result for 20% applications*

Battery Level (v)	Initial Energy (mAH)	Number of nodes	Time (h)	Energy Consumed (kJ)	Remaining Energy (kJ)	Remaining Energy (%)
3.7	Design 1 1500 (19.98kJ)	5	1	0.2223	19.7577	98.89
			12	2.6686	17.3114	86.64
			24	5.3371	14.6428	73.29
		10	1	0.4475	19.5325	97.76
			12	5.3700	14.6100	73.12
			24	10.7400	9.2400	46.25
	Design 2 3000 (39.96kJ)	5	1	0.2223	39.7377	99.44
			12	2.6686	37.2914	93.32
			24	5.3372	34.6228	86.64
		10	1	0.4475	39.5125	98.88
			12	5.3670	34.5900	86.56
			24	10.7400	29.2200	73.12
7.4	Design 3 1500 (39.96kJ)	5	1	0.4447	39.5153	98.89
			12	5.3372	34.6228	86.64
			24	10.6743	29.2857	73.29
		10	1	0.89410	39.0659	97.76
			12	10.7400	29.2200	73.12
			24	21.4933	18.4667	46.21
	Design 4 3000 (79.92kJ)	5	1	0.4447	79.4753	99.44
			12	5.3372	74.5828	93.32
			24	10.6743	69.2456	86.64
		10	1	0.8949	79.0250	98.88
			12	10.7400	69.1800	86.56
			24	21.4800	58.4400	73.12

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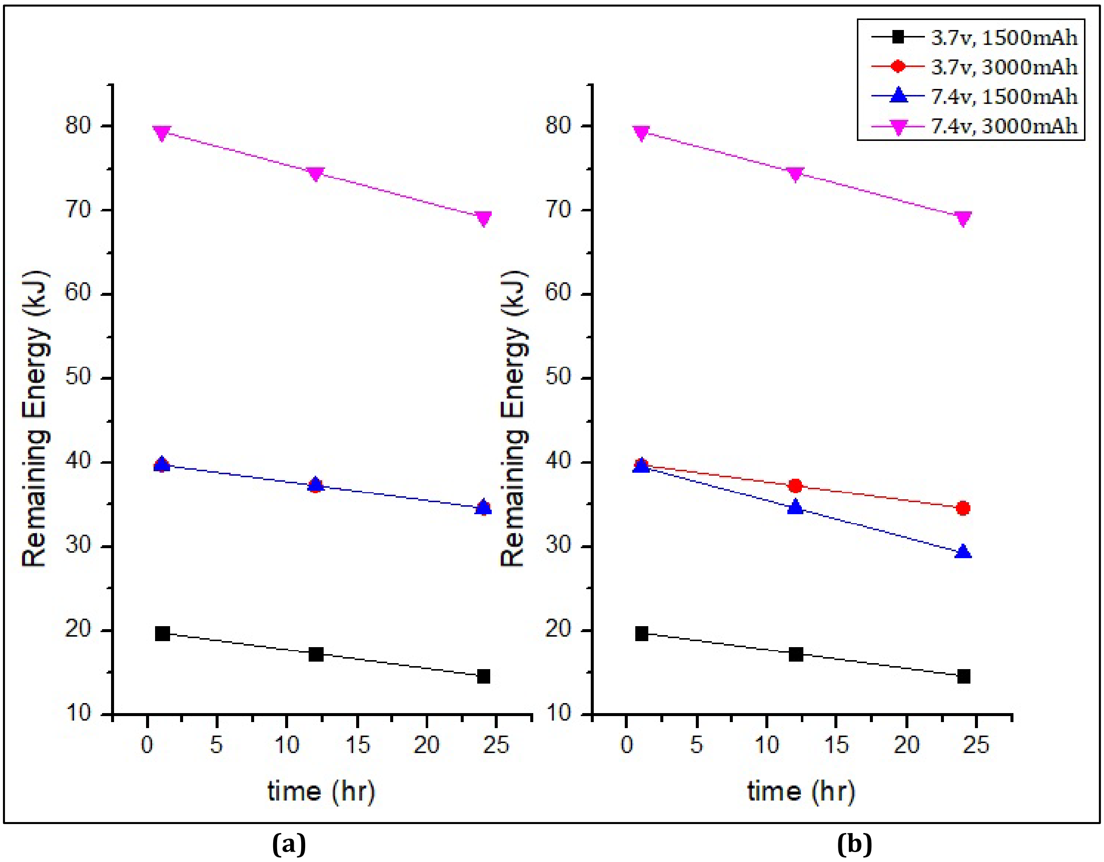

Fig. 6 *Graph for 5 nodes during (a) 20%; and (b) 60% active applications*

Tables 4 and 5 provide insights into the relationship between the number of nodes and the energy consumption of the battery. It is evident that as the number of nodes increases, the energy consumption of the battery also increases, while the remaining energy percentage decreases. For instance, when the system is connected to 15 nodes, the remaining energy decreases by 26.98% compared to the value when the system is connected to 5 nodes. Specifically, for a 3.7V, 1500mAh battery, the remaining energy percentage decreases from 86.67% to 59.69%. Moreover, considering the same battery model, in a 12-hour (43200 seconds) simulation, when 5 nodes are connected to the system, the battery consumes 13.31% of its energy, and the battery is estimated to last for 90 hours. However, when 15 nodes are connected, the battery is estimated to last for 29.77 hours, consuming 40.31% of its energy in the first 12 hours. It is worth noting that the 7.4V battery exhibits a higher energy consumption compared to the 3.7V battery, despite using the same number of nodes. Nevertheless, a 7.4V, 1500mAh battery has the same lifespan as a 3.7V, 1500mAh battery. The estimated lifespan for both batteries, when connected to 5 and 15 nodes, is 90 and 29.77 hours, respectively. This indicates that the battery voltage does affect the energy consumption, but it does not affect the lifespan of the battery.

The increase in energy consumption when the number of nodes increases is perhaps due to congestion and shortages of resources. The likelihood of resource competition and congestion rises in larger networks. There may be competition between different nodes for the same bandwidth or processing power, which can cause delays and inefficiencies. Contention and congestion problems frequently call for additional energy-intensive activities, including retransmissions, queuing, or rerouting, which can lead to even more energy usage. The graph of remaining energy over the number of nodes shown in Fig. 7 decreases linearly for each of the configurations. It shows that as the number of nodes increases, the remaining energy decreases. This indicates that the energy consumption of the battery increases as the number of nodes increases.

Table 4 *Battery capacity 1500mAh with 1 application*

Nodes	1500mAh					
	Design 1 - 3.7V			Design 3 - 7.4V		
	Consumed (kJ)	Remaining (kJ)	Remaining (%)	Consumed (kJ)	Remaining (kJ)	Remaining (%)
5	2.6634	17.3166	86.67	5.3268	34.6332	86.67
10	5.3498	14.6302	73.22	10.6995	29.2605	73.22
15	8.0542	11.92578	59.69	16.1085	23.8515	59.69

Table 5 *Battery capacity 3000mAh with 1 application*

Nodes	3000mAh					
	Design 2 - 3.7V			Design 4 - 7.4V		
	Consumed (kJ)	Remaining (kJ)	Remaining (%)	Consumed (kJ)	Remaining (kJ)	Remaining (%)
5	2.6634	37.2966	93.33	5.32684	74.5932	93.33
10	5.34975	34.6102	86.61	10.6995	69.2205	86.61
15	8.05423	31.9058	79.84	16.1085	63.8115	79.84

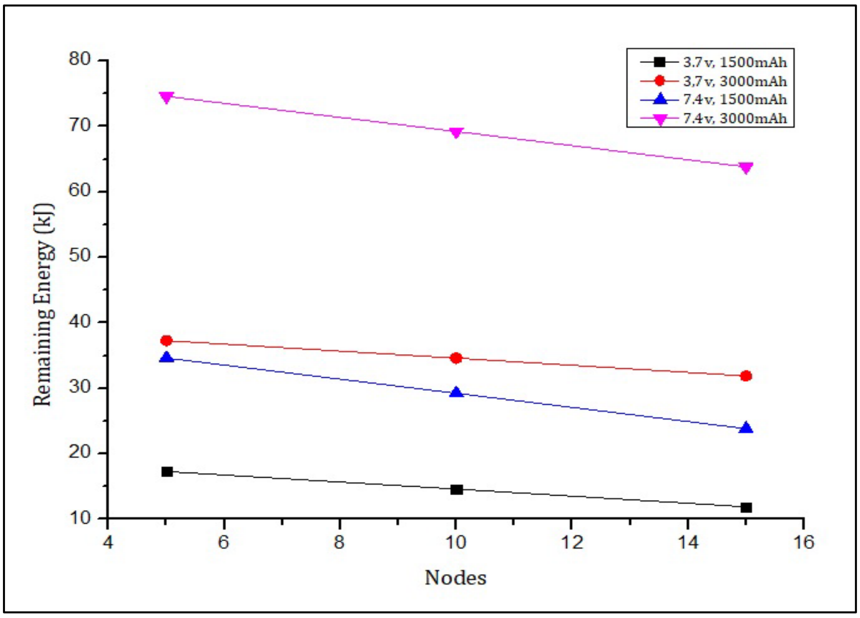

Fig. 7 *Graph for remaining energy vs nodes*

5. Conclusion

This paper has concluded the impact of nodes on the energy consumption of IoT devices using NetSim IoT simulator software which represents a real-life scenario. Based on the simulation done, for 5 nodes 3000mAh 3.7V design, when it was simulated at 12 hours, it has the lowest energy consumption value and highest remaining energy value percentage which are 2.6634 kJ and 93.33 respectively. For 10 nodes, the value of the energy consumed is 5.3497kJ and for the percentage of remaining energy, the value is 86.61. As for the 15 nodes, it has the highest energy consumed value and the lowest percentage of remaining energy which are 8.0542kJ and 79.84 respectively. In addition, the graph depicting the percentage of remaining energy versus the number of nodes shows a linear decrease. From this observation, it can be concluded that the energy consumption of the battery is influenced by the number of nodes in the system. The energy consumption value for a higher voltage battery is larger compared to a lower voltage battery. Next, the longer the system is being used, the larger the value of energy consumption of the battery. When the simulation is run for 1 hour, it has the lowest value of energy consumed compared to simulations run for 12 and 24 hours. Conversely, when the simulation is run for 24 hours, it results in the highest value of energy consumed for each configuration. The increasing value of energy consumption over time might be due to the increased workload. For IoT devices, especially those using batteries or having few power sources, managing electricity effectively is essential. Coordination and power management optimization get increasingly challenging as the number of nodes increases. The recommendation for future study is to focus on the ways to minimize the energy consumption of the battery despite having many nodes connected to the system.

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Conflict of Interest

Authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

*The authors confirm contribution to the paper as follows: **study conception and design:** Yuslinda Wati Mohamad Yusof, Murizah Kassim; **theoretical framework development:** Nurul Hanani Azmi, Murizah Kassim; **software simulation:** Mohd Nazri Ismail; **data collection:** Yuslinda Wati Mohamad Yusof, Nurul Hanani Azmi; **analysis and interpretation of results:** Yuslinda Wati Mohamad Yusof, Nurul Hanani Azmi, Murizah Kassim. All authors reviewed the results and approved the final version of the manuscript.*

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