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Energy in Wireless Sensor Nodes using Extractor-based Wake-up Receiver for IoT Applications

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Abstract

The primary concern in the Internet of Things applications that use wireless sensor networks (WSN) is that the sensor nodes have limited battery power, affecting how well the network functions. The most difficult obstacle to overcome is decreasing the power receivers consume when they are not actively listening to a signal. This is referred to as the "cost of idle listening." Turning off the primary receiver, installing new wake-up circuitry that can detect an incoming signal, and then turning on the primary radio only when required is one approach that can be taken. The wake-up receiver is kept active in the Wireless Sensor Node while the main radio is idle. Most of the previous implementations use active components like an operational amplifier which increases power consumption and Bluetooth low power, thus reducing the total range of the receiver radio. Thus, an effective wake-up receiver can be designed by capturing the wake-up call, and the pattern received can be extracted into individual bits with the help of a pulse extractor and then cross-referenced with an oscillator to find the exact wake-up call intended for a particular WSN node.

Keywords: IoT; Wireless Sensor Nodes; Pulse extractor; Power;

1. INTRODUCTION

The development of the technology behind the Internet of Things has seen phenomenal progress in recent years. The end goal of developing this technology is to enable access to the devices in question from any location and at any time. Wireless sensor networks support the Internet of Things as its skeletal structure[1]. Wireless sensor networks play an important role in the Internet of Things because they do not require any additional infrastructure to function and can do so without fixed node alignment. To ensure continuous operations, it is necessary to design sensor nodes with low power consumption[2][3]. The communication between the nodes can be broken down into three distinct categories. There is synchronous communication, pseudo-synchronous communication, and asynchronous communication. Before the beginning of the data transmission that will take place during synchronous communication, the nodes will simultaneously synchronize the clock. In the mode of communication known as pseudo-random, the transmitter will send a preamble to the receiver to determine whether the receiver is prepared to receive the data [4]. Asynchronous communication is possible in the processes that deal with duty cycles. The problem with these modes is that they all have unacceptable latency levels [5]. The consumption of energy is approximately 70%. Using receivers that are more efficient with their energy use is one way to solve this problem. [6] These particular kinds of receivers are referred to as wake-up receivers. It is common practice to incorporate the wake-up receivers into the main node. The only component that will be in an active state when the system is in the idle mode of operation is the wake-up receiver[7]. When the wake-up receiver receives any request, it immediately sends an interrupt signal to the primary node. This will cause the main node to transition from sleeping to active mode [8].

The architecture of the wake-up receiver is primarily composed of passive devices that can use less energy than other types of devices. After these passive components come the active components, which are the ones that can send an interrupt signal to the main node to wake it up[9]. The envelope detector determines the modulation type applied to the signal received [10]. A Schottky diode may be used in place of the envelope detector. Demodulation of on-off keying signals is possible with these diodes thanks to their ability. Amplifiers are a tool that can be utilized to improve the strength of the signal[11]. Utilizing these components makes it possible to cut down on the consumption of unnecessary amounts of energy [12]. For routing data, the radio frequency transceivers used in wireless sensor networks have a high energy consumption rate, ranging from about 10 to 30 million amps[13]. To solve this problem, it is necessary to implement duty cycle methods with a fixed phase for the various functional parameters, such as transmission, reception, and sleeping[14-15].

On the other hand, this increased the amount of latency that occurred during data transfers. Wake-up radio enables a data transfer that is both low in energy consumption and latency [16]. When they are not being used, the nodes will go into a mode called "sleeping." When there is a requirement for a node to transfer data, the wake-up receivers are responsible for reviving the nodes. Using this technique, it is possible to maintain the current level of energy consumption [17].

2. LITERATURE SURVEY

The implementation of power management in WSNs must be done in a way that does not compromise the integrity of the network if optimal performance is to be achieved. We can lower both our energy consumption and response times by utilizing a multi-model and two-tiered architectural framework. The fact that surveillance cameras are now so commonplace proves this tactic is successful. The passive infrared (PIR) sensor helps detect the presence of people. The data collected by the PIR sensors are transmitted to the camera nodes by receivers equipped with wake-up radios [18]. We can determine whether or not a wake-up radio is practical by calculating the costs and benefits associated with the amount of energy consumed and the amount of time lost. The current healthcare system has set itself the goal of transitioning away from dispensing medications throughout hospitals and towards individualizing dosing for each patient. In medicine, the application of wireless sensor nodes plays an essential part in transmitting information reliably and speedily. Consistently sharing information is necessary for providing medical support over the long term [19]; in collaboration with other researchers, Md. Maruf Hossain Shuvo has developed a method for extracting node energy from the surrounding environment. To fulfil this requirement, we use energy harvesters that can convert the gathered energy into electricity that can be utilized [20]. Using this method, it is possible to create medical devices that do not require batteries and operate very effectively.

In addition to the fact that there are an increasing number of devices that can connect to the internet, the connections themselves are becoming more effective and, as a result, save more power. Keeping the electronic devices powered on at all times is unnecessary because they can be accessed using wake-up radio receivers. Yousef Mafi and his co-authors analyzed the wake-up receiver's performance in uplink and downlink applications. The power requirement demonstrated for their method is sixty nanowatts [21]. The network is being slowed down by the rising amount of energy consumed. Individual nodes can be activated according to necessity [22] if a radio is installed at the network's gateway. Florin Hutu, Aissa Khoumeri, and other researchers have suggested a front-end radio that can differentiate between different sensors.

The front end uses the frequency "footprints" left by the radio. The increase in energy consumption is a natural result of the advancements made in communication. The energy levels of the networks have a significant impact on a variety of parameters, including the data rate, spectral efficiency, and other comparable values. The amount of readily available energy dictates how long individual nodes can remain connected to the network, which in turn places a cap on the network's availability. Wireless networks have many applications [23], such as monitoring healthcare, using household appliances, security, and other areas. Wake-up radio has been the best tactic for optimizing one's ability to capitalize on available energy-saving opportunities [24]. The idea of a wake-up radio may have the potential for several benefits, but it also has the potential for some drawbacks. Researchers such as Sebastian L. Sampayo, Julien Ontavont, Fabien Prégaldiny, and Thomas Noel have discussed this technology's limitations. The COOJA programme [25] was utilized during the analysis to provide assistance.

3. PROPOSED SYSTEM

The proposed work can be better understood with the help of two types of nodes. They are fog nodes or power nodes, and cluster nodes. The fog nodes are more powerful, and they act as sinks. The cluster nodes act as the members of the clusters. The power node is capable of sending messages directly to the members of the cluster. The cluster members are powered with less energy. When the cluster member (say node X) is placed far away from the power node, it cannot transmit data directly to the power node. In such cases, relay nodes are required between the power and fog nodes for data transmission.

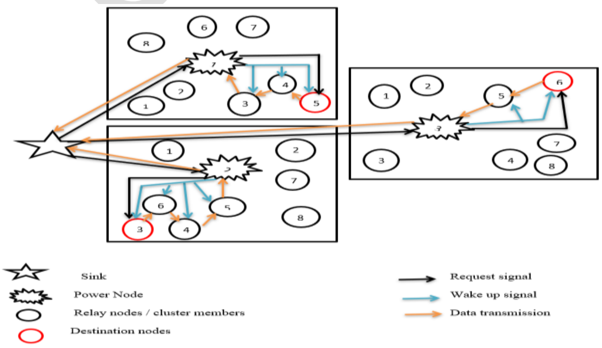

Figure 1: The transmission of data using asymmetric links

The sensor nodes have wake-up receivers within them. This wake-up receiver only wakes up the nodes when required. If the wake-up receiver does not wake up the sensor nodes, the sensor nodes will be in a sleep state and will not consume any energy. Figure 1 shows the transmission of data using asymmetric links. Each user is assigned one power node. About 8 cluster members are given to each power node. The power node can facilitate the communication between the cluster node and the sink node. No other node can do this function within a cluster. But the communication inside the cluster can be done with the help of its cluster members in a multi-hop fashion. The cluster members can communicate with each other and send the data to the power node, which can be forwarded to the sink by the power node alone. In the traditional method of the wake-up receiver concept, when the data has to be transmitted, each node has to wake up the neighbouring node. This waking up of the next node by another node continues until the destination is reached. This method is found to be time-consuming.

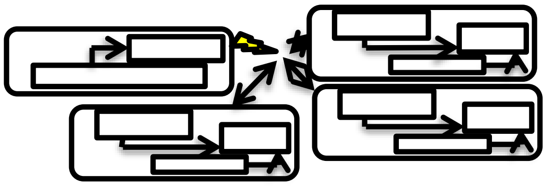

Figure 2: Waking up of nodes using wake-up receiver through existing method

Each node will take some time to wake up and transmit the data to the next node. This method becomes inefficient in several applications, such as the medical field, where instant data transmission is required. Figure 3 depicts the waking up of nodes using the wake-up receiver through the proposed method. Figure 4 shows the block diagram of the proposed method.

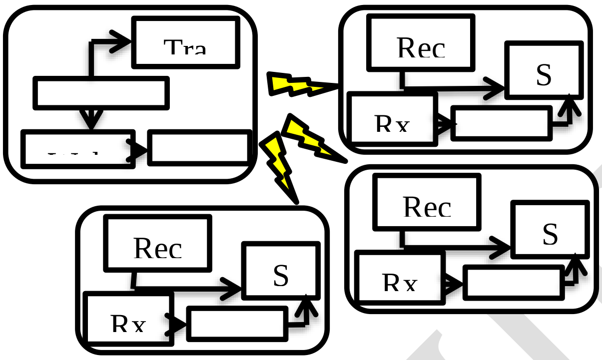

Figure 3: Waking up of nodes using wake-up receiver through the proposed method

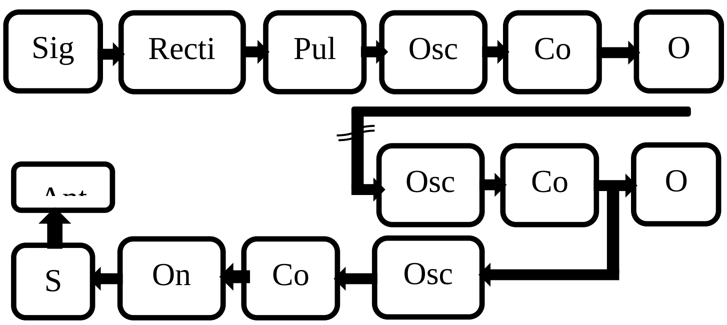

Figure 4: Block diagram of the proposed method

To overcome this drawback, the proposed work enables the power node to wake up many clusters simultaneously to minimize time consumption and to provide faster data delivery to the destination node. The power node uses a source-based routing protocol to determine which relay node to wake up during the data transmission. The list of nodes that will take part in the data delivery will be maintained in the routing table of the power node.

Figure 2 shows the waking up of nodes using the wake-up receiver through the existing method. The signal is received from the antenna, after which it is subjected to rectification and multiplication. The output of this block is fed to the pulse extractor. The function of the pulse extractor is to extract the spatial characteristics of the nodes with the limited parameters taken from the individual nodes. The output of the pulse extractor is given to the counter and the oscillator. The system consists of an N number of counters and oscillators. The sensor node senses the outcome of the counter, and the final output is transmitted over the antenna.

3.1. Description of the routing technique:

The main idea behind the data transmission using the proposed method is that the sink node sends the data, and the power nodes send the wake-up signals

Step 1: The sink node decides the routing time and transmission time of the sensor node. When the sink node wants to transmit data to a particular destination, the sink node checks which power nodes can reach the destination using the routing table. Then the sink node will send the request signal to the corresponding power nodes.

Step 2: The power node is highly powered. The power node will receive the request signal, and the power node will check which nodes to use as relay nodes to reach the destination. The power node will send the wake-up signal to the destination node through the relay nodes using multicast routing. The power node will be in the receiving mode.

Step 3: The destination node will receive the wake-up signal and transmit the data. After transmitting the data, each relay node will go back to sleep mode.

Step 4: The power node will receive the data from the destination, and it will be forwarded to the [redacted]nk node

Step 5: The sink node will receive the data

An energy-efficient delay-reducing routing technique has been proposed in this method. The proposed method consists of two segments. One is the sensor node segment, and the other is the fog node segment. The sensor node consists of the sensors with the energy sources such as batteries. Each sensor node also has a wake-up receiver. The fog nodes are more powered than the sensor nodes. They are kept near the sensor node to help them with complex data transmissions. The fog node is the main node of the cluster. It monitors the data transfer within its cluster members. The

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fog node will maintain a routing table regarding the nodes through which the data or signal transmission should occur.

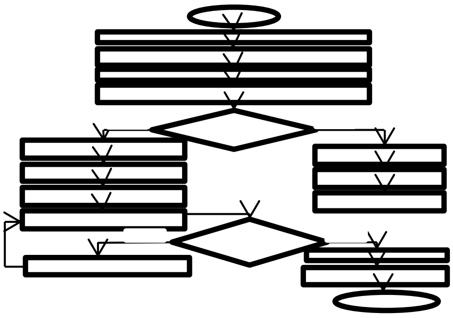

Figure 5: Flow chart of the proposed work

Algorithm for wake-up signal transmission

Process: waking up of the nodes using multi-hop transmission
If (sink asks for data from the destination)
The sink node checks the cluster table for the address to send a request signal to the power node;
If (power node receives the request signal)
Check cluster member table
If (the destination is the direct range of the power node)
Then
Transmit multicast transmission signal;
End

Figure 5 shows the flow chart of the proposed work. Initially, the sink node will request the data from the cluster node. The sink node will check its routing table to identify the corresponding power node. After identification, the sink node will send a request signal to the power node. The power node will now check its routing table to determine which cluster members to wake up. If direct wake-up is possible, the power node will unicast the address to the cluster members. The request will be sent to the destination node by the power node. The destination node will then directly transmit the data to the power node. If direct wake-up is not possible, then the address will be multi-casted to all the cluster members by the power node. The destination node will check its routing table and transmits data to the relay nodes. The relay nodes will, in turn, forward the data to the power node.

Algorithm for transmission of data

Process: Transmission of data after wake-up signals
If (wake-up signal is received)
Check the address bits of wake up signal;
If (cluster and ID bit = own cluster and ID bit)
Wake up the sensor node and change to mode of reception;
If (request received from power node)
Then
The source routing table is checked;
If next hop!= Power node
Then
The source routing table is checked, and data is transmitted;
Else
Send data to the power node and go back to sleep mode;
End
Else
Check the routing table after receiving data;
If next hop != Power node
The source routing table is checked, and data is transmitted;
Send data to the power node and go back to sleep mode;
End

Commercial off-the-shelf nodes are used in the proposed work. These nodes are inexpensive, easy to maintain, expand and develop. 3V battery is equipped for energy saving through the wake-up receiver. 16-bit MSP430G2553 microcontroller is used. This microcontroller operates at 8 MHz frequency, and Texas Instruments designed it. It consumes 2.55 microwatts in the low-power mode.

The radio used for communication is the SPIRIT 1, manufactured by ST Electronics. It's current consumption and operating frequency are 21 milli amps and 868 MHz, respectively. The output power is 12 dBm. AS3933 wake-up chip is used. This chip has a current consumption of 3 microamps. It is the ASK receiver with tri channels. It uses an off-keying modulation technique in the frequency range of 15 kilohertz to 150 kilohertz.

SBS (step-by-step) method

The results compare the proposed work with the SBS (step-by-step) and NTN (Node to node) methods. In the SBS method, once the sink has received the request, the power node will start waking up all the intermediate, so-called relay nodes. The destination will be woken up at the end. When the request from the power node reaches the destination node, the destination node will start transmitting data via the woken-up relay nodes. After data transmission, the sensor node will turn to sleep mode.

NTN (Node to node) method

In the node-to-node technique, the power node will send a wake-up signal before the actual request after receiving the signal from the sink. The destination node will send a wake-up signal to the relay node before transmitting the data. After waking up and obtaining data, the relay nodes will transmit another wake-up signal to the subsequent relay node, followed by data. Now the next relay will wake up and starts forwarding the data. After the data transmission, the relay nodes will go to sleep mode.

4. RESULTS AND DISCUSSION

The single-node energy consumption and activation time with only one relay node are given in Table 1. The results have been analyzed for the proposed SBS and NTN methods. The energy consumption of the sink node using the proposed SBN and NTN methods are 1.19mAs, 1.42mAs and 1.56mAs, respectively. The energy consumption of the power node using the proposed is 1.62mAs.

Table 1: Single node energy consumption and Activation time with one relay

Node	Method	Single node energy consumption in mAs	Single node activation time in ms
Sink	Proposed method	1.19	105.30
	SBS	1.42	135.70
	NTN	1.56	137.05
Fig Node	Proposed method	1.62	110.58
	SBS	1.95	140.39
	NTN	1.95	140.46
Relay Node	Proposed method	0.51	54.26
	SBS	0.72	80.68
	NTN	0.48	45.13
Dest node	Proposed method	0.18	30.85
	SBS	0.19	26.86
	NTN	0.47	54.63

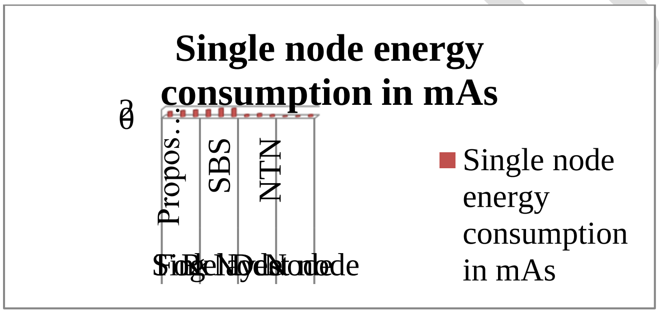

Figure 6: Bar chart representation of Single node energy consumption with one relay

The bar chart representation of Single node energy consumption with one relay is shown in Figure 6. The energy consumption is 1.95mAS for the SBN and NTN methods. The energy consumption of the relay node using the proposed SBN and NTN methods are 0.51mAs, 0.72mAs, and 0.48mAs respectively. The energy consumption by the destination node is 0.18mAs, 0.19mAs, and 0.47mAs for the three methods.

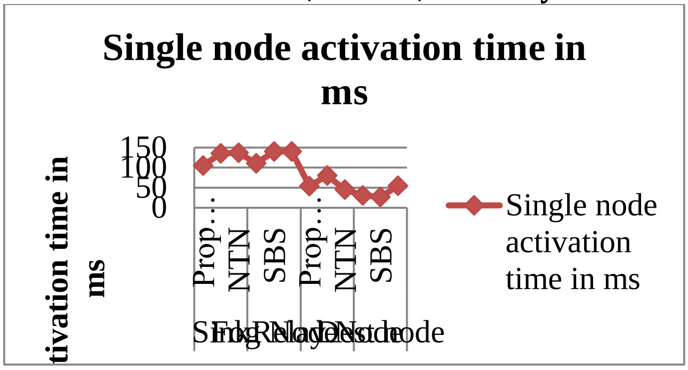

Figure 7: Bar chart representation of Single node activation time with two relays

The graphical representation of the single node activation time is shown in Figure 7. The single node activation time of the sink node using the proposed method, SBS technique, and the NTN method are 105.30ms, 135.70ms, and 137.05ms, respectively. The single node activation time of the power node using the proposed method, SBS technique, and the NTN method are 110.58ms, 140.39ms, and 140.46ms, respectively. The single node activation time of the relay node using the proposed method, SBS technique, and the NTN method are 54.26ms, 80.68ms and 45.13ms, respectively. The destination node has an activation time of 30.85ms, 28.86ms and 54.63 for the three methods.

Table 2: Single node energy consumption and Activation time with two relays

Node	Method	Single node energy consumption in mAs	Single node activation time in ms
Sink	Proposed method	1.48	130.46
	SBS	1.88	181.55
	NTN	1.92	182.34
Fog Node	Proposed method	1.61	137.06
	SBS	2.42	190.04
	NTN	2.50	194.35
Relay Node 1	Proposed method	0.55	82.60
	SBS	1.42	130.27
	NTN	0.43	42.52
Relay Node 2	Proposed method	0.43	50.12
	SBS	0.65	76.58
	NTN	0.54	72.77
Dest node	Proposed method	0.32	25.52
	SBS	0.32	23.81
	NTN	0.46	56.67

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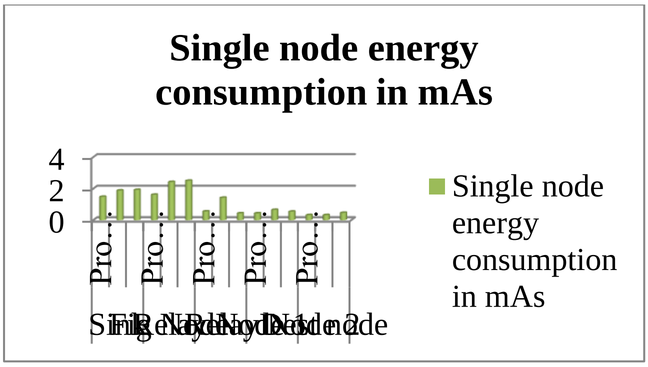

Figure 8: Bar chart representation of Single node energy consumption with two relays

The Single node energy consumption and Activation time with two relays is shown in Table 2. The single-node energy consumption of the first relay node using the proposed SBS and NTN methods are 0.55mAs, 1.42mAs and 0.43mAs, respectively. The single-node energy consumption of the second relay node using the proposed SBS and NTN methods are 0.43mAs, 0.64mAs and 0.54mAs, respectively.

The bar chart representation of the single node energy consumption in mAs is shown in Figure 8. It can be seen that maximum energy is consumed through the NTN method by the sink node, fog node and destination node. The maximum energy consumption by both relay nodes has been obtained using the SBS technique.

Figure 9 shows the single node activation time using two relays. The single node activation time of the first relay node using the proposed SBS and NTN methods are 130.46ms, 181.55ms and 182.34ms, respectively. The single-node energy consumption of the second relay node using the proposed SBS and NTN methods are 82.60ms, 130.27ms and 42.52ms, respectively.

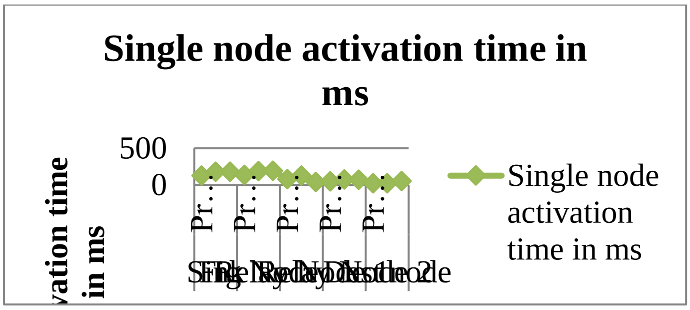

Figure 9: Graphical representation of Single node activation time with two relays

Table 3 shows three relay nodes' single-node energy consumption and activation time. The single node energy consumption of the first relay node for the proposed method, SBS method, and NTN method are 1.06mAs, 2.05mAs and 0.83mAs, respectively. The single node energy consumption of the second relay node for the proposed method, SBS method, and NTN method are 0.83mAs, 1.34mAs, and 0.67mAs respectively. The single node energy consumption of the third relay node for the proposed method, SBS method, and NTN method are 0.53mAs, 0.81mAs, and 0.69mAs respectively.

Table 3: Single node energy consumption and Activation time with three relays

Node	Method	Single node energy consumption in mAs	Single node activation time in ms
Sink	Proposed method	1.76	153.81
	SBS	2.54	234.50
	NTN	2.56	236.23
Fog Node	Proposed method	2.27	165.24
	SBS	3.17	243.67
	NTN	3.23	240.15
Relay Node 1	Proposed method	1.06	109.62
	SBS	2.05	181.57
	NTN	0.46	48.67
Relay Node 2	Proposed method	0.83	84.95
	SBS	1.34	129.68
	NTN	0.67	75.26
Relay Node 3	Proposed method	0.53	60.89
	SBS	0.81	79.34
	NTN	0.69	75.42
Dest node	Proposed method	0.23	31.62
	SBS	0.24	29.68
	NTN	0.45	57.42

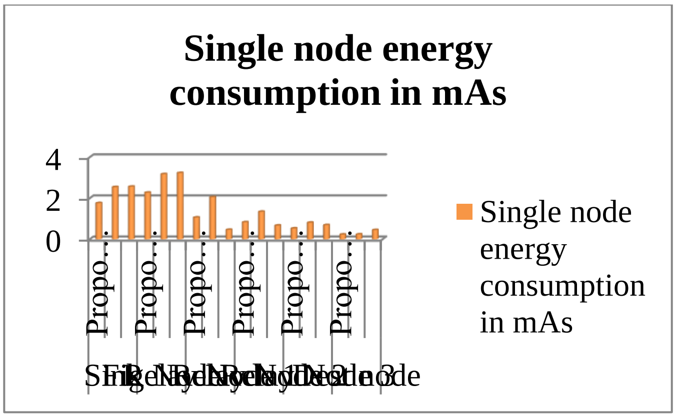

Figure 10: Bar chart representation of Single node energy consumption with three relays

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The bar chart representation of the single node energy consumption in mAs is shown in Figure 10. It can be inferred that the relay nodes have consumed more energy when using the SBS method. All the other nodes, namely the sink node, fog node, and destination node, have consumed maximum energy during the NTN technique.

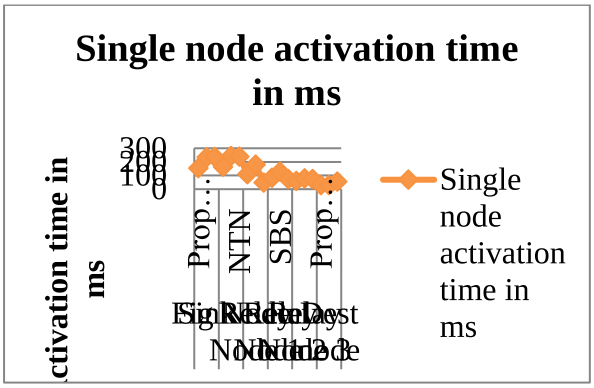

Figure 11: Graphical representation of Single node activation time with three relays

Figure 11 depicts the graphical representation of the single node activation time using three relays. The proposed method's activation time is 153.81ms, 165.24ms, and 60.89ms by the sink node, power node, and destination node, respectively. This is comparatively lesser than the other methods. In the case of the relay nodes, relay one minimum single-node activation time has been obtained using the NTN method.

Table 4: Comparison of nodes' energy consumption and latency with all three approaches

Node	Method	Energy consumption in mAs	Latency in ms
Relay Node 1	Proposed method	3.51	108.24
	SBS	4.52	134.26
	NTN	4.53	136.21
Relay Node 2	Proposed method	4.82	131.25
	SBS	6.95	184.65
	NTN	6.24	185.42
Relay Node 3	Proposed method	6.62	155.62
	SBS	10.12	234.56
	NTN	8.21	236.78

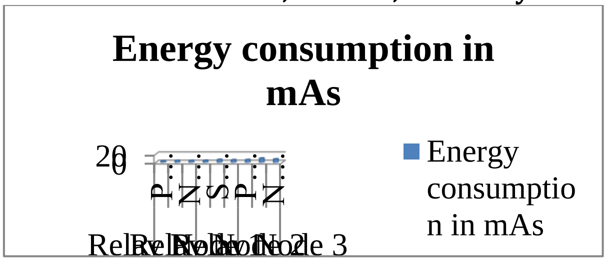

Figure 12: Bar chart representation of Comparison of nodes' energy consumption with all three approaches

A comparison of nodes' energy consumption and latency with all three approaches is given in Table 4. Figure 12 shows the bar chart representing the Comparison of nodes' energy consumption with all three approaches. Figure 13 depicts the graphical Comparison of the node's latency with all three approaches.

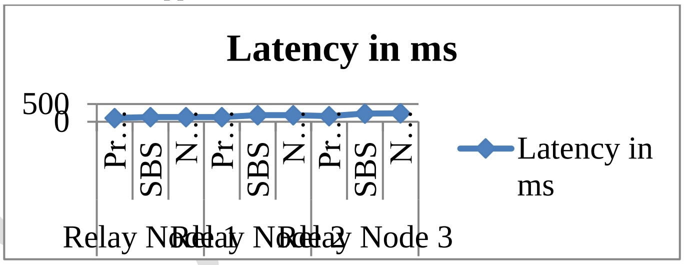

Figure 13: Graphical representation of a comparison of nodes latency with all three approaches

Relay node 1 has latencies of 108.24ms, 134.26ms and 136.21ms for the proposed SBS and NTN methods, respectively. Relay node 2 has latencies of 131.25ms, 184.65ms and 185.42ms for the proposed SBS and NTN methods, respectively. Relay node 3 has latencies of 155.62ms, 234.56ms and 236.76ms for the proposed SBS and NTN methods, respectively. The latency is minimal by using the proposed method for all three relay nodes.

5. Conclusion

The application of wireless sensor networks can be found in various contexts. During deployment, the most significant bottleneck occurs due to the amount of power consumed by the nodes in the network. The power node or the main node should only be active when required; otherwise, it should be put into sleep mode when it is not being used. This is one of the ways that energy can be saved. This is something that can be done with the assistance of wake-up receivers. The wake receiver that was designed for this work has the potential to perform this function with a lower overall amount of energy consumption. The outcomes have been demonstrated by contrasting the work that was proposed with the various other approaches that are currently in use. The findings have been summarised in tables and illustrated through graphical representations.

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