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Energy Efficient Data Transmission Scheme for Internet of Things Applications

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Recently, there is a rapid increase in the use of Internet of Things (IoT) technology, and it is envisaged that in the forthcoming days, billions of devices and things are going to be interconnected among themselves with the help of Internet. To make this technology self-sustainable, there is a need for an incessant energy supply that can be achieved through green energy harvesting. IoT has attracted the attention of researchers as well as practitioners all over the globe by serving as an important architecture for communication systems, but the terminal devices used in IoT are resource-constrained, which results in low energy storage capacity and low computing power. Among several tasks that need to be performed at the level of IoT node, the data transmission is the most energy intensive phase. To provide continuous power to nodes used in IoT systems, it is imperative that the available energy source should be used judiciously and in an optimized manner. In this paper, an energy efficient data transmission scheme for IoT devices has been proposed. The result obtained through extensive experiments depicts that there is a high potential for saving energy during the process of data transmission.

Keywords: Base station (BS), Cloud computing, Energy optimization, Optimization algorithms, Sustainable energy

Introduction

The rapid increase of data services and devices in the industrial domain is because of the unprecedented growth of Internet of Things (IoT) devices that are started connecting the whole world irrespective of the geographical boundaries. For accessing these IoT devices, the information gathered from these devices is to be stored and allowed to be retrieved by the users whenever required. Cloud infrastructures play a major role in storing the data, which is being gathered from the IoT devices. There is a large number of applications which are depending on the data services and are hosted on the cloud for making the work more flexible and efficient. These IoT devices are sometimes meant to be deployed in remote places like agricultural or war fields where there may be a limited source of power. Because of this energy-constraint nature of IoT nodes, researchers are forced to think about energy-efficient data centers and edge devices. There are several technologies available for Wireless sensor networks[1], which are not suitable to be directly applied to the IoT domain due to several reasons. This makes the development of energy-efficient IoT devices a non-trivial issue.

Motivation

The IoT edge devices normally used to be resource-constrained due to their limitations in terms of energy storage capacity. Moreover, IoT application systems need to function at low power. The IoT supports proper communication and collaboration between various devices automatically. Thus, the communication backbone of IoT systems is the main source of energy consumption.[2] Achieving improved packet transmission policies can reduce energy consumption and extend the life of the inbuilt battery of the IoT devices. To reduce the problems of energy efficiency and uninterrupted connectivity, energy efficiency schemes have to be implemented in mobile IoT devices with heterogeneous network interfaces. The word energy-efficient represents different aspects of the system in the IoT in terms of power consumption during operation. The energy efficiency of IoT edge devices depends on several aspects which are as follows:

1) The required energy for receiving the correct data bits and is transmitted to the destination from the sources.
2) The energy required for reporting a particular event.
3) The frequency of transmitting and receiving the data to the events.

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4) The lifetime of the network in which it can perform its task.

The energy of the sensor node is used for performing multiple functions such as data acquisition for establishing communication between the nodes and processing of the acquired data.[3]

Background

Although harvesting energy is a probabilistic solution which is quite attractive, the technology used to achieve the same has its own limitations which depend on various factors such as the source of energy, the technology used for harvesting, application of the harvested energy, etc.

Issues

Very often the energy supplied to the Sensor nodes comes from a source limited in terms of energy storage. Thus the sensor network has a maximum probability to fail due to lack of sufficient energy. Proper power management of an IoT node is a non-trivial problem that may result in overall failure of the network applications. Power source with limited supplies for transceivers are sometimes not sufficient for fulfilling the needs of IoT sensor networks for its lifetime operation. Transmitted information from the IoT sensor consumes comparatively more power in performing calculations. As per the study, the power required for sensing and transmitting a bit of data is equivalent to the energy required for performing 3,000 calculations.[4] Thus the energy requirement for computing power is lesser in comparison to that required for sensing and data transmission task. Sensors present in the sensor networks consist of a processor and memory to store acquired data. Due to the limited capability of processors and memory used, the management ability of the sensors is limited. Generally, an IoT network requires control over perceived objects, which may include temperature and humidity control. Considering this approach, multiple sensors have included control devices and software. The control devices and software are recommended to be placed as a trigger. There is an expansion of automation in the homes, industries, agriculture, etc., which has introduced new energy costs and associated risks for supplying energy to the IoT devices. This is how the energy management in IoT services is being recommended for providing the consumers with easy approach to both local and remote control service requirements in the case of different automation sectors i.e., agriculture and military. The cause of energy consumption in all the mentioned field of IoT applications are as follows:

1. Idle Listening: If the IoT node is kept active, it acts as a major source for the consumption of energy. The ready- to transmit state where the packet is not being received or sent is called Idle Listening.
2. Data over Hearing: High density sensor nodes induce data interfaces in neighboring nodes during data transferals.
3. Collision of Data: It occurs when nodes obtain many packets of the data at same time.
4. Traffic in Data transmission: Congestion or high delays for transmitting data can lead to enhancement in consumption of energy.

Related Work

In the recent past, a number of works are initiated to handle the energy conservation issues in IoT nodes during wireless data transmission.

Abdullah *et al.*[9] illustrated a system design which considers a message scheduling algorithm for time response and consumption of energy. A group of sensors are used collectively following the cluster approach. In this paper, one cluster of sensor nodes is called as IoT subgroup. The messages received from the devices are deeply examined. And with respect to queuing theory, the data received from the nodes are rearranged. This paper shows how rearrangement of messages affects life of the IoT network.

Wu *et al.*[10] showed an energy efficient method which is deployed in the physical layer. They have also elaborated the principle for energy optimization technique. They illustrated different algorithms like multi-level water filling and bisection algorithms for optimizing energy.

Rathna *et al.*[11] introduced an algorithm towards conservation of energy by using TDMA (Time Division Multiple Access) which is based on sleep and wake up time scheduling by minimizing the number of times a IoT node has to wake up, during a time slot.

Suo *et al.* [12] have described the key technologies which includes encryption mechanism, secured communication algorithms. The authors have reviewed the available technologies and implemented the encryption protection.

Jayakumar *et al.* [13] outlined the difficulties involved in efficiently providing power to the IoT devices. They also discussed the role of new memory technologies for constructing energy-efficient devices.

Kim *et al*. [14] showed an energy efficient scheme for minimizing the delays which occurs during data transmission and consumption of energy. The proposed scheme consists of three different aspects which are named as congestion control, duplication transmission prevention, and notification of error. Talwar *et al.*[15] illustrated some techniques of routing and some IoT protocols. Primarily, the author described different characteristics of protocols and some of the challenges during routing protocols.

Marcus *et al.*[16] demonstrated an advanced MAC protocol, and named it as PaderMAC, for WSNs. The principle of PaderMAC was implemented in TinyOS. Their aim was to improve the lifespan of the network by compressing the energy consumption.

Singh *et al.*[17] presented a detailed survey on routing protocols for increasing energy efficiency in wireless sensor network. The authors described the factors that influenced the design of routing protocols for achieving better energy efficiency.

Gerimella *et al.*[18] proposed a scheme for improving energy efficiency of sensor networks. The method illustrated that the base stations are placed in such locations so that the square of the Euclidean distance to the base station from the sensor nodes are minimum.

Abbas *et al.*[19] provided a thorough survey on issues in conservation of energy and their solutions. By using machine communications (3GPP) like Bluetooth Low Energy (BLE), Z wave etc, and the author addressed different functioning features in IoT devices. The solved issues are management of duty cycle, network congestion, sleep and waking up time of the node and selection of different heterogeneous radio interfaces. Foteinos *et al.*[20] presented a cognitive management framework for authorizing the Internet of Things. This type of framework has the ability for dynamically adapting its behavior, by considering self-management functionality, by considering the information and knowledge on the situation.

Though the survey of related works reveal that a number of solutions are proposed for improvement of energy efficiency for wireless sensor nodes but in IoT domain the practicality of these methods are yet to be verified. This warrants the research into some IoT specific energy efficient scheme for data transmission. Here, we have proposed an efficient data transmission scheme which would result in improving energy efficiency in the IoT devices.

Probabilistic Solutions

IoT solutions can be divided into different categories based on their Communication Technology, Network Topology, and Open-Standard Stack vs. proprietary solutions. Enhancement of energy efficiency includes different aspects of the IoT. Out of those, few common aspects are as follows:

1. Energy need for transporting single bit of data from the origin to the destination.
2. Power consumed per communicated events.
3. Energy for communicating urgent events with desired speed.
4. The life span of network for fulfilling its designated tasks.

Hence the probable solutions to realize the energy efficient IoT devices are shown in Fig. 1 and described as given below:

1. Light Weight Protocols: It refers to a protocol that has a lesser and leaner payload when being used and transmitted over a network connection. It is simple, fast, and easier to manage compared to other communication protocols used in IoT networks.
2. Scheduling Optimization: It is based on several custom components that help in fine-tuning the scheduling operations. Optimized scheduling modeling is a process to minimize energy loss, which is dependent on equipment's scheduling energy consumption value and time scheduling of the equipment working in the IoT environment.
3. Cloud-Based Approach: As compared to fog computing, the cloud can access an enormous amount of data.[5] Taking actuation decisions in the cloud, could play a massive role in preserving energy for IoT connectivity.
4. Low Power Trans receiver: Recently developed radio transceivers are achieving high performance at very low power which makes it suitable for use in IoT application that requires long-range, high

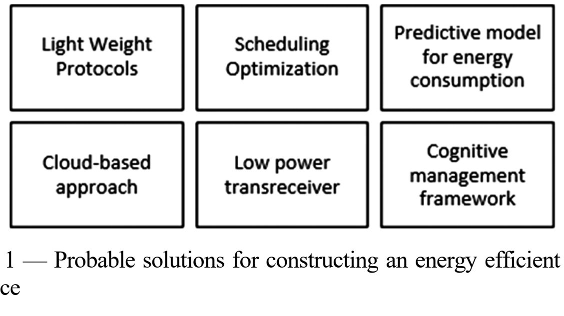

Fig. 1 — Probable solutions for constructing an energy efficient IoT device

robustness. Use of these types of trans-receivers in IoT devices will enhance energy efficiency.

5. Cognitive Management Framework: For improving the services provided to the user this type of framework is implemented.[6] Productive integration of multiple devices, IoT platforms, and technologies is being used very often for power-efficient communication.

Energy Optimization

It requires three main components: (1) Modification in behavior, (2) Standardization, (3) Simple design and Life cycle management. The optimization technique for the consumption of energy begins with managing life cycle of the IoT sensor which is indicated in Fig. 2. Power consumed by the different IoT sensors directly depends on the attached peripheral. If the system becomes stable, the sensor nodes become dependent on the life cycle phase and relevancy of how data is transmitted. Considering the example of a sensor node in sleep state, the energy required would be minimum. Whenever the sensing and transmitting data is initiated, the consumption of energy increases.[7] But for an effective network of sensors, the sensor nodes should be transmitting the data at opportune timings. For this phenomenon, the power available to the sensors must be sensitively used by keeping the frequency of information required and its interval. Thus optimization trade off the timely data vs. the energy level values set for desired system performance.

Simplicity in design involves addressing of multiple obstructions for reduction in energy consumption for the IoT devices.[8] The tenant towards simple design includes:

1. Duplication should be reduced;
2. Reduction of the phases in the life cycle;
3. Transmission time should be reduced [Periodic Optimization];
4. Data Reduction [Management Algorithms];
5. The complexity of the system and circuit should be reduced [System and Circuit Design should be simple];
6. Components used for the hardware design should be minimal [Optimize Work System];
7. Reduce Loads [Optimize Load Balancing Algorithms].

Contribution

In this paper, an energy efficient data transmission algorithm has been proposed and extensive experiments are conducted to study its energy conservation efficacy in realistic IoT environment. Moreover, an efficient communication scheme for energy conservation is being proposed which includes node activity management, aggregation cum transmission of data, transmission protocols and, topology management.

System and Methods

System Architecture

IoT systems are formulated based on varieties of technologies with large numbers of smart sensors and devices. IoT devices are designed to start communication at any moment for any associated services. This initiates that IoT systems subjected to their applications are made by decentralized and complex characteristics. By taking into account the needs and the characteristics of Internet of Things application, a single recommended architecture can never be a unique solution for all the necessary applications. Thus, for a IoT system, heterogeneous architectures are required which follows an open standard.

System Model

For this work, multiple sensor nodes are concurrently connected to the gateway, which is further connected to the cloud. We have implemented Wi-Fi as the ad-hoc network which allows the sensors to communicate with the gateways. In general, there are four layers of IoT Architecture, the first is application and management layer where the sensor nodes read the data from the environment, the second is the data or information processing layer followed by the data transmission network layer and finally data gathering layer. In Fig. 3 the typical model of an IoT system for sending the data from the field sensor to the cloud through the gateway is explained. The gateway used here for the experimentation is LoRa.

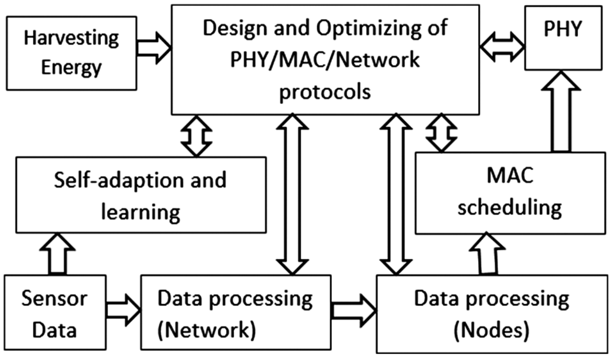

Fig. 2 — Energy Optimization for Internet of Things

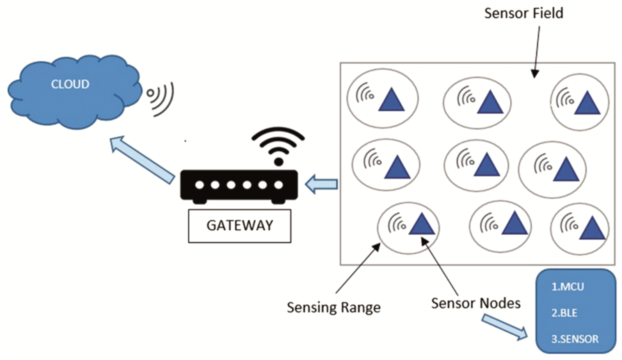

Fig. 3 — Model for sending data to cloud from sensor nodes

The sensor nodes consist of the Micro-Controller Unit, BLE (Bluetooth Low Energy) module and the sensors module for data acquisition and transmission.

The energy-efficient algorithm deals with logic and architecture of the proposed system with respect to the physical components. The input for the Energy Efficient Scheduling Algorithm is the complete network (N) deployed for transmitting data, Sensor nodes (consisting of hardware components i.e., Micro-controller, Sensors, Bluetooth Low Energy module) as (Y) and DuC as the Duty Cycle. Here, Duty Cycle (DuC) is defined as the proportion of time during which the Sensor Node transmits data to the terminal using the underlying network. DuC measures the ON time of the proposed system, where the micro-controller wakes up to transmit data and moves to the sleep modes.

It is generally expressed as percentage. The *DuC* is initialized and the state of Base Station *BS* is set active. After transmitting the data, the node is put in Modem Sleep State for a time interval. The *BS* is awakened from sleep mode and the status of node is checked at every interval of time for availability of new data to be transmitted. The steps, as defined in Algorithm 1, are executed to achieve the Energy efficiency in the IoT system.

Proposed Energy Efficient Scheduling Algorithm

Algorithm1: Steps for Enhancing Energy Efficiency
Input :(N, Y), N = Network of Y nodes deployed for transmitting data, Y_i = SensorNode i. DuC = Duty Cycle, Time (DuC) = T, t = Time of observation

Procedure:

```
1. Network N is deployed.
2. Initialize Duty Cycle (DuC).
3. The Base Station (BS) State is set active at given interval of time.
4. If the event occurs near $Y_i$, then
     a. Data aggregation is done.
        The path is selected and returned with minimum hops for sending data from source to BS.
     b. Sensor Node $Y_i$ sends the data to the IoT cloud through base station and then is put itself in Modem sleep mode.
   end
5. If no event occurs near $Y_i$ for a time t, then
      The Base Station state is set inactive.
   end
6. If no data received for T/2 then
      The Base Station State is set in active.
   end
7. If the sending of data is completed by $Y_i$ then
      Put the Sensor mode $Y_i$ in Sleep
   end
```

Experimental Setup

The hardware component used in this work is an ESP8266 microcontroller. The developed board also has a Bluetooth Low Energy (BLE) module for local transmission of data and sensors which is used for measuring temperature, humidity, and water level (i.e., DHT Sensor and Ultrasonic Sensor). The developed platform is set to be powered by a rechargeable battery which is having a drop-down voltage equal to 3.7 Volt, 2600 mAh. However, according to the data sheet, the current and voltage used by the components present in the list of operative modes is reported in Table 1.

For properly evaluating the amount of energy used by the developed hardware and identifying the different impact of the device implementation, three different configurations are considered:

Configuration 1: the testing is done for measuring the energy consumed during the working state of the microcontroller.

Configuration 2: the test aims to measure energy over-head which is introduced by the BLE and Sensors used with the microcontroller for debugging purposes.

Configuration 3: the test aims for measuring the total amount of energy required when data is being transmitted.

In the experimental setup, ESP8266 micro-controller is put into three different data transmitting modes. The energy consumption by the experimental setup at different modes i.e. working state, modem sleep state, and deep sleep state are illustrated in

Fig. 4. In modem sleep state, the micro-controller reads data from the sensor, but the Wi-Fi is in OFF condition and sending data to the cloud is interrupted. As shown in the Fig. 4, the energy consumption in the experimental setup during the deep sleep mode is significantly lower than that in the working state. So the device is chosen to put into deep sleep mode at a certain interval of time.

Performance Evaluation

In the Wireless communication module of an IoT node, the normal data transfer mode is known as Active Mode. When the micro-controller (ESP8266) of the IoT node is in idle mode, then all features of the micro-controller chip used to be in inactive state. Thus, when the mode is in an active state, it keeps the Wireless communication module, the Processing Unit, and the Bluetooth module ON at all the time. The ESP used for the practical implementation, the micro-controller chip uses more than 240 mA current to operate in the active or working state. It is also observed that there is high power consumption (790 mA) when both the Wi-Fi and the Bluetooth function together. In the case of the modem sleep mode, the micro-controller is kept in the active state but the Bluetooth, Wi-Fi, and radio are being disabled. The processing unit is kept operational, and the clock can be configured to work. In modem sleep mode, the used Micro-controller consumes about 3 mA at a lower speed of data processing and about 20 mA at higher data processing rate.

Table 1 — Current and voltage used for different operative modes for microcontroller board and trans receiver

Component	Voltage	Current
MCU (Working State)	3 V (min), 3.6 V (max)	80 mA (Operating current)
MCU (Deep Sleep Mode)	3 V (min), 3.6 V(max)	10 µA
MCU (Modem Sleep Mode)	3 V (min), 3.6 V (max)	26 µA
MCU (Modem Sleep Mode)	3 V (min), 3.6 V (max)	26 µA
DHT11 SENSOR	3 V (min), 5.5 V(max)	0.5 mA (min), 2.5 mA (max)-Measuring
DHT11 SENSOR	3V (min), 5.5V (max)	100 µA (min), 150 µA (max)-Standby
HCSR-04 SENSOR	5 V	10 mA (min), 20 mA (max)–Working Current
HCSR-04SENSOR	4.5 V	1.5 mA (min), 2.5 mA (max)-Quiescent current
BLE (Fast Advertising Mode)	3.3 V	1.52 mA
BLE (UART Mode)	3.3 V	1.86 mA (avg)

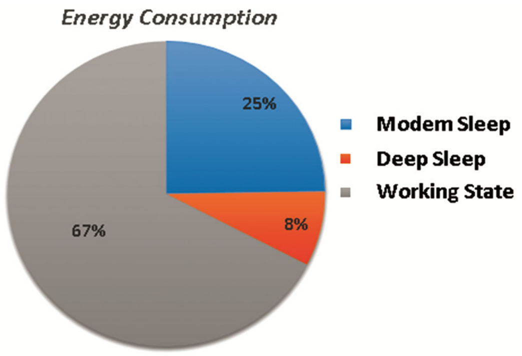

Fig. 4 — Energy consumed by Components in working mode, deep sleep mode and modem sleep mode

The steps performed for transmitting the data are illustrated in Fig. 5. The sensor node is initialized, then it activates the sensor to read data. If data is available at sensor, search for the network availability. In case the network is unavailable, the node is put in deep sleep mode else it checks for the modem wake up condition. If modem is in wake-up mode, the data is transmitted else the search is made periodically for availability of the network.

Several protocols are being used in keeping the MCU (Microcontroller Unit) in the standby modes. The RFID (Radio-Frequency Identification) impulse allows the micro-controller Unit to go into power-down mode and be awoke only when there is an external interrupt through the onboard RFID Tag.

Energy consumed by Micro-Controller Unit, when the node is in idle state is shown as (Eq. 1):

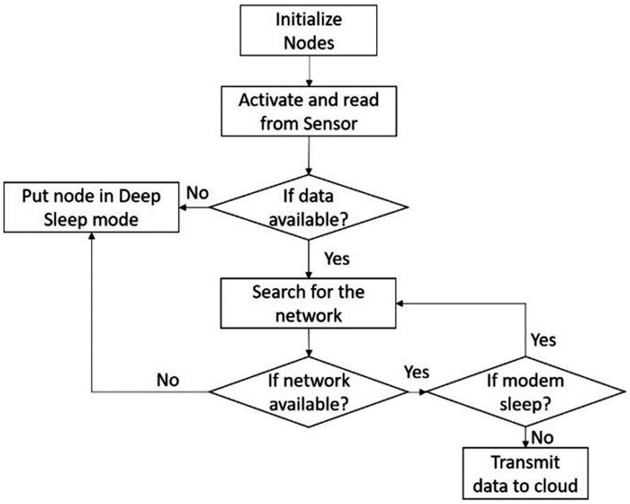

Fig. 5 — Process flow diagram for transmitting data from the sensor node

$$(E)^{idle} = (T)^{Idle} \times (I)^{Idle} \times V \quad \dots (1)$$

Here, T^{Idle} is the time for which the MCU is turned off.

I^{Idle} is the current consumed by the MCU when the node is in idle state; V represents the voltage supplied.

The power consumption plot at different modes is shown in Fig. 6. From the figure, it can be observed that the energy consumed by the experimental setup at working state is maximum, whereas energy consumption decreases when the micro-controller is put to the modem sleep state[21], the least power is consumed by the experimental setup when the micro-controller is in deep sleep mode. Energy consumed by MCU, when the node is active, is expressed as (Eq. 2):

$$(E)^{Active} = (T)^{Active} \times (I)^{Active} \times V \quad \dots (2)$$

where, T^{Active} is the time for which MCU is on.

I^{Active} is the current consumed by MCU at the working state of the node.

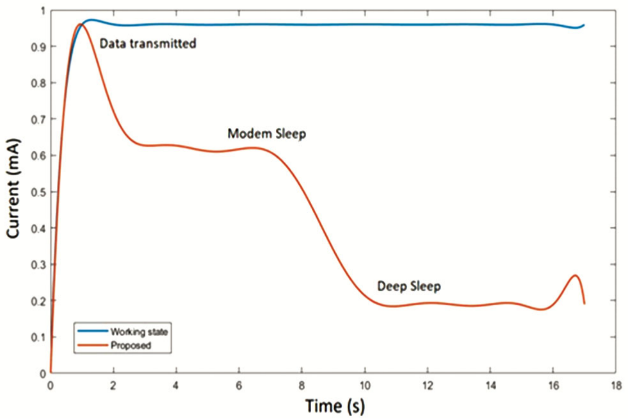

Fig. 6 — Energy consumption at working state vs. sleep states

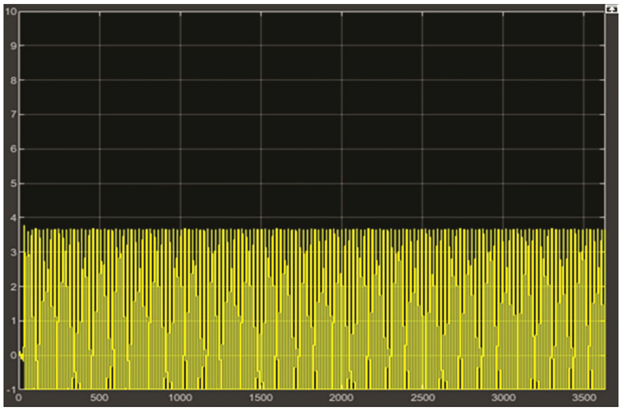

Fig. 7 — Voltage vs. time plot at working state of the micro controller unit

V is the voltage supplied to the MCU.

The plot of the input voltage which is needed for the functioning of the ESP8266 micro-controller with respect to time is shown in Fig. 7. According to the data sheet, the micro-controller needs 3.3 V for its proper functioning. The simulation shows the constant input voltage w.r.t. time which is used by the micro-controller.

When the experimental setup is continuously reading and transmitting the sensor data to the cloud, the energy consumed by the setup is maximum. The energy pulses which are being used by the components during normal working are demonstrated in Fig. 8.

Listening Energy:

Energy consumed when the MCU is active but neither transmitting nor receiving any data packets is computed using Eq. 3:

$$(E)^{l} = S/CK \times (T)^{CHA} \times (I)^{Listen} \times V \quad \dots (3)$$

T^{CHA} demonstrates time when the node becomes awake during every duty cycle.

I^{Listen} is the current drawn during listening. V is the voltage supplied. S is the sampling period. CK means Check Interval.

The sender wakes up the receiver by a Radio Frequency Identification tag following *IEEE 802.15.4* CCA and avoidance of collision technique i.e., listening energy consumed per sent packet is computed by Eq. 4.

$$(E)^{send} = (3 \times (T)^{CCA} \times (I)^{List} + (\text{DuC} + 1) \times (T)^{CCA} \times (I)^{L}) \quad \dots (4)$$

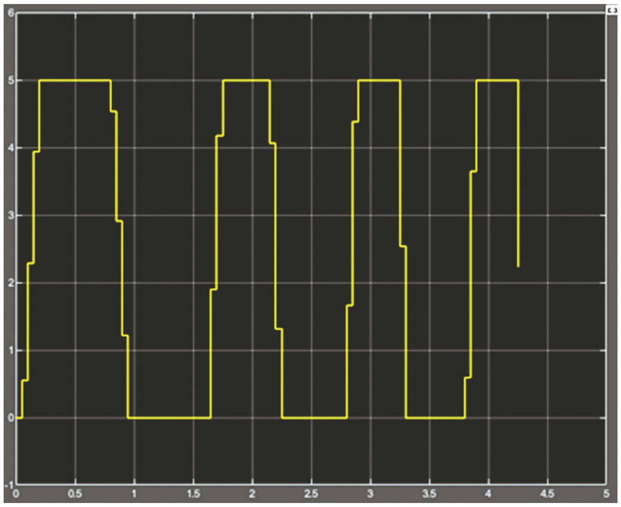

Fig. 8 — Energy Pulses which is generated during normal working

I^{List} is the current consumed when the node is listening for establishing connection. T^{CCA} denotes the minimum time interval for Collision Avoidance.

Transmission Energy:

Transmission energy considers the consumed energy used in transmitting the data packets and their corresponding control overhead. It is expressed by (Eq. 5).

$$(E)^{Trans} = (P)^{Sent} \times (P)^{Lengthofpacket} \times (T)^{B} \times (I)^{t} \times V \quad \ldots (5)$$

T^B denotes the time required to send a single byte of data. I^t is current drawn. P^{Sent} is the power consumed for sending one byte of data. $P^{Lengthofpacket}$ denotes the length of the packet in terms of bytes.

Sleeping Energy:

The energy consumed when the MCU is in sleep mode is given in (Eq. 6)

$$(E)^{Sleeping} = (T)^{Sleep}(I)^{a} \times V \quad \ldots (6)$$

The plot of the power consumed by the ESP8266 microcontroller module when the data is being transmitted are drawn and presented in Fig. 9. The simulation shows the power consumed vs. frequency during transmission of the data.

Modeling of Current Consumed and Time Required for Transmission:

The average current consumed i.e; I^{Avg} by the experimented module can be computed using (Eq.7):

$$(I)^{Avg} = (I)^{Active} \times (T)^{Active} + (I)^{Sleep} \times (T)^{Sleep} \ldots (7)$$

where, I^{Active} is the Active Current; T^{Active} is the active transmission time (Eq.10), I^{Sleep} is the Sleep Current; T^{Sleep} is the sleeptime (Eq. 8).

$$(T)^{Sleep} = (T)^{Total} - (T)^{Active} \quad \ldots (8)$$

where, T^{total} is the time for one cycle i.e.,

$$(I)^{Avg} = \frac{(T)^{Act}}{(T)^{Total}} \times (I)^{Act} + \left(1 - \frac{(T)^{Act}}{(T)^{Total}}\right)(I)^{Sleep} \quad \ldots (9)$$

where, T^{Act}/T^{otal} is the duty cycle.

$$(T)^{Active} = \frac{L^{paL}}{R^{S}} + 2L^{p/R} + T^{IRQ} + 2T\left(\frac{S}{A}\right) \quad \ldots (10)$$

where, R^S is the Data Rate. L^{paL} is the Pay Load of Data Packets. $2L^P$ is the Packet Length. T^{IRQ} is the Interruption Time.

Different cases of the performed experiment are shown in Table 2. CASE I shows the energy saved at a Duty cycle% when the IoT node is triggered from its Deep Sleep Mode (DS) and wake-up for data transfer (WD) from the sensor node and then the controller is tuned to modem sleep state (MS).

The modem sleep event eventually results in Deep Sleep mode for maximum energy saving. The CASE II demonstrates the energy saved when the IoT node after transmitting the sensor data switches to modem sleep mode, and waits for event occurrence in the same state till next set of data is available. CASE III shows the energy saved when after every event detection the IoT node returns to its Deep sleep mode.

Results and Discussion

We conducted extensive experiments by simulating different cases as described in Table 2. We logged the energy saved in each of the mentioned case by implementing our proposed algorithm. The energy required for keeping the IoT node in continuous data transmission mode and in combination of modem sleep and deep sleep mode has been measured and compared.

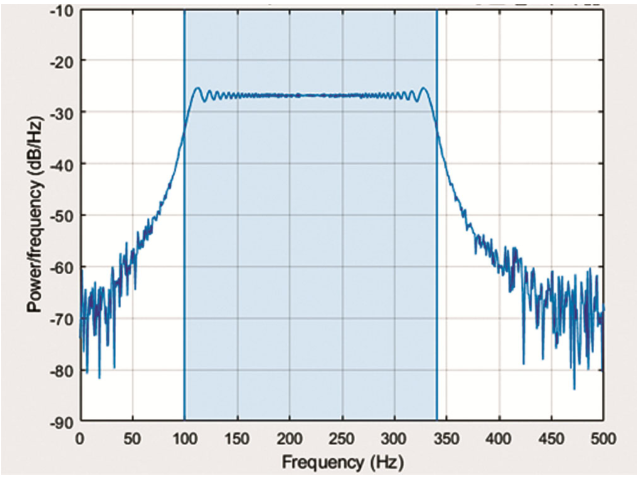

Fig. 9 — Power consumption by the micro-controller during data transmission state

Table 2 — Cases studied and analyzed while performing experiment

Case	Initial State	Event Detection	Post-data Transfer	After Threshold Time-period
CASE I	DS	WD	MS	DS
CASE II	DS	WD	MS	WT
CASE III	DS	WD	DS	DS

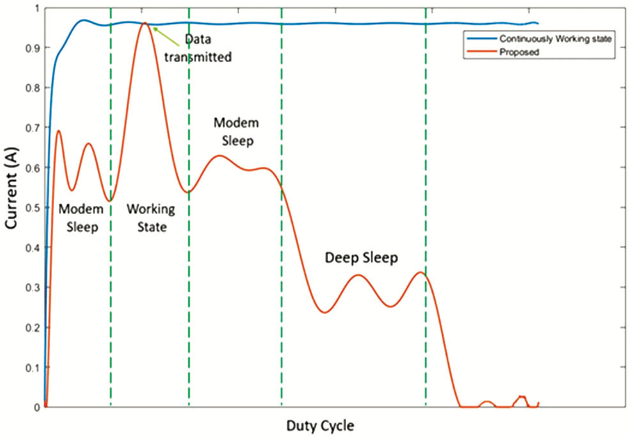

Fig. 10 — Difference between current required for transmitting data for continuous transmission vs. proposed model at a Duty cycle

Table 3 — Energy saved for each case studied at different duty cycle

Duty Cycle	Case I	Case II	Case III
10%	58.24%	32.19%	61.11%
20%	50.00%	29.51%	54.91%
30%	43.80%	27.24%	50.26%
40%	38.93%	25.29%	46.64%
50%	35.15%	23.61%	43.75%
60%	32.00%	22.13%	41.83%
70%	29.38%	20.83%	39.40%
80%	27.17%	19.67%	37.74%
90%	25.20%	18.64%	36.3%
100%	23.61%	17.70%	35.06%

Energy consumption plots in a Duty Cycle and the energy consumption when the IoT node is kept at continuous working state for transferring data from the Sensor node are shown in Fig. 10. From the figure, it can be observed that the power consumed is minimized by our proposed algorithm, a Duty Cycle (*DuC*) is being initiated, and the IoT sensor node is put to modem sleep state after transmitting the data and eventually returns to the deepsleep mode.

The percentage of energy saved at different cases is shown in the Table 3. Also, the energy saved for different Cases are plotted in Fig. 11. From the table, it can be observed that the energy saved is more in Case III as compared to the other cases at similar Duty Cycle%. This is because of the fact that in this case, wake-up mode is activated only when any event occurs. However, at other times IoT node used to be in deep sleep mode. Though, this strategy maximizes the energy saving process but it results in data transmission latency due to time taken in the process of going into deep sleep mode and then wake-up mode again and again. Whereas Case II demonstrates minimum 17.70% of energy saving in comparison to always ON condition of IoT node and also provide slowest data transmission latency.

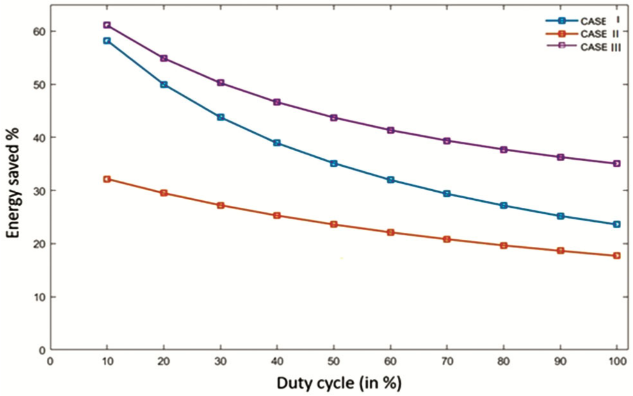

Fig. 11 — Energy saved at each duty cycle for different transmission cases

Previous works done includes an energy efficient scheme for minimizing the delays which occurs during data transmission they included procedures like reducing the distance in between the Sensor nodes and Base stations, where as in our work the sensor node is itself optimized for reducing the energy consumption by introducing three different modes i.e., Deep Sleep, Modem Sleep and Working state.

Though our results indicate a significant saving in the consumption of energy but it also has its own limitations. Here, the duty cycle scheduling technique always has a trade-off between the energy consumption and delay occurrence for delivering IoT data to the target destination. However, based on the actual application requirement in terms of data transmission latency, the appropriate energy saving strategy can be adopted to meet the data latency requirement as well as to minimize the energy consumption by the IoT nodes during its lifetime.

Conclusions

Internet of Things (IoT) is an emerging field of industrial research which has find its place in every domain of a human life. Since, these IoT node is designed to be operated on battery in always ON condition and very often also supposed to be deployed unattended in the remote places, thus it is imperative that the energy consumption in such devices are minimized. In this paper, a naive data transmission algorithm is proposed which can be deployed in different data latency requirement conditions to maximize the energy saving in the process of event sensing and data transmission by

IoT nodes. We implemented our proposed algorithm in real IoT node circuit and conducted extensive experiments in different use case scenario. We have also considered different duty cycles for our experiments. The results obtained through simulation and practical implementation show that the proposed algorithm helps in achieving sufficiently high energy saving during the data transmission process by IoT nodes with a trade-off in terms of data transmission latency. The proposed energy saving algorithm may not be suitable for the application areas, where there is hard real-time data transmission requirement. However, due to resiliency in terms of data transmission latency in precision agriculture domain or other such soft real-time application areas, the proposed algorithm can effectively be utilized. In future, we are planning to extend this research further by implementing the proposed approach for developing self-adaptive IoT networks.

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