International Journal of Electrical and Computer Engineering (IJECE)
Vol. 12, No. 4, August 2022, pp. 3869~3881
ISSN: 2088-8708, DOI: 10.11591/ijece.v12i4.pp3869-3881

Programmable timer triggered energy harvesting wireless sensor-node using long range radio access technology

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Article Info

Article history:

Received May 18, 2021
Revised Mar 19, 2022
Accepted Apr 2, 2022

Keywords:

BQ25570
Energy harvesting
Long range radio access
Programmable timer
Super-capacitor
TPL5111
Wireless sensor node

ABSTRACT

Despite widespread deployment of wireless sensor networks (WSN) in remote and inapproachable locations, energy consumption/storage of WSN hindered its adoption. Similarly, the battery-powered sensor nodes are of no use once the battery is depleted. To overcome this limitation, energy harvesting is one of the key techniques. In this paper, an almost perpetual self-powered sensor node is proposed. This sensor node uses a solar panel to harvest energy while the entire energy management is accomplished by BQ25570. Similarly, a super-capacitor is used as an energy storage unit with long range radio access (LoRa) as a transceiver unit. We measured the power generated/consumed continuously for 15 days with a transmission interval of 10 minutes. The result shows that this sensor node can potentially last for more than 7 days even at a low illuminance. Considering periodic wakeup at every 10 seconds with a sleep interval of 3 sec, a timer-triggered mechanism saves approximately 595 milliwatts of energy in one day compared to a deep-sleep mechanism. Furthermore, it is found that the application of the novel idea of external timer-driven technology in sensor node reduces energy consumption and provides a much efficient power optimization mechanism compared to the deep sleep mechanism that prevailed in WSNs technology.

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1. INTRODUCTION

With the rise of the internet of things (IoT), interest in wireless sensor networks (WSN) consisting of low-power devices has been increased drastically. These wireless networks have been used in many application areas such as agriculture, medicine, transportation, environmental science, and military purposes. In general, a wireless sensor network comprises static or mobile sensor nodes and low-power devices with limited processing capacity to collect environmental information. The tasks of a typical sensor node include sensing the environmental parameters, computing the information gathered, and transmitting them to the gateways. The battery-powered sensor nodes ease the deployment of such sensor networks. However, non-optimized medium access control (MAC) protocols for IoT and battery charging/discharging cycle are bottlenecks for WSNs reducing the lifetime of sensor nodes [1]. Many energy-aware protocols are also suggested to improve the network lifetime of sensor node [2]–[4].

For the sustainable operation of sensor nodes, energy harvesting technology has garnered much interest from the research community [1], [5]. If the sensor node can power itself by harvesting energy from its environment, then this could potentially solve an energy supply problem. Harvesting energy from sources like mechanical vibration [5], radio frequency (RF) [6], thermal differences [7], and solar [8] are promising alternatives to batteries for sustainable WSNs. Solar energy is nearly everywhere, and it has the highest power density (10% to 25%) [9] making it an ideal energy harvesting source to power WSN nodes. Although this harvested energy can be utilized to power the sensor node directly, this is not always a viable method due to the variation in power level emitted by the sources or in the absence of harvesting opportunity. Therefore, super-capacitors and rechargeable batteries can be used to store energy maintaining uninterruptable supply to WSN when the harvesting rate is higher than current usage [10]. Unlike rechargeable batteries that have a typical lifetime of 1,000 cycles, super-capacitors can withstand unlimited charge-discharge cycles maintaining stable performance [6]. Moreover, super-capacitors are not subjected to deep discharge which reduces the need of protection circuits and reduces the system complexity. Likewise, its quick charging nature makes it ideal for energy storage for WSN. Solar irradiance is non-uniform and so is the characteristic of a solar cell which is also non-linear. Therefore, to harvest maximum energy from solar, the maximum power point (MPP) path needs to be tracked which changes along with irradiance intensity [11]. Various MPP tracking methods have been developed and used to track these MPP points to obtain higher efficiency [12]. An energy management scheme attempts to increase the lifetime of a WSN by reducing the energy consumed by computation, communication, sensing, and idling states [13]. Sleep/wake-up and external timer-based interrupt schemes are mostly used schemes to minimize power consumption. The sleep/wake-up scheme is based on controlling the duty cycle of the sensor node. Duty cycling aims at reducing the power consumption of senor-node by periodically alternating between sleep and wake-up. Even in a sleep state, the microcontroller draws a significant amount of power [14]. Figure 1 shows the typical energy consumption of the sensor nodes [13]. To overcome this problem, an external timer-based interrupt scheme has been used. The external timer creates an interrupt, and the microcontroller wakes up from deep sleep, does its work, and again goes to the deep sleep state. Although this method utilizes much less power, it raises two major problems.

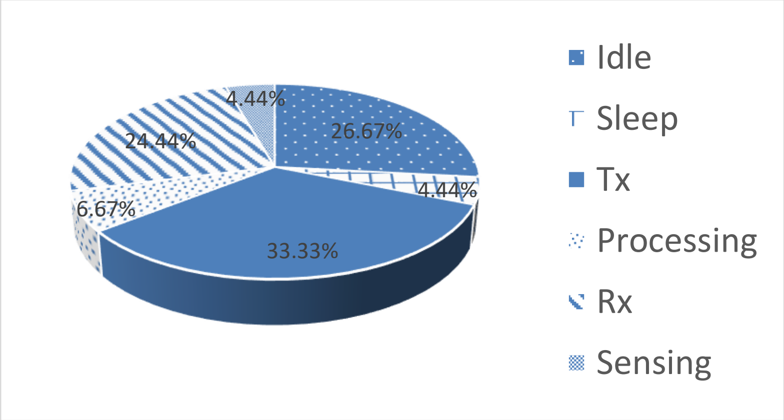

Figure 1. Energy consumption of a sensor node

What if the timer expires before computation and transmission? What if computation and transmission work is completed before the predefined set time. In the first case, there is a high chance of an unsuccessful transmission to the gateway. While in the second case, the controller stays in the idle state even after completing transmission, thereby consuming power unnecessarily. We aim to solve these problems by using a programmable timer that enables the processor after a certain interval. Once processing and transmission is completed, it turns off the entire circuitry consuming no power while continuing harvesting energy. The only unit that is powered all the time is this programmable timer (TPL5111) which consumes a very low current at a timing interval of interest [15].

This paper adopts a combination of hardware and software to selectively deactivate its sub-components (sensing unit, the transmission unit, and processing unit) to improve the overall power utilization and at the same time deploying energy harvester BQ25570 [16] from Texas instruments. BQ25570 includes two programmable converters: nano-power boost charger and nano-power buck converter which can harvest energy even at low illuminance and have the capability to overcome the cold-start operation. Such an arrangement maximizes node life as well as guarantees quality of services (QoS). In this paper, we have designed and developed energy harvesting sensor nodes that enable long-distance communication using long range radio access (LoRa) technology. A programmable timer triggered mechanism is used to power on/off the entire circuitry. Ultra-low-power hardware is selected to reduce the overall power consumption. Similarly, an analysis of the power utilization of the sensor node as well as the charging/discharging rate of primary and secondary energy storage elements (super-capacitor/lithium polymer (Lipo) battery) has been performed.

Numbers of research have been done over the past years to harvest ambient energy by converting them into electric energy and to enable the sustainable operation of WSN. RF-powered sensor node has been presented in [17]. To provide an uninterrupted power supply, energy harvester Enerchip CBC 3150 is deployed. To decrease power consumption, the duty cycle is controlled and current consumption during the different modes of operations is tabulated, and it shows good performance. The key problem with such RF sources is that they provide a very small amount of energy and the received energy depends upon transmitted RF intensity, which is also hindered by the separation distance. However, RF energy does not depend upon seasons and such kind of sensor node is best applicable for intermittent applications where the sensor node needs to send few packets to the gateway.

Lateral movement, rotation, and vibrational energy can also be harvested. In research [18], piezoelectric is used as an energy harvester, MSP4330F2013 is used as a controller, CC22520 as the transceiver, and LTC35588-1 is used as an energy manager. The accelerometer data is stored in flash memory. The harvested energy is stored in a super-capacitor and secondary cell. The secondary cell is charged via a super-capacitor which is used to power the entire node. Likewise, in case of power deficiency of the super-capacitor, the secondary storage is used to drive the sensor node. Similar work is reported in [17], where the sensor node is powered by mechanical vibrational energy as in [18]. Such applications are more suitable to monitor industrial equipment, and suspension bridges where harvesting energy is obtained from its vibrations.

To improve the lifetime of a lithium-ion battery, different mechanisms have been proposed. Most sensor nodes implement energy management in software. Li and Shi [19], proposed such energy management in hardware, which is solar energy harvester based WSN. They also highlighted the deterioration problem of a lithium-ion battery due to repeated charge-discharge cycles. A hardware-based solution for minimizing the charge/discharge cycle has been proposed using an intelligent RS trigger mechanism that triggers the charging unit when the battery voltage falls below a certain threshold, thereby reducing the charging cycle significantly. The experimental results show a significant increase in the lifetime of the lithium battery. Fuzzy logic-based solution is also proposed for energy management [20].

When it comes to monitoring environmental parameters and animal tracking, solar energy harvesting methods offer the best advantages. In study [12], the architecture of the sensor node that harvests energy from solar energy has been presented. This sensor node uses BQ25504 as an energy harvester, TI MSP-EXP430F5438 development board as a controller unit, and CC2420 as a radio transceiver. To reduce power consumption during communication, a time-synchronized channel hoping (TSCH) protocol was used. The author reported microcontroller sleep-power, software stack size, and radio transmitter/receiver were the most energy consumption units and improvement in these units would drastically improve sensor lifetime. To reduce power consumption, a sensing rate dependent on a lookup table and lighting availability has been proposed and implemented in [21] to maximize the life span of a WSN. It uses BQ25570 as an energy harvester to harvest indoor light even at low lumen and utilizes TICC2650 as a transceiver. Depending on the energy stored on super-capacitor and light intensity, the quality of service is traded. The paper claims continuous operation of the node for 15 days for five different lighting conditions. In the last few years, much work has been done on the relationship between energy and sensor life, which is a critical subject in wireless sensor nodes. Most of the papers used short-range communication technology and are either battery-powered, battery with energy harvesting mechanism, or with only harvested energy. In this paper, we aim to rely on a super-capacitor for energy storage using BQ25570 as an energy management chip and have provision for additional battery connection. Energy harvesting is done through solar and ultra-long-range communication technology i.e., LoRa is used for communication. This sensor node uses the SX1278 transceiver that relies on LoRaWAN protocol which is highly optimized for IoT. Similarly, it also possesses the ability to communicate with FossaSat [22] which is one of the open-source satellites for IoT. This ability helps to solve some of the biggest challenges in weather monitoring, disaster management, and warning systems.

Wireless networks comprising of low power devices have been used to collect the required information from static or mobile sensor nodes. These sensor nodes alternate between active mode and sleep mode. Power consumption of the sensor nodes is the serious issue to be considered. Different schemes are used to reduce the power consumption of sensor nodes. To this end, duty cycle control and interrupt triggered mechanisms are used where the subcomponents of sensor node are active all the time. Therefore, it consumes scanty power even during sensing, processing, and transmitting phase. External timer trigger though drastically reduces power during sleep mode of the sensor node but still faces problems during the following conditions: the expiration of timer’s time before computation and transmission and both computation and transmission tasks are completed before the timer time expires. Therefore, to address the above problems, the concept and operation of programmable timer-triggered wireless sensor node along with energy harvesting is discussed. It enables long-distance communication using LoRa and has programmable selective activation/deactivation ability to solve the prevailing problems with timer trigger mechanism.

The rest of the paper is organized as follows: the method is discussed in section 2 which explains sensor node architecture, software design algorithm, and hardware specification. Section 3 deals with result and discussion where performance evaluation, power consumption test and comparison with other nodes have been performed. Finally, conclusion is presented in section 4.

2. PROPOSED METHOD AND ARHITECTURE

Majority of sensor nodes are battery-powered. They do not have a selective switching mechanism and spend significant dwelling time in sleep mode. It is very important to provide efficient energy management in these sensor nodes. These factors play a key role while designing WSN architecture. We have considered all these factors to design an energy efficient the sensor node. The architecture of proposed sensor node is discussed in following sections.

2.1. Sensor node architecture

The proposed energy harvesting sensor node comprises of two components: wireless sensor nodes (WSN) and gateway linked via LoRa transceiver. LoRa network uses a star topology as shown in Figure 2 in which the sensor node sends a message to a central gateway. The central gateway was a low-cost raspberry pi that communicates with the network server. The collected information from the gateway is further transmitted to a webserver via WiFi which can be remotely monitored via internet access. ThingSpeak was used as cloud platform for visualization of data. User can login to his/her portal and visualize the collected information from the sensor node. Sensor node architecture includes energy harvesting and power management unit, microcontroller, RF transceiver, sensor interfacing unit, programmable timer, and selective power switching unit. The simplified design of the proposed sensor node and the prototype version are shown in Figures 3 and 4 respectively. Though low power controllers are available, Atmega328-au [23] (popular among developers) was used as a controller to coordinate and control the sensor node.

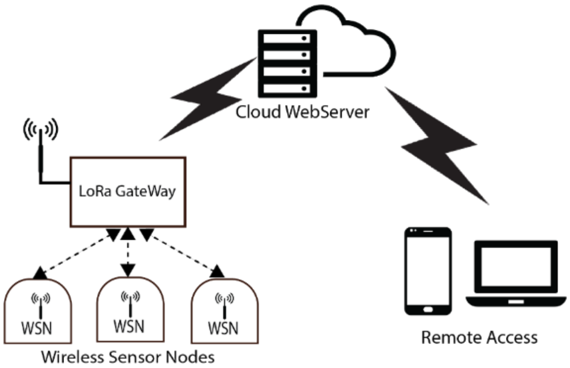

Figure 2. System architecture of LoRa sensor networks

The TPL5111 uses an external variable resistor (variable preset) to select timing intervals from 100 ms to 7200 s with a typical accuracy of 1%. Depending on the power gating (DRV) signal, the system cycles between two states: on-state and off-state for a given time interval. During on-state, i.e., when the DRV signal goes high, it enables the power supply to the microcontroller. The microcontroller then activates the sensor interfacing unit by triggering the low-dropout (LDO) metal–oxide–semiconductor field-effect transistor (MOSFET) which in turn switches the power supply to sensors. After computation on collected data, the transceiver was activated to send data to a gateway and after successful communication, the DONE pin of the timer was pulled down by the microcontroller. Upon registration of the DONE signal, the entire circuit was powered down. This process drastically reduced the overall standby current by partially switching on the required units only at the time of need. The entire sensor node was powered via BQ25570 as an energy management chip, which is a highly efficient boost converter module that converts microwatt to milliwatt from photovoltaic elements. It extracts power from solar panels even at low luminance and can store them in a super-capacitor or a secondary rechargeable cell. BQ25570 has an inbuilt battery management feature and nano-power buck converter which provides power to the sensor node in the absence of solar radiation.

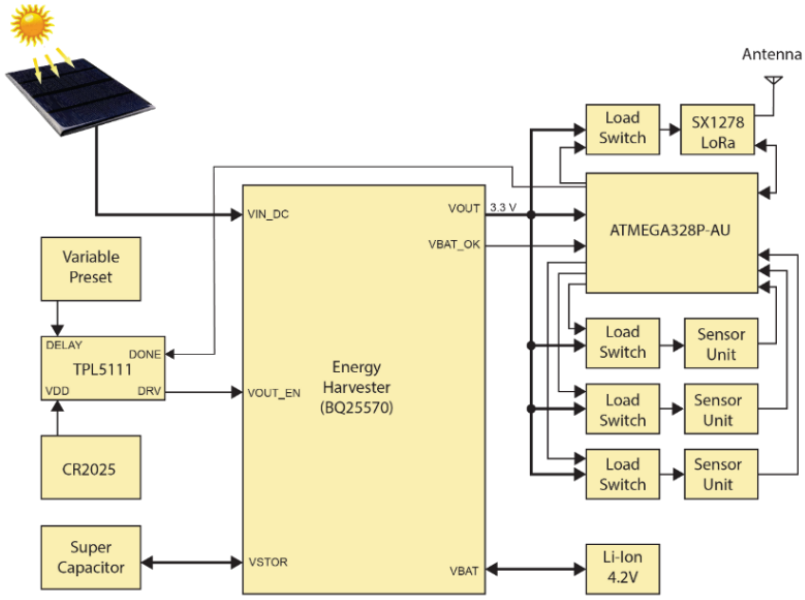

Figure 3. Block diagram of energy harvesting sensor node (TT-Mote)

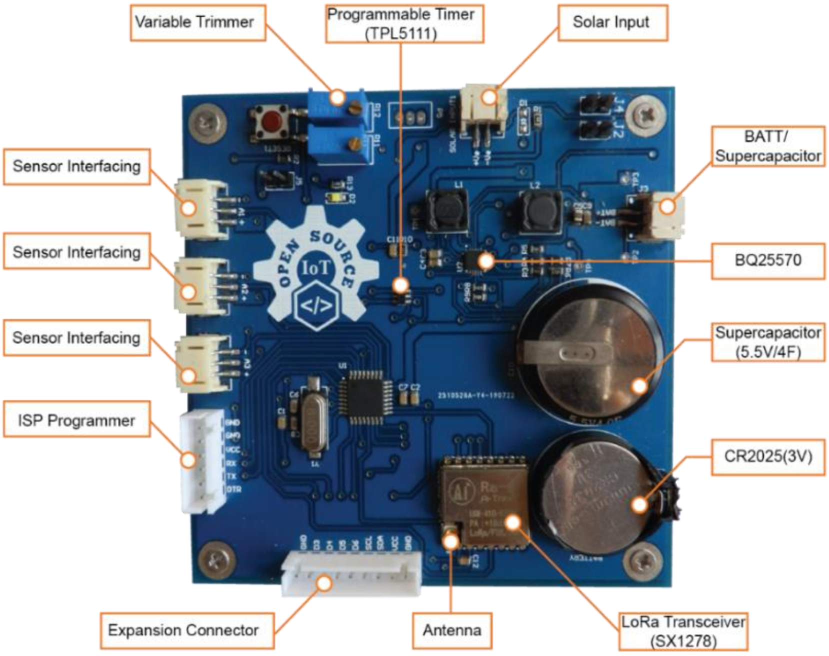

Figure 4. Prototype of the timer-triggered mote (TT Mote)

2.2. Energy harvesting architecture

The energy harvesting unit is responsible for powering the entire circuitry. The energy management was done by BQ25570 which extracts power from a low voltage harvester (solar cell) and stored it in a super-capacitor/rechargeable battery. The BQ25570 from Texas instruments is a nano-powered high-efficient boost charger and buck converter device having a conversion efficiency of 90% with maximum power point tracking (MPPT). A low start-up voltage of 330 mV made the harvester suitable to harvest energy even at low luminance allowing the use of this architecture for indoor monitoring. The entire circuitry can be powered either by a connected Lipo battery or supercapacitor.

Here, in our design, the entire system was powered via supercapacitor only but has a provision to attach a LiPo battery too. The inbuilt battery management unit of BQ25570 takes care of the battery i.e., when the battery voltage drops under 2.85 V, the entire circuitry is switched off and when charged up to 3.25 V, the circuitry is switched on again. The BQ25570 also prevents the battery from overcharging i.e. when the battery voltage rises above 4.06 V. When the battery is not connected, the internal super-capacitor is used as a storage element. Two more pins can be used for enabling and disabling the microcontroller. Setting the VOUT_EN pin of BQ25570 to a low level will disable the power supply to the microcontroller while setting the VOUT_EN high will power the microcontroller without disturbing the harvesting process. The status of the battery can be monitored at run-time via "Battery Good Output Flag" and can be transmitted to the end server for online battery monitoring.

The external programmable timer can activate the output power by enabling/disabling enable (VOUT_EN) pin of BQ25570. The TPL5111 nano timer with integrated MOSFET driver was used for power gating the VOUT_EN pin. This timer consumes only about 37 nA and is powered by an independent complementary metal-oxide-semiconductor (CMOS) battery. This solves the problem of powering the controller all the time and increases the lifetime of the sensor node. The timing interval of TPL5111 ranges from 100 ms to 7200 s, can be utilized for power gating applications. For better energy optimization, the board has three independent selectable powering sections for each RF transmitter, sensor interfacing unit, and microcontroller. The microcontroller can selectively activate independent sections according to application requirements. All these features make this architecture ideal for powering wireless sensor nodes. For RF communication, SEMTECH's LoRa transceiver, SX1278 was used. Its communication range is about 10 km with an output power of +20 dBm and uses an advanced spread spectrum. Anti-blocking as well as low power consumption makes it ideal for IoT applications.

2.3. Design of sensor node software

This sensor node adopts a periodic working and shutdown mechanism for power optimization. Programmable timer TPL5111 was responsible for timekeeping, which is an ultra-low power-consuming device. The software for the purpose of the testing was developed using open-source Arduino IDE. This program is responsible to collect sensor data and send it to the gateway via the LoRa module. Once the sensor data were collected, the sensor was powered off and the transceiver (LoRa) was powered on for data transmission. After the data had been successfully transmitted, the entire sensor node went to an off-state and was powered on only after the preset threshold time elapses. This process drastically reduces power consumption and gives better power optimization than the deep-sleep method which is mathematically explained in section 3.2. The sleep and wakeup time interval was decided by the programmable timer. One should choose appropriate resistance to set timer interval. The sensor node has a provision of selective independent switching of each unit. The programmer can use them as per their requirements. Figure 5 shows the algorithm of developed software.

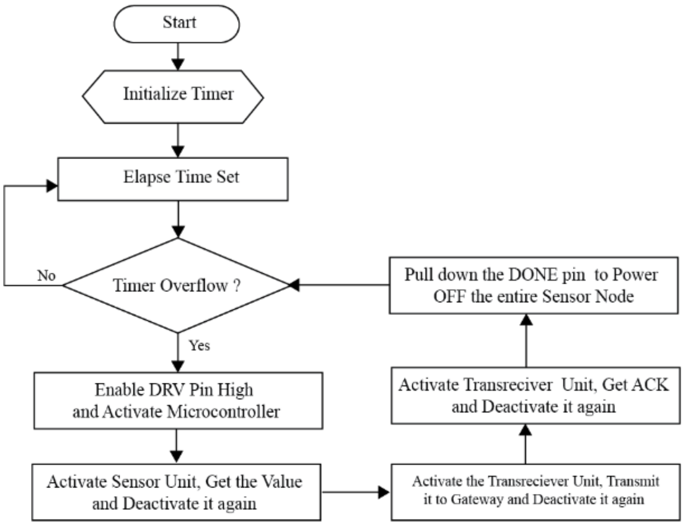

Figure 5. Software algorithm of sensor node in action

The transmitted data frame consists of the unique ID of each sensor node with corresponding temperature and battery status. After sending the data to the gateway, the sensor node waits for preprogrammed time and once the acknowledgment signal is received from the gateway after successful transmission, the timer goes off. If there is packet loss due to interference or unsuccessful communication, then the timer goes off after 5 seconds turning off the entire circuit and avoiding power consumption. Figure 6 shows the communication frame of WSN and gateway using LoRa protocol.

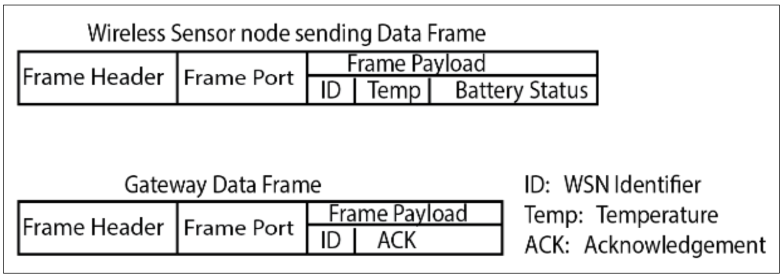

Figure 6. Communication frame between WSN and gateway

2.4. Hardware specification of sensor node

Owing to the requirement of low energy consumption and design complexity, following hardwares were chosen in our design. To make the sensor-node easily replicable, all the hardwares were chosen which are popular in open source community. Moreover, the software developed to test this sensor-node were developed using open source development environment.

2.4.1. Microcontroller unit

Atmel ATMEGA328P-AU is used as controller which is a low power 8-bit microcontroller with 32 KB of flash memory powered by 3.3 V. The chip is clocked with an 8 MHz crystal and all the controlling was done via this IC. This microcontroller is responsible for controlling and coordination with all the peripherals.

2.4.2. Programmable timer

Always on unit, TPL5111 nano timer by Texas instrument with selectable timing interval, powered by independent CMOS battery which consumes only 37 nA was used to trigger the entire sensor node. The timer time out can be chosen based on the fine tunable variable resistors. Based on resistance values appropriate time is generated.

2.4.3. Radio transceiver

Semtech SX1278 transceiver with selectable 137 to 525 MHz featuring the LoRa radio module with long range communication is chosen. It has communication range of 10 km and more with integrated +20 dBm amplifier. Low power consumption and long distance communication ability are its salient features.

2.4.4. Energy harvester unit

BQ25570 is designed by Texas instrument to efficiently acquire and manage microwatt to milliwatt from various dc sources. Different input dc sources such as Piezoelectric, and RF can be interfaced with this energy harvester. BQ25570 has inbuilt battery management with highly efficient MPPT tracker with programmable output voltage as energy harvester unit.

2.4.5. Switching unit

Texas instrument TS5A3160, which offers low ON state resistance and consumes very low power. It is designed to operate from 1.65 to 5.5 V and was used for selectively activating each independent unit. Such switch finds its best application in low power design.

2.4.6. Solar cell

Solar cell of 4.1 V, with maximum power current of 200 mA, short circuit current of 0.55 A, open circuit voltage of 5 V and output power of 200 mw with dimension 200×200 mm was used as solar harvester. This solar cell is capable of harvesting enough energy during day light. The harvested energy is utilized to power the sensor node and also spare energy is stored in super capacitor to power the node in absence of solar energy.

2.4.7. Energy storage unit

A super-capacitor rated 5.5 V with 4F was chosen as storage unit to store harvest energy from solar cell to power the sensor node in absence of solar radiation. Such capacitor has relatively quick charge time. Moreover, there is also secondary energy storage unit where small lithium-ion batteries can be interfaced.

2.5. Hardware specification of gateway

The transmitted data from the sensor unit were received, recorded, and finally transmitted to the cloud via the gateway. The gateway consists of raspberry pi 3 as a master controller and SX1278 as the transceiver. It was also equipped with a global positioning system (GPS) module to identify its location. A python script was implemented in the gateway which just reads the packets, stores them, and finally transmitted the required information to the sensor node. Not much optimization was done on the gateway side as this study was focused only on power optimization of sensor-node. This timer-triggered energy harvesting sensor node was developed considering the popularity of Arduino based on open-source library and cheap hardware popular among hobbyist and research community. The components of sensor node are summarized in Table 1.

Table 1. Components for sensor node

Components	Description
Microcontroller	Atmel ATMEGA328P-AU
Transceiver	Ra-02 AI Thinker
Load Switch	TI TS5A3160
Temperature/Humidity Sensor	DHT22
Solar Panel	4.1Volt Chinese
Battery	CR2025
Supercapacitor	KEMET 5.5V/4F
Programmable Timer	TI TPL 5111
Energy Management IC	TI BQ25570 VQFN
Miscellaneous (Resistor,preset, capacitors, connectors, headers, and others)	1% Tolerance Cap/Res

3. RESULTS AND DISCUSSION

After the successful fabrication of the sensor node, an integrated test was carried out to evaluate its performance. Similarly, power mode analysis was performed to investigate the power consumption of each unit under different states. A comparative study was carried out to demonstrate power saving by timer triggered mechanism over sleep mechanism.

3.1. Performance evaluation test

Several experiments were performed to evaluate the performance of the fabricated sensor node. Initially, the solar panel was disconnected, and the sensor node could send voltage drop status to the cloud. The operating time and voltage status were logged. The sensor and transceiver were powered up all the time and the data were logged in the cloud every second without any optimization in application code. In this experimental setup, a 4F capacitor with 5.5 Volt was used as an energy source.

The capacitor was initially charged to its full capacity before powering the sensor node. It was found that in each cycle, the super-capacitor can supply power to this sensor node for about 59 minutes without charging it up again. Figure 7 shows the voltage drop when the sensor node was powered via supercapacitor alone. The same experiment was repeated with a solar panel attached with all the features were enabled, i.e., individual switching of sensor interfacing unit, a transmitter unit, and the programmable timer was also enabled. DHT22 (temperature and humidity sensor) was interfaced in the sensor interfacing unit and the timer was set to 10 minutes. Figure 8 shows solar radiation that was recorded during experimentation and Figure 9 shows the average charging time of the super-capacitor during experiment. All these data were recorded externally in a local server.

From experiment, it was found that the charging time of a super-capacitor is less than 10 seconds. Figure 10 shows the voltage drop profile of sensor node over time during continuous operation. It shows that our sensor node was able to harvest and store enough energy to power the sensor-node for more than 10 consecutive days showing perpetual nature of sensor node.

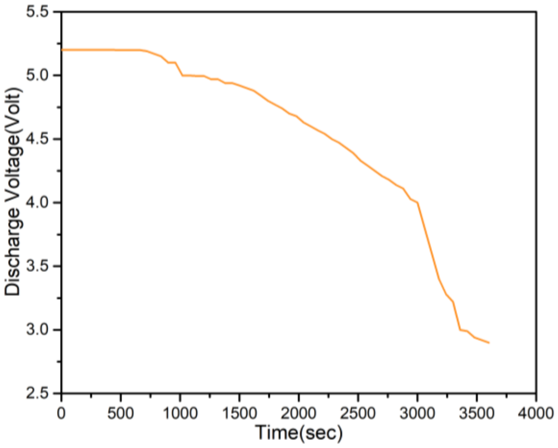

Figure 7. Discharge of super-capacitor when connected to sensor node

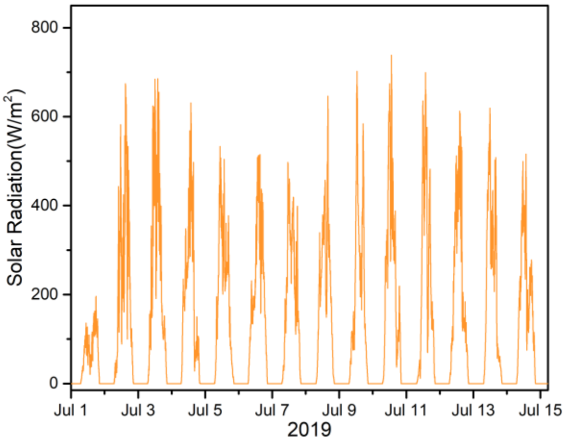

Figure 8. Variation of solar radiation during experiment

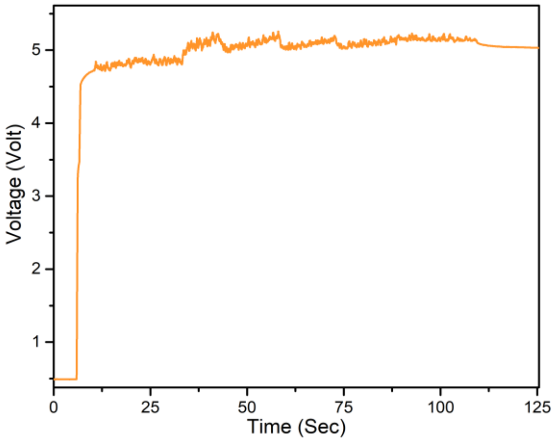

Figure 9. Average charging time of super-capacitor

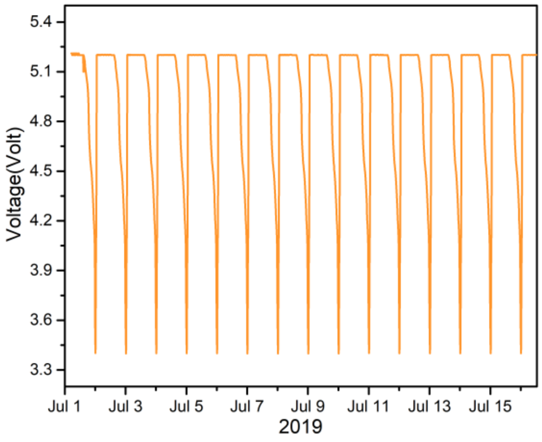

Figure 10. Charge/discharge cycle of the super-capacitor during continuous operation

3.2. Power consumption comparison

In order to compare energy consumption between sleep mechanism and programmable timer triggered mechanism, current consumed during the different operating modes of sensor nodes was calculated and tabulated. The energy consumed during sleep mode is less, but its impacts are of great importance as the sensor node spends a significant amount of time in sleep mode [20], [24], [25]. Moreover, energy consumption depends upon microcontroller operating frequency, payload size as well as transmission range; the same sensor node was used to compare in two different scenarios. For the first one, low power library was deployed [25] to let the controller go to sleep mode after a complete communication cycle. Similarly, for the second one, timer triggered power off mechanism was considered.

Window size of 10 secs was taken and average current consumption during different operating modes was noted. Figure 11 shows current consumption of the sensor node during the sleep mechanism and Figure 12 shows current consumption during the timer trigger mechanism. In both scenarios, all the peripherals were powered by the same voltage, i.e., 3.3 V. A simple, intuitive empirical mathematical model was developed to calculate total energy consumption. Total energy consumption during the complete communication cycle is given by (1):

$$E_{TOTAL} = E_{Active} + E_{Sleep} \tag{1}$$

where E_{Active} and E_{Sleep} denotes energy consumption during active and sleep mode, respectively. E_{Active} and E_{Sleep} can also be expressed in terms of power in active and sleep interval as:

$$E_{Active} = P_{active}T_{active} \tag{2}$$

$$E_{Sleep} = P_{sleep}T_{sleep} \tag{3}$$

where P_{active} and P_{sleep} are power consumed during active and sleep mode and T_{active}, T_{sleep} are active and sleep time interval, respectively.

Total energy consumed during active mode is the accumulation of energy consumed during processor's ideal state, sensor activation state, processing state, and transceiving state. Mathematically it can be expressed as in (4):

$$E_{Active} = E_{Id} + E_{Sen} + E_{Proc} + E_{Tx} + E_{Rx} \tag{4}$$

where, $E_{Id}, E_{Sen}, E_{Proc}, E_{Tx}, E_{Rx}$ are respectively energy consumed during processor ideal state, sensing state, processing state, transmitting state, and receiving state. $E_{Id}, E_{Sen}, E_{Proc}, E_{Tx}, E_{Rx}$ can also be expressed in terms of power times active interval:

$$E_{Id} = P_{Id}T_{Id} \tag{5}$$

Also, $P_{Id} = V_{Id}I_{Id}$ (6)

Similarly, other expressions for sensing, processing, transmitting and receiving can also be deduced. Since, sensor node typically spends around 99% of its lifetime in sleep mode and around 1% in active mode. Owing to this assumption, if we consider power consumption in both the scenarios then the power consumption in the prevailing method i.e., deploying sleep mechanism will consume significantly higher energy than the timer trigger activation method.

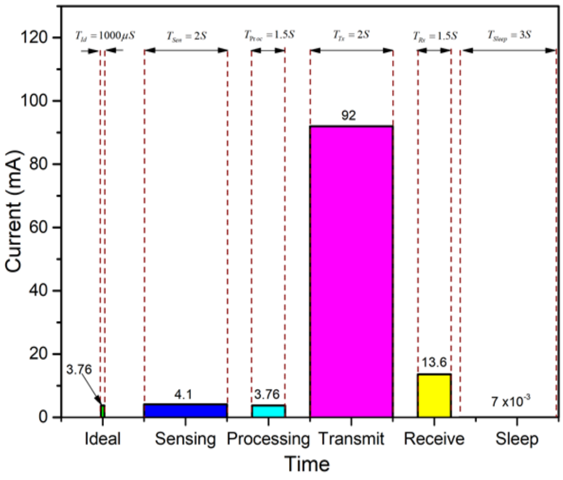

Figure 11. Current consumed in 10 s interval deploying sleep mechanism

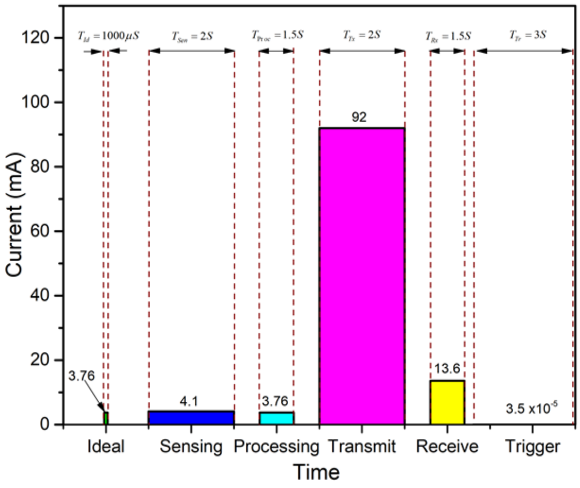

Figure 12. Current consumed in 10 s interval deploying timer triggered mechanism

3.3. Energy consumption tests

Individual units were partially powered up and the energy consumption of the sensor node was measured. Unlike other sensor nodes, this sensor node does not emphasize software for power optimization. Moreover, there is no sleep and deep-sleep mode, and the application can switch individual units respectively for optimization. The sensor node was either in an idle state or in an off state while only TPL5111 was always powered on. Figure 5 shows the simplified algorithm that was implemented in the ATMEGA328-AU microcontroller to carry out necessary actions. In off state, all power sections were switched off, except TPL5111 which was always on, therefore, the only energy consumption was due to TPL5111 timer IC. The current absorbed by this timer chip was 37 nA. In an idle state, the microcontroller was only active, and each unit was selectively activated/deactivated by it for data collection and communication. Table 2 shows the average power utilization of various units of the sensor node during their operation.

Table 2. Average power consumption

Hardware	Average Current	Operation	Duration
TPL5111	37 nA	Always active	-
ATMega328P	3.62 mA	During active Period	5sec
DHT22	1.5 mA	During active	2sec
SX1278 (Tx)	80 mA	Average Power during transmission	2sec
SX1278 (Rx)	12.5 mA	Average Power during reception	1sec

3.4. Comparison of some selected sensor nodes

There are multiple sensor nodes developed by different manufacturers and individuals. These sensor-nodes have both pros and cons. We have highlighted some of the important comparison parameters with existing nodes. The most important limitation of our sensor node is that triggering event is manual. One must measure resistance to set triggering interval. However, we have fine tunning trimmer to ease the process. Table 3 shows the comparison of TT-mote with different proposed motes.

Table. 3. Comparison of selected sensor nodes with our prototype (TT-Mote)

Characteristics	Heliomote [10]	Prometheus [13]	Pible [21]	WaspMote [26]	TT-Mote (Our prototype)
Solar Panel Rating	4 V/100 mA	4.5 V/100 mA	1.5 V/31 µA	12 V/300 mA	4.1 V/200 mA
Energy Storage	Battery Ni-MH	Supercapacitors (5 V/22 F) LiPo (200 mA)	Supercapacitor 1 F/3.6 V	3.3 V/6000 mA	Supercapacitor (4 F/5.5 V)
Energy Harvester (MPPT)	N/A	N/A	YES (TI-BQ25570)	N/A	YES (TI-BQ25570)
Transceiver Type	-	CC2420(ZIGBEE)	CC2650	Semtech SX1272	Semtech SX1278
Communication Range(distance)	-	10-100 Meters	30 Feet’s	21+ km (LOS)	10+ km (LOS)
Radio Standard	-	Zigbee (IEEE 802.15.4)	BLE(IEEE802.15.4)	LoRaWAN	LoRaWAN
Data Rate	-	250 kbps	-	250 to 5470 bps	250 to 5470 bps
Deep Sleep Mode	-	2.6 µA	2.6 µA	33 µA	37 nA (Timer on)
Typical Tx Power	-	17.4 mA	9.1 mA	50.26 mA	80 mA
Typical Rx Power	-	19.7 mA	5.9 mA	49.56 mA	12.5 mA
Processor Type	-	MSP430	ARM Cortex-M3	ATmega1281	ATMEGA328P-AU
Processor ideal Power consumption	-	5 mA	5 mA	17 mA	3.62 mA
Selective Switching of subcomponents	N/A	N/A	N/A	N/A	YES
Typical Life Span	44 Hrs	Almost Perpetual	15 days	Depends on Solar and Battery	Almost perpetual if used for intermittent applications.

4. CONCLUSION

The lifetime of sensor-node and its performance is utmost in wireless sensor networks. To address this issue, we have designed and showed the experimental outputs of self-powered wireless sensor node which is useful for environmental, animal, and agricultural field monitoring applications. This sensor node was equipped with SX1278 a low powered and long-distance transceiver (LoRa), sensor interfacing unit, and trimmer to vary the wakeup time. An experiment conducted for 15 days shows that solar energy can be harvested and can be utilized for powering the entire sensor node. The charging time of super-capacitor, a primary energy storage element, was short during the day and this stored energy was enough to power the sensor node for the entire day with a periodic wake-up of about 10 minutes. The sensor node was fabricated and tested under different test conditions. The results showed that the power consumption of the sensor nodes reduces thereby increasing the lifetime of the sensor node as compared to the deep sleep mechanism. It implies that there is no need for a CMOS battery to power the TPL5111 and the supercapacitor has enough energy to power the timer all the time without any secondary battery. We tapped the power rail of the supercapacitor and connected it directly to the timer power rail without any degradation in the performance. Therefore, in the revision version, battery can be eliminated to power the timer via supercapacitor alone. Similarly, by adding another secondary storage, the developed system can resolve many issues related to lifetime and performance of the sensor node. Moreover, it has a potential to be deployed for real-world applications with a life span of about 10 years (i.e., lifetime of super-capacitor). Therefore, it can be used to eliminate the battery replacement problem forever. Such long-distance communication finds its applications where there is no telecommunication infrastructure and periodic battery replacement is difficult.

ACKNOWLEDGEMENTS

This project was supported by the Faculty Research Grant project funded by the University Grant Commission, Nepal under UGC Award No. "FRG-74/75-Engg-3".

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