# Design and Implementation of a 6LoWPAN-Based Lightweight Wireless Embedded Internet Platform for IoT Applications

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## Abstract

The Internet of Things (IoT) plays an important role in the revolution of the Internet with the rise of Industry 4.0. It is closely related to low-power embedded devices, which have not been entirely IP-enabled until now. The 6LoWPAN (acronym of IPv6 over low-power wireless personal area networks) is an IPv6 protocol for Wireless Embedded Internet. It can help enable even the minimum embedded systems with limited processing capabilities to participate in the IoT. This study investigates a reliable way of future IoT networking by designing and implementing a 6LoWPAN-based lightweight Wireless Embedded Internet platform, named Lowvy (abbreviated from low-power wireless connectivity). Lowvy is characterized by low power consumption, constrained memory, small size, a low-cost IPv6-enabled wireless embedded device, and a constrained application protocol (CoAP). We did different application experiments to test the performance of the platform in terms of received signal strength indicator (RSSI), power consumption, sensor integration, and internet integration application with 6LoWPAN. Comparing Lowvy with other wireless embedded IoT platforms, Lowvy is less expensive and more compact. Moreover, Lowvy has a powerful performance in terms of signal strength for a longer wireless distance transmission of about 25 to 30 meters and has a lower power consumption of 41.60 milliwatts.

**Keywords:** Internet of Things (IoT), IPv6 over low-power wireless personal area networks (6LoWPAN), low-power wireless connectivity (Lowvy), lightweight wireless embedded devices, Wireless Embedded Internet

## 1 Introduction

For the last two decades, the Internet has grown from academic networks to global networks used daily by over 1.4 billion people. The Internet of Things (IoT) means the communication networks to connect various objects to be sensed and/or controlled through routers, servers, computers, and mobile phones. In recent years, it has been widely applied. The vision of IoT is to make embedded devices become IP (Internet Protocol) enabled and a significant part of the Internet [1]. The IoT enables connections among many objects, allowing them to communicate and share related information with users [2]. The IoT is predicted to grow massively year by year [3], with trillions of devices potentially becoming IP-enabled. With the promise of enhanced agriculture technology [4], energy savings [1, 5-6], smart grids [7], more efficient factories [8], a better healthcare system [9-10], smart homes [11], and smart city [2], the IoT dominates the current trends in information and communication technology [12].

The low-power embedded devices may affect the greatest potential growth of the IoT since most of them have not been IP-enabled until 2009 [13]. In 2003, the 802.15.4 low-power wireless personal area network (WPAN) standard was released by the Institute of Electrical and Electronics Engineers (IEEE). It provided the first global low-power radio standard and could be said as a major milestone. Soon after, the ZigBee Alliance developed a solution for ad hoc control networks for IEEE 802.15.4 and has produced much publicity about the applications of wireless embedded technology [13]. However, besides ZigBee having a problem with a frequency-selective environment [14], it still has issues related to scalability, evolvability, and Internet integration, which are critical parts of the current IoT technology. A new paradigm, Wireless Embedded Internet, is needed to enable low-power wireless devices with limited processing capabilities to participate in the IoT [13].

Most Internet-connected devices are powerful embedded devices for networks [13]. However, direct contact with typical IP networks necessitates a plethora of Internet protocols as well as a complicated and maintainable operating system (OS). Based on these issues, the Internet Engineering Task Force (IETF) has set a new standard 6LoWPAN (acronym of IPv6 over low-power wireless personal area networks) for the Wireless Embedded Internet to tackle those problems and specifically enable IPv6 to be used with wireless embedded devices and networks. IPv6's architectural features, such as its simple header format and hierarchical addressing mechanism, make it ideal for usage in wireless embedded networks using 6LoWPAN. Due to the growing popularity of the IoT, various Wireless Embedded Internet platforms are now available on the market. However, most of these platforms consume a huge amount of power and are costly [13]. The loss of power and money will be substantially greater for large-scale systems. In addition, some applications, such as wearable devices and small-size

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robots, also require platforms with smaller sizes.

Due to these issues, this paper mainly focuses on designing and implementing the lightweight Wireless Embedded Internet platform "Lowvy" (abbreviated from low-power wireless connectivity). Since power is one of the key issues in IoT [15-16], Lowvy will utilize low-power consumption components designed to reduce current leakage and offer power efficiency in sleep mode. The designed software for Lowvy must also maximize the hardware's limited resources and put the device to sleep mode as needed. Considering the software side, the constrained application protocol (CoAP) will be utilized in this research. CoAP is a lightweight application protocol for devices and networks with limited resources [17]. CoAP has proven to have lower latency than other mainstream data management protocols [18]. Moreover, CoAP requires fewer CPU resources and bandwidth on the network. Furthermore, Lowvy's physical size will be kept to a minimum size.

The novelty, originality, contribution, and advantages of this research are summarized as follows:

(i) We designed and implemented a 6LoWPAN-based lightweight Wireless Embedded Internet platform named Lowvy including its sensor shield.

(ii) We conducted several experiments including RSSI measurement both indoors and outdoors, power consumption measurement, sensor integration test, and Internet integration application test with 6LoWPAN to discover the performance of Lowvy.

(iii) We compared Lowvy with other IPv6-enabled embedded devices in terms of RSSI, power consumption, price, and size. Lowvy has a powerful performance in terms of signal strength for a longer wireless distance transmission of about 25 to 30 meters, has a lower power consumption of 41.60 milliwatts, has a smaller size of 5.000 cm × 2.500 cm, and has a lower cost of USD 50.61. Lowvy is more compact and less expensive.

The rest of this paper is structured as follows. Section 2 discusses the designed Wireless Embedded Internet platform in terms of hardware and software. Section 3 subsequently summarizes and examines the experimental findings. We conducted several studies to test the performance of the designed Wireless Embedded Internet platform in terms of received signal strength indicator (RSSI), power consumption, sensor integration, and Internet integration application with 6LoWPAN. Finally, Section 4 concludes this work.

# 2 Designed Wireless Embedded IoT Platform

This Section starts by explaining the hardware regarding the designed Wireless Embedded Internet platform, Lowvy. It covers the discussion on the minimum system, Lowvy power management, onboard antenna design, and Lowvy sensor shield. Besides the designed platform, this Section will also present the development environment of Lowvy.

## 2.1 Hardware of Lowvy Platform

To establish the 6LoWPAN network, we designed and built a wireless embedded device based on Texas Instrument's CC2538 SoC (System on Chip), primarily suited for wireless embedded applications, particularly nodes. We named this device "Lowvy", which stands for low-power wireless connectivity. Lowvy is a lightweight wireless embedded device having an IEEE 802.15.4 radio and a 32-bit ARM Cortex-M3 CPU. With 6LoWPAN technology, Lowvy can access the Internet as an independent node utilizing a unique IP address within low-power consumption. As a result, there will not be any problems with the capacity to scale afterward. Figure 1 depicts the features of Lowvy.

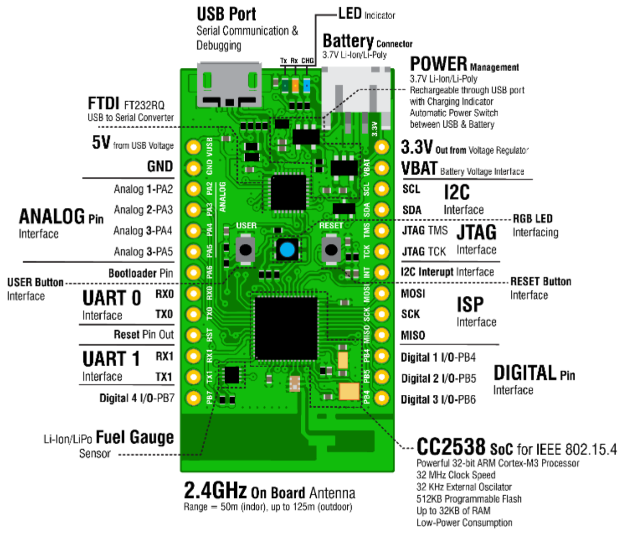



**Figure 1.** Features of proposed Lowvy

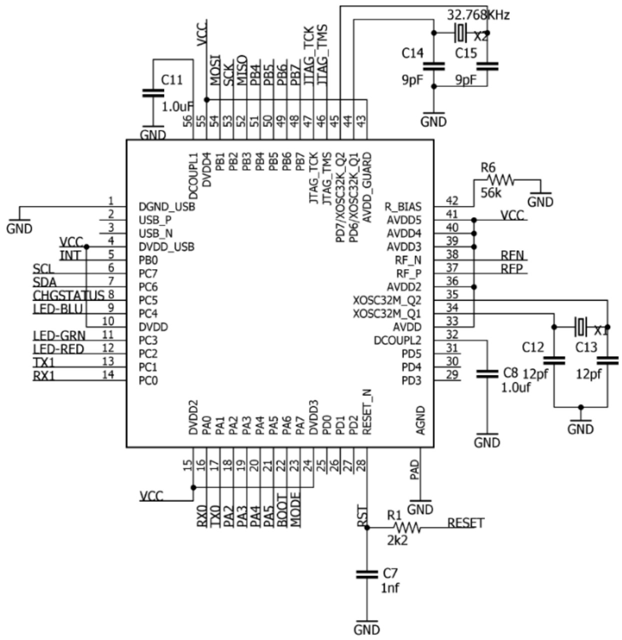
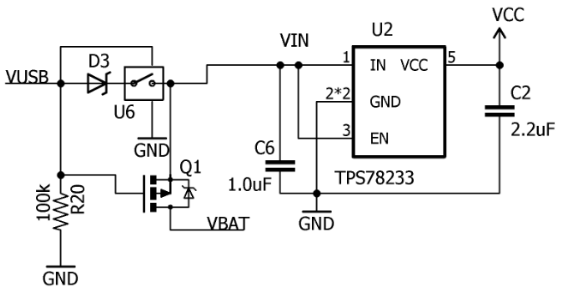


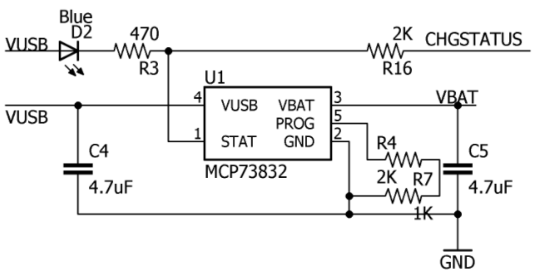

**Figure 2.** Proposed peripheral circuit design for CC2538 minimum system

CC2538 is the ideal microcontroller System-on-Chip (SoC) for high-performance wireless applications. The device combines a powerful ARM Cortex-M3-based MCU system with up to 32KB on-chip RAM and up to 512 KB on-chip flash with robust IEEE 802.15.4 radio. This enables the device to handle complex network stacks with security, demanding applications, and over-the-air flashing. Thirty-two GPIOs and serial peripherals enable simple connections to the rest of the board. Figure 2 shows the minimum system requirements for CC2538 used in the Lowvy wireless embedded device. External oscillators of 32MHz (X1) and 32.768 kHz (X2) are linked to the CC2538 SoC. To reduce voltage drop, 1.0µF capacitors (C8, C11) are connected to the DCOUPL pin on the CC2538 and utilized as decoupling capacitors. Furthermore, the VCC in Figure 2 is connected to a 3.3V voltage supply.

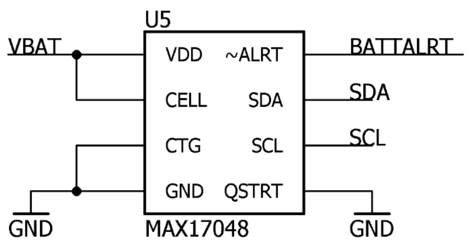
Lowvy was intended to be powered by a rechargeable 3.7V Lithium Polymer battery. Thus, it can be recharged easily from a USB port and is equipped with a Fuel Gauge sensor to monitor the charging state. Figure 3 provides a detailed diagram of the power management systems on the Lowvy embedded IoT platform.




(a) Voltage regulator




(b) LiPo charger




(c) LiPo fuel gauge sensor

**Figure 3.** Proposed peripheral circuit design for Lowvy power management

Figure 3(a) indicates that the 3.3V VCC source comes from the TPS78233 voltage regulator with input VIN from VUSB (Voltage USB) or VBAT (Voltage Battery). If USB Port and VBAT are connected to the Lowvy, U6 (SiP32431: 1A slew rate-controlled load switch with reverse blocking) performs automatic power source switching by receiving logic input from MOSFET Q1. If VBAT is connected to the LiPo battery power source, the Lowvy platform is powered by VBAT from the LiPo battery, and VUSB is used to charge the LiPo battery. As seen in Figure 3(b) and Figure 3(c), this charging process is executed by MCP73832 (LiPo charger) and monitored by MAX17048 through I2C communication.

The PCB antenna design is compatible with Texas Instrument's 2.4 GHz transceiver and transmitter. According to the datasheet, this antenna has a maximum gain of +3.3 dB and an overall size requirement of 2.57 × 7.5 mm [19]. Thus, this is a small, inexpensive, and high-performance antenna. This antenna type is known as an Inverted F antenna. Note that it is essential to replicate the antenna's identical proportions to get the optimal performance.

We also conduct a sensor integration test as part of this research. As the wireless sensor network plays an important role in supporting modern high-demand and short-range communication networks [20-21], we use Lowvy to test the sensor's reading and upload it to the web. As a result, we created a sensor shield to simplify the task. The accelerometer (ADXL346), temperature and humidity (SHT21), and ambient light (MAX44009) sensors are all incorporated within one sensor shield. These sensors use the I2C peripheral (send data & receive commands) to communicate. Because the Lowvy sensor shield has a built-in SD-Card port, we can use ISP interfacing to store our data. The Lowvy sensor shield is shown in detail in Figure 4.

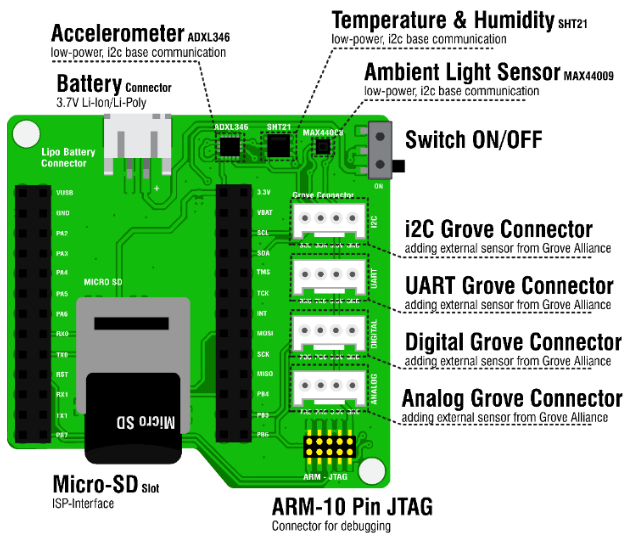



**Figure 4**. Designed sensor shield

### 2.2 Development Environment of Lowvy Platform

Contiki is an operating system (OS) for constrained devices that is small in terms of code size and RAM utilization to provide room for executing programs. It provides a request and response interaction model between application endpoints, supports built-in discovery of services and resources, and includes key Web concepts such as URIs and Internet media types. The kernel provides the most fundamental CPU multiplexing and event-handling capabilities. The rest of the system is implemented as loadable system libraries within the Contiki Core. This library contains a large variety of features with different functionalities. Contiki OS owns all of the functionalities supported by its community and the original developer.

Based on Contiki, the application of 6LoWPAN and the firmware of Lowvy wireless embedded devices were developed. Contiki is an operating system that connects tiny, low-cost, battery-powered, and low-power Internet-based connections, enabling IoT sensor and actuator network connectivity, enabling complete TCP/IP for 8-Bit MCU designs [22], and making TCP/IP viable for wireless sensor networks [23]. This operating system is open-source software, the whole code of which may be freely used for commercial and noncommercial reasons. Contiki offers low-power, lossy links, and high throughput Internet connectivity that supports fully standard IPv6 and IPv4 [24], in addition to the low-power wireless standards 6LoWPAN, RPL, and CoAP.

# 3 Experimental Results

This Section describes in-depth received signal strength indication (RSSI) and power consumption measurement as well as demonstrates how sensors were incorporated with Lowvy devices. Measurement was conducted in a real environment, not in a noise-free laboratory. To replicate actual IoT applications, we configured the Internet integration application with a 6LoWPAN-based protocol. The authors also compare several existing wireless embedded IoT platforms with Lowvy.

## 3.1 Received Signal Strength Indicator (RSSI) Measurement

The received signal strength indicator (RSSI) will be evaluated to evaluate the antenna's performance. The RSSI value can be monitored by users since signal strength might change significantly and impact wireless networking capability. The RSSI measurement results ranged from -100 to 0, depending on the chipset manufacturers and suppliers, and were measured in dBm. If the RSSI number is near zero, it indicates that the signal is excellent and can offer consistent high-speed data transmission.

We set up the experiment for RSSI measurement by connecting a Lowvy to a PC to show the RSSI value through a serial connection; this Lowvy served as the receiver, while another Lowvy platform sent signals to the receiver every second. In addition, we gradually changed the distance between the Lowvy receiver and transmitter and performed the measurement in both an outdoor and an inside setting. Figure 5 shows the experimental setup for the RSSI measurement.

The data shown in Table 1 and Table 2 indicated that Lowvy wireless embedded devices performed better in an outside setting with a maximum range of 80 m. These results are expected to be given that the indoor environment has noises from other radio frequencies, such as Wi-Fi, other appliances, and even from the wall inside the room. Since Lowvy was built to support mesh networking, the range issue in an indoor setting might be resolved by adding an extra Lowvy embedded IoT device as an extension or bridge to cover a greater region. This is a crucial aspect of IoT about scalability.

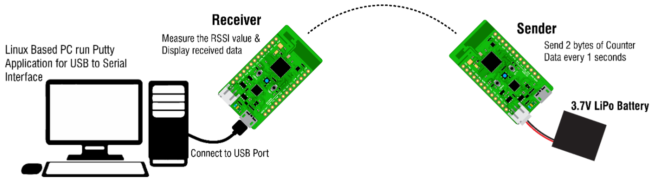



**Figure 5.** Lowvy RSSI measurement

**Table 1.** Mean RSSI measurement value in the indoor environment

| Ranges (m) | RSSI value (dBm) |
|---|---|
| 5 | -62.5 |
| 15 | -79 |
| 25 | -82.5 |
| 30 | -87 |
| 35 | -96.5 |

**Table 2.** Mean RSSI measurement in the outdoor environment

| Ranges (m) | RSSI value (dBm) |
|---|---|
| 5 | -56 |
| 15 | -71.5 |
| 25 | -80.5 |
| 30 | -82.5 |
| 35 | -84.5 |
| 40 | -87 |
| 60 | -91.5 |
| 80 | -96 |

## 3.2 Power Consumption Measurement

The power consumption measurement of Lowvy wireless embedded devices is presented. The core principle of the current consumption measurement is to display the current profile on an oscilloscope by measuring the voltage drop across a fixed resistor. The experimental setup for the power consumption measurement is presented in Figure 6.

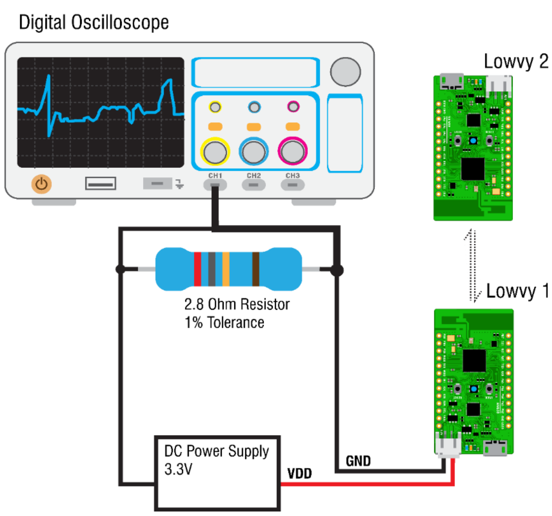



**Figure 6.** Power consumption measurement

Figure 7 displays the current consumption measurement plot of Lowvy. Since there is a linear relationship between voltage and current (Ohm's Law), we could calculate the voltage value and power usage. Table 3 presents the particular current consumption in each region of the current plot in Figure 7.

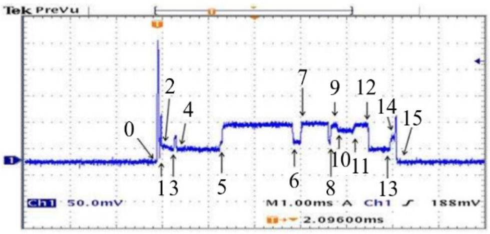



**Figure 7.** Current consumption measurement plot

### 3.3 Sensors Integration

As seen in Figure 4, the Lowvy sensor shield was developed to integrate various sensors and communicate via several peripherals, including UART, I2C, Analog, and Digital signals. In the IoT industry, the ability to interact with the physical world through sensor measurement is a crucial aspect of the future, so we designed the Lowvy embedded platform to easily integrate with a variety of sensors, such as the ADXL346 accelerometer, the SHT21 temperature and humidity sensors, such as the ADXL346 accelerometer, the SHT21 temperature and humidity sensor, and the MAX44009 ambient light sensor, via I2C communication. In addition, we would incorporate air quality and humidity monitoring using the grove sensors module. By building a library for these sensors, we also provided an API (Application Program Interface) that enables users to utilize these sensors through easy programming. Figure 8 illustrates how sensors are included in Lowvy devices.

**Table 3.** Power consumption measurement breakdown

| Region | State description | Voltage (mV) | Current (mA) | Time (ms) | Power (milliwatt) |
|---|---|---|---|---|---|
| Before 0 | Power Mode 2 | 0.0045 | 0.0016 | 0.0000 | 0.0000 |
| Point 0 to 1 | Wake up from sleep peak 1 | 267.9880 | 95.7100 | 0.0600 | 25.6503 |
| Point 1 to 2 | Wake up from sleep peak 2 | 89.9920 | 32.1400 | 0.0480 | 2.8926 |
| Point 2 to 3 | MCU wakes up from sleep 32 MHz clock | 28.0000 | 10.0000 | 0.2320 | 0.2800 |
| Point 3 to 4 | MCU clock changes to 8 MHz | 43.9880 | 15.7100 | 0.0640 | 0.6912 |
| Point 4 to 5 | MCU is running on 8 MHz | 21.0000 | 7.5000 | 0.8760 | 0.1575 |
| Point 5 to 6 | CSMA-CA before sending the MAC data req | 67.9840 | 24.2800 | 1.0630 | 1.6510 |
| Point 6 to 7 | Switch from RX to TX | 35.9800 | 12.8500 | 0.1920 | 0.4626 |
| Point 7 to 8 | Packet TX (MAC data req) | 70.0000 | 25.0000 | 0.5760 | 1.7500 |
| Point 8 to 9 | Switch from TX to RX | 35.9800 | 12.8500 | 0.0480 | 0.4626 |
| Point 9 to 10 | Switch from TX to RX | 63.9800 | 22.8500 | 0.1520 | 1.4624 |
| Point 10 to 11 | Radio is receiving the MAC ACK | 57.9880 | 20.7100 | 0.3480 | 1.2012 |
| Point 11 to 12 | Radio/Code processing | 65.9960 | 23.5700 | 0.0880 | 1.5556 |
| Point 12 to 13 | MCU in active mode is running on 8 MHz | 21.9800 | 7.8500 | 0.9240 | 0.1727 |
| Point 13 to 14 | CPU clock changes to 32 MHz | 45.9760 | 16.4200 | 0.1810 | 0.7553 |
| Point 14 to 15 | Processing shuts down | 82.9920 | 29.6400 | 0.0480 | 2.4601 |
| After 15 | Power mode 2 | 0.0045 | 0.0016 | 0.0000 | 0.0000 |
| Total | | | | 4.9000 | 41.6052 |

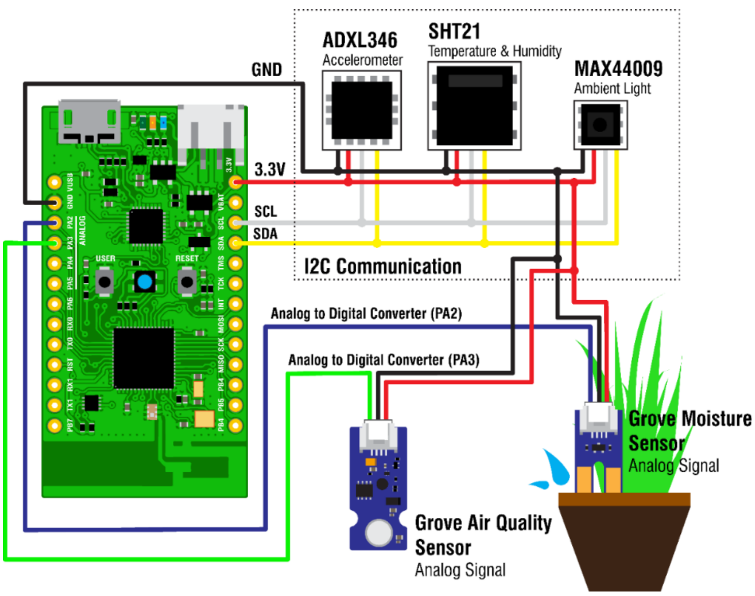



**Figure 8.** Lowvy with the integration of sensors

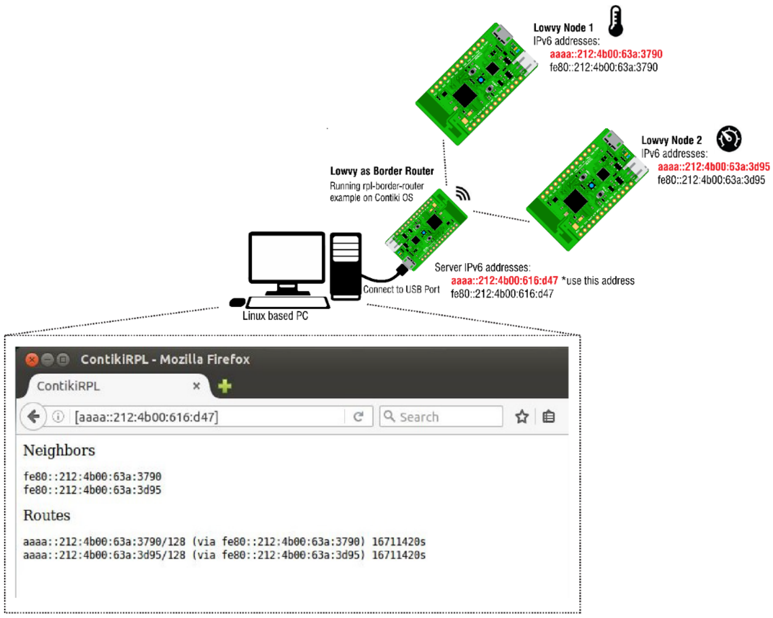



**Figure 9.** Configured network for sensor integration test

As sensor integration is a crucial component of Wireless Sensor Networks, it is presented here. Each node will incorporate a Lowvy with many sensors, as seen in Figure 8. In this experiment, we utilized three Lowvy embedded IoT platforms, two of which served as nodes and the third as a border router. If we access the IP address of these nodes using a web browser, we should be able to view the current sensor readings (temperature, humidity, ambient light, and air quality). If we query the IP address of the border router, the routing configuration would be displayed through neighbor discovery. Figure 9 depicts the implementation's settings.

Once the border router has appropriately identified all system nodes, we can access them through a web browser using their IP address. In this example, we accessed the Lowvy node 1 using the IP address aaaa::212:4b00:63a:3790. As a result, the Lowvy node 1 will display the current sensor reading, as seen in Figure 10.


**Figure 10.** Accessing Lowvy nodes through a web browser with their IP address

### 3.4 Internet Integration Application with 6LoWPAN

In Subsection 3.3, it is shown that the Lowvy worked properly with multiple sensors integration. In this Subsection, we also presented the Internet integration of Lowvy with 6LoWPAN, particularly in the application of an environmental monitoring system. In this application, we used four sensors to measure environmental conditions (temperature, humidity, ambient light, and air quality). We implemented a broadcasting communication scheme and made the border router the subscriber for the particular information from the Lowvy node, as shown in Figure 11. By applying this scheme, we could have more than one subscriber subscribed to the Lowvy node.

On the software side of this particular system implementation, we developed an application that could run on various processes simultaneously, taking care of the sensor initialization and readings independently from other network-related processes. This application made it easier for the users to maintain the program by separating the hardware side operations from the network side processes. After collecting the data, we utilized UDP application protocols to publish the information on the Internet. Since IPv6 was intended for this application, we may operate a local network with an aaaa::1/64 prefix for testing and utilize a public IPv6 prefix for connecting remotely from anywhere in the globe or to other IPv6 devices and networks. As illustrated in Figure 6, a local network was operational with a Raspberry Pi functioning as a Border Router and running an IPv6 UDP server to interact with IPv6-based computers (UDP over IPv6). The Border Router creates a virtual interface called tun0, similar to the wlan0 WIFI interface, so packets or data coming from the 6LoWPAN network are forwarded as IPv6 packets. Finally, to finalize the application, we made a dashboard to monitor the sensor's values using Ubidots cloud service. Table 4 shows the protocol stack of the environment monitoring system with 6LoWPAN in this research. Also, the dashboard made using Ubidots cloud service is shown in Figure 12.

**Table 4.** Protocol stack for the environment monitoring system

| Layer | Protocol |
|---|---|
| Application | CoAP |
| Transport | UDP |
| Network | IPv6 |
| Adaptation | 6LoWPAN |
| Data Link | IEEE 802.15.4 MAC |
| Radio Duty Cycling | ContikiMAC |
| Physical | IEEE 802.15.4 PHY |

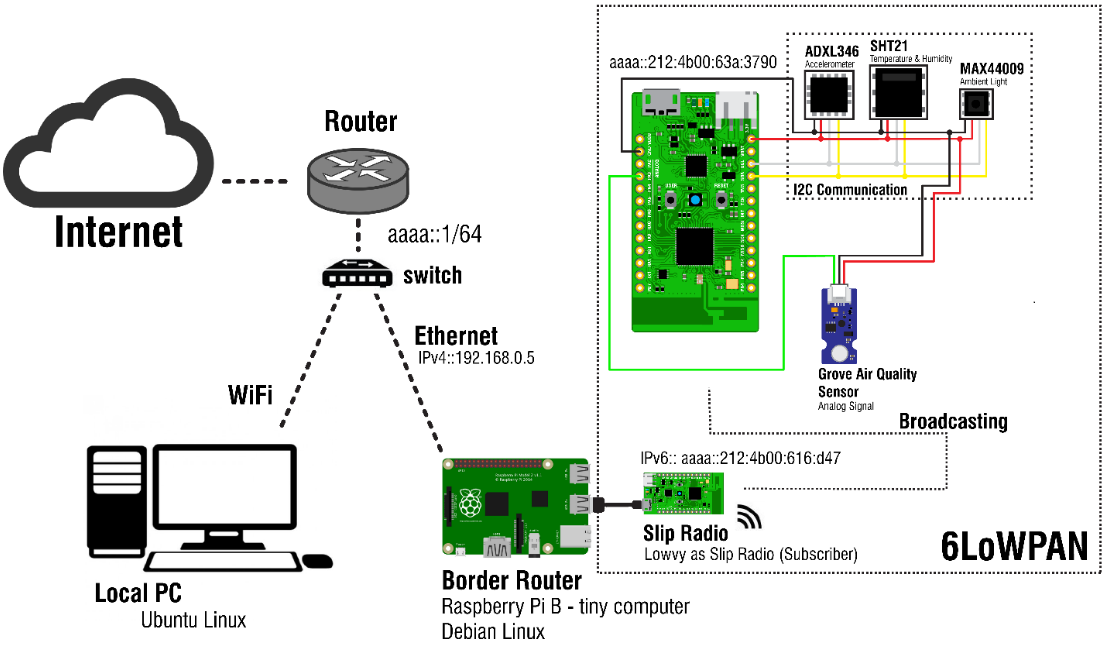



**Figure 11.** Environment monitoring system implementation with 6LoWPAN

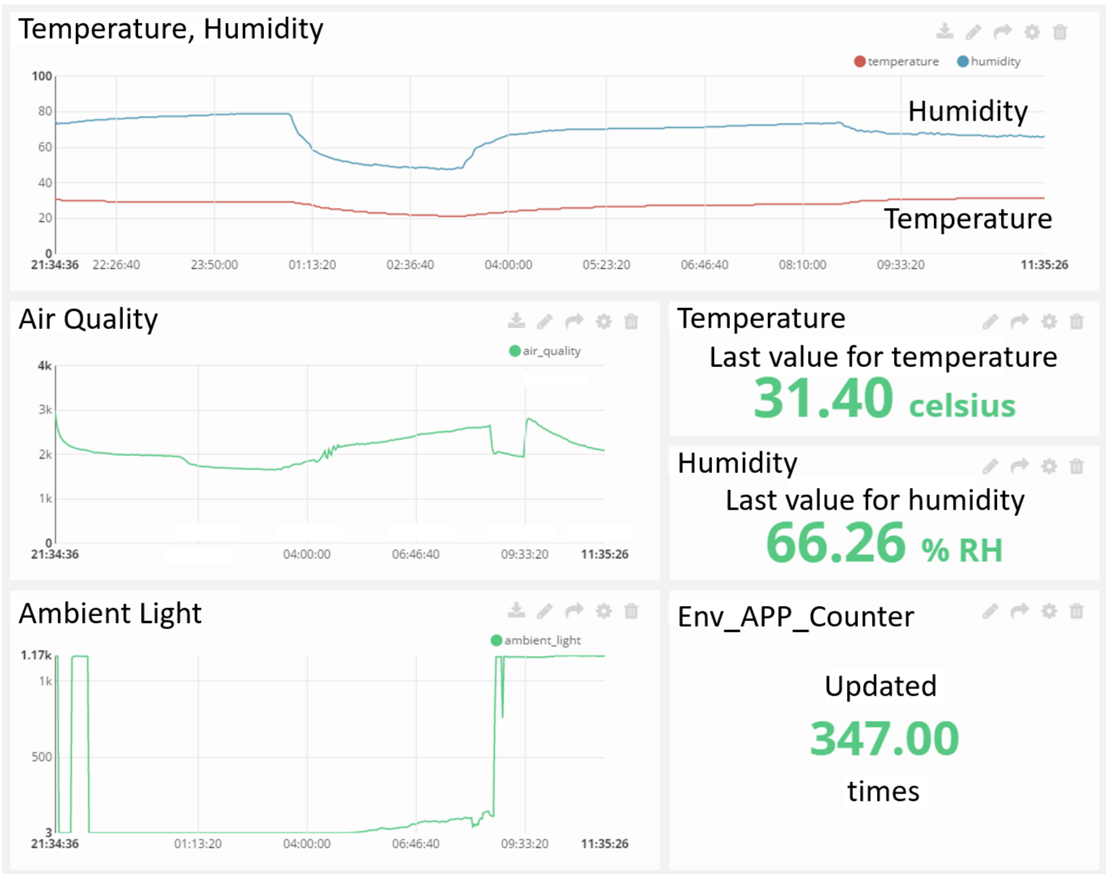



**Figure 12.** Ubidots dashboard interface displaying the measurement results

### 3.5 Comparison with Other Wireless Embedded IoT Platforms

To prove the performance of Lowvy, we compared Lowvy's performance with several popular embedded devices. Efendi *et al.* [25] have successfully utilized TI CC2530 to construct battery-less 6LoWPAN-based wireless home automation with IPv6 protocol, and such a design has been proven better than the previous research. Next, Arduino, as one of the most famous platforms, is also proven to be reliable for IPv6 protocol applications. Patil *et al.* [26] have applied IPv6-based home automation using Arduino. Last, according to the datasheet [27], ESP32 also has supported IPv6 applications.

In this research, we compare the RSSI value and the power consumption of Lowvy with other embedded devices. Next, comparing the size of the board is also necessary. In some applications, such as wearable devices and small robots, considering the size of the board is crucial. Lastly, the cost of a piece of board is a highly essential aspect of large-scale systems. Consequently, we compared the prices of each board. Table 5 compares the mean RSSI value of Lowvy and other embedded devices at various distances. Table 6 illustrates the comparison of power consumption for data transmitting, cost, and size of Lowvy with other embedded devices.

As shown in Table 5, Lowvy outperforms other embedded devices in terms of RSSI value at various distances. By the standard, a device with an RSSI value below -85 dB is regarded to have a weak signal. The parts marked in orange in Table 5 indicate that the RSSI value of the embedded device has been lowered to -85. The MRF24J40 [28] and ZENA [28] reached the RSSI value of less than -85 at 20 m. At 5 and 6 m, Arduino Nano 33 [29] and the CC2530 [30] signals already have attained RSSI values less than -85. Last, the Lowvy RSSI value remained greater than -85 at 25 m and less than -85 at 30 m. This information may indicate whether Lowvy has a higher RSSI value than other embedded devices. It means that Lowvy still can work well for a longer wireless distance of about 25 to 30 meters.

**Table 5.** Comparison of mean RSSI value of Lowvy and other IPv6 embedded devices in the indoor environment without obstacles

| | Embedded device | | | | |
|---|---|---|---|---|---|
| Distance (m) | MRF24J40 [28] (dBm) | ZENA [28] (dBm) | Arduino Nano 33 [29] (dBm) | CC2530 [30] (dBm) | Lowvy (dBm) |
| 5 | -69.600 | | -77.000 | -87.000 | -62.500 |
| 6 | | -65.430 | -85.000 | | |
| 15 | -77.685 | -78.238 | | -96.000 | -79.000 |
| 20 | -93.141 | -85.169 | | -98.000 | |
| 25 | | | | | -82.500 |
| 30 | | | | | -87.000 |
| 35 | | | | | -96.5 |

Table 6 indicates that Lowvy's power consumption is significantly less than other popular embedded devices. The prices were taken from the e-commerce website in Taiwan. Since Arduino, Generic, and RedBoard [32] do not have an integrated wireless module, a wireless module such as Xbee is required, which is more expensive. Although ESP32 Thing [31] is less expensive and smaller than other embedded devices, it consumes more power. In conclusion, Lowvy is demonstrably more energy-efficient, compact, and affordable than competing embedded devices.

**Table 6.** Comparison of power consumption for data sending, cost, and size of Lowvy and other embedded devices

| Embedded device | Power consumption (milliwatt) | Size (cm × cm) | Cost (USD) |
|---|---|---|---|
| ESP32 Thing [31] | 3300 | 6.447 × 2.286 | 22.25 |
| Arduino UNO R3 + Xbee [32] | 1040 | 6.858 × 5.334 | 54.93 |
| Generic + Xbee [32] | 1130 | 6.858 × 5.334 | 37.62 |
| RedBoard + Xbee [32] | 690 | 6.858 × 5.334 | 52.46 |
| Arduino Mega + Xbee [32] | 920 | 10.160 × 5.334 | 65.56 |
| **Lowvy** | **41.60** | **5.000 × 2.500** | **50.61** |

In addition, cited references [25] and [33] did not provide the power consumption based on the milliwatt units or specify the voltage value in each region, so we could not compare it in Table 6. Therefore, we compared the total current consumption of the papers [25] and [33] with that of Lowvy in Table 7.

**Table 7.** Comparison of power consumption based on the total current for data sending of Lowvy and other IPv6 embedded devices

| Embedded device | Total current (amp) |
|---|---|
| Arduino Pro Mini [33] | 691.2000 |
| Wemos D1 Mini [33] | 6393.6000 |
| LOLIN ESP32 [33] | 3456.0000 |
| CC2530 [25] | 624.0800 |
| **Lowvy** | **357.0832** |

## 4 Conclusion

Even though Zigbee has been applied in several applications, it has issues with evolvability, scalability, and Internet integration, particularly for large-scale systems. Utilizing 6LoWPAN (acronym of IPv6 over low-power wireless personal area networks) is one of the feasible solutions for the above-mentioned issue. The 6LoWPAN protocol enables the expanding trend of embedded Internet technology in several aspects of everyday life, mostly because of its low cost, low power consumption, scalability, and flexibility to existing technologies. In this paper, we have designed the lightweight Wireless Embedded Internet platform, Lowvy (abbreviated from low-power wireless connectivity). By implementing IPv6, the most recent version of the IP standard, we could effectively enable Lowvy as a wireless embedded device with low power consumption, end-to-end IP networking, and a vast array of wireless embedded IoT applications. Several experiments have been conducted to evaluate the performance of Lowvy, including received signal strength indicator (RSSI) measurement, power consumption measurement, sensor integration test, and Internet integration test. In addition, we have compared Lowvy to popular embedded devices for 6LoWPAN applications. The results of the experiments indicate that Lowvy is demonstrably superior to competing embedded devices in terms of RSSI value, energy efficiency, size, and cost. Lowvy has a powerful performance in terms of signal strength for a longer wireless distance transmission of about 25 to 30 meters and has a lower power consumption of 41.60 milliwatts. Lowvy is more compact and less expensive.

Although we have successfully designed Lowvy and implemented 6LoWPAN protocols in this paper, there is still room for improvement. Further research will concentrate on expanding the system implementation to ensure the system's overall performance, particularly on very large networks, by investigating the optimal routing path of each node, implementing better node scheduling, and improving the radio duty cycling scheme to achieve greater power efficiency.

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