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Solar Irradiance and Temperature Effects on Signal Transmission Performance of LoRa Network for a Monitoring System on Island

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ABSTRACT

With the increasing interest in wireless technologies, Long Range (LoRa) communication is one of the most promising alternatives for providing long-range and low-power-consumption wireless networks. Low-cost, long-distance communication, and long battery life shelf, are the best description of LoRa technology which is very useful for data transmission from an island environment. This study presents the effect of solar irradiance, air temperature, and onboard temperature on the LoRa transmission signal from the sensor node (Bidong Island). Solar irradiance was obtained from online weather satellite data (Solcast) and a solar irradiance meter, while air and onboard temperature were determined using a temperature sensor and thermal imager, respectively. The findings show that higher solar irradiance significantly decreases signal transmission strength, Received Signal Strength Indicator (RSSI). Likewise, with the decrease in onboard temperature, the RSSI signals perform better.

1. Introduction

The concerns over the long-range, effective cost, and low power consumption of networks have given rise to the interest in Long Range (LoRa) networks as one example of Low Power Wide Area Networks (LPWANs) technologies. LoRa was introduced by Semtech as a single-hop communication technology that uses battery-operated devices with limited bandwidth [1]. Due to the easy accessibility of hardware in the market and openness of its specification, which can facilitate experimental research and rapid prototyping, LoRa has recently gained more popularity than other players in the LPWAN space, such as Sigfox, Ingenue, Weightless, etc. [2].

Furthermore, the study by Liang *et al.*, [3] compared common wireless communication modes and concluded that LoRa shows the highest transmission range, lowest data rate, and energy consumption, as compared to Wi-fi, LR-WPAN, and Bluetooth. LoRa technology is generally

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considered to be a greener option for wireless communication and IoT applications compared to other technologies that consume more power and resources. Energy efficiency in green building development helping to achieve competitive advantages in terms of energy savings, environmental sustainability, and cost-effectiveness [4,5]. On top of that, LoRa has provenly been demonstrated as an Internet of Things (IoT) enabler in various applications such as smart building systems [3], smart waste collection systems [6], offshore data transmission [7], wildlife monitoring systems [2], search and rescue model [8], traffic aware channel assignment [9], CubeSat radio communication system [10] etc. People's ability to manage or monitor things remotely from a long distance away has become easier with IoT technologies. Given that LPWANs are well suited for large-scale outdoor deployments, the reliability of signal quality performance and the links between nodes are subject to environmental parameters' effects [11].

The study of the environmental impact of LoRa technology is reported with various kinds of environmental situations such as harsh environments [7], relative humidity [11], snow [12], solar irradiance and rainfall rate [13], temperature [14], the vegetation [15], etc. However, most of the available studies covered LoRa transmission between points on the land of about 20 km in rural environments and approximately 5 km in urban landscapes [16]. The studies reported by Jeftenic *et al.,* [11] conducted environmental studies of temperature and humidity impacts on four different Getaways' geographical locations in the city region of Banja Luka, and the highest distance studied was 2646 m. Meanwhile, the other study of temperature impact on LoRa from the city to the mountain was performed by Iova *et al.,* [15] with four different sites with different environmental characteristics; airport (1.5 km), bike lane (800 m), mountain (1.7 km), and forest (650 m). All of these studies acknowledged that temperature strongly and significantly impacts signal transmission; the higher the temperature, the weaker the LoRa signal.

Moreover, Elijah *et al.*, [13] conducted an experimental study on the effects of weather conditions such as solar irradiance, humidity, rain, and temperature in the tropical region at a distance of 500 m. Based on the findings of this study's analysis on solar irradiance, the periodic pattern for RSSI value increases as solar irradiance value increases. However, this finding differs from the study by Dagang *et al.,* [17] on radio signals which states that as solar irradiance rises, wireless power transmission decreases.

Despite the literature mentioned above, rare attempts have been made to link the solar irradiance and temperature effects of LoRa transmission for a longer distance, located between two points that are different in geographical land locations. To the best of the authors' knowledge, there is no vast literature addressing the evaluation of environmental conditions in a LoRa monitoring system in an island environment with up to a 23 km wide coverage range to a peninsular land as described in this paper. The aim is to study how signal strength, Receive Signal Strength Indicator (RSSI), and Signal Noise Ratio (SNR) correlates with solar irradiance and temperature between these two points. It is crucial to thoroughly examine both parameters' effects on LoRa communications and comprehend potential mitigation measures.

2. Experimental Set-Up for LoRa

The LoRa system was deployed at Bidong Island (5.6186,103.0584), which is located approximately 23 km off the coast of Universiti Malaysia Terengganu (UMT) (5.412791, 103.086726), to monitor the environmental conditions at the islands (Figure 1).

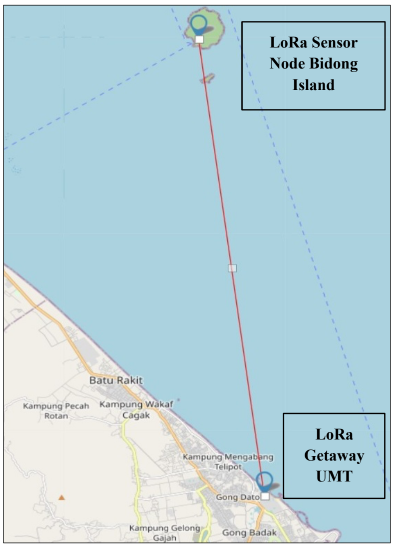


Fig. 1. Location Map of Sensor Node and LoRa Getaway

The LoRa sensor node was installed on a 6-meter-tall transmission tower at the island's peak, as shown in Figure 2.

Fig. 2. Sensor Node at Bidong Island

The environmental data were then transmitted across the South China Sea to the LoRa gateway, which was mounted at the corner of the rooftop of the six-story building at the UMT (Figure 3).

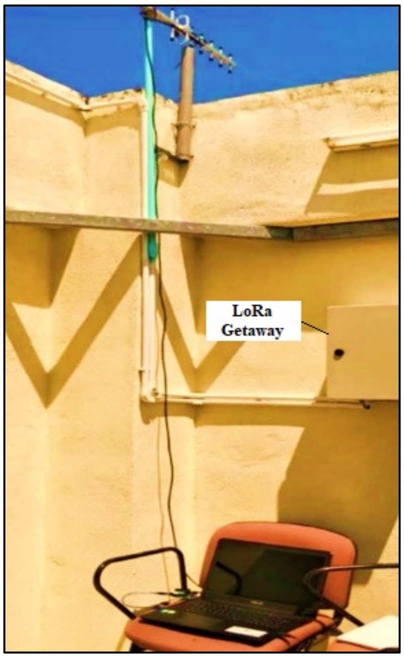


Fig. 3. Getaway at UMT Campus

Figure 4 depicts the system architecture for the LoRa environmental monitoring. To study the effect of onboard temperature on the LoRa signal strength, a temperature sensor (DHT22) was installed together with Arduino Uno (ATmega328p), battery, LoRa module (RFM95W), and Yagi-Uda antenna at the sensor node. The LoRa Gateway consists of Arduino Uno with LoRa module and Yagi-Uda antenna. The temperature profile of the LoRa Gateway was monitored using Thermal Camera FLIR TG165-X.

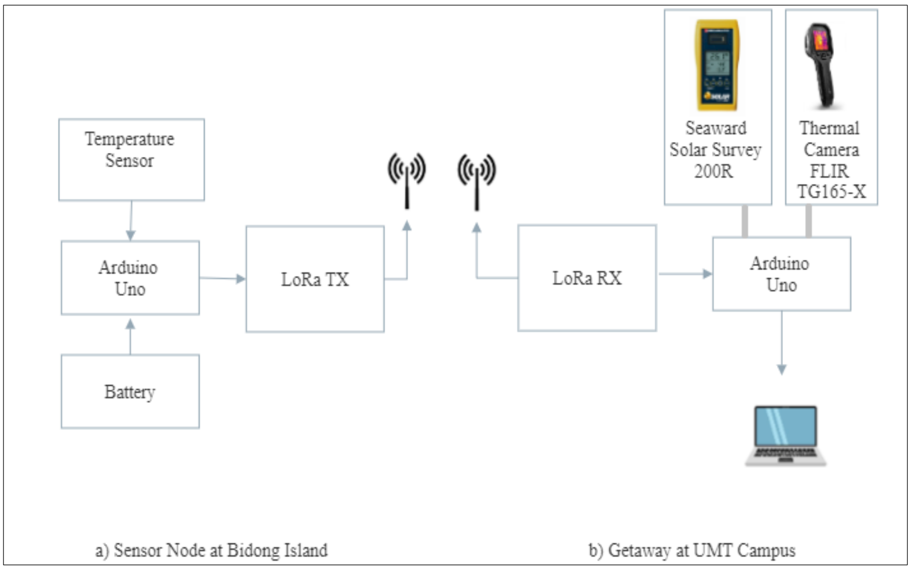


Fig. 4. System architecture for LoRa environmental monitoring

Meanwhile, the correlation between solar irradiance, air temperature, and LoRa signal strength was examined using the online weather satellite data from Solcast website [18] and the solar irradiance meter, Seaward Solar Survey 200R. The details of the environmental monitoring prototype using LoRa technology for long-range communication used in this study can be found in [19] and [20]. Meanwhile, the LoRa configuration settings for this study are listed in Table 1. It has been demonstrated that PHY layer characteristics such as frequency, bandwidth, transmit power, spreading factor, and code rate can have an influence on how effectively LoRa performs [21]. This paper reported the experiment observed for three days, 18th, 29th, and 30th August 2022.

Table 1
LoRa Configuration settings

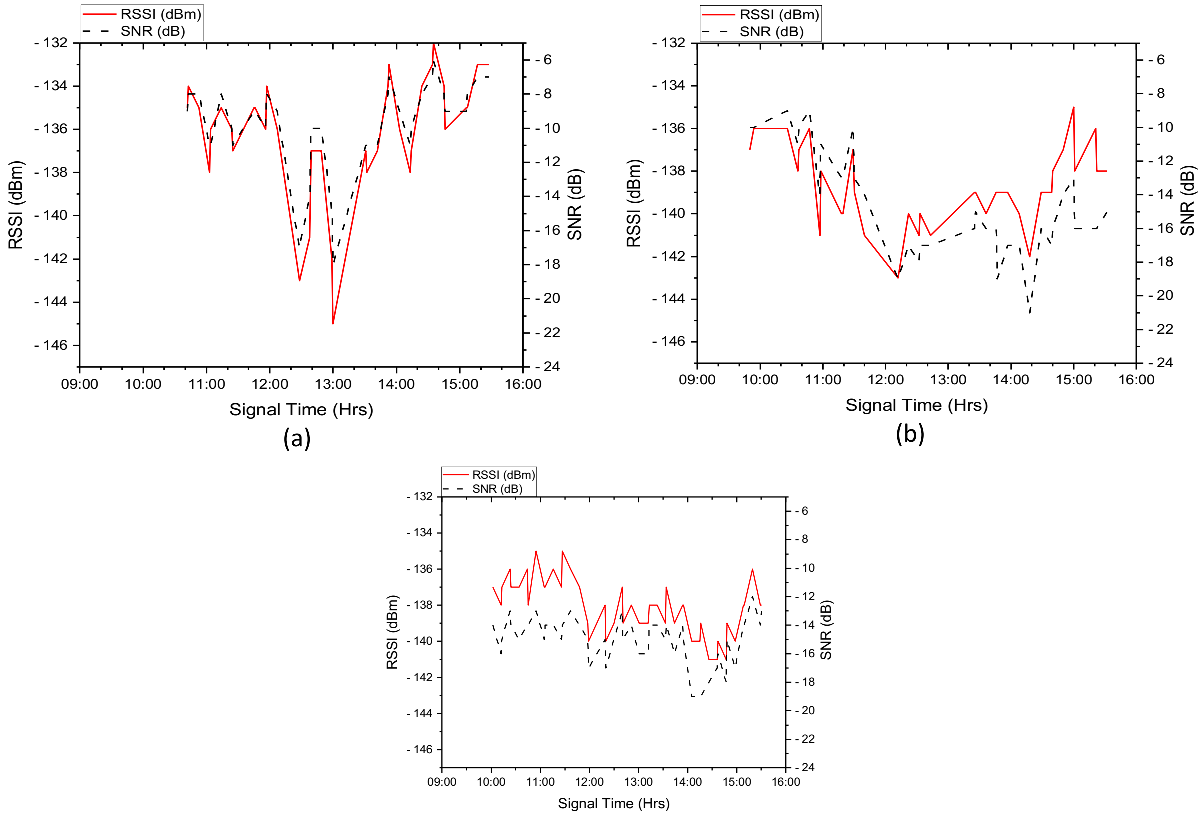
Parameters	Value
Carrier Frequency	921.90 MHz
Experimental Range	23.0 km
Spreading Factor (SF)	SF11
Bandwidth (BW)	125 kHz
Coding Rate (CR)	4/8
Transmitted Power (23)	23 dB
Payload	2 bytes

3. Experiments and Results

This section presents the effects of temperature and solar irradiance variations on the strength of RSSI and SNR from the experiment configuration and conditions mentioned in section 2.

3.1 Received Signal Strength Indicator and Signal-to-Noise Ratio

The results of signal quality performance for three days, 18th, 29th, and 30th August 2022, the Received Signal Strength Indicator (RSSI) and Signal to Noise Ratio (SNR) from the sensor node to the LoRa getaway are presented in Figure 5(a-c).



(a)

(b)

(c)

Fig. 5. RSSI and SNR value (a) 18th August (b) 29th August (c) 30th August 2022

As observed in Figure 5(a), the values of RSSI and SNR for Day 1 fluctuated and changed in a generally similar pattern when measured from around 9.30 am to approximately 3.30 pm as compared to the other two days in Figure 5(b) and Figure 5(c). The descriptive statistics of RSSI and SNR range for these three days is presented in Table 2. The linear relationship strength between these two variables is measured by Pearson correlation, and the correlation is said to be excellent if the value is close to 1.

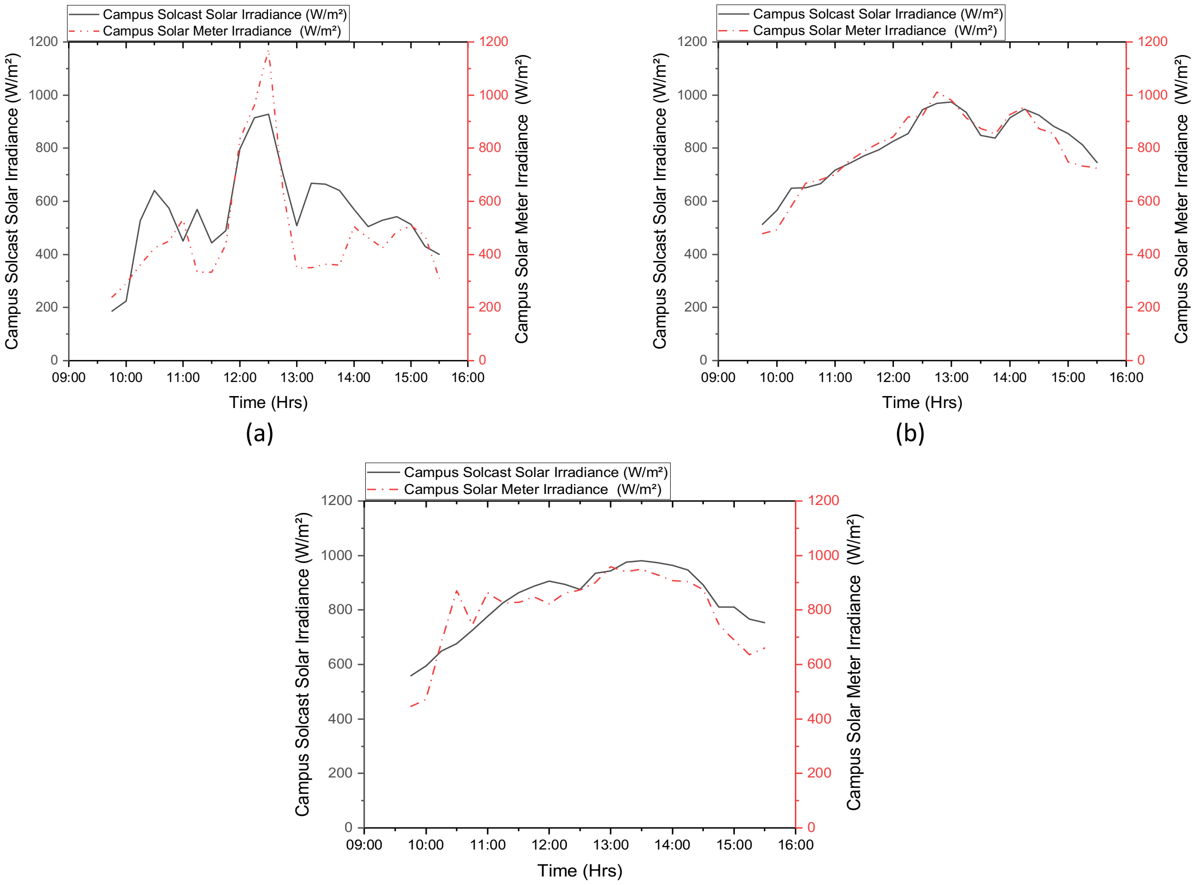
Table 2
RSSI and SNR Range with Pearson's Correlation

Days	Min RSSI	Max RSSI	Average RSSI	Min SNR	Max SNR	Average SNR	Pearson's Correlation
Day 1- 18th August 2022	-145	-132	-136	-18	-6	-10	0.9831
Day 2 - 29th August 2022	-143	-135	-139	-21	-9	-15	0.6727
Day 3 - 30th August 2022	-140	-135	-138	-17	-13	-15	0.7986

For Day 1, Pearson's correlation is close to one with an average value of RSSI is -136, and an average value of SNR is -10. According to Georgiau and Raza [22], the receiver sensitivity value for LoRa with SF11 spreading factor is -134.5 for RSSI and -17.5 for SNR. Therefore, the signal transmission link can be considered to have an excellent connection and optimal reception reliability when RSSI and SNR data are both in a good value for Day 1. Meanwhile, for Days 2 and 3, the average value of RSSI and SNR is -139 and -15, respectively, with Pearson's correlation less than 0.9. According to [23], the received signal is too poor to be demodulated when the RSSI value is less than the receiver sensitivity, which means the signals received have a stronger power when the RSSI value is higher. Various factors can contribute to the instability of this data transmission. The environmental impact on the LoRa transmission range will be discussed in more detail in the next section.

3.2 Validation of Solar Irradiance

Due to constraints of doing measurements regularly on the island, solar data from Solcast is used. Before that, data from Solcast was verified using solar irradiance taken using a solar meter. Solar irradiance values obtained from a solar irradiance meter and solar irradiance data from Solcast are collected and compared for three days, as presented in Figure 6(a-c). The same pattern is displayed for the values obtained from the two sources. Pearson's correlation is used to measure the relationship strength, and the values for Day 1, Day 2, and Day 3 are 0.8057, 0.9597, and 0.8617, respectively. In brief, all three days of data show a strong correlation value. It has been confirmed that on-ground data collection with the solar irradiance meter validates the data from Solcast.



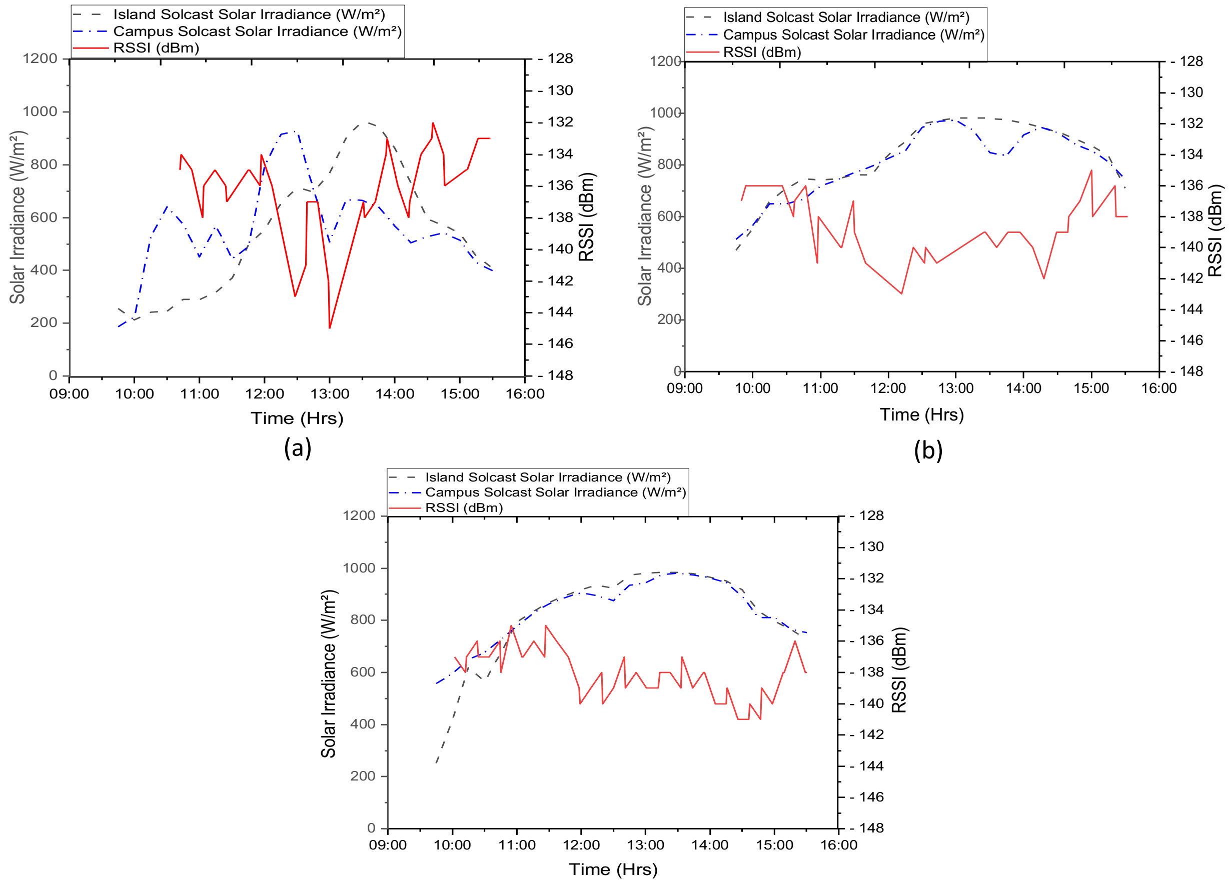
(a) (b)

(c)

Fig. 6. Solar irradiance comparison using online data from Solcast and solar irradiance meter for UMT campus (a) 18th August (b) 29th August (c) 30th August 2022

3.3 Effect of Solar Irradiance

Solar irradiance values from Solcast online data for both location, island, and campus were plotted against RSSI values, as shown in Figure 7(a-c). It can be seen from the figure that solar irradiance during Day 1 is the difference between the Bidong LoRa node and the UMT Lora gateway. Meanwhile, the pattern of solar irradiance for Day 2 and Day 3 for both locations are almost similar. It also can be observed from Figure 7 that the weak RSSI values in the range of -142 to -138 were detected, along with high values of solar irradiance between 700 to 1000 W/m^2, at times ranging from around 12.00 to 2.30 pm.



(a)

(b)

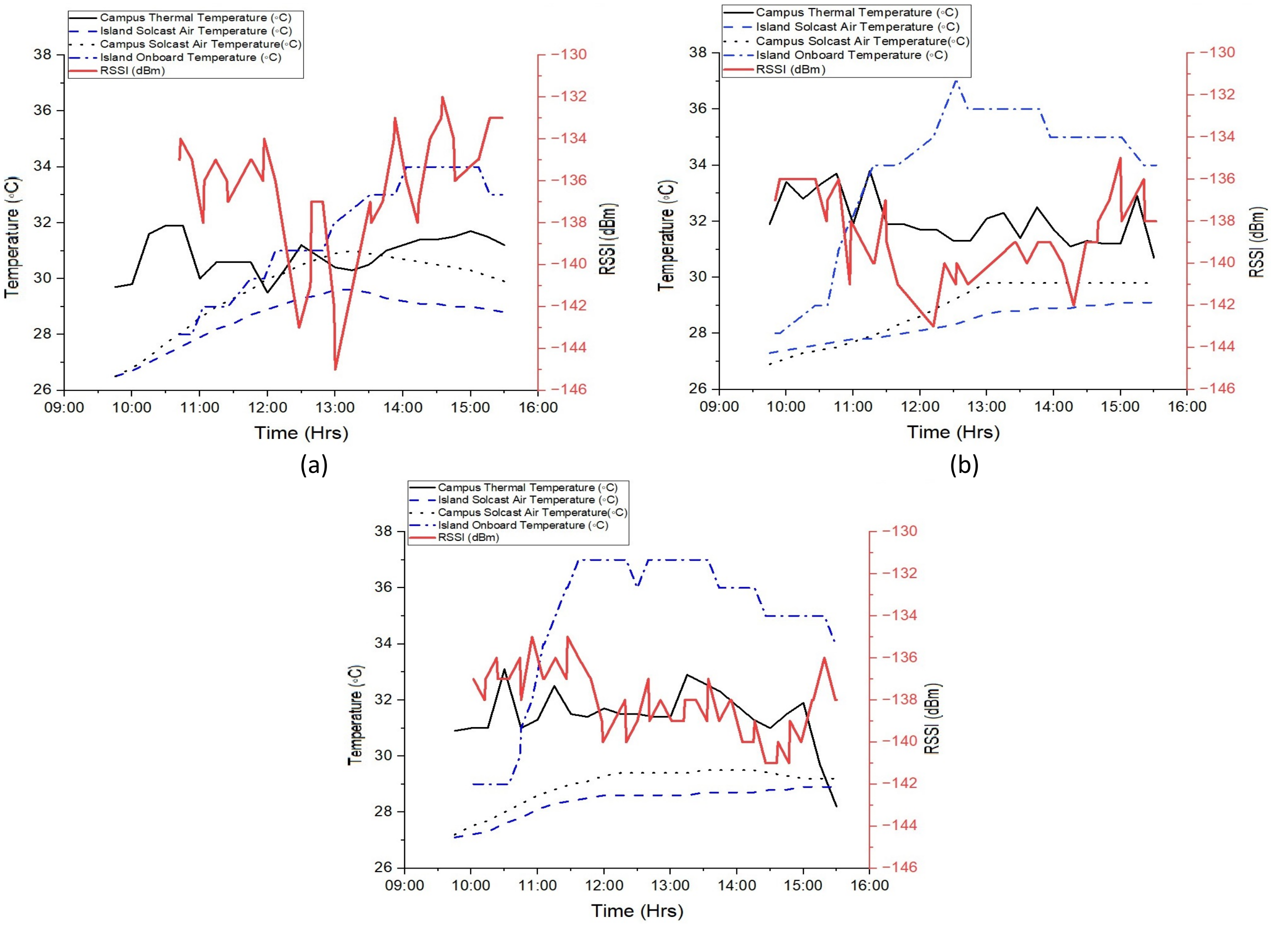
(c)

Fig. 7. Solar irradiance for island and campus versus RSSI (a) 18th August (b) 29th August (c) 30th August 2022

Pearson's correlation values were evaluated to analyse further the relationship of solar irradiance data for these two locations. The findings show a weaker value of 0.5662 for Day 1 compared to the other two strong correlations, Day 2 and Day 3, that is, 0.957 and 0.957, respectively. A similar trend of higher solar irradiance decreases the signal strength, also reported by [17]. However, this result is inconsistent with the study in [13], which reported the strong RSSI value obtained when solar irradiance is high. Considering the shorter distance of 500 meters used by *Elijah et al.,* [13], this factor might contribute to the difference in the solar irradiance impact on the Lora propagation, as compared to the longer distances of 23 km and two different lands used in this paper.

3.4 Effect of Temperature

The onboard temperature of the LoRa sensor node in Bidong Island was measured using the temperature sensor. The air temperature for both Bidong Island and UMT was taken from Solcast. In addition, the temperature for the LoRa gateway was recorded using a thermal imager. The onboard temperature, ambient temperature, and maximum temperature from the thermal imaging profile of the gateway are plotted against RSSI values, as shown in Figure 8(a-c) which show significant effects of air temperature and sensor node's onboard temperature on the signal. However, no significant correlation between the maximum LoRa gateway temperature and LoRa signal for all three days can be observed.



(a) (b)

(c)

Fig. 8. Temperature for island and campus versus RSSI campus (a) 18th August (b) 29th August (c) 30th August 2022

For day 2 and Day 3, the sensor node's onboard temperature is following the air temperature trends, in which the low RSSI is recorded when all temperatures are high. A similar noticeable degradation trend of the network performance of RSSI and SNR with the increase in temperature is also reported in [7-9,15]. Bezerra *et al.,* [12] stated that the weather effects implies that cold weather enhances the signal quality performances, but hot weather causes sensors to pick lower SFs in order to limit time-on-air. The rising ambient temperature has worsened wireless signal strength, packet loss rate, link quality, and radio receive power. In addition, the airtight and waterproof enclosures may shield the node from corrosion, humidity, and atmospheric pollutants, but they may also raise the inner casing temperature [24]. The slower microcontrollers may cause clock drifts which impact protocol that relies on synchronization as the temperature increases [26]. For future studies, a proper airway for the LoRa sensor node and getaway box needs to be done to control the temperature impact and smooth the transmission process.

4. Conclusion and Recommendation

This study evaluates the impacts of solar irradiance and temperature on the LoRa's signal strength, RSSI. The high solar irradiance raises the onboard temperature, resulting in a low RSSI value recorded. The impact of solar irradiance on RSSI transmission can be visible when there is a significant correlation between the two places. In addition to the two environmental aspects highlighted in this study, other environmental factors such as wind speed, wind direction, and air humidity could be investigated to see how they affect LoRa technology.

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