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Empirical Study of Drone-LoRa Enable to Doppler Robustness for Livestock Industry

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Abstracts: This study develops an airborne LoRa gateway system for livestock industry that can help to improve food demand. The objective of this study is to learn the doppler effect on LoRa regarding drone speed, which drone speed can achieve the optimum LoRa performance and the effect of Drone-Lora on LoRa coverage expansion. The method is carried out by developed a LoRa-based water quality monitoring system that detects water level, temperature, pH, turbidity, dissolved oxygen, and electro conductivity for livestock drinking water, as well as the LoRa gateway. Following that, for the coverage extension experiment, LoRa RSSI data is collected every 200 meters, and for the doppler effect experiment, drone-LoRa enable fly at 5 km/h with increments of 5 until maximum speed reaches 95 km/h to 100 km/h. The result is drone-LoRa enabling immune to doppler effect with LoRa spreading factor 12 and drone-LoRa capable of extending LoRa coverage by more than 10 km radius. This research aims to show that drones with LoRa capabilities can be a boon to smart farming in livestock industry by demonstrating that drone speed has no effect on LoRa performance.

Keywords: LoRa, Internet of Thing, drone

1. Introduction

The world population is expected to increase from 7.7 billion people to 9.7 billion in 2050 [1] and food demand from 59% to 98% [2]. With the increase in conventional farming, the demand for food is not appropriate. Thus, the transformation of traditional agriculture into smart farming through the use of the Internet of Things (IoT) requires an efficient way of farming. The Internet of things is a system that allows things to be connected to one another through the Internet and to connect human to human and human to things. Since years ago, IoT has been under the spotlight. More than 21 billion IoT devices are anticipated to exist in half a century [3] from now on. Smart farming can attain a low risk of production, decrease waste and cost management, increase business effectiveness, and enhance product quantity and quality [4].

As the Internet of Things has grown, new technologies have emerged, including short-range Bluetooth, Zigbee, and WiFi, as well as long-range NB IoT, Sigfox, Weightless, and Long Range (LoRa). According to [5], LoRa is the most widely used wireless radio frequency communication technology in the IoT sector due to its long spectrum, low data rate,

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low energy consumption, and cost-effectiveness. This means that LoRa can communicate over long distances while maintaining low bit rates. Due to its modulation, chirp spread spreading (CSS) modulation, LoRa is also resistant to multipath, fading, and the doppler effect. As a result, LoRa is being used in a variety of fields, including smart cities [6], healthcare [7], industrial [8], and agriculture, specifically to monitor leaf wetness for vineyard farms [9], control irrigation pumps [10], and monitor livestock [11]. Despite its exceptional qualities, LoRa's capabilities are constrained by its dense vegetative cover and uneven surface area.

As a result, Unmanned Aerial Vehicles (UAV) technology is implemented to overcome this limitation. The UAV industry, like IoT, has recently seen increased demand due to its ability to reach difficult locations [12] and is expected to reach $43.1 billion in the global market by 2024 [13]. UAV technology is also commonly used in agriculture for precision agriculture mapping [14], crop spraying [15], and livestock tracking [16]. Enabling LoRa technology on a UAV not only overcomes the limitations of LoRa but also allows the coverage to be extended to an open environment.

Despite the fact that the limitation can be resolved, the real concern is how resistant LoRa modulation is to the doppler effect and at what speed the UAV can achieve the best LoRa performance. The following is a list of the paper's specific contributions:

- Development of water quality monitoring for livestock drinking water and drone-LoRa enable.
- Coverage measurement of drone-LoRa enables in a suburban area (Bangi, Selangor, Malaysia).
- Determine the doppler effect on LoRa through real-life experiments with drone speed 5 km/h to 95 km/h.

This paper is organised into a few sections. Section 1 presents this research, Section 2 related work, LoRa overview, drone technology, and doppler effect in Section 3. Section 4 outlines the methodology and the conclusion, Section 5.

2. Literature Review

In the previous study, many works regarding LoRa on Drone has been performed to prove that it can extend LoRa coverage and overcome LoRa communication limitation on thick and busy location. Furthermore, experiments and analyses on previous studies have been done on the effect of speed on LoRa. Thus, in this section, a review of LoRa on Drone on previous work and LoRa on doppler effect is carried out.

The research work in [5] proposed a flying LoRa that would be mounted on a drone to extend LoRa's coverage to rural and remote areas. In [17], a drone with LoRa capabilities can collect data from sensors in a tree farm by flying the drone on a predetermined path depending on the sensor's location. The research work in [18] compared airborne LoRa to traditional grounded LoRa, finding that airborne LoRa can collect data from all nodes. Fixed setting LoRa, on the other hand, does not collect data from a node at high altitude location. In [19], by installing a relaying LoRa gateway to UAV, designed a UAV-enabled LoRa to extend the base station's coverage, resulting in a packet reception rate of more than 90%. Prior studies have shown that the drone-LoRa enable concept can resolve the LoRa limitation of communicating in dense vegetative and inconsistent surface areas. Neither of the papers listed above, however, discuss the effect of UAV speed on LoRa performance. On the other hand, there have been studies comparing LoRa performance to human, lathe, and automobile speeds.

The research work in [20] conducted a nomadic LoRa test in urban and suburban settings, using two different spreading factors (SF), SF7 and SF12. At a maximum speed of 56 km/h with the vehicle, the SF7 lost its connection at a distance of 5 km between the gateway and the node in the urban area and 7 km in the suburban area. This result shows that SF12 is more robust at speed than SF7. The research work in [21] accomplished above 96% of the packet received at SF8 and SF12 by performing a practical LoRa performance experiment at a speed of up to 120 km/h at the line-of-sight path. In [22], 85% of the packet is received at the LoRa gateway at speeds ranging from 50 km/h to 80 km/h with SF12. The research work in [23] carried out two experiments with LoRa attached to a lathe moving at a speed of 11 m/s with SF12 receiving 36% of the packet and a car moving at a speed of 100 km/h receiving 28% of the packet. A further experiment was carried out [24], with LoRa attached to humans at a speed of 5 km/h reaching 80% of the packet received and a car at a speed of 24 km/h receiving 85% of the packet. A simulation test with a drone at a maximum speed of 50 km/h results in a 100% packet which was received [25].

Previous research has shown that LoRa is robust at speeds of over 80% packet received with moving cars, humans, and drones at speeds ranging from 5 km/h to 120 km/h. Three of the researchers used SF12 in the experiment. One study uses SF12 and SF7, which, resulting in SF7, are vulnerable to velocity. Two of the researchers did not describe the SF parameter in their experiment. The aim of this research is to prove that the drone-LoRa enables immune to speed compared to the previous study mentioned above. Attached LoRa performs an experimental test on two types of drones, a speed multirotor of 5 km/h to 50 km/h and a speed fixed-wing of 50 km/h to 100 km/h, and uses two different SFs, SF7 and SF12. Moreover, the verification of drone-LoRa enables may also extend the coverage of LoRa in the suburban area.

3. Overview of LoRa, UAV, and Doppler Effect

3.1 Long Range (LoRa)

Low power wide area network (LPWAN) is a type of wide-area wireless communication network that provides power efficiency for IoT devices to operate on a single battery charge for 10 years [26]. Many types of LPWANs are available, such as Zigbee, Sigfox, LTE-M, NB-IoT, and LoRa.

For its long-range communication, LoRa is the most widely used wireless radio frequency communication technology, as stated in the introduction. LoRa can communicate over distances of 2 to 5 km in urban areas and 15 to 20 km in rural areas [27]. Furthermore, LoRa uses a CSS that includes four key parameters: channel, transmission power, spreading factor, and bandwidth [30]. Each of the parameters can be changed at any time by the user. The options for the parameter [28] are listed in Table 1. Fig. 1(a) is the LoRa gateway used in this research, and the LoRa node both are manufactured by Cytron.

Table 1 - LoRa parameter

Parameter	Options	Explanation
Spreading Factor (SF)	7 -12	Frequency spreading factor
Bandwidth (Khz)	125/250/500	Data bandwidth
Channel (Coding Rate)	4/5, 4/6,4/7,4/8	Error correction data rate
Transmission power (dbm)	2- 14 / 5-20	Power used to transmit

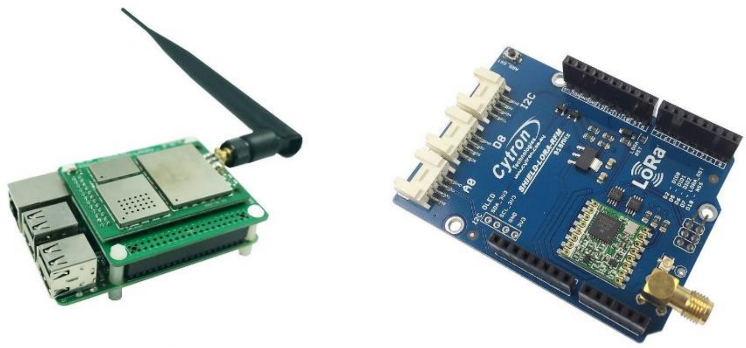


Fig. 1 - (a) LoRa Gateway; (b) LoRa Node

SF is the parameter that the user can change to determine the number of chirps sent per second. According to Table 1, the SF options are 7 to 12, with 7 being the lowest and 12 being the highest. Lower SF allows for more chirps per second, while higher allows for fewer chirps. However, higher SF is more resistant to long-distance communication than lower SF. Higher SF requires more transmission time to send the same amount of data as lower SF and causes the receiver to sample the data of higher SF with a higher signal power [8].

In this study, two SF are compared to test the robustness of drone-LoRa enabled with doppler effect, SF7 and SF12, on the same location and drones.

3.2 Unmanned Aerial Vehicle (UAV)

A UAV, also known as a drone, is a flying vehicle that does not have pilots on it. The use of (UAVs) is common in inspection, surveillance, deliveries, and photography. According to [9], there are four types of UAVs on the market:

I. Multirotor

To generate lift, a multirotor drone employs more than one propeller. It comes in three, four, six, and eight sizes and is known as a tricopter, quadcopter, hexacopter, and octocopter. The greater the number of rotors, the greater the payload a drone can carry [31]. A multirotor, on the other hand, is inefficient in terms of battery usage because it requires a lot of energy to stay airborne in the air. As a result, they are slower than other types of drones [30].

II. Fixed-wing

A fixed-wing generates lift with forwarding airspeed under the wing and does not require energy to stay in the air. As a result, fixed-wing can cover a large area in a short period of time. According to [32], a fixed-wing is capable of surveying up to 10km^2 of surface area in a single flight.

III. Single-rotor helicopter

Single-rotor generates lift using a single large propeller and controls its direction with a tail rotor. It is far more efficient than a multirotor because the large propeller acts like a spinning wing rather than a moving blade. It can hover with a heavy payload.

IV. Fixed-wing hybrid VTOL

It is a hybrid of a multirotor and a fixed-wing. It overcomes each other's drawbacks, such as flying anywhere without a runway as a multirotor and covering a large area in a single flight as a fixed-wing.

In this study, a drone-LoRa experiment is used to test a multirotor with a speed range of 5 to 50 km/h and a fixed-wing with a speed range of 50 to 100 km/h. Different drones are required in this experiment because each available drone has its own speed limit. Fig. 2 shows the Skywalker fixed wing was used in this experiment due to its ability to fly at a range of 50 to 100 km/h, while M200 Multirotor at a range of 5 to 50 km/h, which both of the drone abilities matched the need of the experiment.

Fig. 2 - (a) Skywalker Fixed-Wing; (b) M200 Multirotor

3.3 Doppler Effect

In this study, a drone-LoRa enable is developed, in which LoRa attaches to a drone. As a result, understanding the relationship between drone speed and Doppler shift f_d is required. Furthermore, a comparison with other suitable wireless technology is required. The Doppler shift is represented by formula (1):

$$f_d = \left(v_b . \frac{f_c}{c}\right) \cos \alpha \qquad (1)$$

To achieve the best Doppler Shift, the angle between transmitter and receiver, α, must be equal to zero. However, achieving such an angle in real-world LoRa or any wireless IoT deployment involving fast and dynamic speed objects like drones is difficult. While f_c represent the carrier frequency, c is the speed of the wave, in this case, represented by the speed of light and v_b is speed of the subject, which in this experiment present by the drone speed. To understand the effect of Doppler Shift caused by drone speed, another independent wireless technology known as Zigbee is used as a comparison. Other traditional wireless/cellular technologies, such as 4G, SigFox, and NB-IoT, are excluded because they rely on tower and service provider deployment, resulting in non-independent wireless networks. While WiFi and Bluetooth are independent, it is an unfair comparison because they have proven to provide much less coverage, i.e., less than 1 km.

LoRa operates in a different region on a free license low frequency, whereas Zigbee operates in the 2.5 GHz ISM band [33]. Table 2 is the list of LoRa frequency bands based on regions.

Table 2 - LoRa frequency band bases on regions

Region	Frequency band
Europe	EU863-870
USA, Canada, and South America	US902-928
China	CN470-510
Australia	AU915-928
Japan, Malaysia, Singapore, and Indonesia	AS920-923
Brunei, Cambodia, Hong Kong, Laos, Taiwan, Thailand, and Vietnam	AS923-925
Korea	KR920-923
India	IN865-867

Given that LoRa operates at the AU915-928 band, with a frequency of 915Mhz, Equation (1) can be written as follows:

$$f_d = \left(v_b . \frac{915\ Mhz}{3.6(3x10^8)}\right) \cos 0 = 0.84722 v_b \tag{2}$$

$$f_d = \left(v_b . \frac{2.5\ Ghz}{3.6(3x10^8)}\right) \cos 0 = 2.222 v_b \tag{3}$$

where 3.6 is the transformation value for km/h to m/s.

Table 3 shows the maximum speed of drones:

Table 3 - Maximum Speed of Drone Type

Drone Type	Maximum speed km/h
Multirotor	50
Fixed-wing	100

As a result, the doppler shift for drone speed with two different wireless devices, LoRa and Zigbee, is shown in Fig. 3, with LoRa doppler frequency computed using Equation (2) and Zigbee using Equation (3).

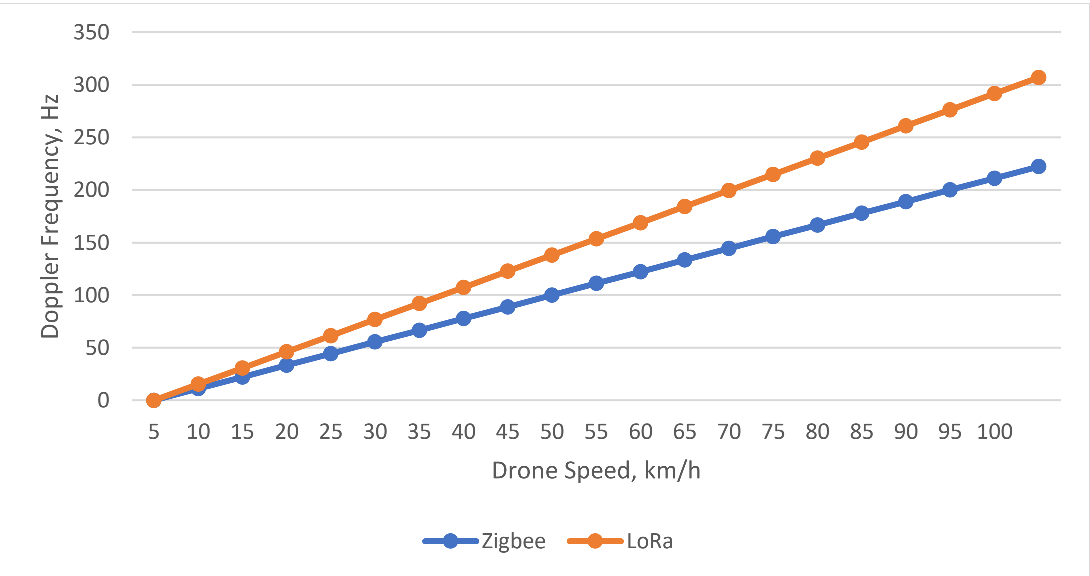


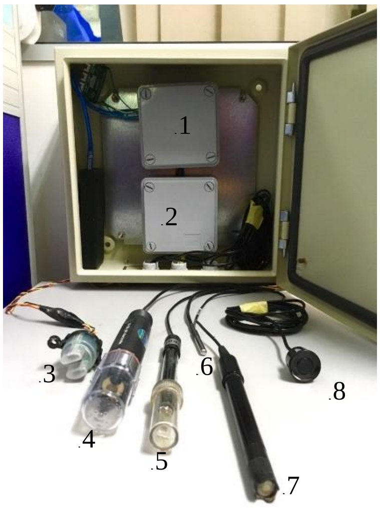
Fig. 3 - Affect of Doppler on LoRa and Zigbee in regards to speed

Fig. 3 shows that when the drone reaches a maximum speed of 100 km/h, the maximum Doppler shift for LoRa is 84.722 Hz, and for Zigbee, it is 222 Hz. In other words, the Doppler Shift from wireless Zigbee is 2.6 times greater than that of LoRa due to the operating frequency band (2.4 GHz for ZigBee compared to 915 MHz for LoRa) and bandwidth size (2 MHz for ZigBee, compared to max 250 kHz for LoRa). Based on this result, it can be concluded that the Doppler shift is much more severe in the case of ZigBee, while it is found to be very minimal in the case of LoRa. The findings are also consistent with the findings of [34], who discovered that higher frequency bands affect Doppler Shift.

4. Methodology

4.1 LoRa as Water Monitoring and Tracking Device

Fig. 4 depicts the developed water quality monitoring. This includes an ultrasonic sensor (to measure level), a pH sensor (to measure acidity/alkalinity), a dissolved oxygen sensor, a turbidity sensor (to measure water clarity), an electrical conductivity sensor (to detect the presence of algae), and a temperature sensor (to measure the water temperature). The sensors are linked to an Arduino Mega, and the wireless device is LoRa.



1. Arduino Mega and LoRa
2. Sensors Board
3. Turbidity Sensor
4. pH Sensor
5. Electro Conductivity Sensor
6. Temperature Sensor
7. Dissolved Oxygen Sensor
8. Ultrasonic

Fig. 4 - The developed water quality monitoring

The data relating to the water quality from the sensors is validated based on five different liquid types: 1) Tap Water, 2) Tap Water + Salt, 3) Lake Water, 4) Soap Water, 5) Coffee. Fig. 5 shows the experiment setup, where the turbidity sensor immerses in a clear liquid. This experimental setup is the same as the other sensors as well, with a different type of liquid. Fig. 6 shows the water taken from one of the five types of water: 1) Lake Water. Fig. 6 shows the sensor's value of all five types of liquid; pH level represents the level of acidity, neutrality, and alkaline of a substance. It can be observed pH level is around 6 to 8, which is the acceptable value as pH level guideline set by WHO on drinkable water is 6.5 to 8.5 [35], Electrical conductivity (EC) measures the water ability to conduct electricity, which it can be determined by the salinity of the water. In Fig. 5, as expected, the value of EC is the highest in tap water + salt. Dissolved oxygen (DO) measures the value of dissolved oxygen in water, and Fig. 6 shows the soap water is the lowest as it is expected, which based on [36], soap water/detergent can decrease the DO in water. Moreover, tap water is the second-lowest because high DO can increase the corrosion rate of the water pipe [37]. The temperature sensor measures the temperature of the water; in this experiment result, the temperature in coffee is the highest. The value measured by each of the sensors is reliable because it achieves the expected result.

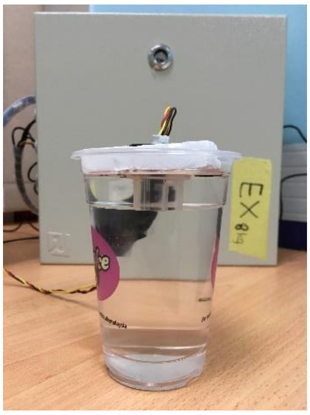


Fig. 5 - Turbidity Sensor in Clear Water

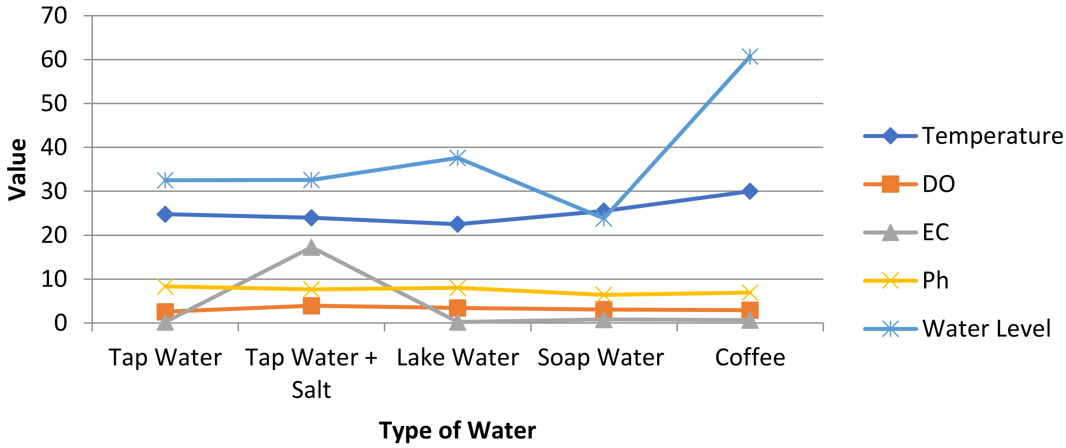


Fig. 6 - Water quality sensor test on various types of water

Fig. 7 shows the sample of water sources to validate the turbidity measurement. For this validation, we used water tap to represent clear water (a) while the dark water, from (b) to (e), are represented by different concentration of the coffee powder. Fig. 8 shows the turbidity value (in Nephelometric Turbidity Unit (NTU)) that has been measured on the turbidity sensors.

a) Clear (b) Slight Dark (c) Dark (d) Darker (e) Darkest

Fig. 7 - Samples of water clarity to validate the turbidity sensors inside the laboratory

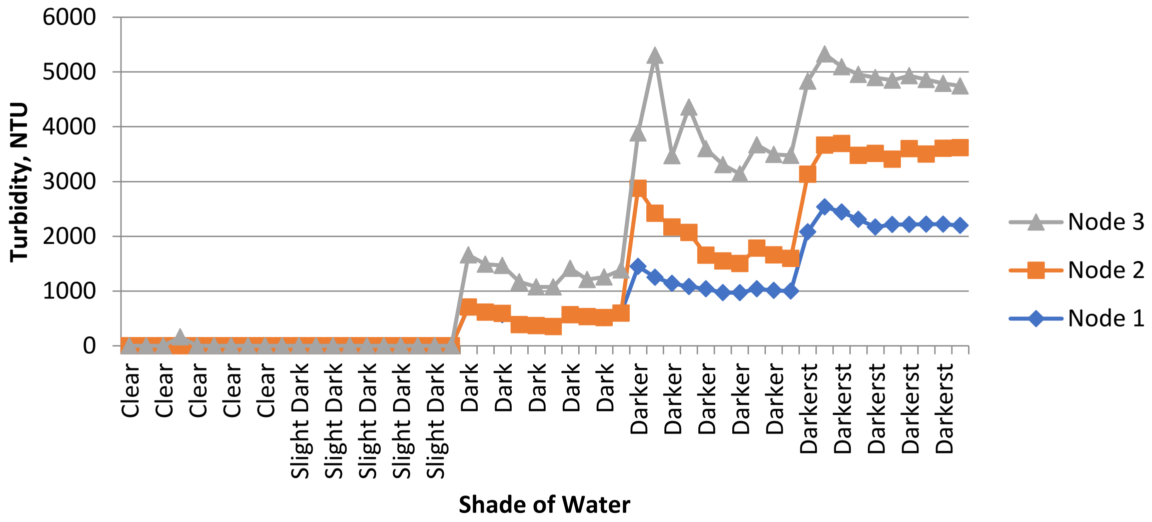


Fig. 8 - Turbidity measurement based on different water sources

Fig. 9 shows the sample water of different types of water to validate the turbidity measurement; for this validation, this research work used tap water to represent clear water (a), lake water (b), and from (c) to (e) are mud water with a different ratio of water and Fig. 10 the measured turbidity value in NTU on the samples in Fig. 9.

(a) Clear (b) Lake Water (c) Mud Water (d) Mud Water (Dark) (e) Mud Water (Darker)

Fig. 9 - Samples were taken from the actual water lake to validate the turbidity sensors

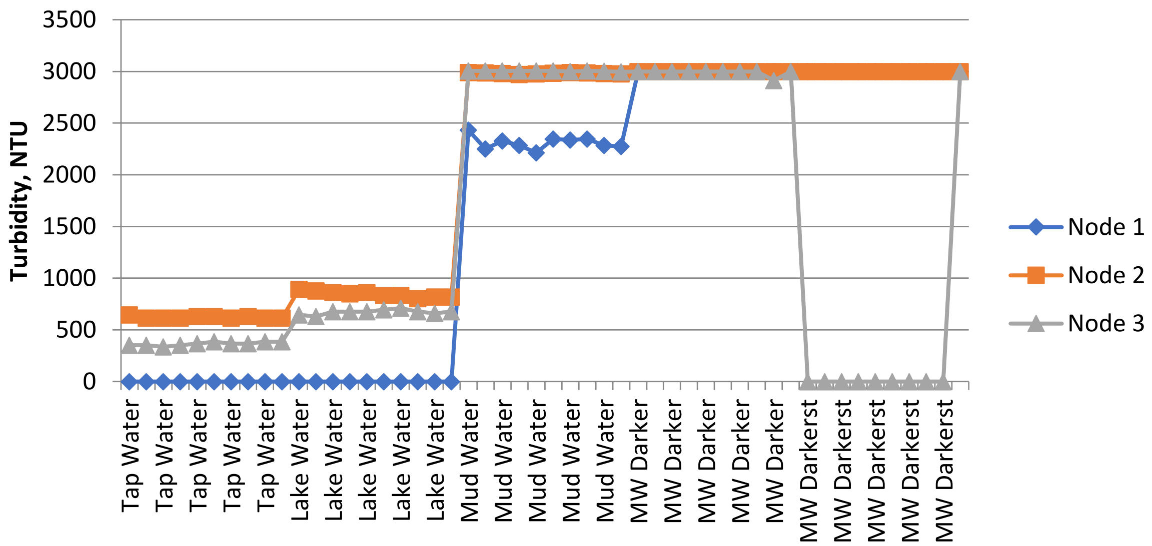


Fig. 10 - Turbidity Measurement Based on Different Type of Water

Based on the results from tap water and water lake measurement, it can be observed that the turbidity sensor is functional since the NTU increase with the darkness of the water. However, the turbidity sensor has a very large resolution and causes the graph generated has drastically increased in value.

4.2 LoRa Gateway

The LoRa gateway is critical hardware that allows data from water quality nodes to be sent to the cloud, allowing the farmer to monitor things from almost anywhere and at any time. A Multi-channel LoRa Gateway was used to combat the high packet loss. A multi-channel gateway is a high-priced device that can support up to eight frequency channels. It can receive LoRa packets with any spreading factor, and it adapts automatically to the LoRa nodes' spreading factor. Furthermore, this gateway has two servers; one server (in online mode) sends packets to the thing network, while another (in offline mode) saves packets received locally, as present in Fig. 11. A toggle switch on the gateway can be used to perform the operation. Table 4 shows the LoRa gateway feature, and Fig. 12 presents how the LoRa gateway is mounted on the drone.

Table 4 - LoRa Gateway Feature

Computing	**Raspberry Pi 3B**
LoRa Chipset	Sx1301
Frequency	920 Mhz
Supply Voltage	5V – 2.5 A
Interfaces	Front: USB Power, HDMI, Audio
	Right: LAN, 2xDual USB Port
Antenna	SMA antenna 915 Mhz 50-ohm 6dBi
Range	Urban 3-5km/Line-of-Sight 15km
RX Sensitivity	-139 dBm

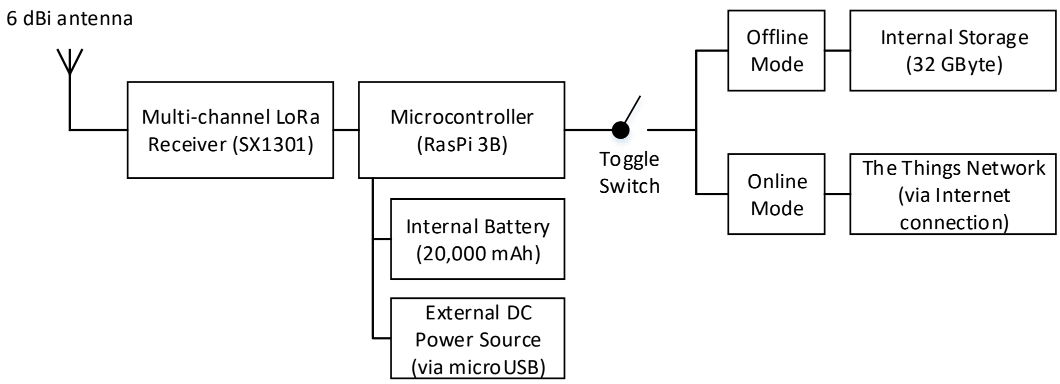


Fig. 11 - Block-level overview of the multi-channel gateway version 3

Fig. 12 - Visualisation of Drone-LoRa enable on multirotor drone

5. Result

5.1 Experiment Test on System

5.1.1 Coverage Measurement

The measurement only took into account the received signal strength indication (RSSI) value between the LoRa receiver (on the tripod with the 2-meter-height; Fig. 13) and the LoRa transmitter (mounted on the drone). Elevation profile and flight path between these two points, as shown in Fig. 14.

With a fixed drone height of 200 meters, the RSSI is measured every 200 meters. From the result shown in Fig. 14, the LoRa can communicate over 10 km by default setting (+20 dBm transmit power) with the stock antenna (0 dBi). The graph in Fig. 13 shows the elevation profile of the drone path, and the highest altitude is 71 meters, where this altitude will not disturb the communication between LoRa receiver and LoRa transmitter as the transmitter is located at 200 meters height from the location of the receiver, which the altitude of the receiver is 63 meters. Based on Fig. 15 at 11km, we obtain an RSSI value -108 dB above the receiver sensitivity threshold (-137 dB). Thus, this shows, there is a strong possibility of achieving maximum coverage of approximately 15 km on the basis of the current finalized distance.

Fig. 13 - Drone-LoRa enable and LoRa on 2 meters tripod

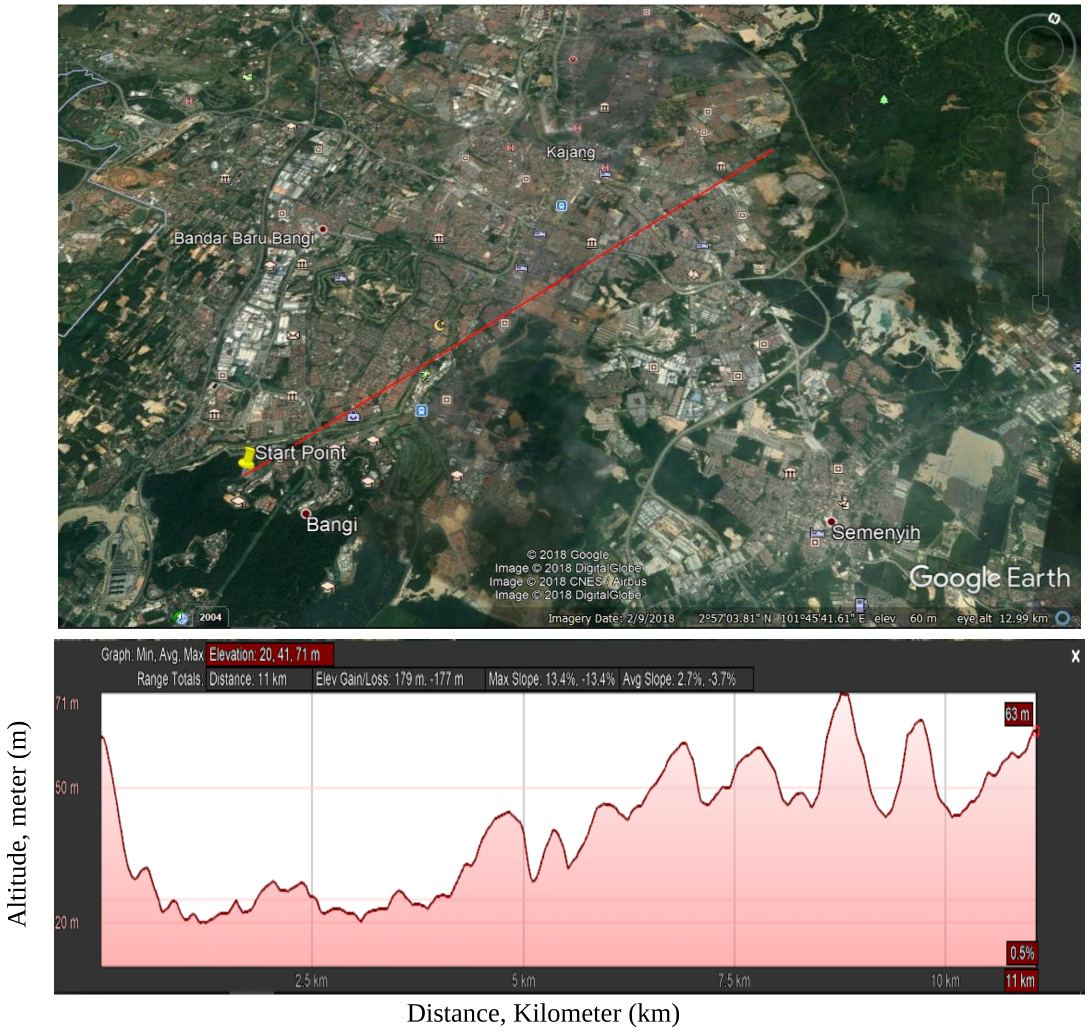


Fig. 14 - Elevation profile and the flight path between the start point and end point

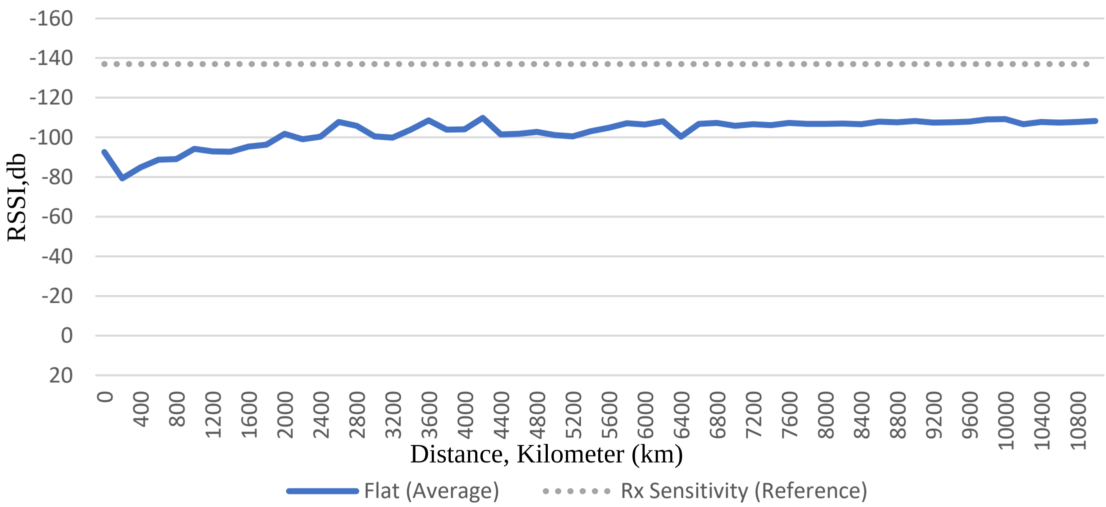


Fig. 15 - RSSI data collected from start point to end point with an increment of 200 meters

5.1.2 Sensor Proof of Concept Test

Fig. 16 shows the drone flight path, while Fig. 17 presents where the LoRa receiver is mounted on the drone and the LoRa transmitter on the water quality node stationed on the ground. Fig. 18 shows the data collected from the water quality monitoring. The water measurement is constant due to the test is only one type of water. The minimum RSSI value calculated is -91 dB with a maximum distance of 675 meters with an altitude of 21 meters between the LoRa transmitter and the LoRa receiver; this shows that without predetermined the drone path, example in this experiment, drone fly randomly in a circle, the communication between LoRa receiver and LoRa transmitter not affected.

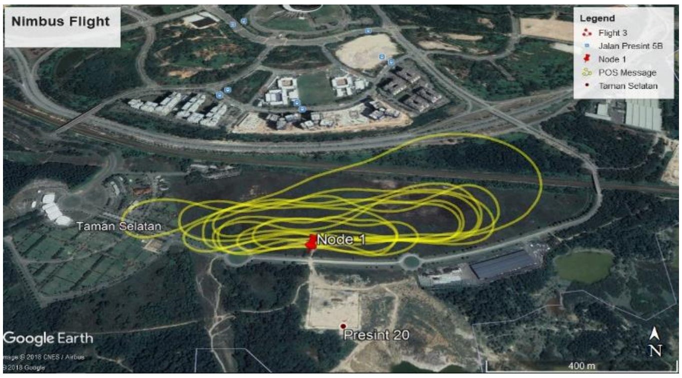


Fig. 16 - Drone flight path

Fig. 17 - (a) Water quality monitoring on the ground with tap water in the green bucket; (b) Drone-LoRa enable on fixed-wing drone

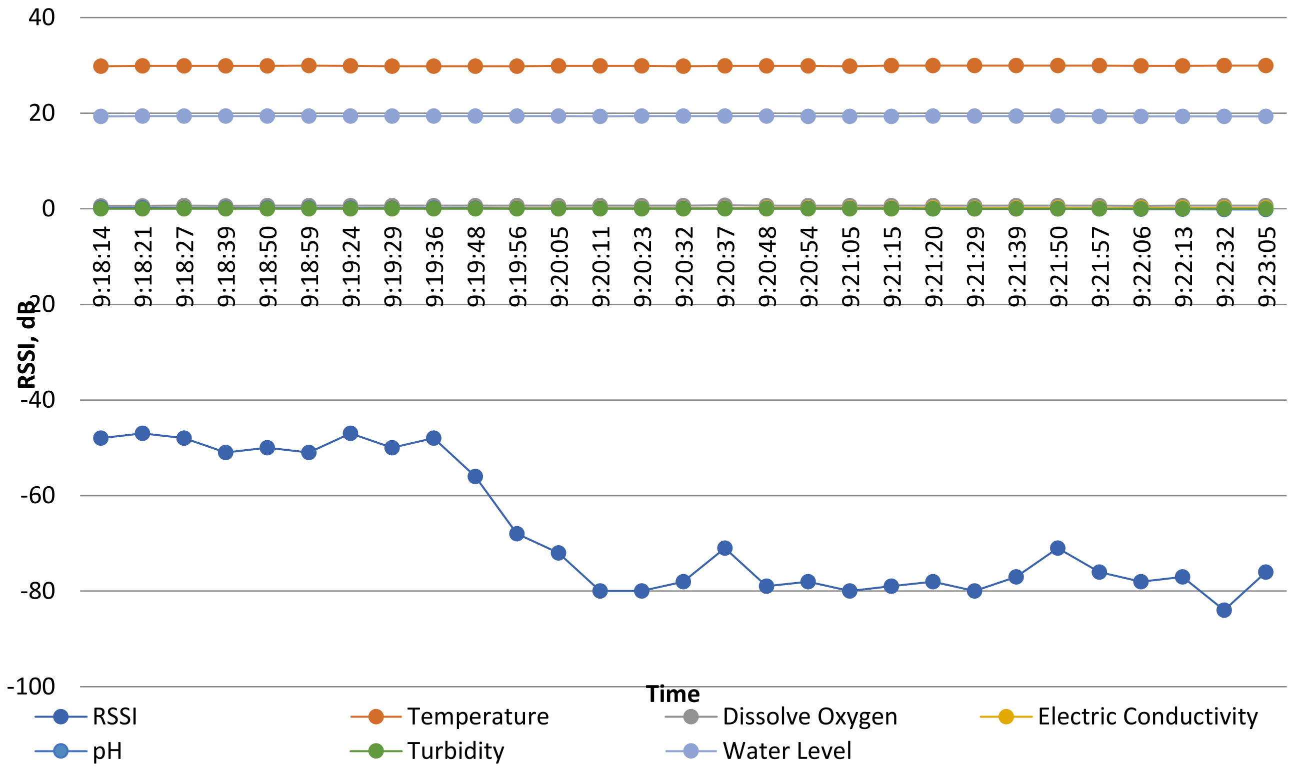


Fig. 18 - Sensor data collected

5.1.3 Doppler Effect Test

Fig. 19 shows the drone flight path, in which the drone flew in a circle. Fig. 20 shows the experiment setup.

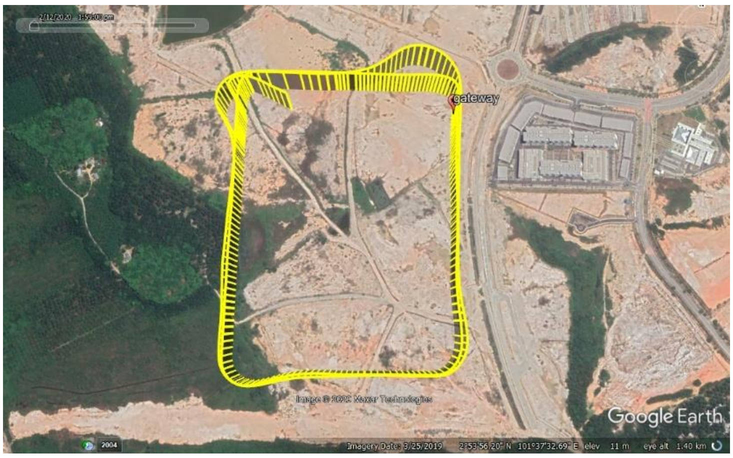


Fig. 19 - Flightpath of Drone-LoRa enable

Fig. 20 - A fixed-wing drone and a LoRa gateway involved during the performance measurement

Data from the LoRa node is transmitted every 5 seconds, while data is received at the gateway every 9 seconds for the LoRa SF12 while the SF7 is transmitted every 7 seconds. The different time of data obtained between spread factors due to on-air time, where SF12 time on-air is the longest, while SF7 is the shortest. The drone flew at a default speed of ±5 km/h due to an unforeseen wind direction during measurement at a fixed altitude of 100 meters above ground level.

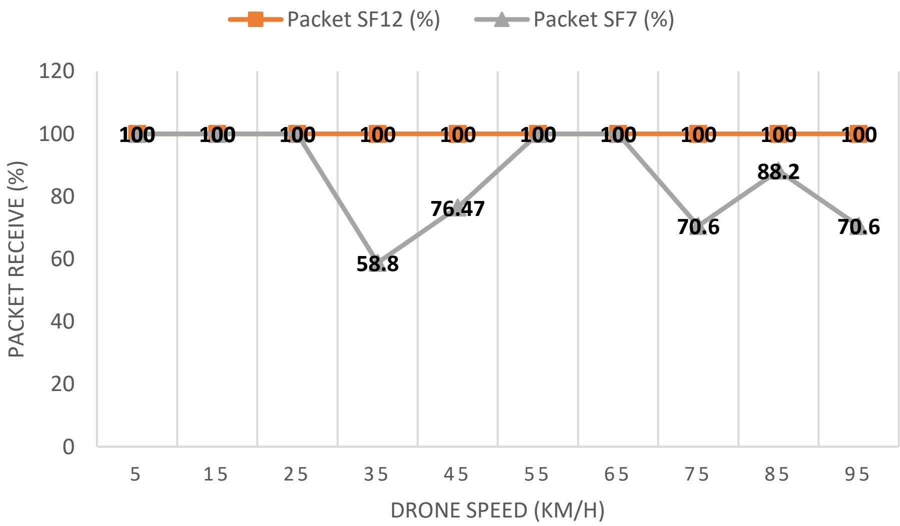


Fig. 21 - Packet receive vs. drone speed

Fig. 21 shows the percentage of packets received by SF12 at 100%, while SF7 at 77.27% on average. This result was consistent with previous research carried out by [20], in which SF12 was robust towards the doppler effect, while SF7, on the other hand, proved to be sensitive to drone speed, particularly at speeds of 35 km/h and above. This is because the transmission time of SF12 is longer in the air than in SF7. Hence it is more sensitive due to the more time the receiver takes to sample signal power [29]. Furthermore, this measurement provided new insight into the LoRa performance on a drone because the previous study [25] only allowed for a maximum speed of 50 km/h, whereas this study allowed for a maximum speed of 95 km/h.

6. Conclusion

The reliability of a water quality monitoring prototype is tested in the laboratory with five different types of water, the coverage of drone-LoRa is measured in a suburban area, and a real-world experiment is conducted to determine the drone-LoRa enable robustness to the doppler effect. The reliability test is carried out to ensure that the sensors' data is accurate and that the sensors provide different measurements for different types of water; for example, electroconductivity is highest when tap water + salt is used. Moreover, it has been found that the impact of LoRa on the Doppler shift is 2.6 times lower than that of the other independent wireless technology, ZigBee. Furthermore, enabling LoRa drones can extend the coverage of LoRa to a radius of more than 10 km in the suburban area. Eventually, drone-LoRa is robust towards drone speed at a maximum speed of 95 km/h with LoRa Spreading Factor 12 and sensitive with Spreading Factor 7, with an average of 77.27% of the packet obtained. Therefore, this research proves drone-LoRa can be used in the livestock industry as it is robust towards the Doppler effect and can extend the coverage of LoRa.

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