Implementation of LoRa in River Water Quality Monitoring

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Abstract

Emergence of Long Range (LoRa) in network technologies become game changer for Internet of Things (IoT) application. Deployment of LoRa enable IoT application of environment monitoring to cover wide area while maintain at low energy and low cost. Water quality monitoring program was developed to maintain and protect quality of water resources for daily purpose. Also, to prevent pollution and disease epidemic peculiarly during Covid19. This research aimed to build autonomous water quality monitoring prototype implemented with LoRa network for support decision system. The Wireless Sensor Nodes (WSN) that embedded with five type of water quality sensors of pH, turbidity, total dissolved solid (TDS), dissolved oxygen (DO) and temperature linked to single gateway. Water environmentalist able to view the result of timely water quality from mobile application dashboard. Though the performance not severely affected, acquired results revealed non-line of sight condition, transmission power and Spread Factor (SF) value influenced LoRa performance in urban environment. In conclusion, a few improvements on the system grant LoRa high capabilities to be integrated with IoT environment application in urban environment.

Keywords: river conservation, IoT, smart river monitoring, LoRa, CSS.

1. Introduction

Cultivation of IoT from industrial revolution 4.0 contribute in improvement of productivity and efficiency of human life. IoT allow connection digital and physical dimension by exchange data from real gadget over the internet. The system reduces human involvement and able to enhance the accuracy of data collection, processing and analytics (1). The communication between two realms executed by wireless network. Implementation of IoT in industry allow people easily to operate things remotely. It is mostly recognized as a solution for monitoring purposes in Smart Earth technologies. Parallel with Sustainable Development Goals (SDG) 6: Clean Water and Sanitation, target 6.3 aim to protect heath of ecosystem and human from harm of pollution and effect of climate changes in water bodies (2). Hence, it is crucial to monitor the ambience of water status.

River is the primary water resources at Malaysia. It maintains human activities and balancing water ecosystem with its freshwater and nutrient (3). Malaysia practiced Integrated Water Resources Management (IWRM) and Integrated River Basin Management (IRBM) program in water resources management. However, due to poor management, rapid development and population increase demand on sufficient clean water. Moreover, clean water also become critical during pandemic Covid19 to reduce the virus epidemic with frequent sanitization (4). However, there were 47% of river in Malaysia classified polluted. Within year 2020 and 2021, the water bodies at Sungai Gong and Sungai Semenyih were contaminated with hazardous chemical and agriculture sewage forced water treatment plant at Selangor to ceased operation. Thus, unscheduled water supply resulted water shortage to a lot of districts during decontamination of pollution (5).

Implementation of water quality monitoring agenda provides data of qualitative analysis on physical, chemical and biological of water characteristics based on standard of Water Quality Index (WQI) and National Water Quality Standards (NWQS) for Malaysia. Autonomous water quality monitor was invented to support manual water quality monitoring. Lack of the autonomous system can reduce the accuracy of data of water properties that can vary over time (6). Embedding IoT feature in water quality monitoring system can reduce human labor as well become a quick decision system for environmentalist for its real time data.

Addressing function of the system and type of data is important to match with the suitable wireless network. LoRa is a long range network derived from Chirp Spread Spectrum (CSS) technology using air interface. It able to transmit low rate data type within geographical area with its vast radio coverage at low power and low cost (7). This research intent to implement LoRa as the wireless network for continuous water quality monitoring system. This paper contributes on providing evaluation of LoRa network performance to be applied in quick decision system to provide water quality status to environmentalist (8).

2. Literature Review

2.1 *IoT Application in Continuous Water Quality Monitoring with Different Wireless Network*

IWRM program utilize water quality monitoring program at operational level for water resources conservation management. It verifies water bodies status and analyzed the environment impact on water ecosystem. Development of continuous water quality monitoring system completing the observed water characteristics result with manual method (9). Benefited from wireless network, the efficiency of the continuous water quality monitoring system can be improved.

Wireless network acts as communication interface between devices and internet platform over information exchange. Cloud act as data storage for IoT platform processing and analyzing data for view purposes for user. The outline process of the autonomous water quality monitoring displayed as Fig. 2 below.

Fig. 1. IoT Structure for Water Quality Monitoring System

Every type of wireless network has its own capability for its service significant to the applied system. Understand type of network of its capacity, limitation and benefit are essential to meet the requirement of the applied system. Previous researcher had investigated and tested various type of wireless network with water quality monitoring system.

Jiang et al. and Li et al. experimenting water quality monitoring system with PAN type of network, Zigbee as radio frequency model. The telecommunication range was extended from GSM version using GPRS. Reflecting water quality data type in low rate, it unnecessarily consumed higher energy and require external SIM card for communication activation (10). However, this method is suitable with application that employ large bandwidth within short distance. Next, Dilshad et al and Pandi et al and Bhisekar et al deployed the most common practical network used in IoT application, WiFi in water quality monitoring system by. As it extracted large amount of data, it able to improve data accuracy. Though, it utilized higher power for low rate data type due to low latency (11).

Joseph et.al conquer the challenge the high cost on extension subscriptions of GSM network, and send data through Short Message Service (SMS) from its autopilot water quality monitor (12). Collaboration Ericsson between with city officials and university researchers at Stockholm operated NB-IOT to replace 4G LTE network for water quality monitoring system. The experiment success in increase range network scale and proficiency of water sensors (13). Nevertheless, the cost was not minimized as the deployment require expensive reserved frequency or channel.

2.2 *Introduction of LoRa Technology*

LoRa technology is a compilation of two different layer. The physical layer (PHY) employs CSS modulation technique that manipulated allocated bandwidth during signal transmission able to improve LoRa strength against noise and any frequency degradation mechanisms. This technique implements modulation of orthogonal spreading factor (SF) to optimize data rates and each nodes power level. Hence, it increases the efficacy of receiver to decode signals even affected by low signal-to-noise-ratio (SNR) while reduces energy consumption.

Build system LoRaWAN created by LoRa Alliance performed as Media Access Control (MAC), network and application layer at top of LoRa architecture. It generates the communication between nodes and gateway operated in star topology from LoRa PHY modulation to exchange data with host layers. The PHY layer control radio frequency signals within transmission line. SF, bandwidth and coding rate adapt the working environment used to constructs LoRa PHY modulation (14).

This paper referred study of LoRa performance in various IoT application accomplished by previous researchers.

2.3 *LoRa Performance Evaluation from Previous Study*

Utilization of SF integrated with bandwidth and coding rate to ensure the transmission services from concluded data rate by LoRa PHY modulation. The higher SF able to increase transmission distance, processing gain and receiving sensitivity but reduce data rate. Coding rate is utilized as the reliable unit in LoRa to control the amount of Forward Error Correction (FEC) within payload data.

LoRa manage the radio frequency signal within transmission line. Verification of wireless medium characterization on path loss, shadowing and multipath fading are required to reflect condition of non-line of sight (NLOS) condition and multipath propagation signal within urban environment. Hence, it is crucial for signal values gain at IoT platform to be attuned with the sensitivity level of transceivers.

The received power, Prx can be defined as in Eq. (1). The value of Prx is influenced with fusion of the transmitted power, Ptx, Gsystem and Lsystem which both are gains and losses related cables and antennas respectively. It also influenced by losses related at transmission channel, Lchannel that affected by surroundings and the fading margin, M (15).

A few of equation models were derived from various of experimental data to manage the problem of non-specific path loss model. It estimated Lsystem for LoRa in different scenario.

Previous researcher study LoRa network performance on different network properties. Researcher from Switzerland implemented LoRa network for flood early detection and notify user at Twitter. The result showed there were no lose packet between receiver node and water level sensor node with distance of 500 m away with each other (16). While Wotherspoon et al. monitoring wildlife at distance of 5.5. km that powered with 20 dBm and obtained frame loss up to 2% (17).

J. Lousado, S. Antunes, proposed IoT concept for monitor and support elderly people that live by themselves. They found the limitation of the system of LoRa to repeatedly send large amount of data repetitively (18). Buyukakkaslar et al. found Frame Air Times and moderated duty cycle are crucial for real time health basis data tracking (19).

Different application and situation differentiate LoRa performance. Referred to previous study, various of network parameter can be used to analyzed its performance depend on the objective of the application.

3. Methodology

The system process involves from selecting water quality sensor, testing send data to LoRa server, design of water station points, Wireless Sensor Network (WSN) of LoRa nodes properties setup and data analysis of water quality parameter and LoRa performance. The flow of the experiment as summarized in flow chart below

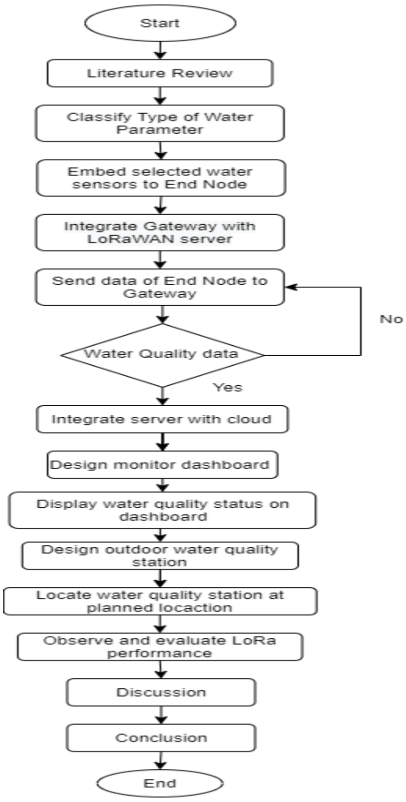

Fig. 2. Process of Water Quality Monitoring Prototype Testing

3.1. *Water Quality Monitor Station Design*

The prototype of water quality monitoring was built with three LoRa nodes at different location of fish pond. LoRa nodes positioned at different height and distance from single LoRa Gateway. The stations supplied up with 5V solar panel. Water sensors were selected based on water characteristics following specified regulations of World Health Organization (WHO). Also, its durability to operate in outdoor environment and datasheet supplied by DFRobot Distributor. Water sensors as listed in Table 1.

Table 1. Water Quality Properties

Water Sensor	Function
pH	Acidification
Turbidity	Water opacity
Temperature	Variable for other parameters
Conductivity	Salinity and total dissolved solid
Dissolved Oxygen	Examine amount of oxygen suitable for aquatic organism

As receiver antenna with gain of 1dB is not suitable for outdoor environment, it was located within roofed balcony at residential area. Following Asia region LoRa frequency band, the receiver operated with 920-923 MHz. Fig. 3 display distances and location of P1 and P3 were positioned within line of sight with the gateway, Rx while P2 located with obstacle in between.

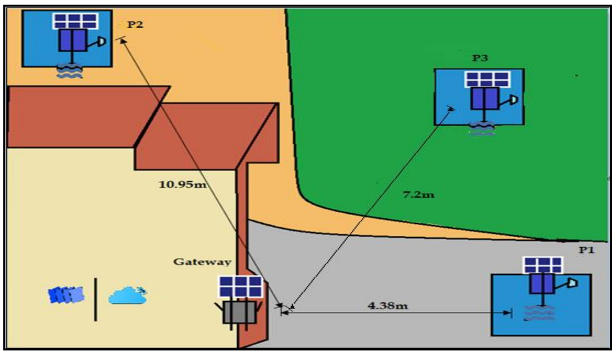

Fig. 3. Water Station Location from Gateway

3.2. *Embedded Transmitter System Parameter*

ESP32-LoRa32 used as WSN with operation frequency of 868M/915 MHz and transmission power up to 20dBm. The device employed Frequency Shift Keying (FSK) modulation mode with data rate from 1.2 Kbps till 300 Kbps. The end nodes transfer data to gateway through LoRaWAN network server, The Thing Stack V3. The data transmission also regulated for every 30 seconds to reduce energy consumption. Below Table 2 and Table 3 show the configurations LoRa properties for all transmitters using two different transmitted power simulated with two different SF.

Table 2. LoRa Parameter Setup 1

Parameter	Tx1	Tx2
Spread Factor	7	9
Bandwidth (kHz)	125	
Frequency Plan	AS920-923 Class A	
Transmitted Power (dBm)	14	
Antenna Gain (dB)	2.5	
Data Transfer Rate (kbps)	5.469	1.758

Table 3. LoRa Parameter Setup 1

Parameter	Tx1	Tx2
Spread Factor	7	9
Bandwidth (kHz)	125	
Frequency Plan	AS920-923 Class A	
Transmitted Power (dBm)	5	
Antenna Gain (dB)	2.5	
Data Transfer Rate (kbps)	5.469	1.758

Deliberated to the total number of end nodes and one gateway, star topology was practiced as preferred in LoRa network technology to prolong the lifetime of the devices (20).

3.3. *Water Environmental Dashboard Design*

The dashboard integrated with LoRaWAN server through LoRaWAN version of MAC V1.0.2 at The Things Stack v3.14.2 and LoRa Cloud. The developed dashboard in apps visualizes data of water quality.

3.4. *Data Analysis*

The properties of water quality data collected through deployed WSN were evaluated with the ideal clean water quality value. The average of data shown in developed dashboard manipulated to determine the state of water and categorized the water class.

LoRa performance on RSSI and SNR observed in The Thing Stack server. Data presented in the server used as the reference to verify packet loss data. Furthermore, the acquired value able to determine received power using equation (1). LoRa performance for each end nodes at different location were recorded and analyzed.

4. Result and Discussion

Movement Control Order (MCO) was executed due to extreme increment of Covid19 epidemic cases, the experiment was deployed at different location from original propose place. The outcome of analysis from collected water quality data were utilized to determine the water quality status.

4.1. *Water Quality Properties Observation and Analysis*

As mentioned in Table I, each of water quality properties cited different information of water status. The result unable to determinate class of water due to absence of Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD) and Ammoniacal Nitrogen that are essential for WQI determination. Those properties can only be gain through manual laboratory test and calibration for higher accuracy. Nonetheless, it able provide real time data to allow environmentalist keep surveillance on water state.

Water properties data collected from water station were processed and analyzed in cloud collected from water station. Fig. 4 below demonstrated the comparison of water quality properties at both water station. The result of water status can be easily view in water quality apps dashboard as visualized in Fig.5.

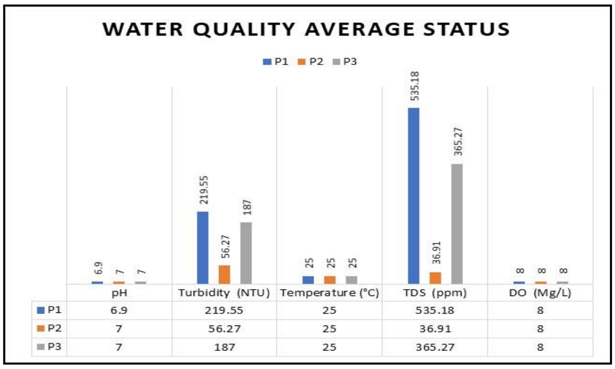

Fig. 4. The Average of Water Quality Parameter Obtained Water Stations


5:09 AM

P1

pH:
6.56

Turbidity:
155

TDS:
530

Temperature
25

Dissolved
Oxygen:
8

Fig. 5. Visual Board of Water Quality Monitoring Station 1

As the temperature remains at 25°C, a slight conclusion indicated that the water bodies did not contain any hazardous substances. However, several parameters of water properties were affected by microscopic objects influenced by aquatic living and weather.

PH parameter effortlessly affected by external factors but it will remain within acceptable range for unpolluted water. Value of pH analysis result were between 6.9 and 7. The acquired pH value can be classified as Class I and Class II respectively. While turbidity properties inspect excess volume of suspended substances that can disturb water ecosystem productivity. The desire range of turbidity within 0 and 5 NTU. As presented, the turbidity value obtained were 219.55 NTU, 56.27 NTU and 187 NTU respectively. Hence, all water bodies descend to Class III for turbidity features as referred to NWQS.

Total Dissolved Solid (TDS) sensor measure organic and inorganic substances in water. The higher the value of TDS, the higher the salinity. Furthermore, it can determine drinkable water and act as indicator on presence of excessive chemical contaminant. The accepted value of TDS for daily utilization are within range of 1000 ppm and for drinking purpose are between 50 ppm and 500 ppm. Thus, only water station 3 was good for drinking purpose as graphed in Fig. 4. Nonetheless, all water bodies were good for utilization purposes.

The last water properties examined in this research was Dissolved Oxygen (DO). DO is important to indicate the amount of oxygen for aquatic organism survival. Average of DO for all water stations gain 8 mg/L thus the water bodies that classified as Class II allow growth of aquatic organism in the ecosystem. Harmful effect on water organism from oxygen reduction can affect water environment.

In a conclusion, water at Station P2 was purer compared to other two station. However, the nutrient in the water bodies was at small scale so it was not suitable for drinking purposes. Nonetheless, the provided result operated as Support Decision System allow water environmentalist monitor the status of water in timely manner.

4.2. *LoRa Performance Evaluation*

The static test was done within dual environment. The receiver with 1 dB of antenna gain located indoor and three LoRa nodes placed outdoor at fish pond. The test was important to evaluate LoRa performance for autonomous water quality monitoring application. All transmitted nodes, Tx, located at similar height of 0.62 m from the ground but different with height of the receiver, Rx at 4.13 m. The distance of node P1 P2 and P3 from the receiver were 4.3 m, 10.95 m and 7.2 m respectively. Total 10 payload were transmitted to receiver by each of end nodes.

The value of RSSI, SNR and loss packet were recorded for both P1, P2 and P3. The acceptable value of RSSI is above -120 dB while good SNR value for LoRa must be more than -20 dB. Implying the Empirical Okumura-Hata Module, the path loss was determined for each water station.

4.2.1. Result of network setup 1 and 2 at P1

Table 4 below summarize the result of network characteristic on RSSI, SNR, loss packet and received power.

Table 4. LoRa Parameter Performance at P1

Setup	Transmission Power	SF	SNR	RSSI	Loss Packet %	Received Power
1	14	7	11.5	-44	0	-16.5
		9	13.75	-63	0	-16.13
2	5	7	10	-65	0	-25.5
		9	13	-71	0	-25.31

P1 was positioned within Line of Sight (LOS) and nearest with Rx, hence the transmission signal able to operate at its optimal capabilities. It can be verified by value of RSSI obtained during transmission. Range of the RSSI of P1 were within usable RSSI for both setup. Furthermore, one of the RSSI value with transmission power of 14 obtained desirable value of RSSI at -44. The value of SNR also showed its good performance as it operated more than +10 dB. There was also no loss packet recorded for P1. The path loss for P1 decrease as value of transmission power and SF increase. The result of path loss for P1 as presented in Fig. 6.

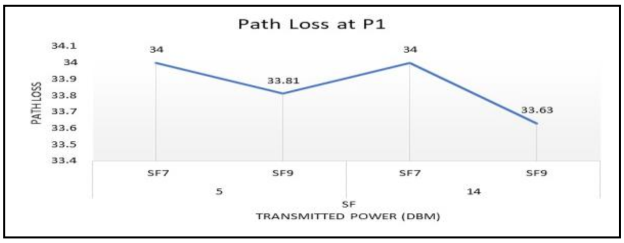

Fig. 6. Path Loss at P1

4.2.2. Result of network setup 1 and 2 at P2

The result of network performance for P2 was summarized as in Table 5.

Table 5. LoRa Performance at P2

Setup	Transmission Power	SF	SNR	RSSI	Loss Packet %	Received Power
1	14	7	9.5	-77	0	-34.91
		9	12.25	-87	0	-33.76
2	5	7	8.25	-89	<1	-45.21
		9	9.75	-95	0	-43.91

P2 was located at NLOS from the Rx and further than P1 location. Based on Table V, value of RSSI were still within acceptable RSSI range though undesirable. The value of RSSI increase as SF is low and transmission power increase. SNR value at P2 show good performance for LoRa network even there were obstacles between end node and gateway. There was notable loss packet for transmission power of 5 and SF7 but the value was still below 1%. Hence, it did not extremely affect packet of data travel. The path loss for P2 is illustrated as Fig.7 below.

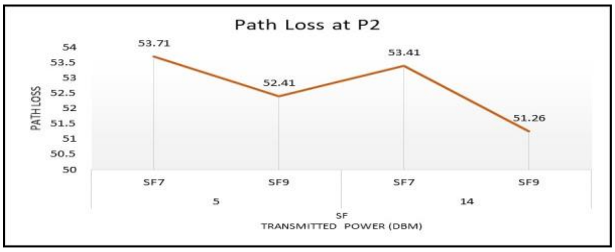

Fig. 7. Path Loss at P2

4.2.3. Result of network setup 1 and 2 at P3

Table 6 portrayed result network characteristic at P3.

Table 6. LoRa Performance at P3

Setup	Transmission Power	SF	SNR	RSSI	Loss Packet %	Received Power
1	14	7	11	-47	0	-19.82
		9	12.25	-65	0	-19.23
2	5	7	9.75	-70	0	-30.78
		9	11.75	-75	0	-29.9

P3 placed within LOS of Rx with present of trees along the transmission path. Though, one of RSSI in setup 1 with SF 7 stay in desirable range while others remain within practical range. SNR obtained for this setup also show good performance with the lowest at 9.75 dB. Also, no loss packet recorded and its path loss result can be viewed in Fig. 8 below.

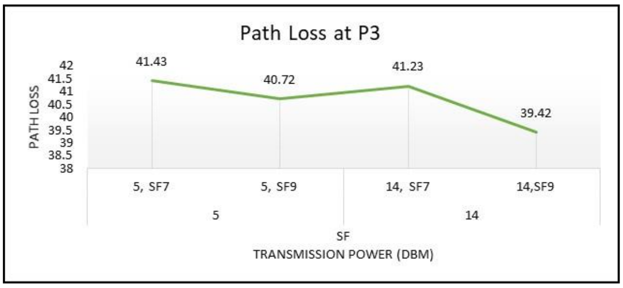

Fig. 8. Path Loss at P3

Analyzing Fig. 6, Fig, 7, and Fig. 8, value of path loss increased with the distance increment of node from gateway and NLOS effect. The pattern of path loss for all location were similar depend on its transmission power and SF. Reduce transmission power save energy consumption but reduce LoRa performance. Furthermore, it is still applicable for low rate data type like water quality data because the range of network properties were still within acceptable range.

5. Conclusion

This research able to reach its objective engaging LoRa in continuous water quality monitoring system. This smart system has potential to reduce the possibility of pollution outbreak as environmentalist able to process quick decision system in real time. Increase SF value can increase the network coverage but it reduced RSSI value and bit rate. Moreover, it increased the energy consumption that can affecting the life of the devices. This research also found that inconsistent weather from sunny to rainy at Malaysia did not influencing LoRa performance. Henceforth, it is suitable to be applied at outdoor environment. The water quality properties value collected from WSN shown in the dashboard verified LoRa ability as wireless network for Smart Environment System at low cost and energy respectively. Though, there were no loss packet recorded in this study, the location of LoRa antenna require LOS and NLOS study effect to reduce undesirable effect on LoRa performance.

In this study, the antenna of gateway used was not suitable with outdoor environment. Nonetheless, LoRa able to connecting gateway and end nodes in semi-outdoor environment. LoRa abilities on SNR, RSSI, packet data loss, the receive power and path loss in this study were evaluated good. Increase the distance of end nodes from each other can reduce redundancy of packet loss data. Moreover, modifying several network parameters of LoRa can improve the system efficiency. As an example, employ suitable antenna for outdoor environment. It is also recommended to operate the system in mesh topology for wide area application to improve the system capabilities.

This paper had exhibited the abilities LoRa within residential environment as experimented in semi-outdoor contemplated with type of antenna used.

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