Long-Range Data Transmission for Online Water Quality Monitoring of the Tembling River in Rural Areas of Pahang, Malaysia

Norashikin M. Thamrin
Agrosen Laboratory, Faculty of Electrical Engineering
Universiti Teknologi MARA
Shah Alam, Selangor, Malaysia
e-mail: norashikin@uitm.edu.my

Mohamad Farid bin Misnan
Faculty of Electrical Engineering
Universiti Teknologi MARA
Pasir Gudang, Johor, Malaysia
e-mail: mohamadfarid@uitm.edu.my

Nik Nor Liyana Nik Ibrahim
Department of Chemical and Environmental Engineering
Universiti Putra Malaysia
Serdang, Selangor, Malaysia
e-mail: niknorliyana@upm.edu.my

Navid Shaghaghi
Ethical, Pragmatic, and Intelligent Computing (EPIC) Lab,
Departments of Mathematics and Computer Science (MCS)
and Computer Science and Engineering (CSEN)
Santa Clara University (SCU), Santa Clara, USA
e-mail: nshaghaghi@scu.edu

Abstract— **Pahang river's main tributary, Tembeling river, flows through the Taman Negara national park in Pahang, which is an eco-tourism attraction in Malaysia. Tembeling river is the main sources of water and food for its surrounding communities. However, agricultural and recreational development on the river banks, monsoon season flooding, and maritime activities on the river have polluted the river water to levels that can cause the extinction of fish and thus the loss of the fishermen's income and livelihood. An automated water quality monitoring system at Tembeling River is therefore believed to benefit the ecosystem immensely. But, the limited mobile network coverage, uneven terrain, and dense forest foliage have made it difficult for wireless data transmission. This paper proposes long-range data transmission via multi-hop short-range Radio Frequency (RF) communication between the remote sensor node(s) and a base station through a network of data extender nodes that utilize the ÂB network layer Energy Aware Communication Protocol (EACP) in order to take advantage of the nodes' sleep cycles. Thus, this work hopes to contribute towards providing stable, reliable, and energy efficient wireless data transfer technology for deploying Internet of Things (IoT) solutions in rural areas.**

Keywords- ÂB; Automated Environmental Monitoring; Internet of Things (IoT); Repeater; Tembeling River; XBee.

I. INTRODUCTION

Malaysia is a country in South East Asia that is bordered by Thailand, Indonesia, Singapore, and Vietnam by sea and land. The country is rich in coastal and mountain diversity and is divided into two sections: Peninsular Malaysia and East Malaysia. Pahang, which is the country's third-largest state after Sabah and Sarawak in East Malaysia, is the largest state in Peninsular Malaysia. Two-thirds of the state is covered by dense forests, intersected by numerous rivers at its center, joining to form the Pahang river that dominates the drainage system in the region and nourishes Malaysia's most significant rainforest, namely Taman Negara, which is estimated to be 130 million years old. Taman Negara is also one of the central regions in Peninsular Malaysia that contributes to the wildlife richness in the country [1]. It has a wide variety of habitat types that host more than 3000 species of plants, 480 species of birds, and 150 species of mammals including some rare species, 30 species of rodents, and more than 80 species of bats [4].

Among the essential ecosystems that are continuously studied in Taman Negara are the freshwater areas [2]-[4] along the Pahang river. The Tembeling river is the main tributary of the Pahang river and a well-known eco-tourism destination for local and international patrons [5][6]. Several major tributaries flow into the Tembeling river, such as Keniam river, Sat river, Sepia river, Tahan river, and Trenggan river. The community utilizes the Tembeling river as a source of water and food. Additionally, places such as the village of Mat Daling (Kampung Mat Daling), Pagi village (Kampung Pagi), Bantal village (Kampung Bantal), and Kuala Sat village (Kampung Kuala Sat) still rely on boats as a means of transportation. Furthermore, a small number of locals perform aquaculture activities in the Tembeling river, where species such as patin (pangasius sutchi) and tilapia are bred [7] for commercial usage.

Unfortunately, extensive anthropogenic activities at the entrance to the Taman Negara including land clearing for the construction of hotels, resorts, and restaurants, improper discharge of wastewater from these amenities, and intense navigation by motor boats, are causing pollution and the destruction of the fish habitat [7][8]. Furthermore, following the monsoon season, a higher concentration of heavy metals such as Silver (Ag) and Cadmium (Cd) are displayed in the river water. The likely source of these minerals is however believed to be from the area's natural geology [9]. The aforereferenced studies suggest that the water supply in the National Park is of acceptable quality for recreational purposes. However, continuous monitoring of environmental pollutants is essential in keeping the water safe and thus preventing any recreational water illness.

II. MOTIVATION

An extreme flood in the states of Pahang in 2014 caused massive damage to the region as well as substantial damage to the infrastructure of the cities. Untreated raw sewage entered the Pahang river during the flood which caused the contamination of the water and surrounding environments [10]. As a result, traces of heavy metals were found in the Pahang river fish. Even though the amount discovered was small, it could still be hazardous to human health as measurements have shown that the trace metal concentration in fish samples almost exceeded the recommended levels by the Malaysian Food Act of 1983 [10][11]. The study presented new data from a survey of fish count and their habitat status in Sungai Pahang, specifically located in the Maran district of Pahang. Three groups of fish that were analyzed in the studies indicated that the fish population in this area were influenced by a combination of water quality parameters such as pH and Dissolved Oxygen (DO). The results also provided an important database for future fishing activities and the conservation of fish in the river area [12]. A qualitative study of the settlers living near the Tembeling river was also conducted to observe the vulnerability of the villagers to environmental changes in the river [7]. The study found the problems of the cleanliness of the river, climate change, and the loss of fish and shrimp, have negatively influenced the villagers' daily lives and income.

A continuous water monitoring system at Tembeling and other tributaries of Pahang river to monitor the impact of ecological and anthropogenic activities on fish habitat is therefore important for the future improvement and development of fisheries. The implementation of an IoT monitoring system has many advantages for a variety of purposes and use cases such as measuring environmental radiation, irrigation or harvesting automation, monitoring cattle, ambient temperature sensing, and much more as discussed in numerous work such as [13]-[18]. The architecture for the proposed IoT river water monitoring system consists of three layers, namely, (1) sensing layer, (2) network layer, and (3) application layer. The sensing layer enables water parameters to be identified, sensed, and measured with a variety of sensor devices. In other applications, these devices can be connected through Wi-Fi, Ethernet, serial bus, 3G/4G/LTE/5G, ZigBee, RFID, or other link layer protocols [18]. The primary constraint to this implementation here however is the limitation of the available networks in rural areas such as Tembeling river. In Malaysia, the Ministry of Communications and Multimedia (KKMM) initiated a telecentre system for rural communities to improve their digital literacy through computer and online activities since 2000. The first telecentres constructed were located in Sungai Air Tawar, Selangor and Kota Marud, Sabah. To date, 42 telecentres have been built in Malaysia. Such telecentres use wireless technology to make it easier for local villagers to access the Internet. In Pahang, there are three telecentres, which were built at Bandar Tun Razak, Bukit Goh, and Sungai Koyan. Sadly, such telecentres are far from the research areas at Kampung Pagi and Tembling river and thus challenging to access. Beyond the challenges of 2G/3G/4G connectivity, another problematic element for wireless data transmission at the remote monitoring site is the uneven terrain that hinders long range Point to Point (P2P) wireless communication by resulting in a Non-Line-Of-Sight (NLOS) link between the transmitter and the receiver.

Previous research typically only investigated the type of fish species, effect on the fish population, and the sociological impact on the Tembeling River community. An IoT implementation to continuously track the river water quality, however, has not been reported so far. Therefore, more work is needed to understand the behavior of communication signals at the remote sites of the Tembeling river.

III. BACKGROUND AND OVERVIEW

There is a demand for a cost-effective and reliable technique to establish a communication medium in rural areas such as Tembeling river's surrounding areas. To address the problem of limited access to mobile signal coverage (2G/GSM, 3G/WCDMA, 4G/LTE, and 5G) at the Tembeling river's remote site, a P2P system can be used. A seemingly easy P2P solution could involve using LoRa modules operating on frequencies between 919MHz to 923MHz in a similar fashion to existing monitoring systems such as the Hydration Automation (HA) system used for continuous monitoring of water tank levels in farms and ranches [14] or the HiveSpy system used for continuous monitoring of beehive frames for honey production in apiaries [15]. Both of these systems use a network of Relay Units (RUs) - a.k.a. repeaters, for propagating the signal from the Sensing Units (SUs) to the base station over several kilometers.

This paper similarly proposes a procedure for wireless data transmission between the water sensor nodes and the base station by using repeaters. However, due to the fact that the uneven terrain and dense forest in the area inhibit long range P2P communication, a much larger network of more closely positioned repeaters is necessary. Therefore, instead of using the more expensive LoRa modules used in HA and HiveSpy, the usage of cheaper but lower range XBee Pro modules is recommended. XBee Pro modules utilize 2.4Ghz RF serial frequency communication for transmitting and receiving the data. Another advantage of using these modules is that they offer the ability to operate on cheap batteries for years [19].

In order to further prolong the battery life on the modules, sleep cycles will be used. However, as the number of repeaters increase so will the complexity of keeping universal time within the system. A proposed solution is to readapt the ÂB networking layer protocol used in the aforementioned monitoring systems [14][15] to work atop of the Zigbee link layer protocol. ÂB is an Energy Aware Communication Protocol (EACP) used to take maximum advantage of individual node sleep cycles in an IoT system and is agnostic to the physical and medium access layers of the communication subsystem [20]. Therefore, ÂB provides a great opportunity for the enhancement of the energy efficiency of the water quality monitoring system proposed here for the Tembling river.

Figure 1 shows the proposed remote site for installing an IoT monitoring system of Tembeling river's water quality in Kampung Pagi. The system's base station is planned to be located at the local primary school, SK Kampung Pagi, which is about 1.28 kilometers from the remote site. Theoretically, this remote site and the proposed base station can be interconnected with a single hop LoRa solution. However, due to the uneven terrain and existence of a dense rainforest in between the sensors and base station, multiple hops will be necessary. And especially since these hops will not have the possibility to cover grate distances each, the advantage offered by the long range of LoRa modules gives way to the disadvantage of their higher cost in comparison to XBee communication modules. Hence a network of low range yet carefully positioned P2P repeaters that utilizes an energy efficient communication protocol such as ÂB, presents itself as a realistic solution for this rural area of Tembling river in this remote corner of Malaysia.

Figure 1. The proposed location for testing the long-range data transmission between a sensor node on the bank of the Tembeling River and a base station at Kampung Pagi, in Taman Negara national park in Pahang, Malaysia.

IV. LONG-RANGE DATA TRANSMISSION PROTOCOL

The proposed RF long-range data transmission system consists of three parts: (1) sensor node(s), (2) data extender(s), and a (3) base station. Each part is equipped with *XBee Pro* RF transceiver modules. The working range of each *XBee Pro* RF module is estimated at around 3200 meters for line-of-sight (LOS) communication [21], so theoretically, the values transmitted from the sensor node can be repeated by adding an extender every 3200 meters until reaching the base station. However, because of the uneven terrain and dense forest in Kampung Pagi that limits LOS communication and attenuates the signal strength, the range of the RF signals and thus the number of data extender modules needed will vary. Figure 2 illustrates the overall module structure in the proposed data transmission system.

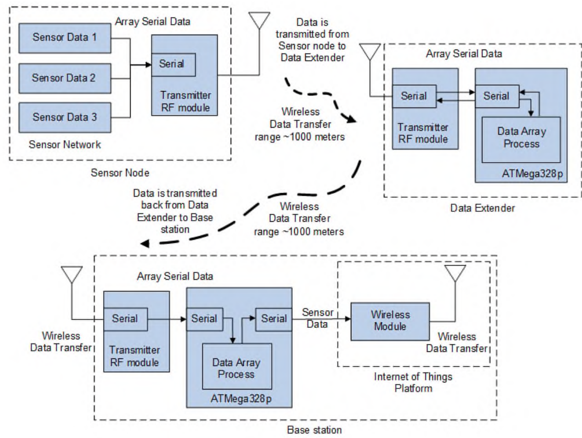

Figure 2. The block diagram of the proposed RF data transmission.

A. Sensor Node

The sensor node has several water quality sensors attached, as shown in Figure 3. The data gathered from each of the sensors is collected and appended to an array. The array is then transmitted using the RF transmitter to the next hop in the system which is either the base station itself or a data extender for systems where the senser node and base station are far apart such as in the proposed system at Tembeling river. Each array packet has a unique identifier in its packet header to identify the sending sensor node so that multiple sensor nodes can be used with a single base station.

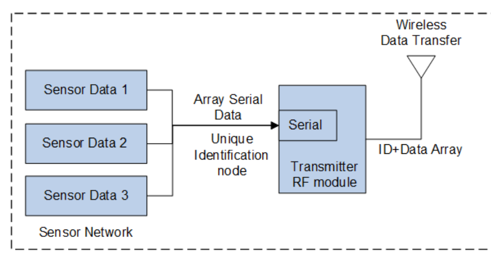

Figure 3. The sensor node to collect water parameters.

B. Data Extender

The data obtained from multiple sensor nodes are received and transmitted to another data extender or directly to the base station using RF transceivers. The network of data extenders is also called a repeater network. Figure 4 shows the innerworkings of a data extender module.

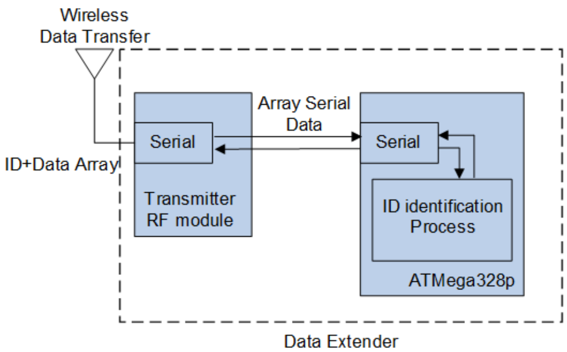

Figure 4. The designed data extender module system.

The data extenders will be placed in appropriate locations between the sensor node(s) and the base station at Kampung Pagi, as shown in Figure 5, which will be determined based on the Receive Signal Strength (RSS) received by the module. The repeaters will be placed at the best places for LOS communication to ensure the reliability in data transmission. However, the terrain and climate will play a major role in the need for specialized or ruggedized extender node casing in order to prevent water from entering the nodes during the monsoon season for instance. Custom ruggedized capsules can however be costly and environmentally un-friendly. Thus, to keep the production cost of the capsules low yet environmentally friendly, they can be 3D-printed using Polyethylene Terephthalate Glycol (PETG) filament which has proven to be resistant to water, prolonged exposure to sunlight, and even acidic conditions [22]. And to esure the capsules are waterproofed, the same best practices for the 3D-printing of such outdoors capsules as depicted in [23] will be followed.

Figure 5. Possible area for placing Data Extenders in Kampung Pagi.

C. *Base Station*

The base station is the part of the system that aggregates all of the data collected by the sensor nodes within an area and relays the data to the World Wide Web. The data gathered from the sensor nodes are transmitted either directly or through data extenders. Thus, the base station must be equipped with the same RF transmitter module as the sensor nodes and data extenders.

As depicted in Figure 6, the received data is filtered and identified based on the unique identification appended in the data array. Then the *ATmega328p* micro-controller, processes the data array by separating it into individual water parameters. The water parameters are then published to the cloud as a JSON payload via an ESP wireless module. The published data are displayed on the online dashboard of the IoT water quality monitoring system in order to enable the remote monitoring of the water quality from anywhere in the world.

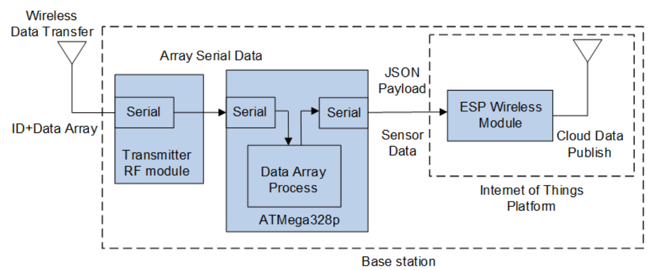

Figure 6. The base station module to transmit the received data onto IoT Cloud platform for online water quality monitoring system.

V. CONCLUSION

The Tembeling river's fish habitat are the primary source of food and income for its surrounding communities. Unfortunately, the erratic monsoon season floods, anthropogenic activities in the form of nearby plantation activities and construction for attraction of tourism, and a major increase in maritime commerce and transportation have impaired the water quality and thus endangered many species of fish. For this reason, an IoT monitoring system for water quality is absolutely necessary.

Such a remote monitoring system has to be fitted with long-range wireless data transmission that can visualize the data online. Due to limited mobile network coverage in rural areas as well as uneven terrain and dense forest foliage that inhibits the propagation of long-range P2P communication signals, the data transmitted from the remote sensor nodes must be propagated through the use of a network of short-range RF transmission repeaters that are positioned to maintain LOS communication. The nodes must all be extremely energy efficient and be encapsulated in weatherized casings in order to withstand harsh environmental conditions for long durations. When the data reaches the base station, it is transmitted to a remote server in order to be displayed on a web-based dashboard.

 ISBN: 978-1-61208-814-3

ACKNOWLEDGMENT

This research was made possible with the funding from the Universiti Teknologi MARA (600-RMC/LESTARI SDG-T 5/3(125/2019). Many thanks to the Faculty of Electrical Engineering at Universiti Teknologi MARA for providing facilities and guidance throughout this work. Lastly, the researchers like to acknowledge the department of Chemical and Environmental Engineering at Universiti Putra Malaysia and the departments of Mathematics & Computer Science (MCS) and Computer Science & Engineering (CSEN) at Santa Clara University, Santa Clara, USA for research collaboration.

REFERENCES

[1] A. Jambari, S. Sasidhran, H. R. A. Halim, K. A. Mohamed, A. Ashton-Butt, A. M. Lechner, and B. Azhar "Quantifying species richness and composition of elusive rainforest mammals in Taman Negara National Park, Peninsular Malaysia," *Global Ecology and Conservation*, *18*, 2019, e00607.

[2] Y. Mohd-Azham and H. R. Singh, "Freshwater fish diversity and their distribution along the Keniyam River, Taman Negara Pahang, Malaysia" In IOP Conference Series: Earth and Environmental Science, IOP Publishing, July 2019, Vol. 269, No. 1, pp. 012034.

[3] F. A. Farinordin, N. N. Nazri, A. Samat, D. Magintan, A. K. J. P. Besar, M. F. Sayuti, and S. M. Nor, "Freshwater fishes of Sungai Sat and Sungai Kelapah, Taman Negara National Park, Pahang". *Journal of Wildlife and Parks*, 2016, *31*, pp. 49-60.

[4] A. M. Radhi, M. F. N. Fazlinda, M. N. A. Amal, and H.Rohasliney. "A review of length-weight relationships of freshwater fishes in Malaysia". *Transylvanian Review of Systematical and Ecological Research*, 2018, *20*(1), p. 55-68.

[5] A. Azlizam, S. N. H.Syed-Alias, J. Mazlina, N. H. Idris, and M. Manohar. "The attractiveness of Taman Negara National Park, Malaysia as perceived by local visitors". *Journal of Wildlife and Parks*, 2018, *33*, pp. 1-13.

[6] A. D. Khairudin and N. H. A. Rahman. "Evaluating the quality experience of ecotourist in Taman Negara Pahang". *E&ES*, 2020, *447*(1), 012014.

[7] S. M. Yassin, A. A. Samah, B. A. Samah, K. Idris, A. Hamzah, and H. A. M. Shaffril. "The sensitivity of communities towards the environmental changes in Tembeling, Pahang and Muar Rivers". Life Science Journal, 2013, 10(3), pp. 2143-2152.

[8] M. S. Adnan, "Development and evaluation of indices to assess the ecological health of the Pahang River", Malaysia. PhD thesis, Kyushu University, 2011.

[9] S. Rajan, N. N. M. Firdaus, M. Appukutty, and K.Ramasamy. "Effects of climate changes on dissolved heavy metal concentrations among recreational park tributaries in Pahang, Malaysia", 2012.

[10] N. Manap, K. Sandirasegaran, N. S. Syahrom, and A. Amir, "Analysis of Trace Metal Contamination in Pahang River and Kelantan River, Malaysia". In MATEC Web of Conferences, 2019, Vol. 266, p. 04003. EDP Sciences.

[11] D. I. Saparuddin, "Determination the concentrations of heavy metals in silver catfish (pangasiussp.) from Sungai Semantan and Sungai Tembeling", 2017.

[12] Z. A. Rashid, M. N. A. Amal, and S.Shohaimi, "Water Quality Influences on Fish Occurrences in Sungai Pahang, Maran District, Pahang, Malaysia". Sains Malaysiana, 2018, 47(9), pp. 1941-1951.

[13] A. Tocchi, V. Roca, L. Angrisani, F. Bonavolontà, and R. S. L. Moriello, "First step towards an IoT implementation of a wireless sensors network for environmental radiation monitoring". In 2017 IEEE International Instrumentation and Measurement Technology Conference (I2MTC), May 2017, pp. 1-6.

[14] N. Shaghaghi, P. Ferguson, J. Mayer, Z. Cameron, and B. Dezfouli, "A Low-power Wireless Sensing Unit for Hydro-System Automation," *2019 IEEE 9th Annual Computing and Communication Workshop and Conference (CCWC)*, Las Vegas, NV, USA, 2019, pp. 0659-0665.

[15] N. Shaghaghi, HiveSpy. In Proceedings of the 5th EAI International Conference on Smart Objects and Technologies for Social Good (GoodTechs '19). Association for Computing Machinery, New York, NY, USA, 2019, pp. 126–127.

[16] T. Natori, N. Ariyama, S. Tsuichihara, H. Takemura, and N.Aikawa, "Study of Activity Collecting System for Grazing Cattle". 2019 34th International Technical Conference on Circuits/Systems, Computers and Communications (ITC-CSCC), June 2019, pp. 1-4.

[17] R. K. Dhammi, K. M. Soni, S. Selvam, and P. Singh, "Real Time monitoring of high temperature of remote places using Wireless Sensor Network without use of any peripheral hardware". *2019 6th International Conference on Signal Processing and Integrated Networks (SPIN)*, March 2019, pp. 850-853.

[18] S. Guoqiang, C. Yanming, Z. Chao, and Z.Yanxu, "Design and implementation of a smart IoT gateway". In 2013 IEEE International Conference on Green Computing and Communications and IEEE Internet of Things and IEEE Cyber, Physical and Social Computing, August 2013, pp. 720-723.

[19] M. Orgon, L. Zagajec, and I. Schmidt, "XBee technology: Complex evaluation of radio parameters". 2019 11th International Congress on Ultra Modern Telecommunications and Control Systems and Workshops (ICUMT), October 2019, pp. 1-6.

[20] N. Shaghaghi, Z. Cameron, N. Kniveton, J. Mayer, W. Tuttle, and P. Ferguson "ÂB: An Energy Aware Communications Protocol (EACP) for the Internet of Things (IoT)". 2020 Web, Artificial Intelligence and Network Applications (WAINA) March 2020, Springer Advances in Intelligent Systems and Computing, vol 1150. pp. 877-889.

[21] Y. Choden, M. Rai, C. Wangchuk, P. Singye, and K. Muramatsu, "Remote Controlled Rescue Robot Using ZigBee Communication". 2019 IEEE 5th International Conference for Convergence in Technology (I2CT), March 2019, pp. 1-5.

[22] B. Kuhn, "Important Advantages of PETG Filament in 3D Printing". MakeShaper, December 2016. [Online] Available: https://www.makeshaper.com/2016/11/15/important-advantages-of-petg-filament-in-3d-printing

[23] N. Shaghaghi and J. Mayer, "A Sustainable 3D-printed casing for Hydro-System Automation Sensing Units," 2019 IEEE Global Humanitarian Technology Conference (GHTC), Seattle, WA, USA, 2019, pp. 1-7.