TẠP CHÍ KHOA HỌC
TRƯỜNG ĐẠI HỌC QUY NHƠN

Hệ thống giám sát và cảnh báo lũ lụt thời gian thực ứng dụng công nghệ LoRa cho lưu vực sông Kôn - Hà Thanh, tỉnh Bình Định

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Ngày nhận bài: 09/07/2020 ; Ngày nhận đăng: 09/08/2020

TÓM TẮT

Trong bối cảnh của biến đổi khí hậu như hiện nay, lũ lụt đã và đang gây ra những thiệt hại nghiêm trọng đến tính mạng và tài sản của người dân trên toàn cầu nói chung, Việt Nam nói riêng, trong đó có Bình Định. Do vậy, việc xây dựng các hệ thống giám sát và cảnh báo lũ sớm với công nghệ hiện đại là yêu cầu hết sức cấp thiết. Trong bài báo này, các tác giả sẽ nghiên cứu và thiết kế một hệ thống giám sát và cảnh báo lũ lụt thời gian thực ứng dụng công nghệ LoRa kết hợp với nền tảng mã nguồn mở Thingsboard. Hệ thống này cho phép thu thập số liệu tại các khu vực khác nhau trên sông một cách đầy đủ, chính xác và kịp thời, nhằm phục vụ cho công tác dự báo và cảnh báo sớm. Hệ thống đề xuất được triển khai thử nghiệm trên lưu vực sông Kôn - Hà Thanh, tỉnh Bình Định.

Từ khóa: *Giám sát và cảnh báo lũ lụt, thời gian thực, LoRa, IoT và Thingsboard.*

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JOURNAL OF SCIENCE
QUY NHON UNIVERSITY

A real-time flooding monitoring and warning system using LoRa technology in Kone and Ha Thanh river basin, Binh Dinh Province

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Received: 09/07/2020; Accepted: 09/08/2020

ABSTRACT

In the context of the recent climate change, flooding has been causing serious damages to the human lives and their properties in the world in general, Vietnam in particular, including Binh Dinh province. Therefore, it is pivotal for local governments to build up real-time flooding monitoring and warning systems supported by modern technologies. Addressing to this aim, in this paper, we will study and design a new flooding monitoring and warning system based on a combination of the Long Range (LoRa) teachnology and an open-source platform of Thingsboard. The proposed system allows collecting effectively and sufficiently data from different locations on rivers in a timely manner, thus supporting the early flooding prediction and forecast processes. A testbed of the proposed system is then deployed in the Kone and Ha Thanh river basin, Binh Dinh Province.

Keywords: *Flooding monitoring and warning, Realtime, LoRa, IoT and Thingsboard.*

1. INTRODUCTION

Flooding has been causing serious damages to the lives and property of people around the world. According to the Center for Research on the Epidemiology of Disasters - EM-DAT Database (https://www.emdat.be/), over the period 2000 - 2018, water-related disasters accounts for 90% of total global natural disasters, of which floods account for about 54%. During the same period, human losses amounted to 93,470 and economic losses to nearly 500 billion USD.[1]

One of the biggest challenges of mitigation of flooding damages to communities is how to provide local residences with warnings of natural disasters in a timely manner. In June 2015, the United Nations adopted the Sendai Framework for Disaster Risk Reduction 2015 - 2030.[2] The Sendai Framework is considered as an effective approach for flooding risk management.[2,3] Especially, the Sendai Framework emphasises roles of Flooding Early Warning Systems (FEWS) and regconises that the FEWS is an important prerequisite to collect data accurately and promptly in different regions and areas. These data are expected to effectively serve the forecast and early warning of weather and climatic extremes [3,4].

In the current global climate change context, flooding is becoming more dangerous and unpredictable. Vietnam, a country located in the monsoon tropics and one of the five "storm centers" of the Asia-Pacific region has been facing various types of natural disasters with increasing severity. Notably, the Southern Central Coastal regions such as Binh Dinh, Phu Yen, Khanh Hoa, Ninh Thuan were severely affected.

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Binh Dinh has a natural area of 6,039 km^2 with a coastline of more than 135 km and a population of 1,486,918 people[5]. The whole province lies neatly on the eastern side of the Truong Son mountain range, with steep and complicated terrain. The slope direction is mainly from West to East, hills and plains alternate to form separate regions and basins under the major river systems including Lai Giang, Kone, La Tinh and Ha Thanh. Due to the influence of natural geographic factors, topography, geology, and climate, Binh Dinh and the Kone - Ha Thanh river basin in particular are often influenced by heavy flooding, causing serious damages to the local residences, property, infrastructure and environment. In this circumstance, the main mission of Binh Dinh authority is to implement early flood monitoring and warning systems in order to mitigate damages caused by floodings.

Towards the above goal, under the sponsorship of the German International Cooperation Organization - GIZ[6] and Rockefeller[7], Binh Dinh authority deployed an early flood warning system on the Kone - Ha Thanh river basin in 2016. In 2018, The Provincial Steering Committee for Disaster Prevention and Search and Rescue built up a rainfall and flooding data transmission and management system in the Kone - Ha Thanh area[8]. A disaster prevention information system introcuded by Hitachi was also deployed in Binh Dinh[9]. The above systems are responsible for collecting data from hydro-meteorological stations, monitoring and sending them to a headquater via available telecommunication infrastructures. Based upon analysing collected data, adequate warnings will be sent to the authorities or the local people through the mass media. After a period of operation, however, the effeciency achieved from the above systems is not high as expected and there are several following limitations:

- In the existing systems, devices using the standards of WiFi and mobile technologies (i.e., 2G, 3G, or 4G) are powered by available electricity grids. In fact, when floodings happen, it is very difficult to maintain electricity sources to ensure the continuous operation of stations and transmission lines, especially in mountainous and remote areas;

- Due to the disruption of communication systems (i.e., broken or swept away broadcasting stations), communication between the authorities and residents in flooded areas is limited, making it difficult for search and rescue activities;

- The number of stations deployed in the area is small and the density of stations is low (e.g., the Rockefeller warning system in the Kone - Ha Thanh river basin has from 4 to 7 stations). As a result, there is a lack of the collected data which is influencing the accuracy of warnings and forecasting models;

- The large-scale deployment of the FEWS requires high costs. Furthermore, these systems are copyrighted systems in term ofs hardware and software. Therefore, it is difficult to for the local authorities to deploy in a large scale.

To solve these limitations, studying and implementing new solutions and technologies for flooding monitoring and early warning are essential. In recent years, Internet-of-Things (IoT) and Low Power Wide Area Network (LWPAN) like Wireless Sensor Networks (WSN), Long Range (LoRa) are emerging as potential technologies for FEWS[10]. Compared to solutions used in the existing systems[6-9], LoRa or WSN can be deployed with open source platforms, hardware and software costs are fairly low. In particular, the LoRa or WSN-based devices can operate in a long time, up to 3 - 10 years by using only AA batteries. Therefore, LPWAN solutions are attracting the attention of the scientific community and industries. Some typical real-time flood warning systems using LoRa or WSN have been proposed, such as Advantech's flood warning system[11], Libelium[12], Semtech[13], Flood-Network[14], or StormSense[15]. These systems ensure the full range of features of a flood warning system with user-friendly interfaces. However, the biggest limitation of the above solutions is the cost of installation and operation. Typically, each toolkit with two or three sensor nodes costs from 5.000 to 7.000 Euros, which is too expensive for the local authorities to deploy in a large scale.

Meanwhile, there are not many FEWS combined with these new technologies in the domestic market. Recently, there is an intelligent flood warning system VFASS[16] allowing to collect data using the LoRa technology and broadcast warnings. However, it has not integrated with tools of visualisation and data management, making it difficult for flooding management.

As analysed above, the deployment of flooding monitoring and warning system upong a combination of IoT and LWPAN is necessary. In this work, the authors will design and implement a real-time flood monitoring and warning system based on LoRa technology combined with an open source platform Thingsboard. The system model proposed in this paper is expected to solve the above limitations. The system will be then deployed and evaluated in some frequently flooded areas of the Kone - Ha Thanh river basin.

The rest of the article includes the following sections. Section 2 describes background of flooding monitoring and warning systems, LoRa technology and the open source platform Thingsboard. Session 3 introduces the proposed real-time flooding monitoring and warning system. The implementation and evaluations of the proposed model are illustrated in Section 4. The conclusion of the paper is presented in Section 5.

2. BACKGROUND

2.1. An overview of FEWS

There are many different definitions of the FEWS. According to the United Nations Office's definition of disaster risk reduction, FEWS is *"an integrated system of hazard monitoring, forecasting and prediction, disaster risk assessment, communication and preparedness activities systems and processes that enable individuals, communities, governments, businesses and others to take timely actions to reduce disaster risks in advance of hazardous events"*[3]. The architecture of FEWS includes basic functional components as described in Figure 1:

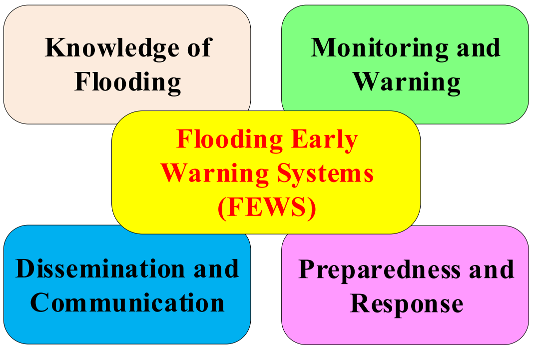


Figure 1. The architecture of FEWS [3]

In this paper, the authors focus on monitoring and warning components. By the end, we will design, build and implement a flooding monitoring and warning system by using the LoRa technology.

2.2. LoRa technology

LoRa (Long Range) is a wireless standard designed for LPWAN to connect devices with low bandwidth and data rates requirements, while focusing on coverage efficiency as well as energy efficiency. The LoRaWAN standard developed by the LoRa Alliance defines the Medium Access Control (MAC) layer and the LPWAN network architecture using the LoRa modulation method at the physical layer as shown in Figure 2. The operational frequency spectrum of the LoRa is from 430 MHz to 915 MHz. LoRa is one of the communication technologies in the low power long range connection group. LoRa works in the physical layer of LoRaWAN architecture Semtech[10]. LoRa technology allows data transmission at distances up to several kilometers without the need for power amplifiers, thereby saving energy consumption when transmitting/receiving data and can operate for a long time before replacing the battery.

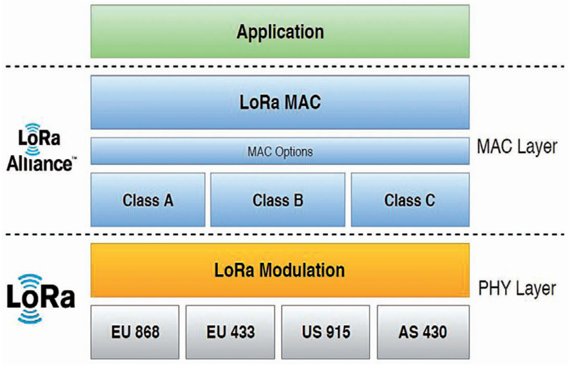


Figure 2. LoRa technology và LoRaWAN[10]

LoRa uses a Chirp Spread Spectrum (CSS) modulation technique. The data will be hashed with high-frequency pulses to produce a signal with a frequency range higher than that of the original data (called chipped). These high-frequency signals are encoded in sequences of Chirp signals (sinusoidal signals whose frequency changes over time). The CSS principle allows for less complexity and improves the accuracy of the receiver circuit so that data can be decoded and reprocessed. Furthermore, LoRa can transmit at a long distance without using a high transmission power level, even when the signal power is lower than ambient noise.

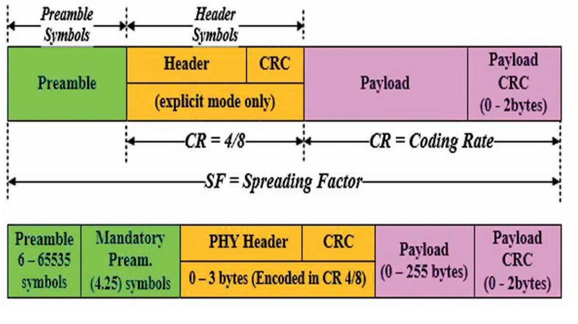


Figure 3. LoRa packet structure [10, 17]

The LoRa packet structure is depicted in Figure 3 and includes the following information:

- Header: contains information about the size of the download (Payload) and PayloadCRC or not.

- Payload: is the length of the application data that needs to transmit.

- Spreading Factor (SF): determines the number of Chirp signal chains when encoding the frequency-modulated signal. The value of SF varies from 7 to 12. The larger SF value is, the data transmission time is longer and the transmission distance is extended.

- Bandwidth (BW): defines the frequency range at which the Chirp signal can change. The higher the bandwidth is, the shorter chipped signal encoding time will be. In this circumstance, the data transmission time is reduced, and the transmission distance is also shortened. The three common bandwidth levels for LoRa are 125 kHz, 250 kHz, and 500 kHz.

- Coding Rate (CR): is the number of bits that are automatically added to each payload in a LoRa packet by the LoRa chipset to help the receiver circuit to restore some of the data bits if there is an error in the reception process. The higher the CR, the more likely it is to receive the correct data; but the LoRa chip has to send more data.

SF, BW, CR are three basic and important parameters of LoRa chipset. SF and BW will affect the time and distance of data transmission; CR only influcences data transmission time. Depending on specific application requirements in terms of distance, data delivery rate, the values of SF, BW and CR can be selected to optimise transmissions over LoRa.

2.3. IoT open sources platform - Thingsboard

In order to store, manage, and display data collected in monitoring and warning models, the selection of the right IoT platform is important[17,18]. The IoT platform will perform the main functions such as: connecting devices, collecting, monitoring, managing and analysing data. Recently, many open source and commercial platforms have been proposed to meet the growing needs of IoT applications. Compared with the open source platforms Thingio, Sitewhere, WSo2, Kaa IoT, DeviceHive, Zetta, and Blynk. Thingsboard is considered a very effective platform to solve the need for collection, processing, and data visualization and device management [17]. Thingsboard includes some basic features as follows:

- Telemetry data collection: support telemetry data collection and storage in a reliable way. The collected data can be accessed using a custom website or server-side API;

- Data visualisation: Thingsboard provides many utilities to visualise data collected in real-time;

- Device management: Thingsboard offers abilities to register, manage devices as well as track devices' properties. Thingsboard also allows server-side applications to send control commands to devices via APIs;

- Dashboard: This functionality allows to display data and control devices remotely in real-time;

- Warning management: Thingsboard provides tools to initiate and manage alerts related to entities in the system, especially real-time alarm monitoring. To connect devices and exchange data, Thingsboard uses industry standard IoT protocols, typically MQTT (Message Queuing Telemetry Transport). MQTT is a Publish-Subscribe messaging protocol, uses low bandwidth, so it is an efficient protocol for IoT applications. In a system using the MQTT protocol, multiple clients connect to a server (called the MQTT Broker). Each client will subscribe to monitoring information channels (topic) or post data to that information channel[18].

3. A PROPOSED REAL-TIME FLOODING MONITORING AND WARNING SYSTEM

3.1. System model

In the paper, the authors build a real-time flood monitoring and warning system based on the combination of LoRa technology[10] and the Thingsboard open source platform[17]. The basic idea of the system is to remotely collect important data, such as: rainfall level *L* (mm), water level *H* (m) and water flow rate *V* (m^3/s). These data will be sent to the processing center and displayed in real time to serve for analytical monitoring and alert decision-making.

- Gateway (GW): is a central device that converts two wireless transmission protocols, LoRa and WiFi. GW will collect data from Nodes (or measuring points). These data will be updated on ThingsBoard MQTT Server to display to users via website interface and on smart phone. At the same time, GW sends control signals from MQTT Server to the Nodes to execute warning commands. In this paper, Nodes 1 and 2 can operate like monitoring nodes as well as controlling nodes (through the I/O pins available connecting to speakers or other warning devices).

- Monitoring nodes: are the terminals. The nodes are responsible for measuring values of rainfall, flow rate and river water level. Data is then sent

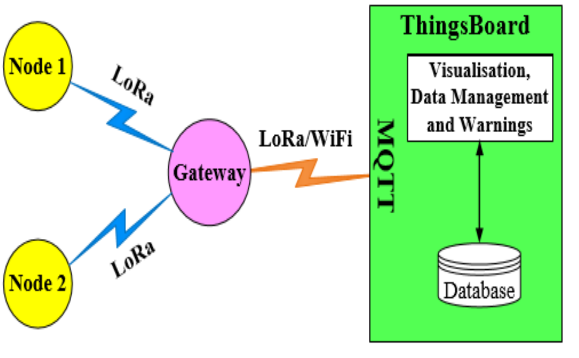


Figure 4. Proposed system model

to GW for further processing. The nodes communicate with GW over the LoRa protocol.

- User interaction: User is provided with an account to be able to access data on MQTT Server, monitor and control via website and smart phone interface.

- Thingsboard: This platform receives data from GW, processes and visualises it. Based on the proposed warning algorithm, Thingsboard will make the appropriate warning decisions and send the control command to GW to execute the warning process.

3.2. Proposed monitoring and warning algorithm

The proposed algorithm's flowchart is described in Figure 5. Warning decisions are released relied on the analysis and evaluation of data stored on Thingsboard. Setting threshold values of *L, H, V* in the Thingsboard platform is dependent on the actual topographic conditions at the considering checkpoints and the authorities' regulations:

- *The threshold value of rainfall L:* Parameter L is determined using the regulation[19]

o Medium rain alarm: L1 = 50mm within 24 hours;

o Heavy rain alarm: L2 = 100mm within 24 hours;

o Very heavy rain alarm: L3 = over 100mm within 24 hours;

- *The thresohold value of river water level H:* The value determined using the regulation [20]:

o Level 1: H1 = 6m;

o Level 2: H2 = 7m;

o Level 3: H3 = 8m.

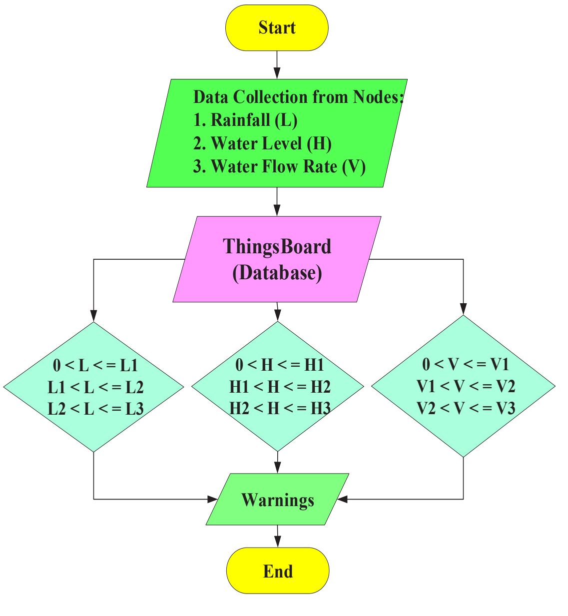


Figure 5. Algorithm flowchart of flood warning process

- *The threshold value of flow rate V:* Assuming that the parameters are set as follows:

o Level 1 alarm: V1 = 5 m^3/s;

o Level 2 alarm: V2 = 10 m^3/s;

o Level 3 alarm: V3 = 15 m^3/s.

The proposed algorithm is executed by comparing parameters of L, H, V with threshold parameters (L1, L2, L3), (H1, H2, H3) and (V1, V2, V3) independently through the use of the "or" (||) operator. There are three levels of warning:

- *Level 1 alarm:*

$(0 \leq L \leq L1) \,||\, (0 \leq H \leq H1) \,||\, (0 \leq V \leq V1)$

- *Level 2 alarm:*

$(L1 \leq L \leq L2) \,||\, (H1 \leq H \leq H2) \,||\, (V1 \leq V \leq V2)$

- *Level 3 alarm:*

$(L2 \leq L \leq L3) \,||\, (H2 \leq H \leq H3) \,||\, (V2 \leq V \leq V3)$

4. IMPLEMENTATION AND RESULTS

4.1. Proposed system implementation

This section will introduce the implementation of the proposed system in the Kone - Ha Thanh River area passing the Nha Phu spillway. Figure 6 shows the experimental model with 02 Nodes and 01 GW:

- Nodes use LoRa configuration and are integrated with sensors to collect information of rainfall, flow rate and river water level. Nodes are distributed at two different locations: Node 2 is located above the spillway surface and Node 1 is located 1000m from the spillway.

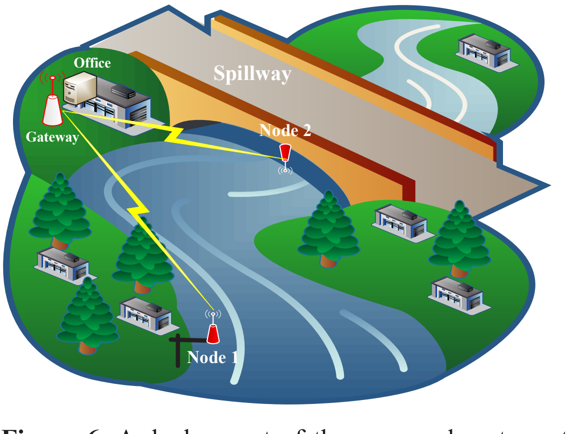


Figure 6. A deployment of the proposed system at Nha Phu spillway, Kone - Ha Thanh river basin.

- GW is set up in the office or at the house. Data at GW will be sent to Thingsboard.

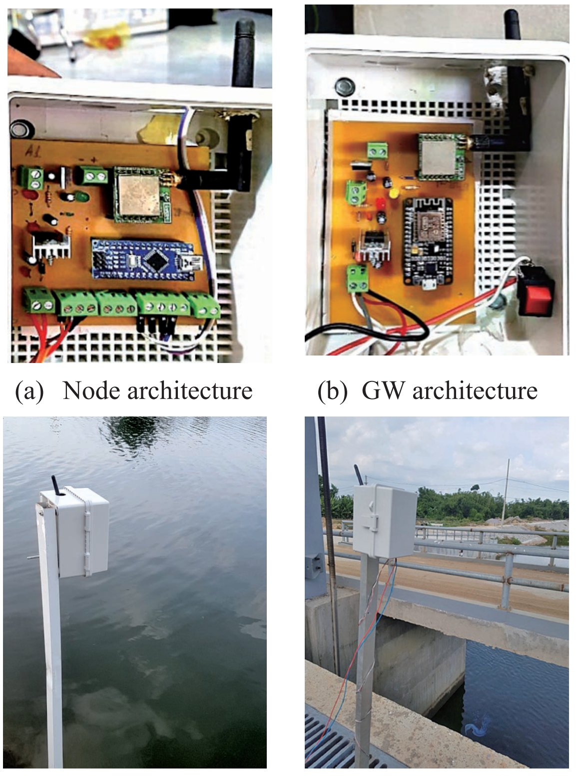
4.2. Results

The parameters of the implementation are shown in Table 1. Figures 7 (a) and (b) describe the internal structure of sensor Nodes and GW respectively. At the same time, the actual implementation of Nodes and GW is illustrated in Figures 7 (c) and (d).

Table 1. Parameters of experimental model

Parameter	Symbol	Value
Frequency	*F*	433MHz
Spectrum factor SF	*SF*	7, 9, 12
Encoded rate	*CR*	5/8
Bandwidth	*BW*	125KHz
Transmitted power	*Tx*	14dBm
Rainfall sensor	Holman WS5070W	
Water flow sensor	YFS201	
Water level sensor	HC-04	
Microcontroller – Node	Arduino Nano	
Microcontroller – GW	ESP32	
LoRa Node	Air4 (SX1278)	
Distance Node - GW	*D*	1000 m

Figure 8 shows an interface for monitoring data collected from Node 1 and 2 on the Thingsboard platform. In addition, Thingsboard also allows for monitoring the quality of the transmission links between the Nodes and GW by using received signal strength indicator (RSSI) and signal to noise (SNR) ratio. The results in Figure 8 (b) show that the Thingsboard platform not only effectively supports flood warning data visualisation, but also enables monitoring of the operability and reliability of the Nodes.



(a) Node architecture (b) GW architecture

(c) Node 1 (d) Node 2

Hình 7. Structures of Nodes and GW

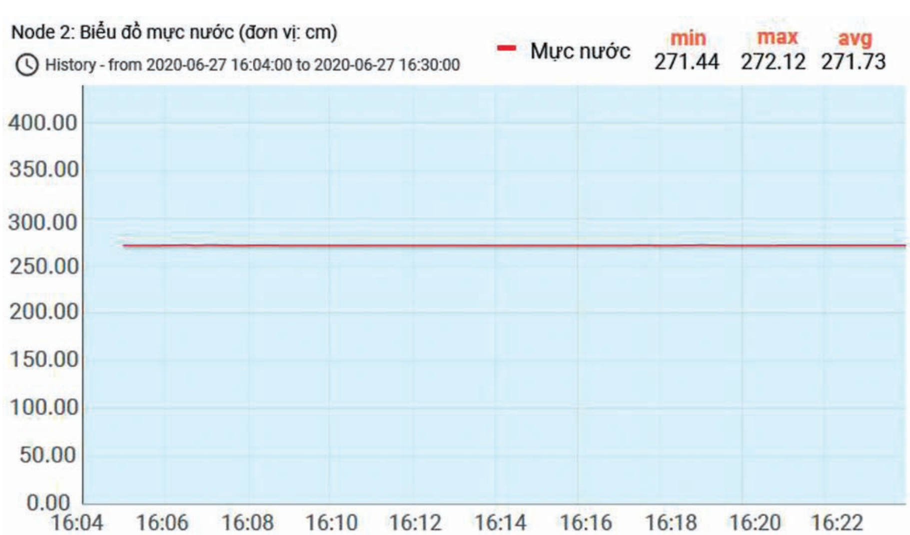
5. CONCLUSION

In the paper, we have proposed and implemented a real-time flood monitoring and warning model using LoRa technology at a low cost (~ 150 Euro). The system works well with the open source platform Thingsboard and is capable of integrating various communication technologies such as LoRa and WiFi. Relying on the functionality of visualisation, the proposed system allows users to access and monitor flooding parameters directly and easily. As a result, the proposed system is expected to widely deploy in reality.

Các thông số Node 2

Time stamp ↓	Mực nước (cm)	Lượng mưa (mm)	Nhiệt độ (độ C)	Độ ẩm (%)	Kích thước gói tin (byte)	RSSI (dBm)	SNR
2020-06-27 16:31:55	271 84	0.00	35.00	69	44.00	-44.00	9.50
2020-06-27 16:31:45	271.94	0.00	35.00	70	44.00	-44.00	9.00
2020-06-27 16:31:35	271.84	0.00	35.00	70	44.00	-44.00	10.00
2020-06-27 16:31:25	272.01	0.00	35.00	70	44.00	-45.00	9.75
2020-06-27 16:31:15	272.02	0.00	35.00	70	44.00	-44.00	9.75
2020-06-27 16:30:45	271.97	0.00	35.00	70	44.00	-44.00	10.25
2020-06-27 16:30:35	271.95	0.00	35.00	70	44.00	-44.00	9.00
2020-06-27 16:30:25	271.94	0.00	35.00	70	44.00	-44.00	9.75
2020-06-27 16:30:05	271 94	0.00	35.00	70	44.00	-45.00	9.75
2020-06-27 16:29:55	271.95	0.00	35.00	70	44.00	-43 00	10.50

(a) Rainfall, water level, temperature and humidity data, and signal level received at Node



(b) River water level

Figure 8. Monitored data at Node 2

ACKNOWLEDGEMENT

This research is conducted within the framework of the student scientific research project for the academic year 2019 - 2020 under the project code S2019.598.35.

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