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DEVELOPMENT OF SMART CAMPUS APPLICATIONS BASED ON WIRELESS TECHNOLOGIES USING OPEN-SOURCE PLATFORMS

Nur Farahin Abdull Rashid, Asma' Abu-Samah*, Aishah Mohd Noh, Noor Zaim Syafiq Azam, Nur Najihah Wahid, Chee Qin Chiang, Haider Alobaidy, Nor Fadzilah Abdullah, Sawal Abdul Hamid, Rosdiadee Nordin

Department of Electrical, Electronic and Systems Engineering, Faculty of Engineering and Built Environment Universiti Kebangsaan Malaysia, 43600, Bangi, Selangor, Malaysia

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*Corresponding author
asma@ukm.edu.my

Graphical abstract

Abstract

Malaysian National Center for Education estimates that students' enrolments will increase to 17.2 million by 2028. The conventional way of managing things around campus work can be improved by applying the smart campus concept. This study showcases the potential smart campus applications with different wireless IoT technologies and their application; LoRa for Internet of Bicycle (IoB), Sigfox for water quality monitoring, IEEE 801.11p for campus active safety application, and NB-IoT for remote mangrove conservation. The prototypes consist of various sensors and online dashboards to demonstrate the open-source IoT ecosystem. For IoB, a 0.5 km radius centered at LoRa gateway's location, proved reliable for real-time e-bicycles location monitoring. It offers locking system security to avoid bicycles steal. The SigFox-based water quality monitoring system received signal performance is adequate (RSSI -80 to -90 dBm) with a tower location approximately 3 km from the lake area. For active safety application based on IEEE 801.11p, communication of braking force, car speed, and position of cars ahead of an obstacle make this application feasible to improve road safety around campus, with the real implementation expected to be achieved in the next five to ten years. Lastly, the application of remote mangrove conservation monitoring using NB-IoT on LTE mobile network from Celcom as an independent wireless platform. It allows researchers and students from the university to use this application for their research on sustainable conservation at remote mangrove sites worldwide. The results have shown that all the wireless IoT is promising for future smart campus deployment.

Keywords: Wireless Sensor Network, Internet of Things (IoT) Technologies, LoRa, SigFox, IEEE801.11P, NB-IoT

Abstrak

Pusat Pendidikan Kebangsaan Malaysia menganggarkan bahawa enrolmen pelajar ke universiti akan meningkat kepada 17.2 juta menjelang 2028. Cara konvensional pengurusan di sekitar kampus boleh diperbaiki dengan mengaplikasikan konsep kampus pintar. Kajian ini mempamerkan potensi aplikasi kampus pintar dengan teknologi Internet Benda (IoT) yang berbeza serta aplikasinya; LoRa untuk Internet Basikal (IoB), Sigfox untuk pemantauan kualiti air, IEEE 801.11p untuk aplikasi keselamatan aktif kampus, dan NB-IoT untuk pemuliharaan bakau jarak jauh. Prototaip terdiri daripada pelbagai penderia dan antara muka dalam talian untuk menunjukkan ekosistem IoT sumber terbuka. Untuk IoB, radius 0.5 km berpusat di lokasi gerbang LoRa terbukti boleh dipercayai untuk pemantauan lokasi e-basikal masa nyata. Ia juga menawarkan keselamatan sistem penguncian untuk mengelakkan kecurian basikal. Sistem pemantauan kualiti air berasaskan SigFox menerima prestasi isyarat memuaskan (RSSI -80 hingga -90 dBm) dengan lokasi menara lebih kurang 3 km dari kawasan tasik. Untuk aplikasi keselamatan aktif berdasarkan IEEE 801.11p, komunikasi daya brek, kelajuan kereta, dan kedudukan kereta di hadapan halangan menjadikan aplikasi ini boleh dilaksanakan untuk meningkatkan keselamatan jalan raya di sekeliling kampus, dengan pelaksanaan sebenar dijangka dapat dicapai dalam tempoh lima hingga sepuluh tahun akan datang. Akhir sekali, aplikasi pemantauan pemuliharaan bakau jarak jauh menggunakan NB-IoT pada rangkaian mudah alih LTE daripada Celcom sebagai platform wayarles bebas. Ia membolehkan penyelidik dan pelajar dari universiti untuk menggunakan aplikasi ini untuk penyelidikan mereka mengenai pemuliharaan mampan di kawasan bakau terpencil tapak di seluruh dunia. Keputusan telah menunjukkan bahawa semua aplikasi IoT menjanjikan perlaksanaan kampus pintar masa depan.

Kata kunci: Rangkaian Sensor Tanpa Wayar, Teknologi Internet Perkara (IoT), LoRa, SigFox, IEEE801.11P, NB-IoT

1.0 INTRODUCTION

Every year the enrolment of students in universities around the world increases. Based on National Center for Education Statistics, between 2000 - 2007 undergraduate student enrollment increased by 22% than the last academic session. Total undergraduate enrolment by 2028 is estimated to rise to 17.2 million students. With this increasing number of enrolments, can the conventional way of managing things around campus work? For example, imagine how long a student must queue to pay for their food? Should the university spend enormous money by adding more cashiers to speed up paying for food?

Alternatively, the student can pay using a cashless system, such as RFID technology embedded in the student identification card to pay for their food. Second, through the basic GSM technology, the card's cash balance is updated to any application wirelessly and regularly [1]. This not only quickens the payment process, but it is also practical in handling more users.

This wireless technology is not limited to paying a service or goods cashless, but it is more than that. It can be applied to most systems such as waste management, air, and water quality monitoring, or traffic/parking management. Many campus residents drive their cars to the campus, and it is tough for them to find available parking. Most universities positioned rubbish bins around their campus, but many students did not responsibly throw the rubbish in the bins accordingly. Besides that, Malaysia's demand for clean water increases by 7 liters per capita every year [2]. Hence, this statistic shows that every university needs a clean water supply for campus residents to use for their daily usage such as on the toilet, drinking water, and for Muslims to take their wudhu'.

These campus issues can be solved by the wireless sensor network (WSN) technology that is enhanced with the Internet of Things (IoT) and complemented with the emergence of Long Range (LoRa), Sigfox, Narrowband-IoT (NB-IoT) low-power wide-area network (LPWAN) protocols, LTE, 5G, and 802.11p. IoT is a concept that allows the devices and services to work autonomously by sending data to a central cloud data management system, with minimum manual human control and operations. It promotes reachability to users anywhere and anytime using their smart devices [3].

The smart campus concept adopts the idea of a smart city and brings it to the campus operation [4], where the system can fulfill the user's needs by controlling the consumption of resources. This work aims to validate and showcase the proof of concepts towards different use of wireless IoT technologies as enablers to the smart campus applications. From the previous study by [5], the exclusive solution to monitor the solid waste bin condition in real-time was made and it uses the wireless sensor network system using Zigbee and GPRS. The wireless IoT module is integrated with various sensors and hardware development, such as Arduino, Raspberry Pi 3, ESP8266 WEMOS, and software, such as The Things Speak (TTS), MATLAB, Ubidots, and custom-made IoT software. Moreover, an application of NB-IoT in monitoring water quality in the mangrove area is explained as a proof of concept to demonstrate the IoT-based remote research activity from campus.

The interest and research development work on smart campuses were developed several years ago. Research by [6], was performed drive-test for three wireless standards of LTE Release 8, 3G and Television White Space (TVWS) at the suburban campus. The drive-test uses real LTE user equipment, equipped with ASCOM's TEMS software on a live 3G and 4G mobile networks for Malaysian mobile service providers Maxis and Celcom. Hence, both operators showed sufficient coverage within the campus area. On the other hand, results from the field experiment indicate that TVWS is available on the campus. The authors in [7] implemented a LoRaWAN-based IoT solution for monitoring PM2.5 air quality on their campus. The sensors were installed on lamp poles and rooftops of a building from the LoRa gateway, with the largest distance of 670 meters. As for the Internet of Bicycle (IoB), much prior research has been done to develop bicycle monitoring system, such as authors in [8] that used Android smartphone connected to the battery of e-bicycle. It was installed with SEMS (Smart E-bike Monitoring System) app as the medium to transfer data from e-bicycle to the server. This method shows a great effect on the bicycle battery life that the battery runs out even though the e-bicycle is stationary for a few days. Research by [9] also shows cyclists' mobile phones as a medium to transfer data to the database. This inconveniences the user that they need to always bring mobile phones during every trip since this system depends significantly on the mobile phone's GPS and mobile network. Research by [10] shows Bluetooth as a data transmission method from the bicycle to the charging station. Data are then uploaded to the server after the bicycle is returned to the charging station. This method was unable to perform monitoring of the bicycle from time to time.

To maintain the quality of raw water sources, especially for lake water, the water quality parameters need to be consistently monitored. The parameters involved are pH (acidity/alkaline) and turbidity (clarity, in NTU unit) [11]. Traditionally, the water quality measurement is done using a manual probe, or the water sample needs to be sent and analyzed in the lab. In [12], the authors focused on developing sensors connected to LoRaWAN to monitor water flow in a utility hole and water supply. Parameters include groundwater level, installation trenches, wastewater temperature, water consumption, quality, and water pressure. The measuring devices were located in deep indoor placement, outdoor between 5 to 15 km from the LoRa antenna.

Besides that, many automotive companies are increasingly developing autonomous vehicles (CAV). In terms of communication, the CAV application establishes a connection between vehicle to vehicle (V2V). This connectivity is one of the concepts of VANET (*Vehicular Ad Hoc Network*) based on the WLAN (*Wireless Local Area Network*) technology standard. IEEE has developed a WAVE (*Wireless Access for Vehicular Environment*) architectural system to provide wireless access in a vehicular environment [13]. WAVE allows fast and reliable communications between vehicles. V2V communications are currently standardized in WAVE, such as IEEE 802.11p, to enable traffic-related security and traffic efficiency technologies developed by authors in [14]. This vehicle-to-vehicle communication (V2V) is based on a platooning system where vehicles move in traffic flow. The lead vehicle controls the speed and direction, while all following vehicles respond to the lead vehicle's movement [15]. A combination of autonomous vehicles and wireless technology is expected to facilitate vehicle safety systems and improve road safety. An advanced system of auxiliary functions has been developed to avoid such accidents and minimize collision effects should one occur. By that means, the car brake itself should have a good software system to assist a driver along the road [16]. This paper proposed an autonomous vehicle active safety application use case via the WiFi module and smartphone, focusing on an automatic emergency braking system to warn the driver of the potential frontal collision and mitigate traffic congestion.

Authors in [17] proposed WSN for mangrove protection and conservation in Taiwan. The study proposed a natural ecology sensing system (NESS), which consists of a natural resource integrated computing server (NRICS), mobile user (MU), and ecological information services system (EISS). The users can acquire collected data in the EISS through a wireless local area network (WLAN) and based on the mobile networks, such as 2.5 (GPRS) and 3G (CDMA/HSPA) through the 3G gateway. Their study found that NESS improved long-term observation by providing a real-time and network surveillance system. Another work published in [18] has developed IoT for freshwater quality monitoring using the NB-IoT network. Their study found that NB-IoT protocols have many suitable characteristics for freshwater monitoring, such as long-lasting battery life and reliable long-range communication. Digital News Asia [19] reported the Ericsson project to plant mangrove saplings around sensors to monitor the surrounding critical information such as soil, weather and water levels. The information is then compiled and sent directly to the cloud where any stakeholders such as farmers, analysts, NGOs and the authorities can access them. Access to the data leads to a better understanding of the status of the seedlings. This IoT project is the first of its kind in Malaysia and is designed to help the community through advanced technologies.

LoRa is an independent and spectrum license-free wireless system with low cost, low power consumption, low bit rate but for long-range communication. With LoRa, a user can build their network, own gateway, and own nodes. It is a cost-effective and practical solution for several Internet of Things applications. LoRa aim used in long-life battery-powered devices. Typically, LoRa works in 433-, 868- or 915-MHz ISM bands. Coverage LoRa depends on the area's surroundings, such as urban, suburban and rural areas. By field test in paper [20], LoRa can offer satisfactory network coverage up to 3 km in a suburban area with dense residential dwellings. LoRa immunity towards interference is very high due to the modulation scheme's design and chirp spread spectrum, resulting in a higher number of spreading factors, a bigger range, and high receiver sensitivity, subject to the bandwidth size [21].

Besides that, Sigfox is another wireless IoT technology in which the modulation type is an ultra-narrow band with differential binary phase-shift keying at 100 bps [22]. It operates like a cellular network. The Sigfox network provider installs a base station on existing telecommunications towers and the data from the Sigfox node is transmitted to the base station. Therefore, a client who intends to use the Sigfox network needs to ensure their area has a sufficient Sigfox connection. Sigfox coverage also differs between areas, such as urban 3-10 km and 30-50 km in rural areas. Sigfox overcomes the interference issue or package loss by sending three uplink packages to improve link robustness [22].

Furthermore, IEEE 802.11, was IEEE Standard for Wireless Access in Vehicular Environment (WAVE). However, because of vehicular networks' operating environment, an amendment of the standard is made, known as IEEE 802.11p. The current WiFi module is based on the IEEE 802.11a standard. The clock rate was reduced by half to change it to 802.11p compliant with a 10-MHz bandwidth. This halving of frequency-domain parameters doubles the time-domain parameters, thus increasing the robustness to multipath fading effects [23].

Lastly, NB-IoT is a short name for Narrow Band-IoT. It is a wireless IoT technology that was specified in the 3GPP (3rd Generation Partnership Project) Release 13 in June 2016. NB-IoT can coexist with any mobile network, such as LTE/LTE-Advanced (Long-Term Evolution) and GSM (Global System for Mobile Communications) under licensed frequency bands of 700 MHz, 800 MHz, and 900 MHz. NB-IoT occupies a frequency bandwidth of 200 kHz, which corresponds to one resource block in GSM and LTE transmission. The NB-IoT communication protocol is based on the LTE protocol. The data rate is limited to 200 kbps for the downlink and 20 kbps for the uplink. NB-IoT coverage is 10 km in a rural area and 1 km in an urban area [24].

Table 1 Comparison between different wireless IoT technologies

Parameter	LoRa	Sigfox	IEEE 802.11p	NB-IoT
Frequency band	EU: 863-870MHz US: 902-928 MHz Australia: 915-928 MHz China: 779-787 MHz, 470-510 MHz	Unlicensed ISM bands Europe: 868 MHz North America: 915 MHz Asia: 433 MHz	Unlicensed ISM bands (5.85-5.92 GHz)	Licensed LTE frequency bands
Data rate	50 kbps	100 bps	3–27Mbps	20-200Kbps
Transmission range	Rural: >10 km Urban: 2 - 5 km	Rural: 30-50km Urban: 3- 10 km	1 km	Rural: 10km Urban: 1 km
Modulation type	Spreading Factor	BPSK	BPSK, QPSK, 16-QAM, 64-QAM	QPSK

Table 1 provides a technical comparison between four (4) wireless IoT technologies that the industries have widely adopted at the moment. These four wireless technologies are expected to drive the growth of IoT applications in the short future.

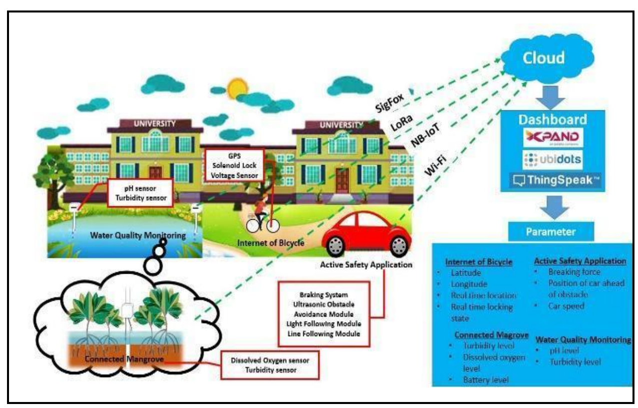


Figure 1 Several smart campus applications that were considered and developed in this paper

Based on the smart campus applications in Figure 1, we have considered four (4) wireless communication platforms in this paper, namely LoRa, Sigfox, WiFi 802.11p, and NB-IoT. In this study, LoRa is used for IoB application location-aware security function, SigFox for the lake water quality monitoring, WiFi for CAV active safety application and NB-IoT for water quality monitoring at a remote mangrove area based on the participation in a Hackathon competition. The Internet of Bicycle and autonomous cars are expected to be part of the campus's transportation modes within the next ten years. Connected mangrove and lake water quality monitoring can be used for conservation and sustainability surrounding the campus environment. In this paper, the sensors that have been integrated were monitored by a dashboard platform, connected to the cloud from the data transmitted through LoRa, Sigfox, WiFi, or NB-IoT. Table 2 summarizes the wireless IoT technologies, hardware, and software that have been used to develop these smart campus prototypes and applications.

Table 2 Wireless IoT technologies with hardware and software platform for various smart campus applications

No	Wireless IoT Technologies	Smart Campus Application	Open Resource Tools	
			Hardware	Software
1	LoRa	Internet of Bicycle	Arduino Uno	The Things Speak and Google Map
2	SigFox	Water Quality Sensors	Arduino Uno	The Things Network, Ubidot, and SigFox online dashboard
3	WiFi 802.11p	PiCar for Active Safety	Raspberry Pi	MATLAB and Dragit
4	NB-IoT	Connected Mangrove	Arduino & Raspberry Pi	Xpand Dashboard (custom-mode)

The contributions of this paper can be summarized as follow:

1. Identified IoT applications that can benefit the campus population, especially the students.
2. Design and development of identified smart campus wireless technologies.
3. The IoT applications performance validation. Their feasibility was also investigated for future smart campus applications.

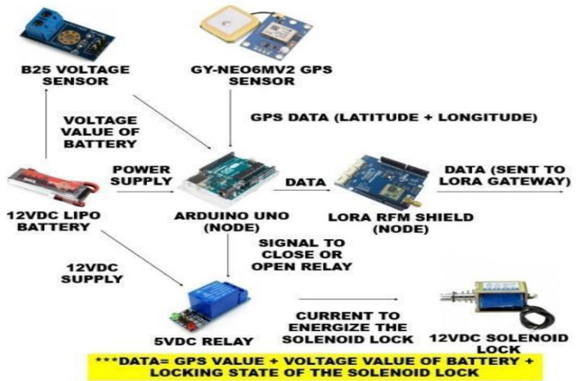
A review of several works in the literature related to smart campus applications and the state-of-the-art of the current wireless IoT technologies, such as LoRa, Sigfox, 802.11p, and NB-IoT, are presented and compared in Section 1, and also together with presents the smart campus applications framework for this paper with relevant hardware and software to develop and integrate the prototypes. Section 2 presents the methodology used to design and develop each application. Results and discussion to validate the prototype's functionality and performance for every application were presented in section 3. Finally, Section 4 highlights the feasibility of adopting the considered smart campus applications and concludes the paper.

2.0 METHODOLOGY

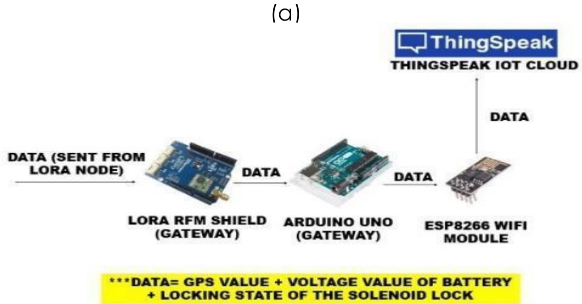
2.1 Internet of Bicycle (IoB)

The Internet of Bicycle (IoB) offers a long-range and low power consumption monitoring system using LoRa, to increase the bicycle's security. Based on the previous research, there are two types of bicycle monitoring systems, using GPS and mobile networks [25] and previously operated a standalone wireless protocol [26], which consumed high power with short-distance wireless data transmissions.

The connection of equipment and direction of data transmission on the LoRa Node and LoRa Gateway developed in this paper is shown in Figures 2(a) and 2(b), respectively. The Think Speak (TTS) is the open-source platform used by this project as a dashboard platform for monitoring all the IoB data. RFM LoRa shield communicates with the Arduino Uno via SPI protocol, while the B25 voltage sensor to safe voltage input to Arduino Uno, GY-NEO6MV2 GPS sensor for the locking system, 5 V_{DC} relay and ESP8266 WiFi module to send all data to The Thing Speak (TTS) All the components are integrated into an Arduino Uno via the serial communication port. To avoid simultaneous communications from equipment with the Arduino Uno, Arduino Uno's pin connected to every piece of equipment was set separately. 5 V_{DC} from Arduino Uno was used as a power source to power up these components: 5 V_{DC} relay, GY-NEO6MV2 GPS sensor, B25 voltage sensor and ESP8266 WiFi module.



(a)



(b)

Figure 2 (a) Component set up for the LoRa Node; (b) Component set up for the LoRa Gateway

The HTML web page was made from HTML and JavaScript using the Notepad++ application to show the LoRa Node location, the latitude and longitude data from The Thing Speak through Thing Speak API key. The dashboard platform was then developed to monitor the received string of data from the LoRa Node via LoRa transmission, divided into Latitude, Longitude, Voltage and Locking state using substring code and assigned to a few unknown variables before being sent to The Thing Speak cloud dashboard.

2.2 Water Quality Monitoring

Water quality monitoring application can help the campus maintenance office or biodiversity researchers to monitor water quality. This serves as a preventive measure before the situation worsens due to pollution or the presence of unwanted chemical substances. Previous researchers [27] and [28] have developed an automatic system that monitors water quality for sampling and analysis purposes. In this paper, the water quality monitoring system is not only for sampling and analysis, but it can also send feedback to the authority when the water parameter exceeds the threshold value to take corrective or preventive action.

This developed system is connected to the pH and turbidity sensors. As shown in Figure 3, the Arduino microcontroller is integrated with the SigFox shield, pH sensor and turbidity sensor. The sensors' data is transmitted by the SigFox shield to the nearest Sigfox gateway and pushed to the SigFox backend or platform. At the SigFox backend, a third-party application, Ubidot [29], is used in this paper to display the sensor data in human-readable form and provide a map for SigFox to use geolocation services and locate the device in the map. Also, the Ubidots is an open-source platform for this project to monitor their data on the Ubidots dashboard. The Ubidots application is integrated with the SigFox callbacks services to extract data from the SigFox backend. In this system, Ubidots equipped with the event could be triggered whenever the parameter exceeds or is lower than the defined threshold and send a trigger message via Telegram application for the user to take action (Figure 4).

Figure 3 Sensors, microcontroller and wireless components used for the water quality monitoring applications

Figure 4 Screenshot from Telegram to show the triggered event from Ubidots

2.3 Active Safety Application

Another smart campus application developed in this paper is active vehicle's safety, which adopts the platooning system [30]. In an autonomous car, when a vehicle moves in traffic flow following a lead vehicle's speed and direction, wireless communication will be triggered to warn the driver to mitigate the traffic accident.

The main part of the design is to build a Pi-Car prototype equipped with several sensors, including an ultrasonic obstacle avoidance module, light following module and line following module. This Pi-Car prototype focuses on a safety application based on an automatic emergency braking system made using the Fuzzy Logic Controller (FLC). The system's response was simulated using the Fuzzy Logic Toolbox in MATLAB. This Pi-Car-S is controlled using an Android phone via WiFi connection, which WiFi module is based on the IEEE 802.11a standard. The clock rate needs to be reduced by half to ensure that the IEEE 802.11p is compliant with a 10-MHz bandwidth size. Figure 5 shows how the system works. The mobile application establishes a connection with a Raspberry Pi 3 microcontroller that involves communication using WiFi. It is designed to control the movement of the Pi-Car prototype. Controlling the direction of the car is done using a remote-control interface. A mobile-based user interface is used to control the car motion that is set up using Python and SSH in the Raspberry Pi.

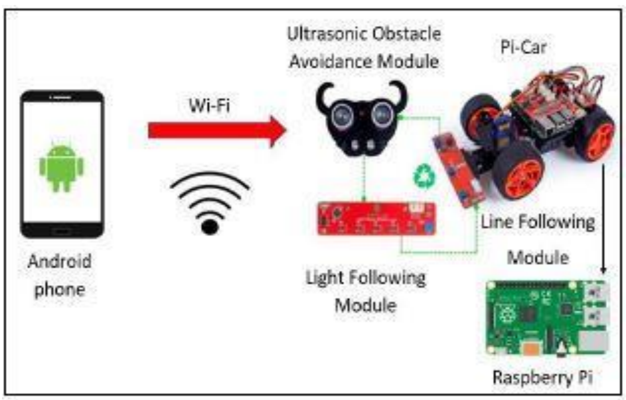


Figure 5 Block diagram of the Pi-Car system

2.4 Connected Mangrove

The Connected Mangrove application consists of the following hardware: Arduino Nano, Raspberry Pi and sensors (Dissolved Oxygen and turbidity), and power supply system, including the solar panel, solar power charge management unit, battery 5000mAh LiPo, and battery charge monitoring unit. The connectivity of the hardware is shown in Figure 6. The battery charge monitoring unit is integrated into Raspberry Pi to monitor the battery LiPo capacity. The Raspberry Pi data was pushed to a custom-made Xpand-IoT dashboard platform using the MQTT connection through NB-IoT wireless device. A LiPo battery with 5000 mAh capacity is used to power up the MangroveTalk device and sustain the Lipo battery life. A solar panel is integrated into the solar power charge management unit to recharge the LiPo battery.

Xpand dashboard platform is an open-source platform that is used by this application. At the Xpand dashboard, a threshold of the sensors has been defined. The threshold is vital to ensure the water's condition is safe; therefore, the user can receive an alarm in their email or Telegram application if the data value received exceeds the threshold. This allows the user to take quick action to overcome the problem.

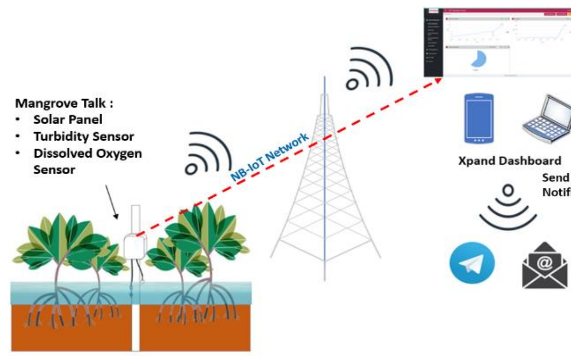


Figure 6 The NB-IoT connectivity between the sensors and the base station

The MangroveTalk sensor is automatically connected to the NB-IoT network and transmits data to the XPAND IOT dashboard using NB-IoT Modem. The sensor is connected to the NB-IoT network and if a NET LED is blinking, it indicates that the modem is attached to the network and connection has been established successfully. The sensor data were then sent to the XPAND IoT dashboard using MQTT.FX.

2.5 Smart Campus Applications Development Framework

Based on the smart campus applications development framework in Figure 7, three smart campus applications were developed: water quality monitoring, Internet of bicycle, and active safety application. The smart campus applications used IoT wireless technologies to communicate between a transmitter and the receiver to send and receive the data to the cloud dashboard platform. The transmitter is the device node that contains sensors to collect the data. When the transmitter sends the data to the receiver, SigFox, NB-IoT, LoRa, and WiFi, the data is pushed to the cloud dashboard to display data. The data analysis can be viewed on the dashboard for monitoring activity.

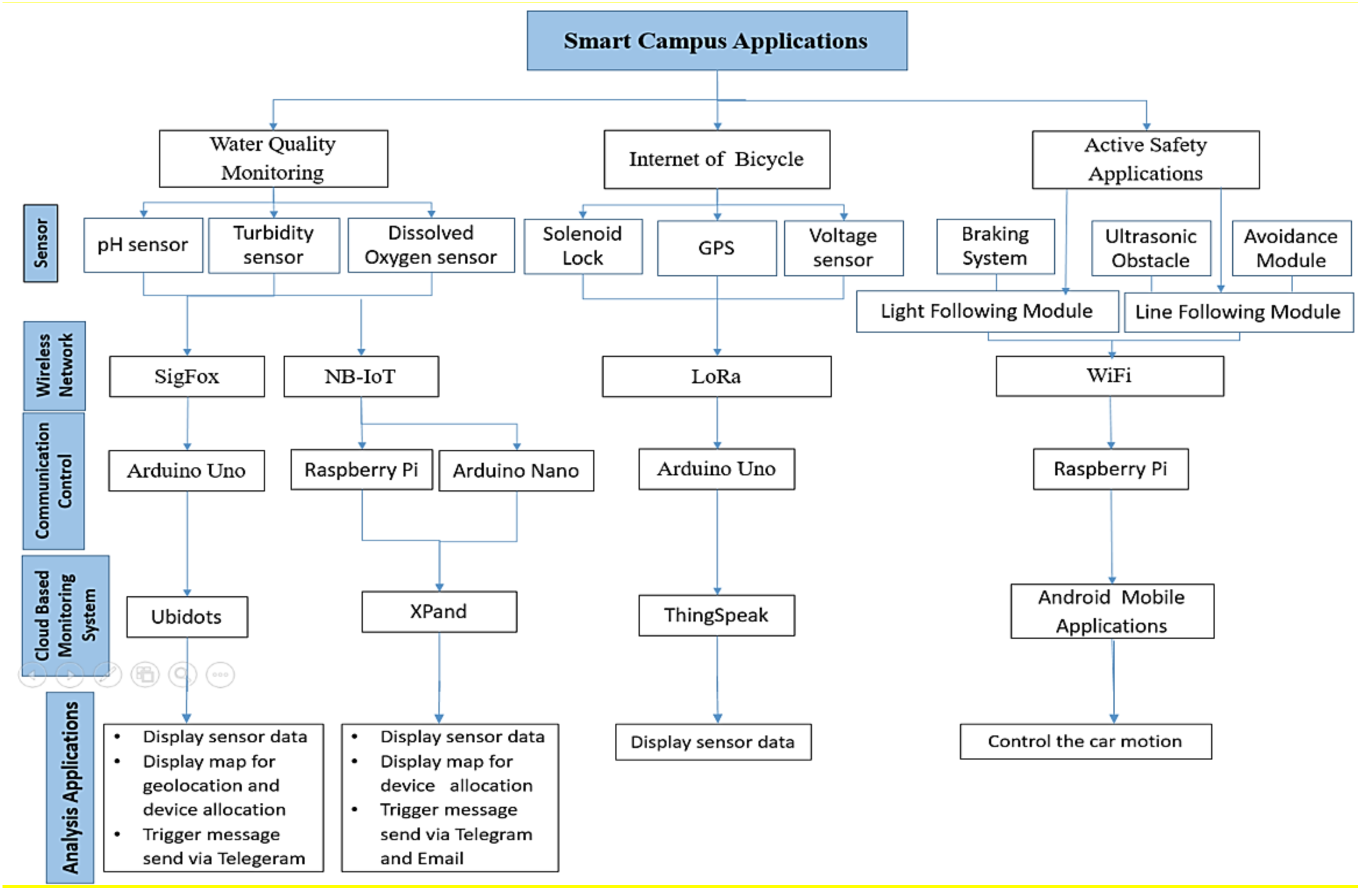


Figure 7 Block Diagram of Smart Campus application development framework

3.0 RESULTS AND DISCUSSION

3.1 Internet of Bicycle (IoB)

In this paper, the solenoid lock activates the bicycle's locking mechanism when the LoRa node is outside the circular area. This study's locking area is configured within the radius of 0.5 km centered at LoRa gateway's location with latitude and longitude given in real-time data from Figure 8(a) and Figure 8(b), respectively. The locking state can be monitored from the dashboard, as illustrated in Figure 8(c). The locking state with the value '0' indicate that the LoRa node is still inside the circular area, $D < 0.005$, solenoid lock is not locked, and the locking state with a value of '1' indicate that the LoRa Node is outside the circular area, $D > 0.005$, solenoid lock is locked. This can be seen from the GPS location changed from (2.922359, 101.771670) to (2.922345, 101.771550). The D value was from the change of value 0.004974 to 0.005063. Hence, it was very easy to monitor all the above data from TTS dashboard as an open-source platform.

(a)

(b)

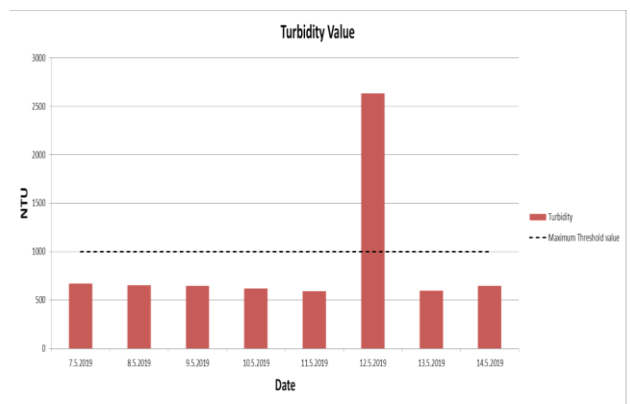
(c)

Figure 8 (a) latitude; (b) longitude; and (c) locking state value

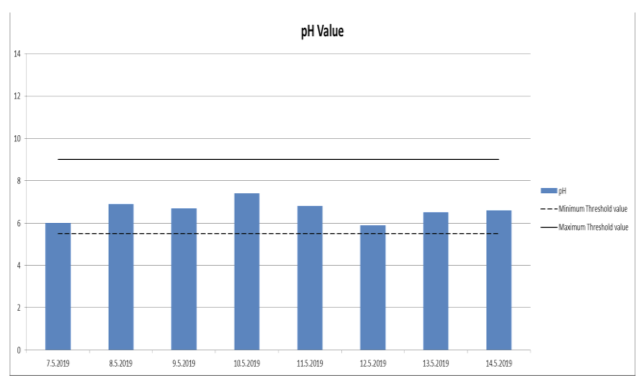
A LoRa-based Internet of Bicycle (IoB) system can monitor the real-time location of the e-bicycle and the automatic locking system's battery voltage has been successfully developed as a prototype. The system has been tested in a lab environment before being tested in a real-world situation and has successfully demonstrated the e-bicycle location detection, battery status and automatic locking mechanism. Based on the global level's current progress, the bicycle plays a crucial role in the Intelligent Transport System (ITS) in smart cities, based on bicycle-sharing IoT technology in China. The authors in [31] did a 169 questionnaire to know the statistic of transportation used by on-campus students and the result showed that the least percentage are bicycle usage. A reliable Internet of Bicycle application and the advocation of its advantages can attract students to use bicycles on campus. The IoB can also benefit campus residents by promoting mobility while sustaining nature and the inside campus environment. Besides, IoB offers security as the prototype has shown that the applications can avoid their bicycle being stolen from the locking system. Besides, using the wireless LoRa, the IoB application can be further extended to cover larger campus areas to take advantage of the large coverage area from LoRa.

3.2 Water Quality Monitoring

The study also measured one-week data from the sensors, as shown in Figures 9(a) and 9(b). The data are displayed at Ubidots dashboard, an open-source platform that can remotely monitor data at any time. From the results, it can be observed that a rainy day has a significant impact on lake water quality. Another factor that affects the lake water quality during a rainy day is the ongoing construction activity near the Technology and Information Science Faculty. The rains carry all the sediment from the construction site to the lake, thus causing the turbidity value to become higher. Meanwhile, the pH value has a slight change on a rainy day. In terms of SigFox performance, the signal received was considered 'Good' (approximately RSSI between -80 to -90 dBm) since the SigFox tower's location is approximately 3 km from the lake area (Figure 7). However, the message size restriction prevents the water quality device from sending more data as the lake water quality parameter contains pH value and turbidity.



(a)



(b)

Figure 9 (a) turbidity value; and (b) pH value during one-week measurement at the lake

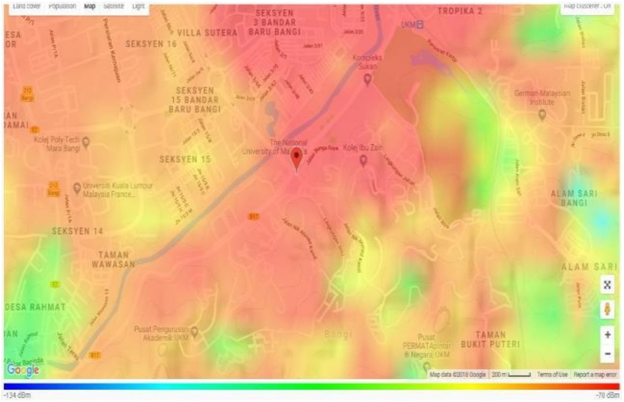
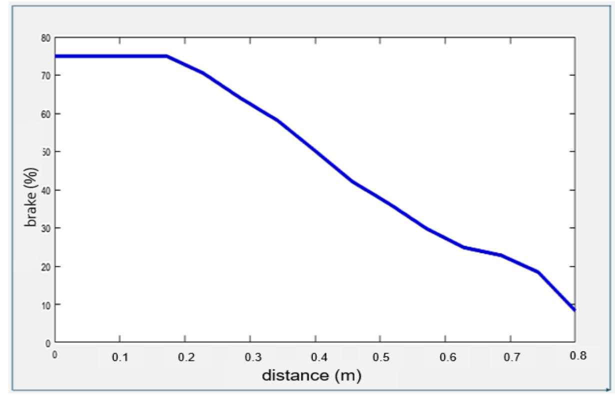


Figure 10 SigFox coverage heatmap surrounding the lake area, as provided by XPeranti, a local SigFox network provider

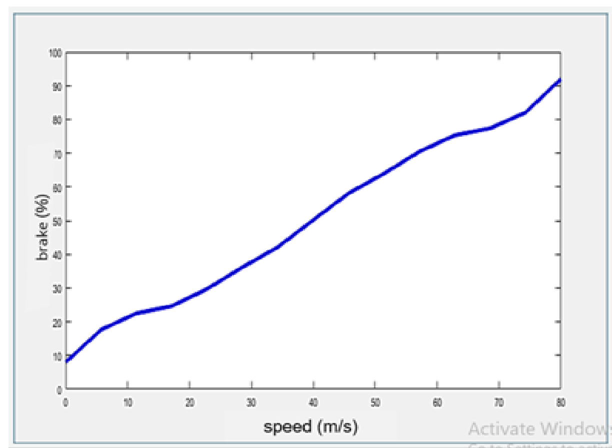
The water quality monitoring application in this study depends on the availability of the SigFox coverage. Based on the coverage heat map provided in Figure 10 earlier, it can be observed that the SigFox-based wireless platform is ready to be deployed within the campus area considered in this paper. However, it is important to note that the SigFox coverage depends on the availability in the area. In this case, the smart campus applications and products must work closely with the SigFox network operator to ensure uniform coverage and reliable communications links from the SigFox towers. The water quality monitoring applications will benefit the campus residents in monitoring water quality and preventing water pollution around the campus.

3.3 Active Safety Application

The parameters to be measured are shown in Figure 9 (braking force, car speed, and car position ahead of the obstacle). Figure 11(a) shows that as the car's distance from the obstacle detected increases, the braking force needed to apply to the vehicle is decreased. This means that when the car's distance from the obstacle detected is far, the braking force required to stop the vehicle is lower. Only a small amount of braking force is needed to apply to the vehicle. From the graph in Figure 11(b), it is clearly shown that as the car's speed towards the obstacle increases, the braking force needed to apply to the car also increases. In this case, when the car's speed is greater, a greater braking force is also necessary to be applied to stop from a collision.



(a)



(b)

Figure 11 (a) Braking force versus distance; (b) Braking force versus speed

The active safety application was built using the Pi-Car as a small prototype to prove the functionality based on an automatic emergency braking system. Based on the overall result that had been measured (such as braking force, car speed and position of the car ahead of the obstacle), this application is feasible. However, considering that it will be deployed in an actual car, it is still far away from the actual implementation, especially for the smart campus. An automatic emergency braking system triggers a warning to the driver when the front vehicle performs an emergency brake. The emergency messages will be broadcasted to the nearest vehicles. Nowadays, connected and many automotive companies are increasingly developing autonomous vehicles (CAV). The combination of autonomous vehicles and wireless technology will facilitate vehicle safety systems and thereby improve road safety. Hence, this application is expected to be convenient to be widely used in the next ten years on the residence campus car for ensuring road safety around campus road.

3.4 Connected Mangrove

The displayed data variables in Figure 12 are dissolved oxygen, turbidity, and battery status. The data are displayed at an open-source platform, which is the Xpand dashboard. NB-IoT modem used in this study is from the existing LTE mobile network from Celcom (one of Malaysia's mobile network operators) and ready to support 5G, as shown in Figure 13. Celcom relies on the Ericsson radio system in the NB-IoT network as part of their current and future related to the mobile network migration to 5G.

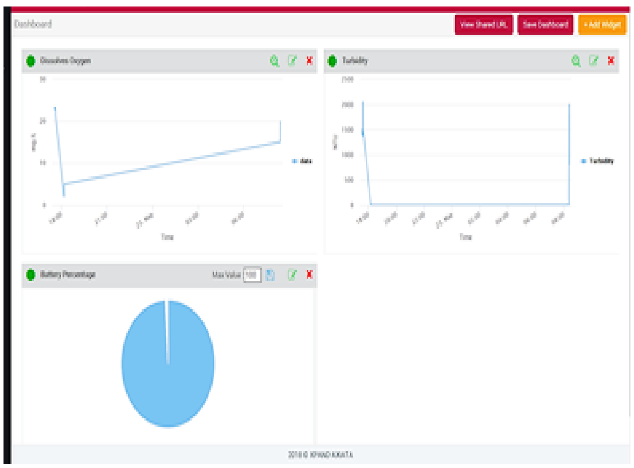


Figure 12 Sensor data that were displayed on the XPAND IoT Dashboard

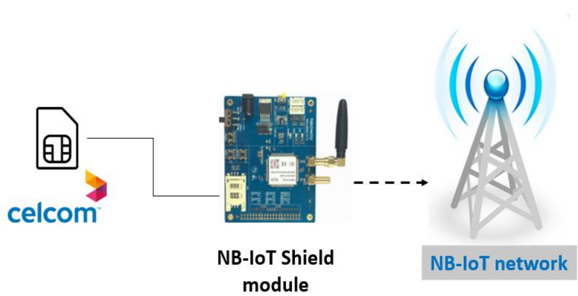


Figure 13 Celcom as the LTE mobile network provider for the NB-IoT modem in this study

The connected mangrove that measures water quality from the dissolved oxygen and turbidity level has been developed and the functionalities have been validated. It is connected through the NB-IoT, a licensed network and dependent on the LTE base station to support the NB-IoT network. Considering that most of the campus locations in Malaysia are in the sub-urban area, NB-IoT's actual deployment is expected to occur in the next 3-5 years. This is because the network operator needs to calculate the demands in the area, together with the capital expenditure (CAPEX) needs to be invested in setting up the NB-IoT services. Hence, for the upcoming several years, sub-urban campus areas can use the NB-IoT network. Also, the mangrove sites are mostly located in remote areas, as such, it is best to utilize independent wireless technologies, such as LoRa, for the connected mangrove application. Using independent wireless platforms allows researchers and students from the university to use this application as a platform for learning or sustainable conservation research at remote mangrove sites worldwide.

4.0 CONCLUSION

This paper highlighted wireless sensor networks for campus application based on several wireless IoT technologies; SigFox, LoRa, IEEE 801.11p and NB-IoT. These wireless IoT technologies are currently available in the market at a cost-efficient price and started to be deployed at a large scale by various industries and mobile network operators to promote growth in IoT technologies and applications.

From the wireless IoT technologies, four different smart campus applications have been deployed, (i) Internet of Bicycle (using LoRa), (ii) water quality monitoring (using SigFox), (iii) active safety for a future autonomous car (based on IEEE 801.11p) and (iv) mangrove conservation (using NB-IoT). Various open-source hardware and software were involved during the research to integrate several components that are part of the IoT ecosystem, such as the sensors, connectivity (wireless IoT) and visualization (dashboard and online cloud platform). Results were presented and several future applications were discussed. This paper has shown that a campus with a mature Internet network connectivity can benefit from the IoT explosions towards a sustainable smart campus.

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