Universiti Kebangsaan Malaysia
The National University of Malaysia

Wireless Research

WirelessResearch@UKM

BRIDGING THE DIGITAL DIVIDE: HOW LORA CAN CONNECT THE UNCONNECTED

MyNOG-11 Conference (5 June 2024)

Assoc. Prof. Dr. Nor Fadzilah Abdulla, UKM
Prof. Ir Dr. Rosdiadee Nordin, UKM
Dr. Asma' Abu Samah, UKM
Dr. Haider Alobaidy, UKM
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Nur Hasinah Najiah Maizan
Nur Amelia Abas, PPTC UKM
Dr. Marco Zennaro, ICTP Italy

https://www.ukm.my/jkees/wireless-technology-and-networking/

FACULTY OF ENGINEERING & BUILT ENVIRONMENT, UKM

WirelessResearch@UKM

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5G and Beyond	Aerial Wireless	IoT
Massive MIMO	FANET	Energy Efficient Wireless Transmission
NOMA	Radiation Monitoring	Performance and Characterization
HeTNeT	Aerial Navigation and Geofencing	Factory of the Future
Dual Connectivity	Low Altitude Platform for Rural Monitoring	Internet of Vehicle
Mobility Management	Mobile Network on UAVs	Multiple applications – Livestock, Mangrove, Health, Plastic Waste, Fisheries, Smart City,..

Hybrid LoRa Network for Underserved Community Internet (LUCI)

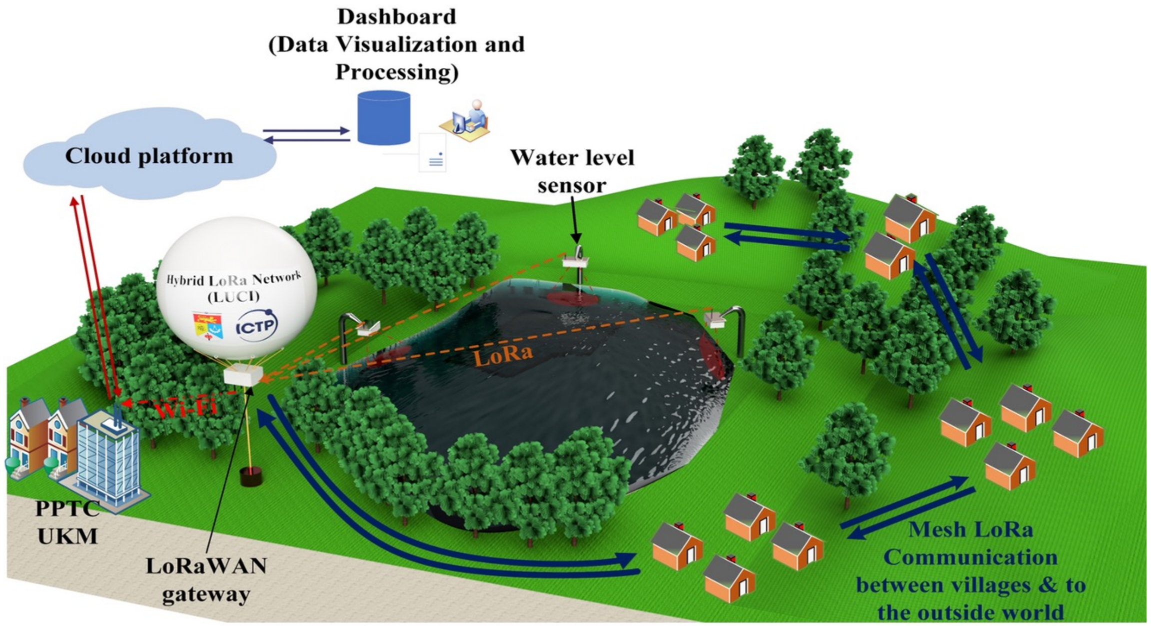
Jan 2022 - Dec 2023

USD85,000 @ MYR353,600 (UKM & ICTP Italy)

ISIF Asia 2021

INTRODUCTION:

Currently, the Chini Lake shores housed around 500 indigenous people distributed across six villages with no access to cellular tower communication coverage. This is mainly due to the challenging terrain profile and dense foliage. Therefore, a high availability but low-cost wireless communication infrastructure such as LoRa is the perfect solution in this scenario. In this work, a novel Internet infrastructure based on a Hybrid LoRa network architecture is proposed. Specifically, this comprises an integrated LoRaWAN gateway, combined with Mesh LoRa architecture with text and voice messaging capability, as well as a cloud-based data management platform. With this solution, the indigenous Orang Asli community in Chini Lake, Pahang, Malaysia will have access to digital contents through the messaging system for both literate and illiterate users, as well as water level alerts for mitigation of flooding and drought situations, and avenue for Internet access for promotion of local products and services.



PROJECT MEMBERS:





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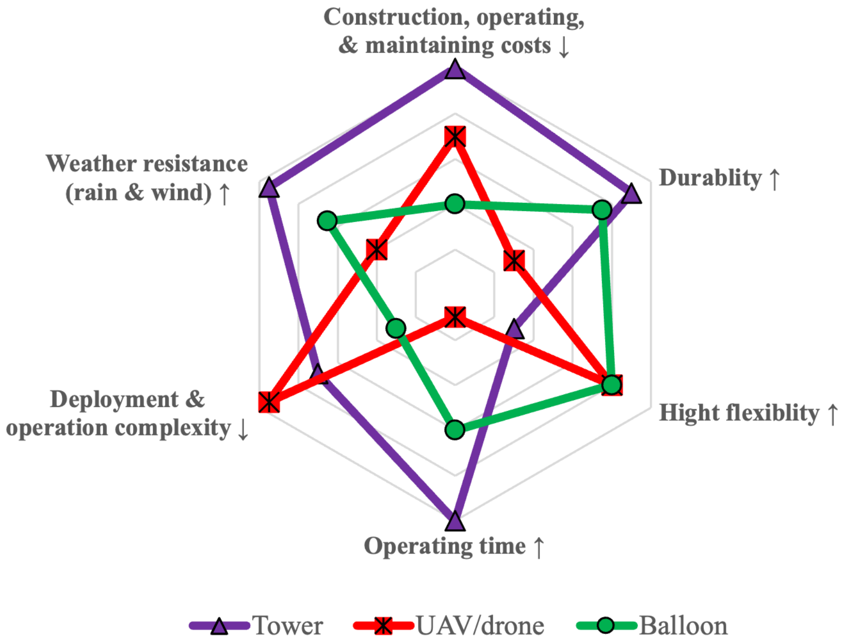
MOTIVATION

- Increased attention from academic and industrial communities on environmental monitoring due to the impact of pollutants on living organisms' biological health worldwide.
- Tasik Chini was recognised in 2009 as Malaysia's first UNESCO 'biosphere reserve'. But **rampant mining and logging activity**
- However, current monitoring methods are **expensive and labour-intensive**.
    - Expensive measurement devices.
    - Water Quality Indices (WQI) involve on-site sample collection and consequent laboratory analysis
    - Sensor data collection at remote rural areas: challenging surrounding environment.



CHALLENGES OF WQI AT CHINI

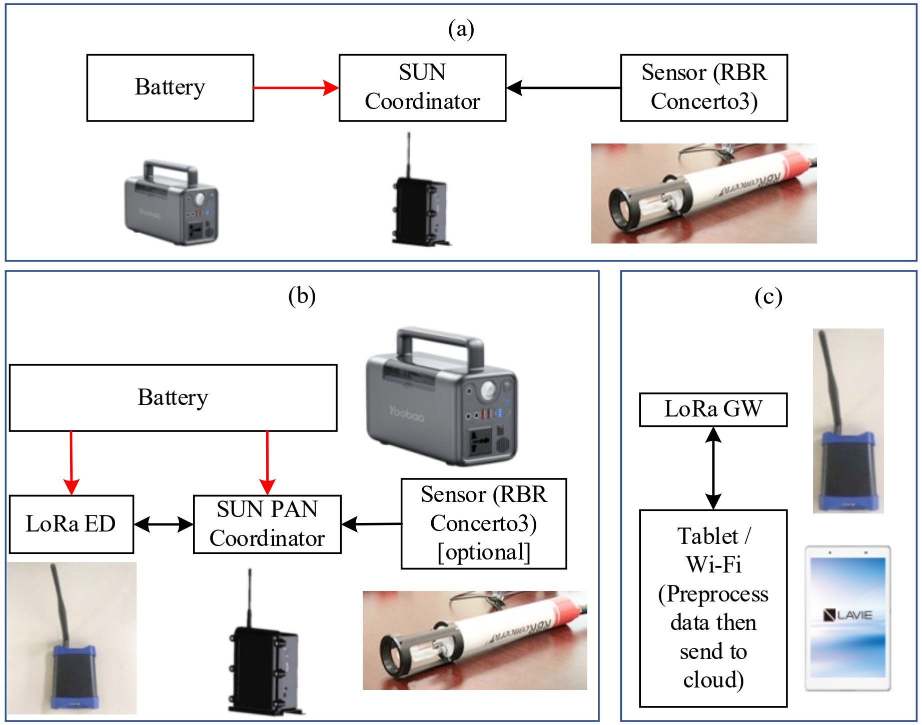
- Thick **foliage** and variable **terrain** profile.
- Obstructed and limited wireless communications coverage between existing WQM stations scattered across the lake area.
- Special focus required for wireless propagation channel characteristics and transmission performance analysis.
- Failure to do so will affect the planning and deployment of wireless IoT applications,

LoRa/LoRaWAN best LPWAN for deployment

THE JOURNEY

AIN (AIRBORNE IoT NETWORK)

- Funded by an internal UKM grant & matching grant by NICT Japan
- Spherical balloon
- Commercial water sensor (RBR Concerto3): measure water temperature, pH, pressure, and depth.
  - Has flexibility of adding additional sensors.
  - Measurement frequency: 1 second.
  - Sensed data stored in a built-in memory within each sensing unit.
- SUN device: connected to each water sensor to form a mesh or tree topology
  - measured data relayed in a multi-hop manner from each sensor to the PAN coordinator, which collects data from all SUN end-nodes.



(a) Internal components of SUN EN. (b) Internal components of SUN/LoRa GW. (c) Internal components of LoRa/Wi-Fi GW.

AIN: NETWORK ARCHITECTURE

- Balloon lifted from a location close to the central station, at a height that guarantees a LOS or near LOS transmission path with the PAN coordinator located on the lake surface.
- PAN coordinator's data transmitted to the balloon using LoRa technology.
- Next, Wi-Fi forwards the data to the cloud server for processing and visualisation on a dashboard.

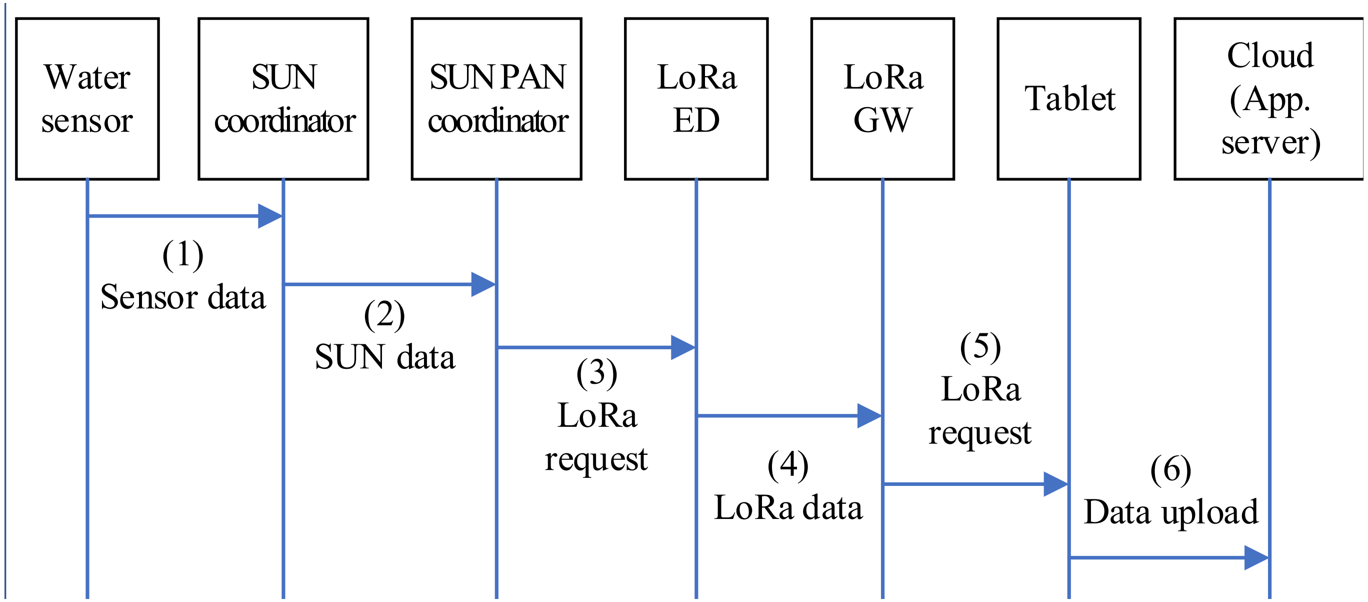
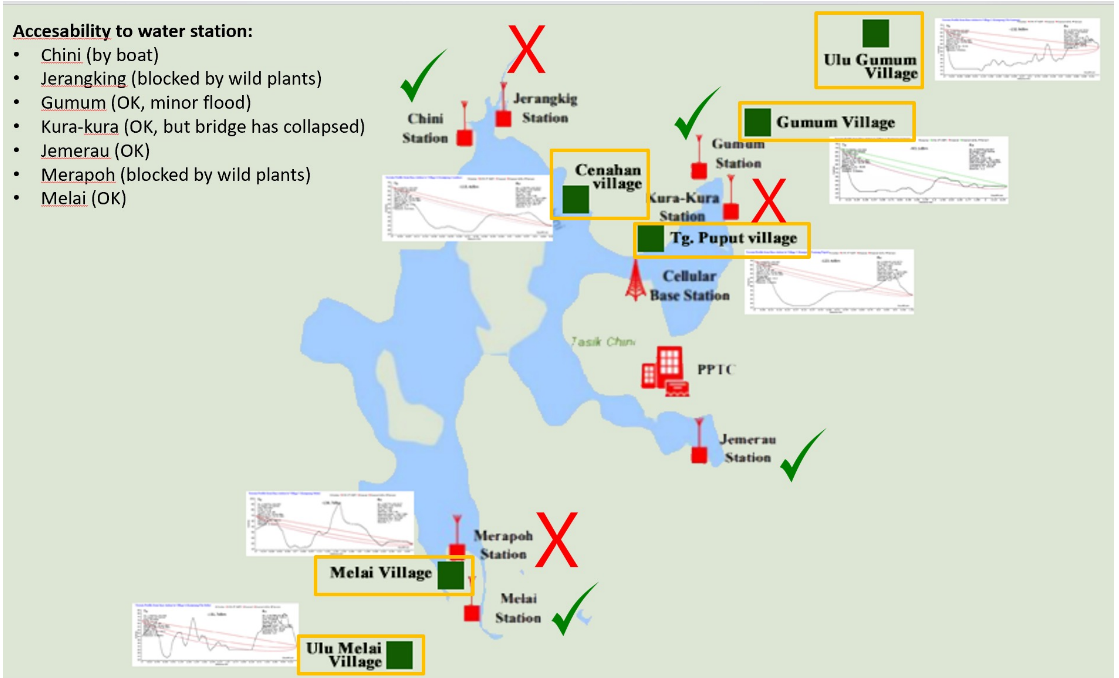
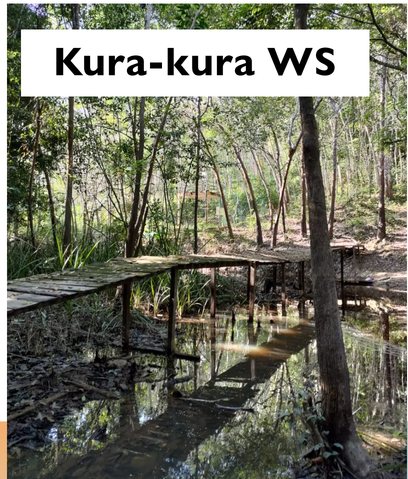
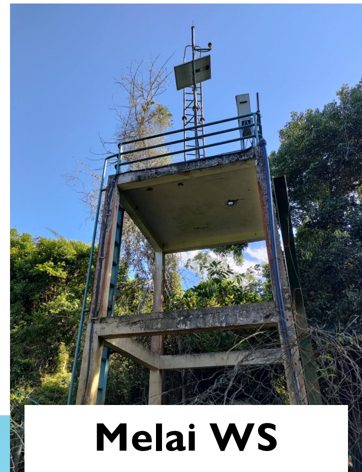


Figure 5. Typical data flow sequence of the proposed system architecture.

Kickoff meeting @ PPTC (18 – 20 Mar 2022)







Field work @ PPTC (May 2022)

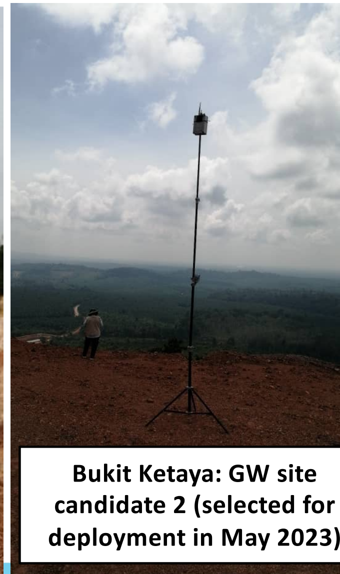
Engagement with the indigenous community

Boat ride to the community

Entrance to 1/6 indigenous area

With rangers (Jabatan Hutan Pahang) to survey gateway installation at Bukit Ketaya

Bukit Ketaya: GW site candidate 1



Bukit Ketaya: GW site candidate 2 (selected for deployment in May 2023)

Field work @ PPTC (29 Aug – 1 Sep 2022)

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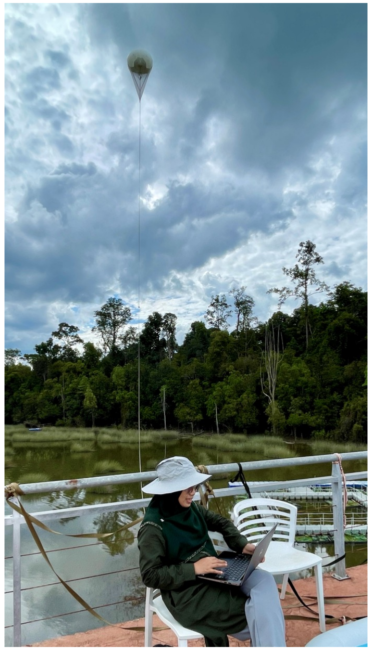
MIMOS

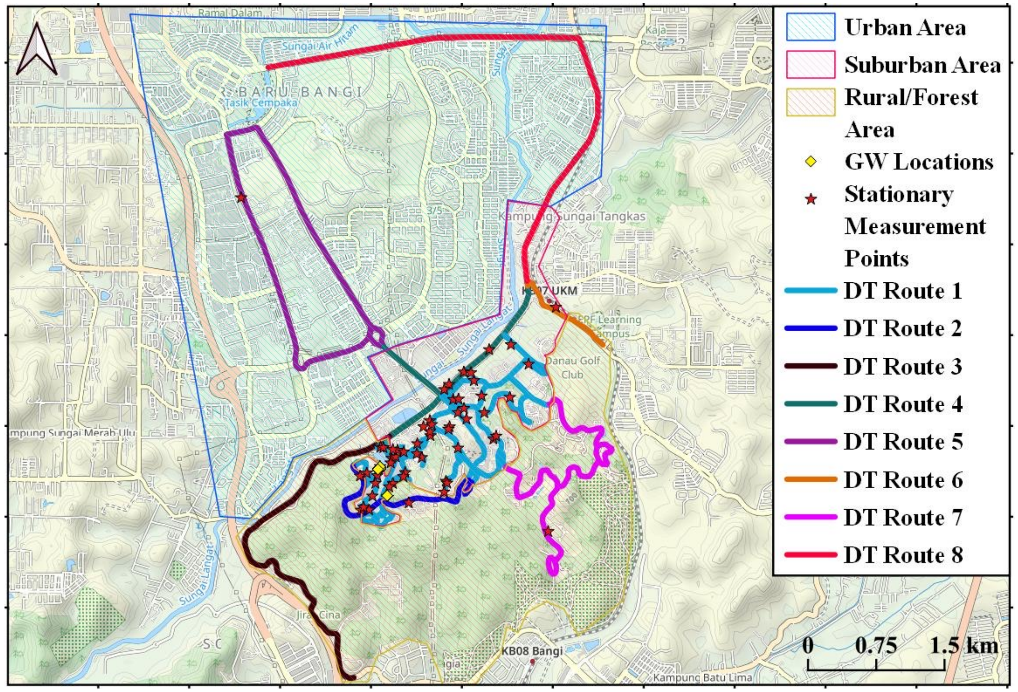
NICT

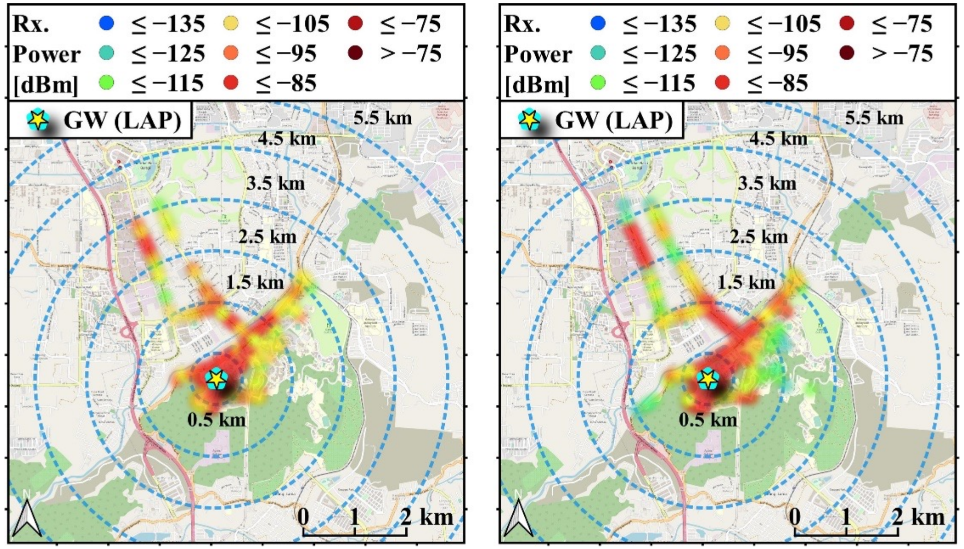


LoRa Gateway Deployment at Bukit Ketaya & Measurement Campaign Around Tasik Chini (With Pahang Forestry Division): 8 – 12 May 2023

LAP: LORA MEASUREMENT (UKM BANGI)

- Area types: suburban area (UKM campus)
- LoRa performance metrics: (1) communication reliability, (2) coverage, and (3) path loss limits
- DT (car drive test), BDT (boat drive test)



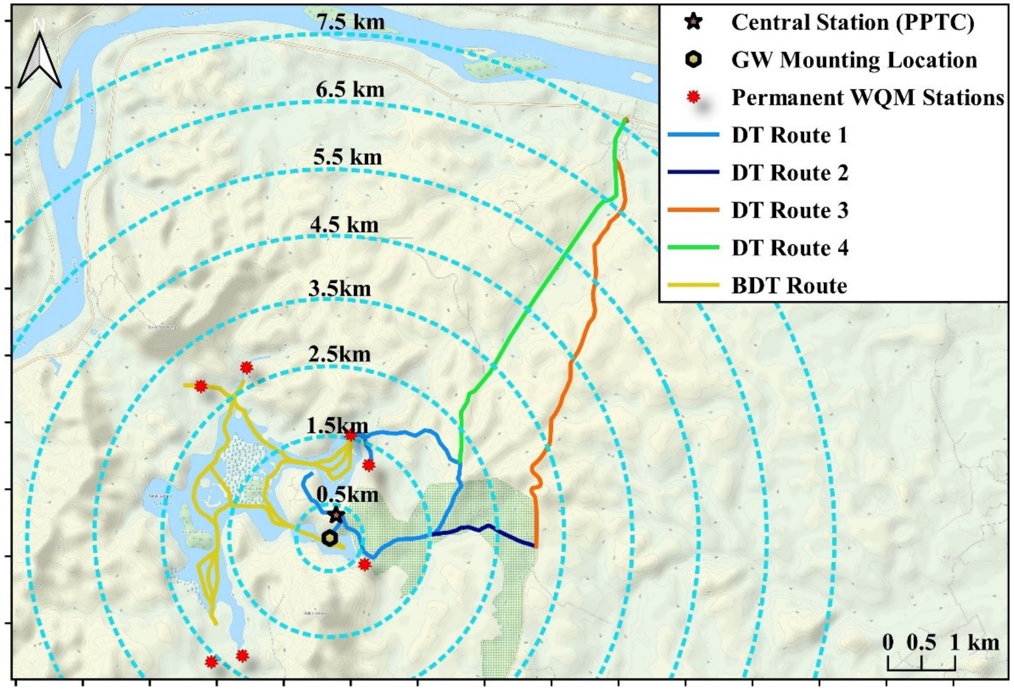


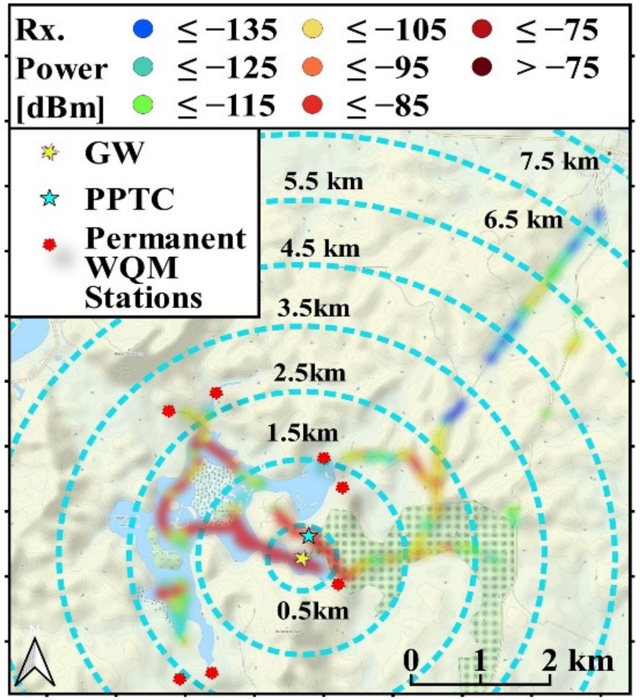
(a) (b)

Heatmap of LoRa coverage at UKM campus area for a GW (attached to a LAP) at:
(a) 50m with **SF7** configuration,
(b) 50m with **SF10** configuration.

LAP: LORA MEASUREMENT (CHINI)

Area types: rural areas (Lake Chini and surrounding areas
DT (car drive test), BDT (boat drive test)

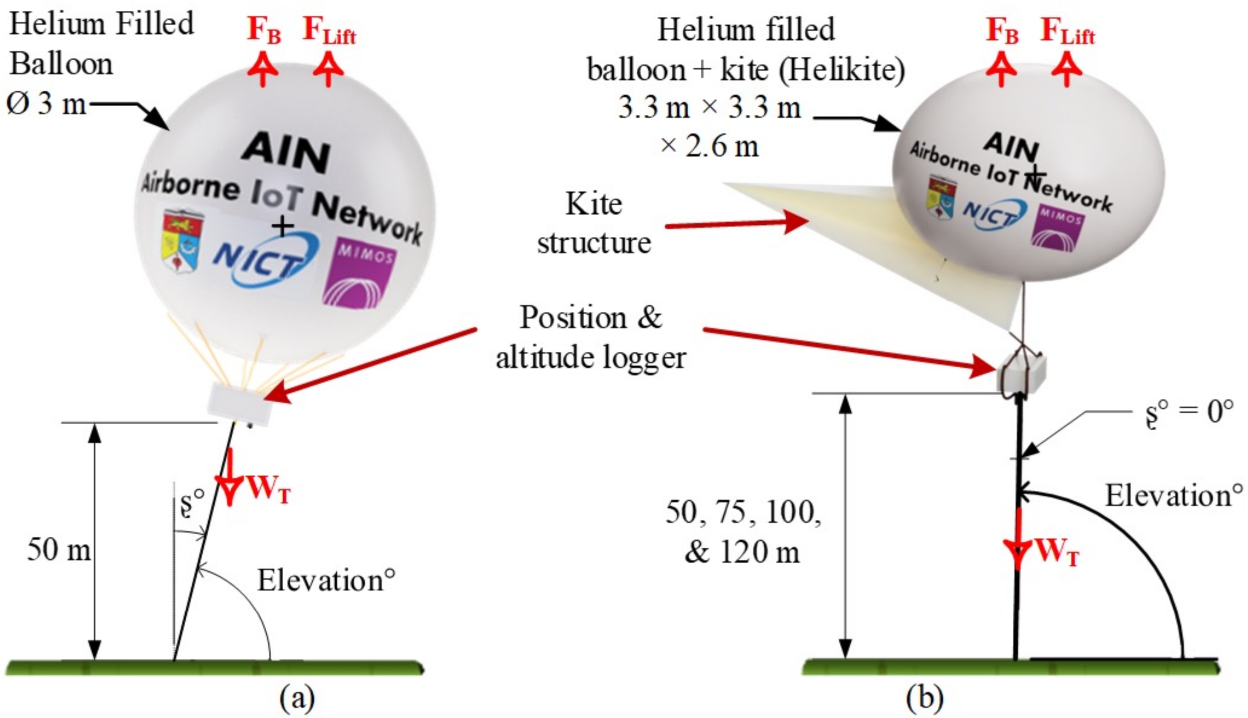




Heatmap of LoRa DTs and BDTs coverage at Chini lake area for a GW at 120m with SF10 configuration for all cases.

LAP: Main challenges

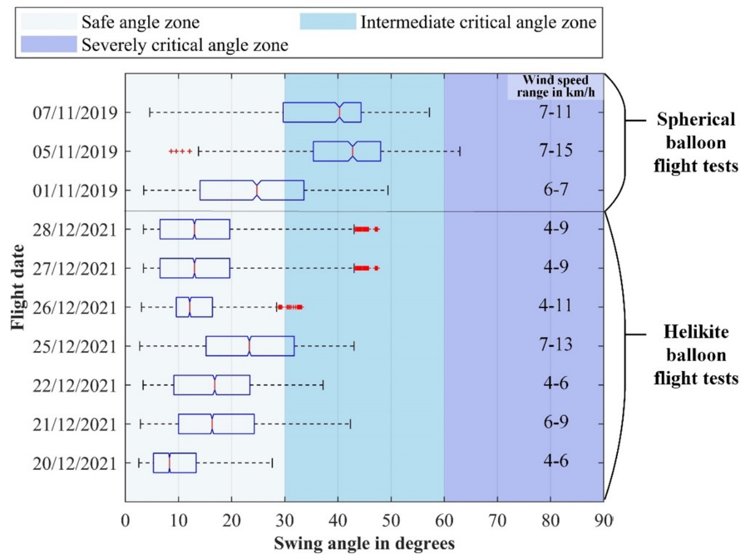
- Ideally, LAP should lift the GW at a fixed height and position.
  - However, this is practically impossible due to varying weather conditions (e.g., temperature variation and rain)
- Helium lifetime (i.e., total period of flight without a refill)
  - Helium atoms can escape through the balloon's thin PVC sheet material → lifting capacity will degrade over time
  - Need to identify the total operating period per refill, lifting capacity loss on average per day, the maximum threshold for a refill, and the payload limit are important factors for successful LAP deployment
- Wind speed and direction: affect balloon stability during the flight & causes fluctuations in balloon altitude. Balloon will swing at various angles (ş°)
- Selection of suitable LAP type for Malaysia's climate.



$$F_B = \rho_{Air} \times g \times V_b$$

$$V_b = \begin{cases} \frac{4}{3}\pi r^3 \; for\ spherical\ balloon \\ \frac{4}{3}\pi \times A_H \times B_H \times C_H \; for\ Helikite\ balloon\ (elipsoid) \end{cases}$$

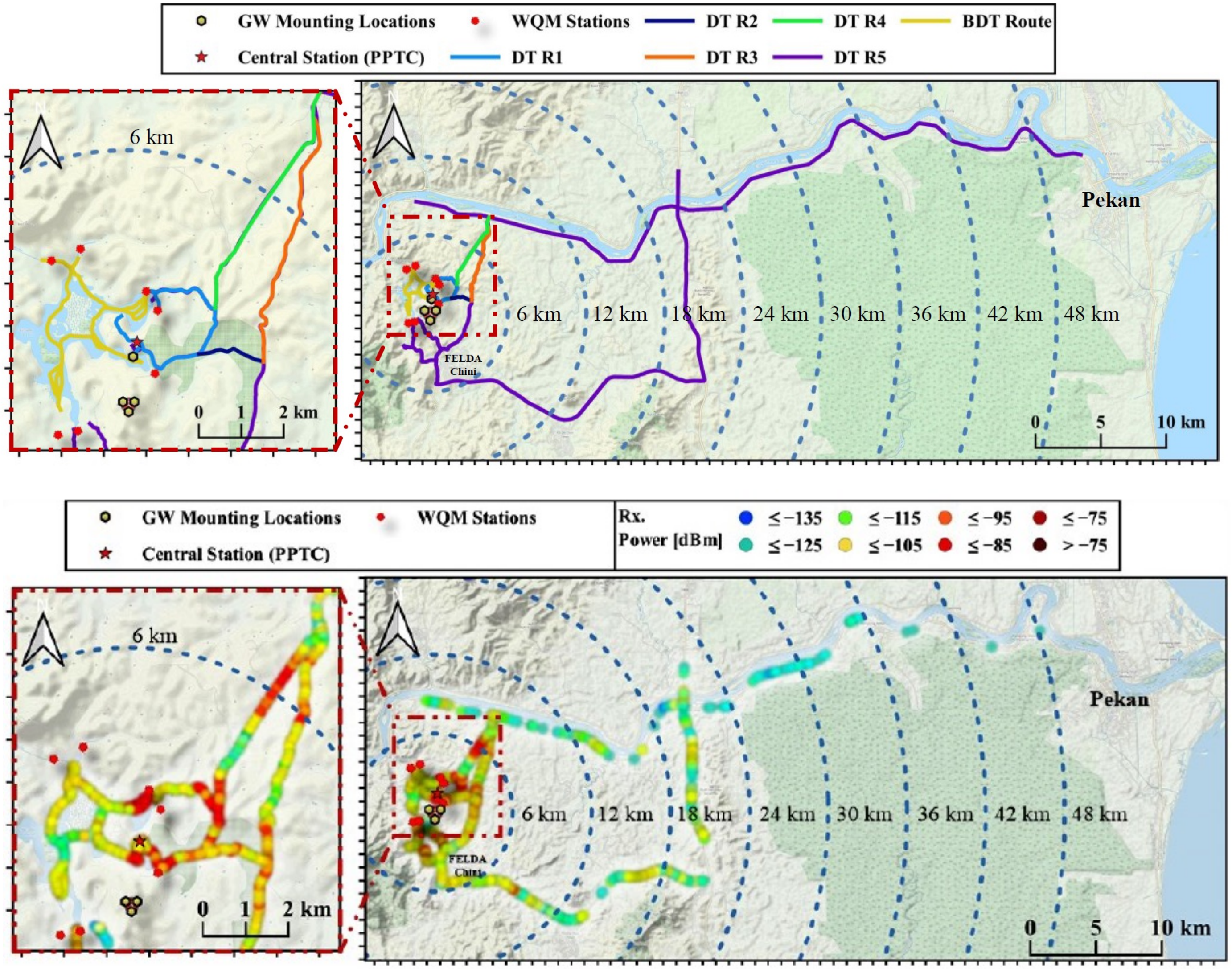
$$W_T = m_T \times g = (m_{He} + m_b + m_{payload}) \times g$$
$$= (m_{He} + m_b + m_{GW} + m_t) \times g$$
$$= ((\rho_{He} \times V_b) + m_b + m_{GW} + m_t) \times g$$
$$F_{lift} = (F_B - W_T)/g$$



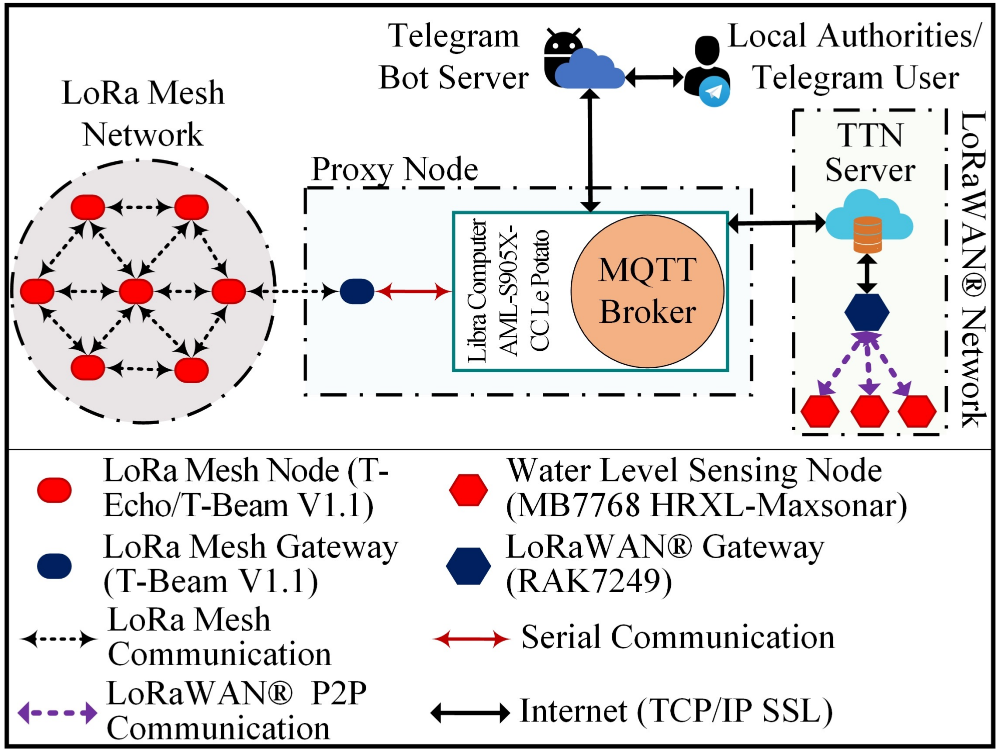
F_B = buoyancy force (N)
ρ_{Air} = density of air (~1.16 kg/m^3)
g = gravitational acceleration (~9.8 m/s^2)
V_b = volume of the balloon (m^3)
r = spherical balloon radius (1.5m)
A_H, B_H, C_H = Helikite balloon semi-axes ($A_H = B_H = \frac{3.3}{2}\ m$ and $C_H = \frac{2.6}{2}\ m$)

W_T = total weight force (N)
m_T, m_{He}, m_b, $m_{payload}$, m_{GW}, m_t = mass (kg) i.e. total, helium gas, payload, balloon PVC sheet material (6.1 kg and 8.5 kg for the spherical and Helikite balloon), GW attached to the balloon (1.25 kg), and tethering robe (1.88 kg), respectively.
ρ_{He} = density of helium gas (~ρ_{Air}/7).

LUCI: MEASUREMENT



<u>Fixed mounting structure:</u>
Longer communication distances (up to 48 km) due to the higher mounting location at Bukit Ketaya (220m ASL) and the use of higher gain antennas for the GWs.



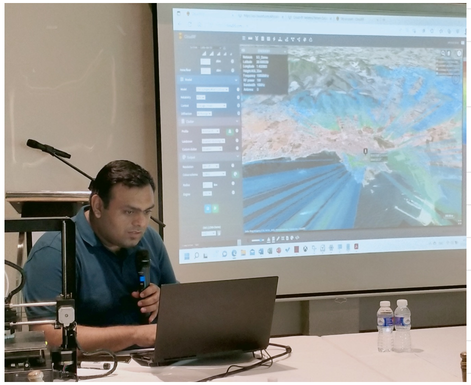
Component		Model/ Specification
Hardware	LilyGo Device	TTGO T-Beam & T-Echo
	Proxy Node	Le Potato AML-S905X- CC & TTGO T-Beam
	Water Level Sensor	MB7368 HRXL-MaxSonar-WRML integrated to Pycom FiPy Development Board & Pycom Expansion Board 3.0
	LoRaWAN® Gateway	RAK7249 Outdoor LoRaWAN Gateway
Software	Messaging Application	Meshtastic®
	Le Potato OS	Ubuntu 22.04.1 Jammy LTS
	MQTT Broker	Eclipse Mosquitto
	Telegram Integration	Telegram Bot

1. A hybrid LoRa system made available using a proxy node able to support simultaneous LoRa mesh and LoRaWAN® networks.
2. A localized communication network for community use in underserved areas for immediate community messaging and flood alerts.
3. Extension to internet-connected users to the outside world, to get assistance from local authorities for the mitigation of natural disasters.

CAPACITY BUILDING

Wireless Research@UKM Upskilling Seminar (21 – 23 November 2022)

SEMINAR PEMANTAPAN PENYELIDIKAN TANPA WAYAR
Tasik Kebun, Semenyih



AGENDA: Wireless Research@UKM Upskilling Seminar

DATE	TIME	ACTIVITY
21-Nov-22	8am	Gather at UKM AST lobby
Monday	9am	Depart to workshop location
	12pm	Arrived at resort. Lunch, prayer and rest
	3pm	**Talk 1: Briefing on Intro to wireless group, workshop activities & expectations (Dr. Fizee)**
	3.30pm	**Talk 1b: Introduction to 3D printing (Mr. Mushfiq)**
	5pm	Free & easy
	7.30pm	Dinner / party
22-Nov-22	8am	Breakfast
Tuesday	9am	**Talk 2. Machine learning basics & edge impulse application (Dr. Mehran)**
	10am	Tea break
	10.30am	**Talk 3: ML with Matlab for propagation modelling (Mr. Fazuwan)**
	12pm	Lunch, prayer and rest
	2pm	**Talk 4: V2X Simulation with NS-3 (Mr. Tahrawi)**
	5pm	**Teambuilding activity (Mdm Illi)**
	8pm	BBQ Dinner & group activity
23-Nov-22	8am	Breakfast
Wednesday	9am	**Talk 5: RF planning with CloudRF & basics of radio propagation (Mr. Haider)**
	10am	Tea break
	10.30am	**Talk 6: Drive test with GNetTrack Lite (Mr.**
	12pm	Closing speech (Dr. Fizee) & check out
	1pm	Depart back to UKM

Basic Artificial Intelligent and Data Analytics Upskilling Seminar (6 – 8 December 2022)

Seminar Asas AI & Analisis Data

AGENDA: SEMINAR ON AI BASICS & DATA ANALYSIS USING MINITAB

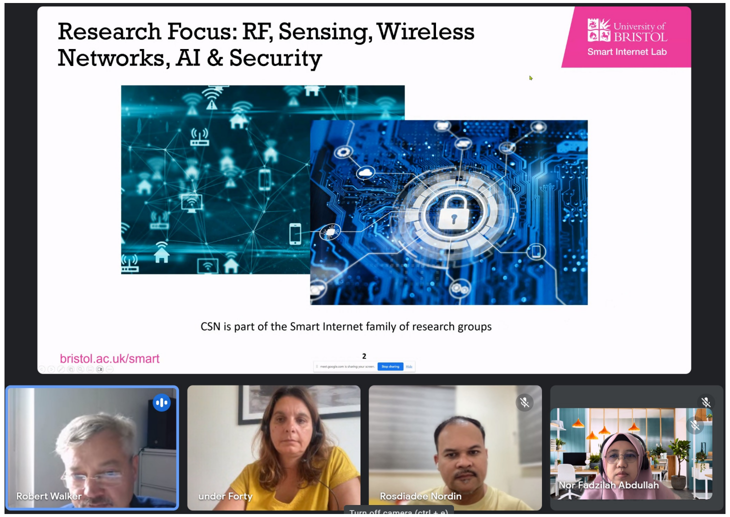
https://bit.ly/AIJKEES

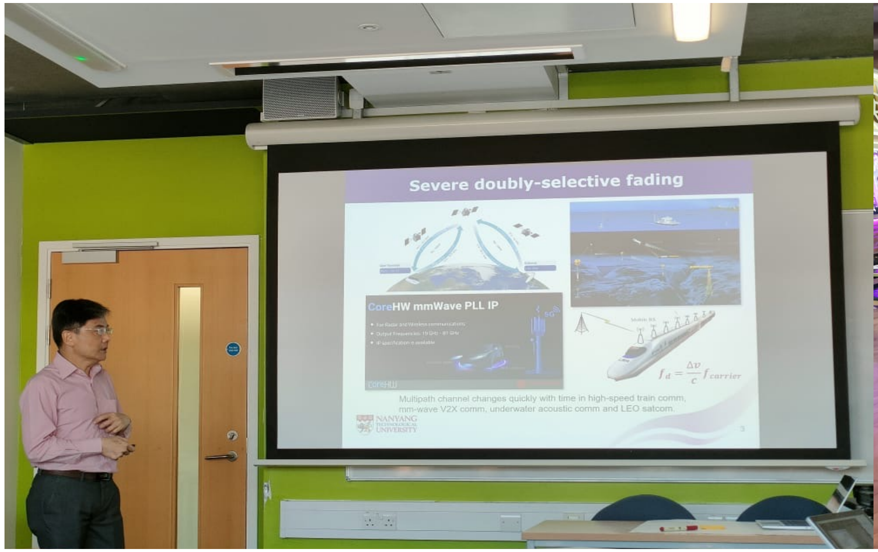
Date	Time	Activity
6 Dec 2022 (Tuesday)	8.00 am	Participants' Registration
	9.00 – 10.30 am	**AI Basics 1: Introduction to Artificial Intelligence (Dr Aqilah Baseri Huddin)**
	10.30 – 10.45 am	Coffee break
	10.45 am – 12 pm	**AI Basics 2: Supervised machine learning (Dr Aqilah Baseri Huddin)**
	12.00 – 2.00 pm	Lunch break
	2.00 – 4.00 pm	**AI Basics 3: Supervised data management (Dr Aqilah Baseri Huddin)**
	4.00 – 4.30 pm	Coffee break
	4.30 – 5.30 pm	**AI Basics 4: Pattern recognition (Dr Aqilah Baseri Huddin)**
7 Dec 2022 (Wednesday)	9.00 – 10.30 am	**Module 1: Data Interpretation 101 & Group Activity 1 (Mr. Adam Daniel Bin Effendi)**
	10.30 – 10.45 am	Coffee break
	10.45 am – 12 pm	**Module 2: Step in Developing General DOE fundamentals including Basic Statistic (Mr. Adam Daniel Bin Effendi)**
	12.00 – 2.00 pm	Lunch break
	2.00 – 4.00 pm	**Module 3: Design of Experiment with Minitab Part 1 & Group Activity 2 (Mr. Adam Daniel Bin Effendi)**
	4.00 – 4.30 pm	Coffee break
	4.30 – 5.30 pm	Continue Module 3 & Group Activity 3 (Mr. Adam Daniel Bin Effendi)
8 Dec 2022 (Thursday)	9.00 – 10.30 am	**Module 3: Design of Experiment with Minitab Part 2 (Mr. Adam Daniel Bin Effendi)**
	10.30 – 10.45 am	Coffee break
	10.45 am – 12 pm	**Group Activity 3**
	12.00 – 2.00 pm	Lunch break
	2.00 – 4.00 pm	**DOE Closing (Mr. Adam Daniel Bin Effendi)**
	4.00 – 4.30 pm	Coffee break
	4.30 – 5.30 pm	**Focus Session & Training Closing Session**
		Seminar ends

Funded by: **ISIF Asia, APNIC Foundation**
Grant code M-202106-00113 (UKM reference: KK-2021-020).

ICTP/IAEA STEP (Sandwich Training Educational Programme)
(1st attachment: 6 Sep – 5 Dec 2023)

Research attachment in UK (Aug - Sep 2023)

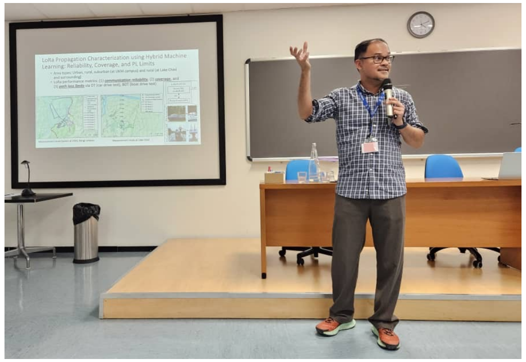




Programming + Wireless Day @Tasik Chini STEM programme (20 – 23 October 2023)

Programming + Wireless Day @Tasik Chini STEM programme (20 – 23 October 2023)

Workshop On Communication In Extreme Environments For Science And Sustainable Development @ ICTP Italy (20-24 November 2023)



20th IEEE Student Conference On Research And Development (SCORED 2022): Invited Speaker

2022 IEEE 20th Student Conference on Research and Development (SCOReD), November 8-9, 2022, Bangi, Malaysia

Wireless Airborne IoT Network for Rural Water Quality Monitoring

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Abstract— **Currently, the Chini Lake shores house around 500 indigenous people distributed across six villages with limited access to cellular tower communication coverage. This is mainly due to the challenging terrain profile and dense foliage. Therefore, it is important to establish a reliable line-of-sight (LoS) data transmission via a low-altitude platform (LAP). The high availability but low-cost wireless communication infrastructure such as LoRa is the perfect solution in this scenario. This will allow better coverage due to good propagation characteristics at lower frequency bands as well as the elevated platform. The solution shall also equip a wireless machine-to-machine (M2M) network, sensors technologies and a big data analytic enablement platform. In addition, the characterization of the wireless channel behaviour in Malaysia's tropical rural areas, where the propagated wireless signal suffers from several imperfections, such as attenuation, diffraction, scattering and absorption due to the presence of various surrounding elements is also being investigated. The outcome of this research is expected to offer a new understanding of the propagation behaviour of current and future wireless IoT technologies, thus helping the network engineer to perform accurate planning and deployment in a rural environment. With this solution, the indigenous Orang Asli community in Chini Lake, Pahang, Malaysia will have access to digital content, as well as water level alerts for mitigation of flooding and drought situations, and Internet access for the promotion of local products and services.**

Keywords—Low Altitude Platform (LAP), Airborne IoT, LoRa, Water Quality Monitoring, Rural area.

I. Introduction

Environmental monitoring applications have received increased attention from academic and industrial communities due to the threatening impact of environmental pollutants on living organisms' biological health worldwide. Chini Lake was recognised in 2009 as Malaysia's first UNESCO biosphere reserve. Unfortunately, it has suffered from rampant mining and logging activities. Currently, the Chini Lake shores have around 500 indigenous people (also known as Orang Asli) distributed across six villages. This directly endangers underwater life and the quality of life of the indigenous people. Extensive monitoring and corrective actions are needed to mitigate this problem.

However, the constant monitoring of the environment usually requires expensive measurement devices. Additionally, such measurements of Water Quality Indices (WQI) generally involve on-site sample collection and consequent laboratory analysis. This is labour-intensive and costly.

To make matters worse, rural areas pose several unique challenges for data gathering from sensors because of the surrounding environment profile. Chini Lake is known for its thick foliage and variable terrain profile. The hilly terrains obstruct wireless communications and limit the coverage to reach the existing water quality monitoring (WQM) stations scattered across the lake area. Hence, these challenges need to be addressed with a special focus on propagation channel characteristics that directly influence wireless transmission performance. Failure to do so will affect the planning and deployment of wireless IoT applications, specifically those enabled by LPWANs, such as LoRa/LoRaWAN.

The rest of the paper is structured as follows: Section I introduces the motivations for the paper. Section II provides an overview of recent works on wireless technologies used for WQM. Section III presents the system architecture of our proposed work, while Section IV provides selective significant findings. Finally, Section V concludes the paper.

II. Related Works

Recent IoT advances have therefore enabled novel approaches to address such challenges and allowed autonomous real-time monitoring by integrating low-cost sensing devices, Machine-to-Machine (M2M) communication, and wireless IoT technologies [1], [2].

Among many, the study in [3] proposed an interesting solution using a drone-assisted IoT relay system. The system aims to provide a low-cost and high-speed environmental monitoring system in hard-to-reach rural areas, utilizing two wireless communication technologies. The first is based on 5 GHz Wi-Fi, for low-latency data transmission between the drone and ground-based monitoring devices. Meanwhile, LoRa technology was adopted as an effective Wi-Fi module wake-up strategy. The study investigated the system's capabilities with a specific focus on throughput performance, showing that the system could collect cached data with a sustained throughput of 3.5 MB/s at an altitude of 140 m. However, the system still requires special operation conditions, utilising high power-consuming and relatively expensive devices, with complicated system operation requirements.

Several other solutions exist in the literature [4]-[14] as summarised in Table 1. Yet, these solutions do not address the issues highlighted earlier. Ideally, the wireless network deployed should be able to form mesh networks autonomously, relay data to be gathered at a central station, and transmit a large amount of gathered data over long distances at relatively high speeds.

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https://doi.org/10.1109/SCOReD57082.2022.9974083

25th Symposium On Wireless Personal Multimedia Communications (WPMC 2022), Herning, Denmark: Contribution To Globalization Of Research Award

2022 25th International Symposium on Wireless Personal Multimedia Communications (WPMC)

Hybrid SUN-LoRa Network on a Low Altitude Platform for Remote Water Quality Monitoring

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***Abstract*—When implementing remote water quality monitoring systems in harsh tropical environments, several issues need to be addressed in order to achieve reliable data collection from many sensors. These issues include poor coverage of existing cellular-based networks, mountainous terrain and thick foliage which may obstruct line-of-sight, and large transmission distances which may be difficult for some existing wireless technologies. This paper proposes a novel system architecture which employs a hybrid of several existing wireless technologies to address the issues mentioned above. A combination of Smart Utility Network (SUN), Long Range (LoRa) and Wi-Fi technologies are utilized to collect water quality sensor data from a lake in a mountainous rural area. This heterogeneous network is assisted by a low altitude platform (LAP) to overcome the non-line-sight (NLOS) transmission and achieve further transmission distance. This paper reports the drive test results in an actual lake environment to determine suitable node locations for preliminary system verification. Results confirmed that the proposed system could collect data from a sensor in NLOS from the center station by relaying data over a ground distance of 2.4 km using multiple SUN and LoRa devices assisted by an air balloon lifted to 93 m.**

***Index Terms*—Low Altitude Platform (LAP), Airborne IoT, SUN, LoRa, Water Quality Monitoring**

I. Introduction

Internet of things (IoT) is a network that enables exchange of data between devices, sensors, actuators and users through the internet or other wireless communication technologies. IoT has been successfully employed for environmental monitoring applications. Such monitoring systems will generally include many sensors placed over a wide area, which are able to measure various physical or chemical values from the environment. Conventionally, measurements from these sensors have to be collected manually, which is very costly in terms of time and labor. A wired connection to these sensors is also rather infeasible especially over large distances in outdoor environments.

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By leveraging wireless IoT technology, we are now able to collect sensor data over large distances in nearly real-time, making it easier for researchers and local authorities to monitor any rapid changes and take measures to preserve the environment. A survey of available literature revealed many proposed wireless sensor networks for water quality monitoring (WQM) for various applications, such as for drinking water monitoring [1] and for fish cultivation [2]. Depending on the application, different types of water quality parameters need to be measured, but a majority include temperature, pH, and dissolved oxygen sensors. To establish the wireless connection between sensors, gateway and server, the use of many different technologies such as GSM [3] , Wi-Fi [4], ZigBee [5] and LoRa [6] [7] were proposed, though a large majority were ZigBee-based systems. Furthermore, to accommodate many different use cases in various environments, a hybrid of several wireless technologies were also proposed, such as GSM and ZigBee [3], 4G and Wi-Fi [4], and ZigBee and Wi-Fi [8].

When implementing wireless WQM systems in rural environments, several issues need to be addressed to achieve reliable data collection from many sensors. First of all, the use of GSM or other cellular-based networks to collect sensor data may not be adequate, due to poor coverage from the cellular base station, especially in mountainous terrain. Furthermore, sensor data needs to be transmitted over long ranges of up to a few kilometers, thus networks utilizing the ISM-band such as Wi-Fi may not be suitable due to shorter transmission distance. Also, due to the mountainous terrain, line-of-sight (LOS) between the sensor and gateway cannot be guaranteed.

In this paper, we propose a novel system architecture which employs a hybrid of several existing wireless technologies to address the issues mentioned above. In our proposed system, a combination of Smart Utility Network (SUN), LoRa and Wi-Fi is utilized to collect water quality sensor data from a lake in a mountainous rural area. This heterogeneous network is assisted by a low altitude platform (LAP) to overcome the non-LOS (NLOS) transmission and achieve further transmission distance. This paper is an extension of the work conducted in [9], and the proposed system was also briefly introduced in [10]. The contributions of this paper are to provide more de-

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APPLIED RESEARCH

Machine Learning-Based Online Coverage Estimator (MLOE): Advancing Mobile Network Planning and Optimization

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ABSTRACT Nowadays, the dependency on high-performance digital mobile connectivity is not limited to human usage but also the intelligent objects increasingly deployed to serve the needs of Internet of Things (IoT) applications. However, the current network planning technique limitation has constrained the real potential of mobile digital connectivity development. This situation has hindered sustainable Internet-oriented economic and technological development. The 3rd generation partnership project (3GPP), through its specification release 18 (Rel.18), has included and leveraged the potential capabilities of machine learning (ML) technologies in advanced mobile network planning. The main objective is to enhance mobile network planning performance and reduce complexity. To materialize this aim, we propose a novel ML-based Online coverage Estimator (MLOE) tool developed based on Random Forest (RF) ML algorithm. It uses seven unique features to predict the mobile network performance through reference signal received power (RSRP). Accordingly, the results showed that MLOE outperformed traditional empirical techniques and previous works. The final trained RF algorithm has achieved an outstanding root mean square error (*RMSE*) of 2.65 dB and a coefficient of determination (R^2) of 0.93. With the dynamic and fast-growing mobile technology, MLOE has been deployed on an online platform using MATLAB® Web App Server, which offers a modular and scalable architecture.

INDEX TERMS Machine learning, MATLAB, mobile networks, path loss, received signal strength indicator, RSRP, web application.

I. INTRODUCTION

Despite the recent technological advances, issues related to unsatisfactory mobile network services are still challenging, as highlighted by the Malaysian Communications and Multimedia Commission (MCMC) [1]. Among the contributing factors to the latter issue is the current network planning techniques' limitation. According to [2], [3], [4], and [5], the traditional empirical techniques primarily applied in the industry are inaccurate. Meanwhile, the deterministic techniques are not practical to apply on real-world operational scales due to their complexity, requirement for high-resolution topographic maps, intense reference information, and high computing power.

Aiming to address the latter issues, 3GPP, through its Rel.18, has included and leveraged the potential capabilities of ML techniques to enhance mobile network planning performance and reduce complexity [6]. In this regard, four main objectives were outlined. The first is focused on identifying a common ML framework, including the functional

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Low-Altitude-Platform-Based Airborne IoT Network (LAP-AIN) for Water Quality Monitoring in Harsh Tropical Environment

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***Abstract*—This article proposes a novel Airborne Internet of Things Network (AIN) system architecture for monitoring water quality, combining existing wireless technologies with the aid of a low altitude platform (LAP) to relay data over long distances in hilly terrain. The proposed system consists of water quality sensors, smart utility network (SUN) devices, long range (LoRa) wireless devices, an LAP air balloon, and Wi-Fi devices. A measurement campaign was conducted to assess the proposed system, focusing on the communication link reliability and the LAP stability and robustness. Several constraints, such as payload limit and safe weather conditions, were also highlighted for operating the LAP with extensive and reliable coverage. On the other hand, characterizing the wireless channel has become a crucial parameter for planning and deploying Internet of Things (IoT) applications. Accordingly, this work proposes a novel hybrid machine learning (ML)-based semi-empirical path loss (PL) model for LoRa wireless communication. The results validated the proposed system's effectiveness, unique characteristics, and capability to monitor water quality in a harsh environment. Results also revealed a significant difference in packet delivery rate (PDR) for different gateway height and spreading factor (SF) configurations. For instance, switching SF7 to SF12 increased PDR by 28.7%. Meanwhile, increasing gateway height increased PDR by 29.2% for similar SF configurations. The evaluation also revealed that none of the established PL models are suitable to represent harsh tropical environments. Finally, the proposed model achieved nearly 90% prediction accuracy for testing samples and 95% accuracy for training and overall measurement samples, vastly outperforming conventional models.**

***Index Terms*—Airborne Internet of Things (IoT), long range (LoRa), LoRaWAN, low altitude platform (LAP), machine learning (ML), propagation modeling, stacked models, smart utility network (SUN), water quality monitoring (WQM).**

I. Introduction

THE Internet of Things (IoT) is a network that connects users and objects using information sensing devices and actuators [1]–[4]. Recently, IoT has drawn academia and industry interest [5] due to the exponential growth of connected devices and the need for innovative or optimized technologies capable of managing many connected devices [1]. As a result, today's number of connected devices is estimated at 26–50 billion [6], expected to accelerate exponentially further, reaching around 75–100 billion connected devices by 2025 [5]. To support this growth, various wireless IoT technologies and network architectures have emerged for the past years [7].

A. Wireless IoT Technologies

These technologies may include conventional cellular-based or short-range technologies, such as Wi-Fi, ZigBee, and smart utility network (SUN). However, the latter technologies are typically used for applications where battery consumption is not critical [2], [8]. Hence, driven by the critical IoT application requirements [1], [9], low power wide area networks (LPWANs) are emerging and have become an exciting new trend in wireless communication systems growth. Its principal characteristics are long-life end devices (EDs), low communication chip costs, and extensive

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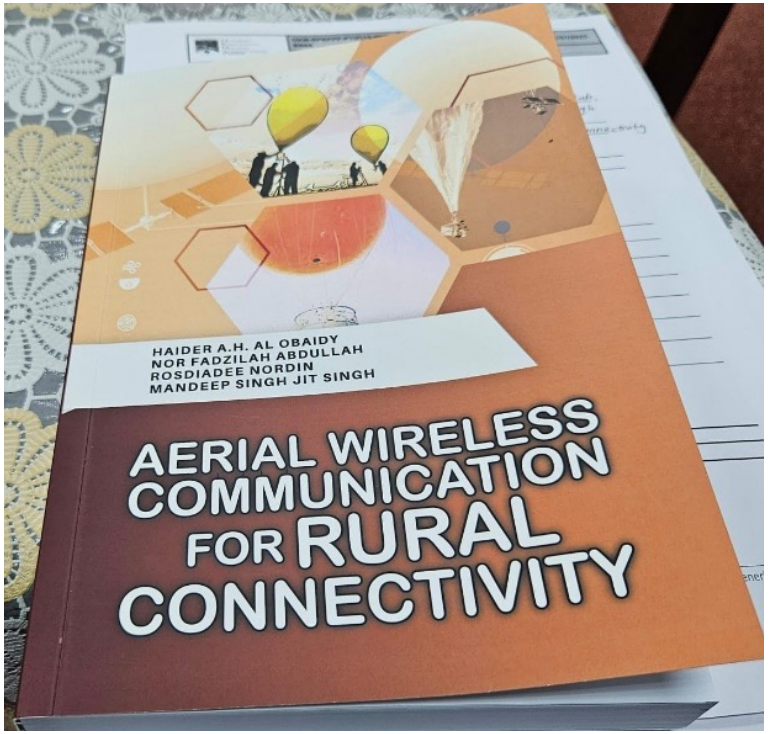

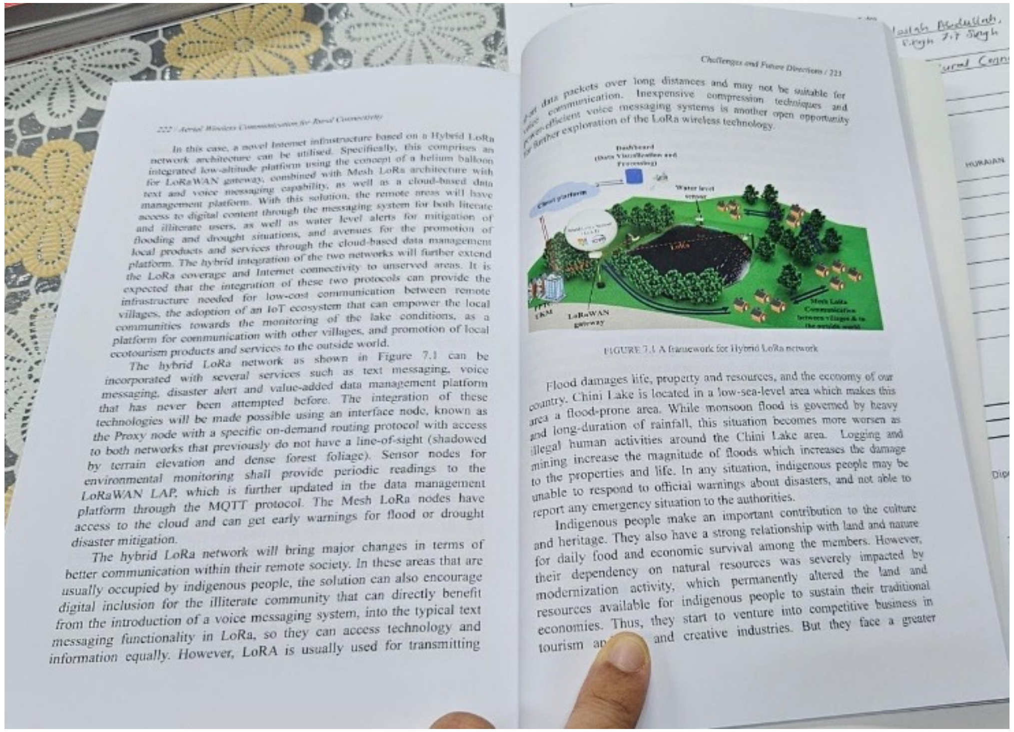

CONCLUSIONS

- This work provides an end-to-end autonomous IoT network for WQM.
- The system provides a crucial ICT solution for people living in such areas by warning them of flooding.
- Several unique challenges that arise due to the surrounding environment were addressed.
- This system can be extended to improve the underwater life of rural/remote areas and can help manage and identify pollution sources in real time impacting the environment and living organisms.

TERIMA KASIH!
THANK YOU!

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