RESPONSE TIME OPTIMIZATION WITH INTERNET-OF-THINGS-BASED WIRELESS SENSOR NETWORK EMERGENCY ALERT SYSTEM FOR FIREFIGHTER

NURULIDAYU BINTI SAINUDDIN

MASTER OF SCIENCE IN ELECTRONIC ENGINEERING

2024

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Electronics and Computer Technology and Engineering

RESPONSE TIME OPTIMIZATION WITH INTERNET-OF-THINGS-BASED WIRELESS SENSOR NETWORK EMERGENCY ALERT SYSTEM FOR FIREFIGHTER

Nurulidayu binti Sainuddin

Master of Science in Electronic Engineering

2024

RESPONSE TIME OPTIMIZATION WITH INTERNET-OF-THINGS-BASED WIRELESS SENSOR NETWORK EMERGENCY ALERT SYSTEM FOR FIREFIGHTER

NURULIDAYU BINTI SAINUDDIN

A thesis submitted
in fulfillment of the requirements for the degree of
Master of Science in Electronic Engineering

Faculty of Electronics and Computer Technology and Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2024

DECLARATION

I declare that this thesis entitled “Response Time Optimization with Internet-Of-Things-Based Wireless Sensor Network Emergency Alert System for Firefighter“ is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :.....

Name : Nurulidayu binti Sainuddin

Date : 4/9/2024

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Electronic Engineering.

Signature : .....

Supervisor Name : Ts. Dr. Juwita binti Mohd Sultan

Date : 4/9/2024

DEDICATION

To my beloved family, who supported me throughout my journey, as well as my supervisor, co-supervisor, and friends.

ABSTRACT

Disasters and emergencies often have a significant impact on the environment and livelihoods, necessitating a rapid emergency response. To ascertain the best outcomes, emergency event reporters and firefighters must respond effectively to minimize adverse impacts and facilitate a swift recovery, in line with the firefighter's key performance indicator which is under 10 minutes. However, manual handling in control rooms introduces delays and human errors. Thus, this research developed an Internet-of-Things (IoT) based Wireless Sensor Network (WSN) emergency alerting system for firefighters which consists of one base station and three sensor nodes to enhance firefighter's response time. Results showed that the average firefighter's response time had improved to 8.54 minutes compared to the previous response time of 15.48 minutes with the usage of the automated IoT-based emergency alert system. In addition, as wireless data transmission in firefighting stations is prone to radiofrequency (RF) interference and collision due to obstacles, limited bandwidth, and shared medium, this research proposed a node addressing scheme with the deployment of Time Division Multiple Access (TDMA) to help manage access to the wireless medium, reduce collisions, and improve the overall reliability of data transmission. As a result, a reduction of 12% packet loss rate was observed for outdoor and indoor transmission when a sample of 100 data packets was transmitted. Lastly, the coverage of radio frequencies is subject to certain limitations and considerations which include type of antenna usage, baud rate setting, node placement, and power control. Consequently, this research studied the network coverage for point-to-point and multipoint transmission in indoor, outdoor, and indoor-outdoor environments. The findings in all environmental scenarios signified that the transmission coverage showed an upward trend when the transmission power was increased. An 8.8% of improvement was seen when transmitting with 20dBm in the outdoor scenario compared to an indoor scenario, which is aligned with the hypothesis that the coverage can be improved with a higher transmission power and suitable node placement. In conclusion, this research improved the average response time of the firefighters by 6.56 minutes, reduced the data collision within the network by 12%, and increased the transmission coverage by 8.8%.

PENGOPTIMUMAN MASA TINDAK BALAS DENGAN SISTEM PENGGERA KECEMASAN RANGKAIAN PENDERIA TANPA WAYAR BERASASKAN INTERNET BENDA UNTUK ANGGOTA BOMBA

ABSTRAK

Bencana dan kecemasan sering memberi kesan besar kepada alam sekitar dan sumber kehidupan, memerlukan tindak balas kecemasan yang pantas. Untuk memastikan hasil terbaik, pelapor kecemasan dan anggota bomba perlu bertindak dengan berkesan untuk mengurangkan kesan negatif dan memudahkan pemulihan yang cepat selari dengan petunjuk prestasi utama bomba, iaitu bawah 10 minit. Walau bagaimanapun, pengendalian manual di bilik kawalan mengakibatkan kelewatan dan ralat manusia. Oleh itu, penyelidikan ini telah mereka bentuk satu sistem penggera kecemasan rangkaian penderia tanpa wayar (WSN) berasaskan Internet-of-Things (IoT) untuk anggota bomba yang terdiri daripada satu stesen pangkalan dan tiga nod penderia untuk meningkatkan masa tindak balas anggota bomba. Keputusan menunjukkan bahawa masa tindak balas anggota bomba telah dipertingkatkan kepada 8.54 minit berbanding tindak balas terdahulu iaitu 15.48 minit dengan menggunakan sistem penggera kecemasan berdasarkan IoT yang automatik. Selain itu, penghantaran data tanpa wayar di stesen pemadam kebakaran rentan kepada gangguan frekuensi radio (RF) dan perlanggaran disebabkan oleh penghadang, jalur lebar yang terhad, dan medium yang dikongsi. Penyelidikan ini mencadangkan skema pengalamatan nod dengan penggunaan Time Division Multiple Access (TDMA) untuk membantu menguruskan akses ke medium tanpa wayar, mengurangkan perlanggaran, dan meningkatkan kebolehpercayaan keseluruhan penghantaran data. Hasilnya, pengurangan kadar kehilangan paket sebanyak 12% diperolehi untuk penghantaran luar dan dalaman apabila sampel 100 paket data dihantar. Akhir sekali, liputan frekuensi radio tertakluk kepada beberapa had dan pertimbangan termasuk jenis penggunaan antena, tetapan baud, penempatan nod, dan kawalan kuasa. Oleh itu, penyelidikan ini mengkaji liputan rangkaian untuk penghantaran titik-ke-titik dan pelbagai titik dalam persekitaran dalaman, luaran, dan dalaman-luaran. Penemuan dalam semua senario persekitaran menunjukkan bahawa liputan penghantaran menunjukkan trenda menaik apabila kuasa penghantaran ditingkatkan. Peningkatan sebanyak 8.8% dilihat apabila menghantar dengan 20dBm dalam senario luaran berbanding dengan senario dalaman, yang selari dengan hipotesis bahawa liputan boleh dipertingkatkan dengan kuasa penghantaran yang lebih tinggi dan penempatan nod yang sesuai. Kesimpulannya, penyelidikan ini meningkatkan purata masa tindak balas anggota bomba sebanyak 6.56 minit, mengurangkan perlanggaran data dalam rangkaian sebanyak 12%, dan meningkatkan liputan penghantaran sebanyak 8.8%.

ACKNOWLEDGEMENT

In the Name of Allah, the Most Gracious, the Most Merciful. First and foremost, I would like to take this opportunity to express my sincere acknowledgement to my supervisor, Ts. Dr. Juwita binti Mohd Sultan, from the Faculty of Electronics and Computer Technology and Engineering, Universiti Teknikal Malaysia Melaka (UTeM), for her essential supervision, support, and encouragement towards the completion of this thesis. I would also like to express my greatest gratitude to Dr. Fakrulradzi bin Idris, from the Faculty of Electronics and Computer Technology and Engineering, co-supervisor of this research, for his advice and suggestions throughout this research journey. Special thanks to UTeM and Balai Bomba Melaka for the grant funding and support throughout this project. Lastly, thanks to all my colleagues and my beloved family for their moral support in completing this research study.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

UTeM	-	Universiti Teknikal Malaysia Melaka
BS	-	Base station
kBps	-	Kilo bit per second
CPU	-	Central Processing Unit
dBm	-	decibel milliwatts
G	-	Giga
Hz	-	Hertz
IoT	-	Internet of Things
k	-	Kilo
M	-	Mega
PER	-	Packet Error Rate
PLR	-	Packet Loss Rate
PRR	-	Packet Reception Ratio
RF	-	Radiofrequency
Rx	-	Receiver
Tx	-	Transmitter
WSN	-	Wireless Sensor Network

LIST OF SYMBOLS

°C - Degree Celcius

LIST OF PUBLICATIONS

The followings are the list of publications related to the work on this thesis:

N. Sainuddin, J. M. Sultan, F. Idris, M. Azuani, 2021. Data Collision and Interference Minimization in Wireless Sensor Network using Node Data Addressing with Random Access Time. *Jurnal Kejuruteraan.,* vol. 33, pp. 1105-1112, 2017 (WoS indexed).

N. Sainuddin, J. M. Sultan, F. Idris, M. Azuani, 2023. Multi-core and Single-core Raspberry Pi Microprocessor's. *Przeglad Elektrotechniczny,* vol. 99 (SCOPUS indexed).

CHAPTER 1

INTRODUCTION

1.1 Background

Immediate response and action by rescuers during an emergency are pivotal in saving lives, belongings, premises, and the environment. While most of the equipment and technologies used are up to date, there is still room for improvements that should be made. The lack of modern technologies in Malaysia's firefighter stations is often neglected, mostly due to the budget allocation and lack of resources. Fire and Rescue Department of Malaysia (Jabatan Bomba dan Penyelamat Malaysia, JBPM) had stated that the Key Performance Indicators (KPI) for the response time of firefighters in Malaysia is 10 minutes, following the national standards and operational requirements. The response time for the firefighter is measured once the call is received at the Public Safety Answering Point (PSAP) until the first unit arrives on the scene of the emergency incident. These KPIs are crucial for ensuring effective emergency response and public safety. Thus, this research focuses on providing a solution by developing a wireless automated emergency system based on Internet of Things (IoT) to improve the response time of the firefighter in Malaysia.

The Malaysian government initiated Emergency Response Service (MERS) 999 to consolidate all emergency numbers in Malaysia into a single hotline for public convenience, covering all types of emergencies such as the police, Fire and Rescue Department, Ministry of Health, Civil Defense Department, and Malaysian Maritime Enforcement Agency. Calls are answered by professional dispatch operator within 10 seconds before redirecting the call to the relevant emergency agency. However, the alarm handling and emergency reporting time are high due to the manual handling and reporting by the dispatch operator. Since the tasks are done manually by the dispatch operator, the firefighter's response time is high

due to delays and human errors in reporting emergency event. Thus, the aim of this research will focus on wirelessly automating these tasks into an independent system using a wireless sensor network (WSN) and Internet-of-Things (IoT) applications along with a cross-platform notification alert system so the firefighters can promptly receive the details of the emergency events. This system will be integrated with the Global Positioning System (GPS) for tracking and monitoring as visual aids during crises.

A wireless sensor network (WSN) is a network that is built from a large group of sensors that are distributed over a wide area. These networks of sensor nodes can perform various tasks such as processing and physical environment sensing and can communicate with other sensor nodes in the network wirelessly. In WSNs, the main goal is often to collect sensing data from the sensor nodes and transmit it to the base station to perform further analysis based on the data gathered. Therefore, data collection is the most common application used in WSN. Figure 1.1 shows the architecture of the wireless sensing system for Internet of Things (IoT) applications, where data is collected from numerous sensor nodes and transmitted to the base station for processing and analysis. The data collected by the base station will be uploaded to the cloud (Internet), making it accessible to users through any mobile application or web browser.

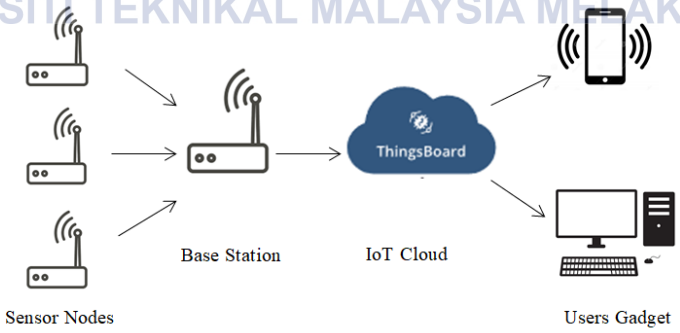

Figure 1.1 WSN architecture in IoT application (Zhong, 2018)

The Internet of Things (IoT) refers to a network that includes physical devices, computing devices, mechanical and digital machines, and other items embedded with electronics, software, sensors, actuators, and connectivity. IoT enables communication between devices and people

through data collection, exchange, and connection. This technology offers remote access, allowing objects to be sensed and controlled wirelessly across network infrastructure. It provides opportunities for direct integration between the physical world and computer-based systems. Embedded with a wireless sensor network (WSN), this technology facilitates the connection between humans and things, enabling data exchange. In recent years, IoT has been applied in various fields such as smart homes, smart cities, smart farming, surveillance, and military applications. Therefore, this research focuses on developing an automated IoT-based emergency alert system for firefighting station. Data collected from sensor nodes will be transmitted to the base station via the internet and visualized on the Thingsboard IoT dashboard, with notification alerts accessible through the Telegram application.

1.2 Problem Statement

The KPI assessment is essential for analyzing firefighter response times and performance to ensure agile and efficient service delivery. The emergency responder's response time to each event is a key indicator used to assess the department's performance rate, as stated by Cicioglu (2020). According to the Fire and Rescue Department of Malaysia (Jabatan Bomba dan Penyelamat Malaysia, JBPM), the KPI for firefighter response time in Malaysia is 10 minutes. However, since data reporting and processing are manually handled in the Control Room by dispatch operators, this introduces delays and the possibility of human error in dispatching case information, which can lead to longer firefighter response times.

In addition, the reliability of RF communication in Wireless Sensor Networks (WSNs) is often compromised by various challenges, such as interference and data collisions. These issues are exacerbated by factors such as firefighter station infrastructure obstructions that hinder radio propagation. Interference from other wireless devices or networks operating in the same frequency range can degrade signal quality and disrupt communication among sensor nodes. Additionally,

data collisions occur when multiple nodes attempt to transmit data simultaneously, leading to packet loss and reduced network efficiency. These challenges collectively undermine the performance and reliability of RF communication in WSNs proposed in this research, impacting the timely and accurate transmission of sensor data critical for emergency alert applications for firefighters.

Lastly, the coverage of radio frequencies (RF) in wireless communication networks is constrained by various factors and considerations that significantly impact network coverage and data transmission reliability. These limitations include the propagation characteristics of RF signals, which can be attenuated or blocked by physical obstacles such as walls and other infrastructures in the firefighter's station. The effectiveness of RF coverage is also influenced by electromagnetic interference from other electronic devices operating in the firefighter's station. These factors collectively dictate the range and reliability of RF coverage, posing challenges for ensuring seamless data transmission across the network. Inadequate coverage can result in dead zones or areas with weak signal strength, leading to communication gaps and data loss. Therefore, it is essential to address these limitations to optimize the design and deployment of WSN, extend the coverage range, and ensure robust data transmission capabilities in diverse and challenging operational environments.

1.3 Research Objective

The main aim of this research is to optimize the response time of firefighters with Internet-of-Things based wireless sensor network emergency alert system. Specifically, the objectives are as follows:

- To design and develop an automatic IoT-based wireless sensor network for emergency alerting systems for firefighter stations.

- To minimize data collisions and interference during the radiofrequency (RF) transmission within the wireless network using adaptive TDMA and node addressing scheme.
- To evaluate and analyze the data transmission reliability and coverage within the network by using RF data transmission.

1.4 Scope of Research

The scope of this research is as follows:

- The WSN is developed in a star topology which compromises 1 base station and 3 sensor nodes.
- WSN is tested with point-to-point and multipoint transmission in indoor, outdoor, and indoor-outdoor.
- Testing environment excludes weather factors such as rainy and windy environments.
- Thingsboard is used as an IoT platform for alerting and monitoring purposes.
- RF HC12 with a frequency band of 433MHz is used for data transmission.
- Baud rates tested are 1200, 2400, 4800, 9600, 57600, and 115200 bit per seconds.
- Transmission powers tested are 1,2,5,8,11,14,1 7,20 miiliwatts.
- 100 data packets were sent for data interference testing.
- 2.4G antenna extension with 3 decibels isotropic (dBi) is used with the RF module.

1.5 Thesis Outline

Based on the objectives previously presented and on the approach proposed before, this thesis is made up of five (5) chapters, which contents are summarized as follows: