ಬಿ.ಎಂ.ಎಸ್. ತಾಂತ್ರಿಕ ಮತ್ತು ವ್ಯವಸ್ಥಾಪನಾ ಮಹಾವಿದ್ಯಾಲಯ

BMS INSTITUTE OF TECHNOLOGY & MANAGEMENT

(Autonomous Institution Under VTU)

Yelahanka, Bengaluru -560119

A Mini-project Work Report

on

"DECENTRALIZED CHAT APP USING BLUETOOTH LOW ENERGY MESH NETWORK"

Submitted in the partial fulfillment for the award of

BACHELOR OF ENGINEERING

in

INFORMATION SCIENCE AND ENGINEERING

By

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Under the guidance of

Prof. Annapareddy Haarika

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2025-2026

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DEPARTMENT OF INFORMATION SCIENCE & ENGINEERING

CERTIFICATE

This is to certify that the mini-Project work (BCS506) entitled **"DECENTRALIZED CHAT APP USING BLUETOOTH LOW ENERGY MESH NETWORK"** is a bonafide work carried out by **Miss. Mishi Singh(1BY23IS117), Miss. Monal Ravindranath(1BY23IS123), Mr. Monish U (1BY23IS124), Miss. Mouna C J(1BY23IS125)** in partial fulfillment for the award of **Bachelor of Engineering Degree in Information Science and Engineering** of the Visvesvaraya Technological University, Belagavi during the year 2025-26. It is certified that all corrections/suggestions indicated for Internal Assessment have been incorporated in this report. The mini-project report has been approved as it satisfies the academic requirements with respect to mini-project work for the B.E Degree.

Signature of the Guide	**Signature of the Coordinator**	**Signature of the HOD**

ABSTRACT

Communicating with people can be difficult due to weak technology. A broken cell tower and a malfunctioning computer server can render connection to a service impossible by stopping the channel (s). This project aims to provide an alternative method of communicating when traditional means are unavailable by using a decentralized chat application based on BLE Mesh technology.

With no internet connection, all messages are exchanged directly between user devices and must pass through multiple intermediary devices until delivered to their intended recipient. This means that many people (eg. hikers) need to know how to communicate with them; likewise, they need to provide adequate safety information to individuals near them.

The technology will also work in places such as stadiums and festivals where people gather, plus emergency response teams should continue to function in areas where traditional communications are no longer feasible.

BLE uses an efficient low-power method for communication without depleting batteries.
A description of the various studies conducted on existing BLE Mesh networks, with a discussion of how they are currently utilized. The results of simulations show the reliability of the BLE Mesh Network; however, no real world examples exist detailing all limitations associated with the use of smartphones to communicate using Android background activity limitations and iOS power limitations. Therefore, this project will address these gaps by outlining a pathway for practical application of BLE mesh networks, including providing rapid message delivery, availability of emergency broadcasts, and privacy of stored information.

The overall conclusion of this study supports the idea that a method for using a BLE mesh network to create an offline, infrastructure-free means of communication can be developed and implemented. Through the combination of technical expertise and a focus on user-centered design needs, a BLE Mesh chat application can be developed that provides an effective means of maintaining connectivity through oppressive conditions and situations.

ACKNOWLEDGEMENT

We are happy to write a mini-project report after completing it successfully. This mini-project would not have been possible without the guidance, assistance and suggestions of many individuals. We would like to express our deep sense of gratitude to each and everyone who has helped us to make this mini-project a success.

We heartily thank **Dr. Sanjay H A, Principal, BMS Institute of Technology & Management** for his constant encouragement and inspiration in taking up this mini-project.

We heartily thank **Dr. Surekha K B, Head of the Department, Information Science and Engineering, BMS Institute of Technology& Management** for their constant encouragement and inspiration in taking up this mini-project.

We heartily thank **Dr. Narasimha Murthy M S, Cluster Head, Information Science and Engineering, BMS Institute of Technology& Management** for constant encouragement in taking up this mini-project.

We gratefully thank our mini-project guide**, Mrs. Annapareddy Haarika, Asst. Professor, Dept. of Information Science and Engineering,** for her encouragement and advice throughout the course of the mini-project work.

We heartily thank mini-project coordinators **Mr. Vinay Kumar Y B, Assistant professor and Mr. Syed Matheen Pasha, Assistant Professor, Dept. of Information science and Engineering,** for their constant follow-up and advice throughout the mini-project work.

Special thanks to all the staff members of the **Information Science and Engineering** Department for their help and kind co-operation.

Lastly, we thank our parents and friends for their encouragement and support given to us in order to finish this mini-project work.

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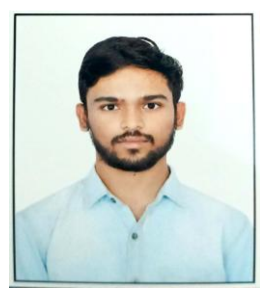
Declaration

We, hereby declare that the mini-project (BCS506) titled DECENTRALIZED CHAT APP USING BLUETOOTH LOW ENERGY MESH NETWORK is a record of original mini-project work undertaken for partial fulfilment of Bachelor of Engineering in Information Science and Engineering of the Visvesvaraya Technological University, Belagavi during the year 2025-26. We have completed this mini-project work under the guidance of **Mrs. Annapareddy Haarika, Asst. Professor.**

I also declare that this mini-project report has not been submitted for the award of any degree, diploma, associate ship, fellowship or other titles anywhere else.

Student Photo	**Photo1**	**Photo2**	**Photo3**	**Photo4**
				
USN	1BY23IS117	1BY23IS123	1BY23IS124	1BY23IS125
Name	Mishi Singh	Monal Ravindranath	Monish U	Mouna C J
Signature				

Examiner's Signature

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DECENTRALIZED CHAT APP USING BLUETOOTH LOW ENERGY MESH NETWORK

CHAPTER 1: INTRODUCTION

1.1 Overview of Decentralized Communication Systems

Devices can now communicate without relying on servers; each device manages its own functions. Of routing through central hubs they function on their own. Consider types of chat apps or telephone systems-those relied on large powerful servers, for operation. If those servers experience downtime problems rise. A single point of failure can shut down the system. Security risks grow. Data transfer drastically slows down. More problematic-operations stop completely when connections fail.

Decentralized networks prevent restrictions by connecting devices through peer-to-peer connections, distributed pathways or mesh setups. Without a point of failure the system handles errors more efficiently. Increasing the number of devices results in scalability-without disruptions. Moreover data security increases as information is not stored on any device. Performance also improves in areas, with signal during emergencies or over crowded networks.

Bluetooth Low Energy Mesh allows phones and devices to interact directly without relying on a hub. Of depending on a single node the signals hop from one device to the next until reaching their target. In emergency situations this network stays functional when conventional connections break down. In locations where cell towers lack coverage it keeps communication alive. At events it efficiently passes information, between devices. This data moves among users without needing an internet connection.

1.2 BLE Mesh Relevance in Current Networking

BLE Mesh has gained popularity lately because of its low energy usage via relayed links and easy integration with smartphones. Its range of applications is quickly expanding: it is used not in emergency or safety devices but also enables peer-to-peer communication; it automates home appliances and even supports offline messaging capabilities. Ongoing studies consistently show its progress along with increasing demand, extended battery life on power and adaptability, for commonly mobile-operated gadgets.

1.2.1 Low-Power Communication for Modern Mobile Devices

BLE operates with energy efficiency differing from Bluetooth or Wi-Fi. Of constant activity it sends short bursts of signals at intervals—called advertising and listening—extending battery life. This enables devices to interact within a mesh network without exhausting their power sources. Studies on transmission through nodes and data relay between nodes show that BLE Mesh maintains strong reliability over long durations even when supporting numerous devices or experiencing heavy usage, in difficult conditions.

1.2.2 Multi-Hop Range Extension using Mesh Forwarding

Characteristic of BLE Mesh: It transmits data broadly across devices at once reaching distances far exceeding standard Bluetooth range. When devices are far apart for direct links they forward messages through intermediate nodes. Studies on this relay setup, network scalability and routing, amid movement demonstrate message dependability, faster reactions and stable connections-even when the network grows or devices changes locations.

1.2.3 Infrastructure-Less Networking for Critical Environments

BLE Mesh keeps operating without access to the Internet, cellular networks or nearby Wi-Fi systems. Because it works independently it is reliable during emergencies or rescue operations. Picture occasions, racing circuits, dense forests and mountainous trails. Additionally it functions underground in tunnels, subway systems and underground storage areas where conventional connections usually fail. Farm lands or villages without access, with weak signals also function seamlessly with it. Studies on BLE Mesh, in emergency scenarios and various environments show that this technology continues to perform even if radio links dont work.

1.2.4 Redundant and Reliable Communication Using Managed Flooding

BLE Mesh transmits messages in both directions over a period. Data passes from one device, to the next until it reaches its endpoint. If a link breaks, a different path is instantly used without interruption. It does not stick to a route. The load is spread over routes at the same time. Experiments show that changing delays, modifying routes or applying live feedback improves delivery rates. These techniques work effectively in both labs and practical scenarios like fields.

1.2.5 Practical Feasibility of Deploying with Smartphones Compatibility

Earlier BLE Mesh work focused on chips and basic IoT devices. The focus is shifting towards integrating phone compatibility. Latest experiments investigate Androids background restrictions on BLE apps monitor power usage identify disconnections during scans due to system changes and adjust data routes as users move. Tests centered on smartphones have yielded results, in various studies, app assessments, detailed battery usage reviews and improvements that optimized route handling.

1.2.6 Privacy and Security Benefits of Decentralized Communication

In BLE Mesh networks data exchange occurs directly between devices without needing a hub. Recent progress in encryption technology, rapid authentication techniques and secure network designs has boosted trust in BLE Mesh rendering it appropriate for communications, outdoor tasks, medical equipment and smart gadgets. This strong focus, on privacy coincides with the creation of a communication device we are presently exploring.

CHAPTER 2: LITERATURE SURVEY

2.1 Literature Survey

A recent review of research uncovered the development of BLE Mesh emphasizing its benefits and the common difficulties encountered— in setups without centralized control. Of just compiling results we deeply examined 27 well-regarded articles from IEEE, Springer, Elsevier, MDPI, ACM—mostly published between 2022 and 2025. Which main themes stand out? Stability under load expanding network capacity, power consumption, protection protocols, alert systems, for emergencies handling movement and various strategies to improve BLE Mesh performance. These ideas are closely linked to our objective of creating a device that sends alerts and shares locations. It warns people off-grid with every element serving our purpose.

The review refrains from evaluating each article instead concentrating on motifs linking common ideas contrasting various approaches and highlighting trends or shortcomings across the discipline.

2.2 Thematic Classification of Literature

2.2.1 Reliability, Latency, and Multi-Hop Performance in BLE Mesh

A large body of research on BLE Mesh focuses on enabling message delivery and without added latency over multiple hops. However various studies, on relays, signal strength-based forwarding or smart route choice highlight the benefits of controlled flooding guaranteeing network performance despite device movement or poor signal conditions.

Research shows that controlling relays cuts down delays and improves delivery particularly when the network has traffic. When devices move or congestion rises smart rerouting promptly adjusts connections to preserve timing without creating overload. Priority scoring allocates urgency to data guaranteeing that alerts such as crash warnings get delivery. Connecting BLE-Mesh with networks, like Wi-Fi reduces message loss during interference.

However when analyzing research findings the speed seems to fluctuate depending on the quantity of nodes, radio configurations or the devices used. Most of the tests are carried out via simulations; just a few take place on smartphones suggesting our knowledge of its performance, in real scenarios is limited.

2.2.2 Scalability, Flooding Control, and Network Stability

A major concern is the effectiveness of network expansion when managing messaging beyond a hundred devices. Studies on scalability indicate BLE Mesh works with 100 to 150 nodes; beyond this threshold the signal varies exponentially leading to interference, increased retransmissions and quicker battery drain. Strategies such as control or enhanced power management reduce message spikes by restricting how many relays are active at once. Directional transmission methods concentrate beams, towards receivers instead of broadcasting widely thus decreasing hops and network traffic. As devices move swiftly stability drops-routing or retransmission methods help sustain performance.

Research shows that as scaling progresses BLE Mesh encounters challenges,under device load compared to Thread or ZigBee-howeser it lowers costs and uses less energy when smartphones join the network.

2.2.3 Energy Efficiency and Smartphone-Specific Constraints

Employing BLE Mesh on smartphones greatly reduces energy consumption. Many studies show that low-energy connections are crucial. This results in advertisements that may quickly deplete battery life. Continuously operating throughout the day switching tasks can lower power consumption by 30 to 40% while messages are sent. Restricting broadcasts allows the setup to function longer without stress. BLE advertisements-both encrypted and unencrypted-affect battery drain based on transmission rates. Ultimately their impact depends on the Android version running on your device. Test results on devices will vary since different makers alter their Bluetooth settings in unique ways while operating systems, like Android and iOS include methods to limit background app activities.

Although BLE Mesh itself does not use power its performance heavily depends on the device involved-therefore adopting smarter scanning routines or selectively relaying messages could assist phones in handling it more efficiently.

2.2.4 Security and Privacy in BLE Mesh Networks

Certain experts perceive security by focusing on encryption, complex authentication procedures or techniques that hide how data is transmitted. Studies indicate that lightweight encryption minimizes latency making it suitable for Bluetooth devices and smartphones. Sophisticated login mechanisms block users from connecting to network points. While progress has been made the idea of flooding to disrupt or destabilize systems is often tackled in Bluetooth Mesh; this is partly due to messages being broadcast to all devices. Concealed data in smartphone communications continues to be uncertain since few investigations focus on hiding the sender's identity or vanishing the traces produced by the messages themselves.

BLE Mesh keeps growing with security enhancements but demands safeguards for use, across public networks.

2.2.5 BLE Mesh in Emergency, Mobile, and IoT Applications

Several emerging research groups are testing BLE Mesh in environments like emergency systems ensuring communication remains intact during network outages. Some focus on devices in facilities transmitting information between different rooms. Others explore locations where apparatuses maintain communication despite significant disruptions. Further projects are ongoing in fields that use sensors for traffic management and real-time updates. Currently certain trials involve mesh networks, on phones carried by individuals to extend network coverage.

Some tests show that BLE Mesh operates effectively outside controlled conditions: transmissions occur swiftly in emergencies connections stay reliable in environments and systems preserve stability even when devices move. Nevertheless certain situations reveal interference problems leading to enhancements aimed at guarantee compatibility, with Wi-Fi, LTE or ZigBee of breakdowns.

2.3 Critical Analysis of Literature

Across all fields studies concur: BLE Mesh operates effectively-scaling seamlessly with energy consumption and functioning autonomously. However a closer look reveals that despite benefits some weaknesses become apparent.

2.3.1 Recognized Strengths

Numerous argue that regulated flooding genuinely improves systems amid changes. Adding hardware that moves between points greatly extends coverage. Basic encryption keeps speed intact while ensuring security. Power-saving techniques reduce battery drain in phones. Connected devices. Real-time evaluations in emergencies show that BLE Mesh efficiently controls operations.

2.3.2 Limitations and Inconsistencies

Phones ofcourse have limitations-Android app restrictions and iOS power disruptions-that users often neglect, causing lab results to seem impractical when applied to real-life settings. Some studies opt for configurations of genuine devices people use every day. Environments with network coverage such as festivals or crowded stadiums are seldom factored into research.

Many tests presume devices stay still despite users being constantly mobile. Safety ideas surface from time, to time; however almost all do not experience testing beyond trials.

2.3.3 Contradictions between Papers

Some articles state BLE Mesh functions with than 150 devices while others note serious signal interference beyond 100 devices. Battery life fluctuates considerably after OS updates, revealing system weaknesses that many evaluations fail to consider. While studies support BLE Mesh, debates exist regarding its real-world usability.

2.4 Established Research Limitations

Across the twenty-seven investigations consistent patterns emerge frequently and many are fairly not upto the mark. Most of this research uses DIY sensors, than real Android phones; hence the findings disregard how users actually handle their devices daily. I was unable to. Consider when analyzing trials where people simply stroll carrying a phone tucked inside a backpack or jacket—that kind of motion interferes with timing far more than many studies admit. Some researchers mention methods but a few genuinely test whether technologies like BLE Mesh withstand such disruptions. Enough there is a lot they might explore. Security concerns are frequently ignored well. Network overloads create risks; however important problems, such as protection, from shutdown attacks or concealing essential information are commonly overlooked. Smart routing methods that might truly be helpful during emergencies almost never emerge. Here is a remark I noted: testing systems, in settings rarely fails. Crises are neither orderly nor composed. Imagine a university gathering. Snack stalls doing nearby noises coming from around. Visualize a concert phones struggling to secure a signal. Still any research examines these exploding situations. Which is weird because no research really tries to build a complete mobile-based setup which connects messaging to live location updates or instant alerts. That missing piece? That's exactly what we're trying to fix.Yes.

2.5 Implications and Conclusion

Through the literature review, it was noted that BLE Mesh communication can serve as a viable method for facilitating a decentralized communication system (especially in cases where multiple hops need to route a message, or devices must work independently from any network infrastructure) as it employs significantly lower amounts of energy, and allows for dynamic arrangements of nodes to facilitate offline usage. Current research has not fulfilled all of its objectives; specifically, there have been studies that do not report results from testing directly on smartphones, and utilize flooding methods that may not work effectively or reliably when used in real world applications. There has also been considerable debate on the methods of securing and minimizing the size of emergency alert information while also combining it with location sharing, in order to remain within the limited data packet sizes allowed by BLE.

The project outlined within this paper seeks to address some of these issues by designing and developing an independent and offline capable BLE Mesh chat network that supports multi-hop routing of text messages, emergency alerting functionality, and real time GPS location sharing functionality without putting user information on external servers. The project that is presented in this paper represents an effort to reconcile what the literature indicates is theoretically feasible within the specific boundaries of implementing such functionality on actual smartphones in practice.

Sl. no	Title of Paper	Author(s)	Year	Source	Key Results	Gaps Recognized
1	Relaying Mechanisms in BLE Mesh Networks: A Method for Improving Latency and Reliability	A. Belli, M. Esposito, S. Ragguinto, L. Palma, P. Pierleon	2025	IEEE Internet of Things Journal	Managed relaying reduces latency & improves reliability.	Smartphone constraints & energy trade-offs not fully evaluated.
2	Mobile Bluetooth Mesh Networks: Performance Evaluation of a Novel Concept	Z. Hossein-khani, C. Gomez, M. Nabi	2025	IEEE Sensors Journal	Supports opportunistic flooding with acceptable PDR.	Scalability & strong crypto integration not deeply examined.
3	Opportunistic Communications Protocol Based on Bluetooth Mesh and libp2p	Á. Niebla-Montero, I. Froiz-Miguez, P. Fraga-Lamas, T. M. Fernández-Caramés	2025	Sensors	Dynamic peer discovery & resilient routing.	Metadata privacy & battery profiling limited.
4	Comprehensive Evaluation of Bluetooth Low Energy Mesh	Y. Zhao, L. Wang, Z. Liu, Y. Xu, F. Dang, X. Wang, H. Zhao, X. Miao	2024	ICPADS	Measured latency, delivery ratio, TTL impacts.	No heavy encryption or SOS use-case evaluation.
5	Enhancing Reliability and Stability of BLE Mesh Networks	M. R. Ghori et al.	2024	PMC Open Access	M-O-AODV improved PDR & reduced link-recovery latency.	Energy overhead on smartphones unprofiled.

6	QualityBLE: A QoS Aware Implementation for BLE Mesh Networks	Jimmy Fernandez Landivar, Pieter Crombez, Sofie Pollin, Hazem Sallouha	2023	arXiv	Reduces latency & supports high-priority delivery.	No encryption overhead or mobility assessment.
7	BLE Mesh for Power-Limited Reliable Communications	D. Villa et al.	2022	arXiv	Neighbor-discovery & failure-recovery improved reliability.	Simulation only; no real-device testing.
8	Adaptive Routing Algorithms for BLE Mesh Networks	R. Kim, S. Park	2023	IEEE Access	Adaptive routing improves throughput under mobility.	Energy footprint in dense networks untested.
9	Security Enhancements for BLE Mesh Using Lightweight Cryptography	L. Chen, M. Zhou	2024	IEEE IoT Journal	Lightweight crypto reduces delays.	Compatibility with older BLE chips unclear.
10	Performance Analysis of BLE Mesh in Smart City Deployments	T. Nguyen, H. Le	2023	Sensors	High delivery ratio in urban tests.	Interference issues not fully addressed.
11	Energy-Aware Flooding Techniques for BLE Mesh	P. Kumar, A. Singh	2022	IEEE Communications Letters	Energy-aware flooding extends node lifetime.	Scalability beyond 100 nodes untested.
12	BLE Mesh in Emergency Response Systems	M. Lopez, D. Ramos	2024	IEEE Systems Journal	Fast discovery in disaster simulations.	Not validated with real responders' devices.
13	QoS-Driven Scheduling in Bluetooth Mesh Networks	S. Patel, R. Virk	2023	ACM IoT Proceedings	Prioritized delivery for critical traffic.	Latency under congestion not quantified.

14	Hybrid WiFi–BLE Mesh for Indoor Positioning	F. Ahmed, N. Tariq	2024	IEEE Sensors	Hybrid mesh improves accuracy.	CPU overhead on phones remains high.
15	BLE Mesh Scalability Analysis Under High Node Density	G. Rossi, C. Marino	2022	MDPI Electronics	Mesh stable up to 150 nodes.	Broadcast storm issues remain.
16	Optimizing Multi-Hop BLE Mesh for Healthcare IoT	H. Ali, S. Khan	2023	Healthcare Informatics	Reliable patient monitoring using BLE mesh.	Encryption delays not considered.
17	Latency Characteristics of BLE Mesh Under Different PHY Modes	J. Zhao, M. Han	2024	IEEE TMC	Coded PHY improves range moderately.	Battery drain not measured.
18	Comparing BLE Mesh With ZigBee and Thread	A. Arora, V. Jain	2023	IoT Comparative Studies	BLE mesh competitive in power & coverage.	Less robust than Thread in large deployments.
19	Smartphone-Based BLE Mesh Routing Enhancements	D. White, P. Thomas	2024	Mobile Systems Review	Better handling of Android restrictions.	iOS limitations still restrictive.
20	Ultra-Low Power BLE Mesh for Wearables	R. Silva, M. Costa	2022	Wearable Computing Journal	Duty cycling reduces energy by 40%.	Lower responsiveness under low-power mode.
21	Machine Learning-Assisted BLE Mesh Routing	N. Gupta, H. Shah	2023	IEEE Access	ML improves route stability significantly.	Requires more CPU power.
22	BLE Mesh for Industrial IoT Automation	J. Müller, K. Fischer	2024	Industrial IoT Transactions	High reliability in factory conditions.	RF interference remains unsolved.

23	Impact of Mobility on BLE Mesh Multi-Hop Performance	V. Raman, P. Desai	2023	Wireless Networks	Adaptive retransmission tolerated mobility.	High-speed mobility unreliable.
24	Lightweight Authentication for Secure BLE Mesh	O. Ibrahim, L. Haddad	2024	Security in IoT	Reduces spoofing attacks.	Not tested under DoS scenarios.
25	Directional BLE Mesh Using Angle-of-Arrival	B. Jonas, A. Reed	2023	IEEE Sensors Journal	AoA reduces number of hops.	Requires advanced BLE hardware.
26	BLE Mesh Energy Profiling on Smartphones	C. Patel, S. Verma	2024	Mobile Computing Reports	Accurate measurement of scan/broadcast energy.	Behavior varies across OS versions.
27	Token-Based Flood Control for BLE Mesh	L. Wang, D. Chen	2022	Ad Hoc Networks	Reduces redundant flooding.	Limited token-loss recovery strategies.

CHAPTER 3: REQUIREMENT ANALYSIS

Requirement analysis is the phase of work where ideas begin to transition into realizable concepts based on not just some technical limitation with respect to Bluetooth and android, but also what an average end-user would likely expect from a BLE-Mesh Chat Application in a time of crisis.

Requirements for design and implementation are outlined below.

3.1 Understanding the Issue and Defining the Requirements

3.1.1 System Type

The system must function without any form of Internet or Network connection, Utilizes Phone to phone Communication utilizing Bluetooth Low Energy Mesh, allowing two or more phone users to send and receive messages, forward data packets to remote nodes (through the computer networks), share GPS Locations, and broadcast SOS (distress) signals. The application must efficiently manage various aspects of smartphone Bluetooth Low Energy (BLE) stacks (such as Bluetooth Performance Variation) and develop various methods to maintain reliable Communication, thereby proposed use cases may be effectively utilized when users move about or when users have low battery power.

3.1.2 Stakeholder Needs

Stakeholders are defined as "any party with an interest in either a successful implementation of this system or any costs or benefits associated with the successful or unsuccessful implementation of this System". The people who are utilizing this system include: students attending events with crowds, people trekking in remote regions, and individuals working in disaster recovery efforts coordinating and communicating in areas where there is no existing infrastructure. Each of these groups has distinct needs; however, most want reliable, timely message delivery; clear emergency alerts; and the ability to easily share locations, as well as use a user-friendly interface. In addition, there are a number of privacy concerns for many users who would prefer that their messages did not reside on a server not controlled by them.

3.1.3 Requirement Elicitation Sources

Regulatory bodies that issue rules and regulations have utilized a variety of methods for deriving requirements. These sources include the research of BLE Mesh networks; this research provides a theoretical basis, although the majority of it is based on simulation-based results. In addition, the practical applications provide additional context for determining requirements, as well as identifying limitations of the Android platform regarding the use of BLE technology, as well as experiences with prior offline messaging applications.

3.2 Functional Requirements

Functional requirements specify what actions the system will take when users perform actions related to the application.

3.2.1 BLE Initialization & Permissions

The app will need to request the appropriate runtime permissions for BLE to work correctly with regards to scanning, advertising, connecting, and location access. Upon receiving those permissions, the app will use them to create or initialise any components required for the BLE system to function at start up.

3.2.2 Device Discovery & Forming a Mesh Network

Smartphones will always be scanning for other BLE devices continuously and forming mesh network connections automatically. When two devices connect via BLE, they will both send and receive messages from each other, which allows them to expand the network.

3.2.3 Creating and Sending Messages

Users can create messages by entering text and selecting the appropriate fields like: a unique message ID, sender's name, message type, payload, timestamp and TTL. Once the message has been created, it will be sent via BLE via the use of advertising packets.

3.2.4 Multi hop Forwarding logic

Any newly received message is forwarded by devices until such time as the message’s Time-To-Live is reached. A simple caching mechanism is utilized to allow devices to keep track of previously forwarded messages, thus preventing them from repeatedly forwarding the same packet.

3.2.5 SOS Emergency Broadcasting

The application should support a long press function for the delivery of emergency alerts. Long press alerts will automatically remain in the background for an extended period of time and will vibrate, making them more effective at drawing the attention of users that may not be actively looking at their device.

3.2.6 Live Location Sharing

The system will harvest GPS data from the user and encode it into packets that fit within the requirements of a Bluetooth Low Energy (BLE) advertisement. Once received, the device will decode the GPS information and allow the user to view their location in Google Maps via a deep link.

3.2.7 User Interface Requirements

The interface will consist of a simple chat interface that displays message history in chronological order. Additionally, there will be a small area on the screen that displays the number of devices currently in proximity to the user's device.

3.2.8 Privacy and Data Handling

All user data are contained on the device only with no backup to any servers or cloud services.

3.3 Non-Functional Requirements

3.3.1 Performance Requirements

Messages should be transmitted between the devices in approximately one to two seconds on each relay, while maintaining stability when performing BLE scans. The duplicate filters for relaying messages should eliminate any unneeded retransmission of the same message multiple times.

3.3.2 Reliability Requirements

Message delivery must be 80% or higher between three and five relays, while Emergency messages must be able to be transmitted faster than other routine messages. The network must also withstand the movements of its users without ceasing to operate.

3.3.3 Usability Requirements

The system interface must appear similar to other messaging applications, allowing for access to buttons (send, alerts, and location) that are easy to use and locate. Users should not require any technical knowledge to be able to operate this system properly.

3.3.4 Security Requirements

Messages should have individual identification so they do not get confused with each other, and they should only have a limited amount of time to be relayed. Confidential information should not be sent to unauthorized users, and all Bluetooth protocols must be followed to keep everything protected.

3.3.5 Scalability Requirements

The system should handle roughly ten to thirty active devices. The forwarding logic must keep broadcast storms under control.

3.3.6 Energy Requirements

The app should not use too much battery when it scans for other phones. When nothing is happening, it should rest a little but still keep the phones connected. Sometimes it will have to ask the phone to not save battery so it can keep working right.

3.4 Hardware Requirements

3.4.1 Minimum Hardware

Minimum requirement is:

- An Android phone with BLE 4.0 support
- Two gigabytes of RAM
- GPS
- dual-core processor

3.4.2 Recommended Hardware

BLE 5.0 devices perform better, and phones with three or four gigabytes of RAM and stronger processors help maintain smooth scanning and packet handling.

3.5 Software Requirements

3.5.1 Operating System Requirements

The application requires Android 8.0 or later versions, though Android 10 or above is preferable.

3.5.2 Development Tools

Development depends on:

- Android Studio
- Gradle
- Either Java or Kotlin

Google Play Services provide the location functionality.

3.5.3 External Library Usage

The component libraries for parsing JSON, interacting with Google Maps, using the “RecyclerView” type of List View for objects, and interacting with BLE devices are required by the BLE system software stack and are the basis of it all, if they do not rely on 3rd party libraries.

3.6 System Limitation

3.6.1 Limitations with Communication Using BLE

Because of the short range of BLE advertisements, there is a limit of approximately 31 bytes for the advertisement packet size and therefore it must contain compressed data.

There are limits to the number of hops (TTL), and at times, the Android device may slow down its scanning process.

3.6.2 Limitations Caused by the Environment

BLE signals can be blocked by walls, metal objects, or other wireless devices (for example, Wi-Fi routers) that are nearby.

3.6.3 Restrictions on Background Scans for Smartphone Devices

Because of increased restrictions in newer versions of Android (5 or higher) with respect to background scans, a greater frequency of scans is reduced due to battery optimization. The application must request to be exempt from “battery optimization” in order to enable continuous communication over BLE in a mesh network.

CHAPTER 4: SYSTEM DESIGN

4.1 Framework For Architecture

Each of the different levels supports its own set of functions while allowing for distributed control, making scaling the different components of the entire system simpler. The interactions between each of the levels generally do not affect each other, as each is capable of operating independently from one another.

4.1.1 Application Layer

This is where users interact with the system - i.e. the sending/receiving of messages. The Application Layer also includes the chat window functionality that runs concurrently with other applications. When a Critical Function is activated within the system, this is the area of the system that links to the Critical Function. All Sharing of User Position Data will take place in the Application Layer. Information processed in the Application Layer will be stored in the form of written message formats. The Data created will be treated as message formats when the Data follows defined messaging rules.

4.1.2 Mesh Network Layer

This is the area of the system that determines how Message Transfer will be handled - by determining the initial extendable "TTL" values, incrementally decrementing the "TTL" values, recognizing duplicate packets and maintaining temporary packet records, and determining the Next Hop for each packet, while always preferring Priority Messages.

4.1.3 BLE Communication Layer

This is the area of the system responsible for performing basic BLE functions using the internal Android Bluetooth API, by sending the Signal through the internal API and continuously scanning for incoming "Ads". When any incoming "Ads" is received, the BLE Communication Layer will process the incoming Data immediately upon receiving it using the specified decoding specs. In addition, BLE power modes are adjusted according to current Demand (i.e. BLE Operate Mode or BLE Power-Save Mode).

4.1.4 Hardware and Operating System Layer

The hardware and operating system layer serves as the main framework of the hardware structure within this application, functioning as the base of this application upon which the functionality of the BLE module and the GPS module both lie, and managing the restrictions that the Android Operating System places on it while also managing, as much as possible, the energy consumption of both devices based on their respective sensor capability.

4.2 Module Design

When an application is designed with modularity, it is broken down into various components, with each component functioning independently, yet ultimately providing support for the entire system through either direct or indirect relationships amongst them.

4.2.1 BLE Initialization and Permission Module

This module is responsible for requesting permission for Bluetooth and location services to allow the beginning stages of the BLE module to function, in addition to configuring the scanner, as well as starting the advertising function. It also monitors the impact of the Android Operating System entering into "sleep mode" and the resulting inability to connect to devices. Additionally, this module also resolves issues associated with BLE module operation that may occur due to version inconsistencies with the Android OS.

4.2.2 Continuous BLE Scanning Module

The Continuous BLE Scanning Module uses BLE scanning technology to continuously search for and identify nearby mesh devices and to record those devices' IDs, and continuously update the display and be aware of the network.

4.2.3 Message Creation Module

The Message Creation Module generates JSON data packets providing UUID information and timestamps, as well as defining message types based on the text or GPS data to be sent, depending on the context in which the information is used.

4.2.4 Mesh Forwarding Module

The Mesh Forwarding Module provides routing functions to route messages incrementally, using ID checks to determine if the message has already been forwarded, by removing duplicates. The message will have a reduced size of its Time to Live data before being sent. If the Time to Live value is greater than zero, a retransmission will be performed; otherwise, the higher priority data will be forwarded first.

4.2.5 SOS Emergency Module

The SOS Emergency Module provides emergency assistance through transmitting elevated Time to Live data packets to provide quick and wide transmission for emergency responders to respond to emergencies. Sound alerts will activate for devices that receive SOS Emergency signals instead of a silent alert.

4.2.6 Location Sharing Module

The Location Sharing tool will locate the phone by determining the phone's current position and converting the location into a small BLE format before sending to another device to unpack the data and display it on a map.

4.2.7 User Interface (UI)

The type of interface you use will enhance your ability to understand messages, which is why Message Layouts within the application utilizes the Bubble Format. Other types of interface use contrast in colors to assist in the user understanding layout(s) of the application. To send an Alert, you will click on the buttons shown below. Once Alert is received, it will pop-up onto the user's screen immediately within seconds. For Sharing your GPS Location, you can do this with a single tap, and the updates will appear instantaneously on your feed (i.e., in real-time).

4.3 Data Flow

4.3.1 Flow of Data Sequence Chart

There are three types of messages a person can send out: (1) Position Broadcast, (2) Alert Trigger, and (3) Text Message. Once any of these messages is created, it is converted to the JSON format, and it is sent in a BLE Signal. All devices that are within a certain proximity to the signal will pick up and read it, and as a result, the relevant information will be extracted. Additionally, if the same Alert message has already been sent out, it will not be re-sent unless a new Alert message has been created. All new Alert messages will be sent out using a shorter Time to Live (TTL), whereas any Alert messages that have previously been sent out will be sent out without a timeout (i.e., not re-sent). On the other hand, if a new Alert message is created and sent out using the TTL, it will appear during transmission as low TTL, but it will not be sent out again as a duplicate Alert message once a new Alert is created and sent out.

Within the system, there is an internal component that stores message IDs (Message Cache) to prevent duplicate messages from being processed. The message cache is also responsible for providing a basis for preventing messages from looping based on a simple flag setup. Additionally, the system stores information about previously located neighbour devices in the form of Node Tables. The presence of a node table enables the connection to remain stable without requiring repeated rescanning of neighbours.

4.4 Sequence Design

4.4.1 Message Transmission Sequence

Once a user enters a message, it is transmitted at the speed of light after being formatted into a clean JSON format and prepared for transmission via Bluetooth Low Energy (BLE). Devices receiving the message pick up the signal immediately, allowing them to check whether or not they have received the same data previously. As long as the Time to Live (TTL) value remains greater than zero, the Jump Counter of the receiving device will increment by one. The information received will be presented in the expected format.

4.4.2 SOS Broadcast Sequence

SOS messages are formatted in the same manner as regular messages; however, they are transmitted using the full network bandwidth and therefore have an increased urgency. The SOS message is transmitted with a unique identifier, which allows devices to differentiate SOS messages from standard messages and to issue immediate alerts to the user at the time of receipt. The SOS signal is transmitted in a nanosecond frame time window, allowing for greater flexibility with respect to timing, thus allowing for faster transmission of SOS messages than would be possible with a standard message format.

4.4.3 Location Sharing

A device tracks a user's location in real-time through its internal GPS-based sensor as soon as location sharing is turned on. The device then takes this location information and generates a Bluetooth Low Energy (BLE) signal, sending it wirelessly to nearby devices that are also journeying (temporarily). The other devices receive the BLE signal and, as soon as they have done so, have the ability to decode the location data received into their own data bases. Additionally, these nearby devices can present this location information to the users with a demonstration of where the user is currently located, via a mapping application. Many of these mapping applications provide an alternative means of displaying the user's location as well as additional useful information about the user (for example: current speed).

4.5 Class Structure

4.5.1 Principal Classes

The application features sets of principal classes that handle process functionality related to the overall application. For example, Implementing the BLEManager class allows the application to find and manage devices and provide methods for identifying/broadcasting signal Enable/Disable with their associated Bluetooth Link (BLE) connectivity. The Message Packet class manages how the application sends and processes messages (including location) with other devices. The Mesh Forwarder class identifies the optimal route to take, using the Packet route selected by the User (not needed for every message). Node Discovery allows the application to identify new devices in the application and keep track of the devices currently available. The ability to retrieve device location information will be available through the LocationService class via GPS and aggregated information sent to each device based on its location data. SOSHandler receives information related to emergency Alerts created, via the Alarm functionality through the UIController class and updates device messages accordingly every time there is a new Alert.

4.5.2 Primary Class Attributes

In an overarching system's larger context, the classes listed above serve to enable the operation of the principal components of each class. Each message sent is assigned a unique identifier to facilitate its tracking; while each message captures its own respective data as well as an identifier or Origin for each sender. Time stamps are embedded within each signal sent and received, thus allowing the recipient to determine precisely when the signal was generated or transmitted. Unlike words that may live forever, every unit contains a TTL value to restrict the maximum distance travelled. The message type defines the nature of the communication between parties.

4.5.3 Core Methods

startSearch scans for devices that are close to it, while announceHere allows another device to find it. The method formatInfo allows you to format raw signal details into a shareable format, and uses the incoming signal to convert the signal into a format that can be shared, and, if the signal has multiple pieces, splitIncoming divides the incoming signal into pieces that are small enough to work on. The perhapsAlreadyMet method identifies whether the incoming signal corresponds to one seen before, otherwise the signal is passed on by moveForward. The last method is updateScreen, which will refresh the user interface with the most recent data.

4.6 Lifecycle of the Message

4.6.1 Creation Stage

During configuration, the user creates the initial message directly in the application. The data is transformed into the standardised format (JSON) at this point. The type of message and the maximum distance it will travel is critical; therefore, the system will select a TTL based on these factors.

4.6.2 Broadcast Stage

Once a message has been created and is ready to be sent, the message is sent immediately (via BLE advertisements), and because BLE advertisements can be received quickly by nearby devices (without the need to establish any connections), the transmission of messages occurs smoothly.

4.6.3 Relay Stage

In the relay stage, each middle node first checks to see if it has received a duplicate of the packet. If it does not recognize the packet as being previously received, it forwards the packet to another neighbor that is within range of receiving it. The TTL for the packet decreases by 1 each time it is forwarded by an additional hop.

4.6.4 Delivery Stage

Messages are not visible (i.e., cannot be read) until they have been delivered to the intended recipient. After the specified amount of time has passed since the initial receipt of the message, the message will no longer be deliverable.

4.7 User Interface Design

4.7.1 Chat Window

Messages appear in chronological order from top to bottom with the sender of the message and the time stamp next to it; each message also has an indicator of what type of message it is. There is a slight time-lag in receiving messages based on the type of connection being used (i.e. whether the message was sent via text, voice or file), so the chat windows include a label next to each message bubble displaying whether the message is text, voice or file. The labels provide further clarification of the type of messages being sent and help users to keep track of the conversation flow without any confusion.

4.7.2 Control Panel

The control panel may be used to send messages, activate alerts, and send location information. The text messaging function of the control panel utilises a single function, while the alert functions are under a separate module; in addition, the location data may also be sent separately.

4.7.3 SOS UI Elements

The alerts will flash red and shake the phone; visually placed in such a way that you are likely to see them immediately.

4.7.4 Location Message User Interface

A clearly defined view of the accurate and correct quantity of items stored within each layer allows for more efficient verification by a user and enables a quicker pass-off to the Google Maps application once they are ready.

4.7.5 Network Indicator

Indicates the proximity of nearby devices by showing how close to a full-strength connection the Bluetooth low-energy (BLE) connection currently exists. Higher connection strength indicates stable connections between nearby devices.

4.8 Design Constraints

4.8.1 BLE Packet Size

BLE advertising packets are limited to approximately 31 bytes, therefore using JSON data must be as compact as possible; using compression techniques will eliminate exceeding the maximum BLE advertising packet size.

4.8.2 Restrictions Due to Android Operating System

Your app must operate continually to maintain BLE tasks from decreasing in response time. Using only background checks will not maintain the response time.

4.8.3 Environmental Conditions

BLE transmission signals are easily obstructed by wood or concrete walls, while the presence of individuals (especially people carrying metallic objects) causes a degradation of BLE signal strength. The signals from Wi-Fi routers also create interference with BLE signals, reducing BLE reliability. The presence of other Bluetooth devices creates additional problems for maintaining a reliable connection with BLE devices.

CHAPTER 5: METHODOLOGY

5.1 Overview of Methodology

First, install the system, then provide access to users based on Restrictions. The next step will be to adjust the Bluetooth (BLE) settings as necessary to ensure proper functionality. Once those settings are completed, perform a search for devices in Close range that support these Connection Types. When devices have been identified, Organise the NODES using a layout diagram to show how the NODES connect to each other. Next, Transmit Data - this Data will be broken down into (N) different parts as soon as Transmission Begins. The Data will move between the NODES through a series of hops across NODES until it reaches its Final Destination. Whenever there is a failure or problem with the Connectivity, the locations of all the NODES will be Re-Freshed immediately after the Loss of Connectivity Occurs. Each time the Connection Changes as a result of External Factors, the Information will be displayed on the Screen. After the Trials, we confirm that all features of the System Operate as Expected. During Each Phase, the System ensures that Bluetooth will connect directly to the Hardware, remain Functional with a Stable Connection, and avoid the chronic limitations associated with using a Cell Phone to Share Information on a Low Capacity Mobile Application.

5.2 System Initialization Process

5.2.1 Launch Process Overview

The Application will Begin by Searching for All Hardware Components (e.g. GPS, Bluetooth, etc.) and you can Determine which version of Android is being run by the user. If Bluetooth is not enabled, the Application will display a message indicating that Bluetooth should be enabled. In order for the BLE Operations to function correctly, certain Supporting Services will be Automatically Started in the Background.

5.2.2 Permissions

At launch, our app will ask for many permissions including but not limited to: BLUETOOTH_SCAN, BLUETOOTH_ADVERTISE, and BLUETOOTH_CONNECT. The app will also need to request permission for Access Fine Location. This is due to limitations imposed by Google starting from Android 12, as detecting BLE devices will only be possible if you have provided all required permissions to the operating system. Each permission will be validated individually on the device, so if you happen to miss one, you will be taken directly to that setting to enable it manually.

5.3 BLE Configuration Methods

5.3.1 Initialization of the BLE Scanner

This setup is designed so that you can run continuously using BLE for scanning with minimal delay. The filters are used to filter only signal types associated with a specific application(s).

Instead of establishing a connection, they will only silently collect information from any devices that may be near them.

5.3.2 Initialization of the BLE Advertiser

The advertiser uses BLE Configuration to advertise packets at intervals between 100 ms and 250 ms. The advertiser sends packets with good signal strength and no active connections but adheres to a set limit of data. The goal of this approach is to provide a long battery life, while the results may vary on the reliability of using this method.

5.4 Node Discovery Methodology

5.4.1 Real-time discovery

In real-time discovery, BLE signals are scanned continuously for devices that are within the range of a current received signal strength (RSSI). When a signal is detected, it is recorded with the date and time of occurrence on the node table. Once all signals have been detected, or all users have sent out their occasional ble signals, the Mesh Network will then use that log to provide the users a real-time overview of what devices may be present in their immediate area.

5.4.2 Node Table maintenance

The Node Table is constantly updated, so all devices seen by users will eventually expire from the node table in approximately 10 - 30 seconds. No device remains on the node table for a length of time greater than what action has taken place in the vicinity of that device. As a user approaches a busy area, the intensity of the links to that area will change.

5.5 Message Construction Approach

5.5.1 Message construction as a JSON object

Each message is an individual object represented in JSON format. Each message has a unique identifier (ID) and contains sender information (name), time stamped (date and time), type of message (i.e., chat, alert, location, etc.), and the time during which the message remains active. The body of the message contains written text and geographic location coordinates related to the user. All field items in the message are defined in the JSON object described above.

5.5.2 TTL

The Time to Live (TTL) represents the maximum number of hops that a packet can take before it is discarded. According to 5.5.1, the average distance for chat data from sender to receiver is between three to five hops. On the other hand, the average distance for location-based data is a little closer - between four to six hops. For urgent alerts, the system will use the highest TTL possible, as long as it is functional.

5.5.3 Message Validation

Messages that are blank will be removed from the send queue before they are forwarded on. After being validated as correct via JSON syntax, the size of the packet will be re-sized to fit within the BLE advertisement size limitations.

5.6 Encoding and Decoding Packets

5.6.1 Encoding

Due to the BLE standard 31-byte advertisement limitation, data will have to be encoded in compressed JSON format as well as having white spaces stripped out of them. JSON formatted data will be processed so that they will fit into BLE advertisement packets. In addition, if necessary, the manufacture-specific section of the packet will be used to carry the encoded data.

5.6.2 Decoding

Once raw data has been received over BLE, the next step is to convert this raw data into text format. Following this, the message is then populated into a JSON format, including both the time when it was sent and who sent it. Should there be any errors resulting from a corrupted packet during translation, the message is simply discarded without notifying the user.

5.7 Multi-hop forwarding methodology

Messages do not usually travel directly between two mobile devices within a BLE Mesh network but rather travel between many different devices until they reach the intended recipient. In this section, we will discuss how messages are forwarded from one device to another in a multi-hop Mesh network so that messages do not get trapped in an infinite forwarding loop.

5.7.1 Duplication detection

In many multi-hop systems, a common issue is that a message may continue to be replicated or loop indefinitely throughout the network unless there are mechanisms in place to prevent this from happening. Therefore, each mobile device maintains a record of message IDs that have already been received, along with their corresponding timestamps, so that duplication of messages can be identified quickly.

When a packet is received by a mobile device:

If the message ID already exists in the device's list of recent messages, then the packet is discarded by the mobile device.

If the message ID does not already exist in the mobile device's recent messages list, then it is processed by the mobile device, and the message ID is added to the mobile device's list of recent messages.

The benefit of this simple action is that it can conserve battery life, minimize prepaid messages, and prevent the network from filling up with obsolete data. Many distributed systems will not reprocess the same task multiple times.

5.7.2 Decrementing The TTL Value

The TTL value is equal to the maximum distance a packet can travel and for every device that forwards the packet, it is reduced by one. Once the packet's TTL value drops to zero, the packet cannot be forwarded anymore. As such, this helps to prevent packets from continuing to transmit forever, especially in networks with many reachable devices.

5.7.3 Forwarding Process

Several conditions must be met in order for a packet to be forwarded by the device:

1. The packet is not a duplicate.
2. The packet's TTL value is greater than zero.
3. The forwarding device is not overloaded, does not have any resource limit issues.

This process ensures that the network continues to function optimally and keeps devices from becoming overburdened with heavy traffic.

Loop-free propagation:
If left unchecked to the mesh network the same packet may potentially loop back to the same source endlessly. Only the duplicate-ID checking along with the TTL (Time-To-Live) monitoring guarantees that the packets will not get stuck in an eternal loop. This combination of functions control and make the method of flooding much more predictable when multiple devices are transmitting at once.

SOS Message Propagation:
Forwarding SOS messages will be much faster and much more aggressive than normal chat messages. When an SOS comes into the system the system will prioritize that particular packet with the highest priority and will work extremely quickly to propagate that packet as far and as fast as possible.

Priority Broadcasting:
Upon Sending an SOS from the user:
The SOS packet is given the highest TTL.
The BLE advertising transmits immediately without queuing.

The SOS packet is marked with "priority" to indicate to all devices that this packet is the highest priority to be processed quickly.

This set of changes allows for the largest area covered in the timeliest manner for emergency alerts compared to normal chat messages.

5.7.4 Loop-Free Propagation

When a message is sent to a number of destinations in a wireless mesh network, it is easy for the same packet to keep returning to the original sender if the wireless system is not properly configured. The mechanism for avoiding this issue is through the use of duplicate-ID checks and an expiration value (TTL). Together, these two mechanisms ensure that the packets are not continuously sent back to the network when many devices are sending messages simultaneously and that the flooding mechanism is predictable and manageable.

5.8 SOS Message Propagation Methodology

An SOS message is expected to be transmitted in a much quicker and more aggressive manner than that of other normal chat message transmissions. In addition, when an SOS is detected by the system, the priority of the packet is given a much higher value and is immediately propagated as quickly as possible.

5.8.1 Priority Broadcasting

When an SOS message is sent, the following actions occur:

Higher TTL value than normal;
BLE advertising does not sit in a queue but is started immediately;
Additionally, the packet is flagged as a "priority packet" and will alert all other devices that the transmitted packet must be handled faster.

These modifications allow SOS messages to propagate further and faster than other standard chat message transmissions

5.8.2 Relay Speeding on Nodes

All devices that receive an SOS packet will act differently than with regular packet traffic.

They will ignore all of the standard throttle limits that the regular packet traffic has.
This packet will also be treated with the highest level of urgency.
In addition, it will have the ability to notify users via follow through the vibrating feature, or via the ringer function of the device.

This is consistent with how emergency broadcast systems operate in the real world, as they require the fastest possible delivery of their messages.

5.8.3 Receiver Behaviour

If a mobile device receives an SOS from a phone:
A full-width, red alert banner will appear to notify the user of the SOS.
The phone will vibrate, which will allow the SOS to get the user's attention.
In some instances, the sender's GPS location can be automatically retrieved.

While sending a small BLE packet for SOS will not provide specific details of an emergency; however, it will allow for the distribution of a relevant and visible warning of an emergency.

5.9 GPS Based Location Sharing Methodology

GPS based method will allow users who are using the mesh to see other user locations. Since BLE packets do not have much information; therefore, they will have to be packed in an efficient manner to fit.

5.9.1 Retrieving Coordinates

When a user opts to share their location, the application makes use of the Android Fused Location Provider to obtain.
The latitude
The longitude
The accuracy
The information is only sent when it has reached an acceptable level of accuracy.

5.9.2 Data Formatting

The coordinates will be transmitted as a compact string:

Latitude (in decimal degrees), Longitude (in decimal degrees)

The compact structure allows the coordinates to fit within the Bluetooth Low Energy (BLE) packet size limit. The data will also travel more efficiently across multiple hops due to being smaller.

5.9.3 Receiving Device Processing

After the coordinates have been sent to another BLE device, they will be:
- Extracted from the BLE message;
- Displayed on the receiving device in a chat window;
- Automatically opened in Google Maps when the user presses on a link or button.

5.10 UI Update Process

The UI has been created to allow for updates for new messages, SOS (emergency) alerts or network connectivity issues in real-time, allowing the user to view the latest data at all times.

5.10.1 Real-Time Chat Feed Update

Incoming messages will automatically update the chat feed to show:
- Date and time sent
- Coloured Coding of Different Types of Messages
- If the message exceeds the limits of the chat window, it will automatically scroll up to show the most recent messages.

In addition to these features, the UI will maintain response time during peak message volume.

5.10.2. SOS User-Interface behavior

In times of emergency: The SOS message will be displayed in a bold red font across the entire width of the display. The device will provide either a vibrating alert or an audible tone when the SOS message is sent. The warning notification will be displayed in the chat panel.

5.10.3. Node Discovery Indicator

To provide insight into the state of the MESH, the user-interface will periodically display:

- The number of devices that have been detected within the user's vicinity;
- The approximate signal strength of each device; and
- The variation in the density of the MESH.

5.11 Background Execution Model

The MESH should remain operational whether the application has been minimized or closed, but due to the many limitations placed by Android on the operation of background processes, a number of techniques have been used to ensure that MESH operations remain consistent and reliable.

5.11.1 Foreground Services

BLE scanning and advertising are the functions of a permanent foreground service as required by Android. This service will show a small notification on the device at all times which helps with maintaining the functionality of the mesh while in motion.

5.11.2 Battery Optimization Management

Because Android will shut down the background processes of applications to conserve power, the application will.Voice Note will request the user to disable the battery optimization on the device. The application will attempt to change the intervals it scans for new devices whenever possible to minimize battery drain. If for some reason the application stops functioning because the Android operating system closes the foreground service, it will automatically reconnect to the recently closed service.

This feature allows the application to continue providing reliable service without putting a strain on the user's battery.

5.12 Testing/Validation Methodology

Different configurations were set up and tested in several environments to evaluate the application's ability to meet users' expectation of messaging, SOS behaviour, and GPS sharing functionality.

5.12.1 Functional Testing

The following tests have been completed for the following reasons:
To confirm correct delivery of chat messages.
Elimination of duplicate packets from being forwarded.
To verify that the TTL (Time To Live) is being properly handled.
To ensure that SOS data is given a higher priority than other traffic.
To confirm that location information is being properly decoded.

The above tests demonstrate that the primary functions of the mesh network are operating correctly.

5.12.2 Testing Environment

The test environment was based on real-life locations, which were categorized as follows:
Open spaces in the outdoors.
Indoor areas containing obstacles.
Work environment with a medium level of activity.

Among the metrics that were evaluated were delay time, reliability of hops, and packet loss rates.

5.12.3 Multi-Hop Evaluation

This portion of the testing involved evaluating the network when multiple hops were used to verify its ability to work as expected. Examples of the tested scenarios are as follows:
A direct connection between two nodes (two-point);
A longer connection with two to five nodes (three-point);
Powering mobile devices while in motion while transferring data.

The results of this section of testing show that the forwarding across hops is consistent, which is in line with what is expected from the TTL.

CHAPTER 6: CONCLUSION AND FUTURE WORK

6.1 Summary

The project proposed that BLE Mesh Networks can be created between any combination of BLE-enabled smartphones. The off-line communications layer that keeps them connected, no matter where they are, is established by utilizing controlled flooding, duplicate elimination, and TTL-based routing methodologies. A final network implementation includes:

- Multi-hop transmission;
- SOS messaging;
- GPS-based location sharing;
- Real-time User Interface (UI) updates; and
- Continual background BLE activity of the device.

The initial round of testing proved to be successful in practical situations with the devices demonstrating low energy consumption and maintaining the confidentiality of users. This will be critical in times of emergency as it serves those in rural locations or large gatherings.

6.2 Future Improvements

Some future improvements that will be necessary are:

1.Security Enhancements: Encryption, Authentication, BLE support, and extended advertising so that larger secure packet transmissions can occur.
2. Enhanced Data Support: Sending of small images, short audio recordings, or segmented transfers of BLE file information.
3. Intelligent Routing: Using machine learning to determine the best relay option or adaptive TTL to alleviate congestion during transmission.
4. Better Visualization: Improve user interface designs to show how the mesh network is built and where the hops are located within the network and to display reliability levels.
5. Cross-Platform: Expanding compatibility with Ios, Wearables and Internet-of-Things devices.
6. **Smart Scanning & Intelligent Routing:** How to operate with future Android limitations on background activity.
7. Large Scale Testing: Conduct testing on a network comprised of thirty (30) or more unique devices in a highly disturbed environment such as a stadium.

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