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Enhanced Campus Communication Hub Through Wi-Fi Optimization and Emergency Earthquake Notifier (ECHOER)

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Abstract: *This research focuses on the development of the ECHOER system, a Wi-Fi-Based Paging System designed to improve campus communication and emergency notification within the Hinang Hall at Caraga State University (CSU). Addressing inefficiencies in traditional methods, the ECHOER system integrates Wi-Fi and IoT technologies, featuring a three-node paging framework and earthquake sensing capabilities for seismic events of magnitude 4.5 and above. Comprising a transmitter at the Engineering department and receivers in specific labs, all managed via a Visual Studio and C#-developed centralized dashboard, the system ensures real-time data transmission with Google Firebase. Testing confirmed significant enhancements in communication efficiency, maintaining latency within 3-4 seconds and surpassing the 150-meter range requirement. Despite minor technical challenges, ECHOER represents a scalable, portable, and cost-effective communication solution, with recommendations for further improvements such as VoIP integration and power supply optimization.*

Keywords: Wi-Fi Based Paging System, IoT Technology, Earthquake Detection, Real-Time

1. INTRODUCTION

According to John [1] in a journal titled Internet of Things (IoT): Systems and Applications, wireless paging systems have transformed organizational communication, replacing traditional wired methods with efficient alternatives. This study focuses on two key technologies: Wi-Fi and the Internet of Things (IoT). While other wireless technologies are also available like the Wireless Sensor Networks (WSN) [2], the researchers believes that Wi-Fi based paging systems are suitable to use in this study since they leverage existing infrastructure, utilizing Access Points (APs) for signal transmission, Paging Servers for message management, and Paging Devices for reception. These systems offer scalability and cost-effectiveness yet are limited by range and susceptibility to interference. Conversely, Ashton [3] finds that IoT-based paging systems capitalize on IoT connectivity, providing advanced features like real-time location tracking and multi-channel communication, though implementation complexity and higher costs are considerations. Ensuring robust security measures is crucial to safeguard sensitive data within IoT networks.

In educational institutions, efficient communication systems are essential for conveying information to students, faculty, and staff. Traditional paging systems, such as numeric pagers, have long been employed for this purpose [4]. However, with the advent of Wi-Fi-based paging systems, educators have gained access to powerful tools for managing campus and district-wide communications [5]. These types of systems offer enhanced capabilities that transcend the limitations of numeric pagers, such as their one-way communication, simple numeric-only messages, and restricted coverage. In contrast, Wi-Fi-based pagers provide two-way communication, rich multimedia capabilities, and broader coverage but depend on Wi-Fi availability and robust security.

In the Engineering Department of Caraga State University (CSU), a critical issue that has persisted is the absence of an effective paging system, creating notable communication gaps. Historically, the campus has lacked a robust mechanism for disseminating important messages, resulting in inefficiencies and hindrances to smooth operations within the department. Furthermore, the existing communication systems at CSU have historically struggled with inefficiencies, causing delays and miscommunications that have impacted various activities within the Engineering Department.

During emergency situations, the absence of an optimized communication system has led to delays in alerting and coordinating responders. This historical challenge has posed risks to the safety and well-being of the campus community within the Engineering Department at CSU. Technological advancements play a crucial role in information dissemination and life-saving measures. For instance, a customizable Wi-Fi-Based Paging System integrated with sensors has the potential to detect and alert people during calamities such as earthquakes.

This study focuses on the convergence of IoT Technology and smart paging systems, with the aim of developing a Wi-Fi-Based Paging System tailored to the specific needs of educational institutions, specifically at the CSU, Hinang Hall. By combining the scalable, portable, and customizable features of IoT with the capabilities of smart paging systems, this research seeks to offer the university an advanced solution for effective communication and emergency earthquake notifier for students, faculty, and staff. The proposed system aims to replace traditional numeric paging methods, bringing forth efficiency and effectiveness in communication [6].

Moreover, in the words of Schwartz [7], the integration of Wi-Fi-Based Paging System holds the promise of enhancing emergency notifier and convenience, while reinforcing the broader benefits of intelligent communication systems. This amalgamation of technologies could potentially streamline communication and provide an innovative means to connect with various stakeholders within an educational institution.

2. LITERATURE REVIEW

2.1 Paging Systems

Paging systems revolutionize wireless communication by efficiently delivering concise messages or alerts to designated individuals equipped with specialized receiving devices. These systems offer a sophisticated alternative to outdated methods such as manual paging devices or traditional public address systems, facilitating targeted communication within defined geographical areas. Traditionally reliant on dedicated radio networks, modern paging solutions harness the advancements in wireless technologies, notably Wi-Fi and the Internet of Things (IoT). Integrating Wi-Fi infrastructure and IoT connectivity, contemporary paging systems boast enhanced functionalities and extended coverage areas. Leveraging these innovations, they provide versatile communication capabilities, catering to diverse organizational needs with efficiency and precision [7].

2.2 Wi-Fi-Based Wireless Paging Systems

Wi-Fi-based wireless paging systems have emerged as a prevalent communication tool across diverse organizational settings, offering a convenient and efficient means to reach designated individuals. Leveraging existing Wi-Fi infrastructure, these systems present a cost-effective and readily deployable solution compared to traditional paging methods. Core components include strategically placed Access Points (APs) for signal transmission, central Paging Servers managing user accounts and message delivery, and portable Paging Devices for message reception. Their advantages encompass scalability, cost-effectiveness, and robust security ensured by modern Wi-Fi encryption protocols.

According to Dash, D. B. et al. [8], evolutionary strides in Wi-Fi-based paging systems have yielded notable advancements. These include improved range and coverage capabilities facilitated by advancements in Wi-Fi technologies such as mesh networking and high-power access points. Furthermore, enhanced security features, encompassing robust encryption protocols and authentication mechanisms, fortify data integrity within the network. Moreover, modern Wi-Fi-based paging systems often integrate seamlessly with other communication platforms like VoIP systems, enabling multi-channel communication through a unified device.

2.3 Proposed System

The authors examined the landscape of Wi-Fi-based and wireless paging systems, elucidating their functionalities, advancements, and potential limitations. Notable advancements include extended transmission ranges facilitated by mesh networking and high-power access points, alongside latency reduction techniques like QoS prioritization. While existing studies have explored diverse paging system designs and applications [9-11], ongoing optimization efforts and the integration of advanced features remain imperative, as indicated in prior researches and technologies [12-14]. Building upon these insights, the proposed system, ECHOER (Enhanced Communication Hub Through Wi-Fi Optimization and Emergency Earthquake Notifier), aims to address key advancements, including enhanced transmission range, real-time latency prioritization, and emergency earthquake notification mechanisms, tailored specifically for the Electronics Engineering Offices at CSU. Through these targeted enhancements, ECHOER endeavors to offer a robust and reliable Wi-Fi-based paging system, equipped with advanced communication capabilities and real-time emergency notification functionalities tailored to the university's environment.

The proposed ECHOER system was evaluated for its efficiency and cost-effectiveness compared to existing systems in terms of wireless capabilities, emergency alarms, and paging functions within CSU. In terms of wireless capabilities, the use of Wi-Fi technology provided significant advantages over LoRaWAN and RF technologies. Wi-Fi offered higher data rates, greater bandwidth, and seamless integration with the existing network infrastructure at CSU, making it ideal for applications requiring robust and real-time communication. Additionally, advanced Wi-Fi systems employed mesh networking, which extended coverage and enhanced network reliability by using multiple access points to relay signals, creating a broader and more resilient network that could easily cover the campus. As the study of Jye et al. [15] emphasizes the importance of safety, disaster warning and prevention, the ECHOER system also integrated earthquake alarm functionalities, addressing critical gaps present in the current safety systems at CSU, which did not include dedicated earthquake alarms. This integration meant that ECHOER could provide comprehensive emergency notification capabilities, ensuring that seismic events with a magnitude of 4.5 and above were detected and responded to promptly. The system's ability to sense and respond to earthquakes was a significant enhancement, providing real-time alerts facilitated by Wi-Fi's low-latency capabilities. This capability was crucial for minimizing notification time during emergencies, something that traditional alarm systems, which lacked earthquake detection, could not achieve.

Compared to Android-based emergency alarm systems, ECHOER's dedicated infrastructure ensured higher reliability and quicker alert delivery. Android-based systems, although cost-effective and accessible, depended on user devices being charged, connected to the network, and within reach, which could be unreliable during emergencies. In contrast, ECHOER's use of dedicated hardware components ensured consistent performance and reliability, overcoming these limitations.

Moreover, ECHOER's use of affordable, readily available components offered a cost-effective solution compared to expensive commercial paging systems. Commercial systems from manufacturers like Bogen and Valcom, while feature-rich, often came with high upfront costs and included functionalities that might not be necessary for CSU's specific needs. ECHOER's approach allowed for customization and scalability according to specific requirements and budget constraints, making it an economical choice for the university. This flexibility meant that ECHOER could be incrementally upgraded and expanded, unlike commercial systems that typically offered fixed features and capacities.

The comprehensive literature review has delved into various aspects of Paging Systems, focusing on Wi-Fi Based Wireless Paging Systems, Alarm Systems, and existing research. It provided detailed insights into wireless paging systems in healthcare, LoRaWAN-enabled paging networks, embedded Wi-Fi communication systems, Android-based emergency paging, Fire detection and alarm systems, in-hospital paging, and commercially available systems such as Bogen and Valcom's SIP-Based Paging System. These studies illuminated the technical intricacies, functionalities, limitations, and applications of diverse paging solutions. Addressing the identified communication gap at CSU, the proposed solution aims to develop a Wi-Fi Based Smart Paging System. Uniquely tailored with features such as Emergency Earthquake Notifier, a Transmitter to Receiver Range of at least 150 meters, and Real-time Data transmission latency, this innovative system endeavors to meet CSU's specific communication requisites. Furthermore, it offers a cost-efficient alternative designed for educational institutions, prioritizing simplicity, efficiency, and enhanced communication during critical situations.

3. METHODOLOGY

3.1 System Block Diagram

In Figure 1, the methodology incorporated a comprehensive block diagram illustrating the ECHOER. Positioned on the left side of the diagram was the Espressif32 (ESP32) transmitter, sustained by drawing power from the connected Laptop/PC. Another ESP32 transmitter was used; integrated into this configuration through serial communication was an Arduino Nano which solely focused on the processing of the continuous reading of the integrated MPU6050 Acceleration and Gyroscope Sensor. Utilizing the wireless LAN as the medium for communication, the ESP32 transmitter and ESP32 Earthquake transmitter wirelessly transmitted data to the Firebase server, where the right-side circuit, housing the receiver module, read data from the Firebase server. This receiver unit was independently powered by a separate battery. The AC power supply was responsible for powering the amplifier module, to which the received data from the ESP32 transmitter was routed and audio selection happened through the SD Card. Subsequently, the amplifier module interfaced with the speaker, facilitating audio output for the system. This comprehensive arrangement ensured the wireless transmission of data from the transmitter to the receiver.

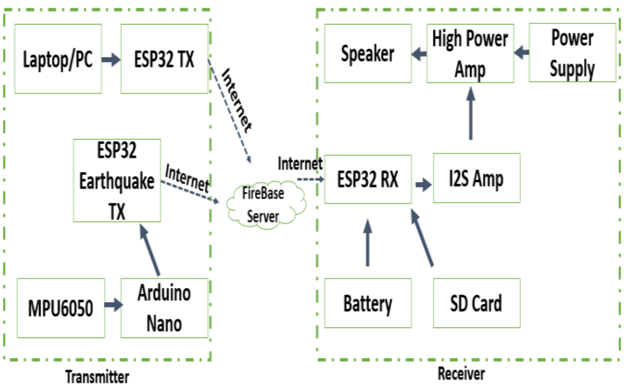

Fig. 1. Block Diagram of the System

3.2 Communication Architecture

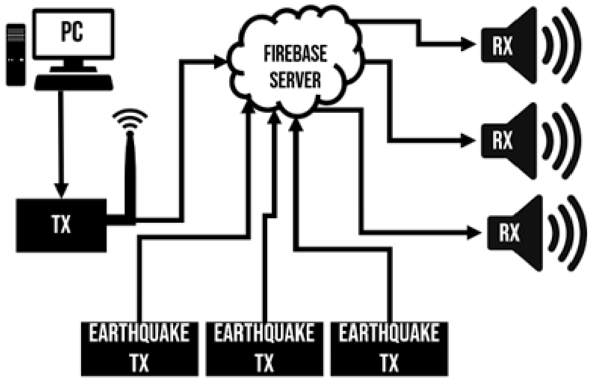

Fig. 2. Communication Structure

The design of the communication architecture depicted in Figure 2 outlines the underlying framework that orchestrated data exchange within the system. This segment details how the ESP32 transmitter and receiver modules interacted via wireless LAN, fostering efficient transmission and reception of audio data. The architecture's blueprint was structured to ensure robust connectivity, enabling the reliable flow of information essential for the system's optimal performance, thereby underscoring its pivotal role in facilitating real-time, wireless audio communication.

3.3 Circuit Assembly

Fig. 3. Circuit Assembly on PCB

After the circuit components were assembled and mounted on the numeric Circuit Boards(PCB), the researchers proceeded with the integration phase of the project as seen in Figure 3. This step involves the interconnection of the various components according to the circuit design and ensuring proper soldering to establish electrical connections. Each component was positioned and secured on the PCBs as per the layout plan to optimize space utilization and facilitate efficient operation. Additionally, the researchers conducted thorough testing procedures to verify the functionality and performance of the integrated circuits, addressing any issues or discrepancies encountered during the assembly process.

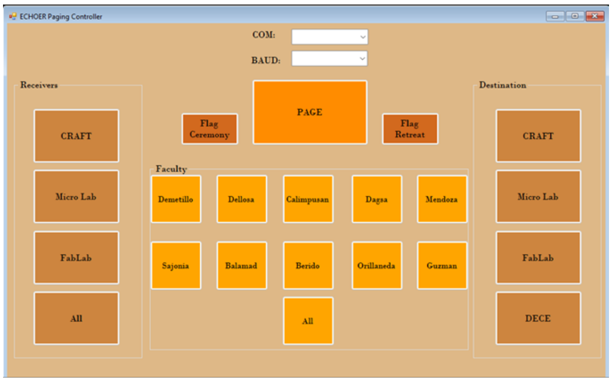

Fig. 4. Graphical User Interface (GUI) of the System

The researchers employed Visual Studio to craft a dashboard or Graphical User Interface (GUI) (seen in Figure 4) using the .NET framework and C#, facilitating the transmission of characters based on button clicks. These characters underwent serial communication to the ESP32, where they were converted into integer values according to predefined conditions. Upon pressing the "page" button, a character was dispatched to trigger the summation of all integer values, subsequently relayed to the Firebase server. Upon reception, the receiver decoded the integer values via a parsing algorithm, correlating them with pre-recorded audio assignments. Furthermore, when audio played, a loop counter initiated, incrementing after each cycle. Once the loop counter equaled 3, data in Firebase automatically reset to 0, halting the loop. Additionally, three earthquake sensors, placed in different locations, transmitted a binary 1 to Firebase when the threshold exceeded 0.8m/s². When all sensors reported 1, an alarm audio played, mirroring the paging code. Upon reaching 3 loops, the system rewrote Firebase data to 0, ceasing the loop.

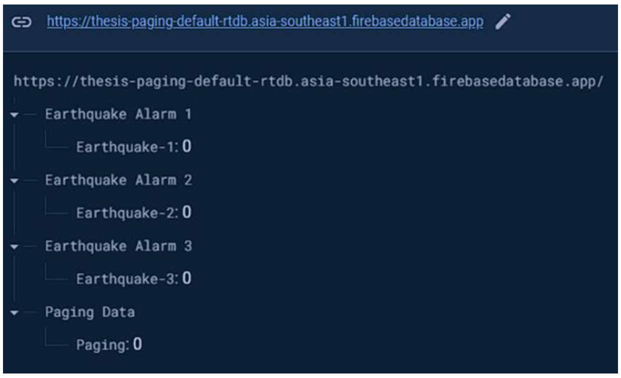

Fig. 5. Firebase Server

Also, Firebase (Figure 5) served as the designated cloud server, facilitating the reception and storage of data transmitted from the ECHOER system. Its robust infrastructure and seamless integration capabilities allowed for efficient handling of incoming data streams, ensuring reliability and scalability in data storage. By leveraging Firebase's cloud-based platform, the ECHOER system could securely transmit data in real-time, enabling seamless communication between the transmitter, receiver, and earthquake sensing devices. Additionally, Firebase's array of features, including real-time database management and authentication services, provided the necessary framework for managing and accessing data remotely, further enhancing the functionality and accessibility of the ECHOER system. The secure nature of Firebase ensured that sensitive data transmitted by the ECHOER system remained protected, mitigating risks associated with unauthorized access or data breaches.

Fig. 6. Developed System with Enclosures

Finally, the researchers integrated the systems inside an acrylic chassis as seen in Figure 6. The transmitter's component consumes less space since it only requires an ESP32. While the Receiver is quadruple the Transmitters size.

4. RESULTS AND DISCUSSIONS

4.1 Audio Testing

During audio testing, the system successfully processed 8-bit, 16kHz, unsigned 8 PCM format WAV files, but encountered clarity issues. Converting the same WAV file to 16-bit, 44.1kHz, signed 16 LE PCM format resulted in increased noise due to higher specifications. Attempts to use MP3 files yielded poor quality output with excessive noise. To address these challenges, an I2S audio recorder was developed.

The I2S recorder used INMP441 MEMS microphones. The INMP441 MEMS microphone by TDK InvenSense, operating at 1.8V to 3.3V [28], offers adaptable voltage and current consumption, with an I²S interface ensuring efficient data transmission. With a SNR of 61dBA , sensitivity of -26dB (TDK Invensense, 2020), and frequency response of 60Hz to 15kHz, it captures a wide range of audio frequencies essential for the paging system. Implementation of a basic RC filter circuit further enhances performance by minimizing noise interference. The ESP32-WROOM-32U was chosen for its higher frequency and superior I2S capabilities compared to Arduino, supporting 16-bit, 44.1kHz audio recording (Art of Circuits, 2014). An SD card module stores recorded audio files for playback on the receiver. Configured for 16-bit, 44.1kHz, signed 16 LE PCM format, and utilizing .raw file format, the recorder produced clearer audio output. However, some noise persisted, likely attributed to the power source of the controller and amplifier.

4.2 Earthquake Notifier Testing

The Earthquake Sensing Device underwent testing by applying a slight force, ensuring that the acceleration remained below the threshold of 0.8 m/s^2. This initial test yielded negative results, with no data transmission to the server. However, a slightly stronger force resulted in the immediate transmission of a Boolean data signal of 1 to the server. To mitigate the risk of false positives, three devices were deployed, each with a high threshold of 0.8 m/s^2. The logic dictates that an alarm will only be triggered if all three devices are activated simultaneously. This approach helps prevent false alarms caused by minor disturbances, such as incidental contact or passing vehicles. Additionally, both the transmitter and receiver underwent 30 rounds of testing to determine average transmission and response times.

The earthquake sensing system demonstrated impressive performance in both data transmission to Firebase and alarm response times. The system was capable of sending data to Firebase in under a second, with an average transmission time of 0.67 seconds across all tests. This swift transmission ensures that seismic activity data is promptly relayed to the cloud server for further processing and dissemination.

Moreover, the system exhibited rapid alarm response times when triggered by seismic events. The receiver successfully responded to the alarm signal from Firebase in an average time of 1.11 seconds. This means that upon detection of seismic activity and data transmission to Firebase, the alarm was triggered and relayed to the receiver in under 3 seconds, well within the acceptable latency range for early warning alarms, which typically ranges from 3 to 5 seconds.

The sub-second data transmission and alarm response times highlight the system's efficiency and effectiveness in providing timely alerts for seismic events. Such rapid response capabilities are crucial for early warning systems, as they enable prompt action and mitigation measures to be implemented, potentially reducing the impact of earthquakes on infrastructure and human safety.

Overall, the earthquake sensing system's performance in data transmission and alarm response underscores its reliability and suitability for real-world applications requiring rapid detection and notification of seismic activity.

4.3 Latency Testing

Table 1. Total Paging Time(in seconds) from Transmission to Receiving

Test No.	Wi-Fi Router	PC Hotspot	Cell Phone Hotspot
1	1.65	5.03	4.72
2	1.89	3.45	3.66
3	1.72	3.24	5.61
4	1.69	3.15	2.86
5	1.50	3.02	3.05
6	1.89	3.85	3.06
7	1.51	3.28	3.05
8	1.65	3.36	3.39
9	1.58	3.54	3.11
10	1.52	3.54	2.99
Average	1.60	3.272	3.36

Latency measurements were conducted to evaluate the efficiency of data transmission and reception for each connection type. The results in Table 1 indicated that the Wi-Fi Router exhibited the lowest latency, meaning that data packets were transmitted and received more quickly compared to the other two options. This low latency is crucial for applications that demand real-time data exchange, such as emergency response systems and live communication platforms. Conversely, the PC Hotspot and Cell Phone Hotspot, while convenient for on-the-go connectivity, showed higher latency and lower overall speeds. These limitations make them less suitable for tasks that require instantaneous data transfer and minimal delays. The findings from this analysis underscore the critical role of selecting an appropriate internet connection based on specific performance requirements, with the Wi-Fi Router emerging as the optimal choice for applications that necessitate high-speed and low-latency connections.

4.4 Cost Evaluation

Table 2. Cost Evaluation

System Type	Cost per Set
1 Proposed System	$155
2 Numeric Pagers	$45 - $175
3 Wi-Fi Based Pagers	$450 - $2,040

The proposed system has an approximate cost of about $155. Based on online pricing [5] [14] [16], some numeric pagers are cheaper but do not have the full capabilities of the proposed system. On the other hand, Wi-Fi-based pagers, which have capabilities almost on par with the proposed system, are seen to be much more expensive based on market data. Therefore, the proposed system is advantageous as it is both cheaper and has capabilities comparable to commercial options.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

The ECHOER system successfully met its objectives by providing enhanced functionality and reliability in campus communication and emergency earthquake response. The inclusion of earthquake sensing devices, which were fine-tuned to prevent false positives by setting a threshold of 0.8 m/s^2 and deploying three sensors per location, ensured accurate detection of seismic activity. The centralized dashboard control and the use of IoT technologies for data transmission and reception contributed to the system’s robust performance. Despite encountering some technical challenges, the system demonstrated significant improvements in real-time communication where the latency, despite an internet speed of 3Mbps, could still manage to send and receive data below an average of 3-4 seconds which fits in the range for real-time which is 30 seconds - 1 minute. In addition, the range for the device surpassed the 150-meter requirement due to the use of IoT Technology where a device can receive anywhere with internet connection.

The ECHOER system was meticulously designed to enhance campus communication and address emergency earthquake response needs within the electronics engineering department at CSU. It comprised a transmitter stationed at the DECE department and receivers for specific offices such as CRAFT, Fab Lab, and Micro Lab, equipped with earthquake sensing devices to ensure reliable response during seismic events.

The system featured a centralized dashboard control developed using Visual Studio and C#, and prioritized audio clarity through a sophisticated setup using a 16-bit 44.1kHz audio format and an i2s recorder. Leveraging IoT technologies and Google Firebase as a cloud server, the system exceeded its initial transmission range expectations of 150 meters. Despite challenges such as intermittent freezing of receivers and a 7-second delay due to Firebase query limitations, the system met real-time transmission and receiving latency requirements.

5.2 Recommendation

To further enhance the ECHOER system, it is recommended to transition to a VoIP system for expanded communication capabilities, providing a broader range of services and more flexible communication options. Additionally, optimizing the power supply could help minimize speaker noise, improving the overall audio quality of the system. Addressing the intermittent freezing of receivers during sensor value fluctuations and reducing the 7-second delay caused by Firebase query limitations should also be prioritized to enhance the system's reliability and performance. These improvements will ensure that the ECHOER system continues to provide robust and reliable emergency response and communication solutions for the university.

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