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Decentralized Mesh Networking

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Abstract

This study delves into the intricacies of decentralized mesh networking, with a specific focus on its implementation within a chat application utilizing WebSocket communication. Departing from the conventional star topology often associated with mesh networks, our approach establishes a decentralized network architecture where ESP32 devices communicate through a central router. Each ESP32 device hosts a WebSocket program, enabling seamless communication among connected devices via a web interface. Our research assesses the feasibility and effectiveness of this approach, addressing challenges such as scalability and network management. Detailed implementation procedures are provided alongside experimental results and discussions on implications for future research and practical deployment. The integration of WebSocket communication enhances the real-time interaction capabilities of the chat application, fostering efficient and instantaneous communication among interconnected devices. Leveraging the capabilities of ESP32 microcontrollers, our implementation exemplifies the potential of Internet of Things (IoT) devices in realizing decentralized networking paradigms. Our method of decentralizing network communication reduces the risk of single points of failure and enhances the overall resilience of the network. Furthermore, the utilization of TCP/IP protocols ensures reliable data transmission across the mesh network, enhancing the robustness of the communication infrastructure. This investigation contributes to the understanding of decentralized mesh networking technologies and their potential applications in facilitating efficient and resilient communication systems. The utilization of ESP32 devices, WebSocket communication, and web interfaces underscores the versatility and adaptability of decentralized networking architectures in various IoT applications. As the IoT ecosystem continues to evolve, decentralized mesh networking presents itself as a promising solution for establishing reliable and scalable communication networks.

Keywords: Decentralized mesh networking, websocket, ESP32, chat application, IoT, router, TCP/IP, web interface

INTRODUCTION

Decentralized mesh networking has emerged as a promising solution in the realm of Internet of Things (IoT) due to its potential to address scalability and reliability challenges inherent in traditional centralized networks. While mesh networks have been widely studied, most implementations rely on a star topology with a central node, which may introduce single points of failure and limit scalability. In this study, we propose a novel approach to decentralized networking using ESP32 devices and WebSocket communication protocol. By distributing communication responsibilities among interconnected nodes, our system aims to enhance robustness and flexibility in dynamic environments.

LITERATURE SURVEY

Prior research in decentralized networking has explored various approaches, including mesh networks, peer-to-peer (P2P) networks, and ad-hoc networks. Mesh networking, in particular, has

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garnered attention for its ability to self-organize and adapt to changing network conditions. However, existing mesh networking implementations often suffer from scalability limitations and reliance on central nodes. Our study builds upon this prior work by introducing a decentralized approach that leverages ESP32 devices and WebSocket communication to facilitate seamless communication between devices, as shown in Table 1.

Table 1. List of Some last year's Literature Review.

Title	Authors	Year	DOI
Network management with semantic descriptions for interoperability on the Internet of Things	Sahlmann [1]	2021	10.25932/publishup-52984
Practical Challenges and Pitfalls of Bluetooth Mesh Data Collection Experiments with Esp-32 Microcontrollers	Marcelo *et al.* [2]	2022	10.48550/arXiv.2211.10696
Performance Validation and Hardware Implementation of BLE Mesh Network by Using ESP-32 Board	Farej and Talab [3]	2023	10.1007/978-981-99-3611-3_27
An Efficient Wireless Sensor Network Based on the ESP-Mesh Protocol for Indoor and Outdoor Air Quality Monitoring	Khan *et al.* [4]	2022	10.3390/su142416630
Wireless Notice Board Using ESP-32	Kaur *et al.* [5]	2023	10.56155/978-81-955020-3-5-13

SYSTEM ARCHITECTURE

The Figure 1 illustrates an ESP32 mesh network implementation, a cutting-edge communication infrastructure. Multiple ESP32 nodes are programmed with the Internet protocol, enabling direct communication using the 2.4 GHz Wi-Fi band. These nodes autonomously form a dynamic hybrid mesh topology through link discovery, eliminating the need for centralized control [6]. One node in the network serves as a web server, hosting a user friendly interface for visualizing the network's topology and status, enhancing user accessibility.

Multi-hop routing is a pivotal feature that empowers nodes beyond direct radio range to relay data packets, expanding the network's coverage and reach. Furthermore, the implementation includes multicast support, enabling one-to-many communication, which is invaluable in scenarios requiring efficient broadcasting of data to multiple nodes simultaneously. To ensure the practicality and reliability of this network design, the Cooja simulator is employed for comprehensive analysis and testing under a variety of scenarios [7]. This simulator provides a controlled environment for evaluating the network's performance, robustness, and adaptability. Ultimately, this ESP32 mesh network implementation represents a resilient and versatile solution for various applications, including those in remote areas or disaster recovery scenarios, where traditional networks may not suffice.

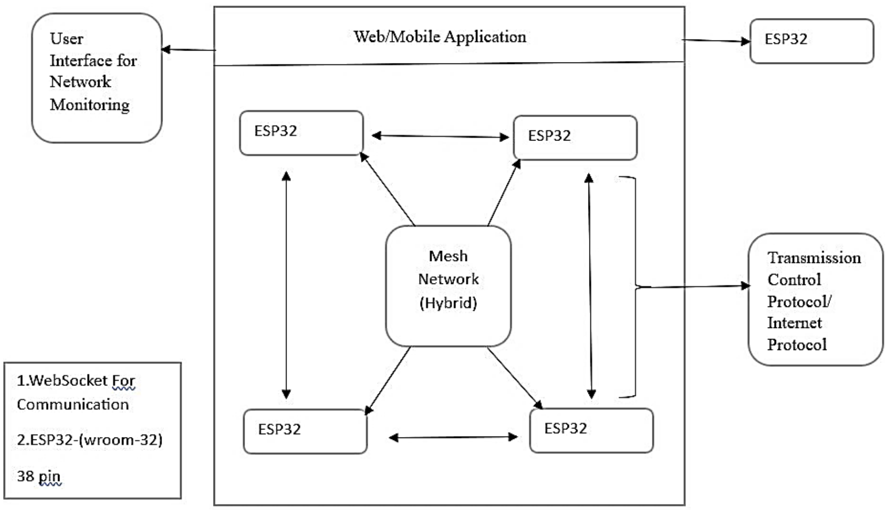

Figure 1. Block diagram of mesh network.

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IMPLEMENTATION DETAILS

The implementation of our decentralized mesh networking solution involves meticulous attention to detail to ensure seamless operation and optimal performance. Each component of the system, including ESP32 devices, router configuration, WebSocket communication, and web interface, requires careful setup and configuration to facilitate effective communication and user interaction [8].

Firstly, the ESP32 devices are programmed to run a WebSocket program that handles communication with other devices in the network. This program utilizes the WebSocket protocol to establish connections with other devices and exchange messages in real-time. Additionally, the program is designed to handle various communication events, such as connection establishment, disconnection, and data transmission, ensuring smooth operation of the mesh network.

Secondly, the router configuration plays a crucial role in providing connectivity to the ESP32 devices and managing IP address assignments. The router is configured to assign static IP addresses to the ESP32 devices, ensuring consistency and reliability in communication. Furthermore, the router's firewall settings are adjusted to allow WebSocket communication, enabling seamless communication between devices within the mesh network [9].

Moreover, the WebSocket communication protocol is implemented to facilitate real-time, full-duplex communication between devices. This protocol is integrated into the ESP32 devices' WebSocket program, enabling efficient data exchange and synchronization between connected devices. Additionally, the WebSocket program includes error handling mechanisms to address potential communication issues and ensure reliable operation of the mesh network.

Lastly, the web interface is designed to provide users with a user-friendly platform to engage in chat conversations. This interface, which is converted into an APK for mobile devices, allows users to connect to the mesh network, view available devices, and exchange messages in real-time [10]. The interface is optimized for mobile devices, ensuring seamless user interaction and optimal performance.

PRACTICAL APPLICATION

College Campus Wireless Mesh Network (WMN) and Announcement System (Figure 2)

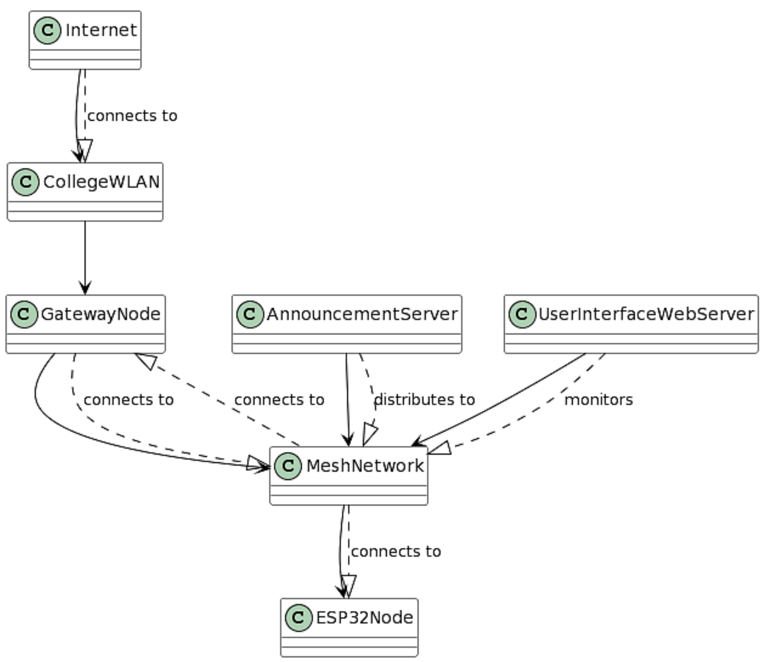

Figure 2. Flowchart of wireless mesh network.

Deploy ESP32 Nodes: Strategically place nodes across the campus. These nodes form a wireless mesh network. They connect to the college's WLAN (Wireless Local Area Network) (Figure 3).

Repeat Announcements: Administrators use a web interface to schedule messages. An announcement server broadcasts these messages to the mesh nodes.

Receive and Store Announcements: ESP32 nodes receive and store these announcements. The announcements can be in *audio or text* format.

Broadcast Announcements: The nodes play the announcements, broadcasting them across the Campus. This ensures that important information reaches students and staff.

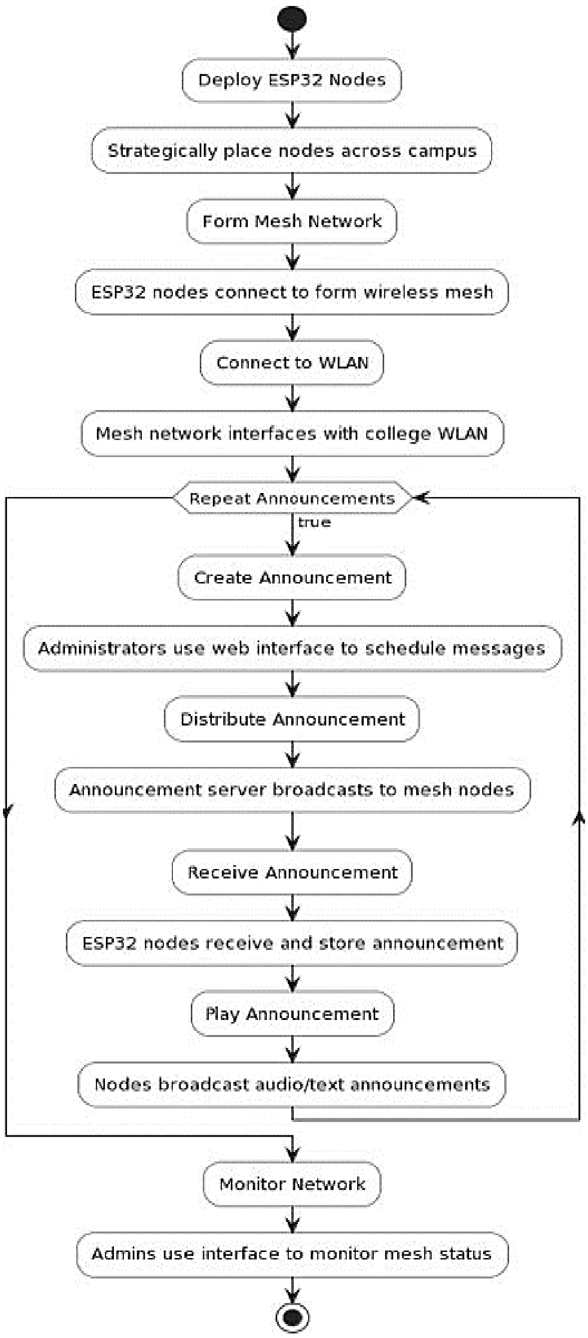

Figure 3. Algorithm.

Monitor Network: Administrators use an interface to *monitor the mesh network's status*. This allows them to ensure smooth communication and troubleshoot any issues.

In conclusion, the flowchart outlines a robust system for efficient announcement distribution using ESP32 nodes within a campus environment.

RESULTS AND DISCUSSION

Simulation Result

A hybrid wireless mesh network using 7 ESP32 nodes as motes were successfully implemented, showcasing self-organization, multi-hop routing, and one-to-many communication. Cooja simulations validated real-world performance, demonstrating topology formation and accurate packet transmission. Key findings include rapid self-organization, successful multi-hop data transmission with a 450 ms end-to-end delay, and effective one-to-many communication. Live network visualization provided real-time monitoring. The project validated WMN capabilities through practical and simulation-based approaches, offering insights for future enhancements such as integrating routing protocols, IoT applications, and security measures (Figures 4–7).

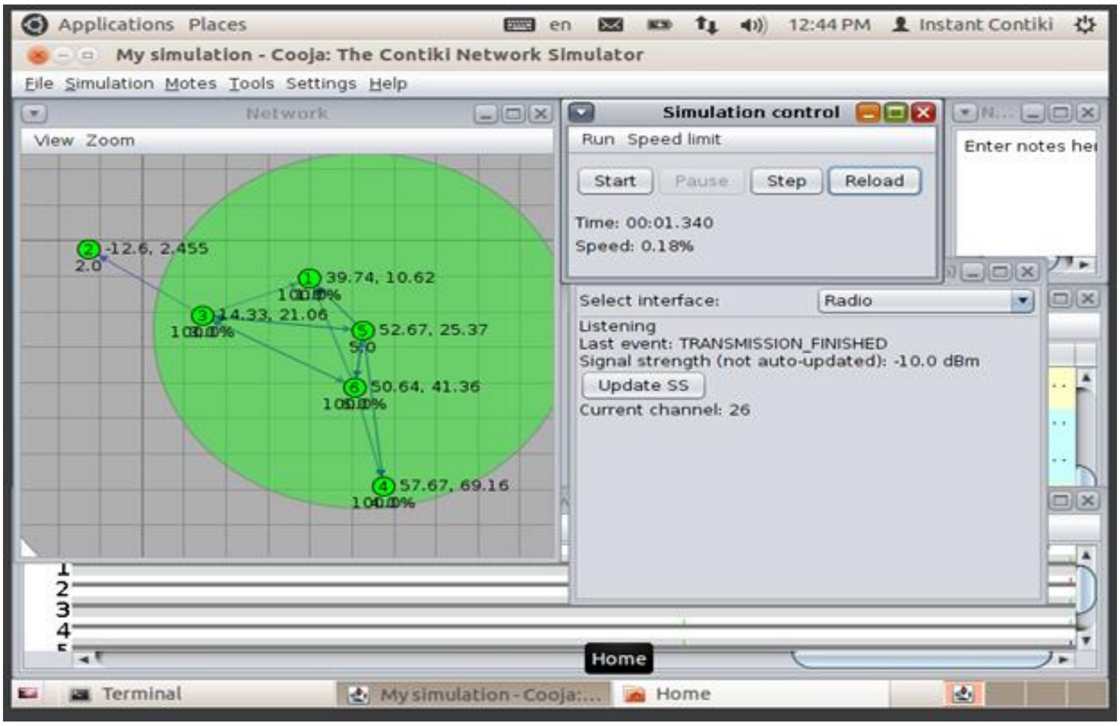

Figure 4. Result of Simulation.

Figure 5. Hardware Setup.

Figure 6. App Interface (connecting).

Figure 7. App Interface (Connected and In-Use).

DISCUSSION

The discussion section delves into the implications of our findings, explores potential challenges and limitations of our decentralized mesh networking solution, and outlines future research directions and practical applications.

1. *Implications of Findings:* Our research findings demonstrate the feasibility and effectiveness of decentralized mesh networking using WebSocket communication for facilitating real-time communication among IoT devices. By distributing communication responsibilities among interconnected nodes, our solution offers greater resilience and scalability compared to centralized architectures, with implications for various IoT applications such as smart homes, industrial automation, and smart cities. Our experimental evaluation highlights low message delivery latency and high network throughput, underscoring the potential of decentralized mesh networking for supporting real-time applications and accommodating increasing data traffic, particularly in areas like remote monitoring, asset tracking, and collaborative robotics, where timely data exchange is crucial for decision-making and control.
2. *Challenges and Limitations:* (1) Network management complexities in large-scale deployments. (2) Security concerns due to distributed nature, requiring standardized protocols. (3) Interoperability issues when integrating with existing infrastructure.
3. *Future Research Directions:* Our research suggests several avenues for future exploration in decentralized mesh networking. Firstly, optimizing network management algorithms and protocols can improve scalability, reliability, and energy efficiency, while enhancing robustness in dynamic environments. Secondly, enhancing security and privacy through tailored communication protocols, authentication mechanisms, and blockchain-based solutions is crucial for mitigating threats and ensuring data integrity. Lastly, exploring novel applications like decentralized edge computing, collaborative sensing, and distributed autonomous systems can leverage the resilience of decentralized networks to innovate across domains such as healthcare, transportation, and environmental monitoring.
4. *Practical Applications:* Our research on decentralized mesh networking presents practical implications across diverse industries. In smart cities, it enables real-time communication among IoT devices, enhancing traffic management, environmental monitoring, and public safety. In industrial automation, it enhances resilience and flexibility, optimizing production processes through real-time monitoring and control. Additionally, in healthcare, it supports critical real-time communication for remote patient monitoring, telemedicine, and emergency response. Moreover, in environmental monitoring, it enables collaborative sensing for real-time assessment of air and water quality, as well as biodiversity in urban and rural areas.

In conclusion, the discussion section highlights the implications of our findings for decentralized networking and IoT applications, explores challenges and limitations, outlines future research directions, and discusses practical applications in various domains. By addressing these considerations, our research contributes to the advancement of decentralized networking technologies and their practical deployment in real-world scenarios.

CONCLUSION

In conclusion, our study contributes to the advancement of decentralized networking technologies and their practical deployment in IoT applications. By demonstrating the feasibility and effectiveness of decentralized mesh networking with WebSocket communication, we provide valuable insights into the technical aspects, performance characteristics, and practical implications of decentralized networking solutions. Our findings pave the way for future research and innovation in decentralized networking and IoT applications, driving advancements in smart cities, industrial automation, healthcare, and environmental monitoring.

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Sincerely,
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REFERENCES

1. Sahlmann K. Network management with semantic descriptions for interoperability on the Internet of Things. Doctoral dissertation. Germany: Universität Potsdam; 2021. Available from https://publishup.uni-potsdam.de/frontdoor/index/index/docId/52984
2. de Souza BJ, Lamenza TD, Endler M. Practical Challenges And Pitfalls Of Bluetooth Mesh Data Collection Experiments With Esp-32 Microcontrollers. arXiv preprint arXiv:2211.10696. 2022 Nov 19.
3. Farej ZK, Talab AW. Performance Validation and Hardware Implementation of a BLE Mesh Network by Using ESP-32 Board. In International Conference on Mathematical Modeling and Computational Science. 2023 Feb 23; 331–343. Singapore: Springer Nature Singapore.
4. Khan AU, Khan ME, Hasan M, Zakri W, Alhazmi W, Islam T. An Efficient Wireless Sensor Network Based on the ESP-MESH Protocol for Indoor and Outdoor Air Quality Monitoring. Sustainability. 2022 Dec 12; 14(24): 16630.
5. Jasmeen Kaur, Muskan Sharma, *et al.* Wireless Notice Board Using ESP-32. In: Vikram Dhiman and Pooja Dhand (eds), Emerging Trends in Engineering and Management. India: SCRS; 2023; 121–127. Available from https://www.publications.scrs.in/uploads/final_menuscript/570287f9fb57b44be0629f8c30882b77.pdf
6. Sengupta S, Ramamurthy R. From network design to dynamic provisioning and restoration in optical cross-connect mesh networks: An architectural and algorithmic overview. IEEE Netw. 2001 Jul; 15(4): 46–54.
7. Osterlind F, Dunkels A, Eriksson J, Finne N, Voigt T. Cross-level sensor network simulation with cooja. In Proceedings, 2006 31st IEEE conference on local computer networks. 2006 Nov 14; 641–648.
8. Mitrović N, Đorđević M, Veljković S, Danković D. Implementation and Testing of Websocket Protocol in ESP32 based IoT systems. Facta Univ: Electron Energ. 2023 Jun 29; 36(2): 267–84.
9. Kovachev D, Renzel D, Nicolaescu P, Koren I, Klamma R. DireWolf Framework for Widget-based Distributed User Interfaces. J Web Eng. 2014 Jul 1; 13(3&4): 203–22.
10. Szymańska E, Petrović L, Marković I, Petrović I. Mobile robot teleoperation via Android mobile device with UDP communication. In 2021 IEEE 44th International Convention on Information, Communication and Electronic Technology (MIPRO). 2021 Sep 27; 1143–1148.

