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# Decentralized User-To-User Communication Architecture For Unstructured Ad-Hoc Mobile Networks

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Abstract: The rapid growth in mobile communication technologies has led to a significant increase in the demand for wireless networks. Mobile communication networks are becoming increasingly complex, with a variety of services, devices, and interconnections. As the applications of mobile devices increased, the network must provide services to all of them. However, as mobile devices move between networks, signaling overhead can cause real-time data traffic issues.

There are two main types of mobile wireless networks: infrastructure networks and infrastructure-less mobile networks, commonly known as ad-hoc networks. Infrastructure networks require access points for communication, while ad-hoc networks are decentralized, with nodes functioning as routers to find and identify routes to other nodes. In unstructured ad-hoc mobile networks, every mobile node device does not have complete information about the topology of network and the node number of queried resources, making it difficult to understand the network behavior of mobile devices. Due to the varying network properties of unstructured mobile networks, mobile devices in these networks depend on flooding query messages to search devices of interest, leading to large network traffic.

To address these challenges, we propose a decentralized user-to-user communication architecture for unstructured ad-hoc mobile networks. This system allows node to share resources from their systems with others and locate resources shared by others on run the network. Each participating node initiates a program that finds nodes to connect to, and nodes that are connected carries the traffic, which consists of queries, replies. This paper proposes an unstructured communication architecture leveraging ESP32 Wi-Fi to create a resilient mesh network. This decentralized user-to-user system allows participants to share and find resources dynamically, ensuring uninterrupted communication even in the event of infrastructural failures. Our approach employs random walk algorithms to mitigate network traffic and delay, providing a reliable solution for emergency scenarios.

*Index Terms* - Unstructured communication, resource utilization, data, internetworking, LMA.

## I. Introduction

Mobile communication networks have become increasingly complex due to the diverse services, devices, and interconnections they must support. The growing number of mobile customers requires networks to efficiently provide services, even as devices move between networks, causing signaling overhead and real-time data traffic issues.

Mobile wireless networks are generally categorized into two types:

1. Infrastructure Networks: Require access points for communication.
2. Ad Hoc Networks: Infrastructure-less networks where nodes dynamically connect and act as routers.

Unstructured ad hoc mobile networks devices have insufficient topology information, leading to significant network traffic due to flooding query messages. This paper presents a decentralized communication system designed to function effectively in dynamic environments.

This system involves setting up and analyzing an unstructured ESP32 Wi-Fi mesh network. The aim is to evaluate its performance in terms of connectivity, latency, and throughput. The ESP32 modules will be programmed to form a mesh network, and various performance metrics will be recorded and analyzed.

In a centralized communication system, data is routed through a central server or network hub, which can become a bottleneck or single point of failure. In contrast, decentralized architectures distribute the communication load across multiple nodes, enhancing resilience and fault tolerance. This approach aligns well with the nature of unstructured ad-hoc networks, where the network topology is constantly changing, and nodes may frequently join or leave the network.

The Mobile IP protocol has been designed to address the problem of roaming between IP networks. However, as a mobile node moves between networks, the signaling overhead causes significant disruption to real time data traffic by introducing the concept of Local Mobility Agent (LMA). Disadvantages of LMA is when the mobile node changes access network and registers the new care of address at LMA, shorter signaling delay can be expected when a nearer LMA is selected. If the mobile node is communicating with any correspondent node during this interval, the registration delay can be translated into packet loss [1]-[2].

**1.1 Related work and Problem Statement**

Small-world (SW) networks tend to have two distinct function as diameter of network is low and high clustering coefficient, meaning sub-networks which have connections between almost any two nodes within them. This follows from the defining property of a high clustering coefficient. Secondly, most pairs of nodes will be connected by at least one short path [16]. New heuristic chaining algorithms are developed for backward, forward, and bidirectional search of network node chains. This system improves search time and chaining accuracy [8]. Some algorithms like heuristic trust chaining has high cost for searching nodes. Using dynamic topology network improve search efficiency and less network load. Time to live (TTL) refers to the amount of time or “hops” that a packet is set to exist inside a network before being discarded by a router. TTL is also used in other contexts including limited flooding mechanism [17]. Dynamic search has two phases, each with a different search strategy. The search strategy used in each phase depends on the relationship between the hop count and the decision threshold. Dynamic Search resembles flooding for short-term search and random walk for long-term search. Flooding searches are an aggressive method of searching a network that covers the most nodes but generates a large number of query messages. As the search time increases, the search efficiency decreases because the number of query messages increases with the size of visited peers. Random walk search algorithm generate a fixed number of query messages at each hop, but it takes more search time [16][17].

The Need for Decentralized Communication:

In a centralized communication system, data is routed through a central server or network hub, which can become a bottleneck or single point of failure. In contrast, decentralized architectures distribute the communication load across multiple nodes, enhancing resilience and fault tolerance. This approach aligns well with the nature of unstructured ad-hoc networks, where the network topology is constantly changing, and nodes may frequently join or leave the network.

Key Benefits of Decentralized User-to-User Communication Architecture:

Scalability: Decentralized systems can easily accommodate a growing number of nodes without the need for extensive modifications to the underlying infrastructure. Each node can act as both a client and a server, handling its own communication and forwarding data for others.

Resilience: By eliminating reliance on central points of control, decentralized networks are less susceptible to single points of failure. If one node fails or becomes unreachable, the network can still function through the remaining nodes.

Flexibility: Decentralized architectures are inherently adaptable to changes in network topology. New nodes can join the network dynamically, and the network can reorganize itself to maintain connectivity and efficiency.

Enhanced Privacy: Direct communication between users can reduce the amount of data exposed to centralized entities, thereby offering better privacy and security for the end-users.

### 1.2 Challenges and Considerations

Despite these advantages, decentralized user-to-user communication in unstructured ad-hoc networks faces several challenges:

Routing Efficiency: With no central authority, routing messages efficiently across the network can be complex. Protocols need to be designed to handle dynamic changes in network topology and ensure messages are delivered reliably.

Scalability of Protocols: Increase the number of nodes, the communication protocols must scale accordingly without introducing significant overhead or latency.

Resource Management: Nodes in an ad-hoc network typically have limited battery power and processing capability. Efficient management of these resources is crucial to maintain network performance.

Security: Ensuring secure communication in a decentralized network requires robust encryption and authentication mechanisms to prevent unauthorized access and data breaches.

## II. SYSTEM ARCHITECTURE

Based on the problem statement we need to consider both proactive and reactive algorithms. Zone based proactive routing protocol used to gather information about nodes which are within zone and discovering global routes in case of reactive protocol. Selecting path can be improved by search algorithms, another method to modify the routing path algorithm by using zone based connectivity for less delay.

Following objectives are aimed at,

1. To develop unstructured communication architecture for multiple node communication.
2. To reduce delay in search algorithm for multiple node communication.

Our proposed system is a decentralized user-to-user network leveraging ESP32 Wi-Fi modules to create a robust mesh network. The architecture comprises the following components:

Nodes: Each participant runs a program on their device (e.g., mobile phone, ESP32 module) that seeks out other nodes to connect with.

Resource Sharing: Participants can share and locate resources dynamically.

Random Walk Algorithm: This algorithm minimizes network traffic and delay by optimizing resource discovery and topology maintenance.

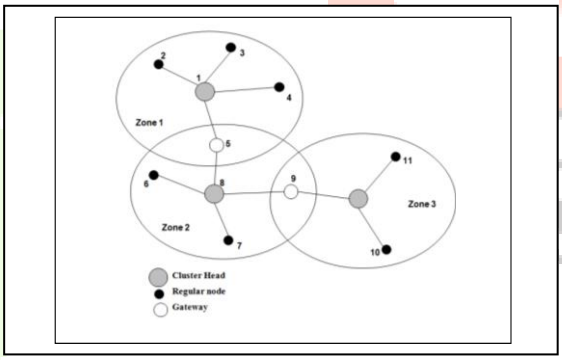


Figure 1 System architecture with zone based network

In unstructured mobile ad hoc networks (MANETs), the dynamic nature of node movement leads to rapidly changing network topologies, which complicates the ability to capture the global behaviour of mobile devices [12]. Mobile devices interconnect randomly in unstructured networks, they depend on flooding query messages to identify devices of communication and thus each mobile node operates without complete knowledge of the entire network topology or the locations of queried resources, making efficient communication and resource discovery challenging [12][13]. In this architecture nodes join zone and leave zone dynamically. To address these issues, the development of effective mobility models is essential. A novel mobility model based on unstructured architecture enhances the flexibility and capability to describe realistic scenarios, thereby improving our understanding of the dynamic properties inherent in these networks.

In the proposed system architecture, nodes in close proximity collaborate to form a backbone network, significantly reducing route discovery overheads. This is primarily achieved through proactive route maintenance, where nodes actively maintain routes to nearby nodes, thus minimizing the need for frequent route discovery processes. The Mobile Backbone Network Protocol (MBNP) facilitates this by implementing proactive routing mechanisms that ensure efficient resource allocation and quality-of-service (QoS) performance. These strategies create a robust and efficient network architecture that effectively addresses the challenges of route discovery in mobile environments. System protocols are zone-based as shown in fig.1, to demonstrate concept three zones are shown with cluster head, regular node and gateway.

The system utilizes the nRF24L01 module and the Arduino Mega 256 as its main hardware components, facilitating efficient data transmission and reception. The Arduino Mega 256 serves as the primary control board, interfacing with a computer to receive information via a serial module. This setup allows for seamless communication between the computer and the Arduino, which processes the incoming data. For wireless communication, the nRF24L01 module is employed to transmit data to other nRF24L01 modules, leveraging radio frequency signals to establish a connection without the need for physical wiring. This module is particularly effective in environments where mobility and flexibility are essential, as it supports robust data transmission protocols [15].

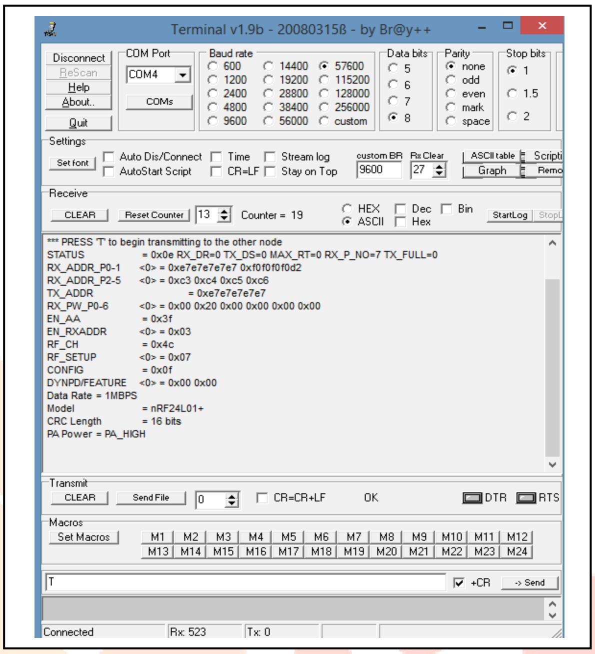


Figure 2 Terminal window for Transmitter

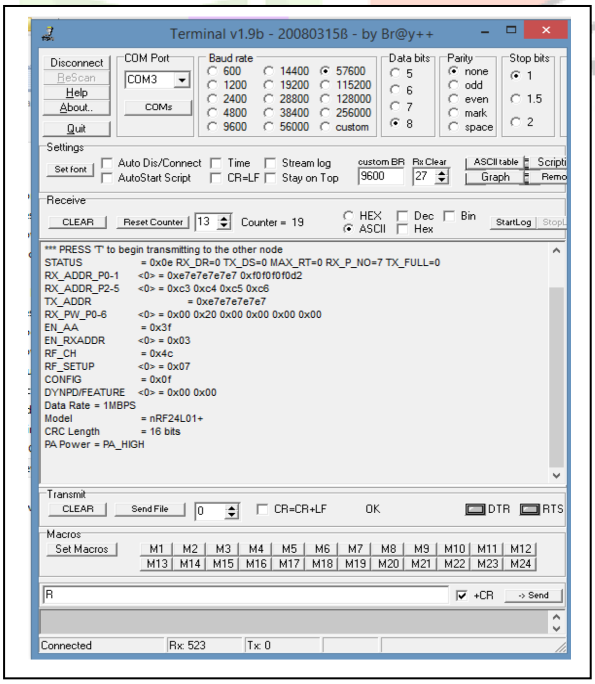


Figure 3 Terminal window for Receiver

Terminal window for transmitter is shown in figure 2. Receiver terminal window is shown in figure 3.
In a networked environment, the program for changing from role as a transmitter to role as a receiver is crucial for effective communication between nodes. When a node is set to 'transmit' role by connecting to a serial monitor and sending a 'T', it initiates the process of data transmission. This setup is part of the node

configuration, which defines the roles and communication parameters necessary for the node's operation. In this scenario, the ping node, acting as the transmitter, transmits the current time to the receiving or pong node. The pong node, upon receiving this data, switches to its receiving mode and replies by transmitting the value back to the ping node. This role management is essential, as it allows nodes to switch between transmitting and receiving functions seamlessly, ensuring efficient data exchange terminal window is shown in Fig. 4 and Fig 5.

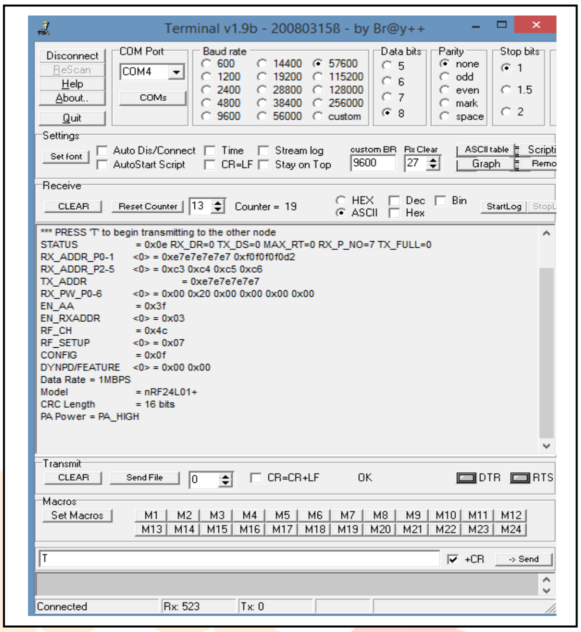


Figure 4 Transmitter Request Response

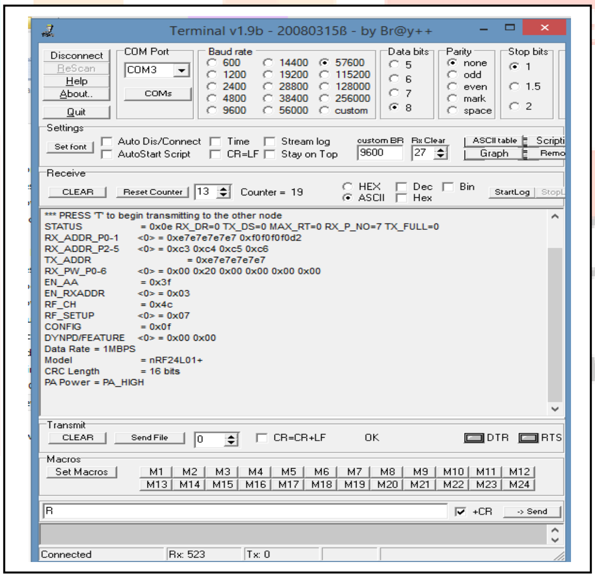


Figure 5 Receiver Request Response

Terminal window role change from sender to receiver is shown in fig 6 and role change from receiver to transmitter is shown in fig 7.

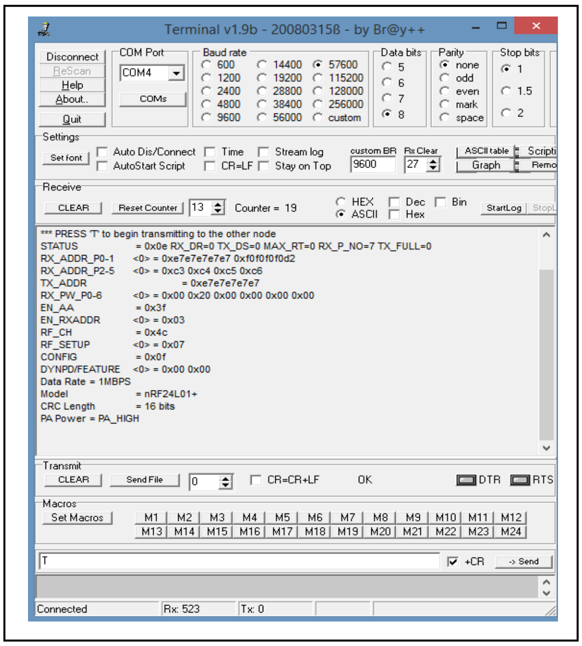


Figure 6 Terminal window role change from transmitter to receiver

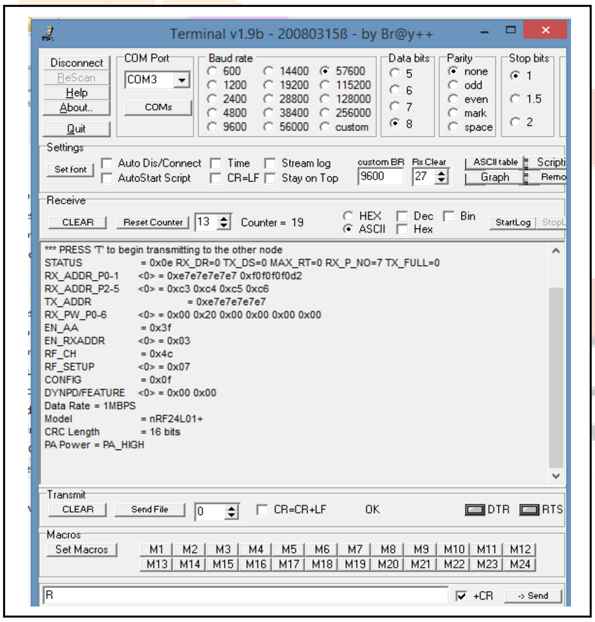


Figure 7 Terminal window role change from receiver to transmitter

## III. RESULT

Performance of the ESP32 mesh network under different conditions is summarizes in table 1

Table 1 Performance of network

| Sr. No. | Metric | Condition | Value |
|---|---|---|---|
| 1 | Connectivity | 3nodes, line of sight | Stable |
| 2 | Connectivity | 3nodes, Obstructed | Stable |
| 3 | Latency | Line of sight, avg. | 50ms |
| 4 | Latency | Obstructed, avg. | 80ms |
| 5 | Throughput | Line of sight, avg. | 500kbpa |
| 6 | Throughput | Obstructed, avg. | 300kbpa |

| | | | |
|---|---|---|---|
| 7 | Round trip delay | End to end nodes | 24ms |

### 3.1 ESP32 Wi-Fi Mesh Network

The ESP32 modules are configured to form a mesh network where each node can dynamically connect to others. Key features include:

Self-Healing: The network can automatically reconfigure itself if a node goes offline.

Scalability: The network can scale to accommodate a large number of nodes.

Low Latency: The random walk algorithm ensures efficient query handling and resource discovery.

### 3.2 Experimental Setup

Nodes: Three ESP32 modules are programmed using the code shown in figure no8.

Environment: Indoor environment with obstacles considered as walls and furniture.

Connectivity: Ability to maintain network connections.

Latency: Time taken for messages to be delivered.

Throughput: Amount of data successfully transmitted.

Round Trip delay: End to end node communication delay

### 3.3 Analysis

The ESP32 mesh network maintained stable connections in both line-of-sight and obstructed conditions.

The average latency increased in obstructed conditions due to interference and signal degradation, average round trip is 24 ms. Throughput was higher in line-of-sight conditions and reduced when obstacles were present.

## IV. CONCLUSION AND FUTURE WORK

The ESP32 Wi-Fi mesh network demonstrated reliable performance in maintaining connectivity and acceptable latency and throughput in varying conditions. This project showcases the potential of unstructured communication architecture using ESP32 modules, providing a robust solution for dynamic mobile communication environments. Future work will involve optimizing the network for larger scales and more complex scenarios for disaster management communication network.

In disaster scenarios, traditional communication infrastructure may fail. Our ESP32 mesh network ensures continuous communication among first responders and affected individuals by maintaining Connectivity. As long as two nodes are active, the network remains operational. Routing table will help resource discovery efficiently locating shared resources such as medical supplies, shelter, and food.

It will ensuring messages and alerts are reliably transmitted across the network due to its robust communication.

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