ROSNet: A WMN based Framework using UAVs and Ground Nodes for Disaster Management

Neelabhro Roy, Sauranil Debarshi, and P.B. Sujit

Abstract—**Communication breakdowns during natural disasters can significantly restrict disaster management operations. Furthermore, the cellular networks may also be unreliable in these scenarios. Hence, establishing communication using alternative means is of importance in these scenarios. In this paper, we propose a prototype system to establish communication (using wireless mesh network - WMN) through the use of stationary and mobile ground nodes, and aerial nodes using unmanned aerial vehicles (UAVs). This network is ad hoc and establishes connectivity without the use of a cellular network or internet. Our system provides a complete end to end architecture, where we deploy an android application on smart phones at the user-end, the ad hoc network comprising of stationary and mobile nodes, and a graphical user interface (GUI) at the base station that shows situational awareness. We evaluate the system with three nodes for different system configurations by using UAV and a semi-autonomous car. Our experimental results show that the system could be indispensable in providing large scale connectivity during disasters.**

Index Terms—**Mobile ad hoc networks, Wireless mesh networks, Unmanned aerial vehicles, Disaster management.**

I. Introduction

Communication network is the backbone for efficient execution of disaster management services. However, when a natural disaster occurs, typically, the existing local network infrastructure (cellular network) fails, leaving the local inhabitants and authorities with minimal to no mode of communication. Therefore it is essential to explore alternative mechanisms to restore communication between the inhabitants and the service personal for effective search and rescue efforts.

One such effort is to use ham radios, however their bandwidth is limited and the type of information that can be transmitted is also limited [1]. Another alternative is to use satellite communication, which also has limited bandwidth [2], [3] and not scalable for large scale operations. Recently, there has been a focus on using wireless mesh network (WMN) consists of several nodes connected as an ad hoc network (MANET)[4] for these applications. WMNs provide a cost-effective and multi-hop routing architecture, resulting in flexibility and scalability. Unlike Wireless metropolitan area networks (WMANs), which require line-of-sight (LOS) and also lack mobility, a WMN offers a reliable and dynamic routing protocol from one point to another because of its ability to re-route information even when some of the nodes fail to operate. A survey of different type of protocols used in WMNs is given in [5]

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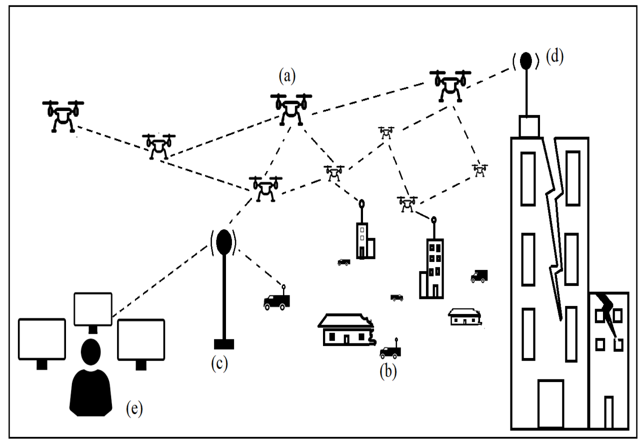


Fig. 1: Wireless mesh network with stationary and mobile ground nodes and aerial nodes. (a) Aerial node (b) Mobile Ground node (c) Stationary node (d) Stationary node in an earthquake affected infrastructure (e) Base station / Central server

UAVs play a key role in disaster management [6], [7], and can perform several functions such as monitoring [8], standalone communication systems [9], medical deployment [10], search and rescue operations [11] and for post-disaster damage assessment [12]. A cross layer design to deploy a mobile ad hoc network (MANET) for establishing wireless communications in a region is presented in [13]. Their approach enhanced the performance of such a network by replacing the standard Open Systems Interconnection (OSI) with a cross-layer technique that allows adjusting parameters in the layers based on the roll, pitch and yaw of the UAV. Shen *et al*. [14] have proposed a new class of ad hoc network called Autonomous Mobile Mesh Network (AMMNET) , wherein the mobile mesh nodes of their AMMNET architecture follow the mesh clients in the application terrain, also organizing themselves into a suitable network topology to ensure good connectivity for both intra and intergroup communications. This has been proposed as an architecture suitable to be used across ground and aerial nodes deployed in cars and UAVs. Hence, adding multiple mobile ground and aerial nodes to our architecture, is tantamount to a greater system capacity. The UAVs can be used as base stations, which can be deployed rapidly as part of the heterogeneous network architecture, wherein, the UAVs can increase the range of terrestrial cellular networks as well [15]. These articles are based on simulations and lack experimental evidence.

There have been several works demonstrating the use of UAVs for ad hoc networking [16], [17], [18]. Brown *et al.* [16] describe a wireless ad hoc network with radio nodes fixed on ground vehicles and in small unmanned aerial vehicles (UAVs). Ad hoc relaying between multiple UAVs extends the communication range. The availability of the UAV node improves throughput, delay, and connectivity measures compared to their mobile ground experiment. However, they have analyzed the performance of the network by only sending packets, whereas our approach uses different data types and is thus, more modular. There are numerous applications of wireless mesh network being used for disaster management for providing reliable and scalable data communication in a disaster site. For example, Braunstein *et al.* [17] investigate the feasibility of using a WMN for medical response using ground nodes only. Taking cues from these two articles, our proposed prototype uses multiple nodes to create a wireless mesh network over a large region (aerial, ground – stationary and moving), and provides a solution which offers seamless connectivity over the disaster affected region.

The type of wireless networks can affect the performance. A high-throughput wireless network is designed in [18] for UAVs communicating via IEEE 802.11a. A performance comparison is carried out between the infrastructure and mesh modes of 802.11 for one-hop and two-hop communications, analyzing MAC layer relaying versus the network layer. Even though the achieved throughput is significant, for large scale networks for multiple hops, this solution is challenging. Morgenthaler *et al.* [19] developed a framework called UAVNet for creating an aerial IEEE 802.11s wireless mesh network using small-scale UAVs. It autonomously establishes a network relay between two systems. Each wireless mesh node acts as an access point and provides network access for regular IEEE 802.11g wireless devices. The information that can be transmitted is limited to messages only, similar to [18]. Our prototype is closely related to [19], however, our approach also integrates a mobile phone in the same architecture using which the users can directly relay information to the airborne nodes, which can then be relayed further, along with the possibility of using multiple UAVs to achieve this. Diverse information can be transmitted using our approach, namely, texts, images, audio and video files. Also, we introduce Robot Operating System (ROS) in the architecture which provides a robust middleware, better compatibility and even allows us to potentially integrate ground robots as part of the same architecture, along with the provision to operate a system using both aerial and ground nodes at the same time.

In this paper, we propose a prototype system based on stationary and mobile nodes for establishing an IEEE 802.11 wireless mesh network in disaster affected regions. In regions where on-ground mobility is not available, nodes can be placed on top of elevated structures such as poles, tall buildings, buoys, etc. to create a unified network of stationary and aerial nodes, which can prove indispensable in disaster affected regions. This is shown in Fig. 1. This system acts as a delay tolerant network gathering messages and/or images from some remote locations and delivering them to a base station located at a safe location. The base station serves as the central node/server. The major contributions of this paper are

- We present a complete end-to-end network architecture based on multifarious mobile and stationary nodes, by providing a means to the affected users to convey their needs using an android application, to their nearest node which stores the information locally on a Raspberry Pi (RPi) and subsequently relays it to the base station.
- We propose a framework based on the open-source Robot Operating System (ROS) [20] for controlling and monitoring the UAVs from ground and as a medium to relay user messages and images from one node to another using ROS topics. Thus, nodes have the ability to send data to another, by publishing it in a ROS topic, consequently reaching the base station through the network of mesh nodes. ROS has primarily been used in our architecture as it serves as the middleware for communication, and provides the necessary tools for deploying UAVs to our network.
- An interactive GUI is developed for the base station, which receives all the information transmitted through the nodes. This software also provides functionalities for monitoring the stationary as well as mobile nodes, and sends appropriate commands based on their status and position.
- The information transmitted via the nodes, can be directly obtained from the end users with the help of the developed android app. The app works without the use of internet, and transmits crucial information by connecting to the networks created by the nodes. The obtained information is locally stored on the respective nodes and is then transmitted to the others via the above mentioned protocols.

The proposed network, being decentralized, reduces the complexity and allows monitoring of all the nodes in the network. Moreover, our algorithm ensures that a ground vehicle or a UAV deployed to an extremely remote area without any network can efficiently relay its information to the base station by coming in contact with its nearest node of the mesh network. Note that we assume that there is no cellular network, and there is no internet.

The paper is organized as follows. Section II describes the hardware and software components used for developing the prototype. Section III discusses the implementation of the network. Section IV presents the experimental and evaluation results of the prototype. Section V concludes our work.

II. Hardware and Software Components

The proposed end-to-end network architecture is composed of hardware and software components which we will describe in detail.

A. Hardware

Our prototype consists of mobile (ground and aerial) and static nodes. We performed experiments with ground vehicles and UAVs to evaluate the performance of the mesh network under different configurations.

Fig. 2: Wireless mesh node.

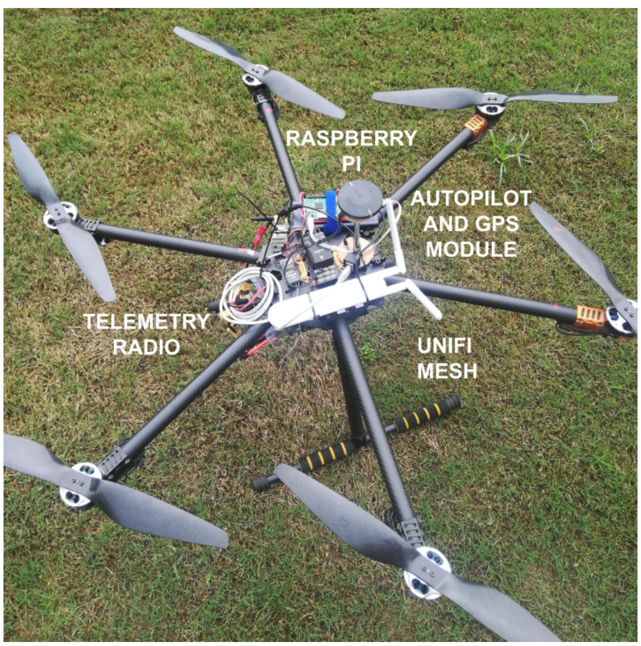


Fig. 3: Hexacopter equipped with a Wireless Mesh Node.

1) Wireless Mesh Node: The mesh radio, coupled with the RPi, constitutes the wireless mesh node. We used the ”UniFi AC Mesh UAP-AC-M” from Ubiquiti Networks [21] to deploy the wireless mesh network as shown is Fig.2.It operates using IEEE 802.11 modes, utilizing dual band communications, having provisions to operate at 5 GHz and 2.4 GHz simultaneously. Since it also uses IEEE 802.11ac, it supports backward compatibility with IEEE 802.11b/g/n.

2) Unmanned Aerial Vehicle: Fig. 3 shows the UAV along with the wireless mesh node. We have used a multi-rotor UAV, ”Tarot 810” for our purpose. It consists of a ”Pixhawk 2” flight controller, GPS module, camera and an RPi 3 along with a 6S 8000mAh LiPo battery.

3) Ground Vehicle: Fig. 4 shows a ground mobile node, mounted on a semi autonomous Mahindra e2o electric car. The wireless mesh node is mounted on top of it.

B. Software on the node

A local app server runs on the RPi of each node, that collects user information and stores it when not connected to any other node. Then it transmits to the base station when it comes in contact with the mesh network again. Our software monitors and relays information from one node to another. The software framework is based on the Robot Operating System Kinetic Kame, which acts as middleware to facilitate the data transfer between the nodes and the base station. Each Node (ground or UAV) consists of an RPi 3, running Ubuntu MATE 16.04 (LTS). ROS provides a collection of essential tools and services for controlling and monitoring the position of the nodes. Moreover, it provides additional functionality of communicating between the nodes by using channels called topics. Nodes use a publisher-subscriber (Pub-Sub) architecture, whereby a node transmits its data by publishing to a topic and another node receives the data by subscribing to the same topic. For the ROS nodes to communicate, we created a master node at the base station. Fig. 5 shows the software architecture and communication interfaces of the model. Node 1 and Node 2 relay images and user data through the /img_topic and /msg_topic respectively using the Pub-Sub architecture.

C. User-end software

We have designed an android app using Python’s Flask framework, as a part of our complete solution towards this problem. This is shown in Fig. 6 (a). It connects to the

Fig. 4: Mobile node mounted on a semi-autonomous Mahindra e20.

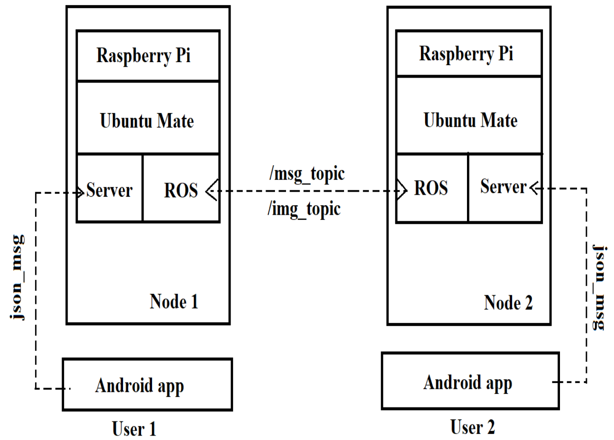
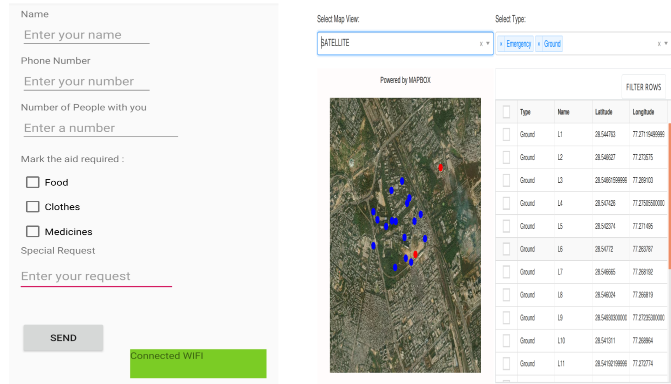


Fig. 5: Software Architecture and Communication Interfaces of the model.



(a) Android application with provisions to provide crucial user data.

(b) Base station GUI showing the locations of nodes.

Fig. 6: Overview of the android application and GUI.

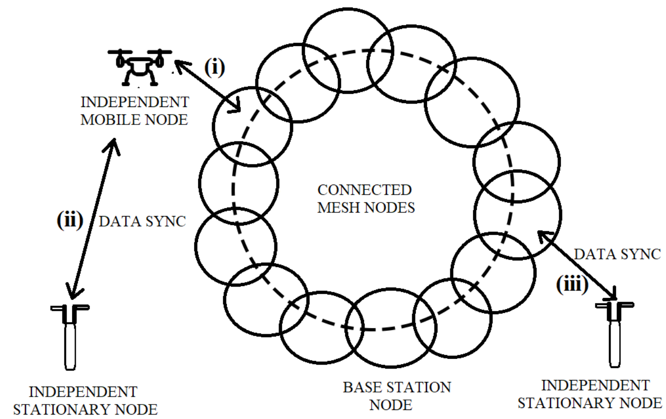


Fig. 7: Data synchronization between various nodes. (i) Independent Mobile node (ii) Independent Stationary node (iii) Independent Stationary node

wireless network created by the respective mesh nodes and sends the data, namely name, phone number, number of people stuck, checkbox for food, clothes, medicines, and a text entry for special requests. The GPS coordinates are also saved by the app without explicit user entry. The app user gets a confirmation message once the information has been sent successfully. The data is stored in the RPi of the nodes in the form of JSON Objects, and are then transmitted as ROS messages to other nodes of the mesh. The node allows multiple users to be connected simultaneously as well.

D. *Base station software*

The base station receives the data sent by the users connected to the network and keeps track of all the ground as well as the UAV nodes by using an interactive Graphical User Interface (GUI) made using python's dash framework. It is shown in Fig. 6(b). The GUI serves the following purpose:

- Receives information through the network of mesh nodes by using the ROS-based architecture.
- The GPS module attached to each UAV publishes its coordinates to a ROS topic, which is received by the GUI by subscribing to that topic in real-time. This allows monitoring of people in need through the ad-hoc network.
- Appropriate instructions such as heading directions, altitude, etc. can be sent to the UAVs/Ground Vehicles and to the people as well.

III. Implementation

A. *Network architecture*

We assign a pre-defined set of IP addresses to each node, comprising of an RPi. The mesh network is programmed to broadcast a single wireless network. This helps in addressing problems concerning duplicate and multiple networks, such as when a user can connect to more than one network, they may be confused to select a particular network to connect send to.

A user in the vicinity of the wireless network of a node can send crucial information via the app. Once the information is received by the node, it is saved locally and transmitted to a node or the base station as ROS messages.

B. *Data synchronization*

1) Data synchronization between single mobile node and connected node: A mobile node such as a car or a UAV acts as an independent node when it is not in contact with the mesh network. Whenever the node comes within the wireless range of a node which is part of the mesh network (connected node), synchronization of data takes places between them. This scenario is shown in Fig. 7(i). Data received by the connected node is relayed to the base station, as both of them are part of the same network.

2) Data synchronization between mobile and independent stationary node: Nodes which are mounted on top of elevated structures act as independent nodes. These nodes store the information obtained through a user, or through some other node. Whenever a mobile node (UAV or Ground Vehicle) comes in contact with the independent stationary node, synchronization of data takes place between them, as shown in Fig. 7(ii).

3) Data synchronization between connected node and base station: Some nodes would be in sync with the base station and would form a part of the mesh network. Whenever these nodes come in contact of any of the independent nodes, a handshake between them takes place, and data is consequently transferred to the base station. Fig. 7(iii) illustrates this scenario.

IV. RESULTS

We performed multiple experiments involving aerial and ground nodes, covering a multitude of cases. We first tested our prototype on a single hop network, and then used multiple nodes to create a multi hop network. A laptop and an RPi have been used as client A and client B respectively, in all the scenarios. We measured the performance of our prototype by testing it on a two way communication. The RPi has been chosen as the computational unit, as it is powerful and light weight, thereby can be mounted on both ground as well as aerial nodes with ease.

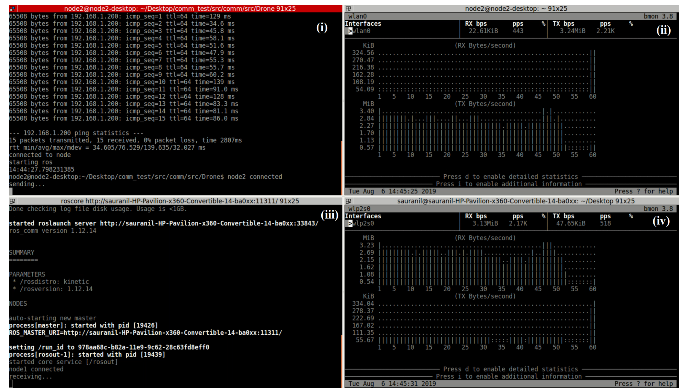
The exchange of information takes place when both the clients come in contact. This exchange of information is shown in Fig. 8.The data stored in client B is transferred to client A in the first stage. This is shown in Fig. 8(a). The transmission and reception throughput associated with client B and client A are shown in Fig. 8(a)(ii) and Fig. 8(a)(iv) respectively. Fig. 8(a)(i) and 8(a)(iii) show the initialization of transfer from client B and the process of reception of information in client A respectively. The second stage comprises of data transfer from client A to client B, shown in Fig. 8(b). A confirmation message is displayed after a successful completion of the transfer, which is shown in Fig. 8(c). Fig. 8(c)(i) indicates the termination of information transmission from client B. Fig. 8(c)(iii) shows the termination of file reception at client A, and thus indicates the completion of the whole process. Fig. 8(c)(ii) and Fig. 8(c)(iv) detail the throughput at the point of termination of transmission for client B and at the point of termination of reception for client A respectively.

A. Single Hop Communication

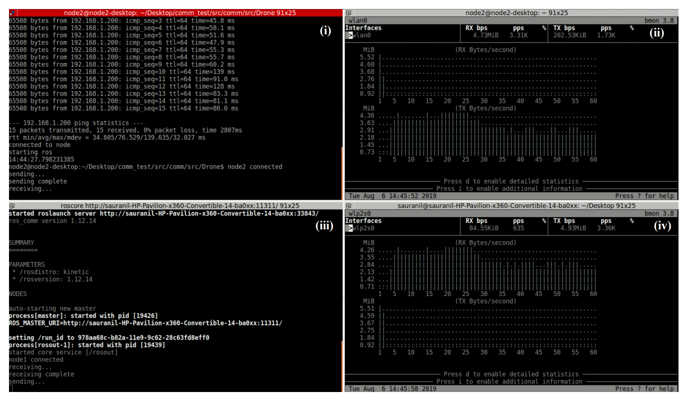
The network performance for single hop communication for different node configurations are shown in Fig. 9.

Case (i): Fig. 9(i) describes the first case where client A and the client B are both connected to a ground node, at a distance of 10 m from each other. Case (ii): Fig. 9(ii) shows the case where client A and client B are placed at a distance of 100 m from each other, with client A being in close proximity to the node. Case (iii): The third scenario shown in Fig. 9(iii) describes the case where client A and client B are kept 180 m apart, with both the clients equally apart from the the wireless node. Case (iv): The scenario shown in Fig. 9(iv) describes the fourth case where the ground node in the third case is replaced by a UAV flying at a height of 40m.

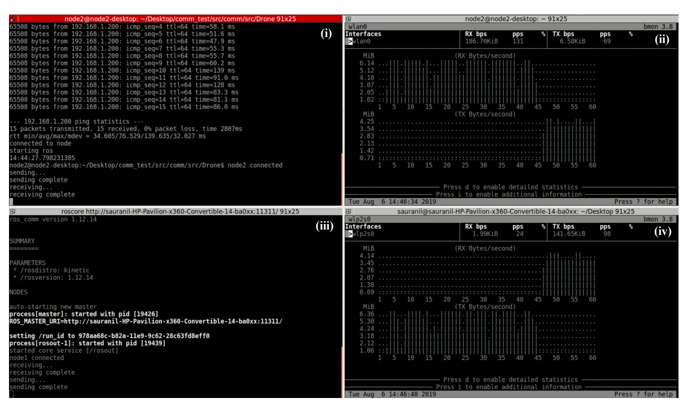
The performance for these cases is analyzed using the Transmission Initialization Delay (TID) and throughput.



(a) Data transfer from client B to client A. (i) Initialization of transfer. (ii) Throughput analysis for client B. (iii) Reception of information. (iv) Throughput analysis for client A.



(b) Data transfer from client A to client B. (i) Reception of information. (ii) Throughput analysis for client B. (iii) Initialization of transfer. (iv) Throughput analysis for client A.



(c) Confirmation message showing the completion of the transfer. (i) Termination of transfer for client B. (ii) Throughout analysis at the point of termination for client B. (iii) Termination of transfer for client A. (iv) Throughout analysis at the point of termination for client A.

Fig. 8: Data exchange between client A and client B.

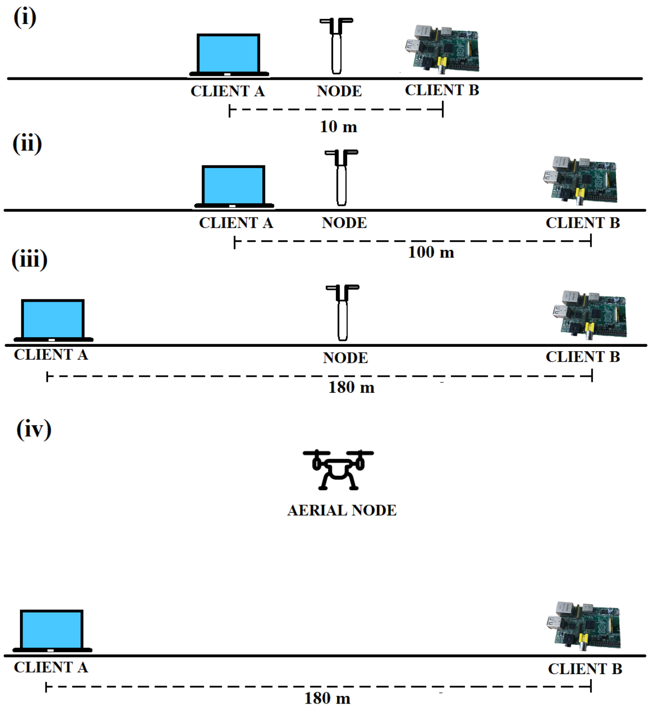


Fig. 9: End-to-end throughput measurement scenarios in single hop communication.

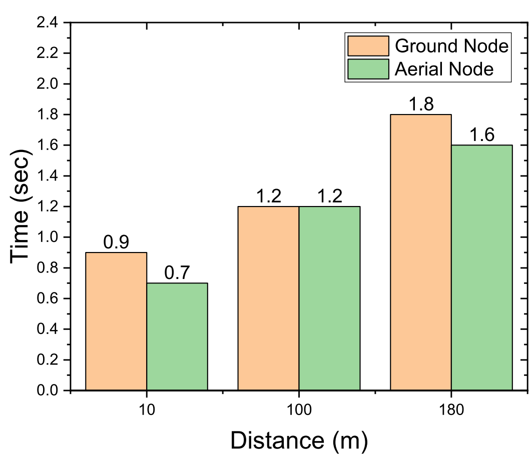
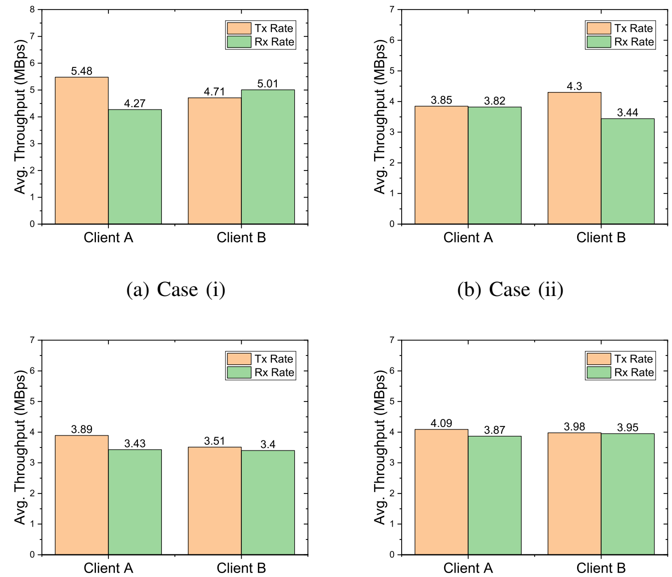


Fig. 10: Transmission initialization delay.

1) Transmission Initialization Delay: We define Transmission Initialization Delay (TID) to be the time taken to initialize the first transfer, once the connection has been established between two clients. The TID varies with distances shown. From Fig. 10, we observe that the TID for the aerial node case is less than the ground node case by 11.11% when the distance between the clients is 180 m.

2) Throughput: We measure the throughput in Mega Bytes per Second (MBps). Fig. 11(a) corresponds to the case described in Fig. 9(i), similarly Fig. 11(b) and Fig. 11(c) correspond to Fig. 9(ii) and Fig. 9(iii) respectively. Fig. 11(d) corresponds to case shown in Fig. 9(iv).



(a) Case (i)

(b) Case (ii)

(c) Case (iii)

(d) Case (iv)

Fig. 11: Throughput measurements in single hop communication.

A general trend that can be observed across all four plots, is that the transmission rate of client A is higher than that of client B. This is due to faster processing units and high-end network interface card of the laptop.

As we can observe from the plots, the transmission rates of clients A and B are the highest in the case denoted by Fig. 11(a), which can broadly be attributed to the close proximity of both the clients to the wireless node. The transmission rate (Tx) of client A increased by 5.14% as compared to its value in the case denoted by Fig. 11(c). Client B's performance improved by 13.39% when compared to its performance in the case denoted by Fig. 11(c). The increase in throughput is because of the presence of the aerial node in the case being described by Fig. 11(d).

B. Multi Hop Communication

The different configurations considered for the multi hop communication scenarios are shown in Fig. 12. The distances between the nodes and the clients are fixed. Both the clients are situated at a distance of 100 m from the respective nodes. Distance between the nodes is 80 m for all the configurations.

Case (i): Fig. 12(i) describes the case where node 1 and node 2 are both ground nodes. Case (ii): Fig. 12(ii) describes the case where the node closer to client A is an aerial node. Case (iii): Fig. 12(iii) shows the case where both the wireless nodes are aerial nodes.

We now analyze the performances in terms of TID and throughput.

1) TID: The TID for each case has been measured for multi-hop communication. From Fig. 13, we can see that the TID reduces as we proceed with the different cases, this can be broadly attributed to the presence of one aerial node for case

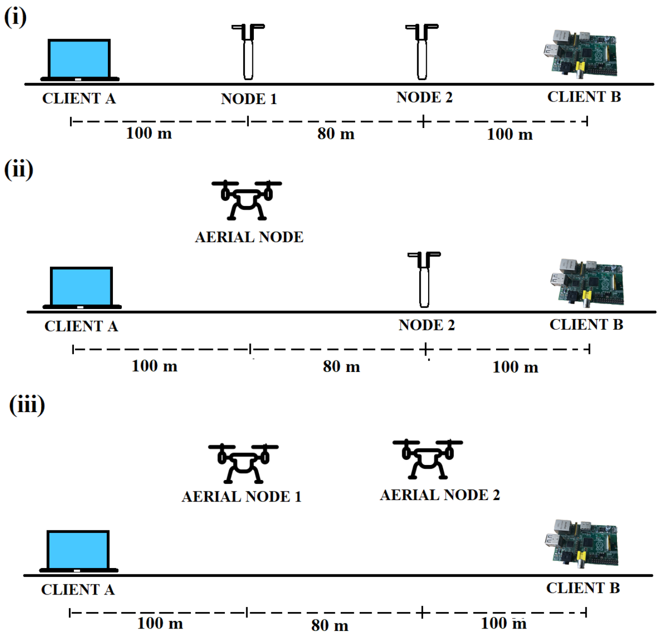


Fig. 12: End-to-end throughput measurement scenarios in multi hop communication. (i) Both ground nodes (ii) Node near client A is an aerial node (iii) Both aerial nodes

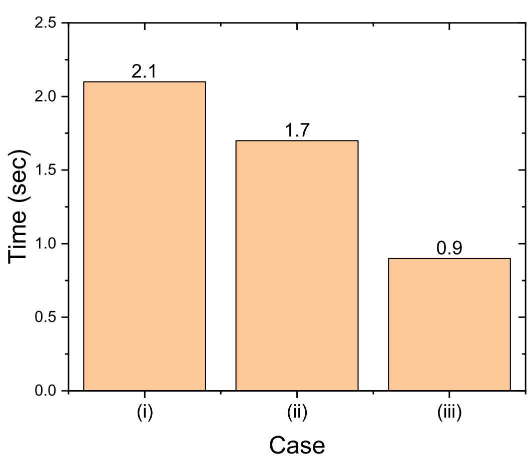
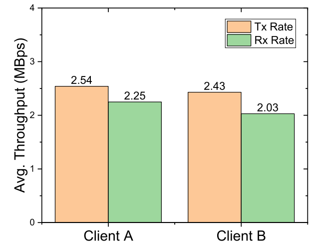


Fig. 13: Transmission initialization delay.

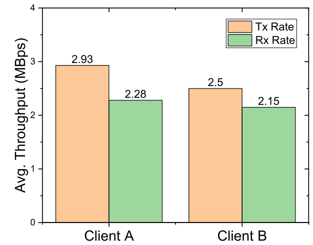
(ii), and two aerial nodes in the case (iii). Case (ii) provides an improvement of 19% over case (i), similarly, case (iii) provides an improvement of 66.66% over case (i), when two aerial nodes are used instead of two ground nodes.

2) Throughput: Fig. 14(a) corresponds to Fig. 12(i). Fig. 14(b) and Fig. 14(c) represent Fig. 12(ii) and Fig. 12(iii) respectively.

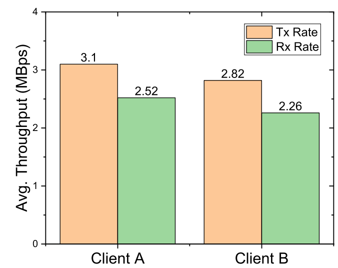
From the figures, we can see that the transmission rate for both client A and the client B has decreased when compared to single hop communication, which can be attributed to the additional delay incurred because of the presence of another wireless node and because of the extra distance involved. Replacing node 1 in the first case with an aerial node,



(a) Case (a).



(b) Case (b).



(c) Case (c).

Fig. 14: Throughput measurement in multi hop communication.

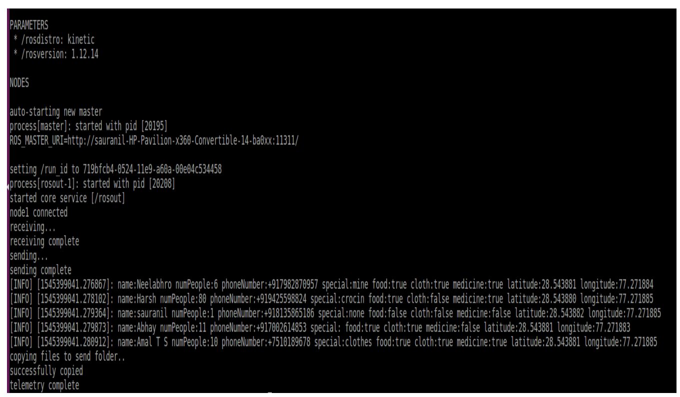


Fig. 15: User information received at base station.

significantly increased the transmission rate of client A by 15.35%. For the third case, when both the nodes are aerial nodes, the rate of transmission has increased for both the clients. The rates from case I increased by 22% and 16% for client A and client B respectively.

C. Transmission of user data

Our end-to-end prototype allows affected users to send and request crucial information during a disaster. Fig. 15 shows the data received at the base station via ROS topics, along with the images. This information can aid the disaster management personnel with their operations.

D. Signal parameters of the network

Signal to noise ratio (SNR) plays a role in the data synchronization by being indicative of the signal strength. Fig. 16 represents the plot detailing the SNR, received signal strength

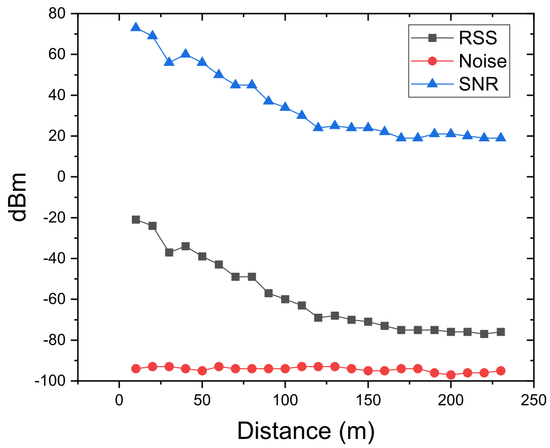


Fig. 16: Received signal strength and SNR over distance.

(RSS) and the noise of our network's performance across different distances. For the experiments, a reasonable signal strength can be obtained until 150 m - 170 m, after which the signal strength reduces. This is primarily due to the official radio range of 183 m.

V. Conclusion

We proposed and implemented a wireless mesh network to aid disaster affected regions using stationary and mobile nodes, including UAVs, on-ground vehicles etc. Our prototype integrates IEEE 802.11 single and multi-hop wireless networks for easing communications across such regions. The android app helps receive the user information, while the developed GUI at the base station provides situational awareness. The ROS middleware provides a robust mechanism to transfer data using WMNs. Moreover, our system can also be used to obtain real time imagery information using a camera mounted on the UAVs along with the GPS coordinates imprinted on the images to identify the affected locations, and transfer those images to other nodes, which are a part of the mesh network, without requiring an active internet connection, and at reasonable transmission rates. From the throughput measurements calculated for single and multi hop networks, it has been been observed that by using aerial nodes like UAVs, the transfer rate of our algorithm significantly improves. We hope to deploy this system to facilitate efficient disaster management efforts in India.

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