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Original Article

Additive Protocol Layer (APL) for the Communication Between Heterogeneous Machines

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***Abstract* -** *Global society faces serious threats from both natural and man-made disasters that have frequently occurred lately, such as the devastating earthquake in Morocco and Libya hurricane "Daniel". Various machines such as robots, autonomous vehicles, and drones have become important and effective tools in information gathering and disaster response, particularly in search and rescue operations. However, several issues are associated with machines, such as heterogeneity and the lack of a communication protocol designed to facilitate communication among them. The purpose of this study is to design an Additive Protocol Layer (APL) to support the communication between heterogeneous machines (HM). The Cooja simulator is used to simulate the proposed protocol. The performance of the protocol will be measured for different scenarios.*

***Keywords* -** *Robots, Drones, Autonomous vehicles, Internet of Things, Networks.*

1. Introduction

Search and Rescue by Robotics is a very important subject of study since human and heterogeneous machine cooperation is a fantastic choice in the event of a natural disaster. Several issues are associated with different types of machines that support anti-disaster, such as heterogeneity and the absence of a communication protocol designed to support communication between heterogeneous machines. When a catastrophe occurs, such as an explosion or earthquake. Numerous fatalities and casualties are left in its wake. Finding and saving the victims under these circumstances is often the responsibility of a rescue team. Nonetheless, there are instances where the rescue crew must deploy robots to find the victims due to the extreme risk they face [1]. Search and rescue is one of the most significant and fascinating areas in which robotic technology is being used. Robots make responders safe by enabling them to go where rescues cannot [2]. With a lot of potential for practical applications, robotic search and rescue is a difficult but promising field of study [3]. Combining distributed decision-making and Machine Learning (ML) techniques with vehicle-to-everything (V2X) networks has been the focus of current research on smart connected cars [4]. One essential vertical use case for 6G is connected autonomous cars. However, 6G networks will face significant problems with autonomous vehicle applications in terms of fast communication, latency, and dependability. [5]. One potential low-cost use for catastrophe monitoring in the future is the use of drones for persistent observation in a complicated, uncharted terrain [6]. The aerial imaging of forest fire sites may be easily collected using airborne remote sensing, usually using UAVs [7]. Drones are a promising new technology that can be used to support relief and search teams throughout all phases of a catastrophe. [8]. Since IoT systems are built with heterogeneous hardware and networking technologies, there is a need to standardize architecture and protocols [9].

High-level autonomous driving, sensing, and smart city development have all advanced beyond the capabilities of the fifth generation, necessitating the creation of the sixth generation [10]. Several issues are associated with different types of machines, such as heterogeneity and the absence of a communication protocol designed to support communication between heterogeneous machines. The purpose of this study is to design an Additive Protocol Layer (APL) to support communication between Heterogeneous Machines (HM). The Cooja simulator is used to simulate the proposed protocol. The performance of the protocol is measured for different scenarios. Several projects explored the design challenges of heterogeneous machines in different uses. The design and communications principles of heterogeneous machine systems in civil uses still need investigation and remain an open issue. We will try to provide solutions using our proposal.

2. Related Work

Several issues are associated with heterogeneous machines, such as heterogeneity and the lack of a standard communication protocol designed to support communication between heterogeneous machines. So, in this section, we briefly summarize some papers related to communication protocols between heterogeneous machines. In [11], Vaigandla et al. presented an overview of IoT network protocols (such as the CoAP Protocol).

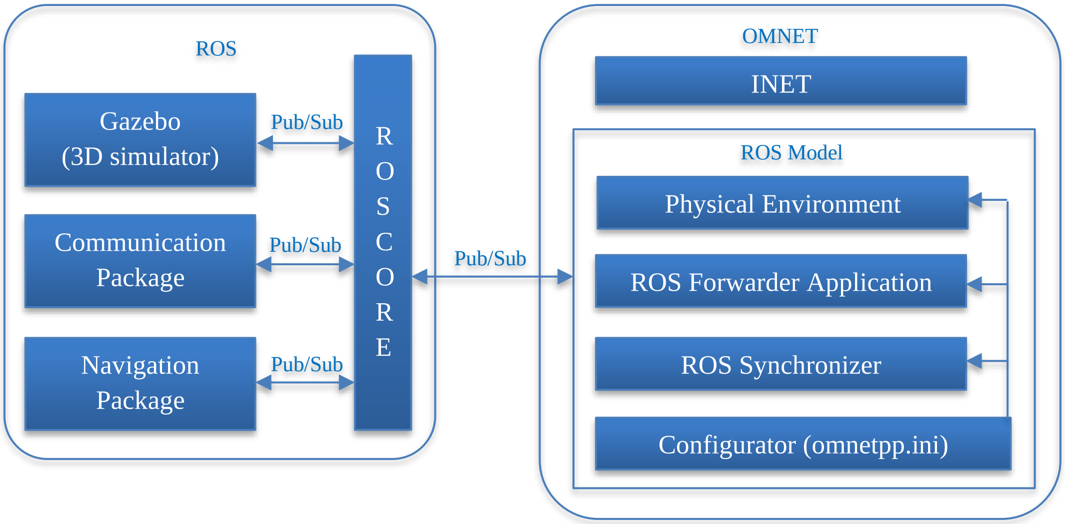


Fig. 1 ROS-OMNeT simulation model [15]

Constrained Application Protocol uses a client-server interaction model. In [12], Vibin et al. concentrated on the design of a wireless communications system between vehicles. In [13], Yanco and Stein described communication between mobile robots working together in intensive activity. After learning a communication language, the robots modify it to help them perform their tasks successfully in the future. In [14], Marcotte presented two main approaches to address the problems with inter-robot communication. In the initial push, a method called adaptive erasure coding was used to increase the dependability of such communication. In the second thrust, Marcotte explained a method by which robots can decide how to communicate by considering how a suggested communication action is likely to affect the team's performance. In [15], Behera et al. carried out studies on wireless communication for indoor multi-robot systems using Robot Operating System-OMNeT platform simulations, as shown in Figure 1.

In [16], Xu et al. built a protocol for robot communication. The developed system is demonstrated to function in the frequency band over 80 MHz. The protocol is coupled with a sound source localization system in robot applications. In [17], Benavidez et al. provided a workable navigation and robotic swarm communication approach in many autonomous applications. ZigBee radio modems and an extensible protocol that can handle various data formats are used for communication. In [18], Ünal et al. described the design of a communication robot system for farming applications involving many robots. The devised system broadcasts the temporal and geographical data of the mobile robots wirelessly over Wi-Fi by combining a GPS receiver with a digital compass. In [19], Salameh et al. investigated the capabilities of drones in indoor environments, as shown in Figure 2. The technique they suggested for adaptive power channel assignment attempts to reduce the per-drone. In [20], Yoo et al. proposed Net-Drone as a multi-drone platform for applications requiring several drones to cooperate. Robust network functions enable Net-Drone to act as a drone fleet control system. In [21], Wang et al. started by taking a look at the protocol architecture and FANET topology. Next, several cloud-based stability control systems and distributed gateway selection algorithms are discussed. In [22], Manasa et al. discussed a novel wireless communication method between the UAVs and the control station. In [23], Luo et al. outlined the communication and network technologies that support drone disaster management systems, reviewed the most recent advancements in drone-assisted disaster management applications, and reviewed the most recent advancements in drone-assisted disaster management applications, such as data collection, emergency communication, early warning systems, search and rescue, and logistics, and presented their initial research to illustrate the advantages and difficulties of drone systems for emergency communication.

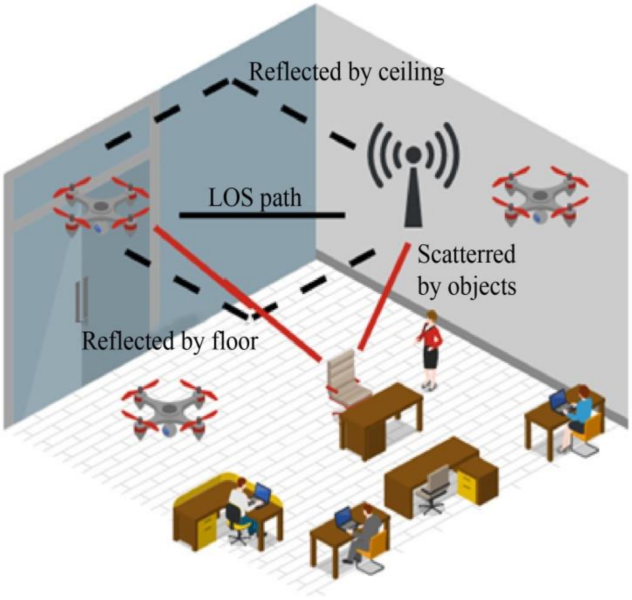


Fig. 2 A network of drones [19]

Lastly, discuss the features and difficulties in designing drone disaster management systems. In summary, previous research in this area only offered partial answers and neglected to address problems holistically; in contrast, the approach used in this study attempts to provide a whole answer.

3. Proposed Framework

As seen in Figure 3, by developing a communication system based on a new additive protocol layer amongst heterogeneous machines, the proposed framework replaces human power with heterogeneous machines. A network will be constructed of diverse equipment. Machines for anti-disaster support will be deployed to the designated sites.

3.1. The Structure of the Framework

3.1.1. Network of Heterogeneous Machines

Using a network based on the newly created additive protocol layer, machines will connect with one another, and information will be delivered from the machine to the control station.

3.1.2. Building Additive Protocol Layer

The new APL that supports communication between machines is implemented in a specified frame structure, allowing heterogeneous machines to communicate with control stations and other machines.

This layer includes headers and payload data for identification. The header and payload, along with the checksum, make up the frame structure.

3.1.3. CoAP Protocol

The CoAP protocol sends the frames by heterogeneous machines to exchange messages with the control station and one another. The machines detect disasters and victims and then send their location to the control station.

3.1.4. Control Station

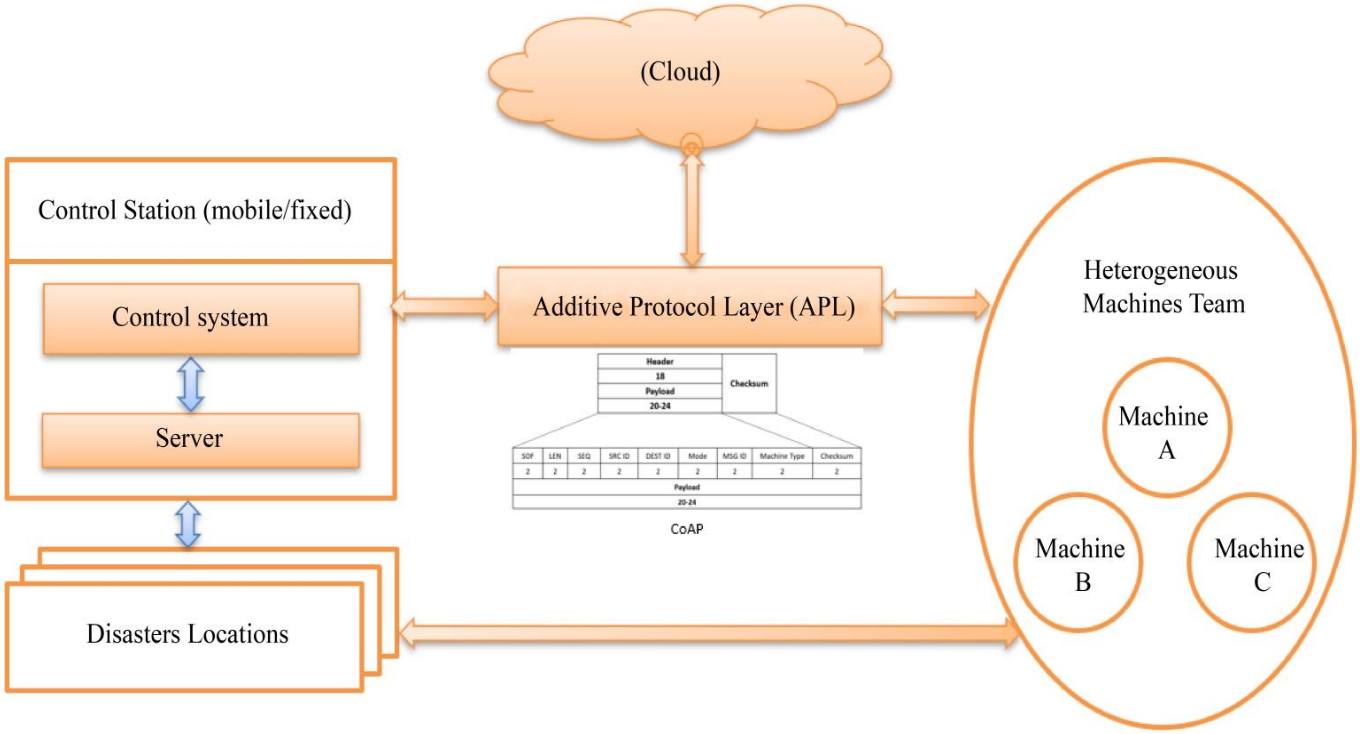
The control station (CS) aids in the command and control of the machines for different missions.

3.1.5. Applications of Heterogeneous Machines

Heterogeneous machines such as robots, autonomous vehicles, and drones have now become a very important and effective tool as an advanced solution for information gathering and disaster response actions regarding search and rescue operations. As shown in Figure 4 flowchart of the proposed framework, a machine network will be built between machines based on the additive protocol layer to be sent to search and rescue support in disaster locations; information will be sent from machines to control stations by network based on the APL.

3.2. Additive Protocol Layer Stack

Adopting a low-cost (lightweight) communication protocol that considers the communication limits of IoT components and heterogeneous machines is one of the main strategies to reduce energy consumption and delay and increase throughput. The protocol stack for the applications of IoT and the additive protocol layer for heterogeneous machines are shown in Figure 5.



Header	Checksum
18	
Payload	
20-24	

SOF	LEN	SEQ	SRC ID	DEST ID	Mode	MSG ID	Machine Type	Checksum
2	2	2	2	2	2	2	2	2
Payload								
20-24								

Fig. 3 Proposed framework

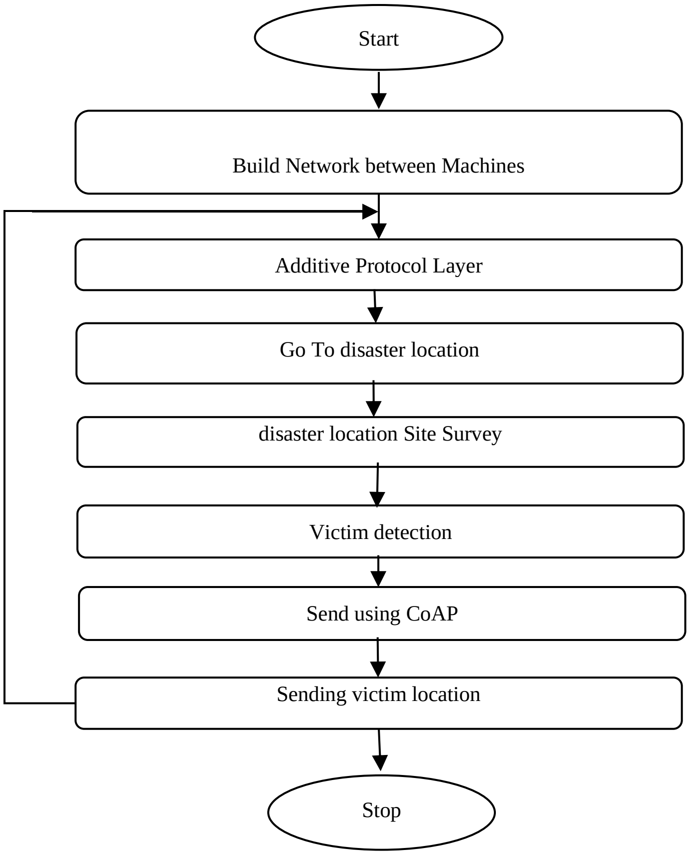


Fig. 4 Proposed framework flowchart

Extra Layer	**APL**			
Application Layer	Web-Socket, XMPP, AMQP, MQTT, DDS, HTTP, CoAP			
Transport Layer	TLS		DTLS	
	TCP		TCP/UDP	
Network Layer	RPL			IPSec
	6LoWPAN			
	IPv6 / IPv4			
Data Link Layer Physical Layer	Bluetooth LE RFID	GSM/LET	IEEE 802.11 WI-FI	IEEE 802.15.4 Zigbee

Fig. 5 APL stack for heterogeneous machines applications

4. Proposed Additive Protocol layer

This study presents a comprehensive approach that involves designing an additive protocol layer to facilitate communication between heterogeneous machines for search and rescue operations during disaster response. The header and payload, along with the checksum, make up the frame structure. The format of the frame of the APL is shown in Figure 6. The frame size is: (38 bytes for the robot - 42 bytes for the drone). The following will provide an explanation of the frame.

4.1. Header

All the payload that must be sent to the machines and the control station is contained in the header of the additive protocol layer frame structure. The header has eighteen bytes. It is predetermined in length and includes the fields listed below.

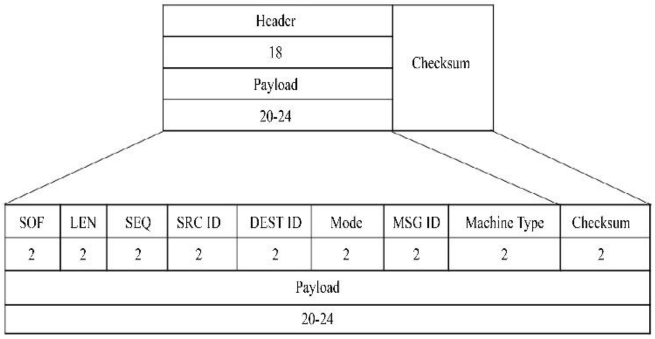


Fig. 6 Proposed frame structure

- SOF: The start of a frame in continuous transmission is indicated by the SOF. There are two bytes in the field. This signals the start of the next frame.
- LEN: This value indicates the payload's length. The payload, which has a length of two bytes, will be (Disaster Location (Latitude, Longitude, Altitude)/Machine Location (Latitude, Longitude, Altitude)). The payload is the original data or message that has to be conveyed.
- SEQ: The sequence of two bytes of the lengthy message may be assembled at the receiving end thanks to its division into multiple packets and numbered.
- SRC ID: Among the different Machines connected to one another, the system's uniqueness is ascertained through source identification. The source ID length is two bytes.
- DEST ID: The destination ID, which stands for Machine/Control station number, stores the address of the receiving destination. The destination ID is two bytes long.
- MSG ID: two bytes A message's unique identifier is called message identification.
- MODE: send to the machine or control station two bytes.
- Machine Type (robot/drone): two bytes.
- EOF: This signifies the conclusion of the preceding frame. A field of two bytes is present.

4.2. Payload

The initial flight data is contained in this; payload is: (20 bytes for robot - 24 bytes for drone).

4.3. Checksum Two Bytes

This is used to confirm the integrity of the data. The frame checksum is computed using ITU X.25 [22]. As seen in Figure 7, the source flowchart A fixed SOF at the transmitter's source side signals the beginning of a new packet. After the payload data is received for the first time, the Sequence field is initialized, and the payload length is calculated and delivered into the LEN field of the frame.

After the DEST ID is chosen and added to the frame, the SRC ID is created. After determining MODE, the frame contains the relevant value. A fixed EOF, which denotes the End of the Packet, is put at the final position of the frame. The payload data is added to this header, and the full frame's checksum is computed. The frame is now prepared for sending. According to the destination flowchart in Figure 8, the decoding process is carried out at the receiver side in accordance with Figure 8. acquiring the source frame at the recipient to confirm the accuracy of the data that was sent; the sent checksum and the received packet are compared.

5. Performance Analysis and Simulation

5.1. Simulation Tool (Cooja Simulator)

An open-source network simulator called Cooja is designed to simulate networks operating on the Contiki OS. Cooja is a versatile, cross-level simulator that enables nodes to be in varying hardware and software tiers [24].

The settings for the simulation are as indicated in Table 1 to run simulations for 5, 10, 15, 20, and 25 different node densities. Among the three possible node placement strategies, random, linear, and elliptic random node positioning is chosen to cover a network.

6. Performance of Additive Protocol Layer

6.1. Performance Metrics

Any network's quality of service may be used to gauge its performance. We use a few standout metrics, including throughput, latency, Packet Delivery Ratios (PDR), and Packet Loss Ratios (PLR) as the quality of service metrics. Figure 9 shows the network performance metrics.

Table 1. Parameters of simulation

Parameters	Value
OS	Contiki 3.0
Simulation Time	30 minutes
Simulator speed limit	No limit speed
Topology	Random
Mode start-up delay	1000 ms
Channel of Wireless	(UDGM)
Transport layer	User Datagram Protocol (UDP)
Type of protocol in the Network layer	IPv6/ RPL
Radio channel No.	26
CCR	128 Hz
Channel Data Rate	250 kbps
Range of (transmission/ interference)	(50 m/100m)
Tx/Rx Ratio	100%
Number of Nodes	5/10/15/20/25
Transmission rate/Traffic	1 packet of 38 bytes per 10 seconds
Data Length	38 bytes

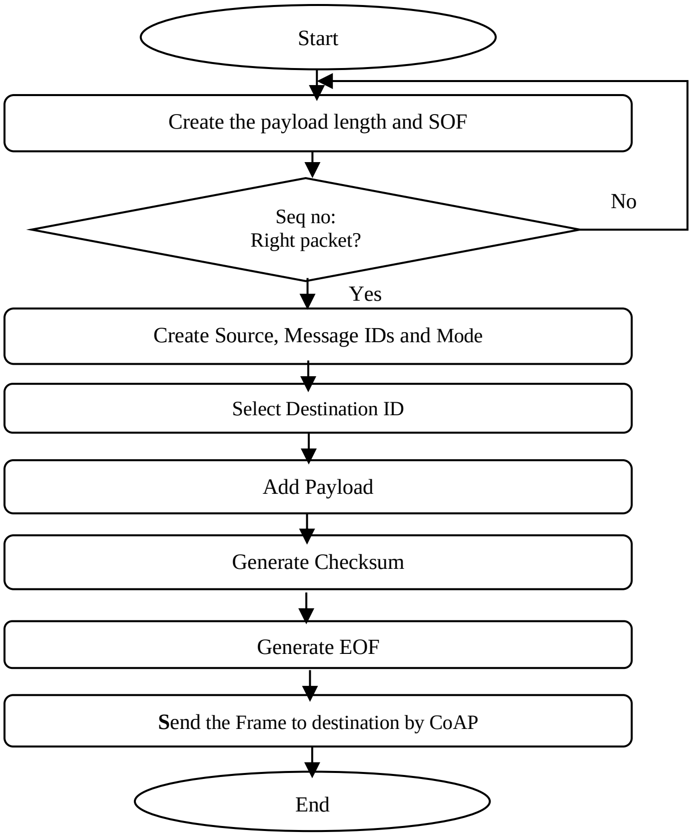


Fig. 7 Flowchart of the source

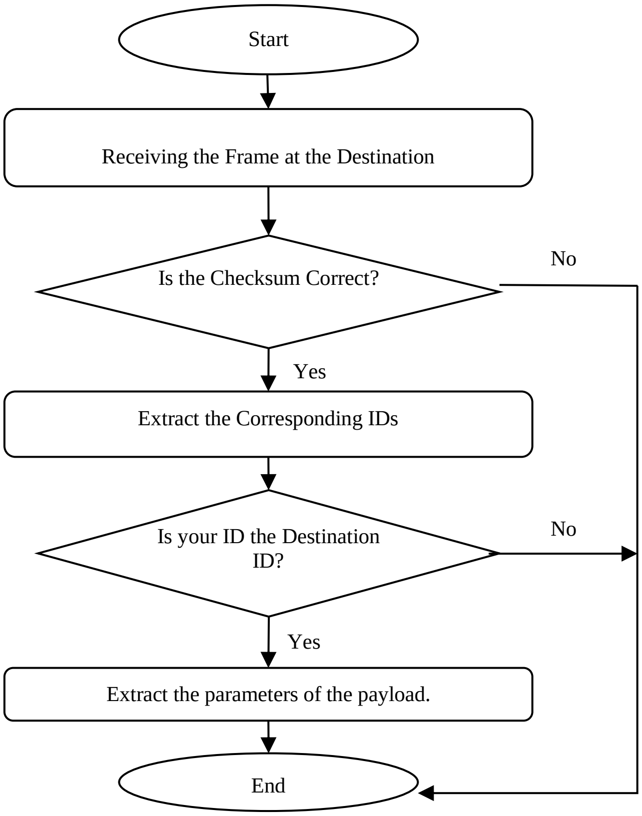


Fig. 8 Flowchart of the destination

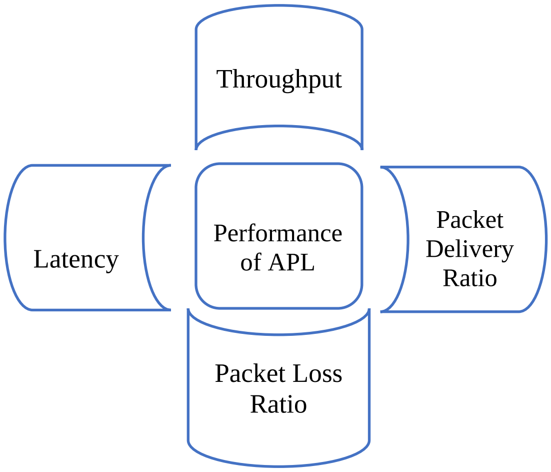


Fig. 9 Network performance metrics

6.1.1. Latency

A packet's latency is the entire amount of time it takes from when it is released until it is successfully received at its destination. The difference between the packet's sending and receiving times at the source and destination may be used to compute latency. [24]. It is calculated using equation (1).

$$Total\ Latency = \sum_{k-1}^{n}\big(Received\ Time(k) - Sent\ Time(k)\big) \quad (1)$$

6.1.2. Throughput

Similar to latency, throughput is likewise determined from the beginning to the finish of the packet's journey over the network. The network's traffic burden affects throughput [25]. It is calculated using equation (2).

$$Throughput = \frac{(No.of\ delivered\ packets*Size*8)}{Total\ duration\ of\ Simulation}\left(\frac{bits}{sec}\right) \quad (2)$$

6.1.3. Packet delivery Ratio (PDR)

The ratio of all the packets sent to a node and all the packets it receives is known as the PDR in a network. The network's dependability increases with increasing PDR value [24]. It is calculated using equation (3).

$$Packet\ Delivery\ Ratio = \left(\frac{Total\ Packets\ Received}{Total\ Packets\ Sent}\right) * 100 \quad (3)$$

6.1.4. Packet Loss Ratio

The PLR is the percentage of packets the sender sends that are not received at the destination. It is inversely correlated with the network's performance. It is calculated using equation (4).

$$PLR = \frac{Pkt_{lost}}{\mathrm{Pkt}_{\mathrm{rcv}} + Pkt_{lost}} \quad (4)$$

7. Performance Measurements of (APL)

The Additive Protocol Layer is implemented by the Cooja simulator. The test cases used in this work are shown in this subsection. Different density networks are established with the aim of observing APL performances under suggested scenarios. The network size and scalability are taken into consideration, and a variety of scenarios are included to highlight the influence of different circumstances. The parameter values for each of the scenarios are displayed in Table 2.

7.1. Latency Measurements

Figure 10 displays the latency values and illustrates how the delay increases with the number of nodes. The lowest latency reading is 10.79 ms at 5 nodes, 49.23 ms at 10 nodes, 66.67 ms at 15 nodes, 77.35 ms at 20 nodes, and 148.05 ms at 25 nodes. Growing packet collisions as a result of an increase in node count are the cause of this rising end-to-end delay.

7.2. Throughput Measurements

Similar to latency, throughput is likewise determined from the beginning to the finish of the packet's journey over the network. Figure 11 illustrates the throughput measurements for different numbers of nodes.

7.3. Packet Delivery Ratio (PDR) Measurements

The PDR of APL in relation to network size is displayed in Figure 12. According to the simulation's findings, the packet delivery ratio decreases as the number of nodes increases. Wherein a node can transmit data to several locations with identical minimum ranks. As the number of nodes rises, the packet delivery ratio falls, as seen in Figure 12. The packet delivery ratio is at its lowest of 92.4% at the 25 nodes and reaches its maximum of 100% at the 5 nodes. As the number of nodes increases, the collision domain expands, causing this drop.

7.4. Packet Loss Ratio (PLR) Measurements

The PLR is the percentage of packets the sender sends that are not received at the destination. The PLR performance of the network is displayed in Figure 13. It demonstrates a growing PLR as the number of nodes rises. The PLR peaks at 7.6% at 25 nodes and reaches its lowest value of 0% at 5 nodes. This rise is the consequence of the collision domain expanding to accommodate more nodes.

Table 2. Parameters values for different scenarios

No. of nodes **Performance metrics**	**5**	**10**	**15**	**20**	**25**
Latency	10.79 ms	49.23 ms	66.67 ms	77.35 ms	148.05 ms
Throughput	67 bps	131 bps	195 bps	254 bps	310 bps
PDR	100 %	98.27 %	96.78 %	95 %	92.4 %
PLR	0 %	1.73 %	3.22 %	5 %	7.6 %

The quality of service measures that were measured were latency, throughput, PDR, and PLR.

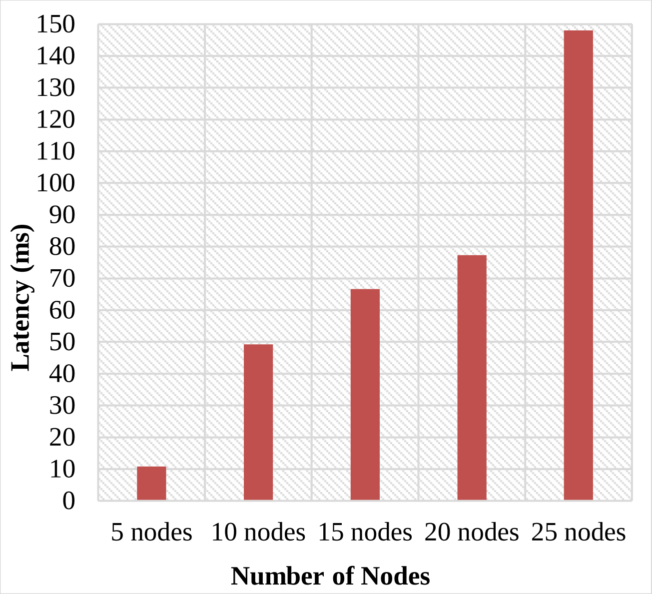


Fig. 10 Comparison of the Latency for different densities of networks

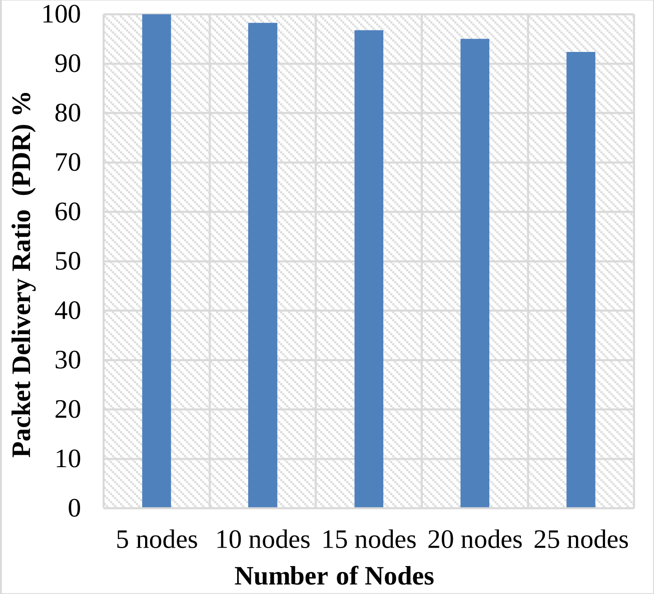


Fig. 12 Comparison of the PDR for different numbers of nodes

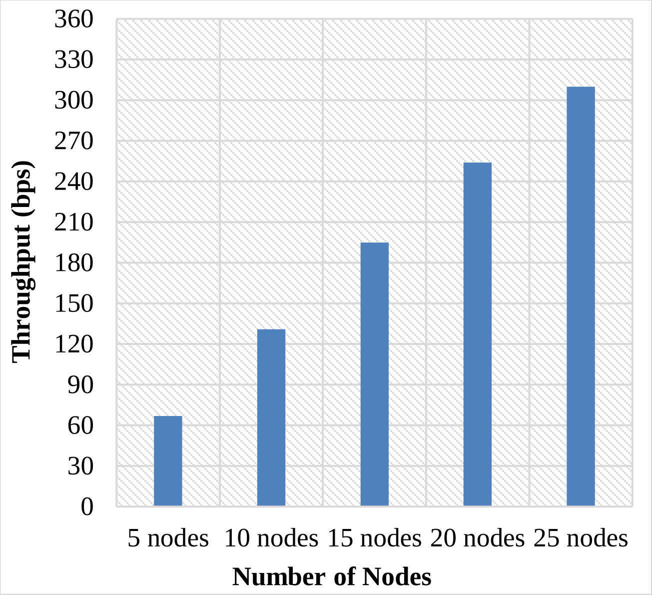


Fig. 11 The throughput measurements for different numbers of nodes

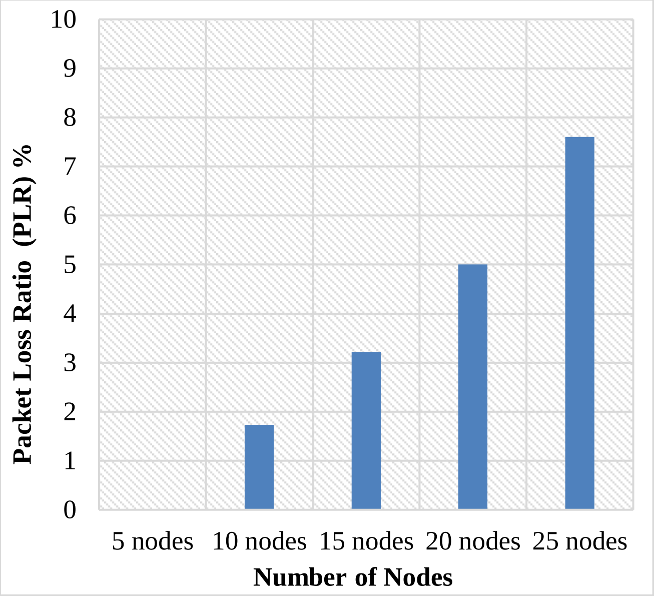


Fig. 13 PLR for different numbers of nodes

Table 3. The previous works limitations

Ref.	Scope	Network	Data rate	Communication Protocol						
				Frame Structure	Packet Length	Throughput	PDR	PLR	Latency	Range
[10]	Framework for intelligent machine-type communication (industrial, Robots, V2V)	IMTC	No	No	No	No	No	No	No	No
[11]	IOT protocols (D2D)	No	No	Message format	No	No	Yes	No	Message format	No
[12	V2V communication (in-vehicle/V2V)	Yes	No	format	Message Length 22 Bytes	No	No	No	No	short range
[13]	Robots Communications	No	No	No	No	No	No	No	No	No

[14]	Communications of mobile multi-robot	No	No	No	No	No	No	No	No	No
[15]	Indoor Multi-Robot Communication System	No	1 Mbps	No	No	No	average 47%	average 53%	No	No
[16]	Communication Protocol for Robot System	No	10 Mbps	Yes	8-262 bytes	No	No	No	No	No
[17]	Multi-Domain Robotic Swarm Communication System	Swarm	No	Yes	No	No	No	No	No	No
[18]	Multi-Robot Communication System for Precision Agriculture	No	No	Yes	Message Frame Length 2346 bytes	No	No	No	No	No
[19]	Networks of Indoor-Flying	No	No	No	No	No	No	No	No	No
[20]	Platform of Multi-Drone	Yes	No	No	No	No	No	No	No	No
[21]	Drones Networks	Yes	No	No	No	No	No	No	No	No
[22]	Micro Air Vehicle Communication Protocol	Yes	No	Yes	total frame is 114 bits	No	No	No	No	No
[23]	Unmanned Aerial Vehicles Communications for Disaster Management	(VANET) (MANET)	No	No	No	No	No	No	No	No
[28]	Communications of Multi-Robot	Yes	No	No	No	No	No	No	No	No
[29]	Drone Swarms Networked	Swarms	No	No	No	No	No	No	No	No
Proposed work	Additive Protocol Layer (APL) Heterogeneous Machines (IOT- Robots- Drones -V2V)	Teamwork	250 kbps	Yes	38 bytes	Yes	Yes	Yes	Yes	Yes

8. Comparison with Other Works

Our idea, as far as we are aware, is the first to provide support for the communications between the heterogeneous machines for use in anti-disaster support.; Tables 3 show the limitations of the previous work.

9. Conclusion and Future Work

An Additive Protocol Layer (APL) was designed in this study to support communication between heterogeneous machines for use in anti-disaster efforts. The APL was used to transfer data between machines and the control station, with the Cooja simulator employed for simulation purposes. The network's and APL's performance were evaluated. The performance metrics for the 5-node case were as follows: latency of 10.79 ms, throughput of 67 bps, packet delivery ratio of 100%, and packet loss ratio of 0%. The performance metrics for the 25-node case were latency of 148.05 ms, throughput of 310 bps, packet delivery ratio of 92.4%, and packet loss ratio of 7.6%. These values are considered acceptable compared with other works (packet delivery ratio of 47% and packet loss ratio of 53%) [15]. In conclusion, this solution will help save lives from the dangers of disasters while addressing previous disadvantages such as high costs, time consumption, and lack of accuracy.

9.1. Future Work

Improving the performance of the designed Additive Protocol Layer (APL) and using heterogeneous intelligent machine teams in more civil applications.

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