A D2D Based Captious Communication Architecture for Automatic Emergency Response and Disaster Management

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***Abstract*—Safety of the public To provide the best possible applications and solutions for disaster management, network communication technologies must crossover to the next generation of architecture. Even in the event of a disaster-related partial malfunction of the cellular architecture, the fifth-generation (5G) architecture is set to have a guaranteed network connection. This paper develops an automatic emergency response and disaster management (AER-DM) system that uses D2D communication technologies in fifth-generation n etworks t o f acilitate postdisaster communication. By passing the need for relay through a network design, it enables direct communication between nearby devices. A crucial D2D network is created when mobile nodes (MNs) under the compromised base station move to D2D communication mode if there is no cellular access. Through a nearby Wi-Fi network or base station, the MNs in the disaster area can establish an active network. Unlike many prior works, this model considers practical wireless channel impairments such as fading and interference, making it suitable for real-world disaster scenarios. To increase the data rate, energy efficiency of individual nodes and the overall network lifetime, a multihop D2D communication associated with the adaptive partial re-inforcement optimizer (APRO) is considered. The number of active participating nodes is then reduced by clustering, and the number of packets in the network is reduced via data aggregation. The proposed method is implemented in MATLAB, and the performance is evaluated via performance measures. Additionally, it is compared with conventional techniques.**

***Index Terms*—automatic emergency response, device-to-device communication, mobile nodes, disaster management, partial re-inforcement optimizer.**

I. Introduction

Networks for public safety and business could lose connectivity as a result of physical or natural disasters destroying the communication infrastructure [1]. Not only is a dependable communication system essential for data transfer, but it is also required for taking the right preventive actions and actions to save lives [2]. Because of factors such as economies of scale and traffic volume, features found in current Public Safety Network (PSN) standards such as Project 25 (P25) and Terrestrial Trunked Radio (TETRA) [3] are not supported in commercial networks. Commercial networks must improve their systems in the interim to guarantee high dependability, resilience, and other unique requirements of emergency services, such as prompt and dependable mobile communication in times of emergency [4]. The third-generation partnership project (3GPP) has begun research on the technologies needed for public safety communications, realizing the importance of PSNs and the chance to create common technical standards for commercial networks and PSNs [5]. The spectrum that is used determines how D2D communication is categorized. In the first category, referred to as licensed class or in-band, communicating devices use licensed spectrum resources to operate in either overlay or underlay mode [6], [7]. The unlicensed class, often known as the outband class, constitutes the second group. It can be further subdivided into two forms on the basis of the base station's (BS) involvement [8]: BS-controlled and BS-uncontrolled. Several difficulties face D2D communication technologies, such as mode selection, power control, resource allocation, and interference mitigation [9], [10]. Making sure that disaster management is in place is also crucial, particularly when sensitive data are exchanged. To minimize interference and increase total network throughput [11], [12], efficient resource management and skillful power management are essential. To solve the problems of optimal clustering and routing in 5G cellular networks, this study explores the use of metaheuristic algorithms [13], [14].

Recent observations from Italy, Nepal, and New Zealand show that the majority of the current networks were damaged in catastrophe areas as a result of earthquakes [15]. This had a major impact on the local population and complicated the work of the first responders. Many victims were left stranded in the disaster areas for several days. A public safety network system that can function effectively in emergency scenarios is necessary for such large-scale disasters [16]. Based on past disaster experiences and associated global projects, the academic community has made efforts to develop a variety of disaster-resilient networks. Creating robust network designs and solutions is the shared objective of all the endeavors [17]. However, the scope of this work is restricted to point-to-point communication with a single cell in an idealized circular coverage area [18], whereas in this work, we address the communication links throughout the multicell multihop network, where D2D relay links are used to extend the network coverage beyond a single cell [19], [20]. The goal of this project is to use optimal clustering and routing techniques to achieve automatic disaster management in D2D communications. The

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research's primary contributions are as follows: This paper develops an AER-DM system that uses D2D communication technologies in fifth-generation networks to facilitate postdisaster communication. By bypassing the need for relay through a network design, it enables direct communication between nearby devices. A crucial D2D network is created when the MNs under the compromised base station move to the D2D communication mode if there is no cellular access. Through a nearby Wi-Fi network or base station, the MNs in the disaster area can establish an active network. To increase the energy efficiency of individual nodes and the overall network lifetime, multihop D2D communication associated with APRO is considered. The number of active participating nodes is then reduced by clustering, and the number of packets in the network is reduced via data aggregation.

The remainder of the article is organized as follows: The research's relevant findings are presented in Section 2. A comprehensive explanation of the suggested architecture is given in Section 3. Section 4 presents the results of the suggested methodology. In Section 5, the paper's conclusions are provided. .

II. Related Works

Data communication between first responders and victims in the disaster area must be efficient for both emergency response and disaster management to be effective. First responders face an extremely challenging challenge when communication networks fail due to disasters. To provide solutions that are robust to disasters, research communities in both academia and the government have proposed several network architectures.

The emergency response was broken down into four stages in a study by Fei Sun et al. [21], and by merging the network features of the emergency response goals at each stage, the study examined the relationship between organizational collaboration and resource flows. Using a multisource mixed data approach, 381 organizations and 2496 organizational links were found for the Luding earthquake of 2022, which was chosen as a case study. Organization-resource two-mode networks and emergency response networks (ERNs) were examined for their dynamic evolution features via social network analysis.

Using cooperative devices with LTE device-to-device (D2D) communication capabilities, Enver Ever et al. [22] presented a performance model for PSN frameworks. D2D communications are used by cell towers that are not within the coverage area of cellular networks. In this scenario, cell towers located in a healthy area can serve as relay nodes [23], sending potential victims' locations to a central system. The interplay between relay nodes and base stations is a significant consideration in this study because relay nodes might become bottlenecks for relatively large-scale disasters.

5G standalone service (5G-SOS), a revolutionary completely 3GPP and 5G-compatible emergency call protocol, was presented by Vishaka Basnayake et al. [24]. A D2D multihop relaying protocol is used by a 5G-SOS-enabled emergency service to connect possible out-of-coverage victim devices to the 4G/5G core network. Keeping this link alive if a significant portion of the network infrastructure is destroyed is the aim of 5G-SOS. 5G-SOS is a completely distributed system whose parameters are adjusted in response to local emergency call congestion while producing zero extra control traffic.

Unique route-finding algorithms and a unique routing metric for D2D communication were introduced by Farrukh Salim Shaikh et al. [25]. MIIS (Metric for Interference Impact and SINR), a unique routing metric, chooses routes with reduced interference and higher SINR. In contrast to a distributed routing technique, reactive centralized routing, a unique route discovery mechanism, minimizes routing overhead by establishing D2D routes via BSs. Additionally, proactive centralized routing is introduced into reactive centralized routing.

The novel phone-based ECS LOCATE, developed by Luca Sciullo et al. [26], allows survivors and rescue teams to communicate over long distances in hazardous environments where 3/4G cellular connectivity is unavailable and traditional geo-localization technologies, such as GPS, can cover only a portion of the area. The suggested system comprises a smartphone app that is Bluetooth low energy (BLE) connected to a LoRa transceiver. Users can send emergency requests via the app, and such requests are relayed by peers until they reach a rescue worker who can address the problem.

For CH selection, Lithungo K. Murry et al. [34] introduced a novel nature-inspired squirrel search algorithm (SSA) that is fuzzy based. This approach passes the information through this relay CH after a UERCH has been chosen. The architecture establishes a multihop routing path with the assistance of an SDN controller to facilitate communication between emergency professionals and victims of natural disasters. A disaster-assisted communication system that uses two-cell cooperative D2D communications was presented by Zheng Chu et al. [35]. In particular, one cell is located in a disaster area, whereas the other is in a healthy area. Using an energy harvesting (EH) relay, a user equipment (UE) in a healthy area helps a UE in the disaster area recover wireless information transfer (WIT).

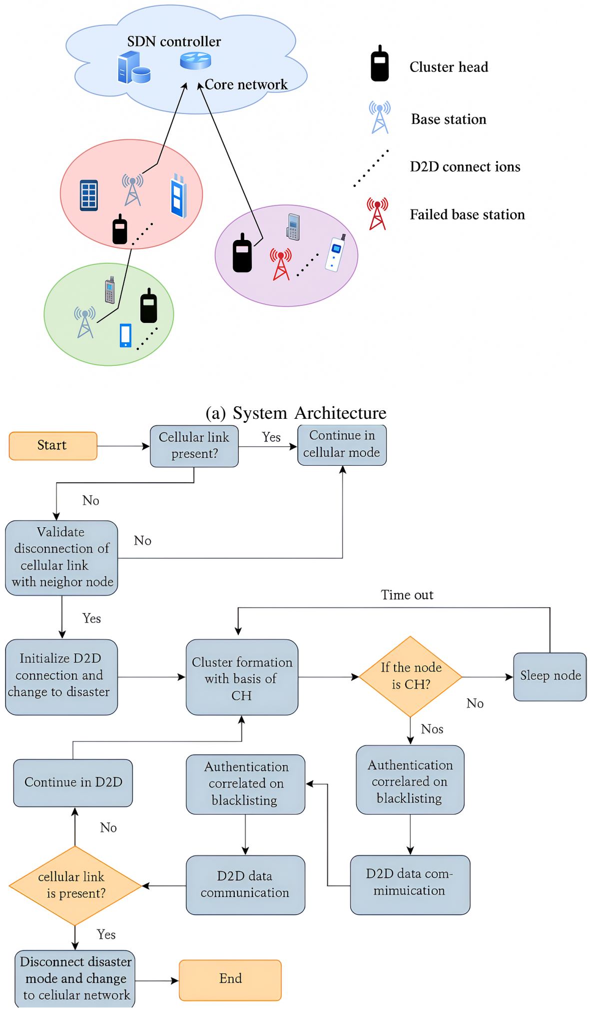
Data communication between first responders and victims in the disaster area must be efficient for both emergency response and disaster management to be effective. First responders face an extremely challenging challenge when communication networks fail due to disasters. To provide solutions that are robust to disasters, research communities in both academia and the government have proposed several network architectures. This study examines a disaster scenario in which a malfunctioning BS causes cellular connectivity to become unavailable as a result of the catastrophic event. Finding and reconnecting the isolated nodes in the disaster area is our main goal, and we do this by using the D2D link to replace the dead cellular connection and create a vital D2D network. Using an energy-efficient routing method further extends the life of this vital D2D communications network.

III. Proposed Architecture

A natural or man-made disaster might destroy the network architecture, allowing the MNs to completely or partially cut the cellular connection. In this instance, a disaster scenario is taken into account, as shown in Figure 1. Not all base stations malfunction; rather, if a base station is offline, the neighboring base station or the remaining HerNets are either partially or fully operational. Saving assets and living requires the MNS in the dead spot—the area without a cellular connection—to transmit vital information to the right place while taking the PSN control center into account. In this instance, we created an AER-DM model to lessen the impact of a disaster on the cellular network and demonstrated how D2D communications could lessen the damage by extending coverage that starts from a nearby, healthy base station to the damaged base station [27].

The cellular design is affected by a disaster propagation condition that is phased out in this proposed model by using a random base station. The inherent randomness of the consequences of disasters, which permits connecting the average architecture features during and after the disaster, is the implicit assumption of the random base station phase-out operation. The network's performance can be tractably validated and formulated via this random phase-out technique. We assume that the base stations are deployed following homogenous PPP with a particular base station density for the sake of simplicity and without sacrificing generality. The viability of PPPs was confirmed by contrasting them with actual deployments. Nonetheless, taking PPP into account while developing a cellular network makes it more tractable without requiring intricate system-level simulations. Furthermore, assume that the mobile nodes are dispersed randomly throughout the failure location. The greatest choice for quick and simple communication is multihop D2D as the cellular link is not available at the dead spot. Through a proxy base station, the mobile nodes beneath the dead spot can send data to the control center via the multihop D2D relay. Here, outband autonomous D2D communications are described as the use of the available unlicensed spectrum to decrease the degree of cellular link unavailability. Operating in the unlicensed spectrum inherently introduces real-world channel conditions such as interference and fading. These effects are explicitly accounted for in our routing and clustering models to ensure robust communication under post-disaster conditions. Furthermore, to utilize the unlicensed spectrum, MNs must provide an additional interface to accommodate other wireless technologies, such as Wi-Fi Direct.

From the standpoint of a disastrous scenario, network longevity is important yet difficult. Data aggregation and energy-efficient routing are used to restrict the energy consumption of the MNs, extending the overall lifetime of the network. The suggested approach uses an effective routing methodology that finds the best route from source to destination by using a low-cost function in the routing table. To store more assets and live, our main goal is to discover the isolated MNs, provide network access to them, and extend the network's lifetime so that data may be transferred from the catastrophe site to the management center for an extended period. Key motivations are said to be the projected D2D communications. The development of a communication architecture to meet public safety standards that emergency responders, police, firefighters, and ambulance drivers can use is the main goal of 3GPP Release 12. Reducing reliance on network architecture—which can malfunction in certain



(a) System Architecture

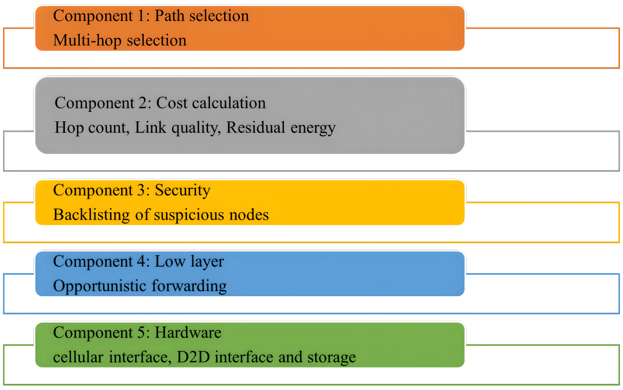
(b) Flow architecture

Fig. 1. (a) System architecture and (b) Flow Architecture

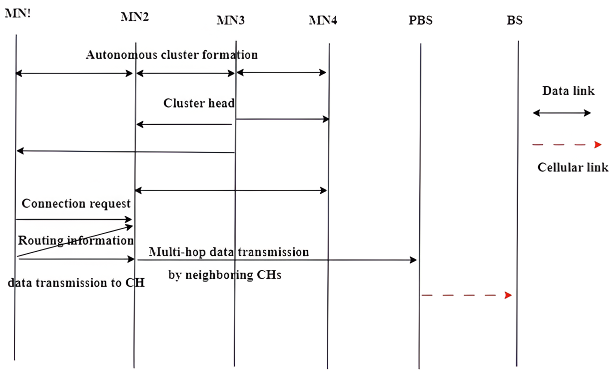
locations or during emergencies—enabling broadband connectivity and minimizing operating expenses are the goals. Furthermore, it is compatible with two essential technologies: group communication and proximity services.

A. *Automatic Emergency Response and Disaster Management*

We define the AER-DM in this part. It is an architecture that uses D2D relay mode instead of a cellular connection to find and reconnect isolated MNs in the disaster location. Sending data from isolated nodes to the active network closest to the disaster area is the goal of this D2D relay. The entire architecture is generated in an ad hoc and random fashion, requiring no additional hardware. The cluster-based data aggregation strategy, which divides the entire area beneath the dead spot into multiple clusters, extends the lifetime of the network. Each cluster has an ideal cluster head. With this configuration, the MN-to-MN relay function is available to any node independently of the base station. Each cluster's MN transmits data to the CH, which then compiles it and relays it to the next operational base station from its database [28]. By enabling coverage of the nearest best BS, the disaster zone can establish network connectivity. Considering SDN controller support from the core network, which has a network view on a global scale, the empowerment of the network connection is handled. The closest base stations (BSs) in the disaster area are managed by the central SDN controller, which enables cellular network coverage for D2D communications. In Figure 2, the elements of the suggested model are displayed.



(a) Components of the AER-DM



(b) CH and data transfer

Fig. 2. (a) Components of the AER-DM and (b) CH and data transfer

With an opportunistic forwarding technique, the lowest layer components can reduce the number of retransmissions and increase energy efficiency. Retransmission from the source node to an intermediate node that has a better link with the receiver node and receives the packet in the first transmission is the idea in the case of packet loss at the receiver node. The data link layer and network layer are where this paradigm is presented. The network longevity and efficiency are increased by this strategy by helping to decrease retransmission from the source. Every node in the network is given a cost parameter by the cost computation parameter, which retrieves information from the bottom layer parameters such as the hop count, link quality, and residual energy. Various cost metrics, including energy, link quality, and distance metrics, are considered to determine the best routing options. Path selection helps determine the best path from source to destination on the basis of the outputs provided by the cost computation parameter. In this situation,multihop-related route selection is used; the CHs between the source and destination serve as the relay. The blacklisting of nodesis utilized as the final security model to isolate questionable nodes that exhibit abnormal behavior throughout the routing process. The entire modules invoke the security model wherever possible to prevent any betrayal of confidence.

1) Finding neighbours and changing modes: Here, the cellular link state, location, energy level, and other data can be used by smartphones or MNs in the disaster area to determine a particular transmission model. Moreover, the MNs also broadcast a message to surrounding MNs to determine the phase of the cellular link once it is down for a predetermined length of time. The MN often transitions to the D2D disaster phase if the nearby devices confirm that the cellular connectivity has been disconnected. The closest MNs would then receive the direct beacon frames that the MNs had broadcast, allowing the nearby MNs to join forces to form a D2D network. Any device that detects a cellular network transmits the connectivity status to the other devices. Complete MNs are reconnected to the cellular network once the phases have been validated and the D2D mode is restricted.

2) Buffering and Clustering: Energy storage is necessary to extend the network's lifespan in the event of a calamity. By connecting the co-located mobile devices to form a cluster with a potential CH node, a clustering technique is applied to store energy. Several variables, including computing power, bandwidth availability, SINR, and battery life of the device remaining, influence the choice of CH. After the CH is selected [29], it unites the cluster under its supervision by sending greeting messages to the other cluster nodes. The remaining nodes send acknowledgment messages to verify the establishment of the cluster. To manage data packets and transmission, the cluster members are coordinated by the CH. Finally, a collection of CH-connected clusters forms in the disaster site. AER-DM uses a double buffer approach at the CH stage to speed up the rescue effort in the disaster region. Two buffers are used in the creation of the CH: one for data and the other for emergency information. While the data buffer holds the cluster member information that needs to be delivered to the network, the emergence information buffer stores vital information including area and medical data. The first task for the CH following a full cluster transformation is to request the emergency information from each cluster member, which is stored in the emergency information buffer. The CHs forward the first emergency information and then the data buffer if there is a sign of an optimal network connection. Therefore, important information is transmitted immediately. Rather than waiting for a connection signal, a cluster member that has to communicate data simply sends it to the CH and enters sleep mode. Information is stored in the data buffer by the CH, which only transmits it when a reliable network connection is detected. The new smartphones' increased memory capacity and lower memory costs confirm the buffering strategy.

3) Destination computation: If any MNs in the disaster area are linked to a live architecture by any method, including Wi-Fi or cellular, the other devices may also share a connection with the external architecture via the multihop D2D connection provided by the base station. The active architecture is achieved and relayed through the intermediary CHS. A node or base station with a live architecture is paired with the destination through dynamic routing table upgrades. To calculate an effective path to the destination, this SDN controller helps the MNs in the dead area. The best SDN controller at the core network can identify the severed cellular connectivity if a base station (BS) is unavailable. Then, by controlling the edge MNs in the active base station to link with the MNs in the disaster area through D2D communications, the SDN controller governs the close base station to increase the coverage of the cellular network. The corresponding BS in the dead spot's neighboring cell performs an algorithm and broadcasts the advertisement packets that flood over the dead spot location to create a base station for the MNs in a disaster area after receiving the control rules from the SDN controller. Information such as the mobile node ID, remaining energy, and maximum number of hops are included in the ADV packet. When a CH in a cluster successfully receives this packet, it copies and broadcasts it to the other CHs that are associated with the remaining constraints or the maximum number of hops, if specified. The CH and the remaining MNs in the catastrophe zone thus arrive at their objective. A few election factors, including link quality, the number of hops needed to reach the destination, computing power, and residual energy, are used to determine which node is best if it does not reach the destination. After the destination has been determined, the CH can use the EPRO approach to determine the best path there. Routing and clustering,which are based on EPRO principles are used to create an optimal and efficient network.

B. Proposed Routing Procedure

The base station serves as the destination node, intermediate CHs serve as relay nodes, a particular CH node serves as the source, and D2D serves as the connecting path in AER-DM routing, which is derived from EPRO. For the forward packets to reach the destination node in the suggested route, they must depart from the source node. In addition to upgrading the routing database via the fitness metric, each CH needs to determine the best route to the nearby relay CH node. The acknowledgement packets travel from source to destination with respect to the conventional fitness parameter. They then combine the forward packets' comparable paths in reverse order to upgrade the fitness table once more. The data packets will eventually be moving along the best path that is open to them. Route computation by full nodes will cause congestion and battery depletion if the number of nodes is high. Because fewer packets and nodes are involved, clustering aids in the management of this problem. The weighted undirected graph is the definition of the MN in the dead spot. Multi-hop communications can show a pair of neighbors for any node in the graph. To find and optimize the routing path between the source and the destination, EPRO uses control packets. This algorithm assumes that the architecture has a legitimate destination and uses two types of control packets, which are referred to as forward and backwards packets. To move from point A to point B, the forward data packets compute new routes and gather network information [30]. To reach the next hop connection on each journey, the forward packet selects the next hop node from the list of neighbors in the routing table at each node. The fitness function defines the data collected from the present path being examined. The fitness parameter increases if a control packet frequently travels along a certain path, and the parameter is discarded if a path remains idle for a specific period. Hence, the fitness parameter comprises both the past and present data instilled by the forward control packets and the backwards control packets. Additionally, the accumulated fitness parameter helps train the routes more properly, and the routing efficiency is increased.

1) Enhanced partial reinforcement optimizer: This method combines PRO with the restart strategy. In the PRO, the restart strategy is applied to resolve the local optima problem. The PRO algorithm's definition is given in this section. It is necessary to develop the PRE theory as an optimization algorithm to translate the ideas and guidelines of the algorithm to the parameters of the system. A human or animal that has to be trained or has qualities that need to be improved via theory—which is intended to be a solution—is referred to as a learner. Behavior: A decision parameter solution characterizes a learner. A group of learners is referred to as the population in the algorithm. Fitness assessment: Using a user-defined objective function on the decision parameters, the fitness of each learner's attributes is determined [31]. Time (interval): The number of iterations that separate two simulations, stages of reinforcement, or calculations that specify the learner's choice parameters during the search process is called a time interval. To increase a character's likelihood of being reinforced in subsequent iterations, the suggested method uses a scoring system.

Restart technique: These methods are used to keep the population from stagnating since they can assist fewer people in escaping the local optimum. When an individual's location has not improved, the RT [32] with a trailing parameter saves those times. If the person's location has not improved throughout this search, their trial parameter is improved by 1. If not, zero is set as the trial parameter. The location is changed to the best fitness parameter location, which is displayed as follows if the trailing parameter is not below the preestablished limit:

$$Y(T+1) = LB + RAND.(UB - LB). \tag{1}$$

$$Y(T+1) = RAND.(UB - LB) - Y(T). \tag{2}$$

Here, UB and LB are upper and lower boundss of the issue. The random opposition-based learning technique is used in place of the aforementioned equations to obtain the opposite position. If the trailing parameter is greater than the limit, the best solution derived from the aforementioned equations is selected.

$$Y(T+1) = (UB - LB) - RAND.Y(T). \tag{3}$$

Fitness function: When calculating the best route in D2D communication, the fitness function is taken into consideration. By taking the Euclidean distance function into account, the best routing method is strengthened. The calculation is as follows:

$$D_{X,Y} = \sqrt{(P_X - P_Y)^2 + (Q_X - Q_Y)^2}. \tag{4}$$

Here, $Y = (P_Y, Q_Y)$, $X = (P_X, Q_X)$ and $D_{X,Y}$ is the Euclidean distance between the X and Y nodes.In designing the fitness function, we incorporate key channel parameters including SINR, link quality, and residual energy. This ensures that routing decisions adapt to channel degradation caused by fading and interference conditions typical in disaster-hit areas with dense or disrupted wireless environments.

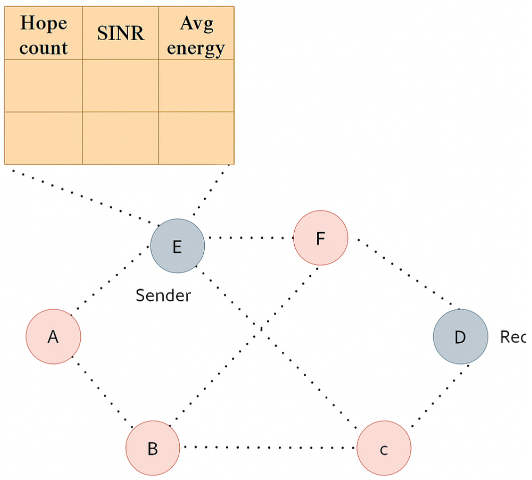


Fig. 3. Routing path selection based on the fitness table.

-4mm

Reaction: The main goal is to obtain more reactions. A successful improvement in the goal function parameter is referred to in this study as a response. Schedule: The notion of a schedule describes the qualities that must be modelled and reinforced at different intervals for a data design [33]. A higher score or priority has a higher probability of being chosen in the subsequent iteration since each scaler sets the priority or score of a particular learner attribute. Furthermore, a stochastic analysis is designed using the variable interval scheduling technique as a dynamic approach.

$$\tau \longleftarrow \frac{FE_s}{MaxFE_s}. \tag{5}$$

$$sr \longleftarrow E^{-(1-\tau)}. \tag{6}$$

$$\mu \subseteq \{1,2,3,...,N\}\forall J\varepsilon\mu, Schedule^{J} \geq Schedule^{*J}. \tag{7}$$

$$\lambda \longleftarrow \{\|\mu\|||\mu\| = [U(1, n\times sr)]\}. \tag{8}$$

Here, $Schedule^{*\lambda}$ is the schedule item, $Schedule^{*}$ is a schedule with a schedule based on sorted priorities, n is the complete number of characteristics, λ is the size of the selected subset, $\mu$is a subset of characteristics selected related to scheduling, sr is the selection rate, $MaxFE_s$ is the maximum number of function evaluations and τ is the time factor. Stimulation: When a simulation of a learner's behavior is created to elicit a response, functions that alter the parameters of a suggested solution are taken into account. Notably any function could be thought of as stimulating a learner's traits. The algorithm takes into account the following processes to provide new solutions:

$$sf_I \longleftarrow \tau + U(0,\bar{\beta}), \quad \text{where} \quad \bar{\beta} \longleftarrow \sum_{j\in\mu}\left(\frac{schedule_{I,j}}{\max(schedule_I)}\right). \tag{9}$$

$$S_I^{\mu} \longleftarrow \begin{cases} (x_{best}^{\mu} - x_I^{\mu}), & \text{if } RAND < 0.5 \\ (x_I^{\mu} - x_J^{\mu}), & \text{otherwise} \end{cases}. \tag{10}$$

$$x_{I,\text{new}}^{\mu} \longleftarrow x_I^{\mu} + sf_I \times S_I^{\mu}. \tag{11}$$

Here, $\bar{\beta}$ is the mean of a priority of the selected decision variables/mean of a normalized score and sf_I is the stimulation factor.

Algorithm 1 Pseudocode of the proposed algorithm

Initialization:
Initialize population
Generate schedules
Create restart technique
$Y(T+1) = (UB - LB) - RAND \cdot Y(T)$
while FEs $\leq$ Max FEs **do**
  for $I = 1$ to n_{pop} **do**
    Compute behaviors of the learner related to the scheduler
    Compute time variable $\tau \leftarrow \frac{FE_s}{MaxFE_s}$
    Compute selection rate $sr \leftarrow e^{-(1-\tau)}$
    Choose the number of behaviors with the highest priority
    $\lambda \leftarrow \{\|\mu\| \mid \|\mu\| = \lceil U(1, n\times sr)\rceil\}$
    Compute fitness function
    $D(X,Y) = \sqrt{(P_X - P_Y)^2 + (Q_X - Q_Y)^2}$
    Stimulate the selected behavior
    Update β and SF
    Apply bound constraints
    Apply negative or positive reinforcement
    if current fitness is better than previous fitness **then**
      Accept new characteristics
      Apply positive reinforcement
    else
      Reject new characteristics
      Apply negative reinforcement
    end if
    Upgrade the optimal solution
    Conduct rescheduling process:
    $\text{schedule}_I \leftarrow \begin{cases} U(0,1) & \text{if STD}(\text{schedule}_I) = 0 \\ \text{Do nothing} & \text{otherwise} \end{cases}$
  end for
end while
Save the optimal solution

Reinforcement: The following method is used to improve scheduling to conceptualize reinforcement. After that, positive reinforcement is used to increase a certain characteristic's score. After the stimulation stage's augmentation, the learner's goal function is used as a response.

$$Schedule_I^{\mu} \longleftarrow Schedule_I^{\mu} - (Schedule_I^{\mu} \times RR) \tag{12}$$

Rescheduling: When a student continuously receives negative reinforcement for every attribute, this theory outlines the process for implementing a new schedule for that student during learning. Here, this procedure is combined:

$$Schedule_I \longleftarrow \begin{cases} U(0,1) if STD(schedule_I) = 0 \\ Do nothing otherwise. \end{cases} \tag{13}$$

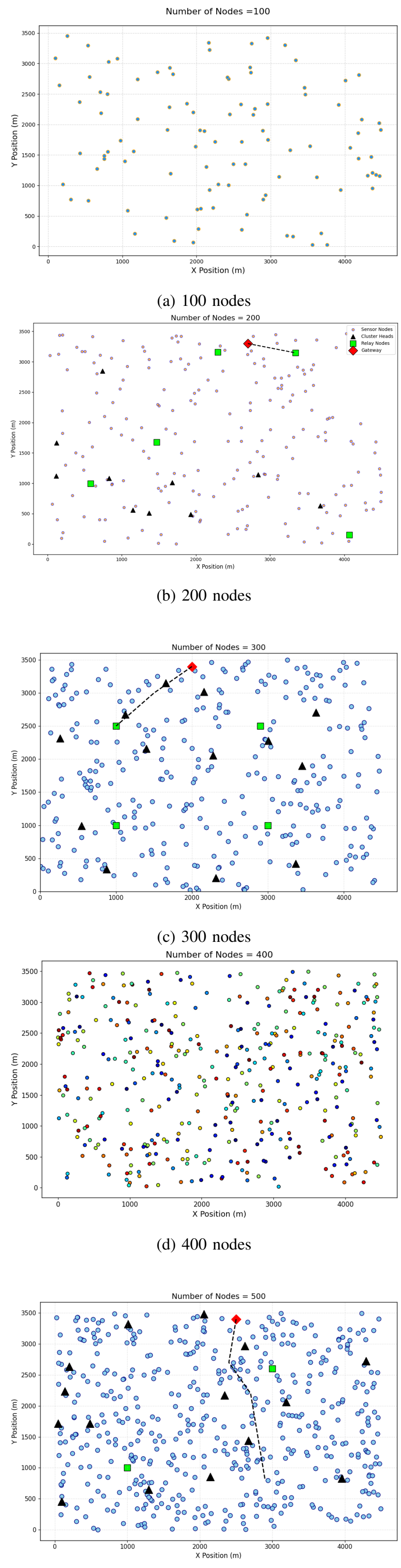
$$x_I = \begin{cases} U(U_b - L_b) if STD(schedule_I) = 0 \\ Do nothing otherwise. \end{cases} \tag{14}$$

Here, $U(U_b - L_b)$ and $U(0,1)$ are random parameters with a uniform distribution between $(U_b - L_b)$ and $(0,1)$, U_b is an upper bound, L_b is a lower bound and $STD(schedule_I)$ is the standard deviation of the schedule of a learner. This procedure yields the best routing for D2D communications, which is then used to strengthen disaster management.

IV. Results and discussion

This section involves the implementation and evaluation of the suggested method. Furthermore, a comparison is made with the traditional methods of different routing approaches. In D2D communications, the suggested approach aims to accomplish automatic disaster management and emergency response. Using MATLAB, the suggested method is implemented and contrasted with traditional methods such as FINDER, the ARNN+ACOA, and HeOp-DRL. The spectral efficiency, residual energy, overhead ratio, execution time, energy efficiency, delivery probability, data rate, fitness, and throughput are just a few of the metrics taken into account when the suggested approach is evaluated. The routing and clustering operations serve as the foundation for this disaster management system.To enable energy-efficient clustering, a residual energy threshold of 0.4 J is defined. We exclude nodes with energy below this threshold from acting as cluster heads, thereby ensuring a longer network lifetime. Additionally, for buffering control, a packet queue length threshold of 20 packets is set. When the buffer reaches this limit, data aggregation is triggered to reduce network traffic and conserve node energy.The implementation parameters are presented in Table 1. In the simulation process, data packet size of 512 bytes is chosen which can commonly be adopted in network simulation and communication protocols. It aligns well with many practical maximum transmission unit (MTU) values in wireless networks, ensuring realistic modeling. Moreover, in disaster scenarios, messages often include status updates, short alerts, or sensor data. These typically require payloads well within 512 bytes, making this size appropriate for evaluating message delivery and energy consumption. As shown in Figure 4, nodes are generated from 100–500 nodes to validate D2D communication.

As shown in Figure 4,nodes are generated from 100–500 nodes to validate D2D communication. As the number of nodes increases, the network becomes denser, providing more relay options for multihop D2D communication. This increased node availability results in shorter and more efficient routing paths, as evidenced by the greater number of direct



(a) 100 nodes

(b) 200 nodes

(c) 300 nodes

(d) 400 nodes

(e) 500 nodes

Fig. 4. Initialization of nodes: (a) 100, (b) 200, (c) 300, (d) 400, &(e) 500

TABLE I
SIMULATION VARIABLES.

S.NO	Description	Parameters
1	Network size	$4500 \times 3400\ m^2$
2	Number of nodes	$100 - 600$
3	Radio range	$100\ m$
4	α, β, γ	1.5
5	Fitness reduction factor ρ	0.8
6	MAC layer protocol	IEEE 802.11n
7	Simulation time	24 hours
8	Initial fitness factor $\phi_{x,y}(0)$	0.01
9	Data packet size	512 $bytes$
10	Initial energy of nodes	4800 mJ
11	Energy to transmit	0.08 mJ
12	Energy to receive	0.05 mJ
13	Minimum D2D distance	∼1–2 meters
14	Maximum D2D distance	100 $meters$

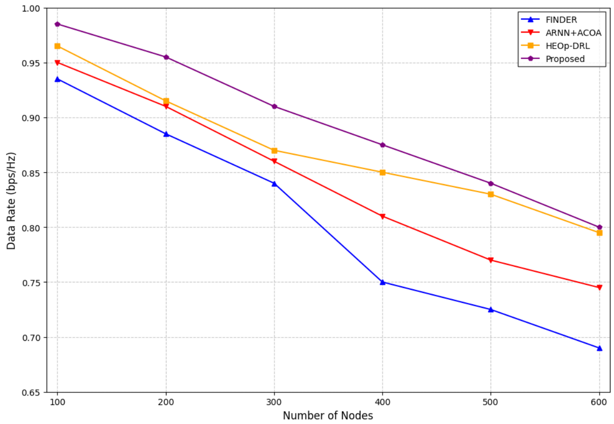


Fig. 6. Data rate.

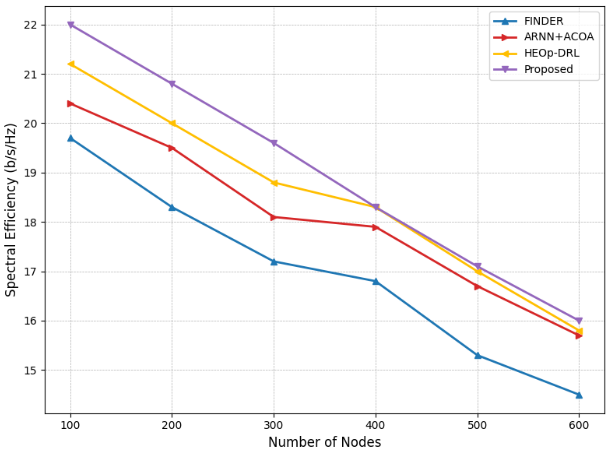


Fig. 5. Spectral efficiency.

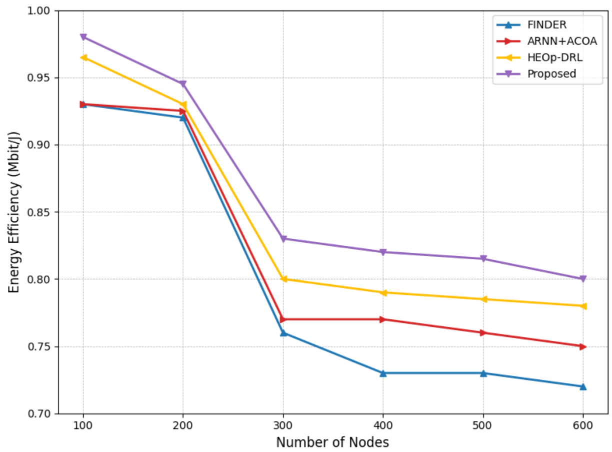


Fig. 7. Energy efficiency.

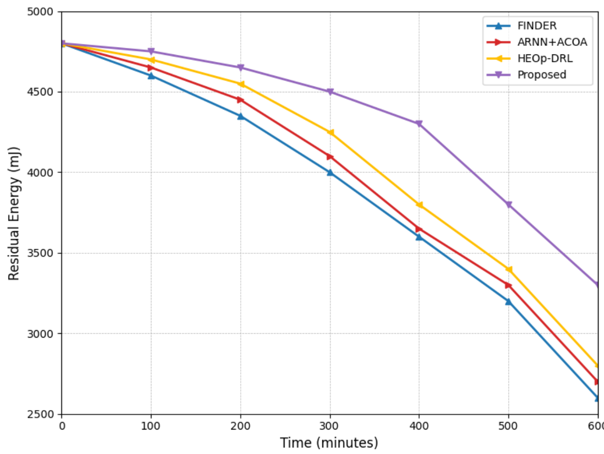


Fig. 8. Residual energy.

trajectories (dashed lines) between the source and destination in higher-density scenarios. At 100 nodes, the path is sparse and elongated due to limited relay candidates, but by 500 nodes, the path becomes more refined and compact, demonstrating improved network connectivity and reduced hop counts. This behavior reflects the adaptive efficiency of the proposed algorithm under increasing iterations and node counts, the algorithm utilizes richer spatial diversity to discover optimal routing routes, thereby increasing the message delivery probability while reducing the delay and energy cost.

Figures 5 and 6 present the suggested approach, which has been validated while taking spectral efficiency and the data rate into account. The spectral efficiency and data rate reflect the system's ability to utilize available bandwidth effectively. The proposed method consistently achieves superior values across all node densities. At 100 nodes, it attains a spectral efficiency of 22 b/s/Hz and a data rate of 0.99 bps/Hz, outperforming FINDER (19.85 b/s/Hz and 0.934 bps/Hz). These gains are attributed to the multihop D2D communication architecture that supports better spatial reuse and routing flexibility, as well as APRO's dynamic adaptation to link quality and network congestion.

Figures 7 and 8 present the suggested approach, which has been validated while considering energy efficiency and residual energy. Energy performance is critical in disaster networks where recharging or replacing devices is infeasible. The proposed system maintains a high energy efficiency of 0.98 Mbit/J and a residual energy of 4778 mJ, even under increased node activity. This improvement stems from APRO's cost-aware routing, which balances the load, minimizes retransmissions, and avoids energy-depleting paths. In com-

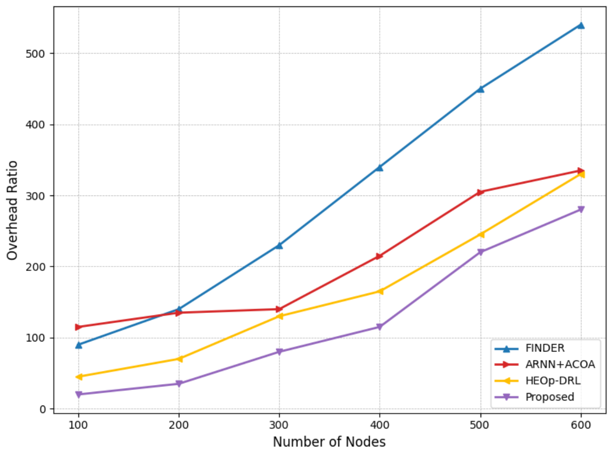


Fig. 9. Overhead ratio.

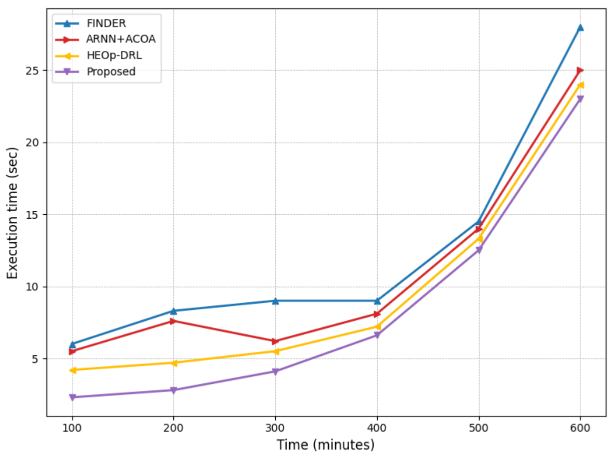


Fig. 10. Execution ratio.

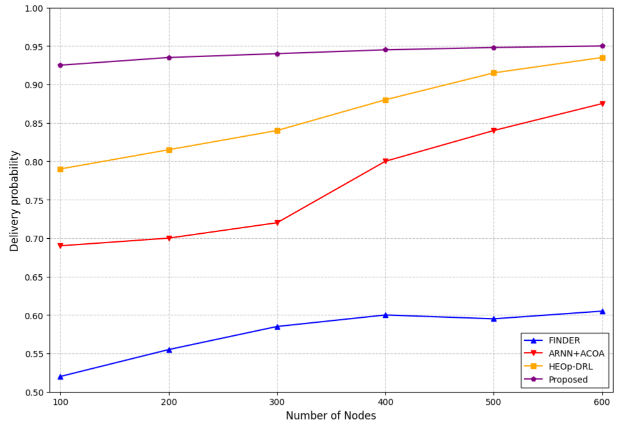


Fig. 11. Delivery probability.

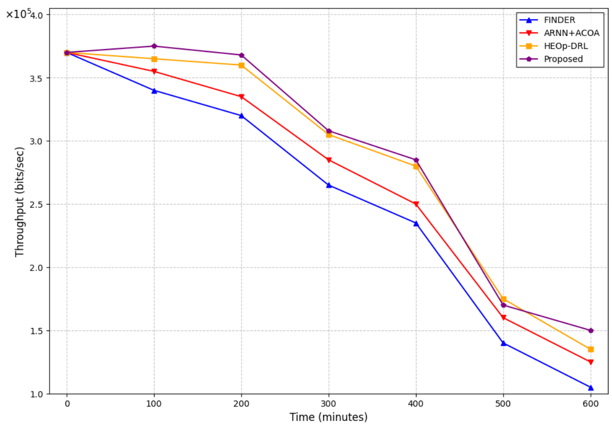


Fig. 12. Throughput analysis.

parison, FINDER and the ARNN+ACOA resulted in greater energy drops because of the use of fewer adaptive routing mechanisms.

Figures 9 and 10 present the suggested approach, which has been validated while taking the execution time and overhead ratio into account. The execution time represents how quickly the routing algorithm completes path discovery, whereas the overhead ratio measures the amount of control or routing-related traffic in relation to data traffic. A high overhead can congest the network, delay responses, and waste energy. In the AER-DM system, these issues are mitigated through clustering and data aggregation, which reduce the number of nodes involved in routing. Only CHs perform path computations, minimizing the computational load. Moreover, the APRO algorithm uses reinforcement learning to quickly converge to optimal routes on the basis of prior experience, eliminating repeated full-network flooding. These mechanisms collectively reduce the execution time to 2.38 seconds and the overhead ratio to 19.81, outperforming older methods such as the ARNN+ACOA, which suffer from longer routing delays and graeter protocol overhead due to reactive or nonoptimized path discovery processes.

Figures 11 and 12 present the suggested approach, which has been validated while taking delivery probability and throughput into account. The delivery probability is the percentage of messages that successfully reach their intended destination, whereas throughput (in bits/sec) measures the rate at which data are successfully delivered across the network. These are essential in emergency communication systems, where delays or losses can be life-threatening. The proposed system ensures a high delivery probability (up to 92.55%) by using multihop D2D relaying, which preserves network connectivity even when the infrastructure (e.g., base stations) is damaged. The routing flexibility provided by D2D paths allows isolated nodes to forward their messages through reachable peers. Moreover, APRO strengthens the stability of these paths by reinforcing routes with consistently good performance. Together, these features increase network throughput (e.g., 3.8×10^5 bits/sec), ensuring that urgent data, such as medical information or location coordinates, are delivered promptly and reliably.

The fitness evaluation with the convergence analysis is analyzed and presented in Figure 13.Initially, the fitness value starts at approximately 1.55×10^5, indicating a less optimal path or higher cost. As the iterations progress, there is a stepwise decline in the fitness value, indicating the algorithm's effectiveness in discovering better routes by gradually improving metrics such as residual energy, link quality, and hop count. At

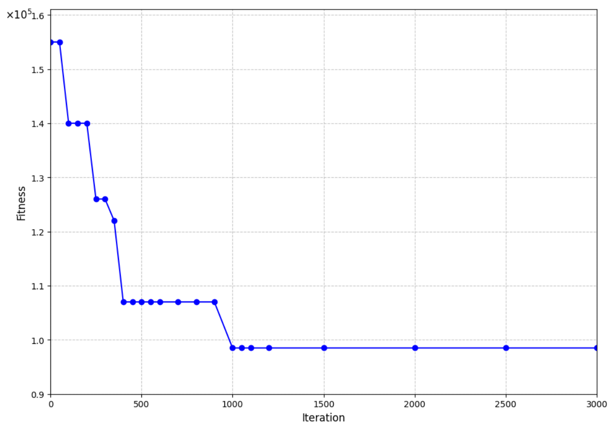


Fig. 13. Fitness analysis.

approximately iteration 1000, the fitness value stabilizes near 0.9×10^5,indicating convergence. This flattening trend suggests that the algorithm has reached a near-optimal solution, where further iterations produce diminishing improvements. This behavior confirms the algorithm's convergence capability and efficiency under practical network conditions.

A comparison of the results of the proposed methodology with those of published methods is presented in Table II. The proposed method achieves the highest energy efficiency (0.98), data rate (0.99), and delivery probability (0.9255), while also significantly reducing the execution time (2.3884 s) and overhead ratio (19.815). These results highlight its balanced design that maximizes network performance and sustainability, especially under disaster scenarios. In contrast, existing techniques often suffer from trade-offs—some show good delivery rates (e.g., Ref [22] at 0.95) but at the cost of higher overhead or lower residual energy. Others,such as the ARNN and HEOp-DRL exhibit acceptable energy efficiency but fall short in minimizing the overhead or execution time. Overall, the proposed method not only ensures reliable and timely data delivery but also prolongs the node lifespan, which is critical in emergency response networks. To provide a deeper understanding of the causal relationships between the proposed innovations and the observed performance improvements, we analyze the individual impacts of multihop D2D communication and the adaptive partial reinforcement optimizer (APRO) on key performance metrics. The multihop D2D mechanism directly contributes to a higher delivery probability (0.9255) and data rate (0.99 bps/Hz) by enabling robust connectivity even in the absence of a cellular infrastructure, as isolated nodes can reach operational base stations through dynamic relay paths. The decrease in the overhead ratio (19.81) and execution time (2.38 s) is largely attributed to efficient path selection and node clustering, which reduce redundant transmissions. Moreover, APRO plays a critical role in optimizing routing by continuously adjusting paths on the basis of real-time feedback such as hop count, residual energy, and link quality. This targeted optimization is reflected in the improved energy efficiency (0.98 Mbit/J) and sustained residual energy levels (4778 mJ), especially when compared to methods such as FINDER and ARNN+ACOA. Together, these design choices synergistically enhance network longevity, reliability, and responsiveness, with multihop D2D extending physical connectivity and APRO ensuring that the chosen paths are resource-efficient and dynamically optimal under changing conditions.

A. *Performance attribution analysis*

The observed performance gains are the result of a carefully integrated design where both multihop D2D communication and the APRO-based clustering and routing mechanisms play distinct and complementary roles. Multihop D2D communication enhances connectivity, delivery probability, and spectral efficiency by enabling mobile nodes to form peer-to-peer relay paths in the absence of a cellular infrastructure. This architecture is particularly effective in disaster scenarios, where base stations may be partially or completely offline. By allowing direct device communication across multiple hops, the system avoids bottlenecks and dead zones, thereby increasing the likelihood of successful message delivery. This directly contributes to the observed high delivery probability (0.9255) and improved data rate (0.99 bps/Hz), as more efficient and shorter paths become available dynamically across the network. Moreover, APRO contributes to energy savings, faster route convergence, and reduced control overhead through its reinforcement-based learning model. Unlike traditional static or greedy algorithms, APRO continuously evaluates routing options on the basis of real-time environmental feedback, including link quality, residual energy, and hop count. It reinforces the selection of consistently efficient paths and penalizes suboptimal paths, which accelerates convergence to stable, low-cost routes. When integrated with the clustering mechanism, where only cluster heads (CHs) handle routing decisions, APRO reduces the overall control burden and energy consumption across the network. This design accounts for the observed reduction in execution time (2.38 s), lower overhead ratio (19.81), and sustained residual energy (4778 mJ), confirming that APRO not only selects optimal paths but also selects optimal paths in a computationally efficient and resource-aware manner. Together, these two components create a synergistic effect: multihop D2D provides resilient connectivity, whereas APRO ensures that communication routes are energy-efficient, adaptive, and scalable. This dual-layer optimization is critical in postdisaster contexts where both infrastructure damage and energy limitations are common constraints.

B. *Computational complexity and deployment considerations*

The computational complexity of the proposed AER-DM system arises primarily from the APRO algorithm and the clustering-based multihop D2D routing. The APRO operates on a population of candidate routes (learners), with each learner's fitness evaluated iteratively on the basis of routing costs such as energy, distance, and link quality. According to the pseudocode and operations described, the complexity per iteration of APRO is approximately $O(P \times F)$, where P is the population size (i.e.,the number of candidate routing paths evaluated per cluster head) and F is the number of fitness

TABLE II
COMPARISON VALIDATION WITH ENERGY EFFICIENCY MEASURE.

Nodes	Energy efficiency	Data rate	Delivery probability	Execution time	Overhead ratio	Residual Energy
FINDER	0.9287	0.934	0.525	6.0374	86.721	4571.429
ARNN+ACOA	0.933	0.952	0.6887	4.7304	110.8158	4695.4
HEOp-DRL	0.9631	0.965	0.7915	4.0389	47.8158	4728.4
REf[21]	0.9512	0.92	0.68	5.87	75.96	4587
REf[22]	0.97	0.95	0.77	6.12	68.54	4258
REf[24]	0.915	0.93	0.85	7.84	54.48	4684
REf[25]	0.951	0.91	0.67	4.68	99.82	4154
REf[26]	0.948	0.89	0.62	4.87	77.12	3897
Proposed	0.98	0.99	0.9255	2.388417	19.81578	4778.532

computations required per learner. Since APRO incorporates a reinforcement mechanism and restart strategies, it maintains diversity and avoids local optima without needing exhaustive search. The overall complexity becomes O(P × F × I) where I is the number of iterations until convergence. In practice, owing to clustering, these computations are localized to a smaller number of CHs, significantly reducing the global processing overhead. As confirmed by simulations, even for dense networks (up to 600 nodes), the execution time remains under 3 s, showing that the method is computationally efficient for time-critical applications. In terms of real-world deployment, several practical considerations must be addressed. First, the use of outband D2D communication requires devices to be equipped with compatible interfaces (e.g., Wi-Fi Direct), which may not be uniformly available on all mobile devices. Second, in highly dynamic environments, maintaining cluster structures and accurate neighbor discovery could be challenged by node mobility or signal obstruction. Moreover, the buffering strategy demands sufficient local memory on devices to store emergency and general data before transmission. Finally, the reliance on SDN controllers for broader topology management assumes partial availability of infrastructure, which might not always hold in severe disaster zones. Addressing these concerns is essential for translating the proposed system into real-world deployments

V. CONCLUSION

This research has built an AER-DM system to enable post-disaster communication in fifth-generation networks by leveraging D2D communication technologies. It permits direct communication between adjacent devices by eschewing the requirement for relaying through a network architecture. When the cellular service is unavailable, the MNs under the compromised base station switch to the D2D communication mode, creating an essential D2D network. The MNs in the disaster area can create an active network by connecting to a neighboring Wi-Fi network or base station. Multi-hop D2D communication related to APRO has been considered to improve the energy efficiency of individual nodes and the overall network lifetime. The model's awareness of practical wireless conditions, such as signal fading and spectrum interference, strengthens its applicability in real-world emergency scenarios where ideal communication assumptions do not hold. Data aggregation is used to reduce the number of packets in the network whereas clustering is used to reduce the number of active participating nodes. The throughput, energy efficiency, execution time, overhead ratio, and residual energy have all reached optimal levels with the suggested methods. Compared with conventional methods, the suggested approach has produced optimal metrics in this validation. To achieve effective disaster management, new approaches will be created in the future and real-time disaster management data will be considered. The proposed approach achieves optimal results with a spectral efficiency of 22 b/s/Hz, residual energy of 4800 mJ, and an execution time of 3 seconds at 100 nodes, outperforming conventional methods such as HEoP-DRL, the ARNN+ACOA, and FINDER. These results demonstrate its effectiveness for enhancing D2D communication in residential microgrids.

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