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Consumer-Centric Disaster Data Collection in MANET Clouds Using Graph Neural Networks and Particle Swarm Optimization

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ABSTRACT: In disaster management for Mobile Ad Hoc Networks (MANETs), reliable and efficient data collection is required for timely emergency response. The study introduce a use of Graph Neural Networks (GNN) and Particle Swarm Optimization (PSO) to enhance data communication in disaster-affected areas. PSO is used to optimize relay node selection based on multiple factors like residual energy, connectivity, distance, and traffic load. GNN is employed to analyze the network conditions and to help routing decisions intelligently. The proposed framework executes data collection, duplicate elimination, priority assignment and data fusion to manage emergency information in an efficient manner. Disaster-aware routing improves reliability through adaptive path maintenance and priority-based forwarding. The proposed system is implemented in NS-2 simulator and evaluate effectiveness through various parameters, such as Packet Delivery Ratio (PDR), residual energy, Packet Drop, End- To-End Delay (E2E) and routing overhead. The purpose of the proposed approach is to achieve fast and reliable communication even in dynamic MANET cloud environments.

Keywords: MANET, Particle Swarm Optimization, Graph Neural Networks.

1. Introduction

Natural catastrophes such as earthquakes, floods, cyclonic storms, landslides and forest fires harm communications mechanisms and create barriers for effective exchanges of important information [1]. In such cases, prompt and reliable communication is vital for locating victims, coordinating rescue actions, providing medical support, and supervising environmental conditions [2]. MANETs represent a viable means of communication since they function without the use of a permanent infrastructure required for communications because of their ability to allow for the direct communication among mobile devices without requiring anything else [3-4].

In a disaster setting, MANET nodes are able to gather and transmit meaningful data to rescue teams, medical staff and disaster management services [5]. Still, due to high dynamics of MANET technology, there are many difficulties, including frequent changes of network topology, limited power of batteries, unstable connection, congestion, packet loss, and increasing communication delays. These obstacles decrease the effectiveness and accuracy of disaster data collection [6].

Currently many routing techniques are utilized for routing and data collection methods to handle these issues. For instance, AODV [7] is a routing protocol in which routes are established only when needed, while DSR [8] employs source routing to transmit data. Moreover, OLSR [9] retains the routing information to provide faster communication. Additionally, energy-aware routing protocols help save energy, clustering-based techniques gather various nodes together into clusters to permit fast communication, whereas priority-based approaches prioritize important data in emergency situations. Despite, these methods enable the improvement of communication in MANETs, it is still impossible to achieve effective outcomes because many obstacles such as node energy, connectivity, distance, link stability, traffic load and the priority of emergency data are tackled at once [10].

In order to address the challenges mentioned above, this paper proposes the application of a new consumer-centric disaster data collection framework in MANET clouds to ensure that disaster data is communicated promptly and effectively even in difficult condition. The main objectives of this research includes,

- GNN analyzes the arrangement of network and the connections between nodes to support routing decisions in a smart and dependable manner.
- PSO identifies the best relay nodes that consume less energy in a network.
- Consumer-Centric Data Collection consists of collecting the data, eliminating any duplicated data, designating the same priority to the data, and performing the data fusion to help with communication during emergencies.

2. Recent Works

Table 1: *Related works of existing method.*

Author/Year	Methods	Merits	Demerits
Anas Ali Alkasasbeh et al [2025]	SVM[11]	SVM delivers good classification accuracy and is effective with small amounts of training data.	It is costly when dealing with large mobile networks like MANET.
Hwanseok Yang et al [2026]	RF [12]	RF shows high accuracy, is capable of coping with many network parameters, and is less vulnerable to overfitting.	It consume more memory and lead to greater computation delay.
Kurkina et al [2026]	KNN [13]	KNN is easy to deploy and does not involve complicated training.	Once big data is used the process of prediction slows down and depends on the chosen neighbours' list
Hande et al [2024]	ANN [14]	ANN is capable of recognizing complex relations between network parameters and help achieve intelligent routing.	The method converge slower in large size networks.
Hassan et al [2025]	LSTM [15]	LSTM has great ability to track time-dependent changes in network environment.	It still needs longer training time and more computing resources.

3. Proposed Methodology

The proposed model GNN and PSO, ensures effective communication in emergency situations by providing secure communication services in areas affected by different types of disasters. The framework of the proposed work is shown in figure 1. In this study, information on disaster-related data, like victims' location, details about victims, requests for assistance and environmental conditions is collected. At the same time, network parameters are assessed such as residual energy, connectivity, distance, link reliability and traffic load. PSO technology helps to distinguish the most efficient relaying nodes with the least energy consumption and successful data transmission. Next, consumer-oriented techniques, including data gathering, data duplication removal, assignment of priorities, and data merging, appear are used. The processes regarding network graph creation, acquisition of local features of neighboring nodes, pattern analytics and routing implementation through GNN are handled. The routing system is managed effectively and characterized by the reliability of routing choices, implementation of prioritization and reduction of queue lengths to limit congestion.

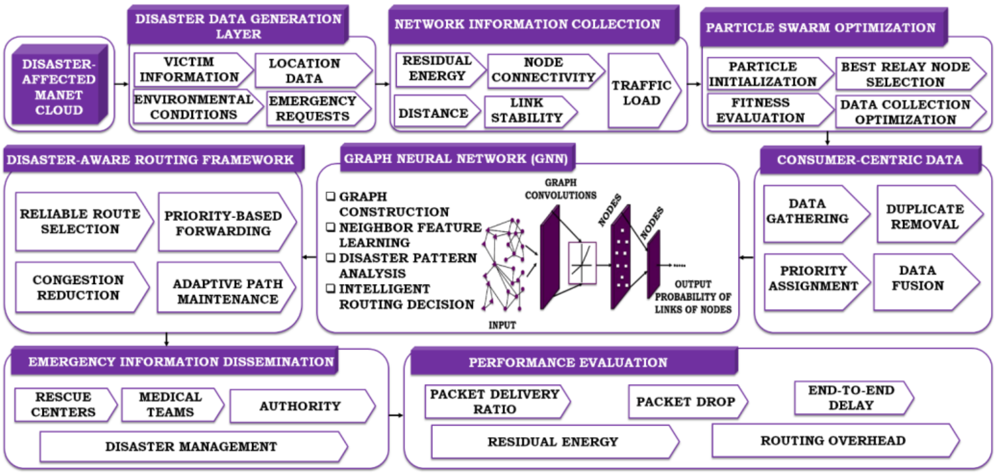

Figure 1: *Proposed framework*

Finally, the emergency data is transmitted to relevant rescue teams and the efficiency of the system is measured in terms of network parameters.

3.1 Disaster data generalization layer

The disaster data collection layer is essential for acquiring imperative data on accident events from users in MANET clouds. This operating layer seeks and obtains information relating to the characteristics of accident victims, as well as their locations, and assesses user requests for emergency services, and the condition of the environment in which the disaster occurred. The information gathered is beneficial because it helps to locate users and the conditions surrounding accident events, so an effective approach to disaster data gathering is employed as discussed further.

3.2 Network information collection

The Network Information Collection layer is essential for gathering the relevant characteristics of the network necessary for effective consumer-based disaster data gathering in MANET clouds. Network parameters include the residual battery level of mobile users to prevent situations of premature breakdown of nodes, their successful link, and the distance between mobile nodes to guarantee efficiency in data transmission. This layer also assesses the link stability to preserve the connection as reliable as required and analyze the traffic load of network to avoid congestion.

3.3 Particle Swarm Optimization

The proposed PSO method is applied for the selection of suitable features or nodes for detection. The PSO begins with a variety of particles, with each individual indicating a solution for detection. The position and movement of the particles is described as,

$$P_i = \{p_i^1, p_i^2, p_i^3, \ldots, p_i^D\}, i \in \{1,2,3,\ldots,M\} \quad (1)$$

$$V_i = \{v_i^1, v_i^2, v_i^3, \ldots, v_i^D\}, i \in \{1,2,3,\ldots,M\} \quad (2)$$

Where, p_i^D indicates position of d^{th} feature or node, M denotes the population size and D indicates the number of features or nodes which are optimized. The flow chart of PSO is shown in figure 2.

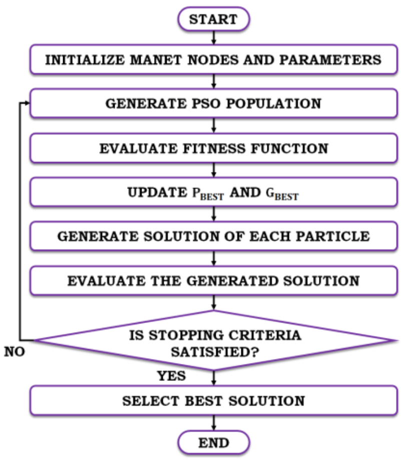

Figure 2: *Flowchart of PSO*

Each particle is evaluated due to fitness function regarding its detection capacity. The individual historical optimal solution p_{best} and the global optimal solution g_{best} are preserved together throughout the procedure of optimization. The solution is provided as follows,

$$o_{i,d} = \begin{cases} r'.p_{i,d} + (1-r)'.gd, if F_i > F_{kd} \\ p_{j,d}, & otherwise \end{cases} \quad (3)$$

Where, r' is the random parameter in [0,1], $p_{i,d}$ indicates the historical optimal position of d^{th} feature or node of i^{th} particle and gd indicates the global optimal position. F_i and F_{kd} show the corresponding fitness values. The solution is evaluated according to its detection capacity and the particle with the highest performance is used as a global optimal solution.

3.4 Consumer- centric data

The Consumer-Centric Data Layer works with disaster-related data gathered from consumers in the MANET environment. It collects data from users on mobile devices, sensor nodes and filters this information by removing duplicates to prevent unnecessary or redundant transmissions. It prioritizes vital information such as urgent requests and fuses data to combine similar information into a meaningful form. This mechanism greatly reduce data transmission costs, ensure high information quality and timely network responses.

3.5 Graph Neural Network

The proposed GNN is utilized for effective and reliable consumer-based disaster information gathering in MANETs. This dynamic MANET is portrayed as a graph $G(t)$ in which consumer mobile nodes are represented as vertices, while communication links serve as edges. Queries from each node provide information including the location of node, queue length and quality of the link for GNN processing, which is characterized by the following initial node representation.

$$h_i^{(0)} t = o_i(t) \quad (4)$$

The GNN collects information from neighboring nodes through different message passing layers. As a result, each node is able to acquire both local and overall information about the network. The node representation is defined as follows.

$$h_i^{(l)} t = \sigma\left(W^{(l)}\left[mean\left\{h_j^{(l-t)}(t) | j \in N_i(t)\right\}, o_i(t)\right]\right) \quad (5)$$

In this expression, $N_i(t)$ is the set of neighboring nodes, $W^{(l)}$ is the weight matrix and σ denotes the ReLU activation. The proposed process contributes to the tracking of such information about nodes and their state as connectivity, status of communication links, queuing state. The diagram of GNN is illustrated in figure 3.

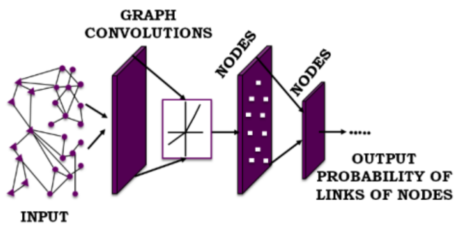

Figure 3: *GNN*

The process provides the final embedding of accumulated information about the local and neighbor nodes. During data gathering, neighboring devices share their current embedding through the control messages in circulation. The information exchanged is processed further, using

$$m_i^{(l)}t = mean\left\{h_j^{(l-t)}(t) | j \in N_i(t)\right\} \qquad (6)$$

$$h_i^{(l)}t = ReLU\left(W^{(l)}\left[m_i^{(l)}(t), o_i(t)\right]\right) \qquad (7)$$

The decentralized processing enables every MANET device to regularly receive updated information about its neighboring devices without relying on a continuously connected central device. The obtained representations allow determining suitable communication links for communication of emergency requests, victim data, location information and other disaster-related data to the necessary cloud resources. The established mechanism based on GNN enhances adaptability and dependability of disaster data gathering focused on consumers, and changing operating conditions of MANET network.

3.6 Disaster aware routing framework

The Disaster-Aware Routing Framework establishes the need of disaster-related information consumers through efficient information transmission paths established by MANET technology. The main purpose of this framework is to provide reliability in route finding so that best ones are established between consumer nodes and cloud resources to apply forwarding based on priority, diminish traffic in the network, and manage adaptive routing to address the frequent changes in the topology.

4. Results and Discussion

The evaluation of the proposed framework based GNN-PSO is evaluated using most important metrics of MANET performance. The parameter specifications are illustrated in Table 2.

Table 2: *Parameter Specifications*

Parameters	Values
Simulator	NS-2
Simulation time	50 s
Transmission power range	50mW
Node selection	PSO
Intelligent Routing Decision	GNN

Table 2 shows that the model was implemented in NS-2 with a simulation time of 50 s and transmission power of 50mW with the use of PSO for node selection and GNN for routing.

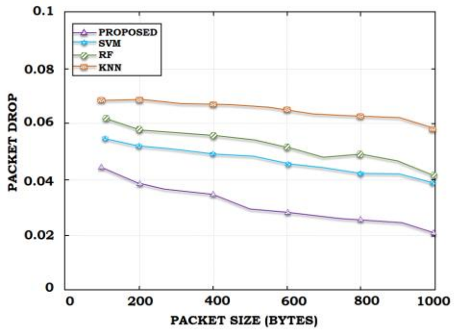

Figure 4: *Packet Drop*

Figure 4 indicates that the proposed method provides the minimum packet drop compared to SVM [11], RF [12] and KNN [13] for different nodes, which shows that the proposed technique provides reliable packet transmission.

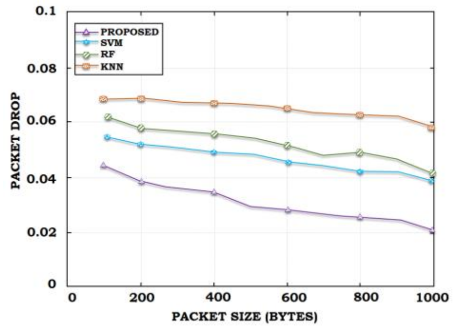

Figure 5: *Packet Drop*

Figure 5 indicates that the proposed method provides the minimum packet drop compared to SVM [11], RF [12] and KNN [13] for different nodes, which shows that the proposed technique provides reliable packet transmission.

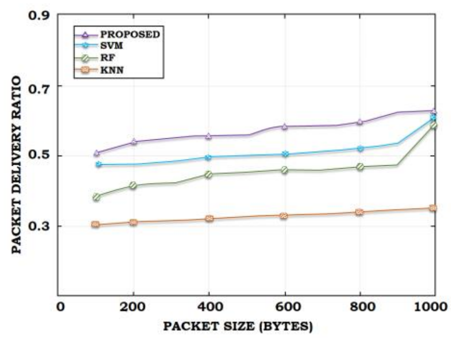

Figure 6: *PDR*

Figure 6 depicts that the proposed method leads to highest PDR compared to SVM [11], RF [12] and KNN [13] for all numbers of nodes. This method provides the maximum level of efficacy and is stable over the progression of experiment.

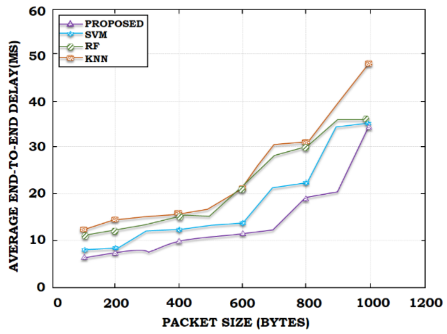

Figure 7: *E2E*

In Figure 7, the proposed method leads to minimum E2E between all methods compared, including SVM [11], RF [12] and KNN [13].

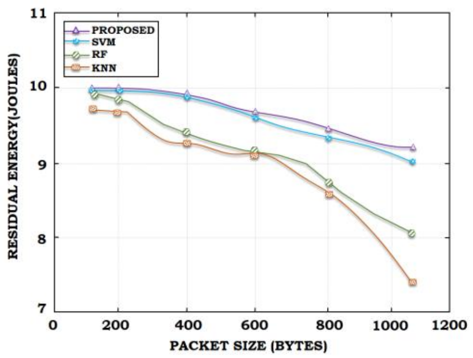

Figure 8: *Residual energy*

Based on the information illustrated in Figure 8, the proposed method maintains the highest residual energy, outperforming SVM [11], RF [12] and KNN [13] across every possible node count.

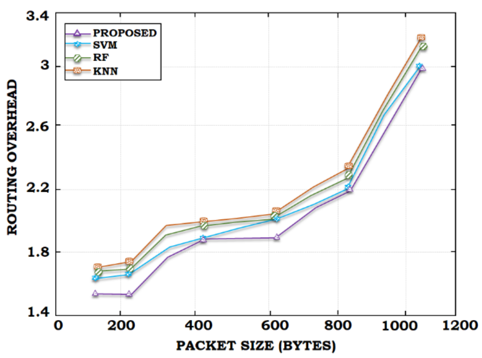

Figure 9: *Routing Overhead*

Figure 9 highlights that routing overhead compares with four protocols SVM [11], RF [12], KNN [13] and proposed method at various nodes. The proposed method demonstrates lower overhead, which indicates high efficiency in contrast to the previously mentioned systems.

5. Conclusion

The proposed GNN and PSO is capable of performing all the required operations regarding disaster-aware communication. The disaster data generation stage collects important emergency data, while the process of gathering network data helps to accumulate information on excess energy, connectivity, distance, link stability and amount of traffic load in the network. The PSO enables selection of appropriate relay nodes for the effective data collection process. The phase of consumer-oriented data processing performs duplicate data removals, assigns the level of priority and executes data aggregation. The use of GNN is possible to facilitate smart routing decisions relying on the peculiarities of network topology and disaster situation. The disaster routing framework ensures the establishment of reliable and flexible routes for the transmission of emergency information. The framework is implemented in NS-2 and the results shown highest PDR, residual energy and low Packet Drop, E2E and routing overhead, which proves the effectiveness of the method in disaster situations.

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