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Energy Efficient Multihop D2D Communication for Disaster

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***Abstract*—An emergency communication system is an important factor after a large-scale disaster to minimize damage. After the disaster, it's impossible to communicate with the victims, due to the communication infrastructure damage and the incapacity of the network. A smart Disaster Management (DM) framework integrated with the latest technology facilitates to automatic reconfiguring of the network to establish communication promptly and respond quickly to prevent damage. Device-to-Device (D2D) communication is able to establish the communication link promptly in absence of the Base Station (BS) or the communication infrastructure. This paper proposed an energy-efficient clustering algorithm for D2D communication for the emergency network. Our focus of this paper is to measure the performance of a DM network architecture energy-efficient relay-based communication to extend the coverage area and enhance the capacity and low energy consumption network.**

Keywords—Disaster network, D2D communication, Clustering algorithm

I. INTRODUCTION

In recent years, extreme weather severity has increased numerously worldwide due to global warming, climate change, human acts, etc. Globally, around 60k people die every year because of the disaster. From 2015-2022, 103377 people died due to the natural hazard. Establishing communication with the disaster-affected people and collecting information from them could quickly reduce impair of disaster, especially from large-scale disasters. After the disaster, an emergency communication system should be deployed promptly to communicate with the people in affected areas, as the first 72 hours are very crucial to save lives. Survival percentage depends on how fast communication between the affected people and the rescue team is established. 95% survival rate within 24 hours of rescue time decreases to 5% if the rescue time exceeds to 72hours. In contrast, establishing communication is the biggest challenge after large-scale disasters [2].

It is impossible to connect with the person inside the disaster area where the BS was damaged due to the disaster's impact. It reduces the delay of rescue operations, misleads the priority section, overhead the operation and increases the fatality ratio. As a result, it is essential to create a resilient wireless communication framework which will enhance the time delay, establish communication where the BS is damaged, enhance the connectivity, reduce traffic congestion and save device energy.

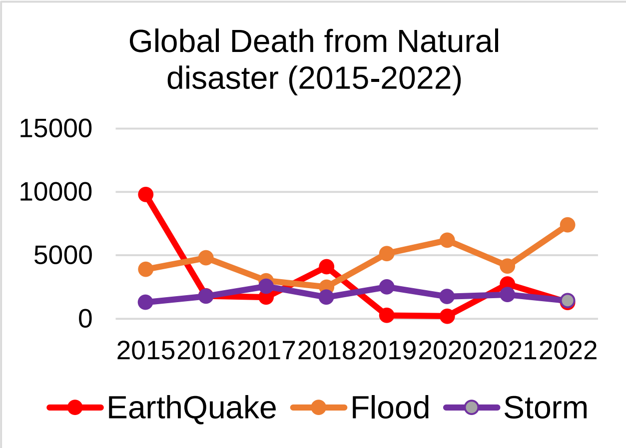

Figure-1: Death statistics from the disaster from 2015-2022

D2D based network can fulfil the requirement to establish an emergency communication network. Today, to satisfy the expectations and challenges of D2D-based networks, we intend to advance in various ways; some of the critical intentions or demands that need to be addressed are connectivity, better capacity, an improvement in transfer data rate, increase in the coverage area and enhance the quality of services. A sustainable DM network should be robust, resilient, and energy efficient. Better quality connectivity and energy consumption are imminent issues in critical and disaster communication scenarios. In addition, clustering is essential for energy efficiency in disaster communication. An efficient clustering protocol should be selected for reduced energy expenditure. In this context, selecting the clustering algorithm is very crucial for the emergency communication network.

In addition, another essential factor in the DM network is to transfer the of data from the user [5]. Entire network nodes are organized into many groups called a cluster. One member inside a cluster who communicates on behalf of the cluster is called the cluster head. CH collects all the cluster member data and forwards it to the next cluster until it reaches the Base station (BS). The large-scale communication network might have many clusters and CH. Data transmission to the BS in emergency communication can be done in two ways- one-hop and multi-hop. In both cases, data collected from CH will be responsible for the data transmission. In single hop data transmission, CH sends data directly to the BS. For multi-hop data transmission, CH is far from the BS end data to the intermediate CH to forward it to the BS [6]. The algorithm should be optimized and energy efficient. The contribution of this paper are stated as below:

1. Proposed a framework for disaster communication where the BS or the communication infrastructure is damaged or partially damaged.
2. Proposed an energy-efficient clustering algorithm where UEs are connected efficiently by grouping them into a cluster and using D2D communication with the close proximity devices to help reduce energy consumption during transmission.
3. Analysis of the framework in terms of coverage and enhance the connectivity of the non-functional area's UEs.

The rest of the paper consists of the following sections. Section II stated the literature review of the previous proposed work in the similar field. Section III described about the system model of the network and the scenario considered for the paper. This section also described the proposed energy efficient cluster algorithms. Section IV describe the simulation results and the finding of the proposed model. The section V conclude the paper with some future work discussion.

II LITERATURE REVIEW

Over the past few years, several researchers have proposed seamless communication technology for pre- and post-disaster communication. The existing communication infrastructures cannot handle the situation in case of Unexpected Events/ natural hazards as they may partially or fully damage the structure. The author [7] proposed a number of parameters of the communication infrastructure to consider for seamless connection in case of emergency communication. The parameters are resilience, robustness, reliability, self-reconfiguration, cost-effectiveness, energy efficiency, localization, coverage, QoS, and security [8]. In [9], authors introduced the D2D networks using physical layer relation concerning mobility, power and reuse spectrum. A local decision-making technique was proposed for the device and service discovery. However, the author considered the single-cell scenario, which will not meet the system's scalability criteria.

The author [10] proposed the solution robustness of the network for the pre and post-disaster by confirming continuous provide the power supply to the network using several power sources and deploying Software Defined Network (SDN). In addition, the author also proposed deploy of an emergency communication network for network recovery and resilience. Deployment of transportable network nodes such as AP, BS, mesh and ad-hoc network is also recommended for the end user device to make a quick response system.

The author proposed deploying an integrated Emergency communication system using the wireless sensor network (WSN) and MANET in the disaster affected area for local communication and data collection. MANET is created using IEEE802.11s wireless mesh network. This mesh network combines Mesh Access Points (MAP) and Mesh clients (MC). The area affected by the disaster uses remote communication and satellite gateway for communication. Based on the network condition, the end mobile users select the communication path, either the MANNET or the satellite link, for communication locally or remotely. This system is also used for the first responders involved in the response system [11].

The author explored the potential to deploy the UAV to integrate into the disaster emergency communication network as the UAV provide a high mobility, flexible deployment, and cost-effectiveness. However, UAVs also have some limitations, such as limited capabilities, resources, and coverage [12-13]. The author proposed power transfer to solve the problem of power limitation of IoT devices for data collection. Another study prosed and presented the combination of multi-hop D2D and Unman Aerial vehicles (UAV) to measure the performance of the downlink transmission capacity [14]. The coverage probabilities and DL performance were measured from UAV to end devices. In addition, the author used a cluster-based communication model for the UAV. However, the author did not mention the clustering technique. The author investigates the stochastic geometric framework for the cluster formation of UAV-based AP to analyze the ground user's coverage probability and optimize the network's energy consumption.
In addition, the author also investigated the key parameter influencing the network's performance. It identified the UAV altitude, transmission power ratio and optimal number of UAVs in the cluster [15]. A machine learning-based clustering algorithm proposed by the author is effective for both UAV and D2D services [16]. The author also described the advantage of using AI in the clustering to get the network's high performance and optimize energy consumption. The author proposed merging UAVs with the LoRa network to establish IoT devices for communication during disasters. These LPWAN network benefits can handle thousands of devices [23]. The author proposed the LoRaWAN Mac and showed that LoRaWAN could handle millions of devices in the case of end devices, only the intermittent uplink traffic [17]. The author suggested another energy efficiency data transfer in D2D communication by using social network information [18]. However, the author did not consider the user's mobility and did not include the disaster context. Another emerging technology, big data based disaster management, is proposed by the authors [19-20]. The information and data analytics was described for the disaster scenario. However, there needed to be more implementation of the result, which should have mentioned how the data would be collected for damaged infrastructure in the disaster area. The author [21] proposed multi-hop D2D communication in the practical test bed and showed improved energy consumption, network delay, link quality and coverage. However, it was not mentioned about the real-life scenarios where a massive number of devices will be present and how effectively the system will handle the system.

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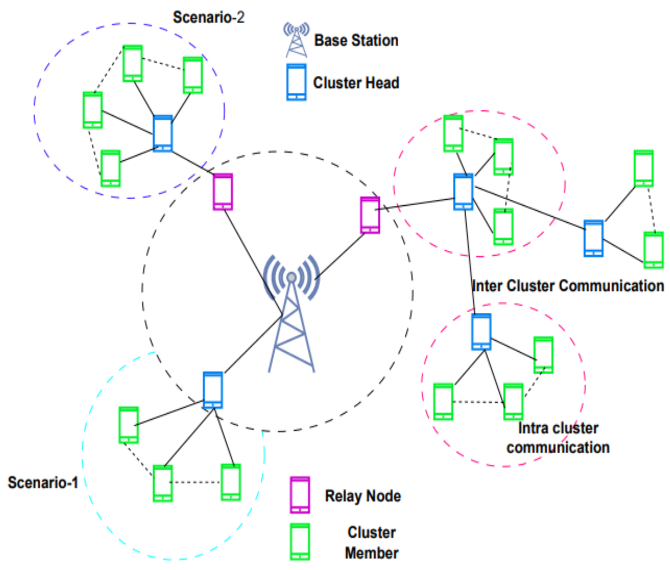

Figure-2: Proposed system model of the DM network.

In this paper, we proposed a D2D communication based disaster response framework and investigated the effectiveness of the framework in terms of coverage probability, network capacity, energy efficiency and overall system performance with different scales of the disaster damage on the network concerning the area size.

III. NETWORK MODEL

The proposed energy efficient framework for the emergency communication network is shown in the figure-2. The proposed model is a clustering based D2D communication allowing to enhance the coverage and connectivity. It was considered the following assumption for the disaster framework.

- A heterogeneous cellular network that has L tier.
- The N number of UEs are distributed in the network homogeneous Poison Point Process (PPP) θ_{UE} with the spatial density λ.UE
- The relay node with the spatial density The relay node has the capability to select decode and forward protocol to receive and forward information toward the BS.
- The battery level are randomly distributed toward the UE. The energy level of the UE are from E_min to E_max.

There are two different situations are considered for the disaster framework for the energy efficient and extend the connectivity and coverage.

Scenari-1 (Partial damage): In this scenario, the CH are reside in the BS coverage range. CH can directly get the radio resource management (RRM) information from the BS. The

BS also receive information of the cluster member or other cluster information directly from the CH connected to BS.

Lets considered the M $M \in$**{1,2,3,….M$_{th}$}** cluster head connected with BS where Mth is the total number of CH. The CH can directly connected with BS and broadcast the information to the other cluster and inter cluster member.

Scenario-2 (Fully damaged): in this scenario, both CH and cluster members are outside the coverage of the BS. A Relay device which inside the network coverage help to transmit and receive signal from the CH. The CH select the relay device out of $R \in$**{1,2,3,….Rth}** where **R** is the total number of relay devices which is inside the coverage. The CH select the relay device based on the highest SINR.

The CH communicate with each other by the inter cluster communication and the cluster member communicate with the CH with the intra cluster communication. The inter cluster communication required higher energy and for the intra cluster communication it required less energy or transmit less power.

We consider D2D communication will be through CH to CH.

We also assume that there is at least one UE from each functional BS to serve a relay node with the cluster head in the disaster area. The outage probability of a link is the probability that SINR of the link falls below a predefined threshold level τ_{th} We consider that $\tau_{th}$is a known parameter.

At first, we calculate the outage probability of the link between BS to UE relay(UER) device. we use relay and UER interchangeably. We have consider the small scale fading channel condition between BS and UER which is denoted by the h_{BS-R} Therefore the received power at the relay node can be written as:

$P_{BS-R} = P_{BS} h_{BS} D_{BS-R}^{-\alpha}$

Where, D_{BS-R} are the distance between BS and relay node. α is the pathloss component. The SINR is can be written as below:

$$\gamma_{R_i} = \frac{P_{BS} h_{BS} D_{BS-R}^{-\alpha}}{I_R^{(i)} + n_R}$$

Where n_R are the thermal noise which can be negligible component to interference in a dense network. So the SINR of the BS to relay node link is which is also considered the first hop of the communication link:

$$\gamma_{R_i} = \frac{P_{BS} h_{BS} D_{BS-R}^{-\alpha}}{I_R^{(i)}}$$

The outage probability of the link between BSi and relay can be expressed as:

$$P_{BS,R} \cong P(SINR \geq \tau_R)$$
$$\cong 1 - \left(\frac{P_{BS} h_{BS} D_{BS-R}^{-\alpha}}{I_R^{(i)}} \geq \tau_R \right)$$
$$\cong 1 - (h_{BS} \geq P_{BS} D_{BS-R}^{-\alpha} \tau_R$$

The total outage probability of the system can be define by the outage link of the first hop which is BS to relay node or BS to CH, the second hop which is relay node to CH or CH to CH.

A. *CH selection*

From the beginning of the clustering phase, all the UEs broadcast the beacon, which has a battery label above the threshold Pth. Peer discovery resource is used for the beacon broadcast. The entire beacon signal consists of battery information, mobility information, and distance from the BS information. When the UE receive a beacon signal from the other UE, it calculates the SINR value. When the SINR value is below the threshold SINR value, UE can understand it is far from other UE. This UE select itself as a CH.

If the beacon signal is above the threshold value, then the UE decode this beacon signal. This signal can be received from the outside coverage UEout. When UEout receives the signal, it replies with a paging signal. This determines the total number of devices outside the coverage and the distance from the BS. It will also help calculate the number of hops required to transmit the data. When the UE receive a paging signal from the UEout, it broadcasts the beacon again to give information about the total number of devices outside the coverage area. UEout determine and compare the battery life among the devices. The devices that have higher battery life select themselves as CH. However, mobility is considered to select the CH when two or more devices have the same battery life. When both mobility and battery life are the same, then it considered the distance and hop required to send data to the BS are considered.

Algorithm 1 CH and Cluster member selection algorithm

Broadcast the beacon
N=Total no of UE
$D = 1, 2, 3, ..., N$ relative distance
$M \in \{1, 2, 3, ...N_M\}$=Mobility of UE
γ_{th}= SINR threasold
$x = 0$
for $i \in \{1, 2, 3, ...N\}$ **do**
  if $\gamma_{i,n} > \gamma_{th}$ **then**
    $N_i \leftarrow CH$
  else $\gamma_{i,n} < \gamma_{th}$
    $N_i \leftarrow ClusterMember$
    $\gamma_{i,n} = \gamma_{i+1,n}$
    if $D_{i,n} > D_{i+1,n}$ **then**
      $N_{i+1} \leftarrow CH$
    else $D_{i,n} = D_{i+1,n}$
      if $M_{i,n} > M_{i+1,n}$ **then**
        $N_{i+1} \leftarrow CH$

The device that have below of the battery label threshold value, received signal from the multiple UE that have higher battery label. The received SINR signal strength determine the CH of a particular UE. The UE determine the signal strength of the UE, the higher signal strength is consider the CH. However, when the two CH signal strength is same, then the distance from the node is considered.
The algorithm for selecting CH given in algorithm-1.

IV.SIMULATION AND RESULT

In order to evaluate of the performance of the proposed model of the cluster-based D2D communication for the disaster network, a simulation has been conducted. For the simulation MATLAB simulation software is used for verification and analysis. Users are randomly distributed in the cell using PPP. The parameter is used for the simulation are given in the below table.

TABLE-1: SIMULATION PARAMETERS

Parameters	Value
Simulation Software	MATLAB-R2019a
Cell Radius	1000m
Number of UE	200
D2D user distance	~50 m
System Bandwidth	5 MHz
BS Tx power	43dB
D2D Tx power	23 dB
SINR threshold	12dB
Decode threshold	-6 dB
Shadowing	Log-normal

The link between BS and the relay node is considered for the first hop communication. The energy consumption of this first hop communication is measured by the bit/Joule. Figure 3 shows the energy efficient performance of the first hop communication. The result shows the different distances between the relay node and the BS. The result shows that energy efficiency decrease with the increase in the distance between the BS and the relay node. When the distance is 100 m between the BS and relay node, the energy efficiency is stable at .38 Mbit/J. This is because of the fixed bandwidth. However, when the distance increase between the BS and relay node, the path loss exponent will change, and energy efficiency will decrease.

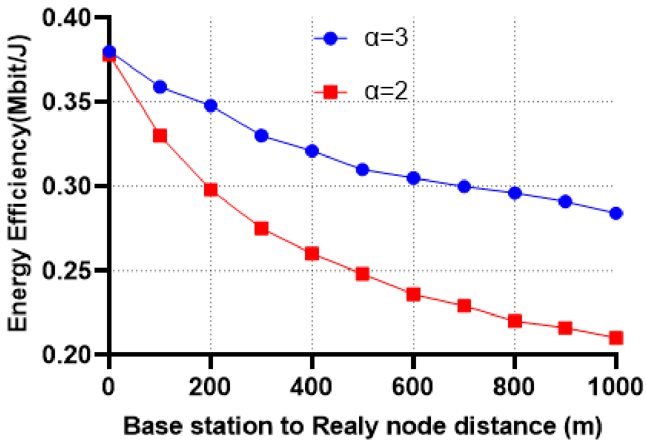

Figure-3: Energy efficieny vs the distance between BS to Relay Node

Figure 4 shows the second hop energy efficiency with the different distances between the relay node and the CH. The distance between the relay node and the CH is considered to vary from 50 m to 250 m. The result shows that it required more energy than sending data from BS to the relay node.

This shows similar pattern output compared with the previous figure. However, the second hop required more energy as no fixed bandwidth exists.

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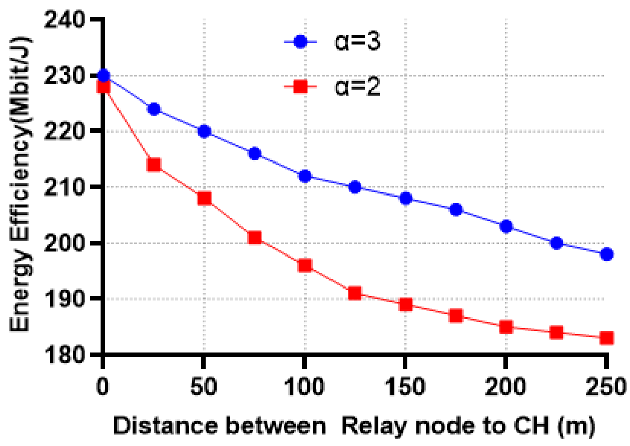

Figure-4: Energy efficiency vs the distance between Relay Node to CH.

Figure 5 shows the third hop energy efficiency with the varying distance from 0-50 m. A higher energy is required for the transmitted data as there is no fixed bandwidth. The path loss exponent value was also high, requiring higher transmission energy. For this, different path loss components do not affect the data transmission much.

Figure 6 shows the coverage probability with cluster based D2D communication and without D2D communication. It clearly shows that cluster based D2D communication has a higher coverage area with reasonable QoS. From the figure, using cluster based D2D communication, 80 % of users receive 20 dB SINR, which is a very high signal. However, without using the cluster based D2D communication, only around 60% of users receive the higher SINR. This service is essential for the disaster network.

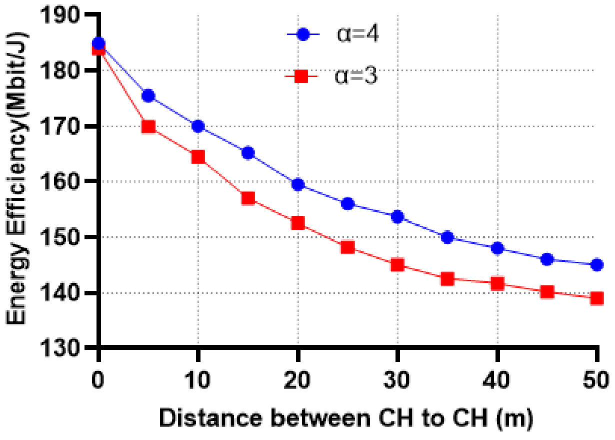

Figure-5: Energy efficiency vs the distance between CH to CH.

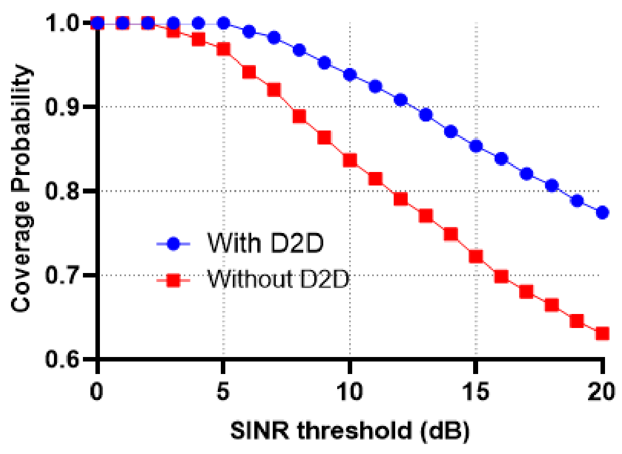

Figure-6:Coverage probability with different SINR thresholds.

Figure 7 shows the cluster size vs the energy consumption of the CH. CH needs to be optimised to the maximum lifeline of the network. The result shows that the cluster's small size is energy efficient, resulting in the longest network lifetime and throughput. However, energy consumption is increasing with the increased size of the cluster.

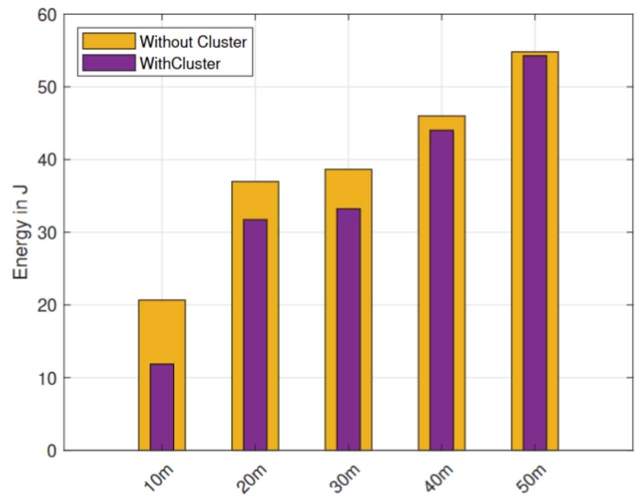

Figure-7: Energy required with different cluster size.

This is because when the cluster size is big, all the nodes require higher energy to transmit the data to the CH and even CH to CH also consume more energy to transmit CH to CH. However, without cluster formation, energy consumption is more than communication via cluster.

V.CONCLUSION AND FUTURE WORK

This paper uses energy-efficient cluster-based multi-hop D2D communication analysis for disaster communication. The analysis emphasises energy efficiency, network performance and coverage probability. This paper proposed a clustering algorithm to select the cluster head and the cluster members. The algorithm is also able to find the UEs which are outside the network coverage. This paper also analysis the different hop energy efficiency with respect to different distances from the BS, relay node and CH. The result also compares with the different path loss components. The significant benefit of D2D communication is measured in the case of a disaster management network. It also measures the percentage of users who can use the services after a disaster. In future, 6G network should consider for the feasibility test of the proposed model.

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