Managing radio resources in public safety situations based on Device-to-Device communications within a hybrid multiple access system in 5G Networks.

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Abstract - *Managing wireless infrastructure is very essential and crucial after natural disasters such as earthquakes, hurricanes, landslides or man-made disasters such as wars. Rapid information gathering after a disaster helps in achieving effective communication management, as the pressure of users to maintain constant communication with family and friends causes bottlenecks and communication failures for other users. Device-to-device (D2D) communication technology reduces this pressure by relying on the proximity of users, thus increasing the efficiency of spectrum utilization. A many-to-many matching algorithm with an adaptive splitting factor and reuse factor was proposed for two scenarios and the results were evaluated using MATLAB simulation software. The results showed that the proposed algorithm outperforms the recently used Gale-Shapley matching algorithms in achieving effective management of radio resources in emergency situations, and it also succeeded in improving productivity and serving a larger number of users effectively.*

Key Words: **Mobile, D2D, MILEACH, CH, Disasters, 5G**

1.INTRODUCTION

Ensuring continued communications is one of the top priorities after a natural disaster such as an earthquake, hurricane, etc. Governments tend to gather information as quickly as possible at the disaster site, so it is essential to manage the wireless network infrastructure efficiently to help rescue workers or people in the same disaster area communicate with people outside [1]. Communications may be disrupted after a disaster either due to damage or due to the pressure caused by the large number of calls users make to family and friends. Device-to-Device (D2D) communications technology helps reduce the number of calls by taking advantage of the proximity and communicate directly bypassing Evolved Node B (eNB) or Next-Generation Node B (gNodeB), and thus enhances the capabilities of wireless networks, especially in the areas of 5G and subsequent cellular systems [2].

Emergency communications systems are typically designed to transmit information across multiple types of devices, from light signals to text messages to live video streaming, with the goal of creating a unified communications system that aims to improve communications during emergencies. Unlike emergency notification systems, which generally deliver emergency information in one direction, emergency communications systems are typically able to initiate and receive information from multiple parties and a variety of sources and locations, from which the system will disseminate this information to one or more target audiences [1].

The post-disaster areas can be classified into coverage areas and out-of-coverage areas. Cellular users can communicate with each other under the coverage of the base station, while users outside the coverage area resort to multi-hop D2D communications to communicate or within the same coverage area but depending on the close distance between users [3].

After the recent earthquake disaster in Syria and Turkey, the cellular communications network in the disaster area collapsed, and whether the collapse was partial or complete, it caused delays in emergency response and saved many lives. Social media such as Facebook launched the Safety Check feature, allowing people to update their safety status to families and friends during a disaster [4]. It was noted that on the ground, locals did not have the capacity to collect and sort through the large amounts of information coming in, leading to confusion due to cell phone limitations.

D2D communications use millimeter waves (mmWave) frequency band from 3 GHz to 300 GHz, complementing the frequency bands currently in use from 300 MHz to 3 GHz.

Although short-range D2D connections can transmit data at a rate of several gigabits per second, they suffer from high propagation loss and poor penetration through obstacles [5].

Non-orthogonal multiple access (NOMA) has recently been promoted as a pivotal technology for 5G networks and several studies have demonstrated its importance compared to traditional orthogonal multiple access (OMA) models, as it allows simultaneous access to resources by different entities, which increases spectral efficiency through advanced decoding strategies, particularly sequential interference cancellation (SIC) [6]. The complexity of power distribution within NOMA frameworks increases, especially when combined with D2D communications, as the challenge arises in intelligently distributing power among users, given the many variables, such as user density, individual channel dynamics, and overall system topology [2].

Power distribution among users is also related to fair access to radio resources, and addressing this is also not easy due to the inherent power disparities among users and their different locations within the network or channel dynamics, and giving them a balanced share of resources needs special attention when a disaster occurs. Energy Efficiency (EE), which is measured as the ratio of relevant information transmitted to the total energy expended, is also affected by power distribution strategies and is a very important parameter in power distribution strategies that aim to achieve a compromise between energy conservation and maximum system performance, ensuring the longevity of the network [7].

Based on the capabilities of D2D communications in 5G networks, this paper strives to address radio resource allocation and power control to enhance network performance and ensure EE. Our contribution involves the deployment of the proposed algorithm within the multi-cell hybrid multiple-access (MC-HMA) framework supposed in [13] for two scenarios in system model. The following sections will elaborate on the proposed algorithm and compare it with other resource allocation algorithms to demonstrate its effectiveness in emergency situations, which is the focus of our research.

2. RELATED WORKS

The field of D2D communication in synergy with NOMA is an important research area that attracts researchers, especially with the increasing demand for high-density data transmission, the increasing number of users in the network, and the increasing occurrence of disasters and network congestion. Our research builds on these fundamental studies, extends their concepts, and addresses their gaps.

Researchers in [8] proposed a resource allocation algorithm based on Gale algorithm to effectively solve the resource allocation problem of D2D users in multiple cellular user channels in heterogeneous cellular network environments by adjusting the signal-to-interference-to-noise ratio (SINR) threshold. They used Kuhn-Munkres (KM) algorithm to achieve the optimal matching between D2D groups and cellular channel to maximize the total capacity of D2D users.

HMILA, et. al [9] improved the energy efficiency of device-to-multi device (D2MD) wireless communications. The optimization focused on optimizing both unicast and multicast D2D communications through a multi-objective optimization framework. The model includes SIC operations in the decoders, so that higher rates can be achieved when multiple sources transmit on the same channel(s). This approach is particularly relevant to our research because it highlights the importance of efficient power usage in MD2D networks, a key consideration in our algorithm's design.

In [10] Logeshwaran et. al proposed an intelligent performance analysis of energy-efficient resource optimization model for D2D communication in fifth-generation (5G). The proposed energy-efficient resource allocation model (EERAM) helped to reduce energy consumption and extend the lifespan of devices.

Elmadina, et.al, focused in [11] on the downlink power allocation of a cognitive radio-based NOMA system in a femtocell with D2D communications. The proposed scheme used the Greedy Asynchronous Distributed Interference Avoidance (GADIA) algorithm to mitigate interference and allocate power efficiently based on the fairness index. The analysis results of the proposed Maximum Rate Under Fairness (MRF) algorithm showed an improvement in the system performance while providing fairness among users. The results of this algorithm were specific to a specific case, non-emergency and did not address the complexity that could arise when the number of users increases and the radio channels become fewer and more variable.

Finally, the researchers in [12] delved into an approach to enhance power allocation and throughput in 5G cellular systems, with the aim of conserving resources and ensuring connectivity through direct end-to-end connections using the device-to-device protocol and the modified Gale-Shapley algorithm. The robustness of the proposed approach was tested in two scenarios: the first in standard 5G operations that focuses on minimizing power usage while maximizing signal reliability, and the second in disaster-induced network outages.

Our research is in line with these studies by providing innovative solutions for resource allocation in 5G D2D networks in disaster situations with the aim of improving overall network performance. By reviewing and building on these diverse studies, our research will contribute to providing a solution that helps in continuing communications in emergency situations by sharing radio resources with less interference and more equitably between cellular users (CUs) and D2D users (DUs) in disaster situations within the MC-HMA framework supposed in [13].

3. OBJECTIVES AND METHODS

5G offers great potential but is a bit complex, the biggest challenge is the scarcity of radio resources and the allocation of power to the very many users within the coverage area. The allocation of power within the available resources is a pivotal factor that affects the efficiency of data transmission. The aim of our research is to focus on the resource allocation to users located in a disaster-prone area that rely on D2D communications.

We have presented the contributions of researchers in this field, but emergencies or disasters have their own circumstances and challenges, and the affected area imposes variable constraints depending on the disaster situation, so the resource allocation algorithm must be dynamic and the preference list that researchers have relied on must be more flexible, otherwise the attempt to continue communications in these difficult situations will fail. Ensuring optimal distribution of radio resources between CUs and DUs is very difficult in disaster situations because demand for resources exceeds supply.

We will deploy the dynamic and greedy algorithm for this purpose within NOMA framework. Although it does not guarantee optimality, it adapts to current state and we can rely on it to reach the best solution in our case.

4. System model

In this paper, we will adopt the concept of in-band underlay D2D communication, where D2D pairs share radio resources with CUs. The disaster area will contain D2D pairs that communicate with each other based on proximity and transmit data within dedicated radio channels. We will consider two emergency scenarios as shown in Fig -1:

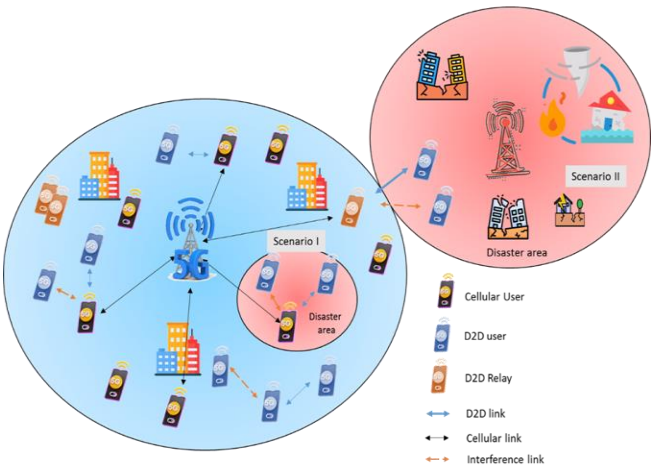

Fig -1: D2D communication system model, two scenarios of disasters situations with the integration of cellular links.

First: The base station is working well, but is under heavy pressure and there is a very high demand for radio resources. Some cellular users (especially devices far from the base station that need more transmission power than nearby users) will change the communication mode to D2D mode in order to relieve the pressure on the cellular network and rely on proximity.

Second: Some devices go out of service due to a malfunction of the base station and some nodes with good coverage start working as relays to help devices communicate in disaster areas.

Such emergency situations are not ideal, in these cases base stations face technical failure or environmental factors, and the number of ongoing communications is required more than ever, and here the possibility of interference between channels increases, in addition to user mobility, which increases the difficulty of service stability, and also maintaining a stable data transmission rate throughout the disaster.

The channel model used in our system is Rayleigh, which takes into account several factors such as path loss and multipath fading. The base station (gNodeB) is assumed to be aware of the channel state information (CSI) of the D2D links, and control channels are required to send CSI feedback to the gNodeB. D2D users rely on SIC to cancel interference from neighboring DUs. This technology is particularly important in a NOMA network, where signals are superimposed with different power levels and decoded sequentially at receivers [12].

4.1 Scenario-I overview

When designing an algorithm for radio resource allocation, we view it as a function that takes into account several parameters, which are DUs, CUs, and downlink or uplink channels. Non Served Group (NSG) is for unmatched DUs. The preferred pairing is which causes the least possible mutual interference for users according to the proposed many-to-many matching algorithm for the first scenario shown in Fig -2.

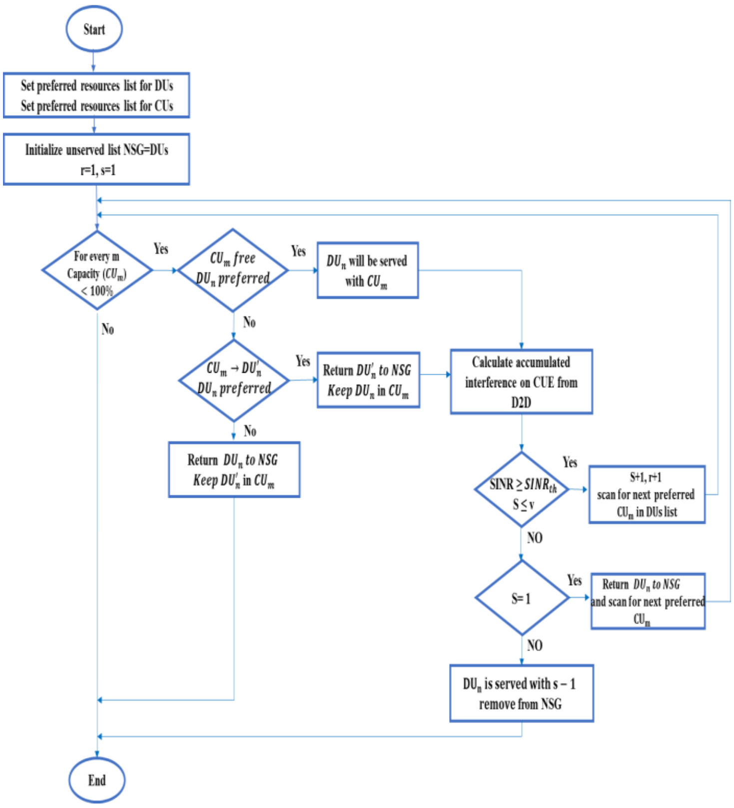

Fig-2: Flow chart of the proposed pairing algorithm for Scenario-I.

The trade-off for choosing the best channel depends on the total interference received on each DUn group when using the CUm channel with the following equation [9]:

$$\beta_n^{(m)} = max_{j \in DU_n} I_{n:j,m} \qquad \forall DU_n \in DU \qquad (1)$$

The of interference for each cellular user CUm is measured by the following equation [9]:

$$\Gamma_m = \sum_{n \in DU} \Gamma_m^{DUn} \qquad \forall CU_m \in CU \qquad (2)$$

This algorithm is adopted to match random sets of DUs and CUs, and the trade-off takes the same form as the many-to-one relationship with the addition of a condition regarding the splitting factor s (which is sharing D2D pairs with more than one channel for cellular users) which is:

$$|\mu(C_m)| \leq r \qquad (3)$$

$$|\mu(D_k)| \leq s \qquad (4)$$

where μ refers to the matching function, s is the splitting factor and r is reuse factor.

The allocation remains open to any adaptive update, meaning that if different DUs want to use the RBs and the second DU pair is more preferred, the swap will be made. For example, if we try to allocate DU2, which has similar preferences to DU1, but it is clear from the CU4 group that DU2 is more preferred than DU1, the first DU is removed and returned to the list of mismatched group (NSG).

4.2 Scenario-II overview

D2D cognitive communications have become increasingly important with the advancement of wireless communications because they use cognitive strategies that enhance efficiency and adaptability. The integration of cognitive processes into D2D communications allows for more intelligent and efficient use of radio spectrum resources. The cognitive cycle in D2D communications includes several stages, including spectrum discovery, decision-making, and adaptation. Thus, D2D devices can intelligently analyze their environment, make informed decisions about spectrum usage, and adapt their communication strategies accordingly. This is especially important in disaster scenarios where dynamic spectrum access is essential. In emergency situations where D2D communications operate independently of the base station, user devices undergo several key control functions, namely [12]:

- Device discovery: They discover each other through specific protocols or technologies, allowing for efficient and direct communication without central coordination.
- Mode selection: Devices decide whether to communicate directly (D2D mode) or through the base station (cellular mode) based on various factors, such as signal strength, proximity, and network conditions.
- Resource and energy allocation: Without a central coordinating authority, D2D devices allocate resources (such as spectrum and channels) and energy among themselves using algorithms or strategies designed for efficient and fair distribution.

This scenario aims to simulate the real-world challenges of an earthquake or natural disaster in which urban 5G networks are partially destroyed or damaged. There are some points that greatly affect the study of this scenario:

1. The demand for voice calls increases with the high density of users, not to mention the potential interference problems.
2. User mobility that affects network stability and reliability of D2D communications.
3. Quality of service under difficult urban conditions.
4. Maintaining high data rates and stable connectivity.

Fig-3 shows flow chart of the proposed algorithm for serving DUs in out-of-coverage disaster area for the second scenario.

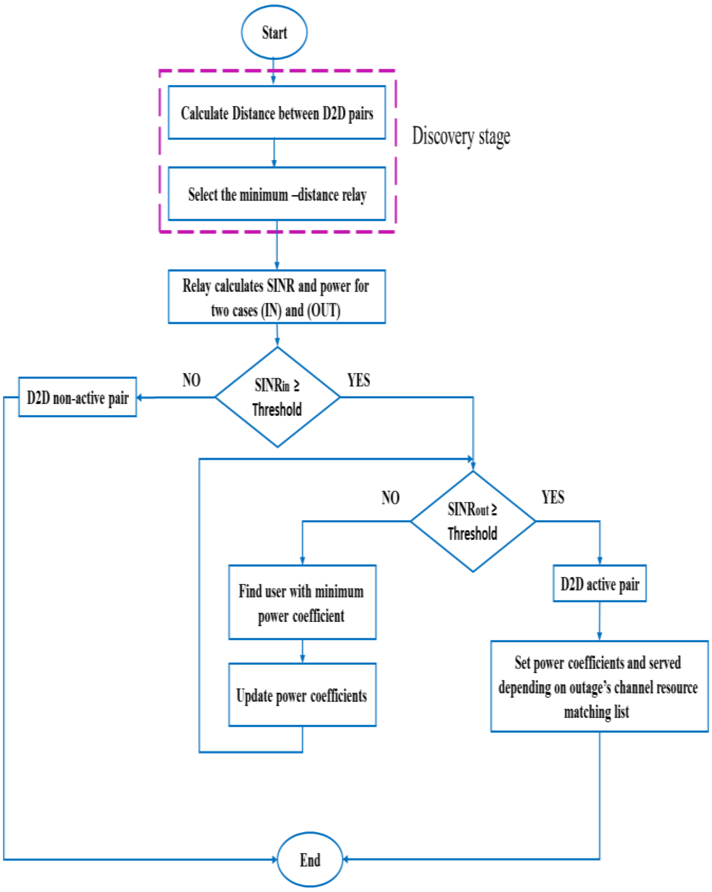

Fig-3: Flow chart of the proposed pairing algorithm for Scenario-II.

In discovering stage, the distance between DUs and the relays is measured to choose the shortest distance based on Euclidean equation [12]:

$$d(a,b) = \sqrt{(X_a - X_b)^2 + (Y_a - Y_b)^2} \quad (5)$$

Next, the SINR is calculated using formula (6) [1], power is allocated to DUs and CUs based on the expected transmission rate (the minimum needed to make at least a voice call).

$$SINR = \frac{S}{S+I} \quad (6)$$

where S is the power of the incoming signal, I is the power of the other signals' interference inside the network, and N to be the noise. This SINR metric is then used to compute the channel capacity:

$$C = W(1 + SINR) \quad (7)$$

where W is the bandwidth. When the transmission is based on a relay, the communication will be divided into two D2D stages, which we will call IN and OUT, as shown in the following Fig-4.

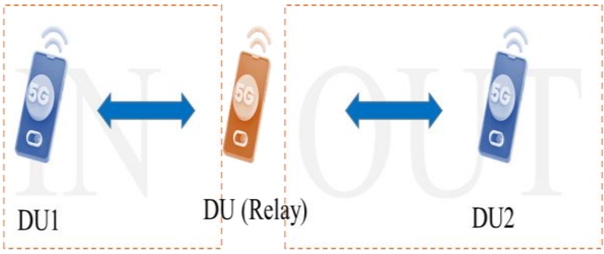

Fig-4: D2D discovery with Relay.

The path loss between two devices, DU1 and DU2 (relay or another near DU), is given as [12]:

$$PL_{DU} = 12\ \log_{10}(d) + 12\ \log_{10}(fc) + 19.54 \quad (8)$$

where d represents the distance between the devices according equation (5), and fc denotes the frequency.

1. Simulation and results

The simulation will be for a system consisting of microcell, within which D2D communications continue in addition to cellular communications, and the base station is located in the middle of this cell as shown in Figure.5. CUs and DUs are spatially distributed following a standard homogeneous Poisson point process (PPP) [14]. The proposed algorithm aims to improve the overall performance by allocating power resources in two scenarios, and evaluating the performance based on the mutual interference ratio and the proximity of the transmitters and receivers. We relied on the MATLAB simulation program for its efficient management and excellent computational capabilities. The following Table-1 summarizes the parameters used in the simulation.

Table -1: Simulation Parameters.

Parameter	Value
Cell Radius	500 meters
gNodeB Position	(500, 500)
No. CUs	125
No. DUs	125
Frequency for path loss	28 GHz
Reuse factor (r)	1~3 (adaptive)
Split factor (s)	1~3 (adaptive)
Path loss exponent	3 (urban)
Minimum Spectrum Efficiency	0.1 bit/s/Hz
Bandwidth	0.5 GHz

The base station is located in the middle of the studied cell and the primary transmission medium is air, which has uniform free space losses. We adopt the mmW band (28 GHz). The locations of cellular and D2D users change in each iteration and during a certain time period.

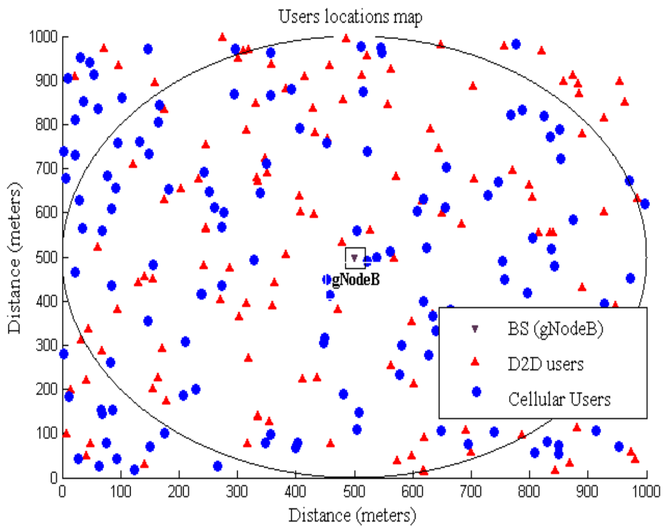

Fig-5: D2D discovery with Relay.

5.1 Results discussion for Scenario-I

As can be seen from the results of the Chart -1, the aggregate rate increases significantly with the proposed algorithm compared to the algorithm proposed in [12], which is based on each cellular user sharing his radio resources with only one D2D user, whereas in our proposed algorithm it is adaptive and the splitting and reuse factor can be controlled according to the capacities of the shared radio resources. Channel reuse means that receivers can exploit SIC to decode weak signals.

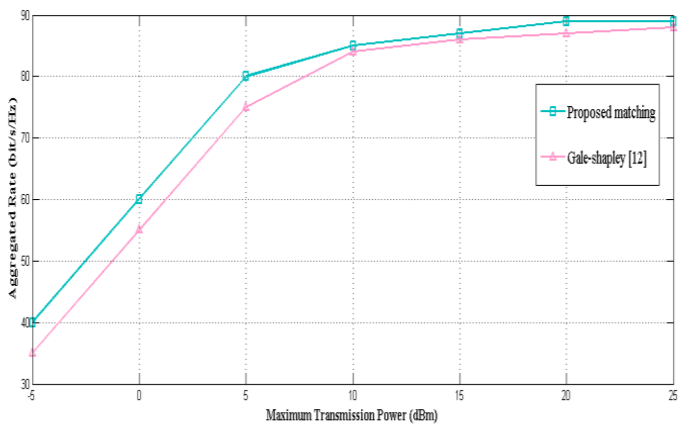

Chart -1: Aggregated rate using many-to-many matching.

The following Chart -2 shows the total amount of energy consumed in the proposed algorithm and [12], which confirms that the proposed algorithm is resistant to the amount of interference by relying on SIC technology and distributing power fairly among users and its ability to serve a larger number of users.

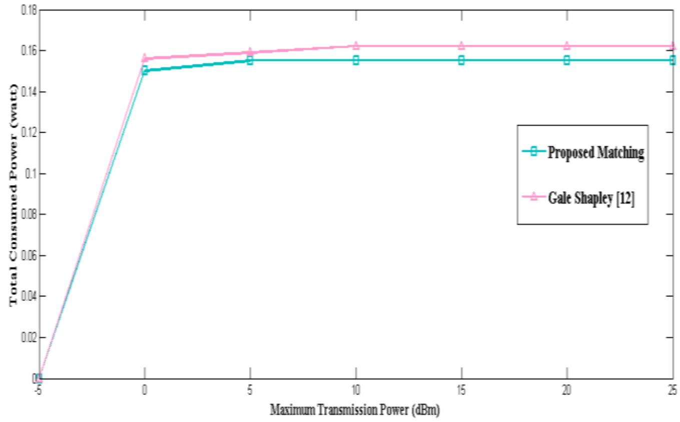

Chart -2: Consumed power for different transmission power levels.

The proposed algorithm was able to reduce the power required to serve the users by relying on proximity and reducing the interference by relying on the SIC adopted in the downlink-NOMA system. This is the goal behind the proposed resource allocation algorithm to ensure the continuity of communication for users in emergency situations.

5.2 Results discussion for Scenario-II

The second scenario is a special case of the first, but it leads to an additional responsibility to increase the total number of users benefiting from outside the cell, and thus additional burdens and the expected impact on the quality of service. Therefore, this sensitive process must be dynamic, as it is not required here to search for perfection as much as to secure the service for the remaining users located within a disaster area and without base station coverage.

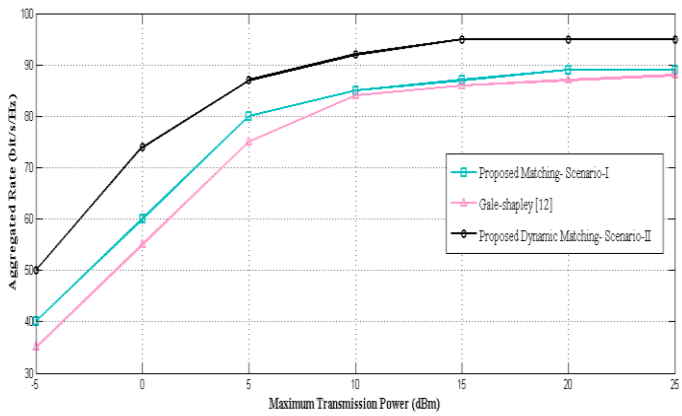

Chart -3: Consumed power for different transmission power levels.

The total data transmission rate will certainly increase when additional users are served, and here the importance of the NOMA framework becomes more evident in eliminating the interference caused by sharing radio resources with D2D users. According to reference [9], the NOMA system's gain in the downlink is clearly greater when the reuse factor r is larger because it allows more free to use of channels.

6. CONCLUSIONS

The aim of this research was to maximize the efficient use of radio resources in emergency situations, which we divided during our study into two scenarios, one of which is that the users' devices in the disaster area are under the coverage area of the cell, but there is a pressure on the communications, so some users change the communication mode to D2D and share the resources with the cellular users according to an adaptive many-to-many matching algorithm with a splitting factor and an adaptive reuse factor to maintain a specific interference level, while the second scenario is more difficult, where the service extends to the vicinity of the cell and the user uses the neighboring devices as relays and connects to them based on D2D technology to reach the radio resource that guarantees him continued communication with the least possible interference. Our study preserves scarce network resources in emergency situations and enhances D2D communications, leading to more robust and reliable data transmission. This is proven by the results shown for our proposed approach to improve the performance and reliability of 5G systems in emergency situations. The proposed algorithm is promising for the future of 5G networks, as it integrates D2D communications with cellular communications for the sake of a large device density in a city crowded with devices, which is the most difficult case.

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