

Study of Cluster-Based D2D Communication in Next Generation Mobile Network for the Post-Disaster Response.

1st Shakil Ahmed

*Department of Mechanical and Electrical Engineering
Massey University
Auckland, New Zealand
s.ahmed1@massey.ac.nz*

Abstract—There are many emerging technologies introduced by the next-generation mobile network (5G), which are very promising for the emergency communication network. Device to Device (D2D) communication is one of the significant adoptions in this 5G network. In D2D communication, mobile devices can communicate with other mobile devices without any help from a Base Station (BS). In addition, it also does not depend on the core switching for routing the traffic. This independent communication feature is one of the critical values for emergency communication when infrastructure is damaged by a natural disaster or human-made disaster. Moreover, clustering-based multi-hop communication provides the communication connection in the disaster-affected people and can enhance the coverage area. In this paper, we analyse and quantify the performance of cluster-based D2D communication in 5G when the existing infrastructure fails in a disaster in a salable format. The analytical parameter is based on the outage probability, Coverage area and QoS which are essential matrices for any emergency communication network.

Index Terms—D2D communication, Cluster Head, Disaster network, 5G.

I. INTRODUCTION

After large-scale disasters such as tsunamis, hurricanes, earthquakes etc., the existing communication networks cannot perform at their maximum capacity because of damage to the infrastructure or traffic congestion and other factors. For example, about 6000 cell towers/Base stations (BS) were damaged by a 9.0 magnitude earthquake, and the tsunami struck the eastern coast of Japan [1]. Due to that natural calamity, massive traffic congestion occurred in the communication channel as a high volume of data and voice passed to the existing BSs and limited capacity of the existing network infrastructure. As a result, affected people were not able to access the communication service in a large area.

It is imperative to implement such a network that can handle the high volume of data, reuse the same spectrum, extend the coverage of the service area, infrastructure less communication and power efficient network due to the limited infrastructure available after the disaster [2]. It is challenging to deploy such an emergency communication network promptly after the disaster due to some disaster constraints such as power, capacity,

road condition, and cost constraints [3]. Therefore, a reliable, cost-effective emergency communication framework should implement worldwide based on the commercial telecom standard. D2D communication paradigm under 5G network could be a potential solution to overcome the above mentioned problems. The next-generation mobile network (5G) has some unique capabilities, such as network flexibility, reconfiguration capacity and resilience, which are crucial for any emergency communication network [3]. In addition, D2D offers several communication advantages, for example, offloading cellular data traffic, reducing energy consumption, and providing a higher data rate. D2D reuses the same spectral band so that the high density of devices shares the same radio resources. Device discovery and multi-hop communication capabilities provide extended network coverage and connectivity where the network infrastructure is partially or fully damaged by the natural hazard [4].

Traditional cellular networks use direct single-hop communication between the mobile user (user node/ UE) and the BS. This connection is beneficial in reducing the delay in communication and providing QoS. However, it causes the problem of high-volume data or voice traffic load as it has limited spectrum resources. As a result, the outage probability increases, and network coverage decreases, especially in emergencies. Handling this high volume of data traffic requires increasing the network capacity.

D2D under 5G can play a significant role in the emergency communication network in case of vulnerable network, traffic congestion/ network congestion, or enhance the network capacity [5]. Due to the low cost and the capability to handle a high volume of data, it is becoming more popular for the public safety network. Though many studies have been done to reduce end-to-end delay and energy consumption and enhance the coverage area in the emergency communication network [6] [7] [8]. However, D2D salable services performance, QoS in different disaster scales and interference management still have some problems for the multi-hop D2D communication for standardisation. The primary focus of this study is to investigate D2D performance in the emergency network on

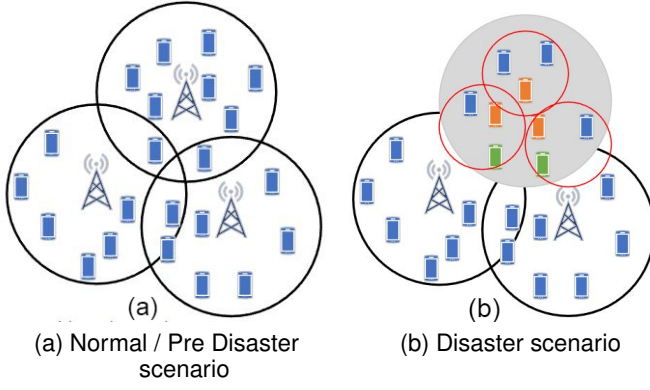


Fig. 1: Overview of the network model

a different scale of disaster impact on the communication network. In this paper, we analysed the performance of a clustering-based D2D emergency communication network under a 5G network for different scales of disaster impact. A mathematical model has been derived and simulated to justify the outage probability and network coverage result. A simulation result shows the outage probabilities with the varying SINR for the different disaster impacts in the network.

The rest of the paper is organised as follows: Section II discuss the network model used for this study. Section III explains the Cluster Head selection algorithm, while Section IV briefly describes the simulation set-up parameter and results in a discussion, Section V concludes the paper.

II. SYSTEM MODEL

Figure 1 shows the network model considered in this work.

This model is considered a heterogeneous cellular network which consists of L tiers. It assumed that the distribution of base station in a tier follows a homogeneous Poisson Point Process (PPP) ϕ_{BS} with spatial density λ_{BS} . The UEs in the network are also considered as homogeneous PPP ϕ_{UE} with spatial density λ_{UE} . In the aftermath of the disaster, it is practical to consider that some of the BS may fail to provide the services. The UEs under the failed BS will form a cluster and establish D2D communication in this situation. The formation cluster and selection of cluster head (CH) are discussed in section 3. All the communication inside the cluster will be through CH. Figure 1 shows the normal network scenario and after the disaster network scenario.

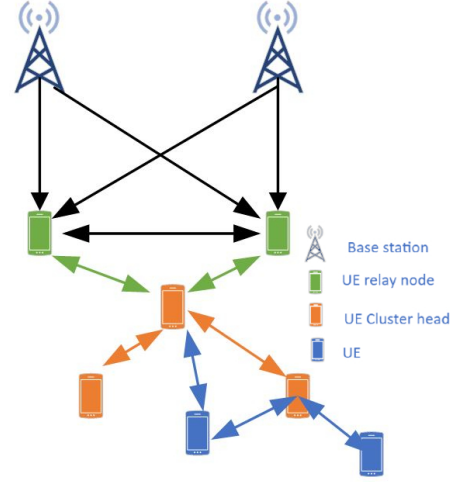


Fig. 2: Analytical model of a disaster network with the interference

For the analytical purpose, it considered that D2D communication will be through CH to CH in case of a disaster scenario (figure-2). It also assumes 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 τ_{th} is a known parameter.

At first, it calculates the outage probability of the link between BS to UE relay (UER) device. It was also considered to use relay and UER interchangeably. It also considers 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:

$$P_{BS_i.R} = P_{BS_i} h_{BS_i.R} D_{BS_i.R}^{-\alpha} \quad (1)$$

Where, $D_{BS-i.R}$ is the distance between BS at the i^{th} tier and the relay node and α is the pathloss component. Hence the signal to noise ratio (SINR) at R_i is expressed as follows:

$$\gamma_{R_i} = \frac{P_{BS_i} h_{BS_i.R} D_{BS_i.R}^{-\alpha}}{I_R^{(i)} + n_{R_i}} \quad (2)$$

Where, n_{R_i} is the thermal noise which is usually negligible component to interference in a dense network. I_{R_i} denotes the received interference at relay R_i . Here equation 2 becomes

$$\gamma_{R_i} = \frac{P_{BS_i} h_{BS_i.R} D_{BS_i.R}^{-\alpha}}{I_R^{(i)}} \quad (3)$$

The overall interference at R_i is the sum of all the BS's transmission from different tiers occupying the same frequency at a given time slot as well as the interference from the cluster head. Hence

$$I_{CH_i} = \sum_{i=1}^L \sum_{Z \in \psi_R} P_{R_j} h_{R_j.CH_i} D_{R_j.CH_i}^{-\alpha} + \sum_{CH_j \in \psi_{CH}} P_{CH_j} h_{CH_j.CH_i} D_{CH_j.CH_i}^{-\alpha} \quad (4)$$

In case of the CH to CH D2D communication which is shown as orange link in the figure-2 the received power at CH is:

$$P_{CH(D2D)} = P_{CH_i} h_{CH_j.CH_i} D_{CH_j.CH_i}^{-\alpha} \quad (5)$$

and the SINR at CH_j is:

$$\gamma_{CH(D2D)} = \frac{P_{CH_i} h_{CH_j.CH_i} D_{CH_j.CH_i}^{-\alpha}}{I_{CH(D2D)}^{(i)}} \quad (6)$$

The $I_{CH(D2D)}$ is the overall interference from the CH and the neighbour UEs [9]. Hence

$$I_{CH(D2D)} = \sum_{CH_j \in \psi_{CH}} P_{CH_j} h_{CH_j.CH_i} D_{CH_j.CH_i}^{-\alpha} + \sum_{D_j \in \psi_{CH}} P_{D_j} h_{CH_j.D_i} D_{CH_j.D_j}^{-\alpha} \quad (7)$$

The outage probability for each link which are BS to UR relay, UE relay to CH and CH to CH. The overall outage probability of the network is the scalar product of the individual outage probabilities. Hence

$$P_{out}^{Overall} = P_{out(BS-R)} P_{out(R-CH)} P_{out(CH-CH)} \quad (8)$$

It was considered the interfering relay's density γ_R around R_i the outage probability can be expressed as follows [10]:

$$P_{out(BS-R)} \cong 1 - \sum_{i=0}^{N_{Ri}-1} \left[\frac{-s}{(i!)} \frac{d^i}{ds^i} \xi I_{Ri}(S) \right]_{s=\tau_R P_{BS_i}^{-1} D_{BS_i R}} \quad (9)$$

Similarly,

$$P_{out(R-CH)} \cong 1 - \sum_{i=0}^{N_{CHi}-1} \left[\frac{-s}{(i!)} \frac{d^i}{ds^i} \xi I_{CHi}(S) \right]_{s=\tau_{CH} P_{R_i}^{-1} D_{R_i CH}} \quad (10)$$

and

$$P_{out(CH-CH)} \cong 1 - \sum_{i=0}^{N_{CHi}-1} \left[\frac{-s}{(i!)} \frac{d^i}{ds^i} \xi I_{CHi}(S) \right]_{s=\tau_{CH} P_{CH_i}^{-1} D_{CH_i CH}} \quad (11)$$

III. CLUSTER HEAD SELECTION

In a disaster network, energy is one of the critical parameters to enhance the network's lifetime. As a result, energy-efficient communication is very crucial for disaster communication. The disaster network is divided into two regions. One is the non-disaster region, where UE is connected with the BS. The

other is the disaster region, where there is no BS for the UE. For this region, UE will form the cluster to communicate with the BS. In a cluster, there is one Cluster Head (CH) responsible for collecting the data from other cluster members and transmitting it. CH selection depends on the number of parameters, e.g. Residual energy, distance from the BS, channel condition, etc. In our model figure -2, we used a clustering algorithm based on the residual energy of the node and the distance from the BS. The node with higher residual energy in the disaster area has a better chance of becoming the CH.

Let's considered that N number of nodes is randomly distributed in the disaster are W x W and the initial energy is distributed non-uniformly among the nodes. For the Cluster selection, we use a distributed algorithm, where nodes make autonomous decisions without any centralized control. We assume that, initial energy randomly distributed. The procedure of CH selection is calculated by the threshold value TCH). All the nodes selected region generate a random number between zero and one $M(0 \leq M \leq 1)$. If the random number is satisfied with $M \geq TCH$, the node is elected as the head node of the cluster for the current round. The threshold value T_{CH} is calculated as follows [11]:

$$T_{CH} = \left\{ \frac{P_{CH}}{1 - P_{CH} * (r \bmod (\frac{1}{P_{CH}})) * D}, N \in G_i \right\} \quad (12)$$

Where, P_{CH} is the probability of the node is selected CH based on the residual energy. r is the current number of round, G_i is a set of nodes that did not selected as a cluster head in the last rounds, $\bmod(\cdot)$ denotes the modulus operator and D denotes the distance from the BS. P_{CH} can be define as:

$$P_{CH} = P_{opt} \frac{E_i}{E_{avg}} \quad (13)$$

where P_{opt} is the optimal probability. E_i is the i th node residual energy and E_{avg} is the average energy of the network. The average energy of the network at round r is denoted by:

$$p_{avg} = \frac{1}{N} \sum_{i=1}^N E_i(r) \quad (14)$$

P_{opt} can obtain by $P_{opt} = \frac{P}{N}$ where P is the predetermined number of CH which is most of the case 10% of the total number [12].

When the node is selected as CH using the threshold equation, the CHs must let to know the other nodes that they are selected for the CH for this round. The CHs broadcast an advertisement message (AVD) to let to know all other nodes in the network. The broadcast message consist of node ID and a header. Each of the member node chose the desire CH for the current round that required less Energy for the communication. This can be determined by the strength of the received signal from the advertisement message of CHs. A random CH will be selected in case of equal strength of received signal. When the node decides the desired CH, the node needs to inform the CH that the node will be the

TABLE I: Simulation Parameter

Parameters	Values
Simulation software	Matlab 2019a
Network deployment	PPP
Cell size	20KM2
Pathloss exponent	4
Number of UER	20
Cluster size	variable
Cell radius	1KM
SINE Threshold	0-30dB
Iteration	10000

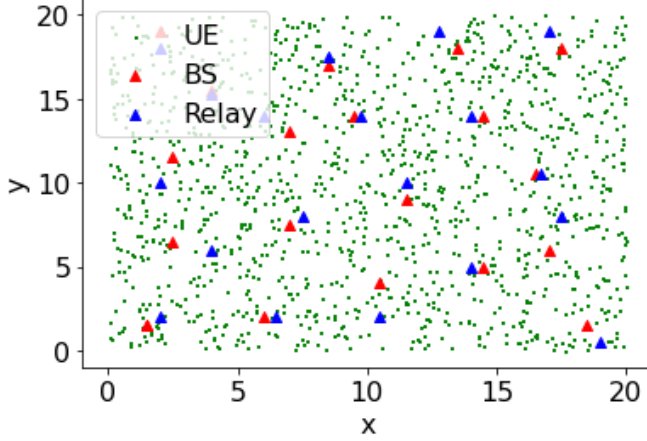


Fig. 3: Simulation network: Node distribution using PPP.

member of that Cluster. The node transmit a Join-request message to the CH which consist of node ID and CH ID.

IV. SIMULATION RESULTS

This section presents the simulation results that analyse the disaster model discussed above. The analytical result shows the availability of the network after disaster impact in different scales. The model simulated to find the outage probability by varying the different values of the SINR threshold. This result will help determine the QoS when there will be infrastructural damage due to disaster impact. The result also calculated and presented the coverage of energy efficiency of cluster-based D2D communication for both normal and emergency communication. The simulation parameters and the value used for this simulation are listed in Table-1. Monte Carlo simulation has been used to analyse the disaster model and validate the result.

There are two autonomous PPPs are used for the simulation. One is UER, which is used for the relay node, also known as cellular users and another is CHi, which is used for D2D users. Figure 3. shows the simulation network model 20X 20 square KM. The red triangles are the BS, and the blue are UE-Relays connected with the respective service stations (either BS/ Micro Cell/PicoCell) inside the same tier. CHi connected with the UER. As mentioned before, the communication link between UER to CH and CH to CH is considered D2D communication. CHs are connected

with the nearby UER, and the Device inside the cluster is connected to the CH. According to the theoretical model, homogenous PPP with the special density of the users is used in the simulation model. BSs are connected with the UER, and all other users are connected with the BS in normal mode. In the absence of BS, when the users cannot connect with the BS, they form the cluster, and all communication occurs via CH. The performance in different disaster impacts that cause infrastructure damage (10%, 20%, 50% and 70%) was also calculated. It was assumed that 10% of disaster impact means 10% of BS damaged due to disaster from the total number of BS deployed in the specific area, 20 % disaster impact means 20% BS absence and so on. Figure 4, SINR vs Outage probability for different disaster impact 5 KM area. It was assumed that 10% disaster in 5KM area means 1 BS damage, 20% damage means 2 BS damage, 50% damage means 3BS damage and 70% damage means 4BS damage. Figure 4 shows that up to three BS damage did not make significant outage probability. However, more than 40% outage probability occur for 4BS damage.

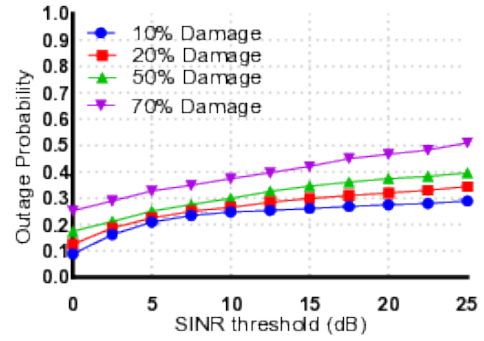


Fig. 4: SINR vs Outage probability for different disaster impact (5KM area)

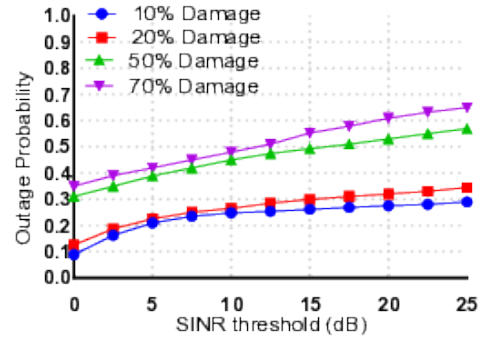


Fig. 5: SINR vs Outage probability for different disaster impact (10 KM area)

Figure 5 and 6 shows the outage probability of the D2D user with respect to the SINR threshold and compare the result with the percentage of the impact of the disaster in different

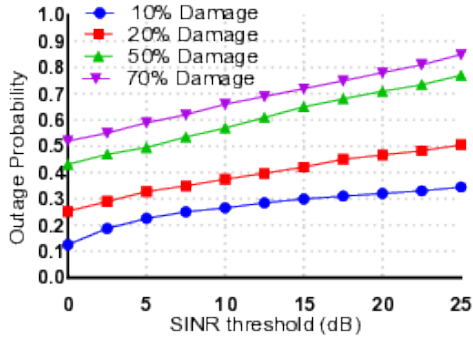


Fig. 6: SINR vs Outage probability for different disaster impact (20 KM area)

scale of the disaster and considering the different area size. When considering the 10 KM area, the 10% disaster damage means 1 BS damage, 20% damage means 2BS damage and so on. On the other hand, when considering the 20 KM area, 10% damage means 2 BS damage, 20% damage means 4 BS damage, and 70% damage means 14 BS damage out of 20 BS. It has been observed that outage probability increase with the increase of SINR. This is because the channel fading distribution is in exponential form and for the interference signal IR, ICH, ICH(D2D). When the disaster impact 10% within 5KM, the outage probability of the D2D users is almost negligible. However, with the increase of KM (10KM, 20KM), the outage probability will start increasing as it will increase the interference, channel fading, link outage and channel congestion. In addition, increasing with the impact of disaster (10%, 20%, 50%, 70%), the outage probability increase but not exponentially. Because multiple network tiers can handle the interference, it reduces channel fading. According to equation 9, channel quality is an important factor for the outage probability of D2D users. For the D2D user, the outage probability also depends on the distance from the relay node. That is why in the figure 4 (within a 5 km area), there is no significant outage probability. However, with the increase in distance and the impact, the outage probability increase because it requires more hops to extend the coverage. In addition, there are possibilities to have channel fading, broken channels and interference from other CH and nodes. The outage probability is below 50% for the SINR threshold of 5dB of disaster impact damage except for 70% damage in 20 KM. The lowest threshold of SINR provides a lower outage probability in the emergency communication network.

The system also analyses the type of services users will get for the different types of disaster impact. The higher value of SINR guaranty the Quality of Services (QoS) for the users. The different SINR values for the different area sizes determine the percentages of users who can get the QoS. Figure 7,8,9,10 shows the percentage of users who get different SINR values for the 10% -70% disaster impact. From figure 8, around 70% of users get 25dB, which is a very good signal, and 80% of users get at least 5dB signal.

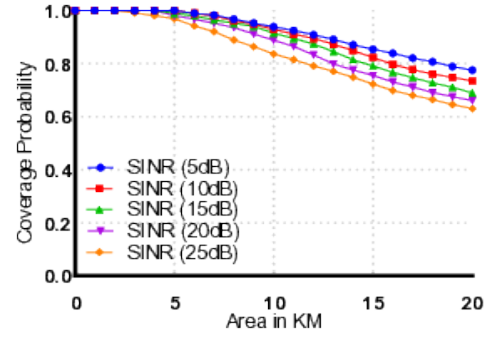


Fig. 7: Measure different SINR value for the different length of area after 10% disaster)

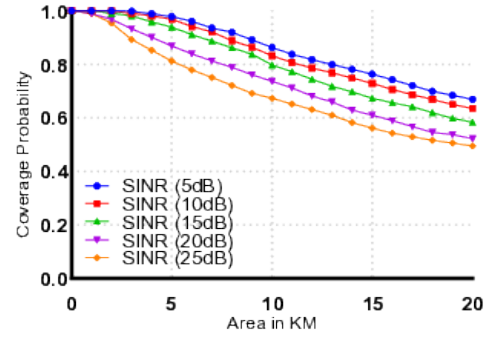


Fig. 8: Measure different SINR value for the different length of area after 20% disaster)

From figure 7-10, around 75% of people get a 15dB signal in 20KM. However, if the impact of the disaster is high, the outage probability is also high due to the distance and channel conditions. As a result, when the disaster impact is 70%, QoS is getting down. From figure-10, only 20% of people get the QoS service in that damage which is 25dB, and 30% of users get 15dB. However, about 50% of the users get the service available for 5dB.

The total outage probability is calculated with the three different hops, which are from the BS to UER, UER to CH and CH-to-CH (D2D) from equations no 8,9,10,11. The overall system outage probability increases as the node density increase, channel fading and interference increases. The overall system coverage is calculated using cluster-based D2D communication in the normal disaster situation and without cluster communication. From figure 11, the overall network coverage probability with and without clusters is significant different. Cluster-based D2D communication, the coverage percentage significantly increases with the increased size of the area. With cluster-based D2D communication, overall network coverage is 20% more for any given km than used without D2D communication. In addition, multi-hop communication extends the coverage in the emergency communication network at a certain distance.

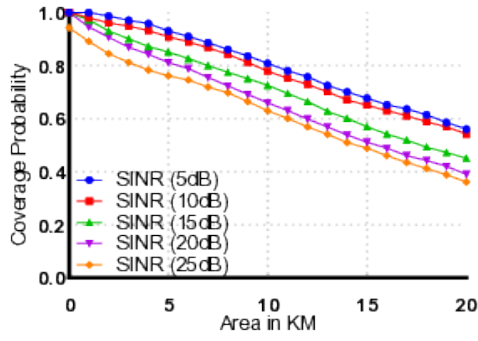


Fig. 9: Measure different SINR value for the different length of area after 50% disaster)

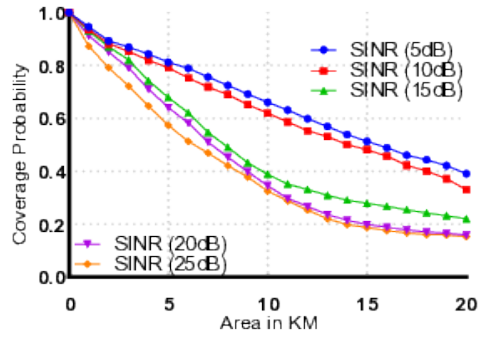


Fig. 10: Measure different SINR value for the different length of area after 70% disaster)

V. CONCLUSION AND FUTURE WORKS

In this paper, we analyse the performance of the clustering-based multi-hop D2D communication performance based on the outage probability and energy efficiency which are the important parameters for the emergency communication network. We show the novel methodology by calculating the mathematical model for the outage probability for both cellular and D2D users in multi-tier network. The result shows the outage probability for both cellular and D2D users for the different impact of the disaster for the different SINR. the result also presents the overall network coverage and network lifetime. In addition, to get the more accurate result ultra dense network during the simulation. Researcher are now finding the feasibility of 6G network. In future, 6G network should be consider for the public safety network.

REFERENCES

- [1] "Japans 2011 earthquake and tsunami: communications and network." [Online]. Available: <http://www.electronicsnews.com.au/news/japan-s-2011-earthquake-and-tsunami-communications>
- [2] K. Ali, H. X. Nguyen, Q.-T. Vien, and P. Shah, "Disaster management communication networks: Challenges and architecture design," pp. 537–542, 2015.
- [3] M. Ulema, A. Kaplan, K. Lu, N. Amogh, and B. Kozbe, "Critical communications and public safety networks part 1: Standards, spectrum policy, and economics," *Comm. Mag.*, vol. 54, no. 3, p. 12–13, mar 2016. [Online]. Available: <https://doi.org/10.1109/MCOM.2016.7432141>

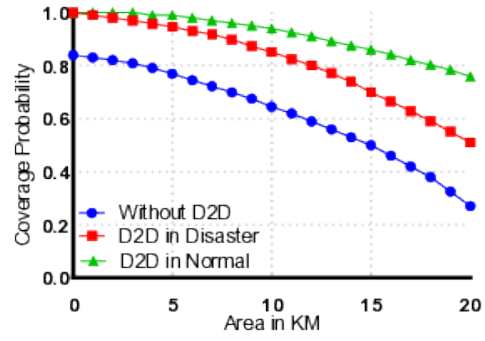


Fig. 11: Network Coverage with D2D and without D2D

- [4] K. Ali, H. X. Nguyen, P. Shah, Q.-T. Vien, and N. Bhuvanandaram, "Architecture for public safety network using d2d communication," pp. 206–211, 2016.
- [5] S. Ahmed, M. Rashid, F. Alam, and B. Fakhrudin, "A disaster response framework based on iot and d2d communication under 5g network technology," pp. 1–6, 2019.
- [6] K. Ali, H. X. Nguyen, Q.-T. Vien, P. Shah, and Z. Chu, "Disaster management using d2d communication with power transfer and clustering techniques," *IEEE Access*, vol. 6, pp. 14 643–14 654, 2018.
- [7] A. Elshrkasi, K. Dimyati, K. A. B. Ahmad, and E. Abdullah, "Employing an energy harvesting strategy to enhance the performance of a wireless emergency network," *Sensors*, vol. 22, no. 12, 2022. [Online]. Available: <https://www.mdpi.com/1424-8220/22/12/4385>
- [8] L. Chiaraviglio, L. Amorosi, F. Malandrino, C. F. Chiasserini, P. Dell'Olmo, and C. Casetti, "Optimal throughput management in uav-based networks during disasters," pp. 307–312, 2019.
- [9] F. Qamar, K. Dimyati, M. Hindia, K. Noordin, and I. Sadeh Amiri, "A stochastically geometrical poisson point process approach for the future 5g d2d enabled cooperative cellular network," *IEEE Access*, vol. PP, pp. 1–1, 05 2019.
- [10] I. Singh and N. P. Singh, "Coverage and capacity analysis of relay-based device-to-device communications underlaid cellular networks," *Engineering Science and Technology, an International Journal*, vol. 21, no. 5, pp. 834–842, 2018. [Online]. Available: <https://www.sciencedirect.com/science/article/pii/S2215098618301848>
- [11] D.-M. Aslam, F. Wang, X. Hu, M. Asad, and E. Munir, "Multihopping multilevel clustering heterogeneity-sensitive optimized routing protocol for wireless sensor networks," *Journal of Sensors*, vol. 2017, pp. 1–14, 08 2017.
- [12] Y. Liu, Q. Wu, T. Zhao, Y. Tie, F. Bai, and M. Jin, "An improved energy-efficient routing protocol for wireless sensor networks," *Sensors*, vol. 19, no. 20, 2019. [Online]. Available: <https://www.mdpi.com/1424-8220/19/20/4579>



Shakil Ahmed received M.Sc degree in Mobile Computing and Communication at Greenwich University, London and B.SC in Computer Engineering from American International University Bangladesh (AIUB). He is currently pursuing his PhD at Massey University, New Zealand. His research interest are Disaster Management, D2D Communication, IoT, Machine Learning.