MIKAILALSYS
Journal of Multidisciplinary Sciences

e-ISSN : 2987-2286
p-ISSN : 2987-3924

Index : Dimensions, Scilit, Crossref, Garuda, Semantic, Lens,Google Scholar,Base, etc

https://doi.org/10.58578/mikailalsys.v3i2.5296

An Improved Power Control Scheme for Device-to-Device Communication Using Hierarchical Cluster Algorithm

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Article Info:

Submitted:	Revised:	Accepted:	Published:
Mar 4, 2025	Mar 20, 2025	Apr 1, 2025	Apr 6, 2025

Abstract

Enabling Device-to-Device (D2D) communication in next-generation wireless networks faces significant challenges, particularly path-loss attenuation and interference, which degrade network performance. Existing studies suggest that interference management techniques such as resource allocation, spectrum sharing, and power control can improve network efficiency. However, conventional power control schemes require further enhancements to optimize energy efficiency, throughput, and outage probability. This study proposes a modified Power Control Scheme for D2D communication (mPCS-D2D) that leverages a Hierarchical Cluster Algorithm (HCA) to minimize interference by organizing D2D User Equipments (DUEs) into hierarchical clusters. The scheme is evaluated in both general and millimeter-wave (mmWave) mode communications. Performance assessment through simulations demonstrates that mPCS-D2D achieves an average energy efficiency of 29.722 kbps/J with a 46.03% imporvement, a throughput of 135.994 kbps having a 4.77% improvement, and improving outage probability by 41.06%, surpassing the existing PCS-D2D schemes. These results indicate that mPCS-D2D is a viable solution for power control in D2D communications over uplink channels in 5G mmWave networks. improving network efficiency while maintaining fairness. The findings suggest potential applications in optimizing power allocation for future D2D communication scenarios.

Keywords: Energy Efficiency, Hierarchical Clustering, Throughtput, Outage Probability, Device-to-Device Communication

INTRODUCTION

Hierarchical clustering has proven to be an effective technique for power control and interference mitigation in Device-to-Device (D2D) communication within 5G millimeter-wave (mmWave) networks. This method organizes D2D users into multiple levels of clusters, with each cluster following a structured power control mechanism to reduce interference and optimize energy efficiency. By integrating hierarchical clustering, D2D communication in 5G mmWave networks can achieve improved throughput, outage probability, and energy efficiency even as mmWave technology faces challenges such as limited range, high path loss, penetration issues, and interference (Zabetian et al., 2019). To address these challenges, D2D communication has emerged as a promising solution for next-generation networks by enabling direct device exchanges without routing through a Base Station (BS). Operating in either overlay or underlay spectrum-sharing modes with underlay sharing offering higher spectral efficiency despite the added cross-tier and co-tier interference (Zabetian et al., 2020). The focus of current research is on underlay sharing due to its spectrum-efficiency benefits. Power control and resource management are therefore crucial for improving D2D performance. Sarma et al., (2021) proposed a power control scheme for D2D communication using uplink channel in 5G mmWave networks. His work was aim at reducing interference and from results obtained, shows the efficacy of the scheme but interference still exist leading to low energy efficiency and reduced throughput. The Clustering-based power control schemes have been developed to reduce interference and enhance throughput (Turgut et al., 2019), ensuring reliable communication and energy-efficient operation in 5G mmWave networks. Nevertheless, the inherent interference whether among D2D user equipments (DUEs), between DUEs and cellular UEs (CUEs), or within D2D clusters continues to degrade network performance by reducing throughput and energy efficiency while increasing outage probabilities. Existing approaches have often optimized one performance metric at the expense of others or relied on computationally intensive methods impractical for real-time deployment. To overcome these limitations, this paper introduces an improved power control scheme based on a Hierarchical Clustering Algorithm (HCA) that seeks to maximize throughput while balancing energy efficiency and outage probability in D2D enabled 5G mmWave networks. Furthermore, recent studies have extended this research area. For example, Gottam et al. (2023) proposed a novel interference mitigation scheme for D2D-enabled cellular networks that dynamically adjusts transmission power based on network topology and interference levels. Similarly, He et al. (2021) introduced a graph neural network–based model for joint beam selection and link activation in ultra-dense D2D mmWave networks, demonstrating near-optimal performance. In addition, scalable power control and beamforming techniques using graph neural networks have been developed to handle interference in heterogeneous D2D networks (Zhang et al., 2021). These emerging approaches underscore the potential of integrating advanced machine learning methods with clustering techniques to further improve power control and interference management in next-generation networks.

METHODS

1. Modified Power Control Scheme (mPCS-D2D) System Model.

A 5G uplink network with one BS and a single cell is considered in this work. The cell contains a number of M cellular users and N D2D users which are randomly distributed within the cell. Resources blocks (RBs) are basically the smallest unit of resources that can be allocated to a user. Each DUEs or CUEs are assigned resource blocks. Each D2D user reuses a single resource block in the cell. RBs is 180 kHz wide in frequency, this 180KHz is the width of the band used by the RBs and 1 slot long in time (indicating of the resource block in time domain). There are two clusters formed. The first hierarchy of cluster is formed using the proximity model of the DUEs which is based solely on the closeness of these DUEs to each other and within the acceptable minimum range and distance to allow DUEs to join a cluster or to establish a D2D communication. The distance range for which D2D general mode communication can take place is represented mathematically as

$$d_{\min} < d_{comm} > d_{\max}\,. \tag{1}$$

Where, $d_{\min}$ is the minimum acceptable distance for establishing D2D communication, d_{comm} represents the allowable range for D2D communication, and $d_{\max}$ stands for the maximum allowable distance for D2D communication. In this study, the distance value for establishing D2D communication is given as:

$$d_{\min} \leq d_{comm} \leq d_{\max} = 10m \leq d_{comm} \leq 20m \tag{2}$$

Now, in order to form cluster for D2D general mode communication, the proximity model equation is given as:

$$d_{G-Cluster} = \frac{d_{\min} + d_{\max}}{2} \tag{3}$$

where, $d_{G-Cluster}$ is the acceptable distance between any DUE for potential cluster formation. This implies that a DUE must satisfy the condition $10m \leq d_{G-Cluster} \leq 15m$ for it to join a cluster.

2. Resource capability

The estimation of resource capability of a node for cluster head selection in D2D communication is based on various factors, such as computational capability, memory, and storage capacity. In order to estimate the resource capability of a node, weights or scores are assigned to these factors and combine them into a single metric using a formula or an aggregation function. The proposed formula for estimating the Resource Capability (RC) of a node for cluster head selection is given as:

$$RC = w_1 v_c + w_2 M + w_3 S \qquad \forall w_1 > w_2 > w_3 \tag{4}$$

where: w are the weight coefficients that represent the relative importance of each factor v_c denote the computational capability of the node**,** M stands for the memory size of the DUE**,** S represents the storage capacity of the DUE**.** After cluster formation, all cluster member node share their resource capability, the node with the highest resource capability is selected as the Cluster Head (CH).

3. Social Relationship-based mode cluster for D2D in mmWave mode

In this mode, the formation of D2D clusters in an mmWave communication environment based on social relationships or associations among devices. The degree of closeness centrality (shortest distance between a reference node and other devices) can be used to estimate the closeness of D2D users which now used to assign weights to users. The proposed closeness of centrality for DUEs is given as:

$$C_c\left(U_{DUE_a}\right)=\frac{\left[\sum_{b=1}^{N_{DUE}} d\left(U_{DUE_a},U_{DUE_b}\right)\right]^{-1}}{N_{DUE}-1} \tag{5}$$

where: N_{DUE} is the total number of DUE nodes

d(.) stands for the shortest distance between reference DUE node and all other node, U_{DUE_a} denotes for the reference DUE node, U_{DUE_b} represents any other DUE node

4. Sum rate, Energy Efficiency and Outage Probability analysis.

The sum rate of a D2D network refers to the total data rate that can be achieved by all the D2D pairs in the network. Thus, the sum rate of D2D users in the general mode, D2D users in the mmWave mode and cellular users is given by equations (6), (7) and (8) respectively Sarma et al., (2021).

$$R_{st_{DUE}}=\lambda_{DUE}R^{n}_{DUE} \tag{6}$$

$$R_{st_{mmDUE}}=\lambda_{mmDUE}R^{n}_{mmDUE} \tag{7}$$

$$R_{st_{CUE}}=\lambda_{CUE}R^{n}_{CUE} \tag{8}$$

Energy efficiency in a communication network refers to the amount of data transmitted per unit of energy consumed. It is a measure of how efficiently the network utilizes energy to achieve its communication objectives. The EE is defined as the ratio of D2D sum rate to the total power consumption. Thus, the total EE of D2D users (general mode), D2D users in mmWave mode and cellular users can be expressed as Sarma et al., (2021):

$$EE_{DUE} = \sum_{n=1}^{N} \frac{R_{st_{DUE}}}{\lambda_{DUE} P_{DUE}^{n}} = \sum_{n=1}^{N} \frac{R_{DUE}^{n}}{P_{DUE}^{n}} \tag{9}$$

$$EE_{mmDUE} = \sum_{n=1}^{N} \frac{R_{st_{mmDUE}}}{\lambda_{mmDUE} P_{mmDUE}^{n}} = \sum_{n=1}^{N} \frac{R_{mmDUE}^{n}}{P_{mmDUE}^{n}} \tag{10}$$

$$EE_{CUE} = \sum_{n=1}^{N} \frac{R_{st_{CUE}}}{\lambda_{CUE} P_{CUE}^{n}} = \sum_{n=1}^{N} \frac{R_{CUE}^{n}}{P_{CUE}^{n}} \tag{11}$$

Furthermore, Outage probability in a cellular network is the probability that the signal quality (usually measured by the Signal-to-Noise Ratio that is, SINR) falls below a certain threshold level, causing the communication link to fail or drop. Hence, to guarantee successful transmission of signal, the outage probability of D2D users in general mode, cellular users, and D2D users in mm-Wave mode, respectively should fall below a certain predetermined threshold, that is Sarma et al., (2021):

$$\Pr\left[\gamma_{DUE}^{n} < \gamma^{th}\right] \leq \Omega_{DUE} \tag{12}$$

$$\Pr\left[\gamma_{CUE}^{n} < \gamma^{th}\right] \leq \Omega_{CUE} \tag{13}$$

$$\Pr\left[\gamma_{mmDUE}^{n} < \gamma^{th}\right] \leq \Omega_{mmDUE} \tag{14}$$

where: Ω_{DUE} is the threshold set for outage of D2D users in general mode, Ω_{CUE} stands for the threshold set for outage of cellular users, Ω_{CUE} represents the threshold set for outage of D2D users in mmWave mode. With respect to transmission power constraint, the sum of transmission power over all the n^{th} channel should be equal to the total D2D transmission power and is given as Sarma et al., (2021):

$$\sum_{n=1}^{N} P_j^n = P \tag{15}$$

Notably, the individual powers in each n^{th} channel should be positive and must not exceed a certain upper bound for D2D users either in general or mm-Wave mode and its given as Sarma et al., (2021):

$$0 \le P_j^n \le P_{DUE}^{up} \tag{16}$$

Using Shannon's formula, the total throughput associated with the D2D users in cluster general communication mode with total bandwidth, B^n is expressed as:

$$R_{CDUE}^n = B^n \log_2(1 + \gamma_{CDUE}^n) \tag{17}$$

This further implies that the total throughput associated with the cluster D2D users in mm-Wave communication mode is expressed as:

$$R_{mmCDUE}^n = B^n \log_2(1 + \gamma_{mmCDUE}^n) \tag{18}$$

The cluster EE is defined as the ratio of D2D sum rate to the total power consumption in a cluster. Thus, the total EE of cluster D2D users (general mode) and cluster D2D users in mmWave mode are expressed as:

$$\begin{aligned} EE_{CDUE} &= \sum_{n=1}^{N} \frac{R_{st_{CDUE}}}{\lambda_{CDUE} P_{i,CDUE}^n} \\ &= \sum_{n=1}^{N} \frac{R_{CDUE}^n}{P_{i,CDUE}^n} \end{aligned} \tag{19}$$

$$\begin{aligned} EE_{mmCDUE} &= \sum_{n=1}^{N} \frac{R_{st_{mmCDUE}}}{\lambda_{mmDUE} P_{j,mmCDUE}^n} \\ &= \sum_{n=1}^{N} \frac{R_{mmCDUE}^n}{P_{j,mmCDUE}^n} \end{aligned} \tag{20}$$

Where: $P_{i,CDUE}^n$ is the transmission power of CHin i^{th}DUE cluster in general mode and $P_{j,mmCDUE}^n$ denotes the transmit power of CH in j^{th}DUE cluster in mmWave mode.

Additionally, guarantee successful transmission of signal, the outage probability of D2D cluster users in general mode and D2D users in mm-Wave mode, respectively should fall below a certain predetermined threshold, that is:

$$\Pr\left[\gamma_{CDUE}^{n} < \gamma^{th}\right] \le \Omega_{DUE} \tag{21}$$

$$\Pr\left[\gamma_{mmCDUE}^{n} < \gamma^{th}\right] \le \Omega_{mmDUE} \tag{22}$$

where Ω_{DUE} is the threshold set for outage of D2D cluster users in general mode and Ω_{CUE} represents the threshold set for outage of D2D cluster users in mmWave mode.

The Signal-to-Interference plus Noise Ratio (SINR) for cellular communication can be expressed as follows Sarma *et al.,* (2021):

$$\begin{aligned} Y^{n}{}_{C_{CUE}} &= \frac{P_i^n h_i d_i^{-\alpha}}{\sum\limits_{\substack{k=1\\k\neq i}}^{M} P_k^n h_k d_k^{-\alpha} + \sum\limits_{j=0}^{N} P_j^n h_j d_j^{-\alpha}} \\ &= \frac{h_i d_i^{-\alpha}}{\sum\limits_{\substack{k=1\\k\neq i}}^{M} \frac{P_k^n}{P_i^n} h_k d_k^{-\alpha} + \sum\limits_{j=0}^{N} \frac{P_j^n}{P_i^n} h_j d_j^{-\alpha}} \end{aligned} \tag{23}$$

Furthermore, the SINR for D2D communication in general communication mode and mm-Wave communication mode can be expressed as follows Sarma *et al.,* (2021):

$$\begin{aligned} Y_{C_{DUE}} &= \frac{P_j^n h_j d_j^{-\alpha}}{\sum\limits_{\substack{k=1\\k\neq j}}^{N} P_k^n h_k d_k^{-\alpha} + \sum\limits_{i=0}^{M} P_i^n h_i d_i^{-\alpha}} \\ &= \frac{P_j^n h_j d_j^{-\alpha}}{\underbrace{\sum\limits_{\substack{k=1\\k\neq j}}^{N} \frac{P_k^n}{P_j^n} h_k d_k^{-\alpha}}_{I_{d-DUE}} + \underbrace{\sum\limits_{i=0}^{M} \frac{P_i^n}{P_j^n} h_i d_i^{-\alpha}}_{I_{c-DUE}}} \end{aligned} \tag{24}$$

Also, the SINR for D2D communication in mm-Wave communication mode can be expressed as follows Sarma *et al.,* (2021):

$$Y_{C_{mmDUE}} = \frac{P_q^n h_q d_q^{-\alpha}}{\sum_{\substack{k=1 \\ k\neq j}}^{N} P_k^n h_k d_k^{-\alpha}} = \frac{P_q^n h_q d_q^{-\alpha}}{\underbrace{\sum_{\substack{k=1 \\ k\neq j}}^{N} \frac{P_k^n}{P_q^n} h_k d_k^{-\alpha}}_{I_{d-mmDUE}}} \tag{25}$$

This implies that the total throughput associated with the D2D users in general communication mode with total bandwidth B^n, by using Shannon's formula, is expressed as Ombongi *et al.,* (2019):

$$R_{DUE}^n = B^n \log_2(1+\gamma_{DUE}^n) \tag{26}$$

This further implies that the total throughput associated with the D2D users in mm-Wave communication mode is expressed as Sarma *et al.,* (2021):

$$R_{mmDUE}^n = B^n \log_2(1+\gamma_{mmDUE}^n) \tag{27}$$

In order to uphold a specific Quality of Service (QoS), a mode selection procedure has been implemented, which guarantees an increased signal-to-interference-plus-noise ratio (SINR) and consequently improved the data rate of the Device-to-Device (D2D) users. The maximum allowable interference that can be tolerated by the cellular user is denoted as $P_{DUE\max}$ which is determined using equations (23) and (24). This is given as Ombongi *et al.,* (2019):

$$P_{DUE\max} = \sum_{\substack{k=1 \\ k\neq j}}^{N} \frac{P_k^n}{P_j} h_k d_k^{-\alpha} + \sum_{i=0}^{M} \frac{P_i^n}{P_j} h_i d_i^{-\alpha} \tag{28}$$

$$\gamma_{DUE} \geq \gamma^{th} \tag{29}$$

The derivation of Equation (29) is based on the requirement that the SINR of the DUEs users must exceed a predetermined threshold value γ^{th} to maintain a particular QoS.

5. Simulation Parameters

Table 1 presents the simulation parameters used to evaluate the performance of the Improved Power Control Scheme for Device-to-Device Comunication using Hierarchical Cluster Algorithm in 5G networks.

Table 1. Simulation Parameter

Parameters	Values
Cell radius	500m
Bandwidth	200MHz
Operating frequency (mm-Wave mode)	28GHz
Thermal Noise density	-174dBm/Hz
Υ_c^{th}	0 dB
Υ_d^{th}	0 dB
Maximum D2D transmit power	15mW
Rician channel K factor	8
Minimum Distance	10m
Maximum Distance	20m
Maximum Power	15mW
Pathloss Exponent	3.5 - 4.5
Number of D2D Users	100

6. Flowchart of the proposed scheme.

An Improved Power Control Scheme for Device-to-Device Communication using Hierarchical Cluster Algorithm (mPCS-D2D) is illustrated in Figure 1. The flowchart outlines the key steps and process used in implementing the algorithm focusing on Energy Efficiency, throughput and Outage Probability.

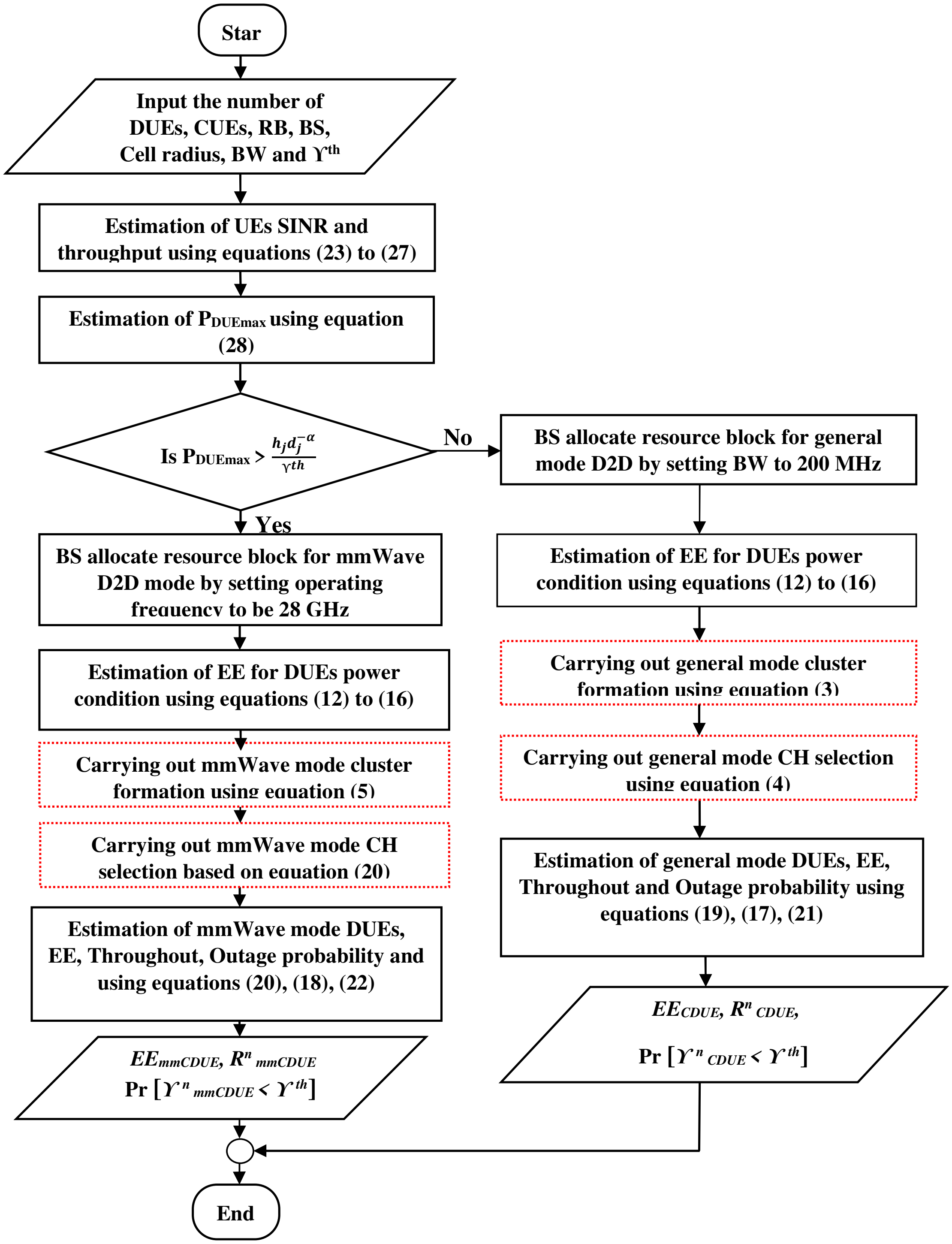

Figure 1. Modified Power Control Scheme flowchart based on Hierarchical Clustering

RESULTS

The performance metrics evaluated include Energy Efficiency, Throughput, and Outage Probability. These metrices are futher discussed as follows.

1. Energy Efficiency

When clustering D2D devices is done, energy efficiency not only optimizes network performance but also supports sustainable deployment of 5G mmwave technologies. This is important for networks that aim to deliver high speed connectivity while managing energy resources efficiently. This study evaluates the impact of clustering DUEs on system energy efficiency (EE) and D2D power consumption. Clustering significantly enhances system energy efficiency by reducing transmission power and mitigatin interference thereby optimizing resource allocation. Results indicate that the proposed mPCS-D2D scheme significantly outperforms the existing scheme PCS-D2D.

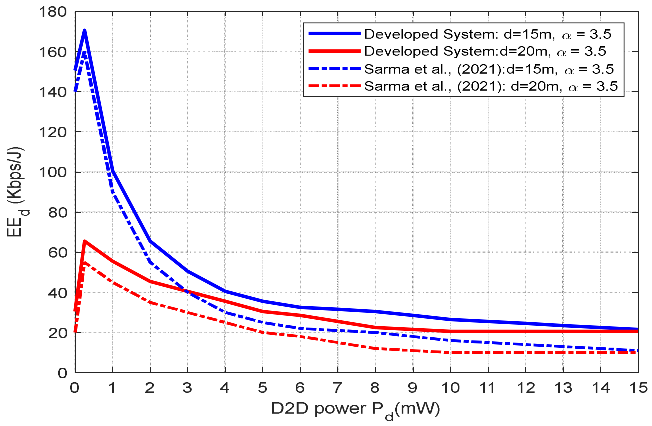

Figure 2. Energy Efficiency of mPCS-D2D and PCS-D2D.

When the distance between DUEs is 15 m, mPCS-D2D achieves an EE of 50.664 kbps/J, reflecting a 24.37% improvement over PCS-D2D 41.294 kbps/J. As the distance increases to 20 m, mPCS-D2D maintains its advantage, achieving 29.721 kbps/J, which is 46.03% higher than the PCS-D2D value of 20.352 kbps/J. With this improvement in energy efficiency, D2D communication networks can achieve extended operational lifespans and improved performance.

Table 2. Energy Efficiency Values for mPCS-D2D and PCS-D2D

	EE (Kbps/J)				**EE (Kbps/J)**			
D2D Power (mW)	**Sarma et al. (2021) d=20m**	**Developed System d=20m**	**Percentage Improvement using equation (3.13)**	**Average Percentage Improvement using equation (3.17)**	**Sarma et al. (2021) d=15m**	**Developed System d=15m**	**Percentage Improvement using equation (3.13)**	**Average Percentage Improvement using equation (3.17)**
0	20.00	29.3700	46.85%		140.000	149.4000	6.71%	
0.25	55.00	64.3689	17.03%		160.0000	169.3689	5.86%	
1	45.00	54.3689	20.82%		90.0000	99.3689	10.41%	
2	35.00	44.3689	26.77%		55.0000	64.3689	17.03%	
3	30.00	39.3689	31.23%		40.0000	49.3689	23.42%	
4	25.00	34.3689	37.48%		30.0000	39.3689	31.23%	
5	20.00	29.3689	46.84%		25.0000	34.3689	37.48%	
6	18.00	27.3689	52.05%		22.0000	31.3689	42.59%	
7	15.00	24.3689	62.46%	46.03%	21.0000	30.3689	44.61%	24.37%
8	12.00	21.3689	78.07%		20.0000	29.3689	46.84%	
9	11.00	20.3689	85.17%		18.0000	27.3689	52.05%	
10	10.00	19.3689	93.69%		16.0000	25.3689	58.56%	
11	10.00	19.3689	93.69%		15.0000	24.3689	62.46%	
12	10.00	19.3689	93.69%		14.0000	23.3689	66.92%	
13	10.00	19.3689	93.69%		13.0000	22.3689	72.07%	
14	10.00	19.3689	93.69%		12.0000	21.3689	78.07%	
15	10.00	19.3689	93.69%		11.0000	20.3689	85.17%	

2. Throughput

Throughput is the rate at which data is transmitted between network devices per unit time. High throughput is required for efficient data transfer, reduced delays and improved network performance. In Hierarchical clustering, interference is minimized and increasing throughput. Figure 3 shows the plot of throughput versus the density of D2D users. It is observed from figure 3 that the more dense D2D users, the throughput value decreases as the number of D2D users increases due to congestion and increase in interference. The mPCS-D2D at path-loss value of 3.5 achieved a throughput value of 172.156 kbps with an average performance improvement of 4.77% over PCS-D2D throughput value of 164. 394 kbps. As path-loss value was set at 4.5, mPCS-D2D obtained a throughput value of 188.653 kbps with an average improvement of 4.33% over PCS-D2D throughput value of 180.864 kbps

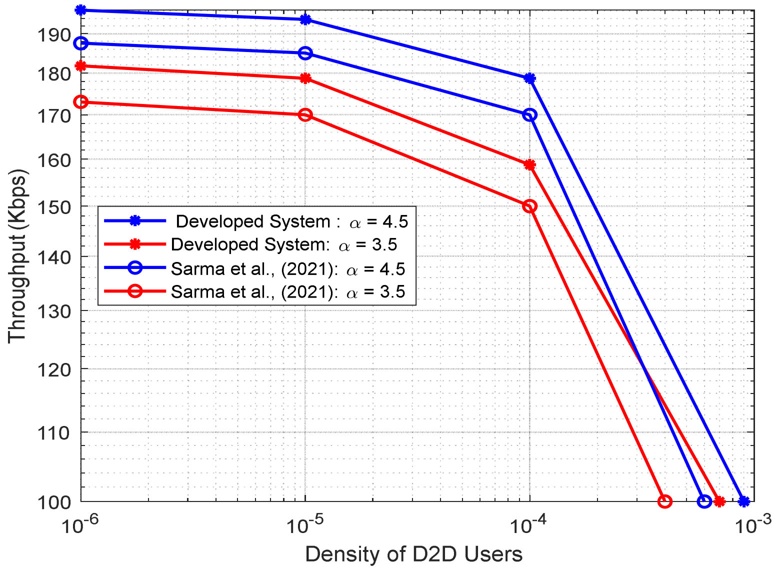

Figure 3. Throughput performance of mPCS-D2D and PCS-D2D

The table below is the table of the results obtained from the simulation of the modified scheme.

Table 3. Throughput Values for mPCS-D2D and PCS-D2D

	Throughput (Kbps)				**Throughput (Kbps)**			
Density of D2D Users	**Sarma et al. (2021) α=3.5**	**Developed System α=3.5**	**Percentage Improvement using equation (3.14)**	**Average Percentage Improvement using equation (3.18)**	**Sama et al. (2021) α=4.5**	**Developed System α=4.5**	**Percentage Improvement using equation (3.14)**	**Average Percentage Improvement using equation (3.18)**
1.00E-06	173.0472	180.8546	4.51%	4.77%	187.5382	195.3456	4.16%	4.33%
1.00E-05	170.000	177.8074	4.59%		185.000	192.8074	4.22%	
0.0001	150.000	157.8074	5.20%		170.000	177.8074	4.59%	

3. Outage Probability

Outage probability is what determines the likelihood that the recived signal falls below a predefined threshold, leading to service disruption, link failure or call drops and overall reduction in quality of service. As the amount of D2D power increases, the percentage outage probability of the D2D user's drops. This is so because as transmit power increases, signal is prune to more interference hence leading to reduction in the signal quality which in turn increases outage probability of D2D users. When the distance between D2D users was 10m with a pathloss exponent of 4.5, the mPCS-D2D gave a value of 0.0879 with a 9.50% improvement over 0.0955 value of PCD-D2D. While the distance increases to 15m with a pathloss exponent of 4.5, a 0.139 outage probability was obtained with a 34.22% improvement over 0.215 value of PCD-D2D. At 10 m distance and 3.5 pathloss exponent, mPCS-D2D obtained 0.110 outage probability value with a 41.06% improvement over 0.186 value of PCS-D2D. As the distance increases to 15 m, mPCS-D2DD gave 0.279 with a 19.79% improvement over 0.354 outage probability value of PCS-D2D. As D2D power increases, outage probability decreases due to higher signal interference affecting signal quality

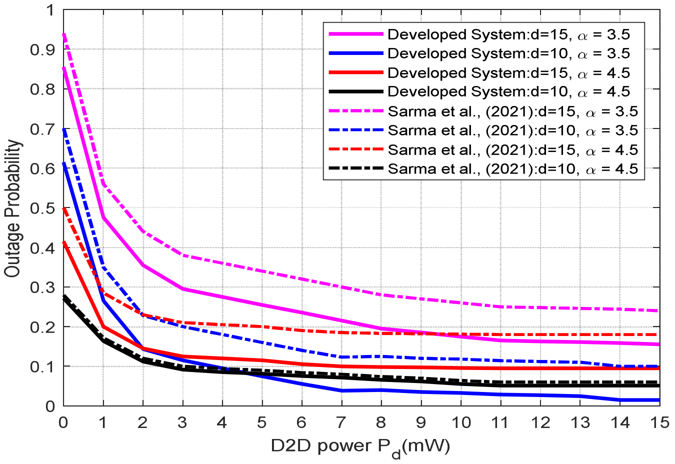

Figure 4. Outage Probability plot of mPCS-D2D and PCS-D2D

DISCUSSION

The developed mPCS-D2D lessens the effects of interference in D2D networks by developing hierarchy of clusters for DUEs in the general and mmWave mode communication. By simulation on MATLAB 2021a, the performance of mPCS-D2D is compared to PCS-D2D. The developed mPCS-D2D achieved EE value of 29. 722 kbps/J compared to 20.350 kbps/J value of PCS-D2D with an average percentage improvement of 46.05%. It achieves a 4.47% improvement in throughput which is vital for efficient data transfer. The outage probability value of the developed mPCS-D2D obtained was 0.110 with an average percentage improvement of 41.06% compared to 0.186 value of PCS-D2D leading to high sustainability and reliability and a more robust communication network. These results show mPCS-D2D advantage over PCS-D2D in terms of Energy Efficiency, throughput and outage Probability. The mPCS-D2D presents an effective approach for managing power in D2D comunications over uplink channels within 5G mmWave networks.

CONCLUSION

In conclusion, this study presents an improved power control scheme for D2D communication using a hierarchical cluster algorithm known as mPCS-D2D. By organizing DUEs into clusters based on proximity and social relationships, the proposed mPCS-D2D effectively mitigates interference and enhances network performance. Simulations was done in MATLAB 2021a confirms that mPCS-D2D surpasses PCS-D2D performance across various metrics. The results demonstrate significant improvements of 46.03% in Energy Efficiency, a 4.47% throughput performance, and a 41.06% improvement outage probability compared to existing schemes (PCS-D2D). Future work could explore integrating advanced resource allocation strategies, such as beamforming and dynamic spectrum access to further optimize network resources.

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