Symbiosis Between D2D Communication and Industrial IoT for Industry 5.0 in 5G mm-Wave Cellular Network: An Interference Management Approach

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***Abstract*—Industrial Internet of Things (IIoT) paves way into Industry 5.0, which incorporates human–machine collaboration, thereby making manufacturing industry efficient. As 5G architecture supports massive IoT connectivity and has higher spectrum efficiency, device-to-device (D2D) communication is favorable at 28 GHz. While transmitting data from sensors to end user through IoT network, interference affects the system. Thus, an efficient resource allocation scheme is needed for minimizing interference and increasing data rate. Here, formulated problem is divided into two subproblems, channel assignment and power optimization in order to lower computational complexity. A partial resource multiplexing scheme is proposed that will allocate channels to available D2D users. Later, power optimization problem is formulated which is determined through Lagrangian dual optimization technique. Dynamic sectorization overcomes issue of increase in user traffic. Stability factor, fairness index (FI), and energy efficiency depict the performance superiority of proposed scheme over existing schemes. Simulation results prove efficacy of proposed system.**

***Index Terms*—5G mm-Wave network, device-to-device (D2D) communication, industrial Internet of Things (IIoT), Industry 5.0, Lagrangian dual optimization technique, resource multiplexing, stability and fairness.**

I. Introduction

INDUSTRY 5.0 paves the way for the interaction and collaboration between machines and humans by introducing the concept of personalization and taking it to a whole new level with the potential of personalized mass production. This collaboration will undoubtedly usher the roles of humans and machines in the production industry. The industrial Internet of Things (IIoT) can benefit the most from Industry 5.0 through a human–machine interface. IIoT may be stated as a network of smart devices, group of machinery or various sensors connected among themselves and the internet [1] and [2]. IIoT enables efficient and sustainable production through a better understanding of the manufacturing process. It is expected that by 2025, the number of Internet of Things (IoT) connections will be around 80 billion, quadrupling the global IoT revenue to \$1.1 trillion dollars, enhancing the productivity as well as the quality of industrial appliances [3]. IIoTs operating at 28 GHz improves the data rate, reduces the latency, and control overhead. However, enabling IoT in the 5G framework at the 28 GHz band has potential issues [4]. The proliferation of IoT devices results in massive data traffic, which is expected to affect the design and implementation of the 5G wireless communication system [5]. IIoT can be applied to a variety of production processes [3]. In particular, oil production companies feel the need to connect to IoT networks at isolated sites of operation which would eventually make the production process more efficient.

In the oil and gas sector, mechanical inclination indicators are single-shot inclination-only survey tools, commonly known as TOTCO, used in drilling. These tools measure the depth from the ground surface along the wellbore, angle of inclination and drift direction of the wellbore [6]. The acquired data from the sensor can be transmitted to the end user by connecting to an IoT network for further operation. Thus, IIoT poses to be a revolution in the field of human touch by upgrading the existing machinery units to a smart production unit, wherein the insights are collected from multiple data sources through monitoring and forecasting techniques. In the IIoT network, these smart sensors acting as a device-to-device communication (D2D) user transmits useful data to the end user for processing data in real time, thereby enhancing the efficiency of the production industry.

D2D is defined as the direct communication between two devices or users which are in propinquity, without traversing the base station (BS) [7]. Bandwidth intensive applications

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such as IIoT; requires large bandwidth for seamless operation, which is not possible at 2 GHz. Thus, D2D communication is favoured at the millimeter Wave (mm-Wave) frequency as it increases the spectral efficiency of the network by establishing a direct link between users without the direct involvement of the BS. In addition to that, D2D communication at the mm-Wave frequency also has larger bandwidth, higher data rate, ultralow latency, and lesser interference at the unused spectrum [8]. The implementation of D2D communication at mm-Wave frequency of 28 GHz has some issues to tackle with. The transmitted signal in the mm-Wave frequency usually suffers from propagation loss due to various interferences and blockages such as atmospheric absorption, rain attenuation, human blockages, foliage loss, etc. [9]. However, the 5G architecture supports massive IoT (mIoT) operations which makes it suitable for IIoT applications [4]. For IIoT applications, D2D communication not only performs the exchange of valuable user information between the machines or sensors in proximity to each other but also helps in data offloading. The D2D feature of LTE-A makes it a reality for transferring information to the Internet by constructing a multihop sensor network [10]. Thus, in the proposed work, the data acquired by the TOTCO surveying tool in the oil and gas field can be transmitted to the control station for further operation. For the data to get transferred to the control station, it must first connect to the IIoT network. Since, D2D communication network, in most cases, operates in an underlay cellular network by reusing the cellular resources, affecting the quality of service (QoS) of the network by introducing interference. Also, the transmitted data from the TOTCO tool, while propagating to the receiver end (human held device), suffers from interference due to traffic and harsh environment in the IIoT network. Here, the transmitter (TOTCO tool) and receiver (human held device) are perceived to be D2D users. Thus, an efficient resource allocation scheme should be explored for enabling D2D communication in the oil and gas sector so as to minimize interference and increase the data rate of the overall IIoT network. As a result, it will usher Industry 5.0 to new heights by establishing a collaborating link between machines and humans.

A. Related Works

A majority of the research work in the field of 5G focuses on the resource allocation schemes in an underlay cellular network, trying to minimize the effect of interference in the received signal. Authors in [11]–[15] propose power control schemes using different techniques for maximizing the D2D data rate. The author in [11] presents a factor graph based approach for power control while implementing the max–min criterion for maximizing the minimum rate of the users. The authors in [12] incorporate a Lagrangian dual optimization method for the power control problem while maximizing the D2D sum rate. The D2D pairs reuse the multiple channels from different cellular users. In [13], the authors propose two modes for D2D communication at the mm-Wave band. It gets switched to the mm-Wave mode in case of higher interference and pathloss attenuation, but the complexity increases significantly. Moreover, the article fails to utilize the spectrum resources optimally. The proposed work provides an efficient method to utilize the spectrum resources by multiplexing the available channels followed by dynamic sectorization.

The authors in [14] optimize the transmit power by selecting the optimal transmission and receiving beam width through particle swarm optimization algorithm. In [15], the authors optimize the D2D power based on the max greedy SNR scheme. But, the technique requires global channel state information (CSI) for each of the nodes, which increases the overhead. However, in the preceding works [10]–[14], the huge number of requests that the BS receives in case of dense mm-Wave network is rarely taken into account, leading to channel assignment issues.

Lv *et al.* [16] propose a mm-Wave nonorthogonal multiple access transmission scheme implemented on cellular machine-to-machine (M2M) communication systems for IoT applications. The proposed system has the ability to support massive connectivity. Mach *et al.* [17] maximize the sum capacity by reusing the channel resources of D2D communication operating at 2 GHz through the use of the Hungarian algorithm. The authors in [18] proposes a cross-cell fractional frequency reuse-based frequency resource multiplexing scheme for multicell D2D communication. Different spectrum resources are allocated to two different regions—namely, center and edge regions of the cell in order to mitigate interference. Rebato *et al.* [19] introduce a hybrid spectrum sharing technique for mm-Wave cellular networks in the sub-6GHz band where data packets are scheduled through two mm-Wave carriers with different characteristics. El Halawany *et al.* [20] investigate an analytical approach to analyze the outage behavior of the D2D communication as an enabling technology for IoT. The work considers a scenario of uniform deployment of D2D clusters in the cell which is rare in a practical environment. Lastly, in [21], energy efficiency and spectrum efficiency of two-way amplify and forward (AF) relaying D2D communication is maximized.

Literature has witnessed several resource allocation techniques to mitigate interference using power optimization. But the existing works lack in considering the huge number of user traffic. Thus, there is scope of work in D2D power optimization along with channel assignment for D2D users in the dense mm-Wave network. Moreover, most of the existing researches focus on the sub-6GHz band. It is known that the interference acting on the system at sub-6GHz is comparatively lower than at 28 GHz. This implies that the proposed work gives us a deep insight into the effect of interference on the D2D network at 28 GHz. At such a higher frequency, with the increase in distance between D2D users, signal strength also falls considerably. This is why resource allocation is required for efficient utilization of spectrum which is discussed in the proposed work. D2D network performance also suffers from the interference acting on it at 28 GHz, and thus, power optimization is required to minimize interference among D2D users. The proposed work formulates an efficient power optimization method in order to minimize interference on the D2D network at the mm-Wave band.

The major contributions of the proposed work are furnished as follows.

1) The proposed partial resource multiplexing scheme allows a D2D user operating at the mm-Wave band (28

GHz) amidst extensive propagation losses, to access a part of cellular resources that help in lowering the interference. The partial resource multiplexing ratio q_{ci}^{dj} maintains the channels to be multiplexed with D2D users for optimal utilization of spectrum.

2) Intracell interference is reduced and D2D communication has a lesser impact on the cellular users. Higher data rates can be achieved by utilizing the same number of resources.
3) Since the formulated problem is a nonconvex mixed integer nonlinear program, it involves higher computational complexity. Thus, to minimize the computational complexity the formulated problem is divided into two subproblems, channel assignment, and power optimization.
4) The optimization of D2D transmit power on the assigned channels lower the computational complexity of the algorithm. Updating the weighted value attached to D2D transmit power P_m^{k*} helps in achieving optimal power.
5) Dynamic sectoring ensures a higher data rate with permissible QoS constraints thereby reducing the interference between the D2D users. This will lead to an increase in SINR value. Sectoring of three or six is done based on the optimal D2D transmit power.

The rest of the article is organized as follows. In Section II, the system model has been described along with the considered pathloss model. Next, the problem formulation is done for channel assignment through a partial resource multiplexing scheme as described in Section III. Also, the problem is formulated for a power optimization scheme with QoS constraints followed by dynamic sectorization. This is followed by Section IV where performance evaluation of the proposed scheme is discussed and simulation results are analyzed. The computational complexity of the proposed system is also described in this section. Finally, Section V concludes this article.

II. System Model

We consider a D2D communication system in a 5G mm-Wave underlaying cellular network, where the D2D pairs communicate with each other reusing the uplink resources of the cellular users. We consider a single cell system consisting of a set of cellular users and D2D users as shown in Fig. 1. The base station is assumed to be situated at the center of the cell. The cardinality of cellular users and D2D users are N and M, respectively. The cellular users and D2D users are indexed by sets $C\epsilon\{C_1, C_2, \ldots C_n, \ldots, C_N\}$ and $D\epsilon\{D_1, D_2, \ldots D_m, \ldots, D_M\}$, where $n\epsilon\{1, 2, \ldots., N\}$ and $m\epsilon\{1, 2, \ldots., M\}$, respectively. The number of channels available is assumed to be equal to the number of cellular users. To reduce the interference between the cellular users and D2D users, resource multiplexing plays a pivotal role which makes us aware of the particular cellular user resource which could be multiplexed to a D2D user and also the quantity of the resources to be multiplexed with the D2D user. An urban scenario is considered for the proposed work where the cell region is

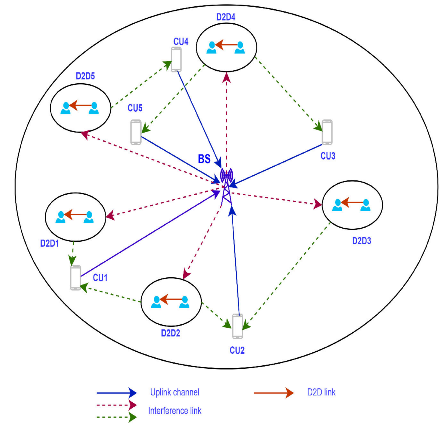

Fig. 1. System model displaying interference links among D2D and cellular users in mm-Wave 5G cellular network for uplink resources.

surrounded by thick concrete structures and reflective glasses. In addition to that, other propagation losses such as human blockages, rain attenuation, atmospheric absorption, foliage loss, etc., also affect the system. As a result, the pathloss exponent within the specified region is high. Thus, it has been assumed that the BS has prior knowledge of the locations of the cellular as well as D2D users along with their respective pathloss exponents [13]. A pathloss model is considered to maintain the signal strength above a certain threshold value. As per the NYUSIM channel model [22], the path loss model considered for free space pathloss (FSPL) is as follows:

$$\begin{aligned} FSPL(f, 1m)[dB] &= 20\log_{10}\frac{(4\pi f_c \times 10^9)}{c} \\ &= 32.4[dB] + 20\log_{10} f_c \end{aligned} \tag{1}$$

where f_c is the carrier frequency and c is the speed of light. The frequency used for mm-Wave mode communication is 28 GHz. $FSPL(f, 1m)$ denotes the free space pathloss in dB with transmitter–receiver (T–R) distance of 1 m. Due to the high penetration losses, large scale pathloss model considered for 1 m reference distance as per the NYUSIM [22] is as follows:

$$\begin{aligned} PL(f, d)[dB] = FSPL(f, 1m)[dB] + 10\alpha\log_{10}(d) \\ + AT[dB] + \chi_\sigma \end{aligned} \tag{2}$$

where d is the separation distance (in 3D) between T–R (D2D users), α and χ_σ denote the pathloss exponent and the log normal shadow fading having zero mean with σ standard deviation (in dB). AT represents the interference due to the atmospheric absorption. The channel gain (Rician fading channel) h between the two D2D users can be represented as [16]

$$h = 10^{-PL(f,d)[dB]/10} \tag{3}$$

h is dependent on the distance between the T–R and is independently and identically exponentially distributed with a mean μ^{-1}.

III. Problem Formulation and Analysis

A. Partial Resource Multiplexing Scheme for D2D Users With QoS Constraints

Let P_i^k and P_j^k be the transmit powers of the ith cellular user and jth D2D user, respectively, on channel k. Thus, we implement a partial resource multiplexing (PRM) technique [18] for sharing resources of the cellular user with the D2D user. Let us assume the partial resource multiplexing ratio of the cellular user multiplexed by the D2D user to be q_{ci}^{dj}, given by [18]

$$q_{ci}^{dj} = \frac{1}{K\epsilon}\left(1 - e^{-\frac{1}{\eta G_{c_i d_j}}}\right), q_{ci}^{dj} \leq 1 \tag{4}$$

where K is the cardinality of cellular users sharing its resources with the D2D users. η denotes the function slope parameter and ϵ is the normalization coefficient. It is also assumed that the resource of one cellular user can only be multiplexed by one D2D user but on the contrary, a single D2D user can multiplex the resources of more than one cellular users. While implementing the PRM, it is seen that the subcarriers are divided into two sub categories, multiplexed and nonmultiplexed subcarriers. Thus, the signal-to-interference plus noise ratio (SINR) of the subcarriers which are multiplexed by the D2D user and the SINR of the subcarriers (nonmultiplexed) of the cellular user, respectively, are given as follows:

$$\gamma_c = \frac{P_n^k G_{B.c_n}^k d_n^{-\alpha}}{\sigma_N^2 + \psi \sum_{j=1}^{M} \sum_{\substack{i=1\\ i\neq n}}^{N} P_i^k G_{c_i d_j}^k d_i^{-\alpha} + \sum_{i=1}^{N} \sum_{j=1}^{M} P_j^k G_{c_i d_j}^k d_j^{-\alpha}} \tag{5}$$

$$\hat{\gamma_c} = \frac{P_n^k G_{B.c_n}^k d_n^{-\alpha}}{\sigma_N^2 + \psi \sum_{j=1}^{M} \sum_{\substack{i=1\\ i\neq n}}^{N} P_i^k G_{c_i d_j}^k d_i^{-\alpha}}. \tag{6}$$

And the SINR of the D2D user due to the multiplexed subcarriers from the cellular users can be written as follows:

$$\gamma_d = \frac{P_m^k G_{dd}^k d_m^{-\alpha}}{\sigma_N^2 + \psi \sum_{j=1 j\neq m}^{M} P_j^k G_{dd}^k d_j^{-\alpha} + \sum_{i=1}^{N}\sum_{j=1}^{M} P_i^k G_{c_i d_j}^k d_i^{-\alpha}}. \tag{7}$$

Here, ψ denotes a Bernoulli's random variable with a binary value of either 1 or 0. When the D2D user multiplexes resources with the cellular user, it displays a 1, otherwise 0. σ_N^2 represents the power of Additive White Gaussian Noise (AWGN). Here, P_n^k and P_m^k represent the transmit power of the nth cellular user and the mth D2D user on the channel k, respectively. Again, $G_{B.c_n}^k$, $G_{c_i d_j}^k$, and G_{dd}^k represent the channel gain for the kth channel between the BS and nth cellular user, ith cellular user and jth D2D user, and T–R D2D users, respectively. d_i denotes the distances between the BS and the cellular user, whereas, d_j denotes the distance between two respective D2D users. Now, the throughput of the multiplexed subcarriers, nonmultiplexed subcarriers and D2D users, respectively, can be formulated as follows:

$$R_c = \log_2(1 + \gamma_c) \tag{8}$$

$$\hat{R}_c = \log_2(1 + \hat{\gamma_c}) \tag{9}$$

$$R_d = \log_2(1 + \gamma_d). \tag{10}$$

Thus, the overall throughput of the cellular network can be formulated as shown as follows:

$$R_{\text{sum}} = \underbrace{\sum_{i=1}^{N}\left[\left(1 - \sum_{j=1}^{M} q_{ci}^{dj}\right) m_c \hat{R}_c + \sum_{j=1}^{M} q_{ci}^{dj} m_c R_c\right]}_{\text{Cellular}} + \underbrace{\sum_{j=1}^{M}\sum_{i=1}^{N} q_{ci}^{dj} m_c R_d}_{\text{D2D}}. \tag{11}$$

In (11), $(1 - \sum_{j=1}^{M} q_{ci}^{dj}) m_c \hat{R}_c$ and $q_{ci}^{dj} m_c R_c$ denote the data rate yielded from the multiplexed as well as the nonmultiplexed subcarriers, respectively. m_c denotes the number of resource blocks allotted to the cellular user. The first term represents the overall throughput of the cellular users and the second term represents the overall throughput of the D2D users. To ensure that the QoS of the cellular network remains intact, the SINR should be above a certain predetermined threshold value γth, i.e., the interference should not exceed a certain maximum value. Let us consider the maximum tolerable interference that the D2D users can withstand be $I_{\max}$ as derived from (7):

$$I_{\max} = \psi \sum_{\substack{j=1\\ j\neq m}}^{M} P_j^k G_{dd}^k d_j^{-\alpha} + \sum_{i=1}^{N}\sum_{j=1}^{M} P_i^k G_{c_i d_j}^k d_i^{-\alpha} \tag{12}$$

and, let the SINR threshold be

$$\gamma_d \geq \gamma_{th}. \tag{13}$$

Now, combining (7) and (13), we get

$$\gamma_{th} \leq \frac{P_m^k G_{dd}^k d_m^{-\alpha}}{\sigma_N^2 + I_{max}}$$

$$\text{i.e.,} \qquad I_{\max} \leq \frac{P_m^k G_{dd}^k d_m^{-\alpha}}{\gamma_{th}} - \sigma_N^2 \tag{14}$$

$$\text{i.e.,} \qquad \frac{(I_{\max} + \sigma_N^2)\gamma_{th}}{G_{dd}^k d_m^{-\alpha}} \leq P_m^k.$$

1) Preliminary Phase: The primary focus of this phase is to allocate atleast one channel to all the D2D users present in the cell. In the beginning, the allocation of these channels is possible using the Hungarian algorithm. It maximizes the capacity of the cellular network if only one channel is allocated to each of the D2D users. To guarantee the QoS, the maximum capacity of the D2D users can be achieved when D2D transmit power, P_m^k will be less than or equal to the maximum attainable D2D power, $P_{\max}$ given as follows:

$$P_m^k \leq P_{\max} \qquad \forall n \epsilon N \quad \forall m \epsilon M. \tag{15}$$

The Hungarian algorithm [16] is applied which assigns each channel to the primary D2D pairs. Two cases may occur in this phase. 1) For the condition $N > M$, the algorithm runs for (N/M) times wherein M channels are allocated to the D2D users during each cycle of the algorithm. 2) For the condition $N < M$, a certain number of the D2D users may not get the access to any channel.

Thus, in the preliminary phase, a certain number of D2D users are left out from resource allocation. The remaining D2D users may also get access to the channel in the second phase where they multiplex the resources of the cellular network.

2) Second Phase: The problem formulation is done to guarantee the overall throughput of the cellular network as shown as follows:

$$\max_{q_{ci}^{dj}} \quad \{R_{\text{sum}}\} \tag{16}$$

subject to constraints

$$a1: \quad \gamma_c \geq \gamma_{th} \tag{17a}$$

$$a2: \quad \gamma_d \geq \gamma_{th} \tag{17b}$$

$$a3: \quad \sum_i \sum_j q_{ci}^{dj} \leq 1; \qquad \forall\ n\epsilon N \quad \forall\ m\epsilon M. \tag{17c}$$

The constraints $a1$ and $a2$ guarantee that the SINR of the cellular and the D2D users are above the minimum SINR required for maintaining the QoS of the overall system. The constraint $a3$ guarantees that the resource multiplexing ratio satisfies the QoS requirements of the cellular network. The constraint $a3$ depends upon the number of cellular users multiplexing its resources with the D2D users and also on the number of cellular users it can multiplex while satisfying the QoS requirements. Since our goal is to estimate the increment in the overall data rate of the network, we have added the multiplexed cellular users and the D2D users. Subsequently, we have negated the nonmultiplexed cellular users from the sum. Thus, the increment in the data rate of the overall network can be shown as follows:

$$\begin{aligned} R_{\text{inc}} = \sum_{j=1}^{M}\sum_{i=1}^{N} q_{ci}^{dj} m_c R_d + \sum_{i=1}^{N}\Bigg[\sum_{j=1}^{M} q_{ci}^{dj} m_c R_c \\ - \left(1 - \sum_{j=1}^{M} q_{ci}^{dj}\right) m_c \hat{R}_c\Bigg]. \end{aligned} \tag{18}$$

B. Power Optimization Scheme for D2D Users With QoS Constraints

The objective of this scheme is to maximize the D2D throughput and at the same time also try to lower the D2D transmit power. The formulated problem for power optimization, ensuring a certain QoS for cellular users is expressed as follows:

$$\max_{P_m^k} \sum_{j=1}^{M}\sum_{i=1}^{N} q_{ci}^{dj} m_c log_2(1+\gamma_d) - \sum_{j=1}^{M} \omega_{j,k} P_m^k \tag{19}$$

subject to constraints

$$a4: \quad P_m^k \leq P_{\max} \tag{20a}$$

$$a5: \quad \frac{(I_{\max} + \sigma_N^2)\gamma_{th}}{G_{dd}^k d_m^{-\alpha}} \leq P_m^k. \tag{20b}$$

As the goal of the scheme is to minimize the D2D transmit power and increase the overall data rate of the cellular network, a fixed weight $\omega_{j,k}\epsilon(0,\infty)$ is attached to the D2D transmit power assuming that it enhances the throughput. The constraint $a4$ denotes the maximum transmit power for the D2D users. The constraint $a5$ signifies a power limit to each of the D2D users which are dependent upon the maximum tolerable interference $I_{\max}$ and the threshold SINR γth of the D2D users. The formulated power optimization problem is concave in nature which is difficult to solve. Thus, an optimal solution for the formulated problem is achieved by applying the Lagrange dual optimization theorem [23]. Hence, the Lagrangian associated with the formulated problem is furnished as follows:

$$\begin{aligned} \mathcal{L}(P_m^k, \lambda_i, \mu_j) = \sum_{j=1}^{M} \omega_{j,k} P_m^k - \sum_{j=1}^{M}\sum_{i=1}^{N} q_{ci}^{dj} m_c log_2(1+\gamma_d) \\ + \sum_{i=1}^{N} (P_m^k - P_{\max})\lambda_i \\ + \sum_{j=1}^{M} \mu_j \left[\frac{(I_{\max} + \sigma_N^2)\gamma_{th}}{G_{dd}^k d_m^{-\alpha}} - P_m^k\right] \end{aligned} \tag{21}$$

where λ_i and μ_j are the Lagrange multipliers. Therefore, the above equation can be expressed in the form as shown as follows:

$$\begin{aligned} &\mathcal{L}(P_m^k, \lambda_i, \mu_j) \\ &= \sum_{i=1}^{N}\sum_{j=1}^{M} \Bigg[\omega_{j,k} P_m^k \\ &- q_{ci}^{dj} m_c \frac{Ln}{Ln2}\left(1 + \frac{P_m^k G_{dd}^k d_m^{-\alpha}}{\sigma_N^2 + \psi \sum_{\substack{j=1 \\ j\neq m}}^{M} P_j^k G_{dd}^k d_j^{-\alpha} + \sum_{i=1}^{N}\sum_{j=1}^{M} P_i^k G_{c_i d_j}^k d_i^{-\alpha}}\right) \\ &+ \lambda_i P_m^k - \mu_j P_m^k\Bigg] - \sum_{i=1}^{N} \lambda_i P_{\max} \\ &+ \sum_{j=1}^{M} \mu_j \left[\frac{(I_{\max} + \sigma_N^2)\gamma_{th}}{G_{dd}^k d_m^{-\alpha}}\right] \\ &= \sum_{i=1}^{N}\sum_{j=1}^{M} P_m^k(\omega_{j,k} + \lambda_i - \mu_j) \\ &- q_{ci}^{dj} m_c \frac{Ln}{Ln2}\left(1 + \frac{P_m^k G_{dd}^k d_m^{-\alpha}}{\sigma_N^2 + \psi \sum_{\substack{j=1 \\ j\neq m}}^{M} P_j^k G_{dd}^k d_j^{-\alpha} + \sum_{i=1}^{N}\sum_{j=1}^{M} P_i^k G_{c_i d_j}^k d_i^{-\alpha}}\right) \end{aligned}$$

$$-\sum_{i=1}^{N}\lambda_i P_{\max}+\sum_{j=1}^{M}\mu_j\left[\frac{(I_{\max}+\sigma_N^2)\gamma_{th}}{G_{dd}^k d_m^{-\alpha}}\right]. \tag{22}$$

The dual objective function $g(\lambda_i,\mu_j)$ is obtained by evaluating the gradient of the derived Lagrangian function w.r.t. P_m^k. Subsequently, the obtained value will be equated to zero. Now, differentiating the above equation w.r.t. P_m^k, we get

$$\begin{aligned}\frac{\partial\mathcal{L}(P_m^k,\lambda_i,\mu_j)}{\partial P_m^k} &= (\omega_{j,k}+\lambda_i-\mu_j)-q_{ci}^{dj}\frac{m_c}{Ln2}\left(\frac{A}{A+P_m^k G_{dd}^k d_m^{-\alpha}}\right)\\ &\times\left(\frac{G_{dd}^k d_m^{-\alpha}}{A}\right)\\ &=\theta-q_{ci}^{dj}\frac{m_c}{Ln2}\left(\frac{G_{dd}^k d_m^{-\alpha}}{A+P_m^k G_{dd}^k d_m^{-\alpha}}\right)\end{aligned} \tag{23}$$

where $A=\sigma_N^2+\psi\sum_{\substack{j=1\\ j\neq m}}^{M}P_j^k G_{dd}^k d_j^{-\alpha}+\sum_{i=1}^{N}\sum_{j=1}^{M}P_i^k G_{c_i d_j}^k d_i^{-\alpha}$ and $\theta=(\omega_{j,k}+\lambda_i-\mu_j)$.

Now, equating (23) to zero, we get

$$\begin{aligned}\theta-q_{ci}^{dj}\frac{m_c}{Ln2}\left(\frac{G_{dd}^k d_m^{-\alpha}}{A+P_m^k G_{dd}^k d_m^{-\alpha}}\right)&=0\\ \left(A+P_m^k G_{dd}^k d_m^{-\alpha}\right)&=q_{ci}^{dj}\frac{m_c}{\theta Ln2}\left(G_{dd}^k d_m^{-\alpha}\right)\\ P_m^k&=q_{ci}^{dj}\frac{m_c}{\theta Ln2}-\frac{A}{G_{dd}^k d_m^{-\alpha}}.\end{aligned} \tag{24}$$

The above (24) gives us the value of P_m^k. For determining the dual objective function $g(\lambda_i,\mu_j)$, we replace the obtained value of P_m^k in (22)

$$\begin{aligned}g(\lambda_i,\mu_j)&=\sum_{i=1}^{N}\sum_{j=1}^{M}\left(q_{ci}^{dj}\frac{m_c}{\theta Ln2}-\frac{A}{G_{dd}^k d_m^{-\alpha}}\right)\theta\\ &-q_{ci}^{dj}m_c\frac{Ln}{Ln2}\left[1+\frac{\left(q_{ci}^{dj}\frac{m_c}{\theta Ln2}-\frac{A}{G_{dd}^k d_m^{-\alpha}}\right)G_{dd}^k d_m^{-\alpha}}{A}\right]\\ &-\sum_{i=1}^{N}\lambda_i P_{\max}+\sum_{j=1}^{M}\mu_j\left[\frac{(I_{\max}+\sigma_N^2)\gamma_{th}}{G_{dd}^k d_m^{-\alpha}}\right]\\ &=\sum_{i=1}^{N}\sum_{j=1}^{M}\left(q_{ci}^{dj}\frac{m_c}{Ln2}-\frac{A(\omega_{j,k}+\lambda_i-\mu_j)}{G_{dd}^k d_m^{-\alpha}}\right)\\ &-q_{ci}^{dj}\frac{m_c}{Ln2}Ln\left[A(\omega_{j,k}+\lambda_i-\mu_j)Ln2\right]\\ &-q_{ci}^{dj}\frac{m_c}{Ln2}Ln(q_{ci}^{dj}m_c G_{dd}^k d_m^{-\alpha})\\ &-\sum_{i=1}^{N}\lambda_i P_{max}+\sum_{j=1}^{M}\mu_j\left[\frac{(I_{max}+\sigma_N^2)\gamma_{th}}{G_{dd}^k d_m^{-\alpha}}\right].\end{aligned} \tag{25}$$

Therefore, the dual optimization problem can be written as

$$\min \quad g(\lambda_i,\mu_j) \tag{26}$$

subject to constraint

$$a6:\quad \lambda_i,\mu_j\geq 0,\quad i=1,2,3,\ldots..,N;\quad j=1,2,3,\ldots..,M. \tag{27}$$

Here, we have taken the gradient of g w.r.t. λ_i and μ_j and then equated it to zero thereby obtaining the required solution for λ_i,μ_j

$$\begin{aligned}\frac{\partial}{\partial\lambda_i}g(\lambda_i,\mu_j)&=\sum_{i=1}^{N}\sum_{j=1}^{M}\frac{A}{G_{dd}^k d_m^{-\alpha}}\\ &+q_{ci}^{dj}\frac{m_c}{Ln2}\frac{1}{(\omega_{j,k}+\lambda_i-\mu_j)}-P_{\max}\end{aligned} \tag{28}$$

and

$$\begin{aligned}\frac{\partial}{\partial\mu_j}g(\lambda_i,\mu_j)=&-\sum_{i=1}^{N}\sum_{j=1}^{M}\frac{A}{G_{dd}^k d_m^{-\alpha}}\\ &+q_{ci}^{dj}\frac{m_c}{Ln2}\frac{(-1)}{(\omega_{j,k}+\lambda_i-\mu_j)}\\ &+\frac{(I_{\max}+\sigma_N^2)\gamma_{th}}{G_{dd}^k d_m^{-\alpha}}\\ =&-\sum_{i=1}^{N}\sum_{j=1}^{M}\frac{A}{G_{dd}^k d_m^{-\alpha}}\\ &-q_{ci}^{dj}\frac{m_c}{Ln2}\frac{1}{(\omega_{j,k}+\lambda_i-\mu_j)}\\ &+\frac{(I_{\max}+\sigma_N^2)\gamma_{th}}{G_{dd}^k d_m^{-\alpha}}.\end{aligned} \tag{29}$$

Updating the dual variable along the direction of gradient gives

$$\begin{aligned}\lambda_i^{\text{presentquantity}}&=\lambda_i^{\text{pastquantity}}+k_d^1\frac{\partial}{\partial\lambda_i}g(\lambda_i,\mu_j)\\ &;i=1,2,3,\ldots.,N\end{aligned} \tag{30}$$

and

$$\begin{aligned}\mu_j^{\text{presentquantity}}&=\mu_j^{\text{pastquantity}}+k_d^2\frac{\partial}{\partial\mu_j}g(\lambda_i,\mu_j)\\ &;j=1,2,3,\ldots.,M\end{aligned} \tag{31}$$

where k_d^1 and k_d^2 denote the required minimum gradient necessary for updating the Lagrange factors. Karush–Kuhn–Tucker (KKT) conditions [15] are employed for evaluating the optimal solutions with zero duality. Let us suppose that P_m^{k*},λ_i^*, and μ_j^* are the solutions for primal and dual optimization problem, respectively.

The KKT conditions for the problems are expressed as follows:

$$\begin{aligned}C1:\partial\mathcal{L}(P_m^{k*},\lambda_i^*,\mu_j^*)&=(\omega_{j,k}+\lambda_i^*-\mu_j^*)\\ &-q_{ci}^{dj}\frac{m_c}{Ln2}\left(\frac{G_{dd}^k d_m^{-\alpha}}{A+P_m^{k*}G_{dd}^k d_m^{-\alpha}}\right)\end{aligned} \tag{32}$$

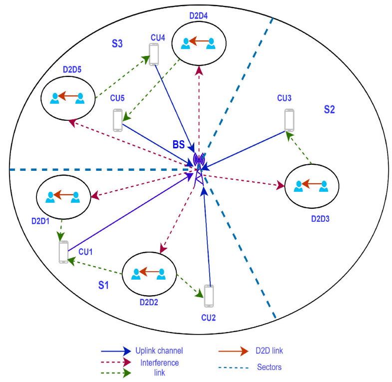

Fig. 2. System model displaying three sectors along with its interference links for uplink resources to enhance QoS of the network.

$$C2 : \lambda_i^* \left[\sum_{i=1}^{N} (P_m^{k*} - P_{\max}) = 0\right] \tag{33}$$

$$C3 : \mu_j^* \left[\sum_{j=1}^{M} \frac{(I_{\max} + \sigma_N^2)\gamma_{th}}{G_{dd}^k d_m^{-\alpha}} - P_m^{k*} = 0\right] \tag{34}$$

$$C4 : \sum_{i=1}^{N} (P_m^{k*} - P_{\max}) \leq 0 \tag{35}$$

$$C5 : \sum_{j=1}^{M} \frac{(I_{\max} + \sigma_N^2)\gamma_{th}}{G_{dd}^k d_m^{-\alpha}} - P_m^{k*} \leq 0 \tag{36}$$

$$C6 : \lambda_i^* \geq 0 \tag{37}$$

$$C7 : \mu_j^* \geq 0. \tag{38}$$

By applying the above KKT conditions (C1 through C7), the solution for the optimal power is obtained as

$$P_m^{k*} = q_{ci}^{dj} \frac{m_c}{(\omega_{j,k} + \lambda_i^* - \mu_j^*)Ln2} - \frac{(\sigma_N^2 + \psi P_j^k G_{dd}^k d_j^{-\alpha} + P_i^k G_{c_i d_j}^k d_i^{-\alpha})}{G_{dd}^k d_m^{-\alpha}}. \tag{39}$$

Equation (39) gives us the optimal value for P_m^{k*} along with the KKT conditions obtained, as shown above, $C1$ through $C7$.

C. Dynamic Sectorization

The number of requests received at BS for accessing the channel of mm-Wave dense user network is high which subsequently leads to increased interference between cellular and D2D users. It is observed that sectoring improves the overall performance of the system [24]. Thus, dynamic sectorization is applied to the proposed scheme to mitigate cotier interference among the D2D users and enhance QoS of the cellular network as shown in Fig. 2. With the increase in interference in dense network, the transmit power is increased to provide better SINR to the users. Thus, conditions for dynamic sectorization are formulated based on transmit power of the D2D users.

Algorithm 1: Algorithm for allocating resources to D2D pairs.

Input: The set of D2D pairs and CU pairs are indexed by D_M and C_N
Output: Allocated D2D users with corresponding q_{ci}^{dj}
1. Initializing the number of D2D pairs
2. Calculate γ_c, γ_d and $\hat{\gamma_c}$ from (5) to (7)
3. k=0, $N > M$
4. **For** n=1:N
5. **For** m=1:(M-1)
6. **If** $P_m^k \leq P_{max}$
7. $\gamma_d \geq \gamma_{th}$
8. $\gamma_c \geq \gamma_{th}$
9. Constraint $a5$ is satisfied
10. Calculate q_{ci}^{dj} from (4)
11. Calculate R_c, R_d and $\hat{R}_c$ from (8)–(10)
12. Sort R_{inc} in decreasing order from (18)
13. Allocate channel k to the D2D pair
14. **Else**
15. Update $\omega_{j,k}$ for unassigned D2D pairs
16. Update P_m^{k*} from (39)
17. **End**
18. Increment k and n
19. Repeat
20. **End**

If $P_m^{k*} \leq P_{\max}$, there is no need for sectorization.

If $P_m^{k*} > P_{\max}$, scenario signifies that there is need of sectorization. The cell is split into three sectors. After the cell is split into three sectors, the P_m^{k*} is again calculated for the respective sectors and then compared with $P_{\max}$. If the resulting value of P_m^{k*} is still above the $P_{\max}$, i.e., $P_m^{k*} > P_{\max}$, then further sectorization of six sectors is adopted. This will eventually maintain the D2D transmit power and will yield a better throughput for the overall network.

IV. Performance Evaluation

A. Stability Factor

Stability factor [18] represents the impact of D2D communication on the cellular network. It will guarantee an improved QoS for a better customer experience. Thus, the system stability can be normalized as follows:

$$\rho = 1 - \frac{R_c}{\hat{R}_c}. \tag{40}$$

B. System Fairness

Jain's fairness index [25] helps in evaluating the distribution of power among the D2D users and enhance the throughput. It can be expressed as follows:

$$FI = \frac{\left(\sum_{j=1}^{M} R_{\text{sum}}\right)^2}{M \sum_{j=1}^{M} R_{\text{sum}}^2}. \tag{41}$$

TABLE I
SIMULATION PARAMETERS

Sl. No.	Parameters	Values
1	Cell radius	500 m
2	Bandwidth	1 GHz
3	Operating frequency	28 GHz
4	Thermal Noise density	-174 dBm/Hz
5	${\gamma_c}^{th}$	0 dB
6	${\gamma_d}^{th}$	0 dB
7	Maximum D2D transmit power	15 dB
8	Cellular transmit power	30 dB

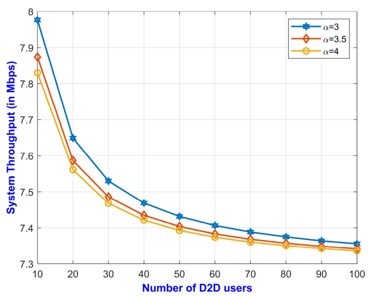

Fig. 3. Number of D2D users versus system throughput for varied pathloss exponents.

C. Simulation Results

This section presents a comprehensive simulation of the proposed scheme to evaluate its performance. Simulations are done for a single cell consisting of a set of cellular as well as D2D users using an uplink channel. The system bandwidth is taken to be 1 GHz with 100 cellular users communicating at an operating frequency of 28 GHz. As the communication occurs at the mm-Wave band, thus, the pathloss model for signal propagation is taken in accordance with the release 15 [26] of the 3rd Generation Partnership Project (3GPP) from (1) and (2). The pathloss exponents ranges from 3 to 4.5 for the distance between D2D users ranging from 5 to 20 m. The rest of the simulation parameters are listed in Table I.

Equation (11) gives the expression for the total system throughput including multiplexed and nonmultiplexed cellular users and D2D users. According to this expression, the number of multiplexed cellular resources with the D2D users has an impact on the total throughput of the communication system. q_{ci}^{dj} is an important parameter for the estimation of the data rate. The data rate of the multiplexed cellular users takes a toll on the total throughput. Also, in (39), the optimal D2D transmit power P_m^{k*} is adjusted by updating the weights for any unassigned D2D pairs.

Thus, in Figs. 3 and 4, we plot a graph depicting the impact of the number of D2D users on the total system throughput as well as D2D throughput taking into account the effect of pathloss exponents. We can see that as the number of D2D users increases, the system and D2D throughput gradually decreases. This happens because, with the increase in the number of D2D users, the interference between the D2D users also increases eventually. The more the number of D2D users, the more is the interference acting upon them. The pathloss exponent does not have a significant effect on the signal propagation since the distance between the D2D users is within 20 m. Increasing the distance between the D2D users will degrade the signal quality thereby lowering the QoS.

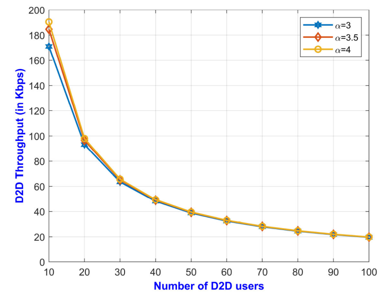

Fig. 4. Number of D2D users versus D2D throughput for varied pathloss exponents.

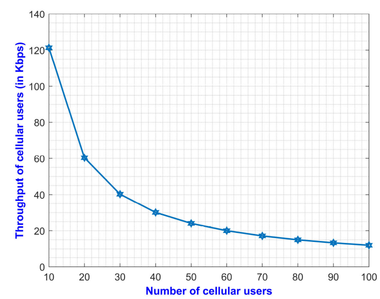

Fig. 5. Number of cellular users versus cellular throughput (multiplexed and nonmultiplexed).

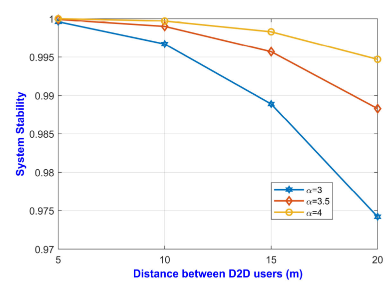

Fig. 6. System stability for increasing distance of D2D pairs.

Again, in Fig. 5, a graph between the number of cellular users (multiplexed and nonmultiplexed) and the cellular throughput is plotted. Similarly from (11), it can be noted that the multiplexing of resources for D2D users lower the cellular throughput. As q_{ci}^{dj} increases, the shared resources for D2D users increases which increases the interference. This in turn lowers the cellular data rate. Thus, the graph eventually decreases with the increase in the number of D2D users.

In Fig. 6, a graph for the distance between D2D pairs and system stability is plotted for various pathloss exponents. For each iteration, P_m^{k*} is adjusted which results in optimal D2D transmit power. The decrease in the stability factor for the increasing distance between D2D pairs is nominal. As a result,

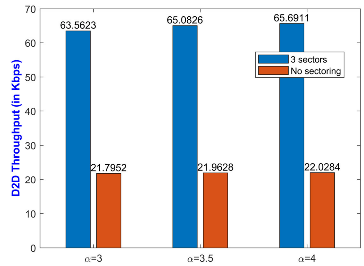

Fig. 7. D2D throughput analysis with dynamic sectoring for varied pathloss exponents.

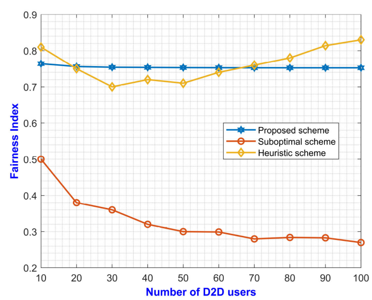

Fig. 8. Fairness index for increasing number of D2D users based on different techniques.

this scheme ensures higher stability for effective communication among users and enhances the QoS of the system.

A bar diagram is shown for the data rate of D2D users for varying pathloss exponents for analysing the impact of sectoring on the communication system in Fig. 7. Due to the increase in D2D pairs, interference rises (in case of no sectoring). This is why the data rate in case of no sectoring is lower in comparison to a system with three sectors. Thus, it can be inferred that sectorization increases the throughput and also lowers the interference.

The proposed scheme is compared with two other existing schemes namely, suboptimal scheme [27], and heuristic scheme [28] in terms of FI, as shown in Fig. 8. One of the schemes, the suboptimal method, distributes power based on interference faced by the user. And in the heuristic method, constant power is allocated irrespective of the distance between the D2D pairs which is a major flaw. While in our proposed scheme, the achieved graph is consistent throughout the plot and has a very little deflection with the increase in the number of D2D users. Thus, it can be inferred that the proposed scheme shows better FI which enhances the QoS. Also in Fig. 9, the proposed scheme is compared with the power control (PC) scheme [13] in terms of energy efficiency concerning D2D transmit power for varying distance between D2D pairs. A tradeoff takes place where higher energy efficiency is achieved for a shorter distance in comparison to the PC scheme due to the optimal use of multiplexing. This is due to the reduction of mutual interference and also D2D communications has a lesser impact on cellular users as proposed in the PRM algorithm. Higher data rates can be achieved by utilizing the same number of resources in the system

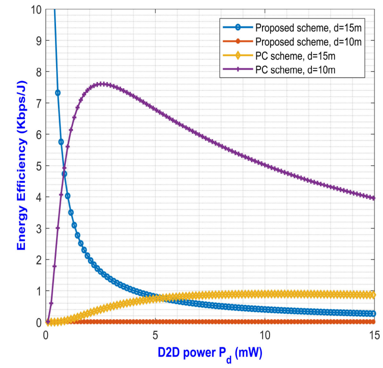

Fig. 9. Energy efficiency versus D2D transmit power for varying distance between D2D pairs.

as the intracell interference reduces and the cellular users have enough resources to communicate.

D. Computational Complexity

The computational complexity of Algorithm 1 can be approximated by line 12 and the "for" loops from line 4 to line 20 and line 5 to line 17. The cardinality of D2D and cellular users are M and N, respectively. The computational complexity for the two loops in the worst case is $O(N \times M)$. For assigning channels for the intended cellular and D2D users, the loop includes $O(N \times M)$ iterations. And for each iteration, the cellular resource is shared with the D2D user along with the permissible optimal D2D transmit power. Thus, the computational complexity of the proposed scheme is approximated by $O(N \times M) + O(k \times m \times f \mid J \mid)$. Here, $f \mid J \mid$ denotes the computational complexity of the formulated problem in (19). Equation (19) portrays a finite number of D2D pairs which implies that the complexity of the second term is negligible and can be ignored. Thus, the computational complexity of Algorithm 1 is $O(N \times M)$.

V. Conclusion

This article investigated the enabling of IIoT in the 5G framework at 28 GHz for its possible application at Industry 5.0. The formulated problem was divided into two subproblems, channel assignment and power optimization, which lowerd the computational complexity. The article proposed a partial resource multiplexing scheme that allowed a cellular user to multiplex its resources with only one D2D pair whereas, a D2D pair might access the resources of more than one cellular user. Hungarian algorithm was used for sorting of D2D pairs for allocation of channels. The formulated power optimization problem was determined through the Lagrangian dual optimization technique. Later, dynamic sectoring was done to ensure higher throughput for D2D users in case of user traffic. Performance evaluation was expressed in terms of stability factor and FI exhibiting better performance ability of the scheme. The energy efficiency of the proposed work was compared with the related works. The simulations also yielded satisfactory results showcasing higher throughput and system fairness of the proposed scheme in comparison to the state-of-art schemes.

References

[1] C. J. Turner, J. Oyekan, L. Stergioulas, and D. Griffin, "Utilizing industry 4.0 on the construction site: Challenges and opportunities," *IEEE Trans. Ind. Informat.*, vol. 17, no. 2, pp. 746–756, Feb. 2021.

[2] E. Sisinni, A. Saifullah, S. Han, U. Jennehag, and M. Gidlund, "Industrial internet of things: Challenges, opportunities, and directions," *IEEE Trans. Ind. Informat.*, vol. 14, no. 11, pp. 4724–4734, Nov. 2018.

[3] D. Minoli and B. Occhiogrosso, "Practical aspects for the integration of 5G networks and IoT applications in smart cities environments," *Wireless Commun. Mobile Comput.*, vol. 2019, 2019, Art. no. 5710834.

[4] B.P. Sahoo, C.C. Chou, C. W. Weng, and H. Y. Wei, "Enabling millimeter-wave 5G networks for massive IoT applications: A closer look at the issues impacting millimeter-waves in consumer devices under the 5G framework," *IEEE Consum. Electron. Mag.*, vol. 8, no. 1, pp. 49–54, Jan. 2018.

[5] C.X. Mavromoustakis, G. Mastorakis, and Batalla, *Internet of Things (IoT) in 5G Mobile Technologies*. Berlin, Germany: Springer, 2016.

[6] D. Tearpock, R. Bischke, D. C. Metzner, J. Brenneke, R. E. Bischke, and D. Metzner, *Applied Three-Dimensional Subsurface Geological Mapping: With Structural Methods*. New York, NY, USA: Pearson, 2020.

[7] S. S. Sarma and R. Hazra, "Interference management for D2D communication in mmWave 5G network: An Alternate Offer Bargaining Game theory approach," in *Proc. IEEE 7th Int. Conf. Signal Process. Integr. Netw.*, 2020, pp. 202–207.

[8] F. Qamar *et al.*, "Investigation of future 5G-IoT millimeter-wave network performance at 38GHz for urban microcell outdoor," *Environ. Electron.*, vol. 8, no. 5, 2019, Art. no. 495.

[9] T.S. Rappaport *et al.*, "Millimeter wave mobile communications for 5G cellular: It will work!," *IEEE Access*, vol. 1, pp. 335–349, 2013.

[10] A. Orsino *et al.*, "Effects of heterogeneous mobility on D2D-and drone-assisted mission-critical MTC in 5G," *IEEE Commun. Mag.*, vol. 55, no. 2, pp. 79–87, Feb. 2017.

[11] S.K. Rashed, R. Asvadi, S. Rajabi, S. A. Ghorashi, and M. G. Martini, "Power allocation for D2D communications using max-min message-passing algorithm," *IEEE Trans. Veh. Technol.*, vol. 69, no. 8, pp. 8443–8458, Aug. 2020.

[12] P. Khuntia and R. Hazra, "An efficient channel and power allocation scheme for D2D enabled cellular communication system: An IoT application," *IEEE Sensors J.*, vol. 21, no. 22, pp. 25340–25351, Nov. 2021.

[13] S. S. Sarma, P. Khuntia, and R. Hazra, "Power control scheme for device-to-device communication using uplink channel in 5G mm-wave network," *Trans. Emerg. Telecommun. Technol.*, 2021, Art. no. e4267. [Online]. Available: https://doi.org/10.1002/ett.4267

[14] Z. Zhang, C. Wang, H. Yu, M. Wang, and S. Sun, "Power optimization assisted interference management for D2D communications in mmWave networks," *IEEE Access*, vol. 6, pp. 50674–50682, 2018.

[15] S.G. Hong, J. Park, and S. Bahk, "Subchannel and power allocation for D2D communication in mmWave cellular networks," *J. Commun. Netw.*, vol. 22, no. 2, pp. 118–129, 2020.

[16] T. Lv, Y. Ma, J. Zeng, and P. T. Mathiopoulos, "Millimeter-wave NOMA transmission in cellular M2M communications for Internet of Things," *IEEE Internet Things J.*, vol. 5, no. 3, pp. 1989–2000, 2018.

[17] P. Mach, Z. Becvar, and M. Najla, "Resource allocation for D2D communication with multiple D2D pairs reusing multiple channels," *IEEE Wireless Commun. Lett.*, vol. 8, no. 4, pp. 1008–1011, Aug. 2019.

[18] Y. Li, Y. Liang, Q. Liu, and H. Wang, "Resources allocation in multicell D2D communications for Internet of Things," *IEEE Internet Things J.*, vol. 5, no. 5, pp. 4100–4108, Oct. 2018.

[19] M. Rebato, F. Boccardi, M. Mezzavilla, S. Rangan, and M. Zorzi, "Hybrid spectrum sharing in mmWave cellular networks," *IEEE Trans. Cogn. Commun. Netw.*, vol. 3, no. 2, pp. 155–168, Jun. 2017.

[20] B.M. ElHalawany, R. Ruby, and K. Wu, "D2d communication for enabling internet-of-things: Outage probability analysis," *IEEE Trans. Veh. Technol.*, vol. 68, no. 3, pp. 2332–2345, Mar. 2019.

[21] Y. Cai, Y. Ni, J. Zhang, S. Zhao, and H. Zhu, "Energy efficiency and spectrum efficiency in underlay device-to-device communications enabled cellular networks," *China Commun.*, vol. 16, no. 4, pp. 16–34, 2019.

[22] S. Ju, O. Kanhere, Y. Xing, and T. S. A. Rappaport, "Millimeter-wave channel simulator NYUSIM with spatial consistency and human blockage," in *Proc. IEEE Global Commun. Conf.*, 2019, pp. 1–6.

[23] Y. Qian, T. Zhang, and D. He, "Resource allocation for multichannel device-to-device communications underlaying QoS-protected cellular networks," *IET Commun.*, vol. 11, no. 4, pp. 558–565, 2017.

[24] N. M. V. Mohamad, P. Ambastha, S. Gautam, R. Jain, H. Subramaniyam, and L. Muthukaruppan, "Dynamic sectorization and parallel processing for device-to-device (D2D) resource allocation in 5G and B5G cellular network," *Peer–Peer Netw. Appl.*, vol. 14, no. 1, pp. 296–304, 2021.

[25] R. K. Jain, D. M. W. Chiu, and W. R. Hawe, *A Quantitative Measure of Fairness and Discrimination*. Hudson, MA, USA: Eastern Res. Lab., Digit. Equip. Corp., 1984.

[26] A. Ghosh, A. Maeder, M. Baker, and D. Chandramouli, "5G evolution: A view on 5G cellular technology beyond 3GPP release 15," *IEEE Access*, vol. 7, pp. 127639–127651, 2019.

[27] G. D. Swetha and G. R. Murthy, "Fair resource allocation for D2D communication in mmWave 5G networks," in *Proc. 16th Annu. Mediterranean Ad Hoc Netw. Workshop*, Budva, Montenegro, 2017, pp. 1–6.

[28] M. Zulhasnine, C. Huang, and A. Srinivasan, "Efficient resource allocation for device-to-device communication underlaying LTE network," in *Proc. IEEE 6th Int. Conf. Wireless Mobile Comput., Netw. Commun.*, Niagara Falls, ON, Canada, 2010, pp. 368–375.