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Many-to-One Spectrum Reusing Resource Allocation for Device-to-Device Communications

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Abstract: The deployment of cellular networks assisted by device-to-device (D2D) communications has great significance to improve spectral efficiency. In D2D communications underlay scenario, the D2D user equipments (DUEs) reuse the same frequency resources assigned to cellular user equipments (CUEs) for spectral utilization. Unfortunately, introducing D2D communications into cellular networks bring interference signals to CUEs and other DUEs. Therefore, to fully reap the benefits of D2D communications, efficient resource allocation with interference management is highly required. In this paper, we propose a system model for D2D communications underlaying cellular network, where multiple D2D pairs reuse the same frequency resources allocated to a single CUE. In addition, we propose a many-to-one frequency reusing resource allocation algorithm for D2D communications with the aim of maximizing the network sum-rate. To solve this NP-hard problem, we first propose an interference management algorithm based on graph theory to find the least interfered D2D pair groups, followed by proposing an optimized power allocation algorithm based on linear programming, and finally proposing a process matching algorithm to find the best sets of CUEs and D2D pair groups for spectral reusing. Simulation results demonstrate that the performance of the proposed many-to-one spectral reusing resource allocation algorithm exceeds the one-to-one resource allocation for D2D communications in terms of sum-rate.

Keywords: Device-to-Device communications, power allocation, interference management, matching process, graph theory, matching theory

I. Introduction

Recently, the amount of mobile data traffic in cellular networks has grown exponentially due to the increase in the number of cellular devices and their applications. However, the existing communication infrastructure cannot adequately cope with such rapid increases in mobile data traffic. In other words, the current cellular network cannot handle the high demand for data traffic caused by the close distance between cellular user equipments (CUEs) in environments such as shopping malls and stadiums with limited network capacity [1]. The traffic congestion caused by the increased number of devices causes severe interference signals. Therefore, it is difficult to meet the traffic environment requiring high network capacity such as high-quality video streaming or augmented reality (AR) in the fourth generation (4G) cellular networks [1]. To bridge the gap between end-user demands and the capacity offered by 4G cellular networks, the fifth generation (5G) cellular networks have been introduced.

The technology of device-to-device (D2D) communications between two nearby devices is one of the core enabling technologies of 5G cellular networks that can solve the problem of the increased data traffic. The direct communication between D2D user equipments (DUEs) would increase the efficiency of spectral usage [2]. Introducing D2D communications into the cellular network cause interference signals to CUEs and other DUEs [3]. However, the performance of D2D communications greatly varies depending on how D2D pairs (i.e., DUE_{Tx}s, DUE_{Rx}s) are reusing the cellular communications' frequency resources [3]. For instance, the base station (BS) that allocates cellular resources to the D2D pairs must consider how to manage the interference signals, allocate power coefficients for each CUE and DUE_{Tx}, and match between CUEs and D2D pairs to find the best sets of DUEs and CUEs for reusing frequency resources [3]. For this reason, research studies on how to allocate cellular resources to D2D communications in order to maximize the sum-rate are being actively conducted. There are many attempts to resolve this by applying different mathematical theories.

In this paper, an overview of the technology of D2D communications along with its categories, benefits, and applications are presented. A system model for D2D communications underlaying cellular network is proposed, where each group of D2D communications reuses the same frequency resources allocated to a single CUE. Then, many-to-one resource

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allocation for spectrum reusing in D2D communications is proposed. The aim of this resource allocation is to maximize the overall sum-rate while satisfying the quality-of-service (QoS) requirements of both cellular and D2D communications. The formulated problem of resource allocation optimization is a mixed integer non-linear programming (MINLP) problem, which is an NP-hard problem. To solve this problem, it is decomposed into three subproblems, interference management, power allocation, and matching process. Therefore, an algorithm for interference management based on graph theory, an algorithm for power allocation based on linear programming, and an algorithm for matching process based on matching theory are proposed.

The contributions of this paper are summarized as follows:

1. A system model for D2D communications underlaying cellular network is proposed. In this model, multiple D2D pairs try to find their CUE partners for reusing its frequency resource.
2. The problem of optimizing resource allocation for D2D communications underlaying cellular network is formulated. The aim of this optimizing problem is to maximize the network sum-rate while satisfying the QoS requirements of both cellular and D2D communications. This is an NP-hard problem that is difficult to solve due to its high computational complexity.
3. To solve this resource allocation problem, it is decomposed into three subproblems and each of which is addressed using a different mathematical theory. Therefore, a graph theory-based interference management algorithm, a liner programming-based power allocation algorithm, and a matching process algorithm based on matching theory are proposed.

The paper is organized as follows, in Section II, an overview of the technology of D2D communications along with its categories, benefits, and applications is introduced. In Section III, the problem of interference management is discussed. In Section IVVI, the related work is presented. In Section V, the system model and problem formulation are explained. In Section VI, the proposed many-to-one resource allocation is introduced. In Section VII, the simulation results are presented. Finally, the conclusion and future work are presented in Section VIII.

II. The Technology of D2D Communications

The technology of D2D communications enables nearby DUEs for direct data transmission between them without passing through the BS or access point (AP) [4]. While conventional cellular communication requires the use of BS to provide cellular communication between two CUEs regardless of their proximity to each other. For instance, CUE transmits its data to BS via uplink resources, and the BS then uses downlink resources to pass the data to a specific CUE [5], as shown in Fig. 1.

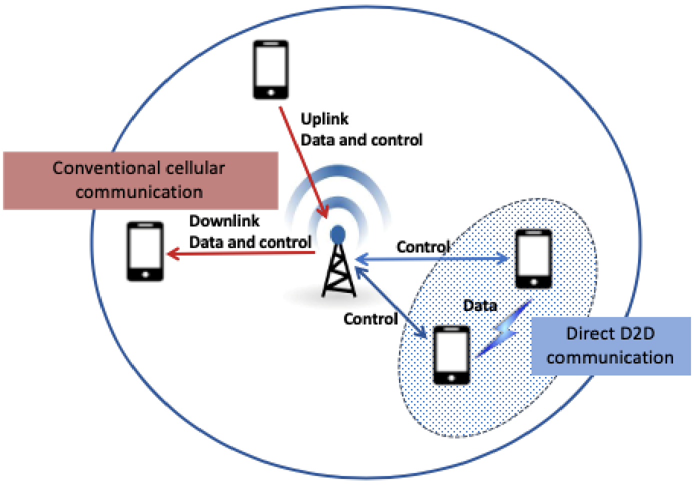

Fig. 1 Cellular communication and D2D communication.

D2D communications promise significant improvements to the cellular network [6][7]. For instance, D2D communications can bring lower latency, higher data rate, more capacity, reduced BS traffic loads, and minimize power usage due to the near proximity of DUEs that communicate directly at lower power consumption. In addition, D2D

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communications that are sufficiently distributed can reuse the same frequency resources assigned to CUEs simultaneously thus providing spectral utilization for dense networks and enhancing the overall spectral performance over the network.

A. D2D Communications Categories Based on Spectrum Usage

D2D communications are categorized on the basis of spectrum usage into in-band and out-band [8]. Most of the available literature works go under in-band communications. In in-band D2D communication, the DUEs are allowed to reuse the licensed cellular frequency bands. The high control over the cellular spectrum is generally the motivation for considering in-band D2D communication. Further, in-band D2D communications are categorized into two modes: underlay and overlay. Cellular and D2D communications reusing the same frequency resources simultaneously in underlay mode, which brings interference to both cellular and other D2D communications. The interference can be managed with efficient resource allocation, and hence improving the spectral efficiency. On the other hand, D2D communications in overlay mode are given reserved frequency resources apart from cellular resources. Therefore, the interference between cellular and D2D communications dose not existed but this mode is insufficient in terms of spectral utilization [8].

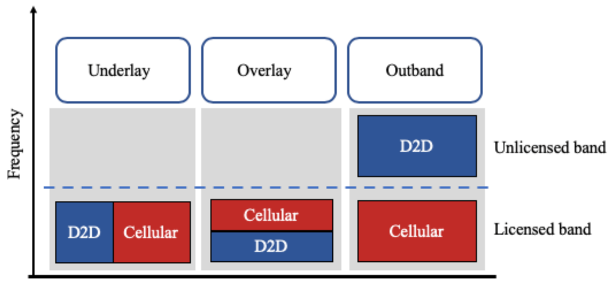

Fig. 2 The different categories of D2D communications based on spectrum usage [8].

In the contrast, in out-band D2D communications operate in unlicensed frequency bands (e.g., the free 2.4 GHz industrial, scientific, and medical (ISM) band or 38 GHz mmWave) where cellular communications do not exist. To access the unlicensed spectrum, it requires having an extra interface that implements WIFI-Direct, ZigBee, or Bluetooth, etc. Therefore, interference signals between DUEs and CUEs do not exist but interference signals between out-band D2D devices are still present. In addition, out-band D2D communications suffer from the uncontrolled nature of the unlicensed spectrum. The operating at unlicensed frequency bands makes D2D communications difficult to control. Furthermore, the coordination between radio interfaces in out-band communications is divided into controlled (i.e., controlled by BS or, AP) and autonomous communications (i.e., the users themselves) [8]. The difference between D2D communications based on spectrum usage is illustrated in Fig. 2.

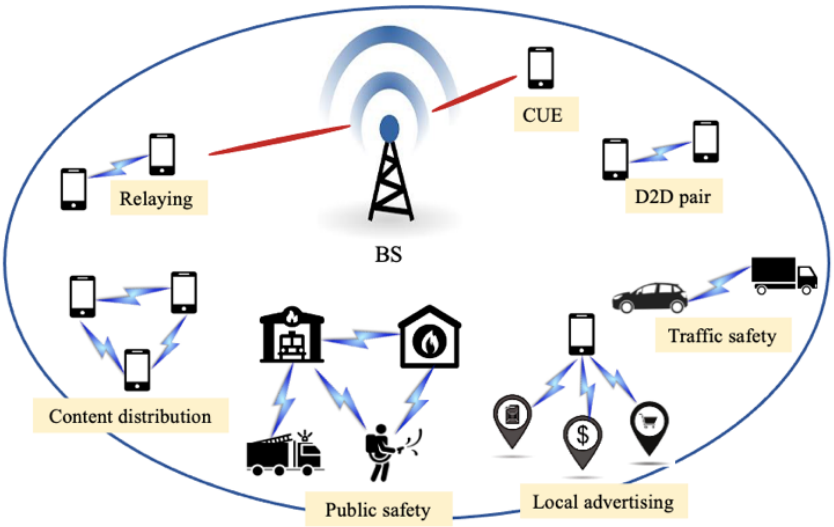

Fig. 3 Applications of D2D communications in cellular networks.

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B. D2D Communications Applications

D2D communications are capable of promoting new local data applications. Fig. 3 depicts the most popular applications in which D2D communications technology is effective, and they are as follows:

1. Public Safety: For the first three cellular network generations, D2D communications were not explored in the licensed spectrum. However, 4G Long-Term Evolution-Advanced (LTE-A) technology was the first platform that implements D2D communications, which is specified by The 3rd Generation Partnership Project (3GPP) in LTE Release 12, as public safety networks [9]. The main goal of public safety networks is to support emergency communications in cases where the BS has been damaged due to natural disasters (e.g., flood, hurricane, earthquake) [10]. In emergency communications, first responders need to know the precise location for managing vehicles, video surveillance, real-time video feedback, and better coordination between different teams. The DUEs in near proximity can autonomously establish D2D communications even in the nonexistence of a network operator or BS [10]. Hence, safety agencies (e.g., police, hospital, fire station) can rely on D2D communications to deliver information between first responders [11].

2. Social Content Distribution: D2D communications provide operators with a new source of marketing, where advertising agencies targeting a specific group of individuals who use social-aware D2D communications to promote particular products [12][13]. For instance, shopping stores broadcast promotional and discount deals to people walking around stores. Theatres broadcast information about movie release dates and showtimes to the people who come to the cinema. Public transportations broadcast information about train schedules at a subway station or updates on flights at airports. Moreover, close-proximity multi-player can establish D2D communications to share their cached information [14].

3. Coverage Extend: when a CUE’s signal quality is poor while connecting to the BS at the cell’s edge or in a disaster-hit area, a near proximity CUE with a better connection can act as a relay for CUE with a poor connection. Generally, D2D can extend the coverage of cellular communications and enable multi-hop communications [10].

4. BS data and computation offloading: D2D communication is a key component to offload BS data and computation traffic. Cellular communication between near proximity CUEs served by the BS can switch to direct mode, thus offloading data traffic due to proximity gain [27]. A CUE with a strong connection to the Internet will serve as a hotspot for offloading/caching data from the BS and allowing other CUEs to download data via D2D communications [6]. D2D communications may also be used by CUEs with minimal computing capacity or energy budgets to offload computationally intensive activities to more powerful CUEs in close proximity [6]. Considerable researches carried out into the design of offloading techniques in [15] and [16].

5. Machine-to-Machine communication is an Internet-of-Things (IoT) enabler technology that provides autonomous networking between low-power devices and powerful computing systems. D2D communications can be used to establish M2M communications in IoT since they are able to provide extremely low latency and real-time responses [17]. A specific application is vehicle-to-vehicle (V2V) communications where D2D connections can be implemented to rapidly exchange road information (e.g., accidents, work locations, traffic conjunctions) to effectively avoided vehicle collision and offload road traffic from vehicles in close proximity [18][19]. Furthermore, D2D communications can be implemented for vehicle-to-infrastructure and vehicle-to-pedestrian communication [18][19].

III. INTERFERENCE MANAGEMENT

Introducing D2D communications into cellular networks in underlaying mode imposes several technical challenges. Interference management caused by DUE_{Tx}s to CUEs and other DUE_{Rx}s is considered the most critical issue. This happens because licensed frequency resources assigned to CUEs are reused by D2D pairs. The basic two-tier architecture for D2D communications underlaying cellular networks was proposed in [20], which is composed of two tiers. In Fig. 4, the conventional cellular communication between the BS and a CUE is established in the first tier while the direct communication between a D2D pair is established in the second tier.

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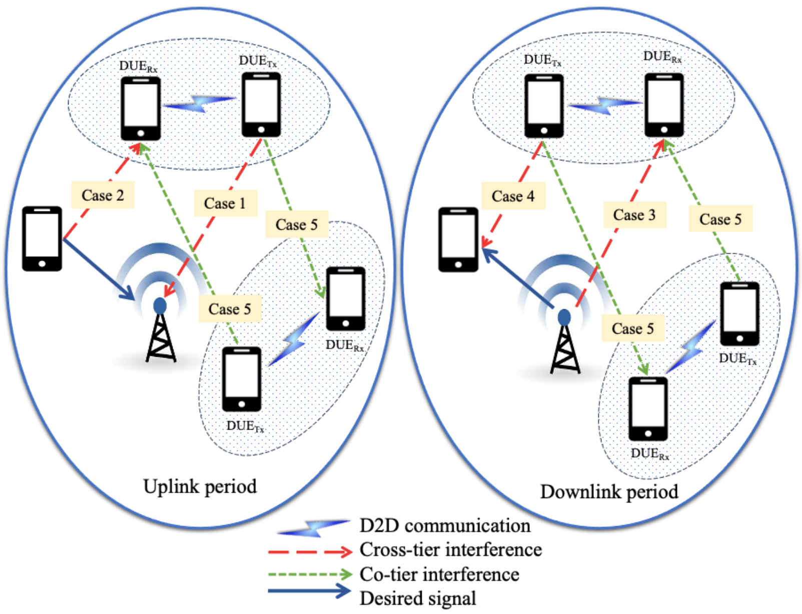

Fig. 4 The two-tier system model for D2D communications underlaying cellular network.

Fig. 4 shows the possible interference cases and they described as follows [3]:

1. Cross-tier interference occurs between the devices located in different tiers. There are four possible interference cases in cross-tier interference.
   - **Case 1:** interference caused by DUE_{Tx}s to BS in the uplink period.
   - **Case 2:** interference caused by CUEs to DUE_{Rx}s in the uplink period.
   - **Case 3:** interference from the BS to DUE_{Rx}s in the downlink period.
   - **Case 4:** interference caused by DUE_{Tx}s to CUEs in the downlink period.
2. Co-tier interference occurs between the different D2D pairs located in the different device tiers which denoted by **Case 5.**

IV. RELATED WORK

Many research studies have been presented to solve the issue of interference management in D2D communications in underlaying scenario. However, mode selection [21] [22], channel allocation [22] [23], and power control [21] [22] [24] are the most often used interference management techniques.

The authors in [24] proposed an interference-limited area (ILA) algorithm for D2D communication along with suitable designed power control algorithm to mitigate the different interference signals caused by D2D communications in **Case 1, Case 2,** and **Case 5**. In addition, an optimal interference-aware channel allocation algorithm based on Hungarian algorithm was proposed in [23] to solve the interference in **Case 1** and **Case 2** in D2D communications. A joint mode selection and power control algorithm was proposed in [21] to solve the D2D communication interference in **Case 1** and **Case 5**. This algorithm was based on controlling of DUE_{Tx}s transmitting power with ILA. Then, depending on the various ILA, users could use different connectivity modes to address the waste problem in spectrum resource. Another joint algorithm with channel allocation, mode selection, and power control for interference management was presented in [22] to solve the interference in **Case 1** and **Case 2**. Another method for interference management was presented in [25], where two interference avoidance mechanisms were developed to incorporate an intelligent system for resource reusing through D2D communications to solve the interference in **Case 1** and **in Case 2**.

Some research studies adopted the different optimization algorithms to address the interference issue in D2D communications. The authors of [26] suggested a particle swarm optimization (PSO) based algorithm for mode selection and resource allocation. This algorithm tried to solve the interference in **Case 1** and **Case 2**. However, it only required one D2D pair to reuse the same frequency resources with one CUE. The hybrid algorithm composed of PSO and Genetic Algorithm (GA) was used in [27] to delegate frequency resources to the CUEs and D2D pairs. This algorithm tried to solve the interference in **Case 5.** However, it only required two D2D pairs to reuse the same frequency resources with a single CUE, and all cell users' power coefficients were assumed to be fixed, limiting the ability to mitigate the interference and increase the network performance.

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The authors in [28] proposed a resource allocation algorithm consisting of two phases to solve the interference in **Case 1 and Case 5**. The Hungarian algorithm assigned all available channels in the first phase such that each channel was occupied by only one D2D pair. Multiple D2D pairs were sequentially added to individual channels in the second phase based on their importance as reflected by channel quality and obtained interference from previously added D2D pairs.

TABLE I A SUMMARY OF INTERFERENCE MANAGEMENT TECHNIQUES RELATED WORK.

Ref	**Scenario**	**Interference case**	**interference Management Techniques**
[24]	One-to-one	**Case 1, Case 2,** and **Case 5**	ILA
[21]		**Case 1** and **Case 5**	ILA
[23]		**Case 1** and **Case 2**	Hungarian algorithm
[22]		**Case 1** and **Case 2**	Convex optimization
[25]		**Case 2** and **Case 4**	Interference tracing approach and tolerable interference broadcasting
[26]		**Case 1** and **Case 2**	PSO
[27]	Many-to-one	**Case 5**	PSO and GA
[28]		**Case 1** and **Case 5**	Hungarian algorithm

The above studies considered the case where a single D2D pair is reusing a single CUE frequency resource, which is known as one-to-one. Furthermore, some of these studies are not easily generalizable to enable the reuse of limited number of frequency resources by multiple D2D pairs in situations with strong interference among D2D pairs. Furthermore, the studies that supported multiple D2D pairs reusing the frequency resources occupied by CUEs, put restrictions on the number of users reusing the same frequency resources as in [27] or caused a delay as it added the D2D pairs into the reusing phase sequentially as in [28]. This paper investigates the scenario where multiple D2D pairs reuse a single CUE frequency resource, known as many-to-one matching, to increase the spectrum utilization. A summary of interference management techniques related work is illustrated in TABLE I.

V. SYSTEM MODEL AND FORMULATED PROBLEM

A. System Model

In this paper, a single cell downlink D2D communications underlaying cellular networks is considered, where D2D communications are allowed to reuse the frequency resources assigned to cellular communications, as shown in Fig. 5. There is a BS at the centre, and it serves multiple randomly distributed M CUEs and N_t D2D pairs. Orthogonal frequency-division multiple access (OFDMA) is used as access technology in which the available spectrum is shared among M CUEs by allocating orthogonal frequency resources to each of them. In addition, there are G groups of D2D pairs, each group consists of N D2D pairs. For simplicity, the number of $G = M$. In this case, each group of D2D pairs tries to find a single CUE partner to reuse its frequency resource. Then, each D2D pair is denoted as $d_{g,n}$, where $g = m$, and m represents the m-th CUE that matched to this D2D pair, and n represents the sequence number of D2D pair in g-th group of D2D pairs. The proposed D2D communication underlaying cellular network system model is shown in Fig. 5.

In this model, the downlink transmission in the cellular network is based on frequency divided duplexing (FDD). However, the focus of this study is to manage the interference in **Case 4** and **Case 5**, as specified in Section **III**. Before CUEs and D2D pairs can transmit in channels, they must meet certain signal to interference noise ratio (SINR) levels.

The SINR of CUE c_m can be expressed as:

$$\gamma_{c_m} = \frac{P_{c_m} H(c_m)}{\sigma^2 + \sum_{g=1}^{G} \sum_{n=1}^{N} P_{d_{g,n}} H(d_{g,n}, c_m)}, \tag{1}$$

where $H(C_m)$ is the channel gain between BS and CUE c_m; P_{c_m} is the power coefficient allocated to CUE c_m; $H(d_{g,n}, c_m)$ is the interference signals caused by $\mathrm{DUE_{Tx}}$s $d_{g,n}$ to c_m, which is known as interference **Case 4**; $P_{d_{g,n}}$ is the power coefficient allocated to $\mathrm{DUE_{Tx}}$ $d_{g,n}$; g represents the group number of D2D pairs; and σ^2 is the additive white gaussian noise (AWGN).

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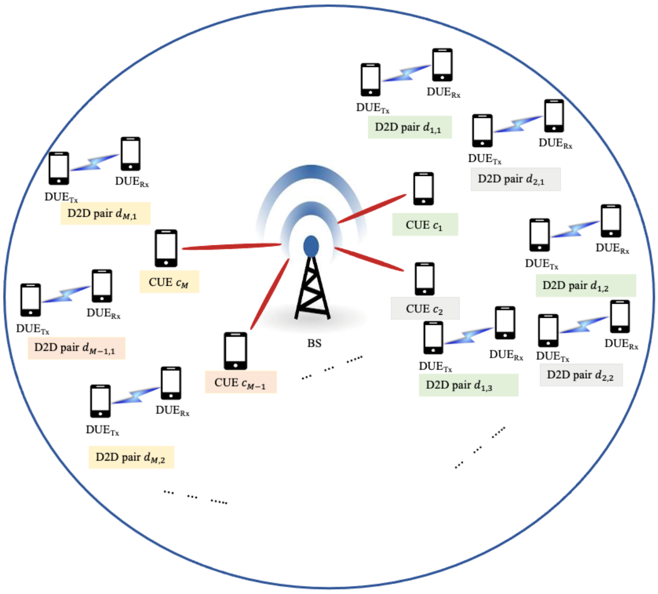

Fig. 5 The system model of D2D communications underlaying cellular network.

The SINR of D2D pair $d_{g,n}$ can be expressed as:

$$\gamma_{d_{g,n}} = \frac{P_{d_{g,n}} H(d_{g,n})}{\sigma^2 + \sum_{g=1}^{G} \sum_{\acute{n}=1}^{N} P_{d_{g,n}} H(d_{g,n}, d_{g,\acute{n}})}, \tag{2}$$

where $H(d_{g,n})$ is the channel gain between DUE_{Tx} and DUE_{Rx} of D2D pair $d_{g,n}$; $P_{d_{g,n}}$is the power coefficient allocated to DUE_{Tx} $d_{g,n}$; $H(d_{g,n}, d_{g,\acute{n}})$ is the interference signals caused by DUE_{Tx}s $d_{g,n}$to DUE_{Rx}s $d_{g,\acute{n}}$, which is known as interference **Case 5.**

Based on Shannon capacity, the overall sum-rate can be expressed as:

$$R = B_m [\sum_{m=1}^{M} \log(1 + \gamma_{c_m}) + \sum_{g=1}^{G} \sum_{n=1}^{N} \log(1 + \gamma_{d_{g,n}})], \tag{3}$$

where B_m is the bandwidth specified for CUE c_m.

B. Problem Formulation

The aim of the resource allocation problem is to maximize the overall network sum-rate, which is defined as the sum of the data rates of all CUEs and D2D pairs in the network while satisfy the QoS reequipments of both cellular and D2D communications. Thus, the objective is formulated as:

$$\max R, \tag{4}$$

Subject to the following constraints:

C1: $\gamma_{C_m} \geq \gamma_{C_m,min}$
C2: $\gamma_{d_{g,n}} \geq \gamma_{d_{(g,n),min}}$
C3: $P_{C_m} \leq P_{C_m,max}$
C4: $P_{d_{g,n}} \leq P_{d_{(g,n),max}}$

where $\gamma_{c_{m,min}}$ and $\gamma_{d_{(g,n),min}}$ represent the minimum SINR required to satisfy the QoS reequipments for CUE C_m and D2D pair $d_{g,n}$, respectively. $P_{C_m,max}$ and $P_{d_{(g,n),max}}$ represent the maximum power bounds for CUE C_m and D2D pair $d_{g,n}$, respectively.

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Equation (4) represents the optimization objective which is to maximize the network's overall sum-rate. Constraints **C1** and **C2** denote that each CUE c_m and D2D pair $d_{g,n}$ must meet the minimum SINR, respectively. **C3** and **C4** represent the maximum power bounds for the CUE C_m and D2D pair $d_{g,n}$, respectively. This optimization problem (4) is an MINLP problem [29], which NP-hard and it is difficult to solve. In the following section, the proposed algorithm to solve this problem will be presented.

VI. Proposed Algorithm

To solve the optimization problem in (4), the problem is decomposed into three subproblems: interference management, power allocation, and matching process. In this section the proposed algorithms for each of these subproblems are presented as follows:

A. Interference Management

The graph theory is adopted here to solve the subproblem of interference management. Particularly, the main focus here is on the interference signals in **Case 5** that are caused by DUE_{Tx}s to other DUE_{Rx}s. The aim of this proposed interference management algorithm is to divide the whole number of D2D pairs into a certain number of groups. For simplicity, we assumed that the number of D2D pair groups is equal to the number of CUEs in the network, where the least interfered D2D pairs are formed a single group. In this way, a single group of D2D pairs can reuse the same frequency resources with the least interference signals. Figure 6-(A) shows a constructed graph for the mutual interference signals between different D2D pairs in which every node represents a D2D pair, and the edge weight represents the interference between two different nodes (i.e., D2D pairs). Figure 6-(B) shows different groups of D2D pairs after applying the proposed interference management algorithm.

The most suitable graph-based objective function that captures the aim of interference management is N-Max Cut [30][31]. The objective function of N-Max Cut relays on sums of the edge weights, in which a particular node is added to a certain group with the minimum sum weight.

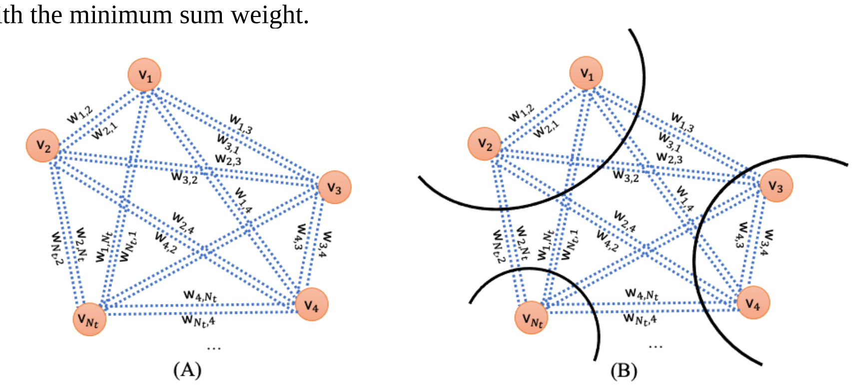

Fig. 6 Graph-based interference management representation.

Therefore, adding v_j into the g-th group Γ_g with the minimum sum weight can be expressed as:

$$\Gamma_g^* = \arg\min \sum_{i\in\Gamma}(w_{i,j} + w_{j,i}). \quad (5)$$

The heuristic algorithm used for D2D pairs interference management is illustrated in TABLE II.

TABLE II THE PROPOSED ALGORITHM FOR INTERFERENCE MANAGEMENT.

Input: a matrix representing mutual interference signals between different D2D pairs and G the number of D2D pair groups, in our case $G = M$. **Output:** groups of D2D pairs $\Gamma_g, g = 1, 2, \dots, G$.
1. Add one note v_i to one group Γ_g randomly. 2. **For** $v_j \in N_t$ and not in any group Do 3. Calculate the sum interference wights $\sum_{i\in\Gamma}(w_{i,j} + w_{j,i})$; 4. **End For** 5. Add v_j to the g-th group, where $\Gamma_g^* = \arg\min \sum_{i\in\Gamma}(w_{i,j} + w_{j,i})$; 6. Return Γ_g;

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B. Power Allocation

The linear programming is used here to solve the subproblem of allocating power coefficients to each CUE and DUE_{Tx}. The proposed algorithm for power allocation begins by determining the acceptable sets. In specific, an acceptable set consists of one CUE and one group of D2D pairs, and it is created when the powers coefficients of a CUE and all D2D pairs in a single group can be saturated to fulfill the minimum SINR requirements and the maximum power bounds.

The acceptable sets can be determined by the following equations:

$$\begin{cases} \gamma_{C_m} \geq \gamma_{C_m,min}, \\ \gamma_{d_{g,n}} \geq \gamma_{d_{(g,n)},min}, \\ P_{C_m} \leq P_{C_m,max}, \\ P_{d_{g,n}} \leq P_{d_{(g,n)},max}. \end{cases} \quad (6)$$

These equations are used to derive the linear relation between power coefficients P_{C_m} and $P_{d_{g,n}}$. If the power coefficients P_{C_m} and $P^*_{c_{g,m}}$ satisfy the four linear relations, a set made up of CUE c_m and one g-th group of N D2D pairs $d_{g,n}$ is considered acceptable. Without loss of the generality, the $P_{d_{(g)}}$ here is the average power coefficients of all N D2D pairs in a g-th group.

According to (6), when a set consisting of P_{C_m} and $P_{d_{(g)}}$ is accepted, different three scenarios are possible, and they are shown in Figure 7. where $l_1 = \frac{\gamma_{C_m,\min}[\sum_{n=1}^{N} H(d_{g,n})/N]}{H(c_m)}$, $l_2 = \frac{H(c_m)}{[\sum_{n=1}^{N}\gamma_{d_{g,n}} H(d_{g,n},c_m)]/N}$, $P_{c_1,min} = \frac{\sigma^2\gamma_{C_m,min}}{H(c_m)}$, $P_{d_{(1),min}} = \frac{\sigma^2\sum_{n=1}^{N}\gamma_{d_{(g,n)},min}}{\sum_{n=1}^{N} H(d_{g,n})}$.

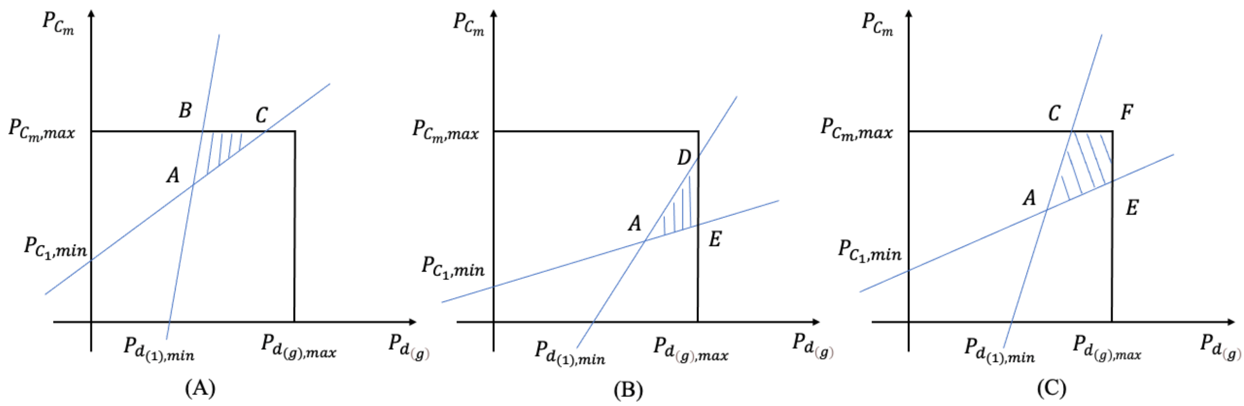

Fig. 7 The illustration of power allocation and different accepted set scenarios.

In the next step, the optimal power coefficients for a single acceptable set of a CUE and a group of D2D pairs are studied.

The optimal power vector can be formulated as follows:

$$(P^*_{C_m}, P^*_{c_{g,n}}) = arg\ max\ B_m[\sum_{m=1}^{M} log(1+\gamma_{C_m}) + \sum_{g=1}^{G}\sum_{n=1}^{N} log\ (1+\gamma_{d_{g,n}})], \quad (7)$$

where P_{C_m} and $P_{d_{g,n}} \in A_{set}$, and A_{set} is the shaded area specified previously. This equation searches for the optimal power coefficients when the overall sum-rate of the accepted set is maximized. To derive $f(P_{c_m}, P_{c_{g,n}})$ defined form (7), $f(\lambda P_{c_m}, \lambda P_n) > f(P_{c_m}, P_{c_{g,n}})$ if $\lambda > 1$. Therefore, it is known that one power coefficient in $(P^*_{c_m}, P^*_{c_{g,n}})$ at least is bounded by the peak value. $f(P^*_{c_m}, P^*_{c_{g,n}})$ is considered a convex function over either one of P_{c_m} and $P_{c_{g,n}}$ when the other value is fixed, as proven in [32].

In the first scenario, to maximize $f(P^*_{c_m}, P^*_{c_{g,n}})$ one CUE c_m should have a power coefficient at peak value, while N D2D pairs in g-th group $d_{g,n}$ should have power coefficients on segment B-C, as shown in Figure 7-(A). In the second scenario,

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to maximize $f(P_{c_m}^*, P_{c_{g,n}}^*)$, the power coefficients of all N D2D pairs in the g-th group $P_{c_{g,n}}^*$ should have power coefficients at peak value, while CUE c_m should have power coefficients on either point B or point C, as shown in Figure 7-(B). In the third scenario, as shown in Figure 7-(C), the optimal power coefficients locate on segment C-F and segment F-E.

C. Matching Process

The match theory is explored here to find the best match of CUE c_m and $d_{g,n}$ for $g = 1, 2, \dots .G$. The result of this proposed algorithm is sets of matched CUEs and groups of D2D pairs, where each matched set can reuse the same frequency resources and those in different sets cannot reuse the same frequency resources. This matching subproblem can be presented as a bipartite graph as shown in Fig. 8.

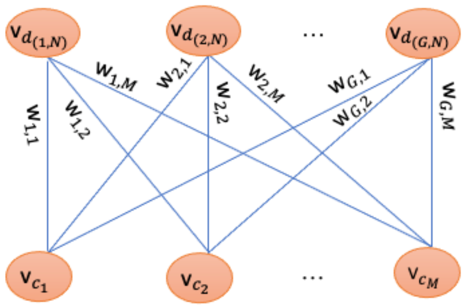

Fig. 8 Bipartite graph for the matching process.

This subproblem can be expressed as the stable marriage problem. A stable matching is described as a complete matching of M CUEs and G groups of D2D pairs, $M = G$. The Gale-Shapley algorithm [33] proposed by David Gale and Lloyd Shapley is widely used to find a stable matching between males and females. A stable marriage problem, for instance, is when each of x male and x female creates a subset of the opposite gender based on their preference lists. Here, the males represent the groups of D2D pairs, and the females represent the CUEs.
The preference list of G groups of D2D pairs is determined based on the highest overall sum-rate, and it is defined in **Definition 1**. While the preference list of M CUEs is determined based on the least interference signals caused by DUE_{Tx}s to CUEs, which in known as in **Case 4**, and it is defined in **Definition 2.**

Definition 1:
The g-th group of D2D pairs prefers m-th CUE rather than $\acute{m}$-th CUE, if $log\left(1+\gamma_{c_m}\right) + log\ (1+\gamma_{d_{g,n}}) > log\left(1+\gamma_{c_{\acute{m}}}\right) + log\ (1+\gamma_{d_{g,n}})$.

Definition 2:
The m-th CUE prefers g-th group of D2D pairs rather than $\acute{g}$-th group of D2D pairs, if $\sigma^2 + \sum_{g=1}^{G}\sum_{n=1}^{N} P_{d_{g,n}} H(d_{g,n}, c_m) < \sigma^2 + \sum_{\acute{g}=1}^{G}\sum_{n=1}^{N} P_{d_{\acute{g},n}} H(d_{\acute{g},n}, c_m)$.

The proposed algorithm base on Gale-shapely for the matching process is illustrated in TABLE III.

TABLE III THE PROPOSED ALGORITHM FOR MATCHING PROCESS.

Input: M CUEs, G groups of D2D pairs, M CUEs' preference list, and G groups' of D2D pairs preference list **Output:** S the matched sets of G groups of D2D pairs, and M CUEs.
1. Initially all m $\in M$ and $g \in G$ are not matched, $S = 0$; 2. **While** $\exists g \in G$ who is not matched, and has not proposed to any m **Do** 3. Let m be the highest-ranking CUE in g's preference list, to whom g has not proposed; 4. Now g proposes to m; 5. **If** m is free **Then** 6. (g, m) becomes matched (add (g, m) to S); 7. **Else** 8. m is matched to $\acute{g}$; 9. **If** m prefers $\acute{g}$ to g **Then** 10. g remains free; 11. **Else**

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```
      m prefers g to ǵ;
      ǵ becomes free (remove (ǵ, m) from S);
      (g, m) are matched (add (g, m) to S);
    End If
  End If
End While
Return the S.
```

VII. SIMULATION RESULTS

The proposed many-to-one spectrum reusing resource allocation algorithm for D2D communications underlaying cellular network is evaluated in terms of sum-rate and numbers of D2D pairs.

In this simulation, the BS is located at the centre of a cell. M CUEs and N_t D2D pairs are distributed randomly within the cell radius varies between 400-1000 meter. The distance between a D2D pair is 5-20 meter. The number of CUEs is 50 and the number of D2D pairs varies between 50-300. The minimum of SINR for a CUE and a DUE_{Rx} is 20 dB and 13, respectively. The maximum transmit power for each cellular is 24 dBm, and the maximum transmit power from DUE_{Tx} is 24 dBm. The common simulation parameters are presented in TABLE IV.

TABLE IV COMMON SIMULATION PARAMETERS.

Parameter	Value
Cell radius	400-1000 meter
Number of CUEs, M	50
Number of D2D pairs, N	50-300
Distance between D2D pairs	5-20 meter
AWGN	-144 dBm
Maximum transmit power for each CUE Maximum transmit power from DUE_{Tx}	24 dBm
The minimum of SINR for CUE	20 dB
The minimum of SINR for DUE_{Rx}	13 dB

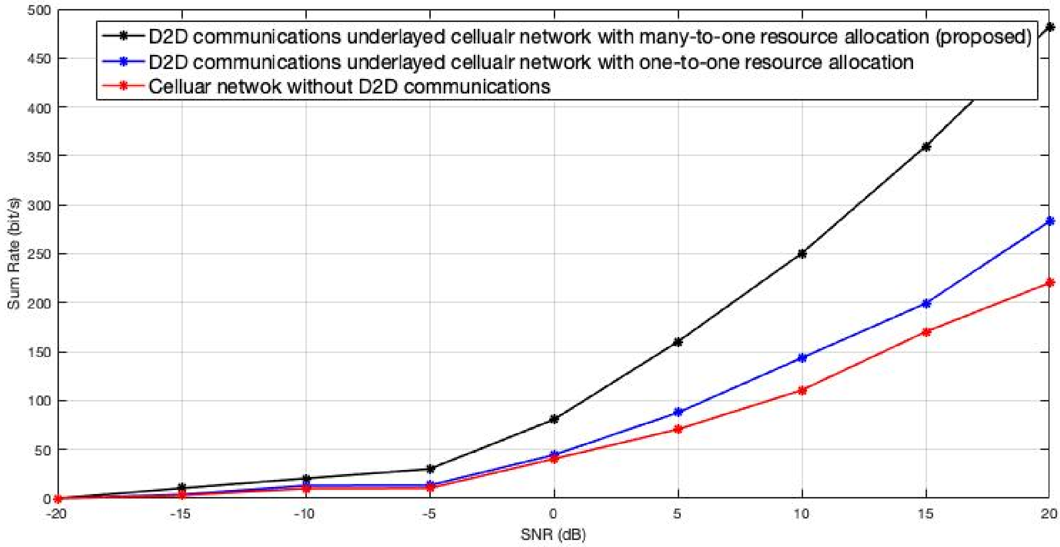

Fig. 9 The overall sum-rate versus SNRs.

Fig. 9 shows the overall sum-rate achieved by three resource allocation scenarios versus different signal noise ratios (SNRs). In the first scenario, D2D communications underlaying cellular network scheme with many-to-one resource allocation is considered, where multiple D2D pairs are many-to-one matched with a single CUE, and $N = 300$. In the second scenario, D2D communications underlaying cellular network scheme with one-to-one resource allocation is considered, where a single D2D pair is a one-to-one matched with a single CUE, and $N = 50$. In the third scenario, a cellular network scheme without D2D communication is considered. The proposed many-to-one resource allocation for

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D2D communications underlaying cellular network achieves the highest sum-rate compared to one-to-one resource allocation for D2D communications underlaying cellular network and cellular network scheme without D2D communication.

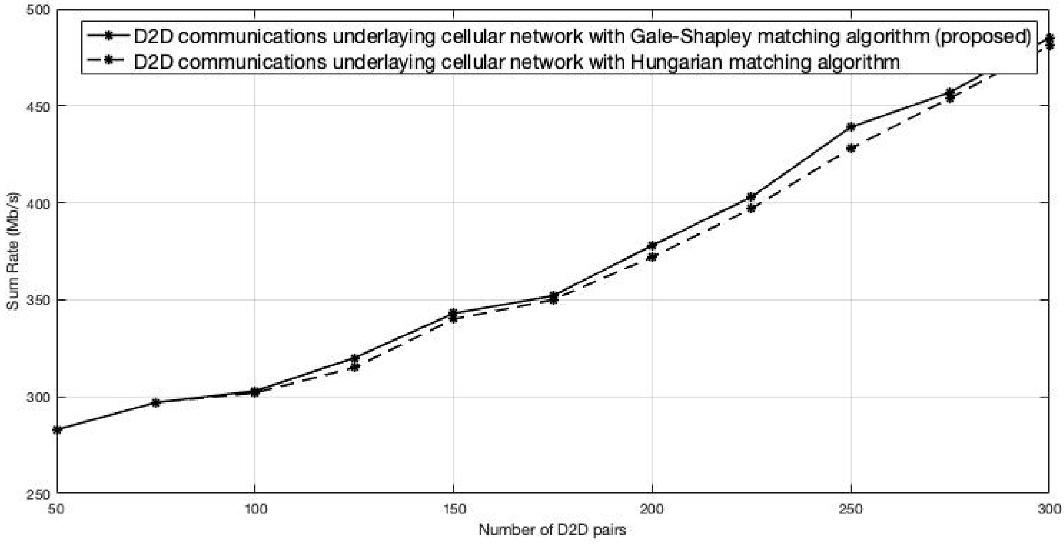

Fig. 10 The overall sum versus number of D2D communications.

Fig. 10 shows the overall sum-rate of D2D communications underlaying cellular network with many-to-one resource allocation algorithms versus the different number of D2D communications. The D2D communications underlaying cellular network scheme with Gale-Shapley matching algorithm achieves a greater sum-rate compared to the D2D communications underlaying cellular network scheme with Hungarian matching algorithm. The preference lists of both communications applied in Gale-shapely give the credit to Gale-shapely since it jointly considers maximizing the sum-rate and minimizing the interference as specified in **Definition 1** and **Definition 2,** respectively. On the other hand, the Hungarian matching considered only the sum-rate maximizing. In addition, this figure implies that the overall sum-rate increased almost linearly as the number of D2D pairs increased.

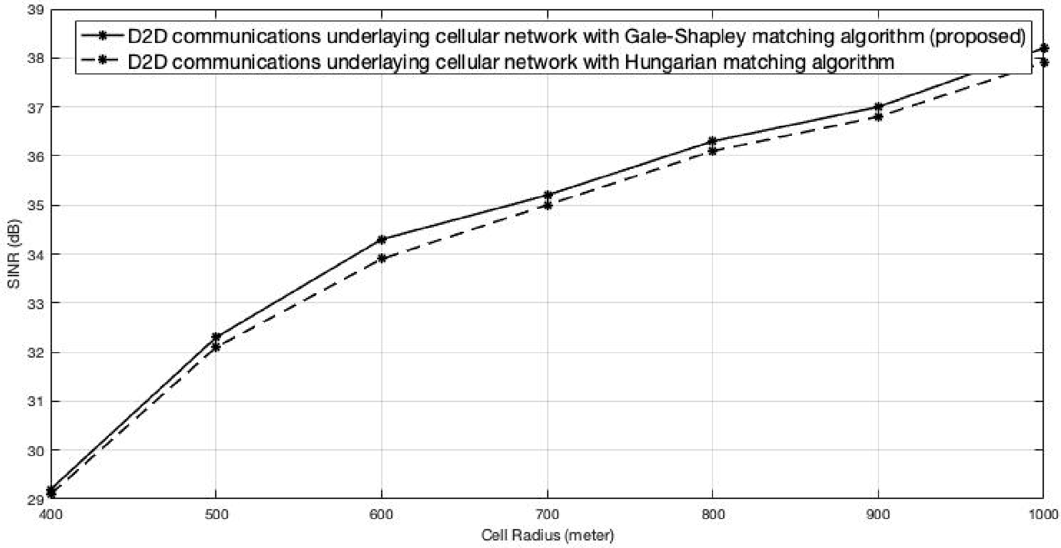

Fig. 11 The SINR versus different cell radius.

Fig. 11 shows the SINR of D2D communications underlaying cellular network with many-to-one resource allocation algorithms versus different cell radiuses. The D2D communications underlaying cellular network scheme with Gale-Shapley matching algorithm achieves a greater SINR compared to the D2D communications underlaying cellular network scheme with the Hungarian matching algorithm. This happens because the interference minimizing as specified in

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Definition 2 is considered in the preference list in the Gale-Shapely matching algorithm. In addition, this figure implies that the SINR increased as the cell radius increased.

VIII. Conclusion and Future Work

In this paper, we proposed a many-to-one frequency reusing resource allocation algorithm for D2D communications underlaying cellular network. The formulated optimizing problem with the aim of maximizing the network sum-rate is considered to be NP-hard. To solve this problem, it decomposed into interference management, power allocation, and matching process. To solve the problem of co-tier interference signals caused by DUE_{Tx}s to other D2D pairs DUE_{Rx}s, which is also known as **Case 5**, and to find the best groups of D2D pairs with less interfered signals, an interference management algorithm is proposed using graph-based solutions. To optimize the power coefficients assigned to CUEs and DUE_{Tx}s, a power allocating algorithm is proposed by adopting linear programming. To find the best set of CUEs and groups of D2D pairs for spectrum reusing, a matching process algorithm is proposed by adopting matching theory solutions.

Simulation results showed sum-rate improvement for D2D communications underlaying cellular network scheme compared to cellular network scheme without D2D communications. In addition, they showed sum-rate improvement for D2D communications underlaying cellular network scheme with many-to-one resource allocation compared to one-to-one resource allocation.

In future work, the interference signals caused by D2D communications underlaying cellular network in the uplink period will be investigated. Furthermore, the deployment of D2D communications with other 5G enabling technologies may be investigated. These technologies can include millimetre wave, which can provide very high bandwidth, or non-orthogonal multiple access, which can provide huge connectivity.

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