

Survey on Device-to-Device Communications: Challenges and Design Issues

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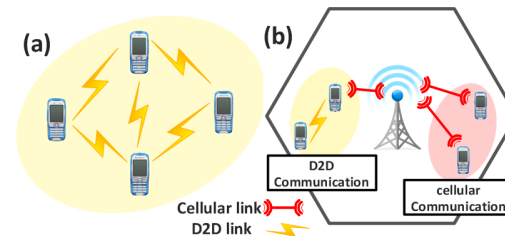


Fig. 1. D2D communications: (a) without infrastructure (Stand-Alone D2D) (b) with infrastructure (Network-Assisted D2D).

D2D通訊可分為以上兩種結構，區別在於是否存在基礎設施(有助於組織單元的通訊和資源利用)

tions, whereas the second structure, illustrated in Fig.1.b, is called *Network-Assisted D2D communications*. The difference between the two structures is the existence of a helping infrastructure in (b) to organize the communications and resource utilization in the cell. On the other hand, in (a), the devices organize the communications themselves without the infrastructure help. Fig.2 delineate the fundamental network architecture of D2D communications, consisting of D2D area network, network management and D2D applications. The D2D area network consists of swarm of D2D devices communicating with each other directly using D2D links. D2D aggregators collect data from devices intending to connect to the core network and send them to gateways which connect to the access network. The access network can be wired or wireless network. The core network connects devices with service providers who manage the different D2D services. The

D2D區域網路由D2D設備組成，使用D2D連結直接通訊

D2D聚合器會收集來自設備的資料，並連接到核心網路後開始傳送資料

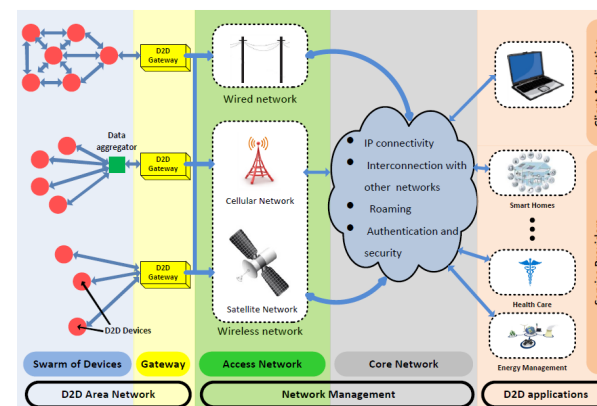


Fig. 2. D2D Network Architecture

基本網路架構，包括D2D區域網路、網路管理、D2D應用

Abstract—Device-to-Device (D2D) communications has been proposed to cellular networks in order to optimize spectrum efficiency and resources utilization. In D2D-assisted networks, the traditional cellular communication techniques are not applicable but rather need to be redesigned to fulfill new requirements. Therefore, new communication techniques are proposed to take the advantages of the D2D connectivity in the network. In this paper, we describe the concept of D2D communications. Then, we review the main challenges and design issues of D2D-assisted networks. This survey focuses on cooperative communications in D2D-assisted networks and addresses challenges which limit the performance of the cooperative D2D-assisted networks such as relay selection, power consumption and multi-casting. Moreover, design issues and approaches to overcome these limitations are explained.

I. INTRODUCTION

DEVICE-TO-DEVICE (D2D) communications were introduced many years ago in the context of wired communication networks. Recently, there are around five billion devices connected to the cellular network. This raised the need for high capacity and energy efficient mobile networks. Hence, D2D communications one of the proposed paradigms in the next generation cellular network. D2D communications is about enabling the direct flow of data between devices. In contrast to Human-to-Human (H2H) communications, D2D communications do not require human interaction. Instead, devices initiate the request for communication with near devices. The cellular network is optimized for traffic characteristics which are different from the characteristics of data traffic between devices. The length of the session, data rate, and communication patterns are the main differences between H2H and D2D communications. The transmission over D2D is a small burst transmission one-way data traffic.

In this survey, we first introduce the concept of D2D communications in section II. In section III, an overview the main challenges and research issues in D2D-assisted cellular networks is introduced. Section IV focuses on the employment of cooperative communications in D2D-assisted networks and summarizes the advantages of using cooperation in such networks. Finally, in section V we address the main challenges in the design process of cooperative D2D-assisted networks and summarize the different approaches in literature to reduce the effects of these limitations on network performance.

II. D2D COMMUNICATIONS

D2D communication networks can be classified into two main structures as shown in Fig.1. The first structure, illustrated in Fig.1.a, is called *Stand-Alone D2D communication*.

區別 H2H, D2D

D2D通訊是蜂巢式網路用來優化頻譜效率和資源使用，而D2D輔助網路需要重新設計來滿足新的需求

本文的重點是在D2D輔助網路中的合作通訊，並解決D2D輔助網路效能限制的挑戰

設計問題、克服限制的方法

D2D通訊是有線通訊網路的一部分，近年因為大量設備連接，提高了高容量與高效能的需求

D2D通訊是一種小型、大量傳輸單向資料的通訊

☀️ 客戶端應用程式會與核心網路連結，並幫助最終用戶控制網路、與設備互動

client application is connected with the core network to help end users to monitor and interact with devices in the network.

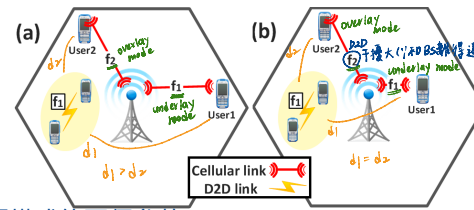
III. D2D CHALLENGES AND DESIGN ISSUES

Enabling D2D communications on the cellular network will allow the network to benefit from the potential advantages of this technology. However, D2D communications will bring new challenges and design problems such as the optimization of power consumption and resource allocation. Another important challenge is the reuse of cellular frequencies which causes interference between the cellular users and D2D users as shown in Fig.3 for both (a) uplink and (b) downlink. Mainly, there are four different interference scenarios in D2D-assisted networks. When uplink frequencies are reused by D2D users in the cell, the base-station receiver will receive interference from the D2D user transmitter (DUT) (see ① in Fig.3.a). Similarly, the D2D user receiver (DUR) will receive interference signal from the cellular user transmitter (CUT) (see ② in Fig.3.a). On the other hand, when downlink frequencies are being reused by D2D users, CUR will receive interference from the DUT (see ③ in Fig.3.b) and DUR will receive interference from the base-station transmitter (see ④ in Fig.3.b). It is worth noting that downlink frequencies are more congested when compared to the uplink especially for applications that require high data rates. Hence D2D communication is mainly based on uplink frequencies and associated interference scenarios.

As mentioned earlier, mitigating the interference will maximize the system throughput for a certain maintained Quality of Service (QoS). This can be achieved in a number of ways as follows:

A. Mitigating Interference Using Mode Selection

Mode selection is considered crucial to avoid the effect of interference. D2D users can communicate using the direct link in two modes which are (overlay D2D) and (underlay D2D) [1]. The work in [1], [2] on mode selection is directed at optimizing the selection between the two modes based on several parameters. Fig.4 illustrates two parameters of mode selection. The first parameter is the distance between D2D and cellular users. In Fig.4.a, both user1 and user2 are equally separated from the BS. However, user2 is closer to the D2D pair compared to user1. In this case, the mode selection algorithm will choose underlay mode for the D2D pair using f_1 . The second parameter of mode selection is the



☀️ 選擇模式的兩個參數

Fig. 4. Illustration of D2D mode selection parameters: (a) distance between D2D and cellular user, (b) distance between cellular user and BS.

distance between cellular users and the BS. In Fig.4.b, both users are equally separated from the D2D pair. However, the interference at the D2D pair is greater from user2 compared to user1 because the distance between user2 and the BS is greater. In this case, the mode selection algorithm will choose underlay mode for the D2D pair using f_1 . In both cases (a and b), when frequency f_2 is available instead of f_1 , the mode selection algorithm will choose the overlay D2D mode to avoid the potential interference.

B. Mitigating Interference Using Resource Allocation

Resource allocation is considered as one of the most important research areas in D2D due to its crucial impact on the system performance. The optimized allocation of resources such as (power), (frequency), and (time) can help in reducing the effect of interference. Novel optimized resource allocation techniques have been proposed in the literature based on a centralized approach [3]. However, using the centralized resource allocation protocols in D2D-assisted networks is very challenging due to the huge number of devices in the cell which will result in increased complexity of the protocol. On the other hand, distributed resource allocation proposed in [4] overcomes the complexity issue since devices are used to sense the network environment and utilize the available resources without causing interference to the cellular network devices.

C. Mitigating Interference Using Power Control

Power control is important for uplink due to (co-channel interference) and (near-far effect). The most straightforward way to implement interference mitigation in D2D-assisted networks is to predefine a maximum power level to D2D users such that the QoS for cellular users is maintained [1]. Improved performance can be achieved using more sophisticated techniques for power control such as those introduced in [1], [5].

IV. COOPERATIVE COMMUNICATIONS FOR D2D-ASSISTED NETWORKS

Cooperative Communications (CC) was proposed in literature as D2D communication paradigm to help in enhancing the network performance. Literature work discussing CC in D2D-assisted networks can be divided into two parts as follows:

A. The Effect Of Cooperative Cellular Networks On D2D Communications

It is well-known that CC in cellular networks improves the performance of cellular users. On the other hand, since

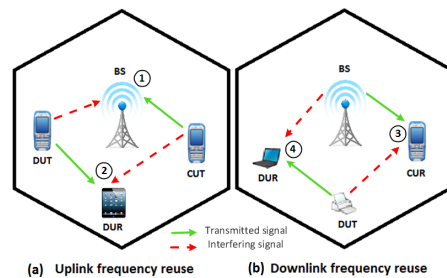


Fig. 3. Illustration of frequency reuse in D2D communications

☀️ 使用集中式資源分配協定具挑戰性，因為設備數量龐大會導致協定的複雜性增加

☀️ 分散式資源分配克服協定複雜性的問題，設備用於感知網路環境，使用可用資源不會對網路設備造成干擾

☀️ 功率控制對uplink很重要

☀️ D2D用戶預先定義最大功率級別，以便維持蜂巢式網路用戶的QoS

☀️ 合作通訊作為D2D通訊範例可以幫助提高網路性能

☀ 考慮合作通訊對D2D用戶的影響，模式選擇是D2D輔助網路的主要挑戰

☀ [6] 在蜂巢式網路引入中繼節點，將增加D2D用戶與蜂巢用戶共享資源的機會

☀ [9] 行動網路內的設備和D2D設備可以充當中繼站，以提高系統性能

☀ [10] 分析具有D2D移動中繼站的輔助網路性能，網路中容量不同的合作方案和QoS改進

☀ [11] 多hop的中繼站在某些限制功率下，降低連線的中斷機率

☀ 目標是使中繼站選擇過程高效率和最佳化

CC is one of the main technologies in the current cellular networks, it is important to take into account its impact on D2D users. Mode selection is one of the main challenges in D2D-assisted networks. The work in [6], investigated the effect of mode selection with and without cellular CC. The results show that the introduction of relay nodes in the cellular network will increase the chances of D2D users to share resources with cellular users because underlay D2D mode is chosen more often by the mode selection algorithm. This indicate that cellular CC increases spectrum efficiency of D2D-assisted networks. On the other hand, the work in [7] proposed mode selection algorithms in Heterogeneous D2D and IMT-Advanced Network. Beside mode selection, we discussed the issue of resource allocation and power control in D2D-assisted networks. Researchers proposed different techniques to optimize these issues in cooperative cellular networks [8].

B. The Performance Of Cooperative D2D-Assisted Networks

Cooperation among D2D users and between D2D and cellular users is widely studied topic in literature. In order to guarantee the improvements achieved by CC, the network should use cooperation when D2D-pairs are far away from each other and the direct communication link is not good enough to allow reliable transmission. Cooperation between users in D2D-assisted network will improve the spectral efficiency and QoS. In addition, CC in such networks can help in the extension of network coverage and reduction of interference. In [9], the authors proved via simulations that the throughput of cooperative D2D-assisted network outperforms the case without cooperation. As mentioned earlier, the user equipment in the cell or the D2D devices can act as relays to improve system performance. The work in [10] analyzed the performance of D2D-assisted network with D2D mobile relays. The results show that cell edge throughput improvements percentage as well as coverage improvements percentage can exceed 150% by utilizing idle users in the network as relays. In the literature, many researchers attempted to analyze the performance of different cooperative schemes in D2D-assisted networks in terms of capacity and QoS improvements. The work in [11] should that multi-hop relaying reduced the outage probability of the D2D links under certain power constrains. The capacity of D2D communication increased even under the influence of strong cellular signals.

V. COOPERATIVE D2D COMMUNICATION CHALLENGES AND DESIGN ISSUES

In order to realize the potential gains of cooperative relaying in D2D-assisted networks, the main technical challenges need to be addressed and proposed solution approaches need to be discussed. These are presented as follows:

A. Relay Selection

Relay selection is a major issue in cooperative D2D networks, since the number of relays that can be utilized is huge. Generally, it is a design goal to make this selection process efficient and optimized. The role of the network in relay selection is an important design question. In the cellular

underlay mode, the network can play an active role for relay selection. In the centralized method, the BS decides the relay selection for D2D transmission. The work in [12] proposes new relay selection methods for D2D-assisted networks where algorithms for relay selection are implemented in the BS. These algorithms enable the BS to choose the best relay for any user in the network. Most of the work on relay selection assumes passive role of the BS in the selection process due to the resulted increase of BS load in the centralized method. Passive network relay selection is achieved using two main methods. The first method is called Random Relay Selection where the user randomly selects one from all optional relays. The second method known as Distributed Relay Selection which was proposed in [13]. This methods eliminates improper relays and uses a distributed algorithm to choose the best relay. Numerical results show that the performance of the distributed method is closest to the centralized method whereas the Random Relay Selection method has the least performance.

B. Multi-cast Services

D2D communications is proposed to enhance the performance of cellular multi-cast services [14]–[16]. The major issue in cellular multi-cast transmissions is the different channel conditions for the multi-cast recipients. For this reason, the BS will find difficulty in choosing the transmission rate which suits all the recipients. In this situation, the BS chooses the transmission rate which suits the recipient with the worst channel conditions which will result in reducing the efficiency of multi-casting transmission. Alternatively in D2D-assisted networks, a number of D2D devices with good channel conditions are identified and used to communicate the multi-cast signal from the BS to nearby devices. Researchers approached this issue in many different ways. In [14] the authors assumed a single predefined multi-cast recipient called cluster head which is responsible for D2D retransmissions. On the other hand, the authors in [15] assumed multiple recipients of the multi-cast signal. Further improvement to the latter approach was proposed in [16] using a dynamic multiple, multi-casting technique which is based on the following:

- ❑ Selecting the optimum number of re-transmitters (or relays) since there is a trade-off between the multi-cast gain and multi-channel diversity.
- ❑ Optimize the retransmission scheme of the relays to enhance the throughput of multi-cast transmission.

C. Optimum Power Consumption

Optimum power consumption is one of the main requirements of D2D-assisted networks due to the limited energy available for the user devices in the network. Cooperative techniques can be used to extend the lifetime of D2D networks. Usually, power expenditure for cell-edge D2D devices is comparatively high due to the large distance between the transmitter and the receiver. However, D2D devices are characterized as low level power consumption devices. In [17] a cooperative scheme is proposed to lower power consumption

☀ 集中式方法導致BS負載增加

☀ 群播傳播主要問題：群播的接收者有不同的通訊條件，BS會很難選擇適合所有接收者的傳輸速率

☀ [14] 假設預先定義的群播接收者為首領，負責D2D重傳

☀ [15] 假設群播訊號有多個接收者

☀ 動態多重群播技術：
1.選擇最佳數量的重傳裝置，平衡群播增益和多通道
2.優化中繼站的重傳方案，以提高群播的傳輸吞吐量

☀ [17] 合作方案來降低蜂巢式邊緣用戶的功耗，以改善D2D輔助網路

☀ [18] 低功耗D2D網路中合作的必要性

☀ [19] 通用框架，合作多樣性來降低功耗

☀ [21] 協助D2D輔助網路的聯合節能資源分配技術，基於群組的D2D通訊是資源分配技術之一

☀ 將設備分組，可減少行動網路和D2D網路通訊數量，和BS通訊功耗減少

☀ 分組通訊資源分配：

- 1.選擇設備、分組、分組數量
- 2.找到每個設備的最佳傳輸功率

of cell-edge users and improve power consumption of D2D-assisted networks. The authors in [18] discussed the necessity of cooperation in low power D2D networks. The work in [19] introduced a general framework to reduce power consumption by exploiting cooperative diversity. In literature, one of the main techniques proposed to improve power consumption of cooperative D2D-assisted networks is relay selection. The first technique is Relay Selection [20]. This technique involves Identifying the optimal relay node as the one that minimizes the total transmitted power. Another technique for optimum power consumption is Resource Allocation. The authors in [21] proposed a joint energy-saving resource allocation mechanism for cooperative D2D-assisted networks. Group-based D2D communication is one of the famous resource allocation techniques used to reduce power consumption in D2D-assisted networks. The main aim of grouping a number of devices is to reduce the number of communications between the cellular and D2D networks. Moreover, the D2D devices will communicate with the cellular network through group headers located near to the D2D devices in the network. This means that D2D devices need less power to communicate with the BS. The design of resource allocation using group communications involves deciding on

- The algorithm to perform devices selection and devices grouping and determine the number of groups.
- The power allocation scheme used with grouping to find the optimum transmission power for each device.

VI. CONCLUSION

In this paper, a survey on D2D communications is presented. The main concept and architecture of D2D communications are introduced. Then, the main challenges and design issues of D2D-assisted networks are explored. The remaining part of the survey focuses on the employment of cooperative communications in D2D-assisted networks and the associated challenges and design issues such as: relay selection, multicasting and power consumption.

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