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REVIEW PAPER

Improvement in SE for D2D Communication: A Review

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Abstract 5G is the advanced technology beyond the 4G, which has faster speed, more bandwidth, wider range, low latency, and better Quality of Services. Device-to-Device (D2D) communication is an innovation that can contribute to the fulfillment of the demand of 5G. Previous researchers in this field demonstrated the improvement in spectral efficiency for D2D communication using various techniques such as clustering, frequency reusing, spectrum sharing, resource block allocation, and implementation of the new generation waveforms i.e., orthogonal frequency division multiplexing, Filtered orthogonal frequency division multiplexing, Filter bank multicarrier, and Universal carrier multicarrier. This manuscript will review the achieved performance in the used network for different algorithms or methods suggested by researchers.

Keywords Spectral efficiency · Clustering · Spectrum sharing · Frequency reusing · Resource allocation · New generation waveform

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Introduction

The number of mobile-connected devices is expected to increase drastically in the upcoming years, which requires the more efficient design of the cellular architecture. Global mobile traffic flow will grow seven-fold between 2017 and 2022. Per capita mobile devices will be 1.5 times, the network connection speed will increase up to 28.5 Mbps, 5G connection will generate approximately 2.6 times more traffic compared to 4G, and average 11 GB traffic will generate by smartphones up to 2022 [1]. D2D communication is the most innovative technology which contributes to the reduction of the heavy traffic problem.

D2D communication is categorized as in-band D2D, i.e., licensed spectrum, and out-band D2D i.e., unlicensed spectrum. In-band communication uses a cellular spectrum for both D2D and cellular links. In-band communication is classified as underlay and overlay. Underlay D2D communication shares the same radio resources for cellular and D2D communication while overlaying D2D communication uses a dedicated cellular spectrum. In-band D2D communication can expand spectral efficiency (SE) by reusing spectrum resources (i.e., underlay) or by allocating dedicated cellular resources to D2D users (i.e., overlay). Interference caused by, D2D users to cellular users or cellular users to D2D users, is the biggest problem for D2D communication.

Out-band D2D communication uses an unlicensed spectrum so interference between D2D link and cellular link affects the system least. Out-band communication is classified as 'controlled' and 'autonomous' D2D communication. Out-band D2D uses other wireless technologies such as Wi-Fi direct [2], ZigBee [3], or Bluetooth [4] for connection between user equipment (UEs). If control of the second interface/technology is given to the cellular network [5–8] then, this is controlled out-band D2D communication. On the other hand, keep the cellular communication control, and leave the D2D communications control to the users [9], then this is autonomous out-band D2D communication. Remember that the out-band D2D communication suffers from the uncontrolled nature of unlicensed spectrum.

The transmit rate of data can be increased up to 1Gbps for a distance of 1000 m [10] in D2D communication. In recent years, the 5G cellular networks have attracted the attention of researchers because of the milestones of 5G, which include almost zero delay, 100 billion links, and 1000 times improved throughput. 5G cellular network uses a D2D communication system to improve SE, system capacity, resource utilization, coverage extension, traffic offloading, energy efficiency (EE), and quality of services [11]. Direct communication between two or more devices without the involvement of the base station (BS) is known as D2D communication. Wi-Fi and Bluetooth are the technologies doing the same job but efficiency is low.

Cellular congestion reduces, by offloading users' traffic with the help of the D2D network. D2D communication requires efficient physical algorithms, user and control plane protocol, and network architecture for cellular network offloading. D2D communication is popular for small-cell networks but network performance and offloading the traffic of the BS can be enhanced by D2D communication for underlying long-term evolution (LTE).

D2D communication was introduced by 3GPP (LTE release 12). LTE D2D communication uses proximity-based services for efficiency, flexibility, dynamicity, and security. One point must be noted that before the D2D communication, Wi-Fi and Bluetooth have supported short-range communication but they use unlicensed spectrum, manual pairing, low-security features, and are independent from the cellular network. Unlicensed spectrum generally doesn't have a problem for low densities but has major limitations on proximity-based services along with security. Additionally, any form of D2D communication based on Wi-Fi and Bluetooth runs parallel with radio operations which may be the cause of significant drain on device batteries. Figure 1 explains, the basic concept of D2D communication along with the role of BS.

D2D communication has some design challenges [11–14] like a choice between LTE uplink and downlink, a choice between OFDMA (orthogonal frequency division multiple access) and SC-FDMA (single carrier frequency division multiple access), a choice between static and dynamic allocation for radio resources, a choice between synchronous or asynchronous D2D discovery, different propagation characteristics, interference, the network

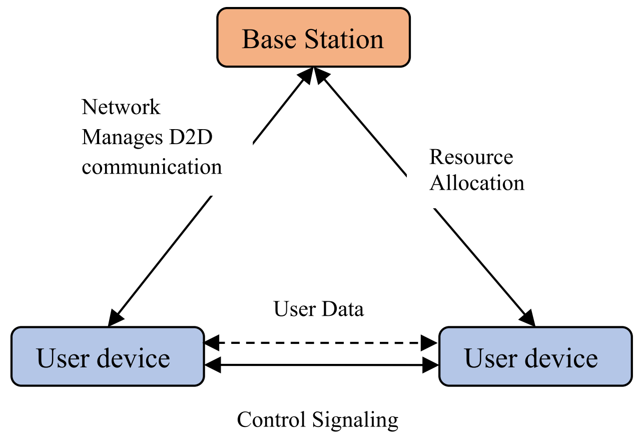

Fig. 1 D2D communication

controlling, reuse of protocols, adding of new features and protocol along with algorithms, frequency discovery, nature and quantity of information, privacy and security, and flexibility options based on a verity of approaches.

5G systems, offer network-controlled D2D communication that has the capability of local traffic offloading. Traffic offloading is defined as, the separation of local traffic with global traffic by the use of short-distance communication link management. It is also helpful in the removal of the load burden of the network and reduction in the effort for managing traffic at central network nodes. D2D communication provides low latency communication which is generated by local communication links between users in proximity. In this way, D2D communication plays a very vital role for 5G. Real-time implementation of D2D in a 5G network faces some challenges, i.e., interference management, network discovery, proximity services, context-aware services, network coding, and security. Future direction and emerging aspects for D2D in 5G are V2V (vehicle to vehicle) communication, mm-Wave technology, social D2D networks, energy harvesting, simultaneous wireless and information power transfer (SWIT), pricing, incentive.

IoT transfers data, over the network, without requiring human-to-human or human-to-computer interaction. With the help of unique identifiers, IoT interrelates computing devices, mechanical devices, and digital devices. Due to the utility of IoT, 5G placed IoT in a vital position in its ecosystem. So, the compatibility of IoT with D2D communication is a challenging task for future 5G.

Spatial diversity, underlying in-band D2D communication can increase spectral efficiency, and this is possible by interference management, mode selection, resource allocate on, and network coding. Wireless communication ought to use the spectrum efficiently. SE may be defined as [15]:

$$\eta = \frac{R/B}{K} \text{ b/s/Hz/Site} \quad (1)$$

Here and now, R is the bit rate, B is Bandwidth and K is the size of a cluster. R/B is the link efficiency. Generally, SE is described as the net data rate in bits per second (bps) divided via way of means of bandwidth in Hz. To higher apprehend, let's have a gadget that has a channel bandwidth of three MHz and raw data rate of 17 Mbps and overhead is 3 Mbps (net data rate = 17 − 3 = 14 Mbps), so the SE will be:

$$\mathrm{SE} = \frac{14 * 10^6}{3 * 10^6} \approx 4.67 \text{ b/s/hz} \quad (2)$$

D2D communication uses higher order modulation technique. Suppose we have an LTE network that uses D2D communication. Here raw data rate is a combination of payload and overhead. Let's, channel BW is 2 MHz, the raw data rate is 15 Mbps, overhead is 2 Mbps. So, the net data rate will be 13 Mbps (15 − 2). Now, (SE) will be 6.5 bits/sec/Hz ($13 \times 10^6/2 \times 10^6$) (Table 1).

Here and now;

$$\text{Symbol Rate} = (\text{No. of subcarriers}) * (\text{Data Rate of individual carrier})$$

For channel BW 20 MHz, each subcarrier is able to carry data at max. rate of 14 Kbps. Note that sub-carrier spacing is 15 kHz. So:

$$\begin{aligned}\text{Symbol rate} &= 1200 * 14 \times 10^3\\ &= 16.8 \times 10^6 \text{ symbol/s}\end{aligned}$$

For 16 QAM; number of bit transmitted is 4 (2^4). So, the raw data rate will be 67.2 Mbps ($1.68 \times 10^6 * 4$). For down link**;** assume 4 × 4 MIMO used, now, the data rate will be 268 Mbps (67 * 4). Here 25% is overhead. So, net data rate will be 201 (268 − 67) Mbps. Similarly, for uplink, there is MIMO not allowed and 25% overhead, so, net data rate will be 51 Mbps (= 67 − 16.75). So, downlink SE for 16QAM = $201 \times 10^6/20 \times 10^6$ = 10 bits/s/Hz and uplink SE for 16QAM = $51 \times 10^6/20 \times 10^6$ = 2.55 bits/s/Hz. Similarly, downlink SE for 64QAM = $300 \times 10^6/20 \times 10^6$ = 15 bits/s/Hz and Uplink SE for 64QAM = $75 \times 10^6/20 \times 10^6$ = 3.7 bits/s/Hz again downlink SE for 256QAM = $403.2 \times 10^6/20 \times 10^6$ = 20 bits/s/Hz and uplink SE for 256QAM = $101 \times 10^6/20 \times 10^6$ = 5 bits/s/Hz similarly downlink SE for 1024QAM = $504 \times 10^6/20 \times 10^6$ = 25.2 bits/s/Hz and uplink SE for 1024QAM = $126 \times 10^6/ 20 \times 10^6$ = 6.3 bits/s/Hz (Fig. 2).

Here, we can understand that the SE depends on the order of the modulation, data rate, bandwidth, MIMO, number of subcarriers, size of overhead, subcarrier spacing, the data rate of the individual carrier, UL/DL, size of the cluster, and link efficiency.

The literature [16–20] suggested interference management algorithms. Additionally, article [6] uses resource blocks that are used by a cellular user in the proximity (system throughput increased by 41%), In [16], there is a dedicated control channel for D2D users (increase the average system throughput up to 374%), article [17] avoids the allocation of the same frequency-time slot to the cellular which is used by D2D user at that time (30% higher capacity gain), manuscript [18] defines an interference-limited area in which no cellular users can occupy the same resources as the D2D pair (gain of 129%), article [19] formed interference-limited areas according to the amount of tolerable interference and minimum SINR requirements for successful transmission, and the reference [20] uses Han-Kobayashi rate splitting techniques [22] (increase the throughput up to 650% higher).

The first order protocol with the necessary functionality and signaling can achieve throughput up to 65% [23]. Estimation of the achievable transmission rate in each mode through utilizing the channel measurements can get a 50% gain [24]. A joint D2D communication and network coding scheme [25], uses an interference-aware algorithm [18] and gets the 30% increment in the number of D2D users. Power control of BS and cellular devices can improve the area of the capacity region of the D2D link and BS-device link by 60% [26].

For overlaying in-band D2D communication, a base station (BS) assisted scheduling and D2D power control used in [27], and authors of [28, 29] focus on relaying to overcome the effect of interference. Article [29] consumes 90% fewer spectrum resources in comparison to the scenario with only one transmitter.

Out-band D2D communication has no interference dispute between D2D and cellular communications. Outbound

Table 1 LTE occupied bandwidth and number of subcarriers for specified channel bandwidth

Channel BW (MHz)	1.4	3	5	10	15	20
Occupied BW (MHz)	1.08	2.7	4.5	9	13.5	18
No. of subcarriers	72	180	300	600	900	1200

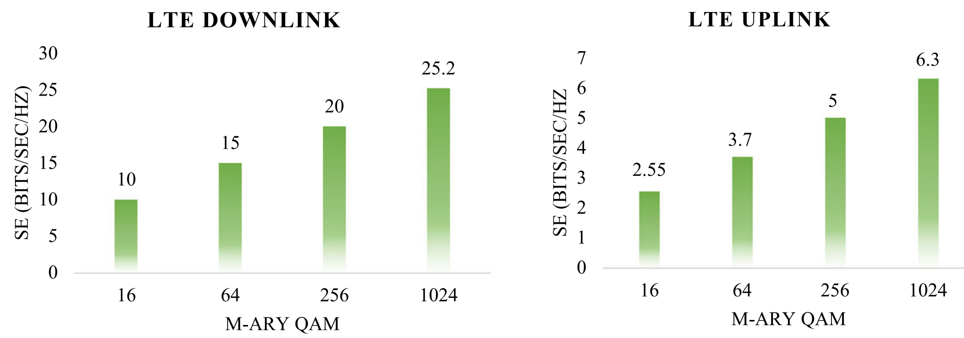

Fig. 2 Spectral efficiency of M-ARY QAM for LTE downlink and uplink

controlled D2D communication uses the cellar network advance management features. The authors of [30] propose the ISM band for communication in LTE as the groups of D2D users who do not sense the same channel at that time and get a 25% increment in the throughput. By creating clusters among cellular users with the help of Wi-Fi, D2D communication can increase the throughput by up to 30% [7, 8, 31].

This manuscript will investigate the path to improve SE by various concepts, models, algorithms, and scenarios. Here we will provide a review for SE improvement for D2D communication based on clustering in the cellular network, frequency reusing, spectrum sharing, resource block allocation, and implementation of the new generation waveform.

Interference Control, Management, and Reduction Methods or Algorithms

An interference is that which modifies a signal in a disruptive manner because it communicates alongside a conversation channel among its supply and receiver. The period is regularly used to consult the addition of undesirable alerts to a beneficial signal.

There are four types of interference in wireless communication systems [32] (Fig. 3):

The internal interference can be reduced with the help of multichannel [33] and scheduling of communication channel with the help of TDMA (Time-division multiplexing) [34] while external interference may be reduced by channel hopping [35], temporary diversity [36], error control mechanisms [37], and network coding [38]. Channel hopping, temporary diversity, error control mechanisms, and network coding also overcome the effect of self-interference additionally, the antenna diversity technique contributes to the same [39]. Interference due to signal attenuation can be controlled by power control [40], multipath routing, error control mechanism, and network coding.

Interference is at once associated with the bandwidth and data rate of the system. As in line with Eqs. (1) and (2), we can see that SE is likewise associated with the bandwidth and data rate. Of course, we can grow the SE with the aid of using enhancing the data rate in addition to lowering the bandwidth, however in each case, there may be an increment withinside the interference which reduces the effectiveness of the system. So, interference management and control together play a completely crucial position in D2D communication. Interference withinside the cellular network may be decreased with the assistance of power control, powerful frequency mission, the use of sensible techniques, and intermodulation.

Research paper [41] evaluates the SE strategies in D2D communication for 5G, right here this article provides the demanding situations withinside the control of interference. The authors of [42] investigated and analyzed the essential idea at the back of the D2D communication gadget to increase an efficient D2D resource allocation scheme with decreased interference. The work in [43] suggests the power control strategies which facilitate to lessen the impact of interference wherein interference management algorithm maximizes the overall performance of D2D communication in LTE-A networks for uplink and downlink transmissions. Moreover, the most appropriate routing selection strategies reduces the entire route distance which facilitates to limit the interference and enhance the general network capacity. The manuscript [44] represents a survey of the interference management for D2D applications for 5G. The article [45] affords the special famous and AI-based interference mitigation and RA strategies advanced in D2D communications which might be contemplated withinside the article [46]. Research article [46] surveyed the artificial intelligence (AI) conventional RRM (Radio

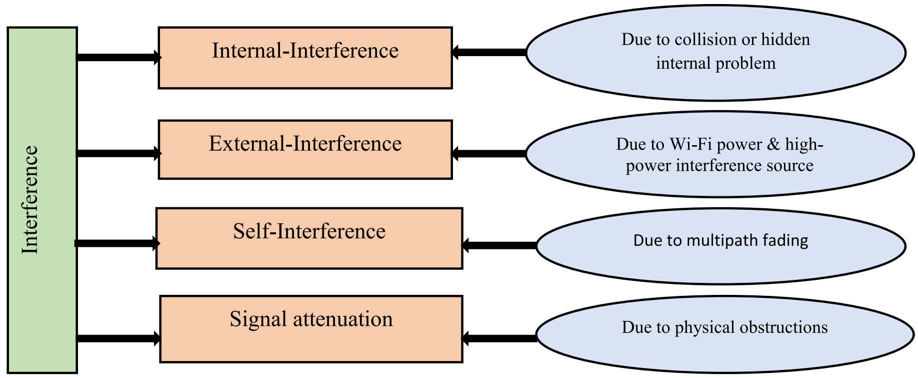

Fig. 3 Type of interference and their causes

Resource Management) and interference mitigation techniques where the authors discussed the mitigation of interference through mode selection, power control, and RRM together with traditional strategies. The MAAC (Multi-Agent Actor-Critic) is an algorithm that is proposed by the researchers of [47], that is used to keep away from interference (Table 2).

Clustering in Cellular Network

Short reuse distances and low transmitting powers by the D2D network, lead to weighty acquisitive interference in the network. Such a densely deployed D2D network requires BS with large capacity, but it also introduces large delays in communication. This problem can be solved by dividing the network into several clusters, where each cluster has its BS for D2D communication. D2D multicast in the cluster, then the user transmits the same file separately to every receiver, which saves time and network resources. Multicast can be used for cellular communication which provides continuity for data sharing in the cellular network [57]. Figure 4 shows the basic clustering of D2D communicating devices in the cellular network, where D2D enabled devices to make small clusters and they are connected to BS.

A set of UEs which communicate with each other for a common objective may be defined as a cluster. Any UE can be added/removed from the cluster at any time by opening/ending a channel configuration. Every cluster must have a

Table 2 Summary of interference control management and reduction methods and algorithm for D2D communication

References	Used network	Algorithms/methods	Achieved performance
[48]	Underlaying LTE-A	Optimize frequency reuse (OFSR)	Interference is close to optimal interference
[49]	5G HeNet	Resource allocation method based on interference control	Improves the overall system throughput
[50]	D2D network	Topological interference management (TIM)	Lessening in signal interference
[51]	D2D	Estimation of distribution algorithm	Near-optimal solution convergence is achieved by the algorithm with the minimal number of iterations
[43]	D2D in LTE-A	Power control technique	Improvement by 4 dB in SINR
[45]	Mm wave D2D	Machine learning (ML) algorithm	Average throughput increases
[52]	D2D	Interference mitigations scheme	Improvement in the data rate
[53]	Mm wave D2D	Vertex coloring based resource allocation algorithm and redefine concurrent transmission conditions by defining a power decision threshold	The throughput per slot of the proposed algorithm is significantly improved by around 12.5%
[54]	D2D in LTE-A	D2D resource allocation and power control (DRAPC) framework	Increment in the signal quality, degree of resource sharing, and network performance also guarantees fairness among links
[55]	D2D underlay 5G cellular network	Interference and power management D2D resource allocation algorithm	Minimization in the interference and power consumption
[56]	Hybrid network system of cellular users and D2D users	A D2D power control algorithm with price control based on no-cooperative game theory	Effectively control the transmission power of D2D users and effectively improve the total rate of the D2D network

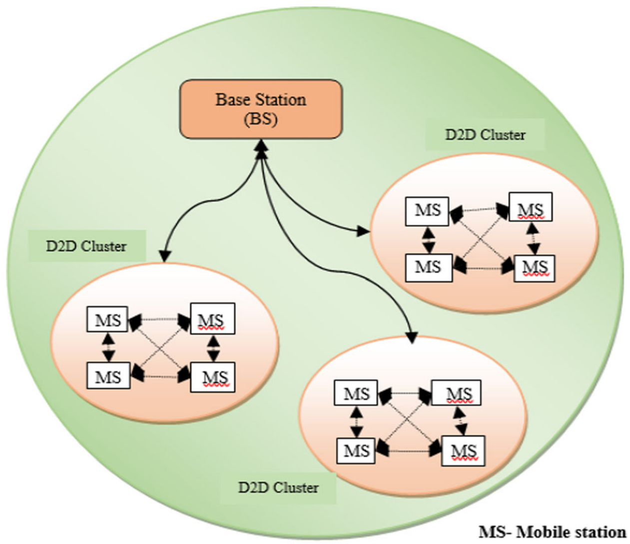

Fig. 4 Basic D2D clustering

master node and at least two worker nodes, and all these nodes perform operations by a shared network. Clusters do not reuse the frequency. While frequency used in one cell can be reused by another cell within the same cluster. So, clusters can overcome the effect of co-channel interference and adjacent channel interference. The size of clusters depends upon the traffic load of the network. But one point must be remembered that the small cluster size generates co-channel interference.

D2D communication performs clustering operations by assigning devices to direct communication mode by utilizing cellular network resources. Direct communication mode removes/ reduces core network involvement while enhancing BS resource utilization. Few services, i.e., mobile multiplayer gaming, file sharing, mobile advertising, streaming, and cooperative downloading could be benefited by clustering operation. D2D cluster mode decides to use radio resources, modulation and coding scheme, transmit/receive slot allocation, and link adaptation [58]. The further cluster head is assigned to each device group. These cluster heads are responsible for the allocated resources division between cluster members. The network controls the cluster member by the control link to the cluster head.

Clustering operation increases resource availability (one severs fails another server in the cluster can pick up the workload), strategic resource usage (allow to use resources flexibility), increased performance (multiple machines provide greater processing power), greater scalability (as complexity increases, resources can grow), and simplified management (clustering simplifies the management of large or rapidly growing system).

Many researchers provide their efforts to improve the D2D communication performance, i.e., increment the pair of D2D, SE, Energy efficiency (EE), sum-rate, throughput, minimization in delay, and complexity. They use uplink and downlink or uplink/downlink transmission for underlay and overlay D2D communication. A few of them are summarized in Table 3.

Frequency Reusing and Spectrum Sharing

A cellular area can reuse the same radio frequency if they are separated by a considerable distance. This is a frequency reusing concept. For cellular communication, band frequencies are allocated to each cell covered by BS, while an adjacent cell uses a different band of frequencies to avoid interference. This concept can improve the SE but co-channel interference is a major concern. Upcoming technology of communication works for short distances and indoor [73] so the concept of frequency reuse is very useful. Figure 5 shows the basic concept of frequency reusing in cellular communication where there are three clusters and seven cells considered for the shake of the moment. Frequency is named as 1, 2, 3, 4, 5, 6, and 7 allotted for each cell in the cluster. Each cluster cell reuses the same frequency.

An important concern for D2D communication while using the frequency reuse concept is the interference between the cellular user (CU) and D2D user (DU). Four scenarios can elaborate on the interference problem in the frequency reuse concept. The first scenario is, BS receiver will receive interference from the DU for up-link transmission. The second scenario is, DU receiver will receive an interference signal from the CU transmitter for uplink transmission. The third scenario is, the CU receiver receives interference from the DU transmitter for downlink transmission, and finally, the fourth scenario is DU receiver will receive interference from the BS transmitter [12]. In this way, frequency reusing can achieve a large coverage area, efficient spectrum utilization, and enhance system capacity. Figure 6 shows the condition of one cell in a cluster when using the frequency reuse concept.

The sharing of resources allows frequency reuse between two networks, i.e., D2D and cellular. This technique can increase SE but interference will degrade the performance. Researchers give efforts to improve the SE, gain, SINR, capacity by using the frequency reuse concept for D2D communication. They work for uplink transmission and downlink transmission for the overlay and underlay D2D communication (Table 4).

The same band of spectrum is utilized by different applications/technologies, in spectrum sharing. Spectrum sharing technique is classified as interweaving, underlay,

Table 3 Summary of clustering scheme and algorithm for D2D communication

References	Used network	Algorithms/methods	Achieved performance
UP link transmission			
[59]	D2D	Decision algorithm, Spectrum reuse concept, User power control	SE and EE improvement
[60]	Underlay D2D	Similarity-based dynamic clustering, Resource allocation algorithm	Improve network performance and reduces complexity
[61]	Out-band D2D	RBC, CGBC	Minimize delay up to 6%, 40% and 49% on various conditions
[62]	Underlay D2D for NOMA	Iterative algorithm applying KKT conditions	Throughput and fairness in NOMA is better than OMA
[63]	Underlay D2D, cellular assisted	Joint D2D cluster formation, sub-optional algorithm	Throughput 25.3%
[64]	Underlay D2D	Clustering algorithm based on hypergraph, Bisection algorithm	The proposed algorithm has a better superior sum rate comped to the conventional graph algorithm
[65]	Underlay D2D	Kuhn-Munkers algorithm	Improves quality and transmission rate
Downlink transmission			
[66]	Out-band D2D, LTE-A WLAN	Merge and split algorithm	Throughput gain increases from 13 to 76% when clustering size increases from 2 to 5
[67]	Underlay D2D	Resource allocation mechanism	Throughput and SE improvement
[68]	Underlay D2D	Socially cluster formation, Radio resource allocation	Increase the SE and EE
Uplink/downlink transmission			
[57]	LTE/ LTE-A D2D	Multicast concept	Throughput increases between closely related devices
[69]	LTE-A FDD	CORE, eCORE, CaLB	Spectral efficiency improved 36.6%, 47.2% and 59.5%, respectively for given algorithm
[70]	Underlay D2D	Mode selection scheme, Clustering selection scheme, CH selection scheme	Improves SE and optimization
[71]	Underlay D2D	Fuzzy C-means clustering based grouping algorithm, DBS grouping algorithm	Overall rate increases proportional to the number of clusters, 33% increment in the overall rate by interference alignment
[72]	Underlay D2D	Optimum channel assignment algorithm, Queuing based algorithm, Greedy clustering algorithm	Increase sum rate in the dense D2D network

and overlay [74]. Secondary system access the spectrum holes dynamically for interweaving spectrum sharing while secondary user concurrently transmitting to the primary user for underlay spectrum sharing (where interference due to secondary user to primary user must be below the threshold level), and finally, secondary user access the spectrum in frequency, spatial and time domain for the overlay spectrum sharing (overlay spectrum sharing is the sharing of a band which is already licensed to an operator with others). Some researchers also suggest dynamic spectrum sharing [75] and cooperative spectrum sharing [76]. Dynamic spectrum sharing access the spectrum dynamically based on wireless technologies, markets, and regularity policies while in cooperative spectrum sharing secondary users relay the traffic to the primary users by exchanging devoted spectrum access time for secondary own communication.

In-band and Out-band D2D communication is based on the type of spectrum sharing, i.e. cellular and D2D transmitters use orthogonal frequency or time resources for overlay and D2D transmitters use the time or frequency resources engaged by CU for underlay [86].

5G communication adopts three approaches to improve the system: (1) Renew the network architecture, (2) explore more spectrum resources and (3) adoption of new communication techniques [87]. Although new spectrum resources are allotted to 5G, due to emerging mobile traffic, upcoming communication system still has an issue with the available spectrum. So proper resource management is very important. Spectrum sharing is one of the best ways for

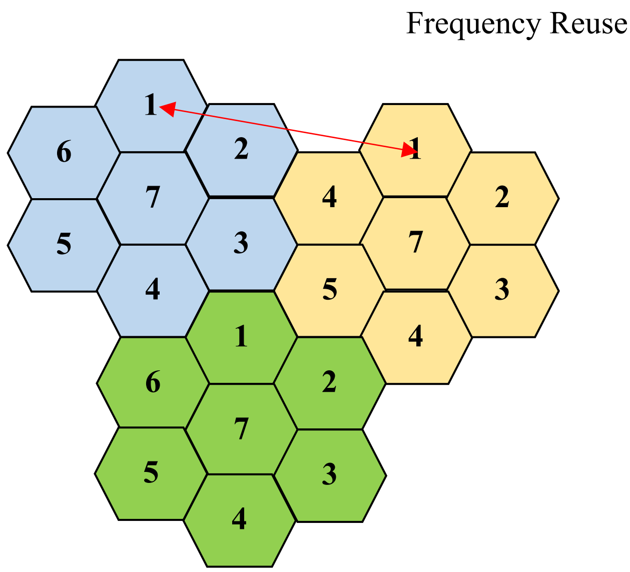

Fig. 5 Frequency reusing

resource management. Spectrum sharing allows the existing communication system to use idle or underutilized spectrum bands temporally and geographically.

The cognitive radio approach also uses spectrum sharing. The cognitive radio concept has two stages, i.e., spectrum sensing and cognitive transmission. The first stage is the cognitive user sense the radio environment and the second stage is the cognitive transmission which collects the spectrum information. Then the cognitive user selects the best spectrum bands and adapts transmission according to the collected spectrum information.

In this way, spectrum sharing increases efficiency, reduces waste, offers more useful dividends to the government, generates recurring revenue, and ensures that the spectrum is more accessible to more people (Fig. 7).

Figure 5 shows that BS is connected with UE by cellular link and two UEs connected with D2D link. Here both links can use the same spectrum depending upon the availability.

Table 5 summarizes the work of authors and researchers for the improvement in the performance of D2D communication. They use uplink, downlink, and uplink/downlink transmission for underlay, overlay D2D network.

Resource Block Allocation

Heavy traffic of users in the communication system, generates interference problems. This interference problem can be faded by using the resource block (RB) allocation concept. RB is the smallest unit of resources that can be allocated to a user. Here RB is 180 kHz wide in frequency and 1 slot long in time. LTE performs on various bandwidths (BW), i.e., 1.4 MHz, 3 MHz, 5 MHz, 10 MHz, 15 MHz, 20 MHz which contains 6, 15, 25, 50, 75, and 100 RBs, respectively. LTE works for frequency division duplex (FDD) and time division duplex (TDD) [105]. This manuscript presents the LTE FDD frame for 1.4 MHz BW, to understand the concept of RB allocation. Figure 8 shows the position of an RB in a given frame and the number of subcarriers in the RB. Remember that the subcarriers are used to carry information from transmitter to receiver.

There is two way to allocate the resources, i.e. autonomous D2D and BS/eNB controlled D2D [123]. The first approach is a sensing technique to obtain resources for the D2D pair. Here BS/eNB, broadcasts the resource allocation in the cellular network and collects the information. Based on this information resources are allocated to the D2D pair. This is difficult to implement due to frequent changes in resource allocation at the BS/eNB. The second approach is, BS/eNB allocates RB to each D2D pair or cluster and schedules the transmission. The disadvantage is the burden on BS/eNB and the requirement of signaling overhead. In this way, resource allocation improves throughput, sum rate, spectrum utilization, source capacity, number of admissible D2D pairs, energy conservation, time and

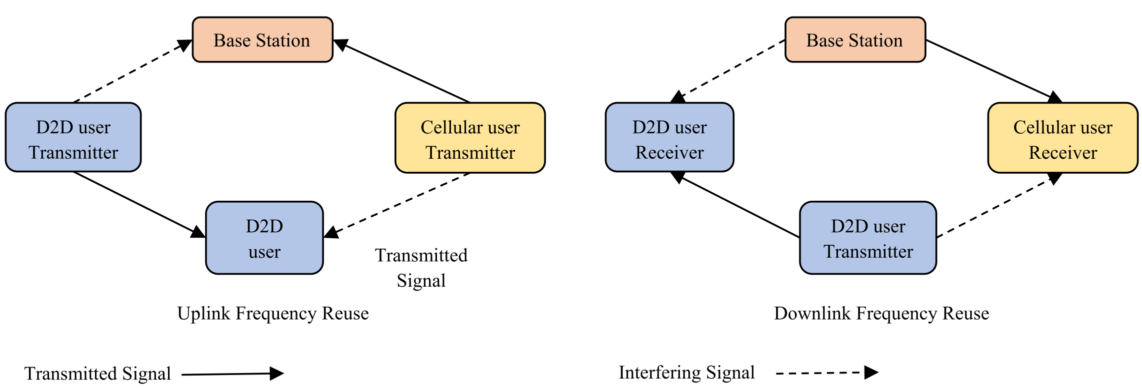

Fig. 6 Frequency reuse for D2D communication in uplink and downlink

Table 4 Summary of frequency reuse techniques for D2D

References	Used network	Algorithms/methods	Achieved performance
UP link transmission			
[77]	Underlay D2D	Multi-cell interference coordination; low power transmission	SE increased 10 times
[78]	D2D	Adaptive soft frequency reuse scheme	Decease interference level, improve average throughput per user
[79]	3GPP LTE D2D	Partially distributed frequency allocation algorithm and distributed and centralized power allocation scheme	SIR level increases almost 40 dB compared to the 10 dB by Samsung algorithm
[80]	Overlay D2D	Resource allocation for microcell and D2D network	Gain in throughput
[81]	LTE-A D2D	Distance base resource allocation, power control scheme using fractional frequency reuse (FFR)	Benefit in SINR around 3.5 dB and improved SE for the outer-cell users as compared to the existing scheme
[82]	Underlay D2D	FFR	Mitigate interference between DUEs (D2D user equipment) and CUEs (cellular user equipment)
Downlink transmission			
[26]	Underlay D2D	Resource block allocation scheme	Throughput increases 1.5–2 times of the previous work
[83]	Femtocell D2D	Cross polarized complimentary frequency allocation (CPCFA)	System capacity increases
[84]	Underlay D2D	FFR	SE increases by increasing the ratio of power
[85]	Underlay D2D	FFR, SFR (soft frequency reuse)	Satisfying QoS requirement along with less interference

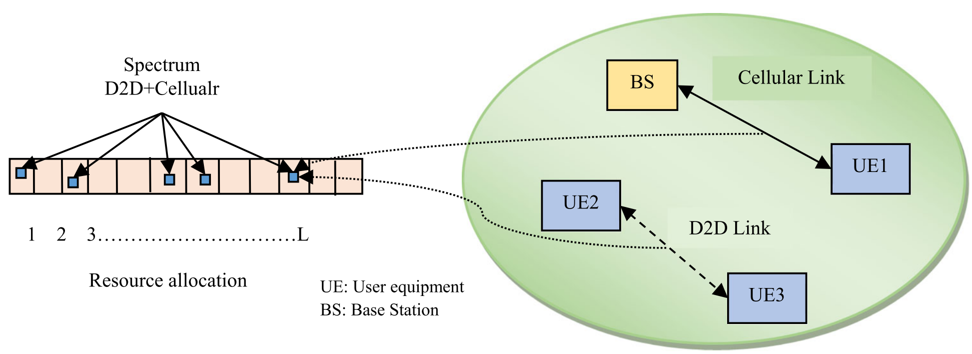

Fig. 7 Spectrum sharing of cellular link and D2D communication

energy-saving, fairness, outage ratio, SE, EE, data rate, and reduces delay.

Many researchers work for improvement in throughput, spectrum utilization, number of admissible D2D pairs, SE, EE, data rate, sum rate, and reduction in delay by using the resource allocation concept (Table 6).

New Generation Waveform

The improvement in the SE of D2D is very important to incorporate with 5G. New efforts are given by researchers to improve the SE by introducing a new generation waveform for D2D communication, i.e. orthogonal frequency division multiplexing (OFDM) [124], Filtered orthogonal frequency division multiplexing (F-OFDM) [125], CP-OFDM (cyclic prefix OFDM) [126], Filter bank multicarrier (FBMC) [127], Universal carrier multicarrier (UFMC) [128], GFDM (generalized frequency division multiplexing) [129].

OFDM is a popular signaling method in broadband wired/wireless channels. IEEE802.11, IEEE802.16, 3GPP-LTE, and LTE-A (long-term evaluation-advanced) adopt OFDM because of its high efficiency and low complexity. But it requires synchronization with users for uplink, which is very difficult to establish. Another limitation is carrier

Table 5 Summary of spectrum sharing scheme and algorithm for D2D

References	Used network	Algorithms/methods	Achieved performance
UP link transmission			
[88]	Underlay D2D	FSA (Full set allocation) and SSA (subset allocation) scheme	SSA distributed between 5.9 and 49.3 dB, obtain 2.12 dB lower SINR of DU on average than FSA
[86]	Overlay and underlay D2D	Spectrum sharing and model selection using a hybrid network model and unified analytical approach	Reduction in optimal spectrum access factor for underlay, optimal spectrum partition in the overlay is almost invariant
[89]	Underlay D2D	(IPPO) Inverse popularity paring order algorithm and Hungaria (Kuhn-Munkers) algorithm	Exhibits low complexity improves sum rate for CUs and DUs with modest performance loss
[90]	Underlay D2D	Secrecy based access control, merge and split based coalition formation algorithm (Max-coalition process)	Secrecy rate performance evolved DUs pair, power control, secrecy capacity, and access control increases
[91]	D2D, V2V, V2I	Spectrum and power allocation algorithm, optimal resource algorithm	Improve erotic capacity of all V2I (Vehicle to infrastructure) connections and ensure reliability guarantee for each V2V (Vehicle to Vehicle)
Downlink transmission			
[92]	LTE D2D	LTE-CR-D2D (LTE cognitive radio D2D algorithm)	Enable more D2D links with compromise of the SINR as high as 10 dB
[93]	Underlay D2D	QARA (QoS aware heuristic resource allocation algorithm and RICA (Resource allocation using a reverse combinational auction mechanism	QARA maintain the outage probability of CUs and DUs pairs less than 10% for the high probability of outage, maximize network throughput while guaranteeing the QoS requirement for CUs and DUs pairs
[94]	D2D	BOCF (Bayesian non-transferable utility overlapping coalition formation) game, the hierarchical matching algorithm	Performance improves for large coverage areas and a large number of the D2D link
[95]	D2D and cellular	Hierarchical stable matching market, distributed algorithm, game theory approach	Improvement in a spectrum sharing capacity
[96]	Overlay D2D	Process POMDP (partially observable Markov decision process) mode optimal power allocation and optimal sensing time algorithm	Achieves 15.2% increment in SE for overlay D2D (Single-band multicarrier), and 5–15% compared to the greedy algorithm (multi sub-band)
Uplink/downlink transmission			
[97]	D2D	A greedy algorithm for source user association and information-theoretic optimality principle	SE increases 488% and 265% for a small library and large library in comparison to the cluster-based approach
[98]	D2D	Hybrid complex network coding	CU approaches the full-duplex upper bound and DU throughput approaches 1 sym/TS at high SINR (signal to interference noise ratio
[99]	Underlay and overlay D2D	Space code multiple access (SCMA)	Improve ASE (Area spectral efficiency)
[100]	D2D	Reuse graph resource allocation, graph coding	Significantly improvement in the performance
[101]	Underlay D2D	Joint guard zone and threshold-based access control scheme	Reduces D2D interference to improve secrecy performance
[102]	Underlay D2D	Transmit power planning with green trajectory, trajectory planning with given transmit power, and joint transmit power and trajectory planning	DUs pair produces interference to the UAV with limiting the power of the UAV along with improved sum throughput under transmit power budget while guaranteeing the co-existence with terrestrial DUs pairs satisfying the information causality and VAVs trajectory constrains
[103]	Underlay D2D	The contract-based co-operative spectrum sharing mechanism	Minimize the data rate of the D2D link
[104]	D2D communication underlaid cellular network	SCMA	ASE can be significantly improved using SCMA 38% over OFDMA under a typical system setting

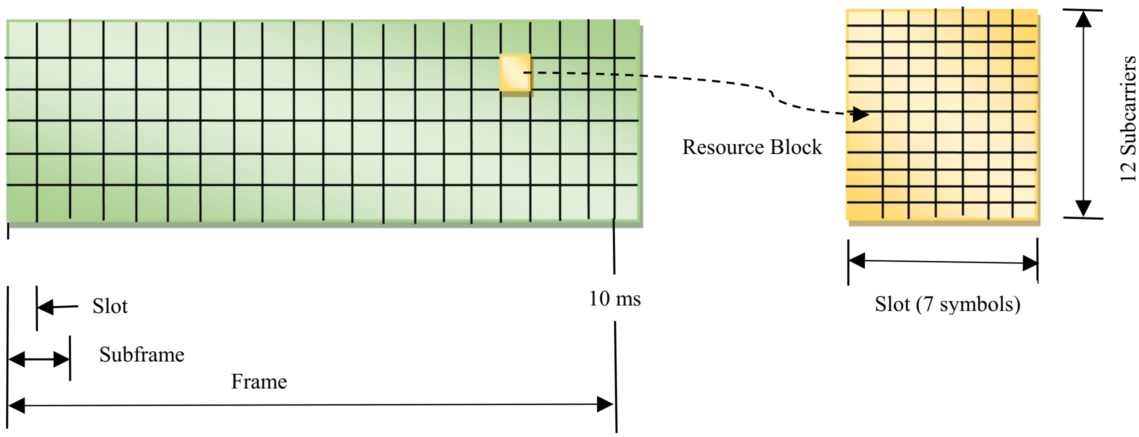

Fig. 8 LTE FDD frame for 1.4 MHz, normal CP

aggregation [130]. For the OFDM, the transmitter modulated input data by QAPSK (Quadrature amplitude shift key) or M-ary QAM (Quadrature amplitude modulation). Modulated waveform now transmitted after performing N-point IFFT (inverse Fast Fourier transform). Now add CP (cyclic prefix) to generate the OFDM signal. Vice versa operations are required for the reception of OFDM (Fig. 9). F-OFDM is the same as OFDM except for the filtering operation and CP removal (Fig. 10).

FBMC modulation uses a set of synthesis and analysis filters on transmitter and receiver. This is also defined as Offset quadrature amplitude modulation (OQAM) [131]. It's derived from a prototype filter that can determine stopband attenuation, inter symbol interference (ISI), and inter-channel interference (ICI). FBMC generation and reception are shown in Fig. 11 [127, 132]. The transmitter applies O-QAM, earlier to the serial to parallel (S/P) conversion. Next is frequency spreading before the extended IFFT (E-FFT). At last, the parallel to serial (P/S) conversion. Exact vice-versa operations are performed on the receiver.

FBMC as an alternative to OFDM. It reduces ingress and egress noises that are generated by carrier aggregation (using high-quality filters). It is also able to reduce the synchronization problem [133]. Three types of FBMC systems are defined: (1) CMT, i.e. cosine modulated multitone (based on change concept) [134]; (2) SMT, i.e. staggered multi-tone (introduced by Saltzberg) [135]; (3) adopted method of frequency division multiplexing [136].

UFMC is the generalization of the F-OFDM and FBMC. F-OFDM filters the entire band while FBMC filters individual subcarriers. UFMC filters group of subcarriers which reduces the filter length of UFMC. At this juncture, QAM with existing MIMO retains complex orthogonality. Here 'N' subcarriers are divided into the various sub-band where each sub-band has a fixed number of subcarriers. Subcarrier interference can be avoided by IFFT. The signals that came from the IIFT operation, go to the band of filter length 'L', where each band is output fileted by a band of the filter of length 'L'. Generally, the Chebyshev window is used for filtering operations. The output of the band filters is added and sent to the receiver by the channel. At this point, an FFT operation is performed which converts data of the time domain to the frequency domain. One point must be noted that the guard intervals of zeros are added to IFFT successive symbols, which will reduce the effect of ISI. This ISI will generate due to transmitter filter delay. Now data is allotted to equalizers before parallel to serial conversion (Fig. 12).

Table 7 summarizes the efforts of researchers in D2D communication to improve the system throughput, SE, system capacity by using OFDM, F-OFDM, FBMC, and UFMC. In this way, the new generation waveform in D2D communication improves data rate, removes inter UE time synchronization overhead, capability improvement, reduces inter D2D interference, and spectral leakage. They use overlay, underlay D2D communication for uplink, downlink, and uplink/downlink transmission. Additionally, manuscript [137] presents a comparative analysis of UFMC and FBMC based on offset QAM with 4G system CP-OFDM.

Miscellaneous

Many researchers give their efforts to improve SE for D2D communication in various ways i.e., concept, technology, algorithms, network architecture, etc. Here, this article is going to present the summary of the efforts by researchers, where they able to find out improved Quality of Services (QoS), SE, EE, reliability, data rate, and coverage area, while the reduction in computational cost, power, size of overhead, network traffic, and latency (Table 8).

Table 6 RBs allocation scheme and algorithm for D2D

References	Used network	Algorithms/methods	Achieved performance
UP link transmission			
[106]	C-RAN D2D	Distributed mode selection	Throughput reaches up to 93%
[107]	Cognitive D2D	The generic algorithm, sub-channel sharing protocol	Improvement in sum rate and spectrum utilization
[108]	Underlay D2D, HetNets	A heuristic iterative algorithm based on the proximity theory	Improve source capacity with fast convergence speed
[109]	Underlay D2D	Interference filling algorithm, power control scheme	Improvement in the admissible number of D2D pair and system throughput
[110]	Underlay D2D	D2D user grouping and CU selection algorithm, D2D power control algorithm	Attain a significant throughput for D2D link with a slight degradation in the throughput of the cellular link
[111]	Underlay D2D	AC (admission control) scheme based on static graph formulation, AC scheme based on dynamic graph formulation, Joint AC and CA (Channel Assignment) scheme in multi-channel scenario	Improvement in the number of admitted D2D links energy conservation, system throughput, EE, and Data rate
[112]	D2D underlaying cellular network	Dynamic cross-layer leave and join based on coalition formation game with non-transferable utility (NTU)	Increasing the number of CUs and D2D pair within the cell, improvement in throughput and system capacity
[113]	LTE-A	Iterative heuristic RB scheduling algorithm, the Uplink Scheduling algorithm	SE improves
Downlink transmission			
[114]	Underlaid D2D	Sum rate priority iterative auction	Improvement in overall sum rate
[115]	MIMO D2D	Subset based on precoding selection method	System capacity improves
[116]	Underlaid OFDMA based cellular system	Suboptimal joint power algorithm, the subcarrier allocation algorithm	Coherence BW of the OFDM system affects the SE and variance of the transmit power subcarrier
Uplink/downlink transmission			
[117]	V2V, D2D	Minimizing the increment of the spectral radius (MISR) resource block sharing algorithm	SE improved 150% and 96% in rush hour
[118]	LTE-A, Wi-Fi direct	MS-CD2D (multicast scheme with cellular D2D), MS-WD2D (multicast scheme with Wi-Fi D2D)	Time and energy-saving, energy consumption, and delivery time reduces
[119]	LTE-A	Pseudocode for the best-fit Heuristic	Higher throughput, reduction in delay
[120]	Underlay D2D	Resource allocation scheme with the embedded online learning algorithm	Throughput, SE, fairness, and outage ratio increases
[121]	Underlay multi-hop D2D	SPR (Shortest path routing algorithm)	EE, and throughput increases
[122]	Underlay D2D	Share resource as donation game using a model of social comparison	The emergence of a coalition is sensitive to network conditions such as node density and noise

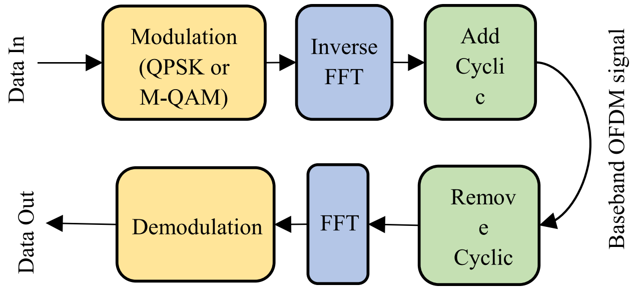

Fig. 9 Generation and detection of OFDM signals

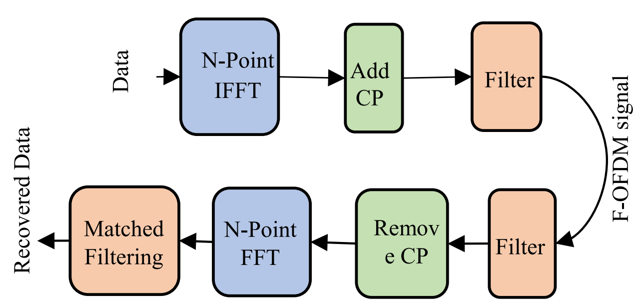

Fig. 10 Generation and detection of F-OFDM signals

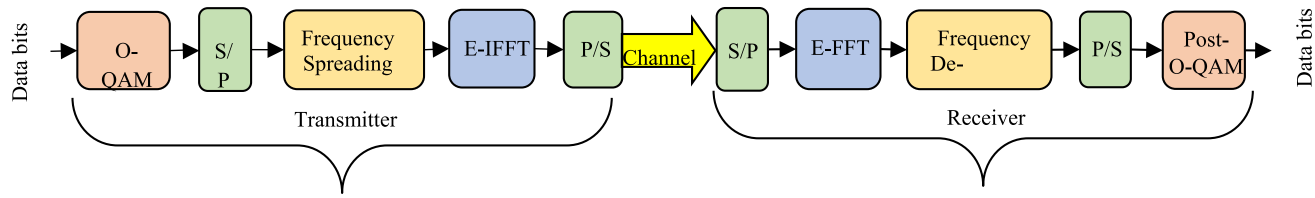

Fig.11 FBMC generation and detection

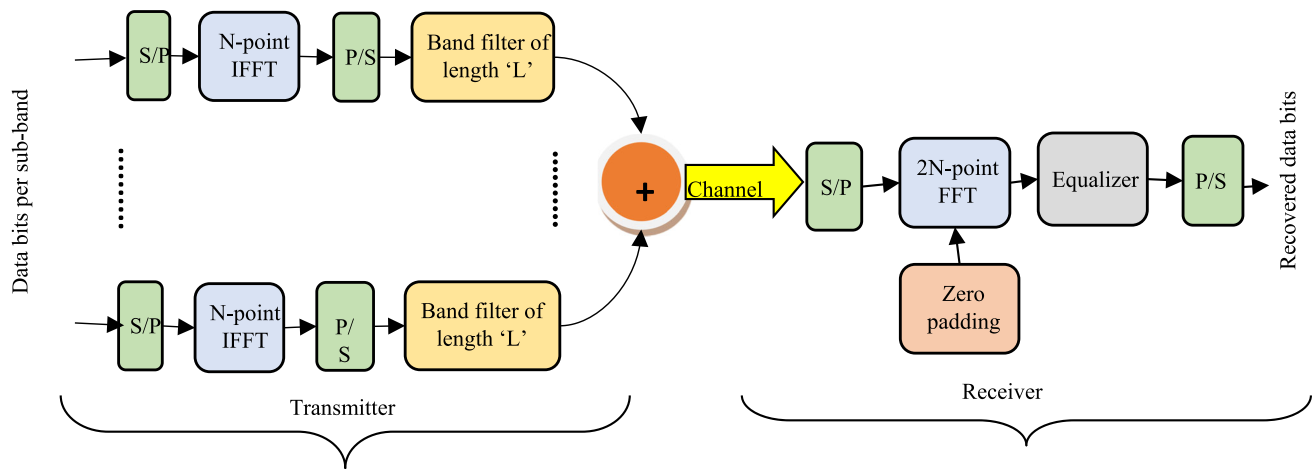

Fig. 12 UFMC waveform generation and detection

Table 7 Summary of the implementation of new generation waveform on D2D

References	Used network	New generation waveform	Achieved performance
[138]	Uplink underlay D2D	FBMC with offset QAM	The achieved rate improved by 43%
[125]	Uplink 3GPP LTE	F-OFDM	Removes inter UE time synchronization overhead, capability improvement, a different part of the waveform can be optimized
[139]	Downlink 5G network	F-OFDM	Improvement in performance for high modulation order
[140]	Uplink underlay D2D	FBMC/OQAM	Reduction in inter D2D interference
[141]	Overlay D2D	OFDM and FBMC	Improvement in data rate by reduction of the interference effect
[142]	Uplink underlay D2D	OFDM and FBMC	Data rate improvement
[143]	Overlay D2D	FFT-FBMC	The interference level in the first adjacent subcarrier is reduced by 10 dB
[144]	Uplink overlay D2D	FBMC-OQAM, CP-OFDM	FBMC-OQAM is more efficient than CP-OFDM
[145]	D2D	UFMC	Reduction in spectral leakage, 40% saving in power
[146]	Uplink D2D communication for cognitive radio scenario	UFMC	Performance improvement
[147]	D2D	UFMC	Better SIR (signal to interference ratio) to improve the robustness against carrier frequency offset
[148]	5G D2D	UFMC with Kalman filter	BER performance improvement for RLS estimator for lower Doppler rate
[149]		FBMC	The higher rate in FBMC than OFDM

Table 8 Summary of implementation of miscellaneous algorithms and techniques

References	Used network	Algorithm/methods	Achieved performance
[150]	D2D in 5G (V2V)	A tool to directly communicate with the UEs without relaying eNB	Improvement in the different metrics for IEEE802.11p standard and LTE-A technology, improve vehicular safety, and QoS performance
[151]	Large scale underlaid cellular network	A link in a cellular network strikes balance between secrecy energy efficiency (SEE) and secrecy spectral efficiency (SSE) by maximizing the weighted product of SEE and SSE	Achieve all the points on the Pareto boundary in SSE-SEE
[152]	Relay assisted D2D in underlay cellular network	Allow a relay user to assist D2D	Higher D2D SE without affecting cellular SE
[153]	D2D undelaying LTE-A	Distributive cooperative D2D transmission scheme, cooperation between CU and D2D pair as well as cooperation among D2D pair	Improved SE and EE
[154]	Undelaying cellular network, D2D network	One-sided auction model is formulated from a unique perspective, enhanced Martello and Toth algorithm	Low computational cost
[155]	LTE-A D2D	Opportunistic discovery scheme	Reduction in power consumption and signal overhead
[156]	D2D	Load balancing by offloading the traffic to microcell BS to an uncongested femtocell BS	Increase QoS and reduction in network traffic
[157]	Multilink D2D in the cellular network	Hybrid space–time block coding, spectral multiplexing (Hybrid STBC-SM)	Improve reliability and data rate
[158]	D2D and D4D	Social trust and social reciprocity-based framework to promote efficient co-operation among devices for co-operative D2D and D4D (a device for device) based fog networking	Higher user throughput, SE, network coverage
[159]	D2D underlying cellular network with uplink	Distributed energy-efficient resource allocation exploiting the properties of the nonlinear fractional programming	Significant EE improvement subject to little SE loss
[160]	LTE based D2D	Feedback mechanism, feedback aided rate adaptation and recovery scheme	Minimize signaling overhead, improvement in goodput and latency under various channel environment
[161]	3GPP LTE-A system to incorporate D2D	Concept of direct UE to UE communication enhanced with a detailed description of the architectural and protocol enhancement necessary to cooperate direct communication between UE into existing 3GPP LTE-A system	Establish and maintain D2D call and efficient mobility between a traditional cellular mode and a D2D mode of operation
[162]	D2D	SIR based multiple access (SBMA)	ASE improves 38% compared to OFDMA under a typical system setting
[163]	Full duplex two-way (FDTW) relay assisted D2D uplink channel	Iterative optimization algorithm, two tiers alternative iteration optimization technique	Minimize EE while satisfying SE requirement

Conclusions

Interference is a basic problem for D2D communication. So, researchers are mainly focusing on various types of interference avoidance methods. Here we investigate clustering methods, frequency reusing, spectrum sharing, resource allocation, and implementation of the new generation waveforms to improve SE for D2D communication. Researchers apply these methods with the help of various algorithms, concepts, and network design. These efforts provide improvement in data rate, system capacity, secrecy performance SIR level, sum rate, energy saving, number of admissible D2D pair, SE fairness, outage ratio for various network conditions i.e., uplink/downlink and underlay/overlay D2D communication. Future research challenges for D2D communication, are interference management, network discovery, proximity and context-aware services, network coding, and security. V2V communications, mm-Wave technology, social D2D networks, energy harvesting, and SWIPT (simultaneous wireless and information power transfer), pricing, and incentive are the future direction in the perspective of 5G D2D networks.

Authors contribution All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by BS, MRT, RA and VS. The first draft of the manuscript was written by BS and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Declaration

Competing interest Financial interest: All authors have no financial interest. The authors have no relevant financial or non-financial interest to disclose.

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