Telecommunication Systems (2019) 71:627–643
https://doi.org/10.1007/s11235-019-00578-4

Interference management issues for the future 5G network: a review

Faizan Qamar[1] · M. H. D. Nour Hindia[1] · Kaharudin Dimyati[1] · Kamarul Ariffin Noordin[1] · Iraj Sadegh Amiri[2,3]

Published online: 14 May 2019

Abstract
The future wireless Fifth Generation (5G) communication network required a higher bandwidth in order to achieve greater data rate. It will be largely characterized by small cell deployments, typically in the range of 200 meters of radius/cell, at most. The implementation of small size networks delivers various advantages such as high data rate and low signal delay. However, it also suffers from various issues such as inter-cell, intra-cell, and inter-user interferences. This paper discusses the issues related to interference management for 5G network from the perspective of Heterogeneous Network and Device-to-Device communication, by using enabling techniques, such as Inter-cell Interference Coordination, Coordinated Multi-point, and Coordinated Scheduling. Furthermore, several pertinent issues have been critically reviewed focusing on their methodologies, advantages and limitations along with the future work. Future directions proposed by the 3rd Generation Partnership Project for interference mitigation has also been outlined. This review will act as a guide for the researchers to comprehend various existing and emerging enabling interference mitigation techniques for further exploration and smooth implementation of 5G wireless network.

Keywords Interference management · 5G · CoMP · ICIC · Coordinated scheduling · HetNet · D2D

1 Introduction

Current demands of high data rates for mobile users are challenging newer technologies to be invented for the progress of 3rd Generation Partnership Project (3GPP) access networks [1]. Several researchers and mobile operators are working with the 3GPP to achieve higher throughput with greater user capacity [2]. The next generation mobile network will be stated as 5G and expected to be commercialized until the year 2020 [3]. The predicted data rate for the 5G network is around 100 Gbps with a minimum of 1 ms latency along with better user capacity and battery life [4, 5]. In order to achieve the acceptable Quality of Service (QoS), various potential solutions are in progress such as, use of Millimeter-wave (mm-wave) frequency band [6–10], Massive Multiple-Input and Multiple-Output (MIMO) [11], Cooperative network using Relay Nodes (RN) [12], Coordinated Multipoint (CoMP) [13], Wireless Software Defines Networking (WSDN), Device-to-Device (D2D) communication [14], Internet of Things (IoT) [15, 16], Ethernet Passive Optical Network (EPON) [17], Big Data and Mobile Cloud Computing [18]. Apart from this, there are several power optimizations [19, 20] and scheduling algorithms [21] are in progress, which can be incorporated in the existing technologies to achieve higher overall network performance.

With the increase in the number of communication devices, the requirement for higher bandwidth is essential [22]. Therefore, a robust solution is to be devised with a focus on providing higher spectral efficiency with acceptable network performance [23]. Higher data rate and greater capacity at the user end can be achieved by allocating more resource blocks (RBs) to each user in the network, therefore, higher bandwidth is imperative [24]. In other words, higher bandwidth will permit larger throughput to mobile users enabling them to download and upload advanced multimedia services including High Definition (HD) video calling, streaming, and other data-hungry applications [25, 26].

✉ Iraj Sadegh Amiri
irajsadeghamiri@tdtu.edu.vn

1 Department of Electrical Engineering, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia

2 Computational Optics Research Group, Advanced Institute of Materials Science, Ton Duc Thang University, Ho Chi Minh City 700000, Vietnam

3 Faculty of Applied Sciences, Ton Duc Thang University, Ho Chi Minh City 700000, Vietnam

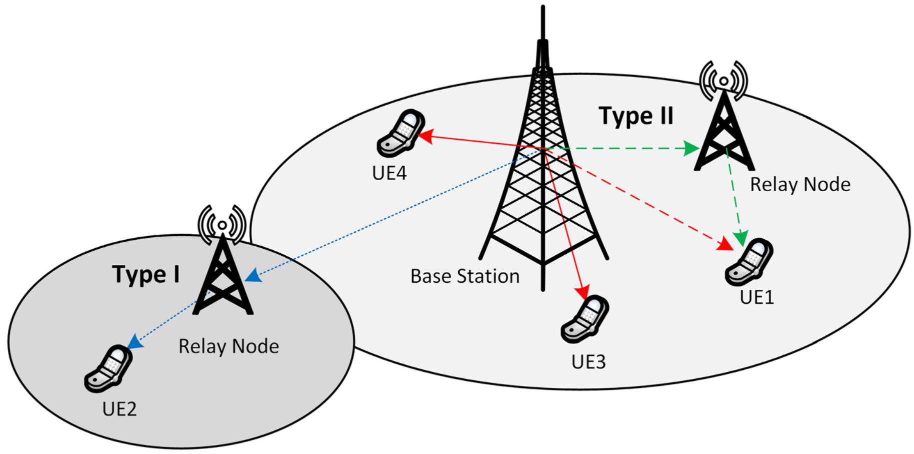


Fig. 1 Relay application: **I** coverage extension, **II** diversity improvement

It can also help to reduce network complexity and provide high QoS by decreasing end-to-end latency [27]. The high-frequency mm-wave bands are considered as an ideal spot for 5G as there is a vast spectrum is still untapped which can provide greater bandwidth [28, 29]. However, in the high-frequency ultra-dense network, the range of transmission is getting shorter due to the smaller wavelength and various intra-cell interferences from nearby devices [30]. Meanwhile, in the wireless urban area network, users suffer more scattering issues due to large number of obstacle present in a small area. [31, 32]. Furthermore, the user equipment's (UEs) located at the edge of the cell received weak signals as compared to the minimum desired signal level requires for communication. In such situation, deploying a small Base Station (BS) within a cell to boost the signal strength is not considered as a viable solution [33, 34], since, it can increase inter-cell interference (ICI), which requires more complex Coordinated Scheduling (CS) algorithm with incurring unnecessary costs [35]. In order to address such issues, a highly feasible solution is proposed; which deploys an infrastructure-based transceiver within a cell to create a multiple-hop communication network [36]. These transceivers act as RN in order to serve mobile users with higher efficiency and low cost [37]. This solution is the key advancement to address increasing demand and deliver effective (I) coverage extensions and (II) diversity improvement as shown in Fig. 1 [38, 39]. It can provide better spectrum diversity and higher user throughput by selecting suitable Modulation and Coding Schemes (MCS) [40]. The fundamental principle of deploying RNs is to receive the information from the BS and deliver it to the UE (or vice versa) while increasing the quality of signal without having a prominent loss of the information [41, 42]. In order words, higher level of improvement in diversity can be achieved by deploying several RNs in the cell coverage area with massive achievable users data rates [43, 44].

Extensive fundamental changes are expected in the local user's demand for 5G networks. However, it is not feasible to restructure the entire network each time it gets clogged up with traffic, therefore, a more realistic approach is to adopt as a reconfigurable solution [45]. Moreover, the data demand for user plane (UP) and control plane (CP) in the 5G network will likely grow at different speeds, resulting in an independently scalable solution and user's demands will increase alongside user's intolerance to underperforming applications [46]. For optimal performance, 5G networks will adopt a more coordinated approach to radio access network (RAN) technology based on CoMP transmission and Inter-cell Interference Coordination (ICIC) as already demonstrated in the recent release-15 systems [47]. It stated that a single UE can be served by multiple BS of different backhaul technologies in a coordinated manner with less interference [48].

2 Contribution

The future generation wireless systems, such as 5G and beyond are expected to implement an interference efficient mechanism for more reliable communications. The current communication system faces various technical challenges like user's mobility, unexpected channel variation, coordinated BS identification, shared spectrum communication, and intra-cell & inter-cell interference. For reliable multi-tier communication cellular networks, an extensive investigation has been undertaken in the area of interference management. Moreover, with the steady rise of number of devices, these interference issues become more intense causing severe degradation in overall network performance. Therefore, this paper studies the issues related to interference management from the perspective of Heterogeneous Network (HetNet) and D2D network, by using enabling techniques such as ICIC, CoMP and CS (as shown in Fig. 2). The future

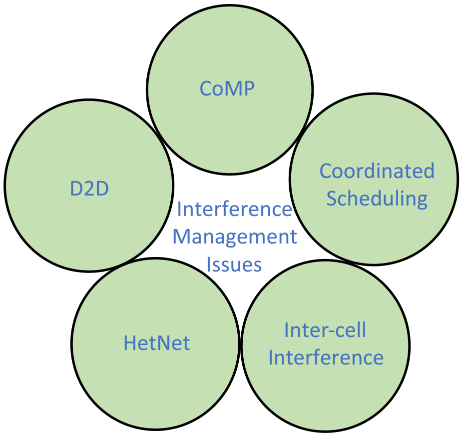


Fig. 2 5G interference management issues

research challenges and few proposed 3GPP schemes to mitigate interferences are also discussed in this paper.

The remainder of the paper is organized as follows. Section 3 discusses the existing interference management issues along with current research conducted to address them. Section 4 explains the research challenges for mitigating the interferences. Section 5 shows some of the proposed methodologies by 3GPP. Section 6 ends with the conclusion.

3 Interference management

3.1 Inter-cell interference (ICI) issues

In a multi-cell cellular environment, especially in full frequency reuse scenarios, one of the major challenges to contend is the issue of ICI mitigation [49]. ICI can easily degrade the system's spectral efficiency (SE) and energy efficiency (EE) especially for the cell edges users [50]. The SE is defined as the measurement of how efficiently the available spectrum is utilized in the system, while the EE is the measurement of efficient energy consumption in the system [51]. In order to improve SE and EE gains across the cells, numerous mitigation schemes either based on dynamic or static resource allocation approaches can be used [52]. However, some of these techniques do not always perform optimal as expected and tend to shorten the available bandwidth of the BS resulting in SE loss. For an efficient system design in a multi-cell cellular network, the trade-off information between SE and EE is significant [53, 54]. However, interference cancellation can be implicitly achieved in practice by removing or spacing out the strongest interferers or by increasing the separation distance between BSs. It can be an effective approach to minimize ICI which can help to achieve higher signal gain than the threshold value [55]. In order to mitigate interferences efficiently, various schemes such as cooperative transmission, resource partitioning, beamforming, and interference alignment (IA) have been proposed and tested in numerous literatures [56–61]. Each of these schemes has its own effective gain and coordination requirements. Some advanced solutions for minimizing ICI in the latest researches are explained in the following subsections.

The authors in [62] are focusing on mitigating ICI for multiple-input-single-output (MISO) channel. Cooperative beamforming scheme which is based on resource allocation and beam selection is used to achieve significant results for higher cluster size. In [63] the authors have focused on reducing the indoor environment ICI by using a network concept stated as a virtual cellular network. They suggested that the virtual cell is needed to be designed in groups for user distribution. Their results have proved that the proposed approach reduced ICI with improved spectral efficiency. Moreover, in order to achieve efficient energy consumption with a minimum interference effect, a study in [64] proposes an energy-efficient framework for high-density cells network. This technique dynamically allocates the spectral resources fairly among users, while keeping the BS into the sleep mode. It delivers more energy efficient results as compared to existing 'interference control only' and 'sleep mode only' schemes. Moreover, mitigating the effect of ICI for adjacent cells especially for cell edge users is studies in [65]. The proposed approach is based on 'Opposite codeword order' and 'Bayesian division classifier' theory used for ordering the division for each codeword. The results show that the proposed scheme delivers better performance for cell-edge communication. Another study to enhance the QoS for self-organized HetNet is discussed in [66]. It proposes a new approach which is based on game theory that optimized cell time transmission muting. It helps to deliver better QoS ensuring more users have a similar level of satisfaction.

3.2 Heterogeneous networks (HetNets)

The concurrent operation of macro-, micro-, pico- and femto-cells are stated as HetNet. Interference management is one of the most critical challenges due to the uncoordinated nature of HetNet deployments. In traditional HetNet configurations, a handover margin power offset is introduced between macro BSs (MBS) and pico BSs (PBS) or between MBS and other lower power BSs. It helps to achieve maximum offloading and extend the coverage area of low power BSs beyond their original coverage limit [67]. However, in this context, UEs at the cell edges under the coverage area of lower power BSs are heavily interfered by macro-cell downlink transmissions and faces serious ICI which causes lower UEs performance [68]. Minimizing the ICI in order to improve users performance at the cell edge is critical in a single frequency network as coordination between adjacent

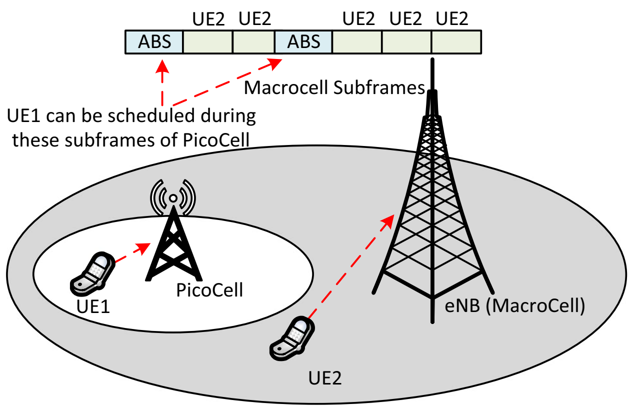


Fig. 3 Almost blank subframe technique for HetNet

BSs is always difficult to manage [69]. Inter-cell coordination technique such as the ICIC is initially introduced as a solution to ICI in multi-cell networks [70]. ICI technique can be categorized as either static coordination such as ICIC or as dynamic coordination such as the enhanced ICIC (eICIC).

In the ICIC technique, the MBS transmits and receives the network management information, such as transmit power, cell load, interference level, and resource allocation information through their high-speed backhaul (X2) interfaces. It helps to jointly coordinate the transmitted power and resources assignments for both cell-center and cell-edge UEs [71]. Whereas, the enhanced version of ICIC, also known as eICIC technique, is introduced by 3GPP to minimize the complex coordination overhead experienced in ICIC standard [72]. The eICIC scheme requires as minimum coordination as possible between two cells. However, in order to maximize the utilization of spectrum resources in time division based multi-cell networks, a single frequency network is commonly deployed [73]. In the eICIC scenario, the multi-cell can function as single-cell where the complete feedback information is available. In order words, multiple BSs can jointly transmit and receive statistics to optimal performance [74]. The eICIC introduces a technique called almost blank subframe (ABS) (as shown in Fig. 3), for macro-cell downlink sub-frame. It helps to suppress the interference of UEs within the coverage of lower power BSs overlaid by MBS [75]. As the name implies (ABS), the MBS does not transmit any data and control signal in some sub-frames in order to allow lower power BSs to synchronize with UEs in that sub-frames [76]. This principle might lead to loss of some resources, however, it surely improves the performance of the lower power BSs, thus, from the system-wide assessment, the overall achieved gain is enhanced [77, 78]. Furthermore, Time Division Duplexing (TDD) is a well-known synchronized technique for next generation of 5G heterogeneous multi-cell networks. As 5G is widely expected to operate in a massive MIMO antenna scheme, TDD helps to perform duplexing in order to achieve optimal system performance [79]. Few of the latest researches conducted to mitigate the interference in the HetNets are discusses below.

A study in [80] is based on ICIC which utilizes soft frequency reuse method for relay based cellular network. The results show that the proposed approach delivers better cell-edge users' performance with efficient and fair resource sharing among users. Another resource allocation scheme using soft frequency reuse is presented for ICIC in [81]. This approach efficiently utilizes the spectrum for cell-edge users that helps to deliver higher throughput for both uplink and downlink network. Another ICIC power scheme is proposed in [82] for the uplink network. It is a transmission power control-based ICI technique, where interference effect is the same for fractional frequency reuse method. The results prove that user throughput is increased as compared to the conventional method. It also suggested that a more realistic traffic model need to be investigated in the future in order to achieve higher overall users' performance.

An interference aware slot allocation technique to improve pico-cell/macro-cell performance is proposed in [83]. It is an eICIC technique based on ABS, which utilizes an unused spectrum and delivers better spectral efficiency as compared to the current fixed ABS ratio approach. Another eICIC scheme for unevenly distributed users is discussed in [84]. The authors proposed a dynamic load balancing algorithm for non-homogenous users' distribution among cells without any additional signaling message. The results give better performance in terms of bandwidth and packet delay as compared to the conventional ICIC approach. Another eICIC scheme is proposed in [85] for small cells network which coordinated the BSs by horizontal beamforming technique for ultra-dense high-rise building environment. The authors prove that the proposed technique helps to increase throughput, however, it requires a highly precise codebook-based precoding algorithm at the antenna side. Another approach that utilizes soft frequency reuse method is discussed in [86]. The study highlighted some of the various issues such as power ratio and traffic loads. The results show that the proposed approach enhances the user's performance in terms of signal-to-interference-plus-noise ratio (SINR), block error rate and throughput.

The research in [87] studies the interference coordination scheme for multi-tier HetNets that utilizes the ABS based semi-distributed algorithm with limited signaling overhead. The results proved that the proposed algorithm improves sum throughput with acceptable fairness among users. Another approach in [88], discusses the joint interference management and cell association technique for HetNet. The reinforcement learning approach is used, which focuses on time and frequency domain interference technique to increase achievable gain. Results show that the proposed approach gives better performance as compared to fixed cell range expansion and fixed ABS techniques. Although, this technique is limited for less RBs sharing which required a more complex algorithm to achieve higher bandwidth. Another eICIC scheme for femtocell in HetNet is studied in [89], which is based on suppressing the interference while effecting the physical downlink control channels (PDCCHs) by blanking two orthogonal frequency-division multiplexing (OFDM) symbols. The approach is backward compatible which can support Long Term Evolution-Advanced (LTE-A) frequency division duplex (FDD) and TDD system. However, its performance is degraded on a single time slot when interference from the same frequency signal is received. Another interference mitigating scheme for arbitrary fading channel has been studied in [90] that estimates the SINR and obtain moment generating function (MFG) for heterogonous Poisson fields of the transmitter and interferes. Its results prove that the SINR statistics deliver better performance in terms of Mittag–Leffler's function. Another interference mitigation approach for low Signal to Noise Ratio (SNR) region is proposed in [91]. In this method, the IA scheme is optimized by the weighted minimum mean square error (W-MMSE). The results give less iteration and better capacity even on low SNR region, although it requires high channel state information (CSI) for precoding the transmission signals.

Moreover, a study based on software-defined networking (SDN) architecture for HetNet is discussed in [92]. It utilizes eICIC and CoMP for SDN/RAN system, based on Monte-Carlo simulation. The results of fairness and capacity are improved for cell-edge users however, it requires stronger and highly capacitive backhaul network. Another approach for uplink interference model for both macro-cell and small cell users is discussed in [93]. In this model, the interference is characterized by both closed subscriber group (CSG) and open subscriber group (OSG). The results achieved high success probability with better average rate for both theatrical and simulation results. Another study is proposed in [94] for moving small cell of HetNets. The simulation was performed using continuous interference cancellation technique for the mobility of small cell. The results proved that this approach can help to improve the cell edge user's performance as well as overall network performance.

3.3 Device to device (D2D)

The higher data rate, low latency, enhanced capacity, and better QoS for the future wireless networks are requisites of new applications [95]. In this regard, 3GPP introduced a new technology named as D2D communication, where users can now choose to communicate with each other over multiple interfaces in the same shared access network [96]. It is a radio access technology which provides users to communicate among them in small proximity, without the need for transferring data through the network infrastructure. For instance, a D2D enabled device has the options for either long-range communications using WLAN, WiMAX, LTE-A, etc., or for short range communication using the Bluetooth or other proximity services (ProSe) protocols [97]. In typical D2D communication, data exchanges are usually via the Bluetooth or Wi-Fi short-range transmission protocols [98]. However, these network protocols are constrained by low transmission capacities as compare to LTE-A, WLAN, or WiMAX network protocols. Recent investigations on D2D and cellular convergence networks reveal that the unlicensed spectrum of LTE-A cellular networks can be shared by D2D users in similar access level within the same network [99, 100]. Hence, D2D can be used to ease the transmission overhead at the access network in order to improve the performance of core network of the cellular system [101]. Setting up D2D networks can be a smart way to maximize the scarce spectrum resources whereby the unlicensed spectrum are utilized through a coordinated radio resource (CRR) management [102, 103]. CRR is the key solution to avoid the issue of high ICI in D2D enabled cellular network. Interference often encountered between various D2D adjacent networks and between D2D and cellular networks due to user's mobility and D2D network boundary ambiguity [104]. Similarly, the overall mobile network system capacity can be significantly improved by deploying a wide range of spectrum bands to serve individual D2D networks (Fig. 4) [105]. D2D network will play a key role in the upcoming 5G network in terms of improved latency, spectrum efficiency, power efficiency, network capacity enlargement and network coverage extension [106–108]. However, an efficient interference mitigation scheme is required to enhance the overall network performance [109]. Few of the related approaches are discussed below for handling interference for D2D communication.

An Interference cancellation approach in [110] investigates the outage performance of D2D users which uses beamforming and IC technique with M-antenna BS two-way decode-and-forward RN. The results confirmed that the closed form exact expressions give high SNR approximation for the outage probability. An Interference-bounded resource allocation heuristic scheme is proposed in [111], which estimates the interference thresholds set by BS and cellular users. The achievable system throughput for the proposed scheme is near to optimal sum-rate value while reducing the interference between D2D and cellular users. In order to solve the optimization problem and increase the overall rate of the cellular and D2D users, an approach in [112] is proposed. It designed a precoder (zero-forcing beamforming) method with the D2D pair association vector search algorithm that can deliver better performance in terms of sum rate as compared to the conventional approach.

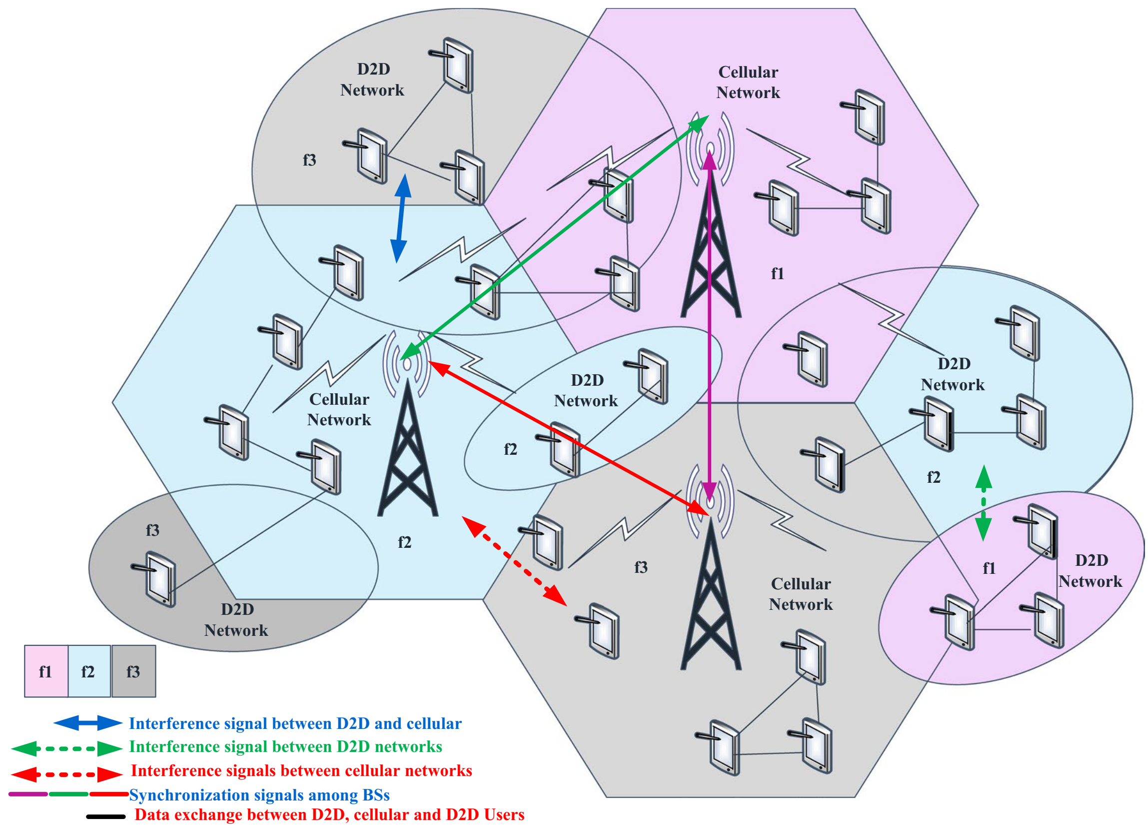


Fig. 4 Interference and spectrum reuse within a converged cellular and D2D networks

The mutual interference between cellular and D2D networks is resolved by the proposed scheme presented in [113]. An efficient power control scheme is designed to obtain the upper bound of D2D transmit power. Moreover, a controlling interference scheme is proposed for the cellular user to the D2D receiver with improved distance-based resource allocation scheme. The results show that the performance of D2D users improves significantly without degrading the performance of the cellular users. Another interference scheme for D2D MIMO HetNet is proposed in [114]. This scheme jointly designs precoder and receive filters for co-tier and inter-tier interference which required lower CSI. It proposes an IA scheme assisted by D2D (DaIA), which outperforms the conventional interference mitigation schemes. An approach in [115] proposed two interference mitigation scheme. First 'interference-free' scheme, which is based on the alignment of orthogonal space for BSs. Second 'interference-limiting' scheme, that works on peak interference power link at the certain threshold value. The results prove that interferences are well controlled with the acceptable QoS however, it is valid only for a limited number of D2D users in a cell.

The scheme proposed for 'η' interference avoidance [116] gives the idea of reusing the uplink resource for a hybrid system of cellular and D2D network. The two proposed schemes are i) interference tracing approach and ii) tolerable interference broadcasting approach. Both schemes are independent and have efficient resource utilization performance. Another approach for D2D underlaid MIMO cellular networks from a new interference-aware perspective is proposed in [117]. The authors designed an interference-free network by adopting the degree of freedom (DoFs) as mode selection criteria with liner interference scheme. The results show that it can achieve high SNR with less interference for large MIMO based small-cell networks. An approach in [118] works on reducing the interference caused during resource sharing among D2D and cellular users. It proposed a power control algorithm to obtain the powers of cellular and D2D users in closed form while considering minimum SINR requirements. The results show that it helps to achieve higher sum rate with acceptable power optimization scheme. Another scheme of resource sharing and interference management for D2D and cellular user is proposed in [119]. This scheme is based on a greedy algorithm and successive interference cancellation (SIC) which gives strengthen resource utilization and higher total cell throughput with better performance gain.

3.4 Coordinated multipoint (CoMP)

CoMP is one of the most viable technique to control ICI in the wireless networks especially for high density heterogeneous multi-cell networks [120]. CoMP is used for the management of co-channel interference (CCI) in a typical frequency reuse scenario, where multiple users are allowed to communicate using the same frequency channel [121]. This highly dynamic interference coordination scheme can be used to mitigate the interference between D2D and cellular transmissions in overlaid cellular networks [122]. It is predicted that CoMP schemes will set the platform for future converged network consisting of various interfaces where cellular networks and D2D communications will coexistence within the same frequency spectrum [123]. The next generation 5G wireless networks will leverage CoMP to maximize cellular coverage and increase the spectrum utilization efficiency [124, 125]. In CoMP systems, a number of co-located antennas interconnected through a high-speed X2 interface which are deployed at various transmission locations [126]. The essence of interconnecting co-located antennas through the X2 interface is to support the coordination of multiple cells transmissions, which helps to reduce the transmission delay and minimizes ICI [127]. The commonly deployed CoMP transmission schemes include CS or coordinated beamforming (CB), and joint transmission or joint processing schemes.

In 3GPP Rel-13 and 14 for LTE-A, CoMP system is based on the concept of several transmission points at various geographic locations. It can cooperate to jointly transmit and receive data from common UEs in an interference avoidance mode [128]. The transmission points participating in joint transmission could be different remote radio units (RRU) and/or typical BSs [129]. CoMP system supports four types of downlink transmission [130], namely; (a) dynamic transmission point blanking as shown in Fig. 5a, in which the best transmission point is selected for data transmission to a targeted UE while blanking any potential high interference transmissions from other transmitters. (b) CS/CB as shown in Fig. 5b, where the beamforming or scheduling information is commonly shared among multiple coordinated transmission points to reduce interference. (c) Joint transmission as shown in Fig. 5c, where multiple transmission points jointly transmit data to a targeted UE. (d) Dynamic transmission point switching as shown in Fig. 5d, where the best transmission point is selected dynamically among various cooperated transmission points in order to transmit data to a targeted UE.

Apart from various advantages of all various CoMP coordination modes, CoMP still suffers from various

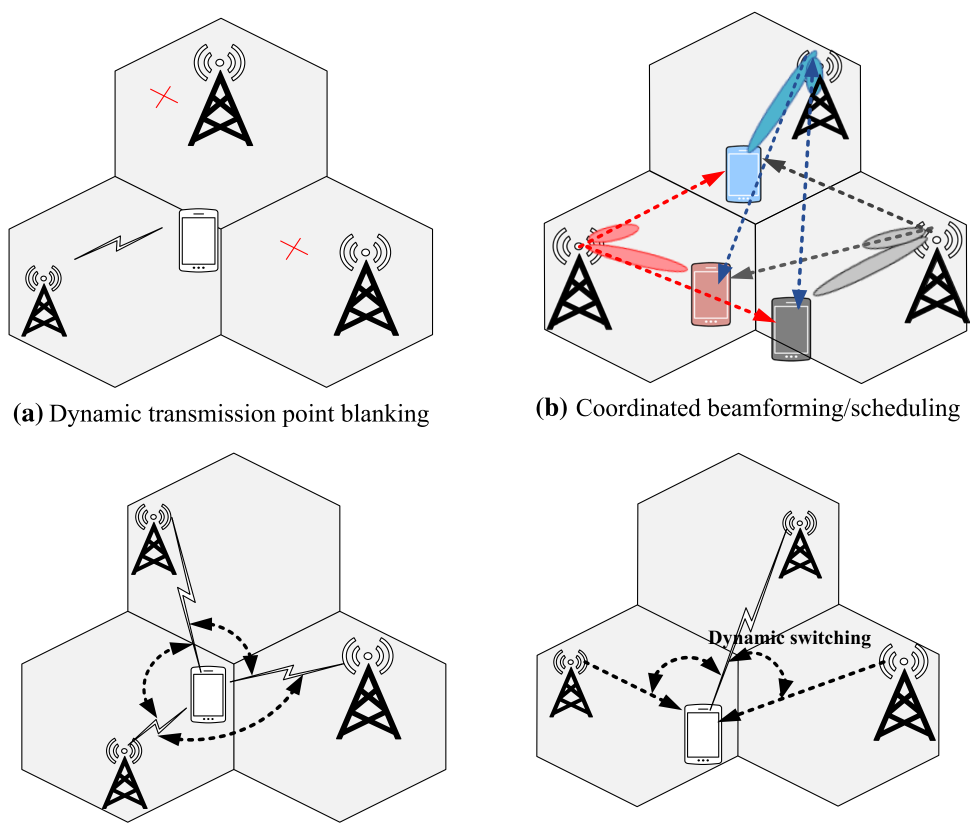


Fig. 5 Different CoMP modes

(a) Dynamic transmission point blanking

(b) Coordinated beamforming/scheduling

(c) Joint transmission

(d) Dynamic transmission point switch interference issues such as intra-cell and ICI, etc. [131]. Several researches have been conducted to deal with these interferences issues, where, some of the latest research for are discussed hereafter. Like an approach in [132] presented the methodology, which performs the experimental implementation of IA and CoMP. The proposed methodology utilizes orthogonal frequency-division multiplexing (OFDM) modulation with higher-order constellations which is based on high-performance low-density parity-check (LPDC) code. The results show that both IA and CoMP deliver improved performance for single-input and multiple-output (SIMO) as well as for MIMO case. Another interference mitigation scheme for time-asynchronous OFDM CoMP systems is proposed in [133]. It uses the geometrical and semi-analytical technique in Rayleigh fading channel for the uplink network which gives better average error probability results even for the high number of BSs. Another study for IA which focuses only LTE-A uplink path is presented [134]. It proposes three different dynamic information selection (DIS) techniques which are based on i) maximizing the sum-rate ii) minimizing the probability of outage iii) maximizing the minimum SINR value. Its results validate that it can increase the sum-rate while reducing the outage probability as compared to conventional UL CoMP system. Another Interference management scheme which utilizing frequency reuse method is proposed in [135]. This technique is based on hybrid dynamic frequency reuse (DMFR) method along with adaptive spectrum allocation and interference management schemes. The results prove that the proposed technique can enhance the cell-edge throughput as well as adjacent sector transmission performance.

An approach in [136] increases the capacity gain through the degree of freedom criterion. It proposes a local cooperation constraint methodology to deliver transmitted messages in an optimal way. The results conclude that the minimum number of receivers are beneficial for zero-forcing beamforming technique. In [137], a signal-to-leakage-plus-noise-ratio (SLNR) based cascaded interference alignment precoding scheme is presented. The orthogonal space of receiving matrix interference is estimated when SLNR precoding is used. It delivers better results in terms of bit error rate and system throughput. An application-based CoMP (ACoMP) scheme where each node is responsible to specify particular active application is proposed in [138]. This technique helps to reduce communication link among coordinated nodes which delivers better throughput, network capacity and packet loss ratio. Another IA based transceiver design algorithm for uplink CoMP is proposed in [139]. This technique uses the block QR decomposition (BQRD) method to resolve interferences among UEs. It utilizes the SIC technique to reduces the number of iterations which helps to improves the rate of convergence.

3.5 Coordinated scheduling (CS)

In a coordinated resource scheduling strategy, ICI is suppressed through user scheduling or user silencing [140]. In this scenario, a cell has the option to assign a resource (channel) to a user or to silence the user (i.e. to keep the channel unassigned) in order to avoid interference with adjacent cells. This can be carried out by assigning the beamforming vectors independently to different directions in each cell [141]. However, in synchronized beamforming system, the beamforming vectors at different BSs are coordinated in order to avoid interference uncertainty [142]. The CS/CB scheme requires only a minimal channel quality information for optimal scheduling decisions [143]. However, in a joint transmission, the co-channel user's statistics and CSI are simultaneously gathered from all cooperating cells and forwarded to the transmit antennas [144], which simultaneously process the signals using the antenna-array transmission scheme [145]. Precise scheduling can be possible when strong channel conditions are present, but in practical, availability of perfect CSI is always not possible [146]. To keep this in mind, many researchers are designing the scheduling algorithm which not only reduces the interference but also shares a fair spectrum among the users with limited availability of CSI [147–149]. Few of the latest work in the area of CS has been discussed hereafter.

A CS scheme which is based on channel estimation error (CEE) for uplink coordinated MIMO systems is presented in [150]. It outperforms the traditional CS algorithms in the practical scenario for CEE and also it gives better tradeoff between spectral efficiency and fairness. The scheduling restriction scheme for interference coordinated HetNet is presented in [151]. It utilizes the proportional fair resource allocation (PFRA) technique that is based on a scheduling restriction scheme. The results show that the minimal performance degradations with a better tradeoff between the performance and feedback reduction is achieved. Another approach based on joint CS and power optimization for cloud-enabled networks is proposed in [152]. It is a graph theoretical approach which introduces joint scheduling and power control graph technique designed for various clusters size. The clusters are formed by a set of vertices, representing the possible association of users, BSs, and power levels (PLs) for the specific power-zones (PZs). It results prove that it achieved substantial performance improvement in comparison to the conventional method. Another approach in which a joint uplink user-scheduling, power control and beamforming algorithm are coordinated across multiple cells has been discussed in [153]. The main contribution of this paper is the recasting of the problem in terms of sum-of-ratio programming and a subsequent quadratic reformulation which allows scheduling and beamforming to be optimized through solving a matching problem. The results show that the proposed approach significantly outperforms both the WMMSE algorithm and the existing uncoordinated scheduling approach.

In order to solve the maximum-weight independent set problem, a hybrid coordinated scheme for cloud-RAN is proposed in [154]. It is based on graph theory technique by constructing the conflict graph that gives a significant increase in signal-level coordination. Another uplink IA based CS (IACS) scheme, which combines the benefits of proportional fairness (PF) scheduling with interference scheduling is presented in [155]. The results show that the proposed scheme delivers better performance even in the high interference scenarios. Another approach for multicell interfering broadcast downlink networks with zero-forcing beamforming is presented in [156]. It consists of low-complexity multicell coordinated user scheduling policies which deliver less computational complexity with higher intercell coordination. The results prove the significant improvement in the system performance as compared to the conventional PF scheduling approach is achieved. Moreover, multi-cell interference coordinated scheduling scheme for urban Non line-of-sight (NLOS) mm-wave cellular system is proposed in [157]. It is a mac layer-based design approach that allows cooperation between adjacent BSs. It works on orthogonality concept that is used in spatial-time domain resource allocation. The results show that it maintains high spatial reuse features of mm-wave signal and also increases fairness among users. Another approach for sub-optimal performance of joint user with beam scheduling is proposed in [158]. It is based on a genetic algorithm that gives better performance as compared to the conventional greedy algorithm.

4 Research challenges

4.1 Inter-cell interference (ICI) issues

ICI is one of the critical issues for cellular communication due to the use of same frequency band in neighboring cells. This issue needs to be mitigated without the loss of any user's information especially for the future wireless 5G network which will be more compact and will consist of highly dense communicating devices. In order to fully realize this in practice, different interference management schemes can be used. Schemes such as cooperative transmission, resource partitioning, beamforming, and IA can be implemented for the more complex cooperative network which suffers from high ICI issues [159].

4.2 Heterogeneous networks (HetNet)

Due to the presence of various small cells such as pico and femtocell, HetNet suffers from the higher ICI issue. These interferences can be resolved by using various time and frequency division techniques. The most common technique is the ICIC and eICIC scheme which uses IA to minimize the volume of network control traffic and cooperation. It allows only information related to channel state where each end user is associated with only one BS. However, IA is not always efficient because of time variations and imperfect channel conditions. To exploit the potentials of IA, it is advisable to design it with the limited feedback, but at the expense of a limited DoFs. The utilization of the ABS approach is also and efficient approch; however, it requires higher CSI value. Moreover, some researches should be conducted for the FDD and TDD approaches which can help to deliver better results even when the interference is very high. This is very critical because the next generation of 5G heterogeneous multi-cell networks is widely expected to operate in TDD mode using massive MIMO antenna scheme for optimal system performance [160].

4.3 Device to device (D2D)

The fundamental challenges in D2D network arises when D2D is converged with the cellular network that is communicating within the same frequency channel. One way to achieve this is to reduce the transmission power of users within the confinement of the D2D region of the network, rather than, reducing the transmission power of cellular systems. However, this is not always an efficient approach to handle since it can reduce the overall network performance. More advance SIC or stochastic geometry-based approaches are needed, which has the tendency to create an imbalance between downlink and uplink coverage with high spectrum efficiency for D2D enabled cellular network [161].

4.4 Coordinated multipoint (CoMP)

In order to mitigate interference issues, CoMP provides various different solutions with better overall network performance. Few of the researches are working on synchronize cooperation techniques, whereas, some proposed A-synchronize cooperation techniques. Moreover, some use the frequency reuse method along with and efficient beamforming techniques. In uplink CoMP, multiple coordinated BS can facilitate a single targeted UEs where they can achieve high network performance by using joint processing technique. In TDD system, the overall system performance can be significantly improved by utilizing various channel reciprocity properties due to les computional complexity with low feedback overhead [162].

4.5 Coordinated scheduling (CS)

Several issues have been augmented when resource scheduling takes place such as complexity and fairness among users. An optimum resource sharing can be achieved by using various methodologies that can be based on priority of users or/and channel availability. In order to avoid interference for a particular user, the shared beam pattern information between two facing sectors of the cell can be used which can help to reduce the interference coming from adjacent cells. Moreover, some scheduling algorithms with efficient advancement are working on maximum largest weighted delay first (MLWDF), exponential/proportional fair (EXP/PF) and time-fair selective scheduling (TFS) schemes [163].

5 Proposed methodologies by 3GPP

As discussed, there are several works has been conducted recently and still various new approaches are in progress to mitigate interferences. Researchers and industries are working along with 3GPP to fulfill the expected demands for the future network. The 3GPP has recently presented various schemes and techniques in oder to mitigate interference which are under consideration for the development of future wireless network.

5.1 Wireless backhauling

Dense deployment of small cells over a traditional macrocell is considered as a key enabling methodology for the emerging 5G ultra-dense HetNets [164]. Various backhaul solutions have been proposed as higher number of access nodes retains more challenges for the deployment and management of the network. The use of wireless backhauls (where a limited range of communication is required) can be useful with an efficient beamforming approach in order to minimize interference and increase spectrum efficiency [165].

5.2 BS identification

In a high-density HetNets, a BS should be aware, capable or connect to its neighboring BSs and all the users associated with these BSs. Information of interferer BS is very essential in order to deal with the ICI and performing handover decisions. However, identification, transmission and detection of an interferer BSs over an air interference is a challenging task, yet the variation in transmission power, BSs trigging and advance reference signal design can be used to mitigate this issue [166].

5.3 Rank calculation

Rank adoption defines the number of independent transmitted streams aimed to balance the tradeoff between multiple received signals at the receiver. It helps to increase the spatial gain and improve the interference resilience property. Several efficient methodologies have been proposed by 3GPP recently, which focuses on an interference-aware inter-cell rank coordination algorithm in order to reduce computational complexity. It also requires a rank selection algorithm which should be based on instant CSI for interference covariance matrix (ICM) [167].

5.4 Receiver designing

In order to deal with the interference efficiently, the 3GPP has proposed an interference suppression and rejection technique at the user side, however, it is limited to a single receiver antenna. The multipath interference degradation reception is the issue which can cause major signal attenuation in the 5G network [168]. The 3GPP stated that, for the reference receiver, Code Word Level Interference Cancellation (CW-IC) receiver can be used for intra-cell inter-user interference mitigation. Moreover, for multi-cell scenario, for both baseline and reference receivers, inter-cell interference suppression with Minimum Mean Square Error - Interference Rejection Combining (MMSE-IRC) methodologies are very useful [169, 170].

5.5 Reference signal

The designing of a reference signal is one of the critical issues to handle, as there is a continuous and unpredictable propagation channel condition for transmitting signal. It can help to differentiate between the information signal's BS and interference signal's BS. For the future 5G network, 3GPP suggested that there is no need of a specific reference signal, however, a new reference signal (named as Demodulation Reference Signal) has been introduced for both Time/Frequency downlink and uplink channels [171, 172].

5.6 Finding adjacent interference cell

In TDD communication of high-density HetNet, the effect of adjacent and remote interference is an essential task because the signal from various BSs can only be differentiated with respect to its received signal time window [173]. Therefore, 3GPP proposed that, when applying the interference cancelation technique, the effect of interference coming from remote BS effect is also under the consideration due to the impact of troposphere bending in transmission channel [174].

5.7 Control channel identification

Signaling and control channels identification are essential in order to control the mechanisms to conserve limited resources. The isolation between the common control channel (CCH) and the dedicated control channel (DCC) is crucial in order to decrease the probability of miss-detection between information and interference signals [175]. The proposed technique by 3GPP shows that the specified reference channel measurement should remain below the given threshold reference value in order to attain optimum performance [176].

6 Conclusion

For the future 5G wireless network, number of users will exponentially increase which makes the communication network an ultra-dense. Various high interference issues are arising such as ICI (which is caused due to signals coming from the adjacent sector of the same cell) and CCI) which occurs because of the reuse of same frequency in the adjacent cells). Futhermore, enabling D2D communications over the cellular networks will give higher capacity enlargement, however, it has to deal with many interferences especially in the ultra-dense network. In this paper, we have discussed a range of interference management schemes for complex and highly dynamic wireless networks. Particularly, it is mentioned that interferences in high-density HetNets networks can be mitigated by using static or dynamic interference cancellation techniques along with efficient resource allocation schemes. The potential solutions of interference mitigation for HetNets and D2D networks have been critically reviewed by focusing on their methodologies, advantages and limitations along with the future work. Moreover, the future researches challenges and few of the proposed 3GPP schemes to mitigate interferences has also been discussed. As discussed, these dynamic interference mitigation schemes are qualified to be considered an evolutionary step towards the 5G networks. The review concluded that the interference can be decreased by applying more advance eICIC techniques with highly efficient fairness-based CS scheme.

Acknowledgements The authors would like to acknowledge EPSRC Grant EP/P028764/1 (UM IF035-2017).

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict interest.

References

1. Prasad, A. R., Arumugam, S., Sheeba, B., & Zugenmaier, A. (2018). 3GPP 5G security. *Journal of ICT Standardization, 6*(1), 137–158.
2. Andrews, J. G., et al. (2014). What will 5G be? *IEEE Journal on Selected Areas in Communications, 32*(6), 1065–1082.
3. Patel, S., Chauhan, M., & Kapadiya, K. (2012). 5G: Future mobile technology-vision 2020. *International Journal of Computer Applications, 54*(17), 6–10.
4. Weber, S., Andrews, J. G., & Jindal, N. (2010). An overview of the transmission capacity of wireless networks. *IEEE Transactions on Communications, 58*(12), 3593–3604.
5. Talwar, S., Choudhury, D., Dimou, K., Aryafar, E., Bangerter, B., & Stewart, K. (2014). Enabling technologies and architectures for 5G wireless. In: *2014 IEEE MTT-S international microwave symposium (IMS)* (pp. 1–4). IEEE.
6. Rappaport, T. S., et al. (2013). Millimeter wave mobile communications for 5G cellular: It will work! *IEEE Access, 1*(1), 335–349.
7. Qamar, F., Abbas, T., Hindia, M. N., Dimyati, K. B., Noordin, K. A. B., & Ahmed, I. (2017). Characterization of MIMO propagation channel at 15 GHz for the 5G spectrum. In: *2017 IEEE 13th Malaysia international conference on communications (MICC)* (pp. 265–270). IEEE.
8. Al-Samman, A. M., Rahman, T. A., Hadri, M., & Hindia, M. N. (2017). Path loss and RMS delay spread model for 5G channel at 19 GHz. In *2017 IEEE 13th international colloquium on signal processing and its applications (CSPA)* (pp. 49–54). IEEE.
9. Qamar, F., Siddiqui, M. H. S., Dimyati, K., Noordin, K. A. B., & Majed, M. B. (2017). Channel characterization of 28 and 38 GHz MM-wave frequency band spectrum for the future 5G network. In: *2017 IEEE 15th student conference on research and development (SCOReD)* (pp. 291–296). IEEE.
10. Abbas, T., Qamar, F., Ahmed, I., Dimyati, K., & Majed, M. B. (2017). Propagation channel characterization for 28 and 73 GHz millimeter-wave 5G frequency band. In *2017 IEEE 15th student conference on research and development (SCOReD)* (pp. 297–302). IEEE.
11. Aslam, S., Jang, J., & Lee, K.-G. (2018). Unified channel management for cognitive radio sensor networks aided internet of things. *Sensors, 18*(8), 2665.
12. Hindia, M. N., Qamar, F., Rahman, T. A., & Amiri, I. S. (2018). A stochastic geometrical approach for full-duplex MIMO relaying model of high-density network. *Ad Hoc Networks, 74,* 34–46.
13. Qamar, F., Dimyati, K. B., Hindia, M. N., Noordin, K. A. B., & Al-Samman, A. M. (2017). A comprehensive review on coordinated multi-point operation for LTE-A. *Computer Networks, 123,* 19–37.
14. Song, J., & Choi, W. (2018). Minimum cache size and backhaul capacity for cache-enabled small cell networks. *IEEE Wireless Communications Letters, 7*(4), 490–493.
15. Zhang, H., Chu, X., Guo, W., & Wang, S. (2015). Coexistence of Wi-Fi and heterogeneous small cell networks sharing unlicensed spectrum. *IEEE Communications Magazine, 53*(3), 158–164.
16. Mavromoustakis, C. X., Mastorakis, G., & Batalla, J. M. (2016). *Internet of things (IoT) in 5G mobile technologies*. Berlin: Springer.
17. Udeshi, D., & Qamar, F. (2014). Quality analysis of epon network for uplink and downlink design. *Asian Journal of Engineering, Sciences & Technology, 4*(2), 78–83.
18. Chung, Y.-L. (2017). An energy-efficient coverage algorithm for macrocell—Small cell network systems. *Energies, 10*(9), 1319.
19. Gachhadar, A., Hindia, M. N., Qamar, F., Siddiqui, M. H. S., Noordin, K. A., & Amiri, I. S. (2018). Modified genetic

algorithm based power allocation scheme for amplify-and-forward cooperative relay network. *Computers & Electrical Engineering, 69,* 628–641.
20. Noordin, K. A. B., Hindia, M. N., Qamar, F., & Dimyati, K. (2018). Power allocation scheme using PSO for amplify and forward cooperative relaying network. In *Science and information conference* (pp. 636–647) Springer.
21. Hindia, M. N., Qamar, F., Majed, M. B., Rahman, T. A., & Amiri, I. S. (2019). Enabling remote-control for the power sub-stations over LTE-A networks. *Telecommunication Systems, 70*(1), 37–53.
22. Alliance, N. (2015) 5G white paper. In *Next generation mobile networks, white paper* (pp. 1–125). https://www.ngmn.org/fileadmin/ngmn/content/images/news/ngmn_news/NGMN_5G_White_Paper_V1_0.pdf.
23. Martín-Sacristán, D., Monserrat, J. F., Cabrejas-Peñuelas, J., Calabuig, D., Garrigas, S., & Cardona, N. (2009). On the way towards fourth-generation mobile: 3GPP LTE and LTE-advanced. *EURASIP Journal on Wireless Communications and Networking, 2009,* 4.
24. Dighriri, M., Lee, G. M., & Baker, T. (2018). Measurement and classification of smart systems data traffic over 5G mobile networks. In M. Dastbaz, H. Arabnia & B. Akhgar (Eds.), *Technology for smart futures* (pp. 195–217). Cham: Springer.
25. Xu, Y., Deng, J. D., Nowostawski, M., & Purvis, M. K. (2015). Optimized routing for video streaming in multi-hop wireless networks using analytical capacity estimation. *Journal of Computer and System Sciences, 81*(1), 145–157.
26. Antonakoglou, K., Xu, X., Steinbach, E., Mahmoodi, T., & Dohler, M. (2018). Towards haptic communications over the 5G tactile Internet. *IEEE Communications Surveys & Tutorials, 20*(4), 3034–3059.
27. Al Katsha, M. Z., & Ramli, H. A. M. (2016). Development of a novel component carrier selection algorithm in Long Term Evolution-Advanced (LTE-A) with carrier aggregation. In *2016 IEEE student conference on research and development (SCOReD)* (pp 1–5). IEEE.
28. Akbari, M., Reza, A. W., Noordin, K. A., Dimyati, K., Riahi Manesh, M., & Hindia, M. N. (2016). Recent efficient iterative algorithms on cognitive radio cooperative spectrum sensing to improve reliability and performance. *International Journal of Distributed Sensor Networks, 12*(1), 3701308.
29. Lee, J., et al. (2018). Spectrum for 5G: Global status, challenges, and enabling technologies. *IEEE Communications Magazine, 56*(3), 12–18.
30. Hattab, G., Visotsky, E., Cudak, M., & Ghosh, A. (2018). Interference mitigation techniques for coexistence of 5G mm wave users with incumbents at 70 and 80 GHz. arXiv:1801.05405.
31. Baldemair, R., et al. (2015). Ultra-dense networks in millimeter-wave frequencies. *IEEE Communications Magazine, 53*(1), 202–208.
32. Zhu, X., Zeng, J., Su, X., Xiao, C., Wang, J., & Huang, L. (2016). On the virtual cell transmission in ultra dense networks. *Entropy, 18*(10), 374.
33. Gupta, A., & Jha, R. K. (2015). A survey of 5G network: Architecture and emerging technologies. *IEEE Access, 3,* 1206–1232.
34. Zhang, H., Liu, N., Chu, X., Long, K., Aghvami, A.-H., & Leung, V. C. (2017). Network slicing based 5G and future mobile networks: Mobility, resource management, and challenges. *IEEE Communications Magazine, 55*(8), 138–145.
35. Hussein, H. H., & El-Kader, S. M. A. (2017). Enhancing signal to noise interference ratio for device to device technology in 5G applying mode selection technique. In 2017 international conference on advanced control circuits systems (ACCS) systems and 2017 international conference on new paradigms in electronics and information technology (PEIT) (pp 187–192). IEEE.
36. Nguyen, N.-P., Duong, T. Q., Ngo, H. Q., Hadzi-Velkov, Z., & Shu, L. (2016). Secure 5G wireless communications: A joint relay selection and wireless power transfer approach. *IEEE Access, 4,* 3349–3359.
37. Pabst, R., et al. (2004). Relay-based deployment concepts for wireless and mobile broadband radio. *IEEE Communications Magazine, 42*(9), 80–89.
38. Aldhaibani, J. A., Yahya, A., & Ahmad, R. B. (2014). Coverage extension and balancing the transmitted power of the moving relay node at LTE-A cellular network. *The Scientific World Journal, 2014*, 1–10.
39. Jeon, S.-W., & Gastpar, M. (2012). A survey on interference networks: Interference alignment and neutralization. *Entropy, 14*(10), 1842–1863.
40. Agiwal, M., Roy, A., & Saxena, N. (2016). Next generation 5G wireless networks: A comprehensive survey. *IEEE Communications Surveys & Tutorials, 18*(3), 1617–1655.
41. Khakurel, S., Mehta, M., & Karandikar, A. (2012). Optimal relay placement for coverage extension in LTE-A cellular systems. In *2012 national conference on communications (NCC)* (pp. 1–5). IEEE.
42. Alsharif, M. H., & Nordin, R. (2017). Evolution towards fifth generation (5G) wireless networks: Current trends and challenges in the deployment of millimetre wave, massive MIMO, and small cells. *Telecommunication Systems, 64*(4), 617–637.
43. Bao, V. N. Q., & Kong, H. Y. (2010). Performance analysis of decode-and-forward relaying with partial relay selection for multihop transmission over rayleigh fading channels. *Journal of Communications and Networks, 12*(5), 433–441.
44. Roden, R. J., & Tayler, D. (1993). Frame relay networks. *Digital Technical Journal, 5*(1), 1–8.
45. Ge, X., Cheng, H., Guizani, M., & Han, T. (2014). 5G wireless backhaul networks: Challenges and research advances. *IEEE Network, 28*(6), 6–11.
46. Seo, J., & Sung, Y. (2018). Beam design and user scheduling for nonorthogonal multiple access with multiple antennas based on pareto optimality. *IEEE Transactions on Signal Processing, 66*(11), 2876–2891.
47. Muruganathan, S. D., Lin, X., Maattanen, H.-L., Zou, Z., Hapsari, W. A., & Yasukawa, S. J. a. p. a. (2018). An overview of 3GPP release-15 study on enhanced LTE support for connected drones. https://arxiv.org/ftp/arxiv/papers/1805/1805.00826.pdf.
48. Checko, A., et al. (2015). Cloud RAN for mobile networks—A technology overview. *IEEE Communications Surveys & Tutorials, 17*(1), 405–426.
49. Bhushan, N., et al. (2014). Network densification: The dominant theme for wireless evolution into 5G. *IEEE Communications Magazine, 52*(2), 82–89.
50. Nam, W., Bai, D., Lee, J., & Kang, I. (2014). Advanced interference management for 5G cellular networks. *IEEE Communications Magazine, 52*(5), 52–60.
51. Feng, D., Jiang, C., Lim, G., Cimini, L. J., Feng, G., & Li, G. Y. (2013). A survey of energy-efficient wireless communications. *IEEE Communications Surveys & Tutorials, 15*(1), 167–178.
52. Hu, R. Q., & Qian, Y. (2014). An energy efficient and spectrum efficient wireless heterogeneous network framework for 5G systems. *IEEE Communications Magazine, 52*(5), 94–101.
53. Onireti, O., Héliot, F., & Imran, M. A. (2012). On the energy efficiency-spectral efficiency trade-off in the uplink of CoMP system. *IEEE Transactions on Wireless Communications, 11*(2), 556–561.
54. Beigh, A. N., & Kaur, Er. P. (2018). Inter-cell interference. *International Journal of Trend in Scientific Research and Development*, *2*(6), 43–46.
55. Yang, N., Wang, L., Geraci, G., Elkashlan, M., Yuan, J., & Di Renzo, M. (2015). Safeguarding 5G wireless communication

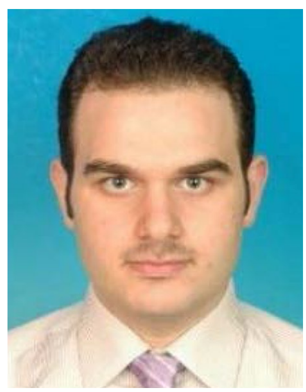
networks using physical layer security. *IEEE Communications Magazine, 53*(4), 20–27.
56. Seo, H., Kijun, K. I. M., & Kim, B. (2016). Method and apparatus for inter-cell interference coordination for transmission point group. US Patent 9,264,204.
57. Pang, J., Wang, J., Wang, D., Shen, G., Jiang, Q., & Liu, J. (2012). Optimized time-domain resource partitioning for enhanced inter-cell interference coordination in heterogeneous networks. In *2012 IEEE wireless communications and networking conference (WCNC)* (pp. 1613–1617). IEEE.
58. Gesbert, D., Hanly, S., Huang, H., Shitz, S. S., Simeone, O., & Yu, W. (2010). Multi-cell MIMO cooperative networks: A new look at interference. *IEEE Journal on Selected Areas in Communications, 28*(9), 1380–1408.
59. Zhang, S., Liu, L., Cheng, Y., Cao, X., & Cai, L. (2018). Energy-efficient beamforming for massive MIMO with inter-cell interference and inaccurate CSI. In *2018 international conference on computing, networking and communications (ICNC)* (pp. 518–523). IEEE.
60. Yang, H. J., Shin, W.-Y., Jung, B. C., Suh, C., & Paulraj, A. (2017). Opportunistic downlink interference alignment for multi-cell MIMO networks. *IEEE Transactions on Wireless Communications, 16*(3), 1533–1548.
61. Seo, H., Lee, D., Kim, B., Kijun, K., & Seo, I. (2017). Inter-cell interference coordination in a wireless communication system. US Patent 9,742,546.
62. Kim, J., Hwang, I. S., & Kang, C. G. (2011). Cooperative beamforming for inter-cell interference mitigation. In *2011 international conference on ICT convergence (ICTC)* (pp. 333–334). IEEE.
63. Chee, D., Kim, J., Ahn, W.-G., Jo, O., Lee, J. Y., & Cho, D.-H. (2011). Design and performance evaluation of virtual cellular networks mitigating inter-cell interference in indoor environments. In *2011 international conference on ICT convergence (ICTC)* (pp. 199–203). IEEE.
64. Jiang, S., Yu, F. R., & Sun, Y. (2013). Distributed energy-efficient inter-cell interference control with BS sleep mode and user fairness in cellular networks. In *2013 IEEE global communications conference (GLOBECOM)* (pp. 2581–2586). IEEE.
65. Al-Doori B., & Liu, X. (2016). Enabling NAICS to mitigate inter-cell interference in evolving wireless networks. in *Military communications conference, MILCOM 2016–2016 IEEE* (pp. 436–441). IEEE.
66. Morel, M.-L. A., & Randriamasy, S. (2017). Quality of experience-aware enhanced inter-cell interference coordination for self organized HetNet. In *Wireless and mobile networking conference (WMNC), 2017 10th IFIP* (pp. 1–8). IEEE.
67. Lopez-Perez, D., Guvenc, I., De la Roche, G., Kountouris, M., Quek, T. Q., & Zhang, J. (2011). Enhanced intercell interference coordination challenges in heterogeneous networks. *IEEE Wireless communications, 18*(3), 22–30.
68. Madan, R., Borran, J., Sampath, A., Bhushan, N., Khandekar, A., & Ji, T. (2010). Cell association and interference coordination in heterogeneous LTE-A cellular networks. *IEEE Journal on Selected Areas in Communications, 28*(9), 1479–1489.
69. Beckman, J. E., Yu, Y., Luo, L., & Fan, Z. (2017). Joint spatial processing for space frequency block coding and/or non space frequency block coding channels. US Patents 9,374,175.
70. Zhang, H., Chen, S., Li, X., Ji, H., & Du, X. (2015). Interference management for heterogeneous networks with spectral efficiency improvement. *IEEE Wireless Communications, 22*(2), 101–107.
71. Deb, S., Monogioudis, P., Miernik, J., & Seymour, J. P. (2014). Algorithms for enhanced inter-cell interference coordination (eICIC) in LTE HetNets. *IEEE/ACM Transactions on Networking, 22*(1), 137–150.
72. Pedersen, K. I., Wang, Y., Strzyz, S., & Frederiksen, F. (2013). Enhanced inter-cell interference coordination in co-channel multi-layer LTE-advanced networks. *IEEE Wireless Communications, 20*(3), 120–127.
73. Sun, S., Gao, Q., Peng, Y., Wang, Y., & Song, L. (2013). Interference management through CoMP in 3GPP LTE-advanced networks. *IEEE Wireless Communications, 20*(1), 59–66.
74. Pedersen, K. I., Wang, Y., Soret, B., & Frederiksen, F. (2012). eICIC functionality and performance for LTE HetNet co-channel deployments. In *Vehicular technology conference (VTC Fall), 2012 IEEE* (pp. 1–5). IEEE.
75. Wang, Y., & Pedersen, K. I. (2012). Performance analysis of enhanced inter-cell interference coordination in LTE-Advanced heterogeneous networks. In *Vehicular technology conference (VTC Spring), 2012 IEEE 75th* (pp. 1–5). IEEE.
76. Soret, B., Wang, H., Pedersen, K. I., & Rosa, C. (2013). Multicell cooperation for LTE-advanced heterogeneous network scenarios. *IEEE Wireless Communications, 20*(1), 27–34.
77. Ghosh, A. et al. (2012). Heterogeneous cellular networks: From theory to practice. *IEEE communications magazine, 50*(6), 54–64.
78. Damnjanovic, A. et al. (2011) A survey on 3GPP heterogeneous networks. *IEEE Wireless communications, 18*(3), 10–21.
79. Niu, H., Fwu, J.-K., & Yang, X. (2016). Method to support an asymmetric time-division duplex (TDD) configuration in a heterogeneous network (HetNet). US Patent 9,504,084.
80. Liu, J., Wang, D., Pang, J., Wang, J., & Shen, G. (2010). Inter-cell interference coordination based on soft frequency reuse for relay enhanced cellular network. In *2010 IEEE 21st international symposium on personal indoor and mobile radio communications (PIMRC)* (pp. 2304–2308). IEEE.
81. Han, Y., Chang, Y., Cui, J., & Yang, D. (2010). A novel inter-cell interference coordination scheme based on dynamic resource allocation in LTE-TDD systems. In *Vehicular technology conference (VTC 2010-Spring), 2010 IEEE 71st* (pp. 1–5). IEEE.
82. Higuchi, K., Saito, Y., & Nakao, S. (2013). Inter-cell interference coordination using coordinated inter-cell interference power control in uplink. In *2013 7th international conference on signal processing and communication systems (ICSPCS)* (pp. 1–5). IEEE.
83. Lu, S.-H., Lai, W.-P., & Wang, L.-C. (2014). Time domain coordination for inter-cell interference reduction in LTE hierarchical cellular systems. In *2014 10th International conference on heterogeneous networking for quality, reliability, security and robustness (QShine)* (pp. 51–55). IEEE.
84. Ezzaouia, M., Gueguen, C., Yassin, M., Ammar, M., Lagrange, X., & Bouallegue, A. (2017). Autonomous and dynamic inter-cell interference coordination techniques for future wireless networks. In *WiMob 2017-13th IEEE international conference on wireless and mobile computing, networking and communications*.
85. Hoshino, K., Nabatame, S., Nagate, A., & Fujii, T. (2015). Inter-cell interference coordination by horizontal beamforming for small cells in 3D cell structure. In *Wireless communications and networking conference workshops (WCNCW), 2015 IEEE* (pp. 364–368). IEEE.
86. Nuraini, H. (2016). Inter-cell interference coordination with soft frequency reuse method for LTE network. In *2016 2nd international conference on wireless and telematics (ICWT)* (pp. 57–61). IEEE.
87. Huang, J., Li, J., Chen, Z., & Pan, H. (2018). HICIC: Hybrid inter-cell interference coordination for two-tier heterogeneous networks with non-uniform topologies. *IEEE Access*, *6*, 34707–34723.
88. Simsek, M., Bennis, M., & Czylwik, A. (2012). Dynamic inter-cell interference coordination in HetNets: A reinforcement

learning approach. In *Global communications conference (GLOBECOM), 2012 IEEE* (pp. 5446–5450). IEEE.
89. Xu, S., Han, J., & Chen, T. (2012). Enhanced inter-cell interference coordination in heterogeneous networks for LTE-advanced. In *Vehicular technology conference (VTC Spring), 2012 IEEE 75th* (pp. 1–5). IEEE.
90. Ermolova, N. Y., & Tirkkonen, O. (2017). Interference analysis in wireless networks operating over arbitrary fading channels with heterogeneous poisson fields of transmitters and interferers. *IEEE Signal Processing Letters, 24*(9), 1388–1392.
91. Zhang, J., Qu, S., & Zhang, H. (2016). Regularized interference alignment for heterogeneous networks. In *2016 8th IEEE international conference on communication software and networks (ICCSN)* (pp. 201–205). IEEE.
92. Narmanlioglu, O., & Zeydan, E. (2017). Interference coordination in SDN-based heterogeneous mobile networks. In *2017 IEEE international black sea conference on communications and networking (BlackSeaCom)* (pp. 1–6). IEEE.
93. Dong, Y., Chen, Z., Fan, P., & Letaief, K. B. (2016). Mobility-aware uplink interference model for 5G heterogeneous networks. *IEEE Transactions on Wireless Communications, 15*(3), 2231–2244.
94. Kang, I., Han, S., & You, C. (2018). A study on the effect of moving small cell in heterogeneous networks with interference cancellation. in *2018 tenth international conference on ubiquitous and future networks (ICUFN)* (pp. 338–340). IEEE.
95. Osseiran, A., Monserrat, J. F., & Marsch, P. (2016). *5G mobile and wireless communications technology*. Cambridge: Cambridge University Press.
96. Mumtaz, S., Huq, K. M. S., & Rodriguez, J. (2014). Direct mobile-to-mobile communication: Paradigm for 5G. *IEEE Wireless Communications, 21*(5), 14–23.
97. Tehrani, M. N., Uysal, M., & Yanikomeroglu, H. (2014). Device-to-device communication in 5G cellular networks: Challenges, solutions, and future directions. *IEEE Communications Magazine, 52*(5), 86–92.
98. Shen, X. (2015). Device-to-device communication in 5G cellular networks. *IEEE Network, 29*(2), 2–3.
99. Qiao, J., Shen, X. S., Mark, J. W., Shen, Q., He, Y., & Lei, L. (2015). Enabling device-to-device communications in millimeter-wave 5G cellular networks. *IEEE Communications Magazine, 53*(1), 209–215.
100. Boccardi, F., Heath, R. W., Lozano, A., Marzetta, T. L., & Popovski, P. (2014). Five disruptive technology directions for 5G. *IEEE Communications Magazine, 52*(2), 74–80.
101. Liao, H.-S., Chen, P.-Y., & Chen, W.-T. (2014). An efficient downlink radio resource allocation with carrier aggregation in LTE-advanced networks. *IEEE Transactions on Mobile Computing, 13*(10), 2229–2239.
102. Rostami, S., Arshad, K., & Rapajic, P. (2013). Aggregation-based spectrum assignment in cognitive radio networks. In *2013 international conference on advanced computing and communication systems (ICACCS)* (pp. 1–6). IEEE.
103. Chayon, H. R., Dimyati, K., Ramiah, H., & Reza, A. W. (2017). An improved radio resource management with carrier aggregation in LTE advanced. *Applied Sciences, 7*(4), 394.
104. Ma, C., Liu, J., Tian, X., Yu, H., Cui, Y., & Wang, X. (2015). Interference exploitation in D2D-enabled cellular networks: A secrecy perspective. *IEEE Transactions on Communications, 63*(1), 229–242.
105. Zhou, Z., Ota, K., Dong, M., & Xu, C. (2017). Energy-efficient matching for resource allocation in D2D enabled cellular networks. *IEEE Transactions on Vehicular Technology, 66*(6), 5256–5268.
106. Mustafa, H. A. U., Imran, M. A., Shakir, M. Z., Imran, A., & Tafazolli, R. (2016). Separation framework: An enabler for cooperative and D2D communication for future 5G networks. *IEEE Communications Surveys & Tutorials, 18*(1), 419–445.
107. Benn, H. (2014). Vision and key features for 5th generation (5G) cellular. *Samsung R&D Institute UK*. https://www.scribd.com/document/293389711/RadioTech-30-01-14-HowardBenn-Samsung-pdf.
108. Asadi, A., & Mancuso, V. (2017). Network-assisted outband D2D-clustering in 5G cellular networks: Theory and practice. *IEEE Transactions on Mobile Computing, 16*(8), 2246–2259.
109. Wu, Y., et al. (2014). Green transmission technologies for balancing the energy efficiency and spectrum efficiency trade-off. *IEEE Communications Magazine, 52*(11), 112–120.
110. Ni, Y., Jin, S., Xu, W., Wang, Y., Matthaiou, M., & Zhu, H. (2016). Beamforming and interference cancellation for D2D communication underlaying cellular networks. *IEEE Transactions on Communications, 64*(2), 832–846.
111. Pan, J.-Y., & Liu, Y.-Y. (2015). Device-to-device interference avoidance underlaying cellular downlink transmission. In *2015 21st Asia-Pacific conference on communications (APCC)* (pp. 464–469). IEEE.
112. Wei, L., Hu, R. Q., He, T., & Qian, Y. (2013). Device-to-device (D2D) communications underlaying MU-MIMO cellular networks. In *Globecom workshops (GC Wkshps), 2013 IEEE* (pp. 4902–4907). IEEE.
113. Duong, Q., & Shin, O.-S. (2013). Distance-based interference coordination for device-to-device communications in cellular networks. In *2013 fifth international conference on ubiquitous and future networks (ICUFN)* (pp. 776–779). IEEE.
114. Zeng, S., Wang, C., Qin, C., & Wang, W. (2018). Interference alignment assisted by D2D communication for the downlink of MIMO heterogeneous networks. *IEEE Access, 6,* 24757–24766.
115. Yang, L., Zhang, W., & Jin, S. (2015). Interference alignment in device-to-device LAN underlaying cellular networks. *IEEE Transactions on Wireless Communications, 14*(7), 3715–3723.
116. Peng, T., Lu, Q., Wang, H., Xu, S., & Wang, W. (2009). Interference avoidance mechanisms in the hybrid cellular and device-to-device systems. In *2009 IEEE 20th international symposium on personal, indoor and mobile radio communications* (pp. 617–621). IEEE.
117. Chou, H.-J., & Chang, R. Y. (2017). Joint mode selection and interference management in device-to-device communications underlaid MIMO cellular networks. *IEEE Transactions on Wireless Communications, 16*(2), 1120–1134.
118. Ramezani-Kebrya, A., Dong, M., Liang, B., Boudreau, G., & Seyedmehdi, S. H. (2017). Joint power optimization for device-to-device communication in cellular networks with interference control. *IEEE Transactions on Wireless Communications, 16*(8), 5131–5146.
119. Tao, Y., Sun, J., & Shao, S. (2013). Radio resource allocation based on greedy algorithm and successive interference cancellation in device-to-device (D2D) communication. In *IET International Conference on Information and Communications Technologies (IETICT, 2013)* pp. 452–458.
120. Jungnickel, V., et al. (2014). The role of small cells, coordinated multipoint, and massive MIMO in 5G. *IEEE Communications Magazine, 52*(5), 44–51.
121. Cui, Q., et al. (2014). Evolution of limited-feedback CoMP systems from 4G to 5G: CoMP features and limited-feedback approaches. *IEEE Vehicular Technology Magazine, 9*(3), 94–103.
122. Gorce, J.-M., Tsilimantos, D., Ferrand, P., & Poor, H. V. (2014). Energy-capacity trade-off bounds in a downlink typical cell. In *2014 IEEE 25th annual international symposium on personal, indoor, and mobile radio communication (PIMRC)* (pp. 1409–1414). IEEE.
123. Österling, J. (2015). COMP operation in cellular communication networks. US Patent 9,071,290.

124. Lee, D. et al. (2012). Coordinated multipoint transmission and reception in LTE-advanced: Deployment scenarios and operational challenges. *IEEE Communications Magazine, 50*(2), 148–155.
125. Burström, P., De Bruin, P., Hagerman, B., Simonsson, A., & Skillermark, P. (2016). Performing coordinated multipoint transmission and reception (CoMP) in a wireless communication network. US Patent 9,281,876.
126. Lee, J. et al. (2012). Coordinated multipoint transmission and reception in LTE-advanced systems. *IEEE Communications Magazine, 50*(11), 44–50.
127. Zhao, J., Quek, T. Q., & Lei, Z. (2013). Coordinated multipoint transmission with limited backhaul data transfer. *IEEE Transactions on Wireless Communications, 12*(6), 2762–2775.
128. Irmer, R., et al. (2011). Coordinated multipoint: Concepts, performance, and field trial results. *IEEE Communications Magazine, 49*(2), 102–111.
129. Wang, Q., Jiang, D., Jin, J., Liu, G., Yan, Z., & Yang, D. (2009). Application of BBU + RRU based CoMP system to LTE-Advanced. In *IEEE international conference on communications workshops, 2009. ICC workshops 2009* (pp. 1–5). IEEE.
130. Nigam, G., Minero, P., & Haenggi, M. (2014). Coordinated multipoint joint transmission in heterogeneous networks. *IEEE Transactions on Communications, 62*(11), 4134–4146.
131. Fu, S., Wu, B., Ho, P.-H., & Ling, X. (2012). Interference coordination in CoMP with transmission scheduling and game theoretical power reallocation. In *2012 IEEE international conference on communications (ICC)* (pp. 4212–4217). IEEE.
132. Zetterberg, P., & Moghadam, N. N. (2012). An experimental investigation of SIMO, MIMO, interference-alignment (IA) and coordinated multi-point (CoMP). In *2012 19th international conference on systems, signals and image processing (IWSSIP)* (pp. 211–216). IEEE.
133. Hamza, A. M., Mark, J. W., & Sourour, E. A. (2018). Interference analysis and mitigation for time-asynchronous OFDM CoMP systems. *IEEE Transactions on Wireless Communications, 17*(7), 4780–4791.
134. Huang, S.-Y., Lin, K.-M., & Deng, J.-H. (2014). Interference alignment with efficient dynamic information selection for LTE-A uplink coordinated multipoint systems. In *2014 IEEE Asia Pacific conference on wireless and mobile* (pp. 72–77). IEEE.
135. Jang, H.-C., & Wend, W.-D. (2015). Interference management using frequency reuse and CoMP for LTE-advanced networks. In *2015 seventh international conference on ubiquitous and future networks (ICUFN)* (pp. 740–745). IEEE.
136. El Gamal, A., Annapureddy, V. S., & Veeravalli, V. V. (2014). Interference channels with coordinated multipoint transmission: Degrees of freedom, message assignment, and fractional reuse. *IEEE Transactions on Information Theory, 60*(6), 3483–3498.
137. Wang, S., Zhao, Y., Zhu, S., & Chen, G. (2015). SLNR based cascaded interference align precoding in CoMP. In *11th International Conference on Wireless Communications, Networking and Mobile Computing (WiCOM 2015)*.
138. Nossenson, R., Bellaiche, Y., & Hababou, D. (2013). On the potential of application based Coordinated Multi-point (CoMP). In *2013 IEEE international conference on microwaves, communications, antennas and electronics systems (COMCAS)* (pp. 1–2). IEEE.
139. Huang, C.-J., Chung, G.-H., Chung, W.-H., & Lee, T.-S. (2013). Efficient interference alignment aided transceiver design for LTE-A uplink coordinated multipoint systems. In *2013 IEEE 24th international symposium on personal indoor and mobile radio communications (PIMRC)* (pp. 1436–1440). IEEE.
140. Zhang, H., Venturino, L., Prasad, N., Li, P., Rangarajan, S., & Wang, X. (2011). Weighted sum-rate maximization in multi-cell networks via coordinated scheduling and discrete power control. *IEEE Journal on Selected Areas in Communications, 29*(6), 1214–1224.
141. Dahrouj, H., & Yu, W. (2010). Coordinated beamforming for the multicell multi-antenna wireless system. *IEEE transactions on wireless communications, 9*(5), 1748–1759.
142. Yu, W., Kwon, T., & Shin, C. (2013). Multicell coordination via joint scheduling, beamforming, and power spectrum adaptation. *IEEE Transactions on Wireless Communications, 12*(7), 1–14.
143. Michaloliakos, A., Ao, W. C., Psounis, K., & Zhang, Y. (2018). Asynchronously coordinated multi-timescale beamforming architecture for multi-cell networks. *IEEE/ACM Transactions on Networking, 26*(1), 61–75.
144. Hong, M., Sun, R., Baligh, H., & Luo, Z.-Q. (2013). Joint base station clustering and beamformer design for partial coordinated transmission in heterogeneous networks. *IEEE Journal on Selected Areas in Communications, 31*(2), 226–240.
145. Venturino, L., Prasad, N., & Wang, X. (2010). Coordinated linear beamforming in downlink multi-cell wireless networks. *IEEE Transactions on Wireless Communications, 9*(4).
146. Baracca, P., Boccardi, F., & Braun, V. (2012). A dynamic joint clustering scheduling algorithm for downlink CoMP systems with limited CSI. In *2012 international symposium on wireless communication systems (ISWCS)* (pp. 830–834). IEEE.
147. Chen, X., & Yin, R. (2013). Performance analysis for physical layer security in multi-antenna downlink networks with limited CSI feedback. *IEEE Wireless Communications Letters, 2*(5), 503–506.
148. Ahmed, Y. N. (2017). A novel multiuser MIMO scheduling technique for limited feedback systems. In *2017 13th international computer engineering conference (ICENCO)* (pp. 354–357). IEEE.
149. Deghel, M., Assaad, M., Debbah, M., & Ephremides, A. (2018). Traffic-aware scheduling and feedback allocation in multichannel wireless networks. *IEEE Transactions on Wireless Communications, 17*(8), 5520–5534.
150. Liu, S., Cui, J., Xu, J., & Tao, X. (2016). A channel estimation error adapted uplink scheduling algorithm in coordinated MIMO systems. In *2016 IEEE 27th annual international symposium on personal, indoor, and mobile radio communications (PIMRC)* (pp. 1–6). IEEE.
151. Jeong, M. R., & Miki, N. (2013). A simple scheduling restriction scheme for interference coordinated networks. *IEICE Transactions on Communications, 96*(6), 1306–1317.
152. Douik, A., Dahrouj, H., Al-Naffouri, T. Y., & Alouini, M.-S. (2016). Coordinated scheduling and power control in cloud-radio access networks. *IEEE Transactions on Wireless Communications, 15*(4), 2523–2536.
153. Shen, K., & Yu, W. (2016). Coordinated uplink scheduling and beamforming for wireless cellular networks via sum-of-ratio programming and matching. in *2016 IEEE international conference on acoustics, speech and signal processing (ICASSP)* (pp. 3531–3535). IEEE.
154. Douik, A., Dahrouj, H., Al-Naffouri, T. Y., & Alouini, M.-S. (2018). Distributed hybrid scheduling in multi-cloud networks using conflict graphs. *IEEE Transactions on Communications, 66*(1), 209–224.
155. Yang, Y., Zhang, Q., Shang, P., & Liu, J. (2014). Interference alignment based coordinated scheduling for uplink small cell enhancement. In *2014 IEEE 25th annual international symposium on personal, indoor, and mobile radio communication (PIMRC)* (pp. 1109–1114). IEEE.
156. Li, M., Collings, I. B., Hanly, S. V., Liu, C., & Whiting, P. (2016). Multicell coordinated scheduling with multiuser zero-forcing beamforming. *IEEE Transactions on Wireless Communications, 15*(2), 827–842.

157. Chen, C.-Y., Chen, Y.-Y., & Wei, H.-Y. (2016). Multi-cell interference coordinated scheduling in mmWave 5G cellular systems. In *2016 eighth international conference on ubiquitous and future networks (ICUFN)* (pp. 912–917). IEEE.
158. Kim, J., Park, J., & Kang, C. G. (2012). Performance of user and beam scheduling for coordinated multi-cell system. In *2012 international conference on ICT convergence (ICTC)* (pp. 685–686). IEEE.
159. Hossain, E., Rasti, M., Tabassum, H., & Abdelnasser, A. (2014). Evolution toward 5G multi-tier cellular wireless networks: An interference management perspective. *IEEE Wireless Communications, 21*(3), 118–127.
160. Dao, N.-N., Park, M., Kim, J., Paek, J., & Cho, S. (2018). Resource-aware relay selection for inter-cell interference avoidance in 5G heterogeneous network for Internet of Things systems. *Future Generation Computer Systems*, *93*, 877–887.
161. Noura, M., & Nordin, R. (2016). A survey on interference management for device-to-device (D2D) communication and its challenges in 5G networks. *Journal of Network and Computer Applications, 71,* 130–150.
162. Łukowa, A., & Venkatasubramanian, V. (2019). Centralized UL/DL resource allocation for flexible TDD systems with interference cancellation. *IEEE Transactions on Vehicular Technology, 68*(3), 2443–2458.
163. Seyama, T., Tsutsui, T., Oyama, T., Kobayashi, T., Dateki, H., Seki, M., et al. (2016). Study of coordinated radio resource scheduling algorithm for 5G ultra highdensity distributed antenna systems. *IEICE Technical Report*, *115*(472), 181–186.
164. Siddique, U., Tabassum, H., Hossain, E., & Kim, D. I. (2015). Wireless backhauling of 5G small cells: Challenges and solution approaches. *IEEE Wireless Communications, 22*(5), 22–31.
165. Shaat, M., Lagunas, E., Perez-Neira, A. I., & Chatzinotas, S. (2018). Integrated terrestrial-satellite wireless backhauling: Resource management and benefits for 5G. *IEEE Vehicular Technology Magazine, 13*(3), 39–47.
166. Cariou, L., & Stacey, R. (2018). Report for inter-bss interference avoidance. US Patents 15/384,934.
167. Mahmood, N. H., Pedersen, K. I., & Mogensen, P. (2017). Interference aware inter-cell rank coordination for 5G systems. *IEEE Access, 5,* 2339–2350.
168. Shafi, M., et al. (2017). 5G: A tutorial overview of standards, trials, challenges, deployment, and practice. *IEEE Journal on Selected Areas in Communications, 35*(6), 1201–1221.
169. Wu, S., Liu, F., Zeng, Z., & Xia, H. (2016). Cooperative sleep and power allocation for energy saving in dense small cell networks. *IEEE Access, 4,* 6993–7004.
170. Ma, W., Zhao, H., Liu, Y., Shao, S., & Pan, W. (2018). A Co-channel interference rejection method for 5G ultra dense heterogeneous networks. In *2018 IEEE international conference on communications workshops (ICC Workshops)* (pp. 1–5). IEEE.
171. 3GPP TS 38.212. (2018). *NR: Multiplexing and channel coding (Rel-15)*, v15.3.0. www.3gpp.org/ftp/Specs/archive/38_series/38.212/.
172. 3GPP TS 38.213. (2018). *NR: Physical layer procedures for control (Rel-15),* v15.3.0. www.3gpp.org/ftp/Specs/archive/38_series/38.213/.
173. Yang, L., & Zhang, W. (2014). Interference alignment in device-to-device LAN underlaying cellular networks. In *2014 IEEE international conference on communication systems (ICCS)* (pp. 21–25). IEEE.
174. 3GPP RP-80. (2018). *3GPPRAN#80 - Meeting #80 RP-181345*. https://portal.3gpp.org/Home.aspx#/meeting?MtgId=18663 .
175. 3GPP RP-79. (2018). *3GPPRAN#79 - Meeting information RP-183836*. https://portal.3gpp.org/Home.aspx#/meeting?MtgId=18659.
176. Ng, B. L., Chandrasekhar, V., Nam, Y.-H., & Kim, J. (2018). Beam management of downlink data channel and downlink control channel for 5G next radio systems. US Patent 10/148,337.

Faizan Qamar received his M.E. degree in Telecommunication in 2013 from NED University, Karachi, Pakistan and B.E. degree in Electronics in 2010 from Hamdard University, Karachi, Pakistan. He has more than 7 years of research and teaching experience. He is currently pursuing his Doctorate Degree in Electrical Engineering (major in wireless communication) from the Faculty of Engineering, University of Malaya, Kuala Lumpur, Malaysia. He has authored and co-authored a number of ISI Journals and IEEE Conference Papers. His research interest includes Wireless networks, Interference management and Millimeter wave communication for 5G.



M. H. D. Nour Hindia Obtained his Ph.D. In University of Malaya, Faculty of Engineering in Telecommunication in 2015. He is working in the field of Wireless Communications Especially in Channel Sounding, Network Planning, Converge Estimation, Handover, Scheduling and Quality of Service Enhancement for 5G Networks. Additially, He is working with Research Group in Modulation and Coding Scheme for Internet of Thing for Future Network. He Has Authored and Co-Authored a Number of Science Citation Index (SCI) Journals and Conference Papers. He has also participated as a Reviewer and a Committee Member of a Number of ISI Journals and Conferences.

Kaharudin Dimyati received his Bachelor of Engineering in Electrical from the University of Malaya in 1992. He then continued his Ph.D. in communication systems at the University of Wales Swansea, UK in 1993 and was subsequently awarded a Ph.D. in 1996. He is currently a professor in the Department of Electrical Engineering, University of Malaya, Kuala Lumpur, Malaysia. His research interests mainly includes wireless communication, optical communication and coding theory. He has supervised to completion to date 15 Ph.D. and 33 Master by research students. He had published more than 100 papers in reputed journals. He is a member of IET (UK), IEEE (US), IEICE (Japan), and IEM (Malaysia). He is a Professional Engineer, Malaysia and Chartered Engineer (UK).

Kamarul Ariffin Noordin received his B.Eng.(Hons.) and M.Eng.Sc from the University of Malaya, Kuala Lumpur, Malaysia in 1998 and 2001 respectively, and his Ph.D. in communication systems from Lancaster University in 2009, UK. He is currently an associate professor in the Department of Electrical Engineering, University of Malaya, Kuala Lumpur, Malaysia. His research interests mainly include resource allocation in wireless networks, cognitive radio networks, device-to-device communications, network modeling, and performance analysis.

Iraj Sadegh Amiri has been doing research on several topics such as the optical soliton communications, laser physics, fiber lasers, fiber grating, electro-optical modulators, nanofabrications, semiconductor design and modelling, Lumerical modelling, plasmonics photonics devices, nonlinear fiber optics, optoelectronics devices using 2D materials, semiconductor waveguide design and fabrications, photolithography fabrications, E Beam lithography, quantum cryptography and nanotechnology engineering.