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Next generation wireless cellular networks: ultra-dense multi-tier and multi-cell cooperation perspective

Baha Uddin Kazi[1] · Gabriel A. Wainer[1]

Abstract
The next generation wireless cellular network is aimed to address the demands of users and emerging use cases set by industries and academia for beyond 2020. Hence, The next generation 5G networks need to achieve very high data rates, ultra-high reliability, extremely low latency, energy efficiency and fully connected coverage. To meet these demands, ultra-dense networks (UDN) or ultra-dense heterogeneous networks (UDHetNet), millimeter wave (mmWave) and multicell cooperation such as coordinated multipoint (CoMP) are the three leading technology enablers. In this paper, we have made an extensive survey of the current literature on 5G wireless communication focusing on UDN, mmWave and CoMP cooperation. We first discuss the architecture and key technology enablers to achieve the goals of the 5G system. Subsequently, we make an in-depth survey of underlying novel ultra-dense heterogeneous networks, mmWave and multicell cooperation. Moreover, we summarize and compare some of the current achievements and research findings for UDHetNet, mmWave and CoMP. Finally, we discuss the major research challenges and open issues in this active area of research.

Keywords Cellular networks · 5G networks · Ultra-dense networks (UDN) · Millimeter Wave (mmWave) · Coordinated multipoint (CoMP)

1 Introduction

Smart devices and the mobile internet have unveiled a new world with unbound possibilities. The telecommunication industry has witnessed an explosion in a wide range of applications and services such as video streaming, network gaming, and social networking, these have become part of peoples' life. As a result, the number of mobile broadband users, the demand for data rates and the total volume of data traffic are increasing very fast. The number of mobile broadband subscriptions is growing globally by around 25% each year, and it is expected to reach 7.7 billion by 2021 [1]. The growth rate of mobile data traffic between the first quarter of 2015 to the first quarter of 2016 was about 60 percent and is expected to reach 351 Exabyte by 2025 [1, 2].

In this context, the main challenges in wireless cellular networks are providing services to the massive number of users, achieving higher data rates and the increasing demand for mobile data traffic by the users. With all of the above challenges, using long-term evolution (LTE) and LTE-Advanced (LTE-A) with the current 4G standard may not fully satisfy users' needs. Therefore, a new standard, such as fifth generation (5G) cellular networks have captured the attention of researchers and industry. 5G networks are expected to provide approximately a system capacity of 1000 times higher, 10 times the data rates, 25 times the average cell throughput, 90% reduction in energy usage and 5 times reduced latency when compared to the 4G networks [3–6].

To achieve the goals listed above, three key research directions are: network densification, enhance spectral efficiency and spectrum extension. The ultra-dense heterogeneous cellular networks (UDHetNets) is the densification approach that aims to improve network coverage

✉ Baha Uddin Kazi
bahauddinkazi@sce.carleton.ca

Gabriel A. Wainer
gwainer@sce.carleton.ca

[1] Department of Systems and Computer Engineering, Carleton University, Ottawa, ON, Canada

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and increase spectrum reuse. World leading cellular design and manufacture industries such as Qualcomm, Rakon, etc. stated that more small cells are the foundation to support 1000 $\times$ capacity challenge in the next generation wireless cellular networks [7, 8]. In UDHetNets, small cells are added to the legacy macro cells to increase the network capacity. It comprised of different types of wireless access nodes with different capabilities. Thus, UDHetNets consist of coexisting macrocells and low-power nodes such as remote radio head (RRH), pico eNB (PeNB), home eNB (HeNB) and relays. These low power small cells can reduce the load of the macrocells, increase the coverage and improve the user performance.

However, the coexistence of macro and low-power cells and densification of networks bring technical challenges such as interference management and backhauling. Hence, it is important to improve the spectral efficiency by coordinating, canceling or exploiting interference through advanced signal processing techniques. Multi-cell cooperation such as coordinated multipoint (CoMP) transmission and reception is considered as an effective method to achieve the expected gains of UDHetNets by mitigating the interference [2, 9–12]. The idea of CoMP is to evolve from the conventional single-cell multi-user system to multi-cell multi-user system so that user equipment (UE) close to the cell edge can be served by multiple base stations. In CoMP enabled systems, the base stations or evolved node Bs (eNBs) are grouped into cooperating clusters. The eNBs of each of these clusters exchange information with one another and jointly process signals by forming virtual antenna arrays distributed in space. The eNBs of each of these clusters exchange information among them and process signals and provide services to the users jointly. Furthermore, UEs, such as mobile phones can receive their signals simultaneously from one or more transmission points in a coordinated or joint-processing method [9, 13]. Although by now there has been some research done on CoMP for 3GPP LTE and LTE-Advanced networks, it is still a key feature of 5G wireless cellular networks to improve the spectral efficiency, throughput and cell edge performance.

Finally, millimeter wave communication is the key technology to extend bandwidth for higher data transfer in future wireless network. In UDHetNets, backhaul between macro eNBs and low power small cell eNBs should provide large bandwidth with reliable link transmission to achieve expected gain. In the mmWave bands, there are large chunks of bandwidth available and expected to enable Gbps user experience. Therefore, millimeter wave (mmWave) communication is considered the wireless backhaul solution as well as access link solution for UDHetNets. As a result, UDHetNets, mmWave and CoMP have complementary benefits and need to be combined to achieve the expected key capabilities of next generation wireless networks.

Interference mitigation is a serious challenge in UDHetNets. Therefore, the authors in [14] studied how to achieve maximal per area spectral efficiency in UDHetNet base on CoMP joint processing as CoMP is considered to be an effective approach to mitigate ICI. Marotta et al. in [15] proposed a joint use of CoMP and network function virtualization (NFV). They also studied the performance in terms of delay and overhead of centralized and distributed CoMP over NFV deployment. The physical layer technologies such as massive multiple-inputs multiple-outputs (massive-MIMO), millimeter wave (mmWave) and the deployment of small cells for 5G networks are discussed in [4]. This work does not cover the details about the multicell cooperation. In [16], the authors briefly reviewed the overall architecture of 5G including massive-MIMO, spectrum sharing, interference management, device-to-device communication (D2D), mm-Wave, multiple radio access technologies (m-RAT) and cloud technologies. This survey also discussed current research activities being conducted in different countries by research groups and industries. This study again lacks to provide a survey on multicell cooperation in the perspective of the dense next-generation networks. GSMA Intelligence and Ericsson in [17, 18] presented promising applications and requirements of 5G networks. Another important research area is the existing solutions for the backhaul used in 5G networks. Jaber et al. in [11] presented a comprehensive survey that explains backhaul problems, proposed solutions in the different literature. The authors in [19] provided a comprehensive survey on CoMP clustering schemes, however this article did not review the overall CoMP architecture in the context of UDHetNets. A theoretical analysis on coverage of UDHetNet where CoMP is adopted is presented in [20]. This paper also discussed about the impact of outdated channel state information (CSI) due to feedback delay. Rapaport et al. provided an overview on mmWave for 5G wireless network focusing on propagation model [21]. The authors in [22] also provide a comprehensive survey on mmWave communication. Gotsis et al. presented a general overview on fundamental issues related to UDN deployment [23]. An extensive survey on ultra-dense networks (UDN) was presented in [24]. This work also presented some research directions such as user association, interference mitigation, energy efficiency and backhauling. In [25], the authors provide a survey on UDN focusing on the current challenges and future research directions. This paper also lacks to provide state-of-the-art review on cooperative communication in the context of UDN. The authors in [26], discussed mmWave based UDN. They also proposed an energy efficient mmWave based UDN optimization framework. However, a review on mmWave and

CoMP within the coverage of UDN was not included as they have complementary advantages. Based on this, we are interested in providing an extensive survey on the 5G system in the context of mmWave, CoMP and UDHetNet though there has been a number of research done on the 5G system in terms of overall architectures and enabling technologies.

We aim at presenting further common understanding, potential gain and open issues of network densification in combination with the spectral efficiency enhancement technique of the next generation wireless cellular networks. In this light, we survey the published research in different areas of ultra-dense heterogeneous networks (UDHetNet), mmWave and coordinated multipoint (CoMP) communication. We first identify and quantify the vision and motivation of the 5G wireless cellular network with some future applications. Then, we discuss the state-of-the-art on UDHetNet, mmWave and CoMP, and we give a categorization of the different methods. We also discuss challenges and open issues that require further investigation. Our objective is to shed light on the passage of the successful deployment of UDHetNet with the combination of CoMP and mmWave to achieve the goal of the next generation wireless cellular networks.

The rest of the paper is organized as follows. In Sect. 2, we present the key features of different generations of cellular networks. In this section, we also present the architecture of the next generation wireless cellular networks and the key technology enablers. A complete review on the ultra-dense heterogeneous networks with open challenges are discussed in Sect. 3. In Sect. 4, we present the mmWave communication in the context of ultra-dense heterogeneous networks with open challenges. The coordinated multipoint (CoMP) operation is presented in Sect. 5. Finally, we conclude in Sect. 6.

2 Next generation cellular networks

Four generations of cellular technologies have been adopted up to now. A new generation has emerged approximately every decade roughly since 1980. A brief overview of the technological evolution from 1st generation to 4th generation of the cellular networks is presented in Table 1. However, the number of mobile subscribers increases every day, the demand for the data rates doubled every year and new bandwidth-hungry and low latency applications and services are introduced often [1, 12]. These are the factors that are considering the major drivers towards a new generation such as the 5G systems.

The fifth generation (5G) cellular networks have received significant attention from both academia and industry, as they are intended to overcome the challenges of existing cellular systems, such as the exponential growth of data traffic, coverage, lower latency, energy consumption, reliability, and cost as we mentioned earlier. Merging the different research works by academia and industries, the aim of the next generation 5G networks is to provide approximately a system capacity of 1000 times higher, 10 times the data rates, 25 times the average cell throughput, 5 times reduced latency and 10 times longer battery life compared to the 4G networks [2, 3, 5, 6, 17].

The 5G requirements and vision are derived from a set of requirements and potential use cases set by several industries and research bodies. For example, autonomous vehicle control enables driverless cars, which can improve traffic safety, increase productivity, and so on. Remote surgery and eHealth will provide us remote health monitoring such as electrocardiography (ECG), blood pressure, blood glucose and surgery for disaster response. In case of remote surgery, it is crucial for the surgeon to get the correct control and feedback with very strict requirements in terms of latency, reliability, and security. Moreover, smart cities will need remote monitoring of real-time traffic system, public safety, pollution, etc. The aggregation of all of these services leads to a very high density of interconnected devices with distinct characteristics in a communication framework. Figure 1 summarizes the key enablers, challenges, expected values, and some promising applications of the next generation of wireless cellular networks [6, 18].

To achieve these goals, the 5G cellular networks will adopt a set of new technologies. In the next subsection, we briefly discuss different key technology enablers adopted.

2.1 Key technology enablers

As discussed in the previous section, it is unlikely that one technology enabler will be able to fit all use cases and applications. Therefore, based on several research results, different promising concepts have been identified. These technical enablers can be categorized into three groups: *core network enablers*, *access network enablers and backhaul/cross-haul enablers*.

The key focus of the access network enablers is to improve the system bandwidth, spectral efficiency, and coverage. Ultra-dense network (UDN) or ultra-dense HetNet (UDHetNet), non-orthogonal multiple access (NOMA), massive multiple inputs multiple outputs (Massive-MIMO), coordinated multi-point (CoMP) communication, device to device (D2D) and machine to machine (M2M) communication, millimeter wave (mmWave) communication and energy harvesting are the key enables for access networks. The UDHetNet is one of the leading enablers, which is considered the foundation of 1000 fold data traffic growth [8, 12, 23]. The basic idea of UDN is to

Table 1 Key features for different generations (1G–4G) of cellular networks

	Generations			
	1st G	2nd G	3rd G	4th G
Year introduced	Late 1970s	Early 1990s	Early 2000s	Mid 2010s
Service technologies	Analog	Digital	Digital	Digital
Switching	Circuit	Circuit/Packet	Packet	Packet
Standards	Advanced Mobile Phone System (AMPS), Total Access Communication System (TACS), Nordic Mobile Telephone (NMT)	Global System for Mobile communications (GSM), General Packet Radio Services (GPRS), Enhanced Data GSM Environment (EDGE)	Universal Mobile Telecommunication System (UMTS)	Long Term Evolution (LTE) and LTE-Advanced
Access technologies	Frequency Division Multiple Accesses (FDMA)	Time Division Multiple Access (TDMA) and Code Division Multiple Access (CDMA)	Wideband Code Division Multiple Access (WCDMA), Code Division Multiple Access (CDMA) 2000, High-Speed Packet Access (HSPA) and HSPA+	Orthogonal Frequency Division Multiplexing (OFDM)
Carrier frequency	800 MHz	850, 900, 1800 and 1900 MHz.	800, 850, 900, 1800, 1900 and 2100 MHz	1.8 and 2.6 GHz
Bandwidth	30 kHz	200 kHz	5 MHz	20 MHz
Data rate	2.4 kbps	10–200 kbps	0.3–30 Mbps	0.7–1 Gbps
Applications	Voice	Voice and Data	Voice, Data, Video call, Mobile TV etc.	Voice, Data, Video call, Mobile TV, Online gaming, Video streaming etc.

densify the access nodes in per unit area that actually makes the access nodes closer to the UEs. We will discuss UDHetNet in Sect. 3 in details. Massive multiple inputs multiple outputs (Massive-MIMO) is another method that uses antenna arrays with few hundred antennas simultaneously serving many tens of UEs in the same time–frequency resource. The arrays of antennas capable of directing horizontal and vertical beams. This approach has gained attention for use in future wireless networks due to their high data rates, connection reliability, energy efficiency [27–29]. UDHetNets and Massive-MIMO require intelligent inter-cell interference mitigation. The coordinated multipoint (CoMP) operation provides an effective way for inter-cell interference coordination and cancellation among the closely located eNBs. Therefore, CoMP combined with UDHetNet and Massive-MIMO will play a vital role in improving coverage, energy efficiency, spectral efficiency and throughput of the next generation of cellular networks [4, 30, 31]. However, channel state information (CSI), associated with a large number of eNB antennas and coordination among multiple eNBs in massive-MIMO and CoMP induce a huge amount of information exchange overhead into the networks. As a result, managing CSI is also a vital issue to achieve the gain of multi-antenna systems.

Nonorthogonal multiple access (NOMA) is another access network technology, which is considered a candidate multiple access scheme for 5G networks to improve the spectral efficiency, reduce latency and provide massive connectivity to the system. NOMA exploits the user multiplexing in the power domain and demultiplexes on the receiver side adopting successive interference cancellation (SIC) [32, 33]. As we mentioned before, energy efficiency and battery lifetime are two of the key challenges in 5G networks. Harvesting energy from energy sources is an attractive solution to prolong the battery lifetime and to improve the energy efficiency of the overall system. In the radio frequency energy harvesting (RF-EH), a UE can recharge their batteries from hybrid access point using RF signals instead of traditional energy sources [34, 35].

To improve the overall system capacity, 5G core networks should also be much faster, flexible and scalable. Software-defined networking (SDN), network function virtualization (NFV) and cloud RAN (C-RAN) are the three main technologies of 5G core networks. The combining SDN and NFV solutions will achieve various

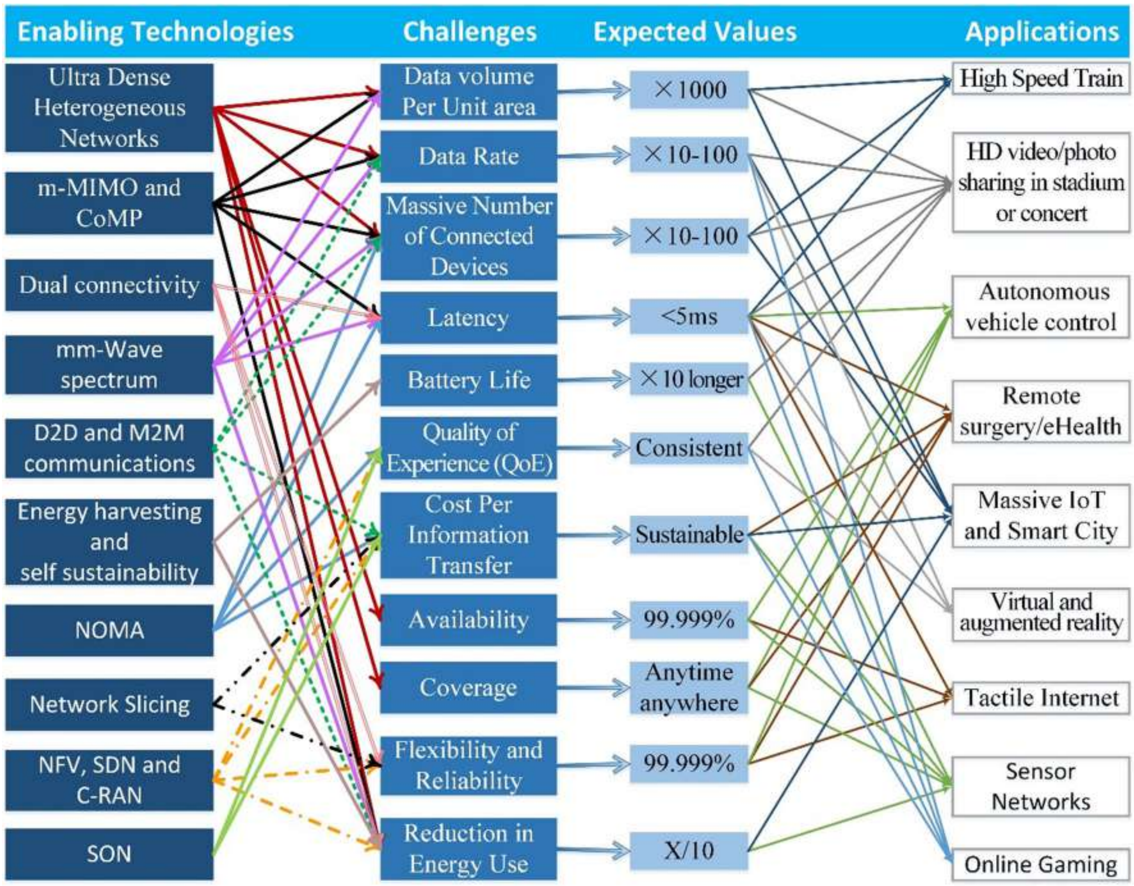

Fig. 1 5G requirements, enabling technologies and future applications

network control and management goals [36, 37]. In C-RAN architecture, baseband resources are separated in a shared pool, which is deployed on commodity hardware. This resource pool is shared by all the eNBs. C-RAN will improve the energy efficiency, reduce the operation cost and improve the network capacity by load balancing [38, 39]. Another solution to provide flexibility and scalability is Network slicing [40, 41], which provides multiple isolated logical networks in a single physical network. The 3GPP has defined network slicing as "a concept to allow differentiated service types depending on each customer requirements" [42, 43]. Likewise, self organizing networks (SON) enable reducing capital expenditure (CAPEX) and operational expenditure (OPEX). According to the 3GPP, there are three main functional areas for SON: *self-configuration*, *self-optimization and self-healing* [44–46]. The idea of self configuration is that a newly deployed eNB will configure its physical cell identity, transmission frequency, S1 and X2 interfaces automatically [47]. Once the network has been configured, it will be optimized according to the status of the system. Self optimization includes automatic optimization of coverage, capacity, interference and mobility load balancing. Self-healing functions detect and mitigate faults automatically by triggering appropriate recovery actions based on trigger condition [48]. Finally, the SON architectures can be categorized as *centralized*, *distributed and hybrid* [44].

With this rise of enabling technologies for 5G networks, the backhaul network has evolved to a composition of *fronthaul*, *midhaul*, and *backhaul* sections. The section connecting the remote radio head (RRH) to the baseband unit (BBU) or eNB directly is called *fronthaul*. The inter-eNB, and eNB and small cells link based on X2 interfaces is called *midhaul*. Finally, the network connections between eNBs and the core (such as mobility management entity (MME) and serving gateway (SGW)), based on the S1-interface have retained the name *backhaul* [11, 49]. In this research we use the term *backhaul* including for the three of them. The major backhaul solutions for 5G networks is summarized in Table 2.

There are two fundamentally different solutions for backhaul: wired and wireless. Wired solutions include fiber and copper (although the use of copper is gradually decreasing). A sophisticated technology, G.fast will be capable of providing up to 1 Gb/s bandwidth for short-range backhaul links. Moreover, non-standard technology

Table 2 Major backhaul solutions for 5G

	Properties				
	Topology	Technology	Frequency band	Capacity	Distance
Wired solutions	Fiber				
	(P2P)	P2P Fiber	1.31 μm laser	10 Gb/s	~ 20 km
	(P2MP)	Uni-PON	1.31 μm laser, WDM	10 Gb/s	< 10 km
		OTN/WDM	1.31 μm laser, WDM	Up to 100 Gb/s	> 10 km
		CWDM	C-Band 1.55 μm	Up to 100 Gb/s	> 10 km
		DWDM	C-Band 1.55 μm	Up to 100 Gb/s	> 10 km
	Copper	G. fast	Up to 212 MHz	1 Gb/s	20–500 m
Wireless solutions	NLOS				
	(P2MP), (P2P)	Sub 6 GHz	Sub 6 GHz	Up to ~ 500 Mb/s	< 1 km
	LOS				
	P2P	FSO	1.31 um laser	Up to 10 Gb/s	< 5 km
	(P2MP), (P2P)	Microwave	6–60 GHz	Up to 5 Gb/s	< 5 km
	(P2P)	Millimeter wave			
		V-band	57–66 GHz	1 Gb/s	< 1 km
		E-band	70–80 GHz	10 Gb/s	< 1 km
		W-band	92–114.25 GHz	100 Gb/s	< 1 km
		D-band	130–174.8 GHz	100 Gb/s	< 1 km

such as XG-fast can provide up to 10 Gb/s for few tens of meters. Fiber is the most preferable solution in terms of capacity, delay and cost for 5G backhaul solution. The optical transport network (OTN) with wavelength division multiplexing (WDM) provides full protection and operation, administration and maintenance (OAM) for long distance (more than 10 km) backhaul. OTN/WDM adopt a ring topology. Coarse WDM (CWDM) provides up to 200 Gb/s using separate fibers for uplink and downlink for a link distance more than 10 km [50, 51]. Moreover, dense WDM (DWDM) supports a higher number of channels than CWDM with the same channel capacity. A point to multipoint unified passive optical network (Uni-PON) can be used for short distances (less than 10 km). Uni-PON uses optical splitters to aggregate WDM signals from multiple cells [11, 51]. However, the reuse of deployed fiber infrastructure for 5G is a challenge. For future generation backhauling, wireless solutions have been attracting interest due to their implementation flexibility and cost. The Sub-6 GHz frequency supports non-line of sight (NLOS) propagation, which makes point to multi point (P2MP) and point to point (P2P) backhauling possible. With the line of sight (LOS) propagation, free space optical (FSO) provides several gigabits capacity for the backhaul. Microwave spectrum (6–60 GHz) provides up to 5 Gb/s capacity but favorable for relatively short distance due to signal attenuation. Millimeter wave (60–300 GHz) opens the opportunity of abundant bandwidth for wireless communications [21, 52, 53]. The details about the mmWave technology will be discussed in Sect. 4. In the next subsection, we discuss the general architecture of the next generation 5G networks.

2.2 5G wireless cellular networks architecture

The next generation 5G wireless cellular communications need a major change in the network architecture. It requires a mix of new concepts with the existing system to achieve the goals as discussed earlier. A general observation is that wireless users stay indoors approximately 80% of the time and stay outdoor only 20% of the time [3, 16]. In the conventional cellular architecture, an outdoor eNB in the middle of the cell helps the user to communicate each other whether they are indoor or outdoor. For indoor uses to communicate with the outside eNB, signals should go through different obstacles such as building walls. As a result, a very high penetration loss has happened which significantly reduces the spectral efficiency, data rate and energy efficiency of the wireless communication. Moreover, in current cellular networks, a single point for mobile communication is mainly used and the frequency reuse factor is 1, which creates strong inter-cell interference for the UE by the neighboring cells. Finally, the number of connected devices and the data traffic increase very rapidly as we mentioned in the introduction section. In this context, UDHetNet and Massive-MIMO with CoMP are the key concepts for the next generation wireless cellular networks [11, 12, 23]. Figure 2 shows a simplified general architecture of the next generation cellular access networks.

Ultra-dense heterogeneous network (UDHetNet) is a multi-tier network that includes legacy high-power macro cells and very dense low power small cells such as picocells, femtocells, relays and RRHs. These small cells are considered multiple radio access technology enabled (multi-RAT) and we will discuss details about them in the next section [54, 55]. The proximity of eNBs in dense networks increase the cell-edge area significantly, where UEs experience poor SINR. Consequently, interference mitigation is extremely important in UDHetNets. The coordinated multipoint (CoMP) operation can construct large cooperative multiple inputs multiple outputs transmission to avoid inter-cell interference, thus improving the UEs' SINR. Therefore, CoMP is considered a very effective technique to improve the coverage of high data rate, cell-edge throughput as well as system throughput. Though CoMP was introduced in LTE-A, it is also considered as a key feature for future dense cellular networks [19, 31]. Moreover, mmWave is considering for wireless backhaul links and access links to provide extended bandwidth in UDHetNet. In the next three sections, we discuss UDHetNets, mmWave and CoMP in details, including with the challenges that need to be investigated.

3 Ultra-dense heterogeneous wireless cellular networks

The idea of UDHetNet is to have a very dense deployment of small cells combined with legacy macro cells. It is a multi-tier network with multi-radio access technologies (multi-RAT), where dense low power small cells are multi-RAT capable. The distance between UEs and eNBs become shorter, spectrum reuse increase, and transmission power reduce. As a result, three primary gains of UDHetNets are: improved link quality, energy efficiency and capacity improvement. In order to understand better how the capacity of the network significantly improves, the

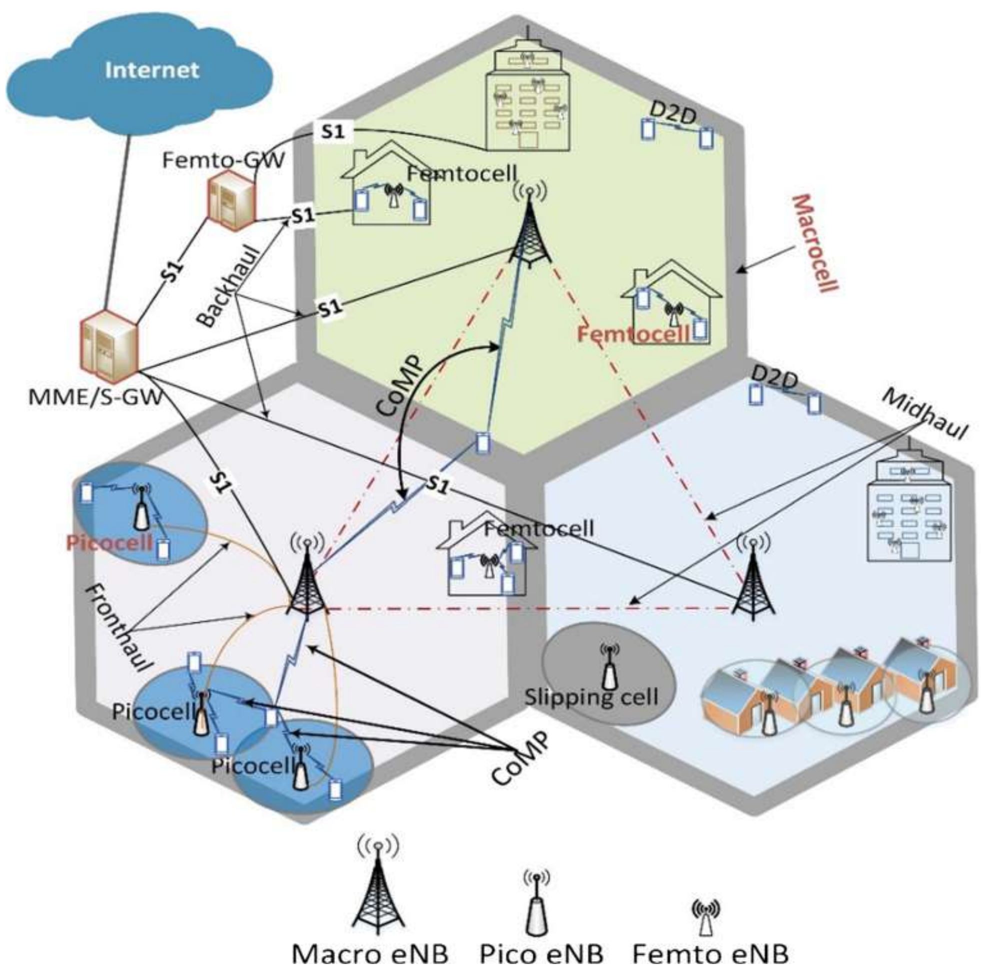

Fig. 2 A simplified general architecture of 5G multi-tier wireless cellular access networks

network capacity can be defined as follows based on the Shannon theory [56].

$$C = \sum_{eNB_1}^{eNB_M} \sum_{UE_{1m}}^{UE_{nm}} BW_{nm} \log_2(1 + SINR_{nm}) \quad (1)$$

where, $\{eNB_1 \ldots eNB_M\}$ is the set of eNBs deployed in the networks, $\{UE_{1m} \ldots UE_{nm}\}$ is the set of UEs connected to the eNB_m and $m = \{1 \ldots M\}$. BW is the total available bandwidth and BW_{nm} is the bandwidth allocated to UE_n connected to eNB_m. The $SINR_{nm}$ represents the quality of the signal experienced by the UE_n connected to eNB_m.

The network densification increases the number of eNBs into the network that linearly increases the reusability of available BW, which eventually increase the capacity of the network. On the other side, cell densification reduces the cell size which results in the lower number of connected UEs to an eNB. Therefore, a larger BW is available per UE. Moreover, as the cell size reduces, the average distance between a UE and the serving eNB reduces, which increase the quality of UE received signal.

However, Ding et al. in [57] present new pathloss model for ultra-dense networks. To obtain more accurate pathloss model, they consider 3D distance (d) between the serving eNB and a UE and pathloss is a multi-piece function of d as described below.

$$p_{L(n)}(d) = \begin{cases} p_n^L(d) = A_n^L d^{-\propto_n^L}, & for\ LoS \\ p_n^{NL}(d) = A_n^{NL} d^{-\propto_n^{NL}}, & for\ NLoS \end{cases} \quad (2)$$

where, $p_n^L(d)$ and $p_n^{NL}(d)$ are the n-th piece of the pathloss functions for the LoS and NLoS transmission respectively. A_n^L and A_n^{NL} are the pathlosses at a reference distance $d = 1$. The distance d is the 3D distance between eNB and a UE and $n \in \{1, 2, \ldots, N\}$. $\propto_n^L$ and $\propto_n^{NL}$ are the pathloss exponents for LoS and NLoS transmission respectively. Table 3 summarizes the major research works with key points related to the UDHetNet.

In the following subsections, we provide a basic background of different types of cells considered for deployment in UDHetNets. We also discuss the fundamental features and architectures. Moreover, we present some future challenges and open issues of UDHetNet.

3.1 Deployment of cells

Ultra-dense heterogeneous networks (UDHetNet) consist of various access technologies, each of them is having different operating functions with different capabilities and constraints. It enables efficient reuse of spectrum across the area of interest, which is one of the key solutions to achieve capacity increase for the next generation wireless cellular networks [8, 12, 55]. In general, cells in UDHetNets can be classified into three types. (a) fully functional high power macrocells (legacy cells); (b) fully functioning small cells (picocells and femtocells), which are capable of performing all the functions of macrocells with low power in a smaller coverage area; and (c) macro extension access points, such as relays and remote radio heads (RRHs), which are the extension of the macrocell to extend the signal coverage without the baseband unit (BBU). Table 4 summarizes the features of different types of cells stated above [24, 54, 75, 76].

The details of the different cell types are discussed as follows:

- **Macrocells** consist of conventional operator installed outdoor eNBs. They are deployed in a planned manner, providing open public access and covering a wide area typically of a few kilometers. They are usually intended to provide a guaranteed minimum data rate under a maximum tolerable delay and outage constraints. Macro eNB (MeNB) typically transmit high power level such as 43–46 dBm.
- **Picocells** consist of low power operator installed eNBs, named PeNB. They are typically deployed in outdoor and indoor by the provider in a planned manner. The transmit power range from 250 mW to 2 w for outdoor and about 100 mW for indoor. However, picocells have the same access features and backhaul as macrocells to provide high bandwidth and low latency.
- **Femtocells** are usually deployed by users indoor (home, office, meeting room etc.). They are low power access points deployed in an unplanned manner with typical transmit power is 100 mW or less. They serve very few home users, where most of the data traffic generated as we discussed before. The backhaul network for femto eNBs (FeNB) is facilitated by the consumers' broadband connections such as digital subscriber line (DSL), cable or fiber. According to the access of a femtocell, it operates in three different modes: open, closed and hybrid. Closed femtocells are restricted to the closed subscriber group (CSG). In this case UEs can not connect to the strongest cell always, which might cause strong interference [56]. On the other hand, in the open access mode all subscribers of a given operator can access the node. This deployment mode reduces the load of the macro cell but might strain the backhaul capacity of the small cells. In hybrid mode, all the subscribers can get access but the quality of service (QoS) is guaranteed only for the subscriber of the CSG [65]. Moreover, some recent works also consider cognitive radio to enhance the interference condonation among the dense macro-cells and femtocells [77, 78]. The authors in [79] present an extricated system model for cognitive femtocell based resource

Table 3 Major related works in ultra-dense heterogeneous networks

References	Work area	Key points presented in the corresponding referred articles
[12, 23, 56–59]	UDHetNets density	Analysis of the pathloss model to study the performance impact in small cell networks (SCNs)
		UDHetNet capacity
		Network configuration in terms of density, frequency band and number of antennas
		Coverage probability
[60–64]	Mobility	Scheduling algorithm for UDN
		Frame structure for UDN
		User/Control plane separation
		Handover procedure for data only carrier
[23, 56, 65, 66]	Densification challenges	Interference management
		Energy efficiency
		Backhaul
		Architecture
[11, 54, 67]	Backhaul distribution	Gateway based distribution architecture
		Backhaul energy efficiency
		mm-wave Backhaul
		5G backhaul architecture
[68–70]	Massive-MIMO	MIMO in small cell networks
		Cell reassignment of UEs to gain spectral efficiency
		User association
[71–74]	Modeling and simulation	Types of simulation approaches
		Comparative study of network simulators regarding UDHetNet

Table 4 Key features of different types of cells

Types of nodes	Deployment scenario	Transmit power	Coverage	Backhaul	Placement
Macrocell	Outdoor	43–46 dBm	Few km	S1 interface	Planned
Picocell	Indoor/outdoor	23–30 dBm	$<$ 300 m	X2 interface	Planned
Femtocell	Indoor	$<$ 23 dBm	10–50 m	Internet IP (non-ideal)	Unplanned
Relays	Indoor/outdoor	30 dBm	300 m	Wireless	Planned
RRHs	Outdoor	$\geq$ 30 dBm	300–500 m	Fiber (ideal)	Planned

allocation. This paper also studies the outage impact in cognitive femtocell deployed in macro networks.

- **Relays** are operator-installed access points that are typically deployed to cover poor coverage areas and dead zones in the macrocells. The backhaul that connects the relay node to the macro eNB is wireless and uses the air interface resources of the cellular system. Relays transmit the users' data back and forth from and to the macro cell. Therefore, relays are actually an extension of the macro eNB not a fully functional access point.
- **RRHs** are low-weight RF units, which are mounted outside the macrocells to extend the coverage of the central eNBs. The RRH has no baseband unit ((BBU). RRHs are connected to the Macro eNB (MeNB) or BBU pool via high-speed fiber or millimeter wave. The Central eNBs or BBU pools do all of the signal processing. The BBU pool is composed of BBUs that process baseband signals and optimize the network resource allocation. Therefore, RRHs are deployed for centralized densification instead of distributed densification. RRH can be relatively simple and cost-effective.

3.2 Ultra-dense heterogeneous networks architectures

The idea of small cell has appeared to raise the throughput and save energy in cellular networks [54]. Moreover, as we mentioned before, industry and research community also state that more small cells are needed to increase throughput in wireless cellular networks. Therefore, the first step is how to design the architecture of the networks. In this section, we summarize the architecture of UDHetNet with the following key features: densification of access points, deployment architecture and distribution architecture. In Fig. 3 we classified different approaches of the architecture we found in the literature.

3.2.1 Cell densification

Network densification of wireless cellular networks primarily takes place by the deployment of increasing number of small cells with legacy macro cells to improve the coverage and the capacity. There are two different approaches we found to densify the network: *horizontal densification* and *vertical densification*, depicted in Fig. 4 [24].

In horizontal densification, the access points are densified in the horizontal plane. Thus, denser the deployment of the access points smaller the size of the cells. Vertical densification takes place in the elevation axis. In this case, users deploy low power eNBs in their offices, apartments, shopping centers etc. in a high-rise structure [24]. Therefore, in the indoor scenarios both horizontal and vertical densification is possible but in the outdoor scenarios, mostly horizontal densification occurs.

3.2.2 Deployment architecture

There are two different deployment architectures for radio access networks (RAN): *centralized and distributed*. In a centralized architecture, a central eNB or a pool do the coordination among the different entities of the network. This eNB or pool can be equipped with a distributed antenna system (DAS) or a massive-MIMO system or a cloud radio access network (C-RAN). In a centralized architecture, there is a possibility of performance bottleneck in the central entity. In the distributed or flat architecture, traffic is forwarded in a distributed manner making use of cell level and core network level. In this case, IP-enabled access points are directly connected to the IP core infrastructure or gateway, which provides convenient interoperability among wireless heterogeneous access technologies [65, 80]. However, a distributed architecture

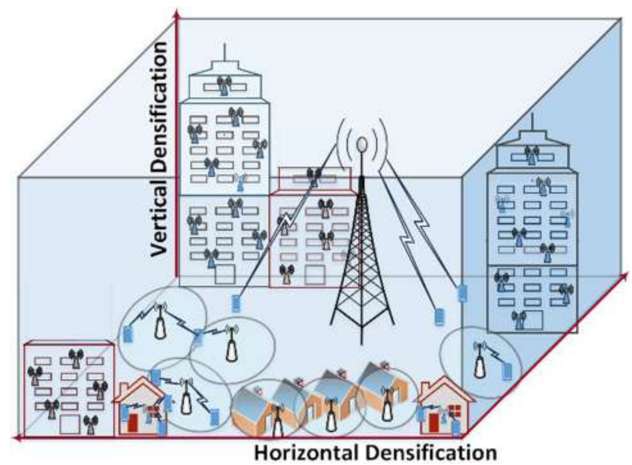

Fig. 4 Densification approaches in UDHetNets

requires scalable algorithms for the collaboration among the nodes.

3.2.3 Backhaul distribution architecture

Forwarding the backhaul traffic is another challenge in UDHetNets. In this case, we need to consider two key issues. First, the cost and deployment challenges for forwarding the backhaul data of every small cell by broadband internet or fiber links in the urban area. Second, it might not be possible for all of the small cell eNBs forwarding data directly to the gateway because of the restricted transmission distance of wireless technology. Based on the above issues, in [54] the authors proposed two backhaul distribution architectures: *ultra-dense cellular networks with a single gateway* and *ultra-dense cellular networks with multiple gateways*. In the first case, the MeNB is configured as a gateway with massive MIMO. This gateway will receive the backhaul traffic directly from the small cells, or the small cells will relay the backhaul traffic to the adjacent small cell by millimeter wave links. These relayed backhaul traffic will be forwarded to the MeNB by multi-hop links. Finally, the MeNB will forward the aggregated traffic to the core network by fiber links. On the other hand, in the ultra-dense cellular networks with multiple gateways, the gateways are deployed in multiple small cell eNBs based on the requirement of the backhaul traffic and geographic scenarios. Different eNBs will forward the backhaul traffic to the nearest gateway using millimeter

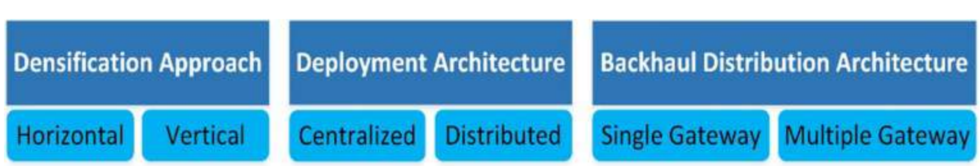

Fig. 3 Different types of ultra-dense HetNets architecture

wave links, and the gateways will forward the aggregated traffic to the core network by fiber links.

3.3 Open issues and challenges

Network densification has a significant impact on the improvement of coverage, throughput and spectral efficiency of wireless cellular networks. Ultra-dense heterogeneous networks (UDHetNet) are considered one of the key enablers for 5G wireless to achieve capacity increase with respect to LTE. In this section, we focus on the challenges facing the successful deployment of UDHetNet to achieve the expected performance. Many of the related papers also discuss the challenges of UDHetNets. However, here we summarize the open issues and challenges that require further investigation.

- How much ***densification*** can be possible to deploy the eNBs is still an open issue. To define the densification limit we need to consider both access network technologies and backhaul networks. As shown in Table 5, different research shows different values for the number of eNBs per km^2. Therefore, cellular densification limit needs to be investigated further.
- **Interference management (IM)** is still one of the most challenging issues in UDHetNets [11, 55, 65]. In [2], the authors also mention that suppressing interference through advanced signal processing techniques to attain the potential gain of UDHetNet is very critical. In [83], the authors identify three specific challenges for interference management in UDHetNets. First, as the density increases, the interference level becomes less distinguishable. Next, the interference becomes highly correlated as the channels between neighbouring cells are more likely to be spatially dependent. Finally, interference distribution is more unpredictable compared to traditional homogeneous networks. They also discuss state-of-the-art IMs such as power control methods, multiple access methods, successive interference cancellation and CoMP based on the above-mentioned challenges. Cao et al. in [84], also discusses that co-channel interference in UDHetNet is severe because of the density and randomness of small cell deployment. Therefore, interference management requires more investigation in the context of UDHetNets and might need adopting advanced techniques or enhancement of the state-of-the-art techniques.
- Several research works and surveys show that most of the operators consider the **backhaul** as one of the key challenges to small cell deployment [11, 51, 56]. Backhauling is identified as a bottleneck for the widespread deployment of ultra-dense HetNets. There are some wired and wireless backhaul solutions proposed in the literature in order to address the backhaul needs in dense heterogeneous 5G RAN [11, 67]. In [54], the authors investigated backhaul energy efficiency and capacity of ultra-dense wireless cellular networks and proposed two backhaul distribution architectures. Therefore, the study on wired and wireless backhauling is still an open issue.
- Working concurrently with multiple radio access technology (multi-RAT) and multi-connectivity, the eNBs and the UEs must be equipped with multiple **radio transceivers**. To realize the multi-RAT and multi-connectivity with various communication standards, both the UEs and the eNBs need to include multiple separate transceiver radio units, which will increase the overall size and cost of the system. Therefore, future UEs and eNBs might need major architectural change to support dynamic and concurrent multiband spectrum access [85, 86].
- The **handover** process is used to support the seamless mobility of the UEs in the wireless cellular network. The handover process allows a UE in active mode to transfer from the serving cell to a neighboring cell with the strongest received power without awareness of the user. UDHetNets comprised of different tiers of cells with different frequency bands that intensify the existing challenges of handling handover for UEs. The 3GPP in [87] showed that the increase in the number of handovers in small cell networks compared to macro only networks can be 120–140% depending on the speed of the user equipment (UE). Moreover, in HetNets a mobile UE cannot consider the same set of

Table 5 Number of access points per km^2 in UDHetNets

References	Traditional networks	LTE-A with HetNets	Next generation wireless cellular networks with UDHetNet
[54]	4–5eNBs/km^2	8–10 eNBs/km^2	40–50 eNBs/km^2
[81]	7 eNBs/km^2	21–26 eNBs/km^2	93 eNBs/km^2
[55]	–	–	100 eNBs/km^2
[57, 58]	–	–	10^3 eNBs/km^2
[82]	3–5eNBs/km^2	–	1000 eNBs/km^2

handover parameters in all the networks as those used in macro-only networks. Therefore, in UDHetNets, the handover process is also a challenge.

- **Energy efficiency** plays a significant role in the operating expense of the network, which is an important factor to consider. This is referred as the ratio between the area spectral efficiency and the total power consumed in a network [65]. The maximization of energy efficiency considering the quality of experience (QoE) is an interesting area to be investigated in UDHetNets. To investigate the energy efficiency, we should consider the access networks as well as the backhaul networks.

Though densification of access points is shown to have a significant impact on the performance of wireless cellular networks, it is important to consider signaling, overhead, computational complexity, cost etc. alongside the above-mentioned challenges measuring the viability of the deployment of UDHetNets. However, it provides the ideal propagation environment for millimeter-wave bands [88]. Thus, as UDHetNet are considered to be a key enabler for the next generation of wireless cellular networks, it should also be studied with other potential enablers that enhance the spectral efficiency and bandwidth such as coordinated multi-point (CoMP) and millimeter wave communications. In the next two sections, we present the state-of-the-art research works on millimetre wave and CoMP operation.

4 Millimeter wave communication

UDHetNet is considered a promising technology to meet the 5G and beyond key performance indicators (KPIs) we discussed in Sect. 1. In this architecture, the backhaul requirements between macro eNBs and small cell eNBs should differ from macro only networks in terms of capacity and cost. It has been shown that backhaul links with 1–10 Gbps are required for effective deployment of UDHetNets [22]. Likewise, the cell coverage area reduces when the density increases, exploiting spatial reuse. Recent studies show that mmWave frequencies allow for larger bandwidth allocation than the present 20 MHz channels used by 4G. By increasing the radio frequency (RF) channel bandwidth, the data transfer rate can increase. Because of its new capacity and characteristics, mmWave is considered for both backhaul links between eNBs and access links between eNB and devices. In this section, we discuss mmWave communication in the context of UDHetNets.

4.1 Millimeter wave spectrum

There are four broad categories of carrier frequencies: sub-3 GHz band, sub-6 GHz band, microwave (6–60 GHz) and millimeter wave (60–300 GHz) [52, 53, 89]. Figure 5 shows the 5G micro wave and millimeter wave spectrum bands.

Most of the current mobile communication systems use the 300 MHz to 3 GHz spectrum. The sub-6 GHz frequencies support NLOS propagation, thus both P2P and P2MP links are possible. The typical micro wave frequency links are reported as 10.5, 13, 15, 18, 23, 26, and 32 GHz [52]. Moreover, the authors in [90] investigated the 28 and 38 GHz bands rigorously, where 1 GHz of bandwidth is available. Micro wave frequencies are favorable for short range communication such as UDHetNet because of high signal attenuation. Recent studies suggest that mmWave could be used to achieve multi-Gbps data rates augmenting the wireless spectrum currently used. The mmWave offers high bandwidth and propagation for high capacity short-range links. V-band (57–66 GHz) and E-Band (70–76 and 81–86 GHz) have been deployed for several years, and it is considered that they will be suitable for 5G as well. Moreover, standardization of new bands such as W-band (92–114.25 GHz) and D-band (130–174.8 GHz) is ongoing, which will provide 5 times more spectrum than E-band [91, 92]. Hence, the next generation millimeter wave wireless channel bandwidth is expected to be 10 times greater than today's 4G channel bandwidth.

4.2 Millimeter wave channel model

Since the wavelength of mmWave is shorter, the diffraction and penetration of materials will incur greater attenuation. Thus, accurate propagation models are needed for the design and standardization of new bands. Over the past few years, several research groups presented propagation models of mmWave for different scenarios [93–96]. Table 6 summarizes the pathloss models for small cell scenarios based on 3rd generation partnership project (3GPP) cellular standardization body. 3GPP technical documents serve as the international industry standard for 5G cellular networks.

In the above equations PL is the pathloss according to the scenario, d_{3D} is the Euclidean distance between eNBs and UEs. The σ_{SF} is the shadow fading in dB and f_c is the carrier frequency. h_{UE} and h_{BS} are the heights of UE and eNB respectively. The breakpoint distance $d'_{BP} = 4 \cdot h'_{BS} \cdot h'_{UE} \cdot f_c / c$. Where, h'_{BS} and h'_{UE} are the effective antenna height of eNB and UE. h'_{BS} and h'_{UE} calculate as follows: $h'_{BS} = h_{BS} - h_E$ and $h'_{UE} = h_{UE} - h_E$. Where, h_E is the environment height and is considered

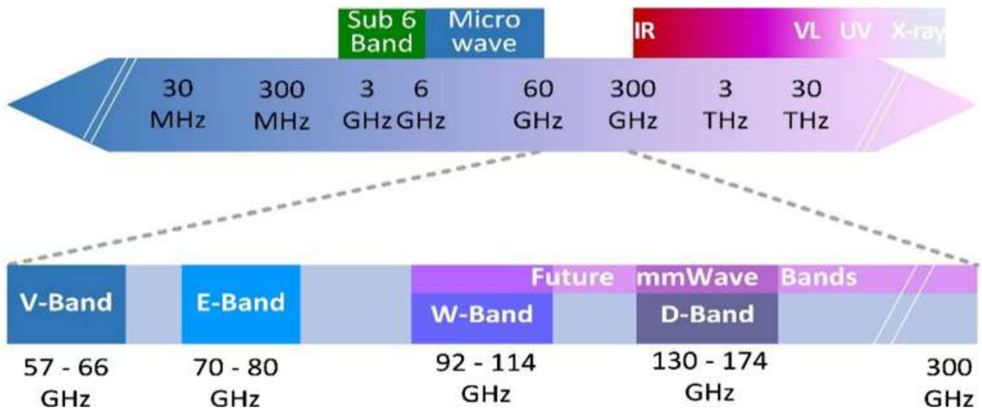

Fig. 5 5G Wireless micro wave and millimeter wave spectrum

Table 6 Pathloss models for urban micro and indoor hotspot scenarios

Scenarios	Pathloss models	Evaluation parameters
Urban Micro (UMi)		
LOS	$PL = \begin{cases} PL_1 & 10\text{ m} \le d_{2D} \le d'_{BP} \\ PL_2 & d'_{BP} \le d_{2D} \le 5\text{ km} \end{cases}$ $PL_1 = 32.4 + 21\log_{10}(d_{3D}) + 20\log_{10}(f_c)$ $PL_2 = 32.4 + 40\log_{10}(d_{3D}) + 20\log_{10}(f_c) - 9.5\log_{1o}(\left(d'_{BP}\right)^2 + (h_{BS} - h_{UT})^2)$	$\sigma_{SF} = 4.0$ $0.5 \le f_c \le 100$ GHz $1.5\text{ m} \le h_{UE} \le 22.5$ m $h_{BS} \le 10$ m
NLOS	$PL = \max\left(PL_{LOS}, PL'_{NLOS}\right)$ $PL'_{NLOS} = 35.3\log_{10}(d_{3D}) + 22.4 + 21.3\log_{10}(f_c) - 0.3(h_{UT} - 1.5)$	$\sigma_{SF} = 7.82$ $0.5 \le f_c \le 100$ GHz $10\text{ m} \le d_{2D} \le 200$ m $1.5\text{ m} \le h_{UE} \le 22.5$ m $h_{BS} \le 10$ m
Indoor Hotspot (InH)		
LOS	$PL = 32.4 + 17.3\log_{10}(d_{3D}) + 20\log_{10}(f_c)$	$\sigma_{SF} = 3.0$ $0.5 \le f_c \le 100$ GHz $1\text{ m} \le d_{3D} \le 150$ m $h_{UE} = 1 - 1.5$ m $h_{BS} = 2 - 3$ m
NLOS	$PL = \max\left(PL_{LOS}, PL'_{NLOS}\right)$ $PL'_{NLOS} = 38.3\log_{10}(d_{3D}) + 17.30 + 24.9\log_{10}(f_c)$	$\sigma_{SF} = 8.03$ $0.5 \le f_c \le 100$ GHz $1\text{ m} \le d_{3D} \le 150$ m $h_{UE} = 1 - 1.5$ m $h_{BS} = 2 - 3$ m

1.0 m for urban micro (UMi) scenario. Finally, c is the speed of light, 3×10^8 m/s [94, 95].

4.3 Key challenges of mmWave

Some open research issues for mmWave in the context of dense heterogeneous networks are:

- The wavelength of mmWave is much shorter than conventional microwave and sub-6 GHz frequencies. Hence, the **pathloss** of mmWave signals is very high if all other parameters are the same. Moreover, atmospheric conditions such as rain and molecular absorption also increase the pathloss. However, by using directional antennas it is possible to communicate at a distance of few hundred of meters or even few kilometers in clean air conditions [22, 90, 96].

- mmWave signals cannot easily penetrate materials because of its high **attenuation**. For example, brick can attenuate signals by as much as 40–80 dB, and the human body itself can attenuate 20–35 dB. Therefore, it is difficult to cover an inside area from transmitting outside base stations and vice versa [22, 97].
- **Hardware implementation and design** is complex; the transceiver is impaired by phase noise and the non-linear power amplifier, these may limit the channel capacity as well.

According to the challenges discuss above, designing accurate propagation model is important. Moreover, designing circuit components and antennas for higher and larger frequency bands of mmWave communications is another issue. However, mmWave will be a suitable for UDHetNets because of the closer proximity of eNBs and eNB to UEs. In the following section we discussed the cooperative communications in UDHetNets.

5 Multi-cell cooperation

The coordinated multi-point (CoMP) operation was adopted for LTE-Advanced in release 11 to provide coverage of a large number of users with the high data rate, improve the cell-edge throughput as well as the system throughput [10]. Before LTE-Advanced, each cell serves to its own users' equipment (UEs). As a result, the UEs in the cell border may receive low signal quality from its serving eNB and high inter-cell interference from the neighboring cells. The core idea of CoMP is to evolve the conventional single-cell multiuser system to multi-cell multiuser systems. In this approach, UEs close to the edge of a cell can be the central point of an area served by multiple eNBs. Therefore, the UEs with low signal quality will get better service by the cooperation of nearby eNBs. For example, in case of the CoMP joint transmission, a UE receives services from more than one eNBs together and the interference changes into the useful signal as demonstrated in the following equation [98]. We will discuss CoMP joint transmission in Sect. 5.3.1 in details.

$$C = BW \log 2\left(1 + \frac{p_S}{1 + p_N}\right) \quad \textit{Without CoMP cooperation} \tag{3}$$

$$C = BW \log 2\left(1 + \frac{p_S + I}{p_N}\right) \quad \textit{With CoMP cooperation} \tag{4}$$

where, C is the capacity, BW is the bandwidth, p_S is signal power, p_N is the noise power and I in the interference. In Eq. 4, interference converted to a useful signal for the UE. As a result, UE experiences better SINR in CoMP operation that eventually improves the system capacity. A typical multicell cooperative networks with three base station is shown in Fig. 6.

As we mentioned before, UDHetNet is a promising technology to achieve the goals of 5G but inter cell interference (ICI) is extremely serious in UDHetNets due to the dense deployment of small cells and its pseudo-random network topology [99, 100]. Recent research has shown that CoMP has the potential to improve the performance by mitigating the ICI. Moreover, 3GPP release 14 also included CoMP in the study item for further enhancement focusing on the dense networks [101]. Therefore, although CoMP has been studied in LTE and LTE-Advanced as a new ICI management technology, it should be further investigated. We summarize the recent works and key point related to CoMP and UDHetNet in Table 7.

5.1 CoMP deployment scenarios

The 3GPP standardization body considered four different scenarios for the study of CoMP [9, 10, 109]. The first two scenarios focus on homogeneous networks deployment, and the remaining two focus on heterogeneous networks deployment. They are presented in Fig. 7.

Scenario 1: Homogeneous networks with intra-site CoMP. A cell site is composed of three sectors (cells), and an eNB controls all the radio resources of the site. In this scenario, external connections between different sites are not required, but the coordination is limited to the sectors of the same site.

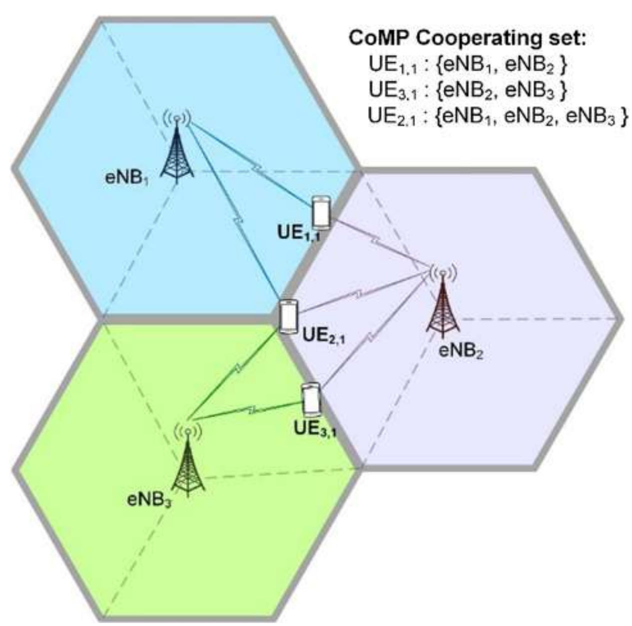

Fig. 6 A typical Multicell Cooperative Communication

Table 7 Major related works in CoMP and UDHetNet

References	Work area	Key points presented in the corresponding referred articles
[10, 101–103]	Technical report	CoMP scenarios
		Signaling support for CoMP
		Channel state information (CSI)
		Protocol specification
[9, 19, 98, 104–109]	Architecture	CoMP Architectures: Centralized, distributed and user-centric architecture
		Clustering CoMP overhead
		CoMP schemes such as JP, CS/CB
[110–112]	Interference coordination	Interference measurement
		Interference coordination in HetNets
		CoMP for mitigating interference in heterogeneous cloud small cell environment
[14, 30, 31, 100]	Performance of CoMP in UDHetNets	Performance analysis of CoMP JP, CS/CB and user-centric in UDN
		Cluster size
		Interference management in UDN
[99, 113, 114]	Enhancement of CoMP for UDHetNets	Importance of CoMP for UDN
		Coordinated spatial resources management strategies for UDN

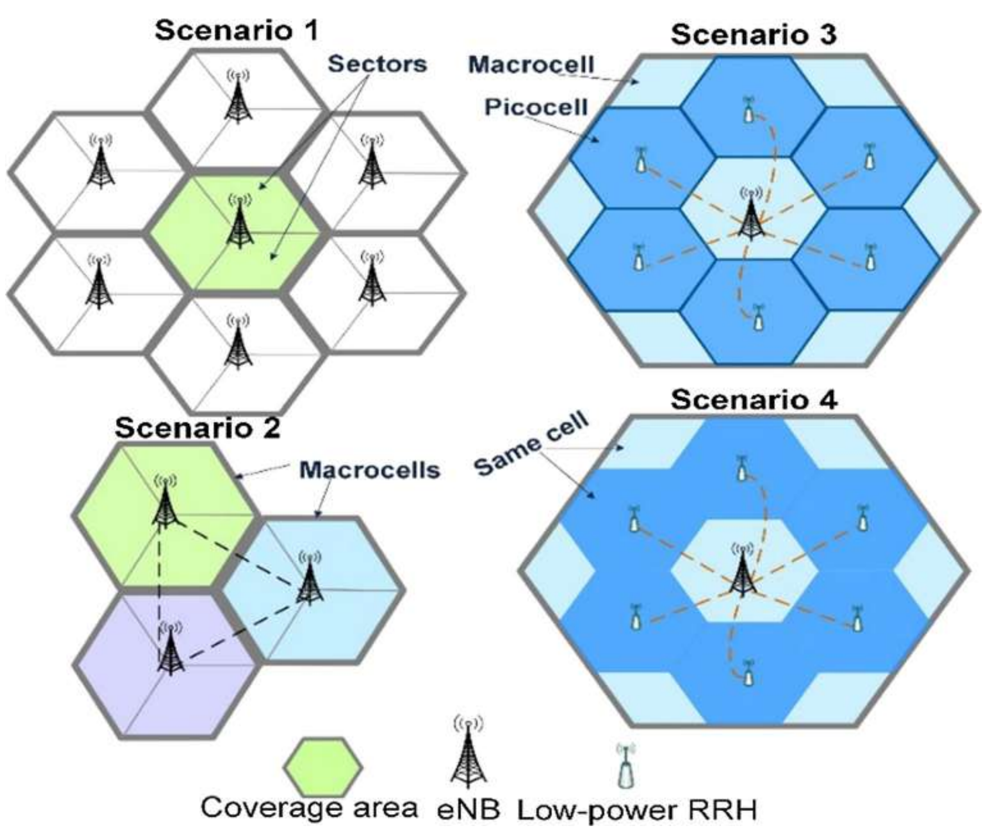

Fig. 7 CoMP scenarios

Scenario 2: Homogeneous networks with inter-site CoMP. This scenario extends scenario 1 by including multiple cells of different sites. In this scenario, multiple eNBs at different sites coordinate with each other or one controlling eNB and the other high power remote radio heads (RRHs) of different sites within the coordination area. The performance gain of this scenario over scenario 1 depends on the number of cells involved and the latency of connections between the sites. Scenario 2 in Fig. 7 depicts this type of CoMP network with multiple eNBs at different sites [10, 101, 109].

Scenario 3: Heterogeneous network with low-power picocells within macrocell coverage. In this scenario, macrocells with high transmission power and picocells with low transmission power coexist. Each picocell has a low power RRH or Pico eNB connected to the macro eNB within the macrocell coverage area. Each picocell has its own physical cell identity (PCI) independent from the macrocell [110, 115]. In Fig. 7, scenario 3 depicts one macro eNB and some low power RRH or Pico eNB in each picocell within the macrocell [9, 10, 109].

Scenario 4: Heterogeneous networks with low power RRHs within the macrocell coverage. The difference between this scenario and the scenario 3 is that all low power RRHs share the same physical cell identity as the macrocell. Since each RRH does not create an independent cell, coordination is done among distributed antennas within a single cell. Consequently, conventional mobility support such as handover procedures among the RRHs is not needed. In addition, low-delay and high-capacity backhaul connection are required between eNB and RRHs [9, 101, 115].

5.2 CoMP sets

3GPP specifications define some new terms to distinguish how different cooperating eNBs participate in the coordinated multipoint communication [10, 98]. The set of cells or eNBs that coordinate in order to improve the spectral efficiency is defined as CoMP set. Following are the three core types of sets used in the CoMP operation as shown in Fig. 8.

CoMP cooperating set: the CoMP cooperating set is a set of geographically separated eNBs, directly and/or indirectly participating in data transmission to a UE.

CoMP transmission points: CoMP transmission point(s) are the set of eNBs transmitting data to a UE.

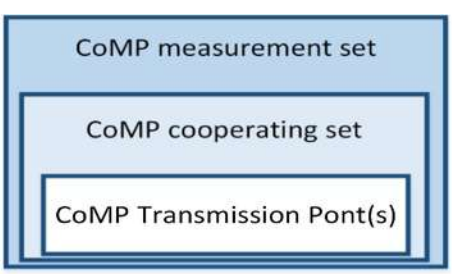

Fig. 8 CoMP sets

CoMP transmission point(s) is (are) a subset of the CoMP cooperating set.

CoMP measurement set: this is a set of eNBs about which channel state information (CSI) is reported by the UE. The CoMP measurement set may be the same as the CoMP cooperating set.

5.3 CoMP schemes

A variety of CoMP schemes have been identified and proposed. In this section, we outline the downlink and uplink schemes presented in 3GPP release 11 as well as 14 [10, 101]. There are three main types of CoMP transmission schemes: coordinated scheduling/coordinated beamforming (CS/CB), joint processing (JP) and dynamic cell selection (DCS).

5.3.1 Joint processing (JP)

In JP, data for a UE is transmitted jointly from more than one eNBs in the CoMP cooperating set to improve the received signal quality and cancel interference. Cooperating eNBs should exchange both user data and channel information among them. Therefore, low latency and a high bandwidth backhaul are required [10, 101, 109]. Figure 9 shows the CoMP joint processing scheme.

5.3.2 Coordinated scheduling/coordinated beamforming (CS/CB)

in CS/CB, data for a UE is only available at one eNB in the CoMP cooperating set but scheduling and/or beamforming decisions are taken with coordination among the eNBs corresponding to the CoMP cooperating set. This coordinated beamforming reduces interference and improves throughput [10, 101, 109]. To perform the scheduling and beamforming eNBs, it is necessary to know the channel status information (CSI). Therefore, UEs need to feedback CSI and it is required to exchange within the cooperating set. In CS/CB, backhaul load is much lower than JP since only channel information and scheduling decisions need to be exchanged among eNBs [10, 109]. Figure 10 shows the coordinated scheduling/coordinated beamforming (CS/CB) scheme.

5.3.3 Dynamic cell selection (DCS)

The UE data is available at multiple eNBs within the cooperating set but at any one time it is transmitted by a single eNB, as shown in Fig. 11. This single transmitting/muting point can dynamically change from time-frame to time-frame within the cooperating set to provide the best transmission for a UE [10, 115]. Channel conditions are

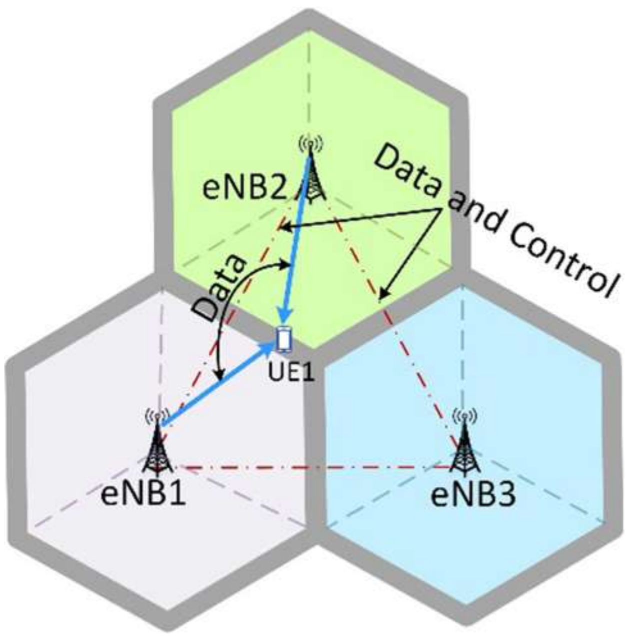

Fig. 9 CoMP joint processing (JP)

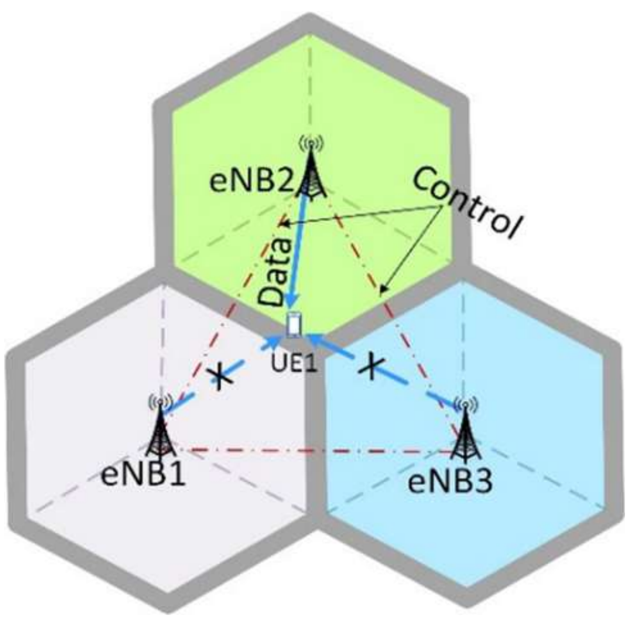

Fig. 10 Coordinated scheduling/coordinated beamforming (CS/CB)

exploited to select the best serving cell at each sub-frame [19].

5.4 Reference signals design and CSI feedback

Multi-cell channel estimation is an important issue in cooperative communication, which must be provided by the UE. Therefore, two new reference signals have been adopted in LTE-A to support CoMP and MIMO. One

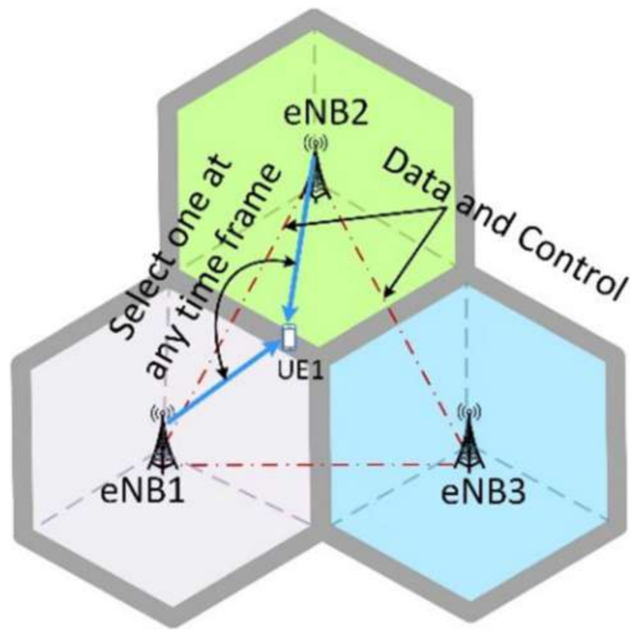

Fig. 11 Dynamic cell selection

reference signal is for channel measurement (CSI-RS) and the other one for demodulation (DM-RS) [109, 116].

CSI-RS transmitted from eNB antenna port (AP) to UE in order to estimate the downlink channel quality and determining CSI feedback. It supports a configuration of 1, 2, 4, 8 antenna ports and are transmitted on antenna ports p = 15, p = 15, 16, p = 15, 16, 17, 18 and p = 15, 16, 17, 18, 19, 20, 21, 22 respectively. A UE uses the CSI-RS for channel estimation when it is configured in transmission mode 9. There are three CSI-RS patterns for normal cyclic prefix (CP). These patterns depend on the number of antenna ports. Figure 12 shows the CSI-RS mapping patterns in physical resource blocks (PRB) [98, 102, 117]. The CSI-RS patterns have large reuse factor depending on the number of antenna ports. In case of 1, 2, 4 and 8 antenna ports, CSI-RS has 20, 20, 10 and 5 reuse factors respectively [98, 117]. The CSI-RS reuse patterns allow different eNBs to avoid a mutual CSI-RS collision. The density of CSI-RS effects on the channel estimation accuracy. In general, higher CSI-RS density provides better CSI estimation accuracy while reducing downlink resource utilization. Therefore, to reduce the CSI-RS overhead, the transmission frequency is considered every 5, 10, 20, 40 or 80 ms [109, 117].

Regarding the download CoMP transmission, the network needs information related to the downlink channel condition, so that eNBs can perform the appropriate radio resource management and adaptive transmission. Therefore, a UE needs to estimate the channel state information (CSI) of the neighboring cells and report it to the eNBs. The throughput of a downlink CoMP channel heavily relies

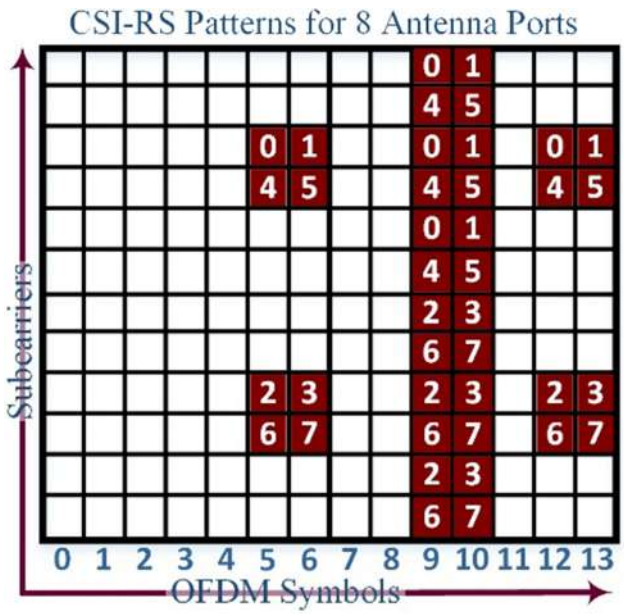

Fig. 12 CSI-RS pattern for 8 antenna ports

on the quality of the CSI feedback available at the transmitter [9, 106, 110]. The CSI includes a rank indicator (RI), a precoding matrix indicator (PMI), and channel quality indicator (CQI). The RI is the preferred transmission rank of a number of usable data streams or layers for CoMP transmission. The precoding matrix determines how the individual data streams are mapped to the antennas. The received PMI indicates which precoding matrix should be employed for downlink transmission to an eNB. The CQI reflects the channel quality corresponding to the reported PMI. It is a reference to modulation and coding scheme with a block error rate of no more than 10% [9, 110].

5.5 CoMP overheads

Multi-cell cooperation raised a concern about overheads related to the inherent need for channel state information (CSI) feedback and makes it available to the cooperating eNBs. These overheads directly impact on the system performance [9, 110]. The overhead related to the cooperative communication can be classified into two main categories: *signaling* and *infrastructural*.

Signaling overhead: these are largely the CSI estimation and its feedback to the cooperating eNBs. The UE estimates the channel status and reports that to the eNB so that eNB can perform adaptive transmission and appropriate radio resource management.

Infrastructural overheads: in multi-cell cooperation, a control unit (CU) might need to gather CSI from eNBs to perform scheduling. Low-latency backhaul links are also needed among the cooperative eNBs to exchange the CSI, as well as scheduling decisions and sometimes user data.

In CoMP operation, cooperative eNBs require exchanging CSI among them, resulting in additional CSI delay. The performance of CoMP transmission and reception is also sensitive to the delay of CSI exchange. This CSI delay and the signaling overheads are mainly influenced by two actors, CoMP coordination architecture and backhaul technology. In the next subsection, we discuss the coordination architectures of CoMP.

5.6 CoMP coordination architectures

The architecture of CoMP can be defined as the way participating cell sites coordinate to exchange the information, handle interference and scheduling. There are three kinds of coordination architectures can be categories for CoMP transmission and reception with respect to the way this information is made available at the different transmission point: centralized, distributed and user-centric. However, the existing CoMP architectures, as a multicell cooperative processing scheme suffers some overhead related to signaling and infrastructure of the network that will be discussed later [108, 118, 119].

5.6.1 Centralized architecture

In the Centralized architecture, a central unit (CU) is responsible for handling radio resource scheduling by centrally processing the feedback information from the cell sites. At first, the UEs estimate the CSI related to all the cooperating eNBs and feed it back to their serving eNBs, which forwards the local CSI to the CU. Finally, the CU calculates the global CSI, and based on that, it takes the scheduling decisions and communicates them to the eNBs, as shown in Fig. 13. This framework suffers from signaling overhead and infrastructure overhead as well as increase the network latency [104, 105].

5.6.2 Distributed architecture

In a distributed architecture, the coordinated cells exchange data and channel state information (CSI) over a fully meshed signaling network using an X2 Interface. Prior to downloading, the UEs estimate the CSI related to all the cooperating eNBs and feeds it back to all cooperating eNBs. The eNBs are scheduled independently based on their acquired global CSI. This architecture increases the feedback transmission, and it is more sensitive in terms of error patterns since these can be different for different eNBs. This could potentially cause a further performance degradation [104, 105]. Figure 14 shows the CoMP distributed architecture.

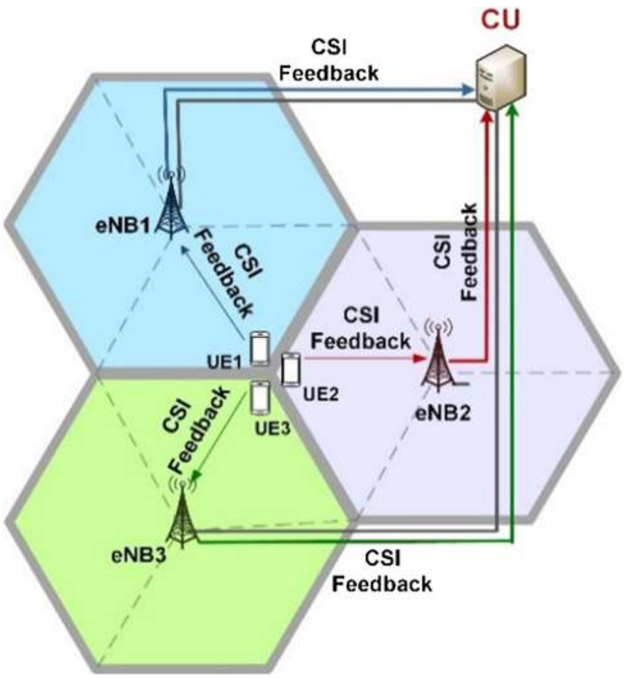

Fig. 13 CoMP centralized architecture

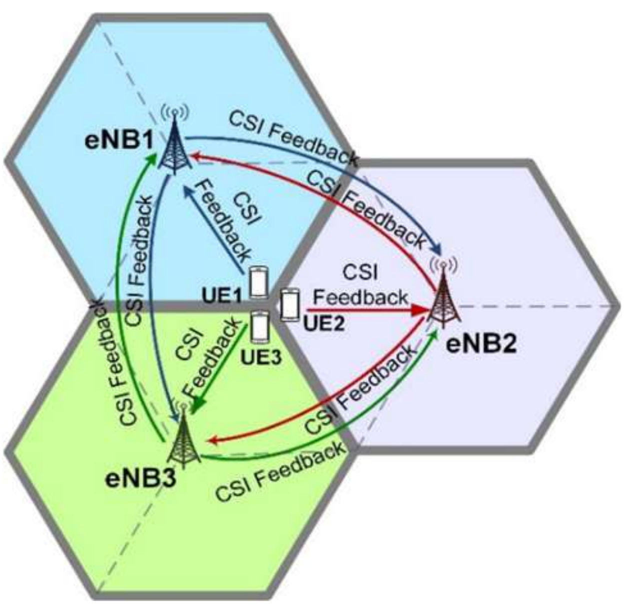

Fig. 14 CoMP distributed architecture

5.6.3 User-centric architecture

In the user-centric architecture, the UEs assist the eNBs for allocating the cluster of cells or the set of cells to participate in the CoMP transmission for the UEs [107, 108, 119]. In [119], authors proposed a load-aware user-centric CoMP clustering algorithm within a limited group of cells. In [107, 108] we presented a user-centric architecture named

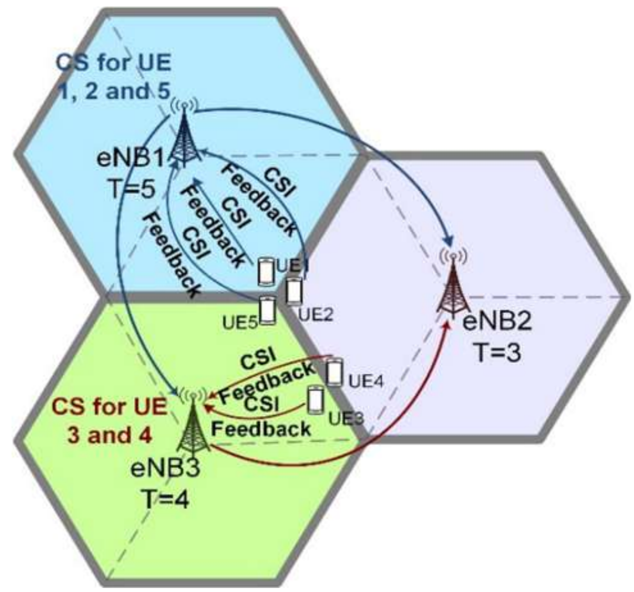

Fig. 15 User-centric CoMP architecture

direct CSI-feedback to elected coordination-station (DCEC). DCEC showed it can reduce the CSI feedback overhead and latency. In this approach, one of the eNBs in the CoMP cluster will be selected dynamically as a coordination station (CS), and the UEs in the same CoMP cooperating set will send the CSI feedback to the CS only, as shown in Fig. 15. Thereon, the CS will calculate the global CSI information, determining the cooperating set, and will be in charge of scheduling. The CSI does not need to travel through the X2 interface after the CS has been elected, which reduces the feedback latency as well.

5.7 Backhaul issues

The X2 interface is used for the backhaul links among the eNBs in LTE-Advanced and will also be used for future cellular networks. This is a logical point-to-point interface between two eNBs within the evolved terrestrial radio access network (E-UTRAN). This logical point-to-point interface is possible even though there is no direct physical connection between the two eNBs. The X2 interface supports the exchange of signaling information among the eNBs. This interface also exchanging user data based on the CoMP schemes discussed before. Because of the X2 latency, the CSI exchange may be delayed among the cooperating eNBs to 10 ms or more. Therefore, the success of cooperative communication also depends on the design, latency, and bandwidth of the backhaul since a large amount of control and user data may need to exchange among the eNBs [120].

5.8 Challenges of CoMP in the context of ultra-dense network

There is no doubt that CoMP will continue attracting the attention of researchers and industry, as the next generation networks techniques such as UDHetNet and MIMO need to improve spectral efficiency by coordinating interference. Therefore, some of the significant issues that need to be reinvestigated with respect to the next generation ultra-dense heterogeneous networks are outlined following.

- The benefits of CoMP greatly depend on the coordination among the eNBs, which requires the high capacity of **backhaul** links. In practice, the capacity of backhaul links is restricted by the deployment scenarios and cost. In the next generation of ultra-dense HetNets, the backhaul problem will become even more serious because of the density, heterogeneity and the randomness of the cells. Therefore, backhauling technologies in CoMP demand more investigation with respect to UDHetNets [30, 31, 109].
- CoMP performance relies heavily on the efficiency of the **CSI** in the network. In dense deployment networks, it is difficult providing CSI to all the coordinated eNBs. Moreover, the CSI feedback might consume scarce control resources, which could overwhelm the network. However, exploiting the CSI is necessary for cooperative communication in UDHetNets. Therefore, CSI feedback needs further investigation in the context of UDHetNets [20, 109, 110, 121].

Having addressed the above issues, some other issues might also need to reinvestigate such as **reference signals (RS) design** and **mobility management** for CoMP operation in the UDHetNets. Reference signals are also responsible for CSI accuracy and overhead into the networks as we mentioned before. In the following section, we summarize and conclude the survey.

6 Conclusions

The next generation of wireless cellular networks expects that the applications beyond 2020 will be notably different from today. Three fundamental areas that focus on improving in 5G networks are capabilities, flexibility and efficiency, and support for a diverse set of services, applications and users. Network densification and multicell cooperation are the two front row enablers to achieve the vision of the next generation networks. In this survey, we presented an introduction to ultra-dense heterogeneous networks (UDHetNets), mmWave and coordinated multipoint (CoMP) operation. We reviewed the state-of-the-art research in different directions. More in-depth research activities are needed on control parameters such as density of eNBs, transmission power, interference management, and active and idle mode compatibilities of eNBs, to optimize the performance of ultra-dense heterogeneous networks. To overcome the bandwidth requirement for UDHetNets to satisfy users' need, mmWave communication is the key enabler. We also provide an ample discussion on mmWave communication including upcoming frequency bands and pathloss modes for different scenarios.

Moreover, to address the interference issue in UDHetNets and fully utilize the radio resources, a number of advanced technologies are proposed, including CoMP. The core objective of CoMP is leading to a more adaptive and opportunistic system for coordinated interference management and resource allocation. This will be effective for improving spectral efficiency, throughput performance and end-user experience in ultra-dense networks. Finally, we point out major open issues or research challenges with respect to UDHetNet, mmWave and CoMP that might need reinvestigation. We believe that this survey is a good platform to motivate the researchers for major future research works in the next generation wireless networks.

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Baha Uddin Kazi is a Ph.D. candidate in the Department of Systems and Computer Engineering at Carleton University. He received his M.A.Sc. in Computer Networks from Ryerson University, Canada. He has reported his work in about 20 peer-reviewed publications, including patent, journals, research monograph and conference papers. He is serving as a member of the technical committee of several international conferences. His research interests focus on 5G and beyond networks, data science and machine learning, network protocols, performance engineering and modeling and simulation.

Gabriel A. Wainer FSCS, SMIEEE, is Professor and Associate Chair for Graduate Studies, Department of Systems and Computer Engineering (Carleton University). He held visiting positions at the University of Arizona; LSIS (CNRS), Université Paul Cézanne, University of Nice, INRIA Sophia-Antipolis, Université Bordeaux (France); UCM, UPC (Spain), and others. He is the author of three books and over 350 research articles; he helped organizing over 100 conferences, being one of the founders of the Symposium on Theory of Modeling and Simulation, SIMUTools and SimAUD. Prof. Wainer is Special Issues Editor of SIMULATION, member of the Editorial Board of IEEE/AIP CISE, Wireless Networks (Elsevier), and others. He received the IBM Eclipse Innovation Award, the First Bernard P. Zeigler DEVS Modeling and Simulation Award, the SCS Outstanding Professional Award (2011), the SCS Distinguished Professional Award (2013), the SCS Distinguished Service Award (2015) and various Best Paper awards. He is a Fellow of SCS.