Generalized Coordinated Multipoint Framework for 5G and Beyond

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The characteristic feature of 5G is the diversity of its services for different user needs. However, the requirements for these services are competing in nature, which imposes the necessity of a coordinated and flexible network architecture. Although coordinated multipoint (CoMP) systems were primarily proposed to improve the cell edge performance in 4G, their collaborative nature can be leveraged to support the diverse requirements and enabling technologies of 5G and beyond networks. To this end, we propose generalization of CoMP to a proactive and efficient resource utilization framework capable of supporting different user requirements such as reliability, latency, throughput, and security while considering network constraints. This article elaborates on the multiple aspects, inputs, and outputs of the generalized CoMP (GCoMP) framework. Apart from user requirements, the GCoMP decision mechanism also considers the CoMP scenario and network architecture to decide upon outputs such as CoMP technique or appropriate coordinating clusters. To enable easier understanding of the concept, popular use cases, such as vehicle-to-everything (V2X) communication and eHealth, are studied. Additionally, interesting challenges and open areas in GCoMP are discussed.

Index Terms—5G, beyond 5G, CoMP, eMBB, generalized CoMP, mMTC, multi-TRP MIMO, network slicing, uRLLC.

I. INTRODUCTION

The fourth generation (4G) of mobile communication primarily focused on improving the data rates for users. While the fifth generation (5G) has catered to the enhancement of data rates under the enhanced mobile broadband (eMBB) service, it has also expanded its vision to incorporate the increasing number of wireless devices and stringent reliability and latency requirements under the massive machine type communication (mMTC) and ultra-reliable low latency communication (uRLLC) services, respectively. The latter two services are of particular importance for the fourth industrial revolution which is signified by unprecedented automation, driven with massive connectivity. If we talk quantitatively about 5G goals, it envisions a 1000 times increase in the volume of data and number of connected devices per km², 100-fold improvement in data rates, and reduction in latency by a factor of five [1]. These demands are unlikely to be achieved without significant technological advancements.

Some of the well-established 5G enablers include millimeter wave (mmWave) communications, small cells, massive multiple-input multiple-output (MIMO) antenna systems, beamforming, full duplex systems and more flexible and adaptive physical (PHY) and medium access control (MAC) layer designs [2]. Furthermore, technologies like terahertz (THz) communication, reconﬁgurable intelligent surfaces (RISs), integrated hybrid aerial-terrestrial-satellite networks, and artiﬁcial intelligence empowered communication systems are being explored and studied for beyond 5G scenarios [3].

Like the previous generations, 5G needs to address the increased throughput and capacity requirements of eMBB which necessitates more frequent spectrum reuse, leading to smaller cells. This, combined with the envisioned 1000-fold increase in the number of connected devices, results in a signiﬁcant increase in the number of user equipments (UEs) affected by inter-cell interference (ICI). Traditional approaches for ICI management have focused on minimizing it by increasing the reuse distance. However, these schemes are only capable of scheduling a cell’s own resources without any knowledge of the neighboring ones. Access to such knowledge can help transmission points (TPs) schedule resources such that ICI can be minimized across the network without wastage of resources. This led to the proposition of inter-cell interference coordination (ICIC) and coordinated multipoint (CoMP) transmission in the 3rd Generation Partnership Project (3GPP) Rel-8 and Rel-11, respectively.

Moreover, the use of higher frequencies has made the utilization of beam-based transmission imperative in future networks. While these beams have lesser interference as compared to omnidirectional transmission at cell edges, they are much more prone to blockages. This makes meeting the reliability constraints for uRLLC applications considerably more challenging. In such cases, coordinated transmission from different TPs is a possible solution. Although the primary motivation of CoMP was to improve the performance of cell edge UEs by utilizing coordination between neighboring TPs, the spatial diversity provided by CoMP can be exploited for addressing various 5G and beyond requirements. What we propose is to utilize CoMP to satisfy the requirements such as reliability, throughput, latency, and PHY layer security. Such a generalized realization of CoMP requires a solid framework, with well-deﬁned inputs, decision mechanisms, and outputs.

This paper attempts to address the above-mentioned gap in the present literature by contributing the following:

• The idea for generalized CoMP (GCoMP) is presented

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and its associated framework is proposed, which takes into account the specific user requirements.

- Emerging technologies for future wireless networks - such as cloud-RAN (C-RAN), RIS, and hybrid networks - are discussed in relation to the GCoMP framework.
- Specific use cases such as vehicle-to-everything (V2X) communication and eHealth are discussed under the GCoMP framework.
- Possible improvements and current challenges for the framework are discussed.

The rest of this article is structured in the following manner. First, a summary of the emergence of CoMP as an interference management technique is presented. Next, its potential as a solution to various conflicting goals of future networks is motivated, which is followed by a description of the proposed GCoMP framework. To demonstrate the applicability of the framework, V2X and eHealth use cases are considered as examples. Finally, different challenges that need to be faced in realizing such a framework are discussed.

II. ICIC EVOLUTION AND CoMP FOR 5G

This section follows the developments in ICIC techniques, from the earlier generations of mobile communications to the proposition of CoMP in 3GPP Rel-11. Afterwards, projections are made regarding the compatibility of CoMP and 5G technologies.

A. ICIC Evolution

Since early stages, the evolution of cellular systems has been hindered by the ICI problem, which significantly degrades the performance of cell edge UEs. Early cellular technologies, like 2G, increased the frequency reuse distance to minimize the interference. Integer frequency reuse schemes, such as reuse-3 and 7 are primary examples of this approach. While this resulted in a significant reduction of interference, it also decreased the system capacity. Since the interference at the cell edge is the primary concern, solutions like fractional frequency reuse (FFR) were proposed, which split the cells into inner and outer regions and assigned the frequency bands such that inner regions have reuse-1 and outer regions have reuse-3 or reuse-7. A further extension to FFR is soft frequency reuse (SFR) which allocates higher power to the frequency bands allocated for cell edges. Such an approach improves the capacity of the system as compared to integer reuse, while still mitigating ICI [4]. Figure 1 illustrates the different schemes described above.

Despite the simplicity and effectiveness of the above-mentioned techniques, they are hampered by their standalone nature since there is no mechanism for different TPs to coordinate with each other for interference management. This led to the emergence of the ICIC concept in 3GPP Rel-8. The basic working principle of ICIC is that neighboring cells communicate with each other to figure out the best way to allocate resources for the cell edge UEs with minimum interference. ICIC utilizes different flags, namely relative narrow-band transmission power (RNTP), high interference indicator (HII) and overload indicator (OI), for coordination between TPs over the X2 interface [4]. RNTP indicates to neighboring TPs the physical resource blocks (PRBs) scheduled with high power. This enables the neighboring TPs to avoid assigning the same resources to their cell edge UEs, reducing the ICI. HII is the uplink counterpart of RNTP. On the other hand, OI is a reactive function that indicates a high detected interference level on a specific resource block to neighbor TPs. When a cell scheduler receives OI, it will change the scheduling to decrease the interference generated on these PRBs.

Since ICIC approaches focused on the data channels only, they allowed potential interference over control channels. This problem was compounded by the disparity in transmission powers in the case of heterogeneous networks (HetNets). Consequently, enhanced ICIC (eICIC) was proposed where the different tiers use orthogonal resources to mitigate the interference. One example corresponding to this is the absolute blank subframe (ABS) concept, where the small TP only transmits
during the transmission time interval (TTI) where the macro TP is muted. However, the rapid increase in device density, and with it the severity of the ICI problem, necessitated more sophisticated and dynamic approaches. Consequently, CoMP was introduced in the Rel-11 of 3GPP as a potential solution [5].

B. CoMP for Long Term Evolution (LTE)

Unlike ICIC approach and its variants (i.e., eICIC) where ICI is mitigated by restricting radio resource usage in either frequency or time domain, CoMP incorporates spatial domain in resource allocation, which enhances spectral efficiency in addition to the interference mitigation. Figure 2 illustrates the different CoMP schemes. Coordinated scheduling (CS), which is essentially the evolution of previously mentioned interference mitigation techniques, reduces interference by ensuring instantaneous exchange of channel information between coordinating TPs. Coordinated beamforming (CB) allows the edge UEs to use the same frequency resources as long as the beam patterns for different UEs do not interfere with each other. Due to the significant use of beamforming in 5G networks, CB has attained increased importance. Joint transmission (JT), arguably the most interesting CoMP technique, constitutes of UE data being transmitted from different TPs, potentially providing macrodiversity against path loss, shadowing, and blockage. Dynamic point selection (DPS) is a special case of JT, where even though the UE data is available at different TPs, it is only transmitted from one TP at any given time [6]. Here, it is important to note that even though CoMP mechanisms are devised to reduce the cell edge interference, they also improve the overall performance of the cell and network by more efficient resource allocation at the cell edges.

When the initial concept of CoMP was introduced in Rel-11 [5] to improve the cell edge and system throughput, it was limited to TPs connected with ideal backhaul. It was not until Rel-12 that the concept was extended to multiple eNodeBs (eNBs) connected with non-ideal backhaul [7]. This required the standardization of signaling over X2 interface to enable exchange of CoMP hypothesis set and its associated benefit metric between cooperating eNBs. In addition to these, reference signal received power (RSRP) measurements were also used to validate these hypotheses. The sharing of this information with the neighboring eNBs helps improve the radio resource management [8].

Enhancements to inter-eNB CoMP were introduced in Rel-13 relate to the use of channel state information (CSI) and enhanced RNTP (eRNTP). The latter is particularly useful to control the power allocation in a coordinated setting [9]. The strict requirements of JT regarding synchronization and accurate CSI necessitated exploration of other alternatives, leading to discussion around non-coherent JT (NC-JT) in Rel-14. The performance results indicated the suitability of NC-JT and CS/CB in low and high traffic load scenarios, respectively [10]. A study for creation and management of CoMP sets based on network conditions was carried out under the umbrella of self-organizing networks (SONs) in Rel-15 [11]. This study focused on monitoring two parameters, i.e., X2 characteristics and the spatio-temporal traffic variation.

C. CoMP for 5G and Beyond

Unlike 4G, where the focus is primarily on improving the data rates, 5G and beyond networks have a myriad of requirements and objectives that need to be fulfilled. This requires a multitude of technologies to be introduced in the 5G and beyond networks. The following items look at the potential role of CoMP for some of these mechanisms:

- 3GPP Rel-14 specifies eight different functionality splits between central and distributed units for 5G [12]. The functional split has a major impact on the backhaul and can potentially relax the corresponding requirements regarding overall capacity, delay, and synchronization. This is also applicable to the concept of C-RAN which is a potential implementation of CoMP network. However, a study showing the feasibility of lower split options illustrates the preference of standardization in this regard [13].
- MIMO enhancements in 5G, including multi-panel/transmission-reception point (TRP) operation distinguish 5G MIMO from the LTE MIMO operation. Furthermore, improved (type II) codebook, flexible CSI acquisition and reference signal design (including zero-power signals for interference measurement), and beam management for higher (> 6GHz) bands promise significant boost in MIMO performance [14].
- Different 5G services are expected to have different coverage areas. This diversity of application requirements would be further pronounced in 6G. This can be intuitively interpreted as equivalent to cell edges in previous generations. Figure 3 shows the preliminary simulation of coverage areas for different throughput requirements. The lack of uniform coverage motivates coordinated and cooperative communication to ensure a smooth user experience.
- The lofty goals of 5G have motivated the exploration of higher frequency spectrum (mmWave and THz). However, they are susceptible to higher path loss and blockages. Technologies like beamforming and RIS have been
introduced to facilitate communication in this portion of the spectrum. Moreover, the use of macrodiversity offered by CoMP has been experimentally shown to provide link and capacity improvement in the 73 GHz band [15].

• Like 4G, 5G is also looking to incorporate unlicensed spectrum like 4G in its fold for improved network capacity, as evident from the presence of work item/study in Rel-16. 5G also enables cells to operate standalone in unlicensed spectrum, connected to a 5G core network [16]. Coordinated networks have the potential to improve resource utilization in the unlicensed and shared spectrum.

• Related closely to this is the access traffic steering, switching and splitting (ATSSS) concept, enabling the simultaneous use of 3GPP and non-3GPP access networks with the 5G core network. This is essentially one step beyond mere coexistence of different networks, leading to their convergence.

III. GCoMP FRAMEWORK

The aforementioned 5G services require massive connectivity with high system throughput and improved spectral efficiency which imposes significant challenges for network design. We believe that the scope of CoMP can be widened from mere interference mitigation to intelligent network resource utilization, helping achieve these diverse requirements. This section is dedicated to the description of the conceptual GCoMP framework, illustrated in Fig. 3. The first row of elements represents the inputs to the GCoMP decision mechanism. The decision making is the intermediate stage, followed by the outputs at the end. Here, it should be noted that while most options in the inputs/outputs are well-established, we have taken the liberty of identifying some additional ones, shown in red, that are either relatively new in general or at least recent to CoMP.

A. Inputs

The input elements include user requirements, CoMP architecture, and scenarios. The requirements are considered first since everything that follows revolves around them. These include reliability, throughput, capacity, mobility, and so on. CoMP systems, also referred to as distributed MIMO due to the presence of physically separated antenna locations, are capable of exploiting the spatial dimension to satisfy these requirements. For instance, if the multiple TPs are used for multiplexing, it increases the capacity of the system. On the other hand, reliability can be enhanced if different links are used to provide macrodiversity [18]. In addition to the above-mentioned requirements, security is also a concern for mission-critical applications. Different PHY and MAC layer security algorithms can leverage the spatial diversity of CoMP for providing security using techniques like directional modulation [19].

Following requirements, the second input considered is the architecture. The conventional categories include centralized or distributed coordination. In the former, all administrative tasks are controlled through a central unit, while in the latter, one of the cooperating TPs acts as a master cell and performs all resource management and communication tasks. Here it is pertinent to mention the concept of centralized or C-RAN, which has gained significant traction with operators due to its promise of reduced capital and operating expenditures. Despite its promise, one major challenge for C-RAN is to balance the tradeoff between easier network management offered by centralized control and the increasingly strict backhaul bandwidth and latency requirements. This might be critical for use cases like V2X communication. In light of this, recent works have proposed the utilization of fog/edge computing to provide intelligence to components of the network close to the UE [20].

The third input element is CoMP scenarios. 3GPP proposed three different CoMP scenarios for both homogeneous and HetNets [5]. The first scenario is homogeneous intra-site CoMP, in which the coordination takes place between different TPs (sectors). Due to the colocation, there is no additional load on the backhaul. The second scenario is inter-site CoMP which is also implemented on a homogeneous network. It uses high power remote radio heads (RRHs) to expand the coverage. The third scenario is implemented on HetNets and utilizes low power RRHs. Inter-site CoMP and HetNet scenarios require high-speed backhaul links, like fiber, to make the connection between the macro cells and their respective RRHs. In line with HetNets, another scenario that may be of interest is hybrid aerial-terrestrial networks. The wireless propagation channel characteristics of the air-to-ground channel are fairly different as compared to the conventional terrestrial channel, and can be taken advantage of to provide a better quality of service (QoS) to the UEs [21]. This can be extended to incorporate the non-terrestrial network or satellite communication scenarios, aimed at improving network coverage [22]. The logical next step to exploiting the variation in the propagation environment is the capability of modifying the environment itself to improve the coverage and user experience. RIS is a technology that promises exactly that by selectively modifying the incident signal’s properties, such as phase, amplitude, and polarization [3].

Here it is important to categorize the nature of the above-
mentioned inputs in terms of their dynamicity. User requirements are expected to change depending on the application being used. The architecture is static, while the scenario might change, particularly in terms of intra/inter-site coordination.

B. Decision Making

The GCoMP decision-making process evaluates the above-mentioned input elements, network constraints, and channel conditions to make informed decisions regarding the appropriate resource allocations, namely, selection of the best suited CoMP scheme and coordination cluster. The approaches for this process can be categorized into user-centric, network-centric, or hybrid. The user-centric approach would make decisions on a per-user basis, targeted at fulfilling that particular user’s requirements. The network-centric decision making, on the other hand, places more emphasis on simplifying the implementation from the network perspective, including the architecture and overhead while trying to optimize the performance of all connected users. The overhead includes information (data and CSI) sharing between the nodes and processing of the information necessary for the said decision-making. The hybrid approach provides a tradeoff between both the above-mentioned methods by optimizing the decisions for a group of users while keeping the network overhead bearable.

Given that the future networks are expected to have an exceedingly high number of devices, the available resources might be insufficient to serve them. There are two ways to go about solving this problem. The network can prioritize the users depending on the required QoS where the prioritization information associated with 5G QoS identifier (5QI) can be used for this purpose [23]. Alternatively, it can try to optimize the varying and occasionally competing user requirements. An example of this is the tradeoff between latency, reliability, and throughput, as illustrated in Fig. 5. While it is possible to optimize any two of the requirements, it comes at the cost of the third [24]. This is visible for point A in Fig. 5 where reliability and latency are optimized, but throughput is compromised. Point B, on the other hand, provides the opposite. In such scenarios, a single optimum solution is not possible. Rather, there is a set of (possibly infinite) Pareto-optimal solutions where improving one objective would lead to degradation in the other(s) [24]. Network slicing is capable of complementing the optimization problem for resource allocation by providing portions of the network resources for different use cases. The framework governing network slicing in 5G is quite generic and allows the possibility of assigning multiple network slice instances (NSIs) with different characteristics to a certain communication service [25]. This can be leveraged to support the otherwise competing user requirements like the ones mentioned above.

Since these decisions are dependent upon variable parameters such as user requirements and spatio-temporal traffic patterns, they need dynamic updates. These updates can either be periodic or triggered. As the name suggests, the former analyzes the network situation repeatedly after a fixed interval and revisits its earlier decisions, while the latter can be set off by certain nodes and/or conditions. This may include variation in the backhaul availability or traffic patterns.

C. Outputs

The first output of the framework is the selection of the appropriate CoMP scheme. These schemes have different backhaul requirements and provide varying benefits. Since coherent JT (C-JT) performs joint beamforming, it requires backhaul links with high capacity and low latency as well as strict synchronization among coordinated TPs. NC-JT, on the other hand, provides a complexity-performance tradeoff by removing the burden of joint precoding and strict synchronization while still providing significant gains as compared to other schemes such as CS, CB, and DPS [10]. Therefore, the

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Fig. 4. GCoMP conceptual framework. User requirements, CoMP architecture and scenarios serve as inputs to the decision mechanism. The outputs of this mechanism include (but are not limited to) selection of CoMP scheme and coordinating cluster.
IV. Use Cases

5G networks are envisaged to support a large number of verticals, ranging from healthcare to industrial automation, intelligent transport to immersive entertainment, and so on. The variety of targeted verticals leads to diverse requirements, which are grouped under different 5G services. Figure 6 illustrates the services and concerned requirements for some selected use cases discussed under 5G [28]. These include virtual/augmented reality and high definition video as examples of the eMBB service, public safety networks, which form part of the urLLC fabric and smart homes and wearable technologies under the category of mMTC service (the latter is yet to be properly addressed in the standard even though Rel-16 provides some enhancements for NB-IoT and enhanced machine type communication (eMTC) [29]). Additionally, we have certain cross-service use cases such as eHealth and V2X communications. The following passages provide a brief overview of these use cases, their requirements, and how they may be facilitated under the GCoMP framework.

A. V2X Communication: Overview and Requirements

Autonomous vehicles or intelligent transportation systems (ITSs) are driven by two primary motivations, firstly to reduce traffic accidents and consequent fatalities or injuries and secondly, to reduce traffic congestion. The efficient commute also has the advantages of lowered fossil fuel consumption and reduced carbon dioxide emissions. Ubiquitous communication between vehicles, on-board sensors, and the environment is imperative to ensure the smooth operation of ITS. V2X communication is the umbrella term used for the vehicles’ communication with other vehicles, infrastructure, network, and pedestrians.

Considering the various aspects and scenarios of V2X communications, the following requirements can be listed:

- **Provision of ultra-reliable and low-latency communication** to ensure proper operation of ITSs.
- **Mobility** is a key characteristic of ITSs which causes rapid channel variation, making the communication very challenging. Providing ubiquitous connectivity to these UEs is of paramount importance.
- **Since autonomous vehicles rely heavily on V2X communication, they are susceptible to various forms of attacks to the communication that may disrupt transport or even hurt people. Identifying these security concerns and coming with appropriate solutions is a relatively new challenge that requires significant research efforts.**

As mentioned earlier, user prioritization and QoS information can ease the burden of GCoMP decision-making. Therefore the availability of different aspects of V2X communications under 5QI values 83-86 in [23] can be leveraged for this purpose.

B. eHealth: Overview and Requirements

eHealth refers to the use of information and communication technologies for improved healthcare. One of the major reasons for this push from health organizations is the lack of  

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Fig. 5. A sketch illustrating the tradeoff between latency, reliability and throughput (inspired from [24]).
qualified professionals in the developing world. Remote services like monitoring, consultation, and surgery are primarily being focused on under this 5G vertical.

The components of this 5G vertical include monitoring of patient information such as blood glucose or blood pressure using a wide variety of sensors, online consultation of patients by medical practitioners, and arguably the most hyped use case, remote surgery. The following requirements can be extracted from these scenarios [30]:

- **Ultra-reliable and low-latency** communication for the control of surgical robots is needed.
- **High throughput** for video monitoring, consultation, or remote surgery is required.
- There can be a wide variety of sensors under use, some of which might be implanted *in vivo*. In such a case **energy conservation** becomes critical.

It is interesting to point out that depending on the above-mentioned requirements, this particular use case seems to lie on the intersection of eMBB and uRLLC services which maps neatly to the standardized 5QI value of 80 [23].

### C. GCoMP Decision Flow

This section describes the working of GCoMP mechanism for instances of the use cases defined above, as shown in Fig. 7. It can be seen that for both use cases/applications the requirements are derived using 5QI [23] while the CoMP architecture and scenarios are considered as inputs from the network. For easier understanding, we do not put any restriction on either at present and allow the use of different network slices for both applications. Depending on if there is a single or multiple users belonging to the same application requirements (and consequently the concerned network slice), the decision-making approach can be considered as user-centric or hybrid, respectively.

This approach allows the independent selection of clustering and CoMP scheme for both use cases. However, since both applications need high reliability and low latency, the use of JT seems suitable since it allows the transmission of multiple copies of the same signal to the UEs. DPS can also be considered for V2X due to the mobility-induced handovers. ATSSS is also capable of supporting the mobility (handover) and throughput requirements with its switching and splitting aspects, respectively [21].

In terms of clustering, a dynamic approach is needed for the V2X case while static clustering can suffice for eHealth. As mentioned earlier, the network itself is dynamic and needs to be taken into consideration in our framework. Owing to the increased spatio-temporal traffic variation in the V2X case, it can use the triggered feedback approach, where the decision making can be updated depending on both user requirements and network variation. eHealth, on the other hand, is not expected to observe much variation in that regard, so a periodic update should be able to suffice.

The authors would like to reiterate that this is a very simple example to illustrate the GCoMP framework. It is possible to incorporate more variables and improve the decision flow to either optimize specific scenarios or generalize it to cater to a wider variety of applications.

### D. CoMP-based Solutions

Described below are the different approaches used under the context of coordinated networks for the requirements pointed out in Sections [IV-A] and [IV-B]

1) **Reliability and Latency**

Out of the different services of 5G, uRLLC is arguably the toughest challenge owing to the targeted reliability with strict latency bounds. There are generally two approaches to address the uRLLC requirements, increasing reliability of one-shot transmission or to lower the latency between retransmissions. CoMP, with its JT approach, can provide different versions of the transmitted signal at the receiver at the same time reducing the necessity of retransmission and addressing the latency constraint. Properly combining the received copies of the signal can improve the signal-to-interference-plus-noise ratio (SINR) performance and hence reliability of the system. Macrodiversity is an approach to provide multiple paths for the communication of the same signal, targeted to exploit the variation of path loss and large scale fading in the different paths. An interesting idea related to this is to utilize hybrid aerial-terrestrial networks, which provide additional diversity in the wireless link owing to the different propagation characteristics of the air-to-ground channels [21]. In these networks, the
aerial TRPs provide a much higher probability of line of sight and reduced shadowing, resulting in improved reliability of communication. An alternative to this is the packet duplication approach supported in Rel-15 [32] which is a higher (packet data convergence protocol (PDCP)) layer complement of the PHY layer diversity techniques [33].

2) Mobility

Due to the inherent mobility of TRPs in V2X communications, handovers are a major concern. This becomes critical especially when talking about cell densification, small cells, and the strict reliability and latency requirements. Additionally, the signaling overhead associated with each handover and possible service interruption are undesirable from the perspective of network and UE. To ensure continuous connectivity, dual connectivity based solution was considered (though not eventually standardized) in addition to Make-Before-Break (MBB) handover technique [34]. CoMP or C-RAN can be a form of implementation for multi-connectivity. Additionally, CoMP also reduces the number of handovers as long as the UE is within its coordinating cluster. A CoMP scheme like DPS seems particularly suitable for mobile UEs, owing to the similarity in nature of handover and DPS concepts since both revolve around the dynamic selection of best-suited TP. Along the same lines, the switching aspect of ATSSS is capable of supporting smoother handovers by leveraging Multipath transmission control protocol (MP-TCP) [35].

3) Security

The spatial diversity offered by CoMP can be leveraged to establish secure wireless communication links between legitimate UEs if it is merged with PHY layer techniques. The geographically separated TRPs can be used to transmit the signal such that data is only decodable at the intersection of their transmission beams [19], providing location-based security against eavesdropping. Jamming is another threat to communication. These attacks include transmission of noise or noise-like signals to interrupt the legitimate transmission. The spatial diversity offered by the geographically separated TRPs may be utilized to combat such attacks.

4) Throughput

As mentioned earlier, the spatial diversity offered by CoMP systems can be used in various ways. JT-CoMP promises significant gains in terms of network capacity and UE throughput.
by combining signals from different TPs either coherently or non-coherently. Coherent JT is capable of providing higher throughput as compared to its non-coherent counterpart since it uses a joint precoding procedure while the latter focuses on improving the received signal strength \(^6\). Multi-TRP MIMO utilizing beamforming at mmWave bands promises increased data rates. Furthermore, this requirement can also leverage the MP-TCP and underlying ATSSS concept to split the traffic over multiple access networks, resulting in improved throughput for the user \(^{31}\).

5) Energy Conservation

Energy conservation, particularly for the UEs, is a major concern in wireless networks. It especially holds true for sensors that are not easily accessible, medical implants being a perfect example. In the case of multiple devices that need to communicate, it is possible to consider DPS with energy conservation as a goal. A similar idea in drone-based disaster recovery scenario is proposed in \(^{56}\), where the uplink TP is selected from the UEs while taking into consideration the remaining battery of the UEs.

V. CHALLENGES AND FUTURE DIRECTIONS

There are considerable challenges that need to be overcome in order to make GCoMP a reality. Some of these issues are identified below:

A. Optimization

Owing to the diversity of future wireless networks both in terms of user/application requirements and device/node capabilities, optimized resource allocation is going to become even more challenging. Multi-objective optimization is, therefore, going to be imperative. This also includes the need for improved network slicing capabilities which will be necessary to support future applications.

B. Inter-RAT Coordination

The emergence of ATSSS signals the convergence of different radio access technologies (RATs). Furthermore, the upcoming amendment of the Wi-fi standard, i.e., IEEE 802.11be has introduced multi-access point (AP) coordination concept which is similar to CoMP. This illustrates the importance of and need for coordination within and between different RATs. However, the interface and exact mechanisms to carry out these tasks need to be defined and standardized (current Wi-Fi activities related to multi-AP coordination are in infancy stages \(^{37}\)).

C. Next Generation Networks

Since 6G is still an abstract concept at this point, with most works considering it an extension of the original 5G requirements, we have not delved much upon the issue. However, from recent activities it is evident that secure, smart radio environments (using RISs) and intelligent networks are going to be an imperative part of future communications \(^{4}\) \(^{38}\). The fact that GCoMP concept itself originates from the need for an intelligent and proactive system highlights the possibility of pushing it even further with these enablers.

D. Network Overhead Considerations

Some guidelines that need to be considered for a system as extensive and comprehensive as GCoMP can be borrowed from \(^{11}\). This includes analyzing the convergence of the CoMP function on an appropriate time-scale, impact on eNB complexity, additional signaling, and any impact of the network configuration.

E. Spatial Diversity Tradeoffs

The spatial diversity afforded by the geographical separation between TPs can be utilized to provide capacity, security, and reliability gains. However, all of these are competing objectives which means one can only be achieved if the others are waived. Optimizing these tradeoffs remains a challenge.

F. Adaptive CoMP Schemes

The concept of GCoMP includes selecting the best CoMP scheme for a given UE taking into account the network architecture and scenario. However, the capability of a network to support multiple CoMP schemes simultaneously still needs to be studied and its advantages weighed against the potential costs.

G. CoMP Triggering

Traditionally, cell edge is defined by static thresholds of parameters like SINR and this is where CoMP was applied. However, with diverse services, these thresholds are going to vary with requirements. In such a situation a better triggering mechanism is required.

H. Traditional CoMP Issues

Some of the problems that have limited the practice of CoMP include imperfect CSI, insufficient backhaul, and clock synchronization \(^6\). Generally speaking, these issues degrade the throughput, reduce the number of connected UEs, cause inter-symbol or inter-carrier interference, and so on. Here it is necessary to mention that these impairments would affect the various CoMP schemes differently, which needs to be taken into consideration when selecting a scheme for given requirements.

VI. CONCLUSION

5G embodies a significant evolution in wireless communication by incorporating services like eMBB, mMTC, and uRLLC. However, the fulfillment of these services is quite challenging owing to the diversity in their requirements. Driven by the realization that presently available techniques are unable to support the lofty targets set for 5G unless a significant effort to build a coordinated network is made, we have proposed the generalization of CoMP concept. The aim is to expand the scope of CoMP from mere interference management at cell edges to enhancing the throughput, decreasing latency, increasing reliability, improving coverage, and providing seamless connectivity to UEs with varying requirements. To this end, a generalized CoMP framework has been discussed in this paper, which we believe will prove to be a stepping stone towards the realization of fully coordinated 5G and beyond networks.
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