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INTERFERENCE REDUCTION SCHEME FOR FEMTOCELL ULTRAL-DENSE-NETWORK: CONCEPT AND RESEARCH CHALLENGES

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ABSTRACT

In recent times, the demand for mobile broadband communications has increase exponentially due to the creation of new multimedia applications. To cater for this trend, dense deployment of cellular networks with aggressive frequency reuse patterns has been proposed. In this regard, densification of femtocells is a promising concept to meet growing mobile service requirements and for sustainability of users' Quality of Service (QoS). However, an ultra-dense network (UDN) faces serious interference problems. One of this is the Inter-Cell Interference (ICI) caused by the simultaneous usage of the same spectrum in different cells. The problem becomes more complex when femtocells are located on cell edge area of macrocell. ICI reduces system throughput and network capacity, and has a negative impact on cell-edge users. Therefore, reducing the effects of interferences is an important issue in UDN. Hence, a critical issue arises: are conventional reduction scheme still effective to tackle the interference in UDN? To shed light on the problem, this paper provides a comprehensive survey of the methods for reducing interference in femtocell UDN. This survey aimed to provide a concise introductory reference for early researchers in the development of interference reduction scheme in femtocell. These methods are classified based on the nature of operation, investigated as to their strength and weaknesses, and then examined via several research studies which make use of each approach. Furthermore, technical challenges in each research study were identified. Finally some remarks for enhancing the research study were provided and potential direction for future research were highlighted.

I. INTRODUCTION

Since the introduction of intriguing mobile devices and multimedia applications, user demands for wireless data communications in cellular networks have been rising quickly. Applications with high traffic volumes have a significant impact on increasing the data rate. According to a study by Kovacs [1], there has been a significant increase in the demand for mobile data traffic over the past five years, as seen in Figure 1. Additionally, since consumers pay telecommunications firms more for data services than for voice-only services, they anticipate higher-quality services. Because of the numerous walls and obstructions found indoors, the channel quality between the mobile node and the cellular base station may be poor. As a result, indoor wireless communication systems need to be built with the necessary service quality in mind for consumers. Even so, as 90% of data traffic and over 60% of voice traffic are anticipated to be generated indoors, the scarcity of wireless resources in cellular networks will worsen [2]. Unquestionably, more network infrastructure is needed in order to increase cellular network capacity.

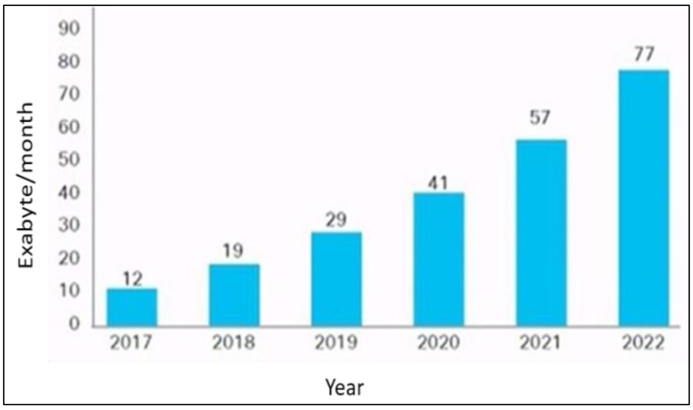

Figure 1: Global mobile data traffic from 2017 to 2022.
Soucer: [1].

The application of femtocells placed on top of the conventional macrocell-based based cellular networks is a crucial subject for the economical installation of new infrastructure [3]. A femtocell is an inexpensive, small-sized cellular base station that uses low power. It can be implemented by service providers or customers anywhere wired IP access is available. Given that this low-cost femtocell is typically installed indoors and linked to the backhaul via a general IP connection, such as digital subscriber line (DSL), with cable modem and fiber-to-the-home (FTTH), cellular networks can secure wireless resources more affordably while enabling customers to use high-speed, low-power wireless data communications. On the other hand, demonstrating a higher number of channels per area (cell) usually increases capacity. This can be achieved by increasing channel reuse by decreasing the area of each cell. Cellular service demand can also come from indoor sources. Previous research in [4] have revealed that 18% of phone conversations and data sessions start indoors. The in-building wireless market is expected to grow rapidly by $18 billion by 2025 due to rising consumer data usage and the growing demand for smartphones [4]. Given that more sophisticated multimedia applications are anticipated to be deployed, it is inevitable that the capacity demand for indoor communications will continue its horrifying upward trend. Therefore, in order to support the multitude of data traffic-intensive applications, more sophisticated indoor communication networks are needed. By nature, buildings are physical barriers to wireless communications which may lead to penetration losses. Consequently, quality of services may be compromised. Thus, reliable and quality of service is essential for indoor users. Due to the penetration losses, the indoor user requires high power from the serving Base Station (BS). It is also very expensive to have a large number of outdoor BSs to meet the needs of a high capacity network. The large number of BSs would pose larger burden on network planning and optimization. Femtocells have been widely used in wireless communication systems as a solution to this issue because of their many benefits, including enhanced indoor coverage, low cost, and energy efficiency [5]. In order to achieve this, a large number of densely deployed femtocells, referred to as an ultra-dense network (UDN), are anticipated to underlay the current macro network. Large-scale femtocell deployments have the potential to increase wireless network interference. The effective deployment of femtocell networks is hampered by this interference, which reduces network performance, particularly when adjacent femtocell frequencies overlap [6]. Due to the potential of femtocell to improve indoor localization and coverage, reducing the interference level generated by the densely deployed cells has been a focus of many research studies [7-10]. In this paper, a survey of different scheme for reducing interference level in femtocell network is presented.

II. FEMTOCELL CONCEPT

Femtocells are majorly used for indoor radio coverage. They provide nearly all cellular functionalities to users and are installed indoors by the user, much like a Wi-Fi router [11-13]. The user's broadband internet connection is then used to link the femtocell Access Point (FAP) to the operators' core network. Figure 2 depicts the link between an end user and the mobile operators' core network. Figure 3 depicts a typical indoor femtocell deployment. The femtocell in this scenario allows various indoor User Equipment's (UEs) to connect to the FAP and make use of voice and data services. Femtocells, also known as Home Node B (HNB) in WCDMA systems and Home e Node B (H(e)NB) in LTE systems, are standardized since 3GPP release 8 and employ physical layer technology comparable to that of cellular networks. A crucial feature of 3GPP release 8's femtocells is the Closed Subscriber Group (CSG). Every H(e)NB has an access mode that only allows limited and registered UEs to connect; all other UEs are unable to access it since their connection is refused. These H(e)NB are utilized in homes and small offices. Release 9 improves this control over access modes by offering hybrid and open access modes. Every user has the ability to ad hoc deploy femtocells within a macro cell and even relocate them from one place to another within their residence. As a result, operators find it difficult to dynamically manage radio resources [14–15].

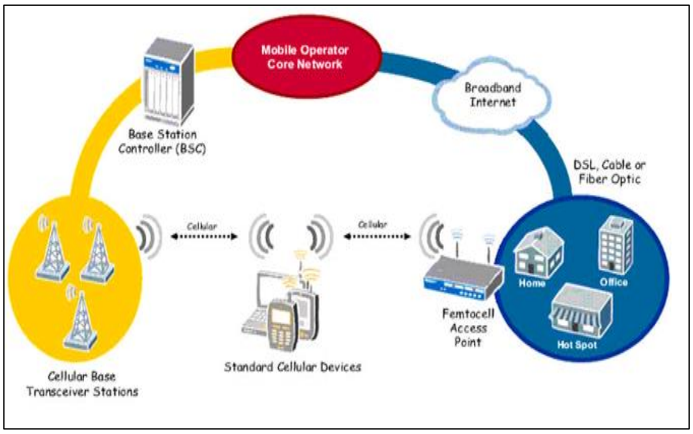

Figure 2: UE connected to an operator's core network in a femtocell.
Source: Authors, (2024).

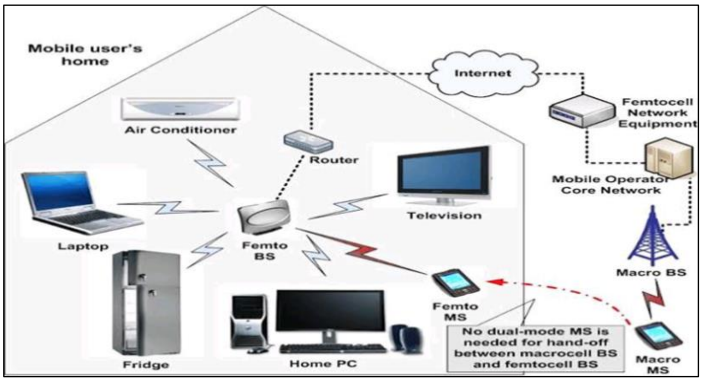

Figure 3: UE connected to an operator's core network in a femtocell.
Source: Authors, (2024).

In order to ensure that it is aware of its surroundings, it also needs effective self-organizing mechanisms. Distributed optimizing approaches should be used to reduce interference. Apart from potential spectrum shortages during dense co-channel femtocell deployment, opportunistic spectrum access is another feature that femtocells should have. This means that in order to be more intelligent, femtocells must possess cognitive functions. Cognitive femtocells are femtocells that possess cognitive functions. This is because of its additional features, which may offer effective answers to the problems that dense femtocell deployment may present in the future [16–18]. Cognitive femtocells can identify any empty spectrum areas (also known as spectrum holes or white spaces) by detecting spectrum in their immediate surroundings. The cognitive femtocells then make use of these spectrum gaps to give their users connectivity. Their ability to collaborate and synchronize with nearby cognitive femtocells allows for more precise spectrum detection. When spectrum holes are unavailable, cognitive femtocells can function similarly to regular femtocells by using the licensed band [19–20]. The idea of femtocells first appeared in the 1999 where Bell Labs first studied a home base station. The Alcatel announced a GSM based home base station to be brought to the market in 2000 [21]. Although their demonstration devices demonstrated functionality over a Plain Old Telephone System (POTS) line, the equipment's exorbitant cost prevented them from becoming commercially successful. Following this, Motorola unveiled their 3G home base station in 2002, although the idea was still somewhat novel [21]. The term "femtocell" was first used in 2006; however this concept became widely recognized in 2005.

II.1. TECHNICAL AREA OF FEMTOCELLS

Femtocells present an improved solution to the indoor coverage problem. Their small cell radius essentially reduces the distance between transmitter and receiver, resulting in less attenuation of the transmitted signal and a good Received Signal Strength (RSS) for the receiver. Typically, the quality of a signal at the receiver is measured in terms of the signal to interference Noise ratio (SINR), which is a function of the transmitted power from the desired base station (BS), transmitted power from interfering transmitters, shadowing, fading, and path losses [22]. The SINR is a function of the transmitted power from the desired base station (BS), transmitted power from interfering transmitters, and shadowing, fading, and path losses. The weak interfering signals are caused by walls' penetration losses. Due to their high bit rate operation, higher frequencies—which are frequently employed in 3G technology show a greater loss of signal strength. Femtocells use this insulation in the form of these losses to communicate at low power levels while preserving high-quality interior coverage. Femtocells can offer high data rate services to users by using more sophisticated modulation and coding algorithms when the channel circumstances are favorable. Furthermore, a femtocell may dedicate a large amount of its resources to the users that are accessible because it typically serves a smaller number of users (home residents/office workers) than a macro cell (for example, Vodafone femtocells can handle a maximum of four users). Femtocells can offer better (QoS) to their consumers than macrocells, which must serve more users concurrently over a greater region [23]. Femtocell installations can be done in two primary and popular ways [13]. Both the co-channel and distinct channel deployments. A dedicated channel that is not utilized by the macrocell is set aside for the femtocell network in a separate channel deployment. By using the same channels as the macrocell in the co-channel deployment, interference between femtocell and macrocell users can be avoided [23]. The operators strongly like this since it could be costly to set aside a specific amount of spectrum for femtocells because spectrum is a valuable resource. Additionally, the co-channel deployment greatly expands the system's total capacity. The possibility of users of femtocells and macrocells interfering with one another increases with co-channel implementation [23]. Therefore, effective and thoughtful interference management is necessary for a co-channel femtocell deployment to be successful. Femtocells, with their increased capacity, also offer a practical answer to issues with coverage outdoors. Femtocells are able to fill in the coverage gaps in a macrocell's footprint. In this sense, the femtocell can cover macro cellular users in the vicinity and within its coverage radius of the femtocell. This property of femtocells can be of importance at the macrocell edges. In a femtocell, the femtocell access point's (FAP) capacity to operate as a BS is crucial. While there are some parallels between the FAP and Wi-Fi access point, there are also some differences. Since both rely on the internet as a backhaul network, the backhaul is primarily responsible for the QoS. However, the FAP implements cellular technology while Wi-Fi are WLANs and mainly used for data services [24]. Table 1 shows the main difference between femtocells and Wi-Fi. Several FAPs have been developed by various manufacturers as reported [25–28]. Different air interface technologies coexist nowadays, which leads to the development of various kinds of femtocells based on different technologies. For example, 2G and 3G femtocells have been developed. Femtocells with newer technology like LTE and WiMAX are being developed.

Table 1**:** Differences between femtocells and Wi-Fi network.

Specification	**3G Femtocell (HSPA)**	**Wi-Fi**
Data rate	7.2-14.4Mbps	11Mbps
Operational frequency	1.9-2.6GHz	2.4-5GHz
Power	10-100mW	100-200Mw
Service	Primarily voice and data	Voice and data
Range	10-30m	100-200m

Source: Authors, (2024).

The selection of a femtocell based on a particular technology depends on the need of the user. Figure 4 illustrates the main types of femtocells depending on the technology used. Each of these types is discussed accordingly.

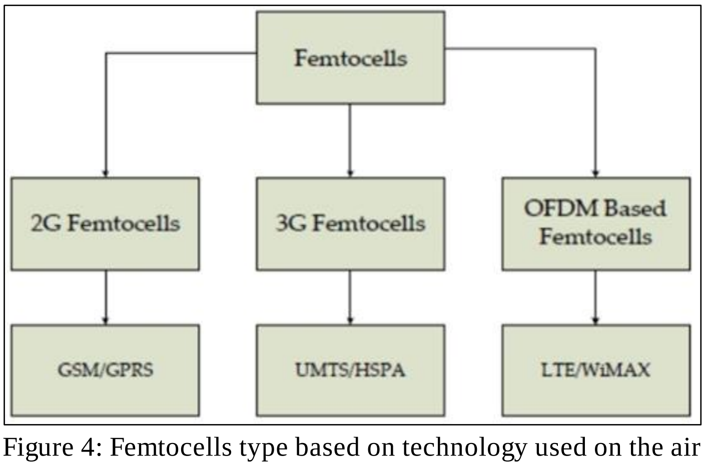

Figure 4: Femtocells type based on technology used on the air interface technology.
Source: Authors, (2024).

(i) **2G Femtocell**: The 2G femtocells are based on the Global System for Mobile Communication (GSM) air interfaces. Majority of the manufacturers concentrate on the production of 3G femtocells, when compared with the old GSM, however, GSM holds a huge number of subscribers around the world. Many developing countries like India and Pakistan are still expanding the GSM cellular network, in such a scenario, providing users with 3G and beyond femtocells would be of no use [29]. Low cost is one of the main reasons for the development of 2G femtocells, as compared to the newer versions [30]. One good example is the development and improvements of GSM femtocells by Ericsson in 2007 [31]. 2G, or second-generation mobile technology, introduced digital voice communication and limited data services. The data rate for 2G typically ranged from 9.6 kbps to 64 kbps, providing basic internet access, email, and SMS.

(ii) **3G Femtocell:** These femtocells are primarily based on the UMTS Terrestrial Radio Access (UTRA) air interface, which allows them to provide higher data rates than 2G femtocells [32]. The UMTS technology can connect through IP-based networks, which makes it more suitable for femtocells. In contrast to GSM-based femtocells, 3G femtocells have better power allocation schemes, which can be used to prevent interfering with the usage of macrocells [33]. The UMTS femtocells are also standardized by the 3GPP as HNBs. This motivates manufacturers to produce these kinds of femtocells. HSPA femtocells, which provide higher-quality services, are femtocells that have been designed with extra improvements in UMTS [34, 35]. A set of mobile telecommunications standards known as 3G, or third generation, were unveiled in order to improve data transfer speeds and open up new applications beyond simple messaging and phone calls.

(iii) **OFDM based Femtocell**: Examples are WiMAX and LTE femtocells. As the name implies, the physical layer technology used by these femtocells is orthogonal frequency division multiplexing, or OFDM. The primary indoor technology of the future is thought to be LTE femtocells, which are better recognized. The end consumers can receive a range of high data rate services from these femtocells [36]. It is also a hot research area nowadays and a lot of research is going on in order to efficiently execute LTE femtocells in the future [28-34]. OFDM (Orthogonal Frequency Division Multiplexing) based femtocells are small cellular base stations deployed in indoor environments to enhance wireless coverage and capacity.

Table 2 presents a comparison of the OFDM-Based femtocell with other femtocell network types. In terms of the data rate, OFDM-based femtocells can offer data rates comparable to or even higher than traditional macrocell networks, typically ranging from a few Mbps to several tens of Mbps e.g. 200mbp. This allows for high-speed internet access, video streaming, and other data-intensive applications within homes or small businesses. Also, OFDM uses a modulation technique that divides the available spectrum into multiple orthogonal subcarriers, which are then modulated with data. This technology allows for efficient use of the spectrum and mitigates the effects of multipath interference, making it well-suited for indoor environments where signal propagation can be challenging.

Table 2: Overview of the femtocell network types.

Technology	**2G**	**3G**	**OFDM Based Femtocell**
Data rate	14-64kbps	2mbps	200mbps
Technology	TDMA	Broad bandwidth/ CDMA/IP technology	Unified IP and seamless combo of LAN/WAN/WLAN
Service	Digital voice, short messaging	Integrated high quality audio, video and data	Dynamic information variable devices access
Power allocation	Low	Low	High
Switching	Circuit /circuit for access network and air interface	Packet except for air interface	Packet except for air interface
Core network	PSTN	Packet network	Internet

Source: Authors, (2024).

II.2 FEMTOCELL ULTRA-DENSE NETWORKS

The network's deployment was modified from the conventional macro cell-only network, which was dispersed across the macro cell's service region. It is now possible to increase network capacity by 1000 times by deploying ultra-dense tiny cells in a Heterogeneous Network (HetNet) in which small cells are as shown in Figure 5, UDN consists of UEs, moving nodes, network server/controller, macro Base Stations (BS), densely deployed small cells, and moving nodes. The increasing number of UEs can be supported by a large number of tiny cells, as shown in Figure 5, and the mobile UEs handle connection, disconnection, searching, and reconnection.

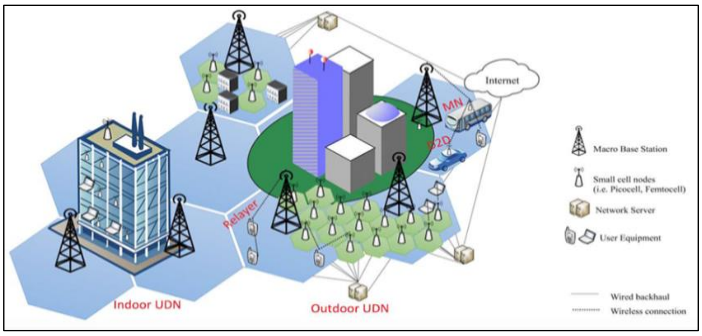

Figure 5: An example of a UDN.
Source: [37].

Furthermore, Device to device (D2D) communication must be available for the UEs at a cell edge to use relaying (as a forwarding node) for connection. Similarly, the moving nodes can facilitate vehicle-to-vehicle (V2V) communication. The following are the main characteristics of the UDN:

(i) **A large number of access points and small cells (more than or equal to the number *of UEs*).** Similar to how close proximity and spectrum sharing function in macro cells, the abundance of small cells can enhance frequency reuse. By shifting macrocell traffic, distributing network loads, and clearing congestion, the dense small cells increase the network's capacity.

(ii) **Dense and richly interconnected cross-tier deployment**. This includes relay, D2D linkages, macro cells, small cells (such Pico and Femto), and other components that add to the overall complexity of the network environment. The overlapping region receives transmissions of several frequencies due to the multi-tier deployment (e.g., macro cell and small cell). Similarly, a high frequency reuse factor results from small cells' close proximity to one another. Thus, in order to mitigate intra-tier interference (such as macro-macro and small-small), inter-tier interference (such as macro-small), and facilitate resource management (such as energy and spectrum), enhanced interference coordination is required [38].

(iii) **Fast access and flexible switching (e.g., handovers).** The mobile user equipment (UE) may regularly switch the connection between access nodes in a densely deployed environment in order to guarantee optimal connections, improved service etc. Excellent handover (HO) performance is required to ensure connections are seamless and easy to use.

II.3 ULTRA-DENSE NETWORK TAXONOMY

UDN are grouped based on access point and network connectivity. The former has to do with the particular connectivity paradigm that is applied. It encompasses a variety of access technologies and architectures for network access. Figure 6 displays the UDN taxonomy. This section covers each of these categories.

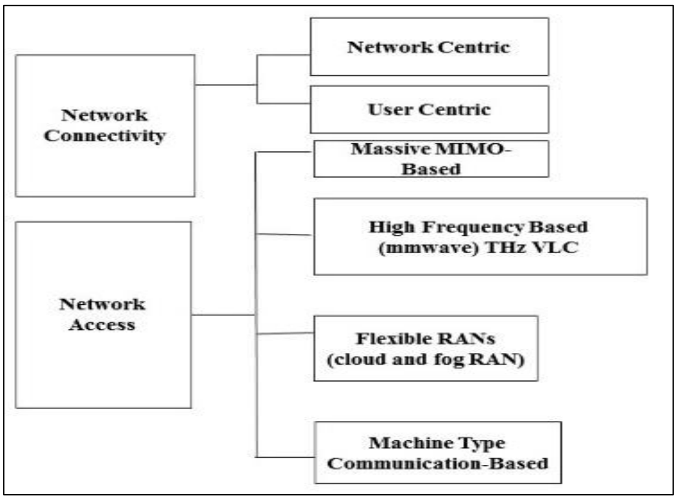

Figure 6: Taxonomy of ultra-dense networks.
Source: Authors, (2024).

II.3.1 NETWORK CONNECTIVITY

Under the network connectivity, there are two categories. These are network centric and user-centric.

(i) Network-Centric Connectivity

A network centric connectivity's typical architecture is shown in Figure 7. The Heterogeneous Ultra-dense Networks (HUDNs) represent the foremost instance of implementing the concept of network-centric connection. HUDNs were made up of a range of access technologies, each with unique limitations and capabilities. One of the primary methods for boosting the capacity of next-generation wireless networks is to effectively reuse spectrum over the region of interest, which is made possible by this [39–41].

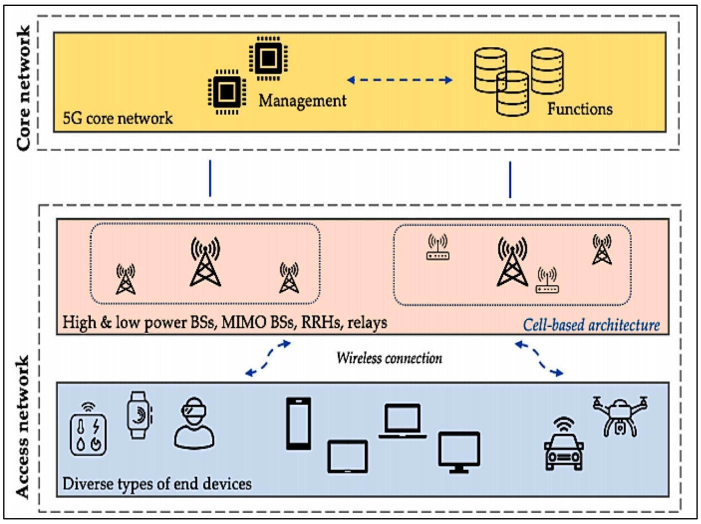

Figure 7: Network-centric connectivity architecture.
Source: Authors, (2024).

An HUDN typically consists of three different types of cells: (a) fully functional, high-power macrocells, also known as legacy cells; (b) fully functional small cells, also known as picocells and femtocells, which can perform macrocell functions in a smaller coverage area and with less power; and (c) macro extension APs, such as relays and remote radio heads (RRHs). Macrocells are composed of external eNodeBs (eNBs) that the operator has strategically placed to allow for unrestricted public access across a broad area, typically several kilometers. However, picocells are low-power, fully functional eNBs that may be used both indoors and outdoors. They are typically delivered by a provider in accordance with a certain plan. The backhaul and access features of macrocells are also shared by picocells. Allowing for low latency and high bandwidth. Femtocells are widely utilized for interior applications (in homes, workplaces, conference rooms, etc.). With an average transmission power of 100 mW or less, these are ad hoc low-power access points. Depending on its level of access, a femtocell can operate in one of three modes: open, closed, or hybrid. Relays are access points that the operator installs and uses to cover dead zones and limited coverage areas in macrocells, much like macro extension access points. The Users' data is transmitted back and forth between the macro cell and the relays, which in this instance are merely macro eNB extensions rather than fully functional APs. Finally, to enable the core eNBs to cover a wider area, the RRHs are small, lightweight RF devices that are placed outside of macrocells. The RRH does not have a baseband unit (BBU). RRHs are connected to the BBU pool or Macro eNB (MeNB) by millimeter waves or high-speed fiber. BBU pools or central eNBs manage all signal processing. As a result, instead of distributed densification, RRHs are utilized to give centralized densification. RRHs can be simple and inexpensive to manage. Table 3 briefly presents the characteristics of various AP/cell types in HUDNs.

Table 3: Comparison of the HUDNs cell type features.

Type of AP/Cell	Deployment Scenario
Macrocells (fully functioning)	Outdoor (planned)
Picocells (fully functioning)	Indoor/outdoor
Femtocells (fully functioning)	Outdoor
Relays (macro-extensio)	Indoor/outdoor
RRHs (macro-extension)	Outdoor

Source: Authors, (2024).

(ii) User-centric connectivity

Due to dense deployment and very large coverage overlap, AP distribution in a UDN is particularly challenging. This means that severe inter-cell interference, high signaling overhead, and challenges with resource management will arise from the conventional network-centric (cell-based) connectivity method. Furthermore, because of the uneven cell design, some users will be positioned in areas that overlap and cause a lot of interference, while other users might be found at the cell border or in an area without service. Situations like these will have a big impact on the overall quality of service. In [42], a paradigm-shifting user-centric UDN is suggested in order to effectively utilize UDNs' potential. UDNs define a development in the UDN notion by using the de-cellular technique to shift the design concept from a cell-centric to a user-centric paradigm [43–44]. In a UDN, every base station turns into an access point. To provide dependable access and data transfer, the network establishes an AP group (APG) for every user (Figure 8). Because of this, the idea of user-centric connectivity can be explained as a cell-less structure in which the access point group replaces the conventional cell unit.

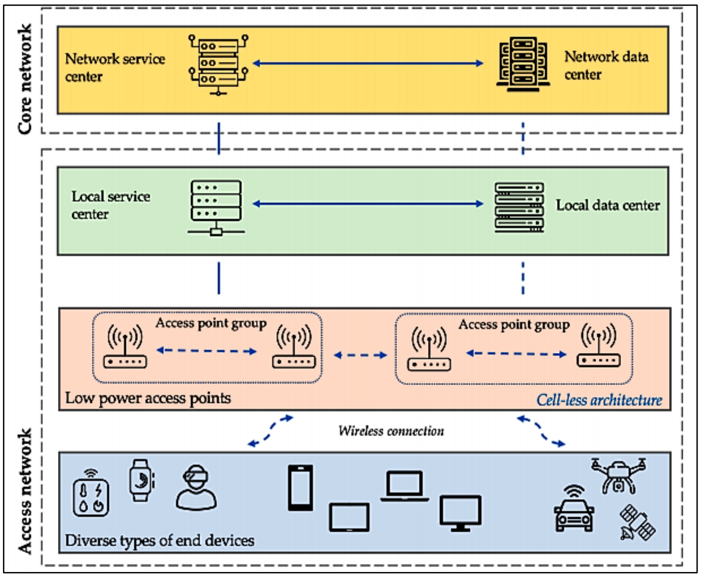

Figure 8: User-centric connectivity.
Source: Authors, (2024).

Moreover, every AP that was taken into consideration for HUDN deployment might be used for UDN. One of the main planned benefits of UDNs is that the UDN network can identify the unique capabilities, specifications, and radio environment of the end devices automatically. Furthermore, APGs are created and constantly updated based on the needs of the end devices as well as their location. All of the APs in this particular scenario are able to collaborate and share data to improve user experience and energy/spectrum efficiency (EE/SE). Lastly, to guarantee the highest levels of security and protection, network authentication processes are carried out [45]. Table 4 provides a comparison between the network-centric and user-centric solutions. It is clear that a user-centric approach is more dynamic and able to offer a wider range of flexible connectivity possibilities. Furthermore, because the idea of cell construction has been replaced by the dynamic grouping of APs, which continuously monitor the behavior of EDs, the user-centric approach eliminates the necessity for handover. Aps are able to collaborate more cleverly as a result, which greatly enhances system performance, resource efficiency, and interference resistance. Finally as previously mentioned, HUDNs and UUDNs employ asymmetric connectivity because of the many AP types, point-to-multipoint communications, dynamic resource access, etc.

Table 4: Comparison between network-centric and user-centric concept.

Aspect	**Network-Centric**	**User-Centric**
Network architecture	Network-centric cellular structure	User-centric de-cellular structure
Serving entity	Single serving BS	Dynamic APGs
Mobility management	Handover and terminal	Dynamic grouping of APs without involvement of terminal
Connectivity	Symmetric	Asymmetric
Network sensing	Incapable	Capable
Radio resource management	independent cell unit	Cooperation, usr-centric
Interference management	independent cell unit	Cooperation, user-centric

Source: Authors, (2024).

II.3.2 Network Access

Under network access, there are four other subcategory of UDN. This includes, Massive multiple input multiple output (MIMO)-based access, high frequency-based access, and Flexible RAMs and Machine–type Communication-based access

(i) Massive MIMO-Based Access

Large-scale antennae systems, also known as Hyper MIMO, are systems that use a significant number of service antennae across active terminals and operate in the time-division duplex mode by focusing energy into ever-smaller sectors of space. Massive MIMO-capable base stations (BSs) will have hundreds, if not thousands, of antennae. This could be considered one way to spatially densify the network, as projected by 5G use cases [46]. Any given resource unit of a certain BS can provide a greater number of users, yielding substantial benefits. By combining low-cost, low-power components with less complex signal processing methods, massive MIMO can provide ultrahigh reliability, improved throughput and radiated EE, resilience to intentional interference, and decreased latency as compared to standard MIMO [47].

(ii) High Frequency-Based Access

The mmWave communication is thought to be the superior choice because a significant portion of modern wireless communications systems depend on spectrum scarcity in the 300 MHz to 3 GHz frequency range. In comparison to current cellular spectrum allocations, the 6 to 100 GHz frequency band may offer orders of magnitude more spectrum, enabling the utilization of beamforming and spatial multiplexing with a large number of antennas [48]. The networks ought to have improved coexistence, increased isolation, and bandwidth as a result of directional antennas [49]. Even though the shift in frequency bands has drawn a lot of attention, there are still a lot of problems, including severe cross-link interference, significant mmWave frequency penetration loss, and extremely volatile link and channel conditions [50]. BSs in mmWave networks are capable of broadcasting and receiving in the mmWave band, hence providing coverage for particular geographic regions. In order to provide sufficient coverage, mmWave BSs must be placed densely. MmWaves' ultra-dense construction makes it simple to integrate them into UDNs. However, because so many BSs are needed, backhauling a dense mmWaves network can be costly. This suggests that other BSs could serve as a conduit for connecting some mmWave BSs to the backhaul [51].

(iii) Flexible RANs

The Cloud Radio Access Network (CRAN) is a radio access network architecture that combines cloud computing with cellular technologies. In CRAN, baseband processing tasks are carried out in a central cloud or centralized BBU pool [52]. As a result, base stations have been reduced to simple Radio Remote Heads (RRHs). Front haul lines link the several RRHs to the central cloud. Communication between the network's core and central cloud is facilitated by the transport network. In CRAN's initial plan, the RRH and central cloud connection is described as optical fiber front haul.CRAN offers a number of benefits, ranging from simpler BSs to cloud-based processing. Similar to modern IT cloud computing, cloud computing facilitates the full utilization of available resources. In addition, CRAN considers the separation of handling and transmission, enabling the use of information plane collaboration techniques like coMP [53]. Through the dense deployment of the available RRHs in CRANs, a novel and attractive network design known as ultra-dense CRAN is produced. In comparison to ordinary cellular networks, ultra-dense CRANs may significantly improve both energy and spectrum efficiency (SE) due to the centralization of resource allocation and collaborative signal processing among the RRHs. Moreover, mmWave wireless front haul may be utilized in ultra-dense CRANs to exchange data between the distributed RRHs and the central CPU, reducing costs and improving deployment flexibility [54].

(iv) Machine-Type Communication-Based Access

One of the challenges facing the IoT in order to enable the development of billions of smart devices is massive device connectivity. To provide ubiquitous IoT services, a wide range of high efficiency communication infrastructures should be incorporated, such as machine-to-human (M2H), machine-to-machine (H2M), human-to-human (H2H), and machine-to-machine (M2M) communications [55]. Future use cases will include smart building, smart agriculture, industrial automation, and auto-drive robot interaction. At the same time, the network will grow to encompass a bigger IoT ecosystem. Massive IoT is expected to be developed with the aid of numerous novel technologies and techniques, including information sensing, cloud computing, and artificial intelligence (AI) [55]. Massive IoT is anticipated to develop into an international network of interconnected systems, facilitating a variety of data exchange, collecting, and decision-making processes as well as improving measurement and management effectiveness [55]. Proximity-based communication that can manage data flow has acquired a lot of interest with the rise of smartphones and tablets. D2D-enabled users can exchange data directly without going through BSs or the main network, enabling proximity-based communication. A new network topology called an ultra-dense D2D network has been developed as a result of the high number of D2D-enabled users [55, 56].

II.4 INTERFERENCE PROBLEM AND CATEGORIES IN FEMTOCELL UDN

i. Co-tier interference

This is related to two different kinds of interference between femtocells that are next to each other. Uplink co-tier and downlink co-tier interferences are the two types [57]. Network components that are part of the same network layer are the cause of this kind. As indicated by indicator 1 in Figure 4, uplink co-tier interference occurs when femtocell users (aggressors) interact with the nearby femtocell base station (victims). As seen in indicator 2 in Figure 9, a downlink co-tier interference occurs when a nearby femto-user (victim) experiences interference from a femtocell base station (aggressor). Since they are next to one another, the femtocells that interfere with one another are typically immediate neighbors. Femtocell placement is random, and they can be placed in close proximity to one another, perhaps with insufficient wall separation to prevent interference. When there is a dense deployment and multiple nearby interferers, the total interference detected at a certain femtocell is probably more than the sum of the individual interfering femtocells.

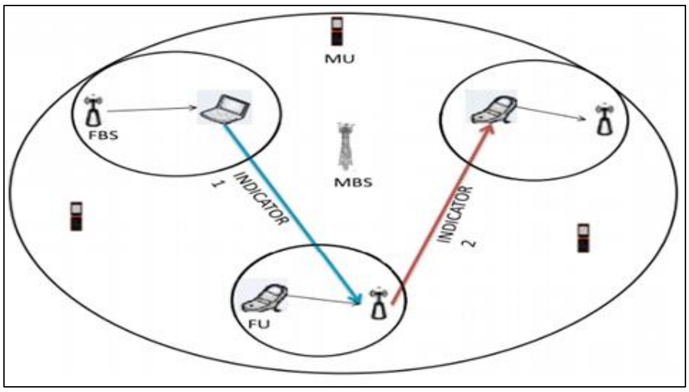

Figure 9: A typical co-tier interference scenario between neighboring FBSs.
Source: Authors, (2024).

ii. Cross-tier Interference

This has to do with interference between the femtocell and macrocell layers, as well as vice versa. A typical cross-tier interference scenarios is illustrated in Figure 10.

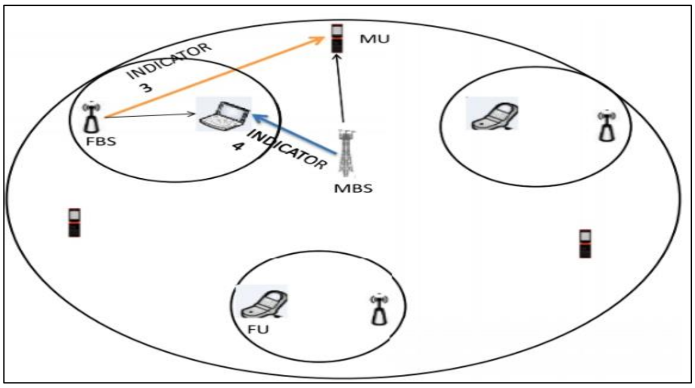

Figure 10: A typical cross-tier interference scenario between FBSs.
Source: Authors, (2024).

As indicated by indicator 3 in Figure 10, uplink cross-tier interference occurs when femtocell users (aggressors) interfere with the operations of a nearby macro-cell base station (victims) or when macro-cell users interfere with the operations of a nearby femtocell base station. However, as indicated by indicator 3 in Figure 5, downlink cross-tier interference occurs when a macro-cell base station (aggressor) interferes with a nearby femto-user (victim) or when a femtocell base station (aggressor) interferes with a nearby femto-user (victim).

iii. Multi-tier Interference:

In the UDN, both the macrocells and small cells are cross deployed throughout the network. The interference caused by multi-tiers include the various emit powers, cell topologies, radio accesses, etc. For example, small cells reuse the frequency band from the macrocell, which brings interference to the Macro cell UE (MUE), especially to the MUEs at the cell edge. The MUEs at the cell edge received signal with strong path loss and fading. When the small cell uses same sub-channel for communication, the interference to MUE become severe. On the other hand, the MUE near the cell edge will increase the emit power due to the power regulation, which interferes with the small cell UEs (SUE) [58]. Four examples of multi-tier interference are given in Figure 11. The interference signal and direction are shown by the red line in each of the sub-figures. For instance, the macro cell UE (UE1) is receiving signals from the macro cell in Figure 11(a). At the same time, UE1 may experience interference from tiny cell transmissions. As UE2 communicates with the small cell in Figure 11(b), the macro cell may cause interference for the small cell UE (UE2). In Figure 11(c), while UE2 is transmitting to the small cell BS, the transmission signal from UE1 to the macro cell interferes with the small cell BS. In Figure 11(d), while UE1 is transmitting to macro cell BS, the UE2 m ay pose interference to the macro cell BS when transmitting to the small cell BS.

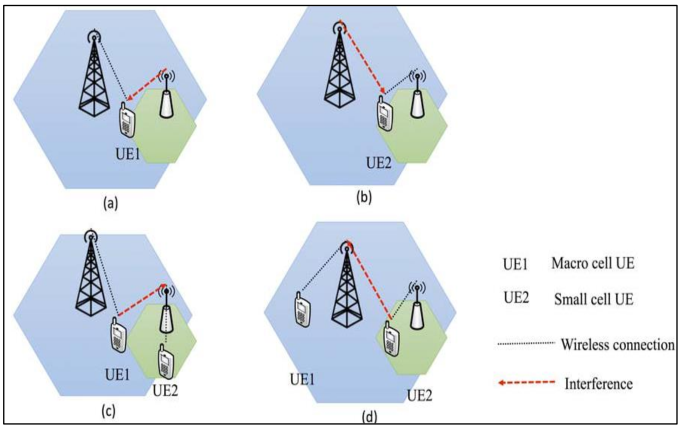

Figure11: Multi-tier interference cases.
Source: Authors, (2024).

II.5 INTERFERENCE REDUCTION METHODS FOR FEMTOCELL UDN

Various interference studies have been proposed, with differing degrees of success, and numerous research publications addressing this issue have been published. As illustrated in Figure 12, the interference reduction techniques used in this investigation was classified into four groups. These include the application of game theory, dynamic resource allocation, user clustering, and graph theory.

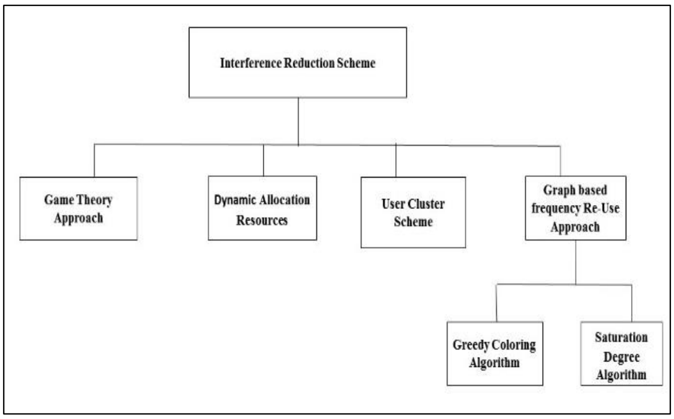

Figure 12: Interference reduction scheme in femtocell UDN.
Source: Authors, (2024).

II.5.1 GAME THEORY APPROACH METHOD

The game theory approach to reducing interference involves analyzing the strategic behavior of multiple users or nodes competing for limited wireless resources, such as bandwidth or frequency channels. It aims to develop algorithms and protocols that optimize resource allocation and transmission strategies to minimize interference and improve network efficiency. This approach considers factors such as channel conditions, user preferences, and network topology to design decentralized decision-making mechanisms that lead to better overall network performance. Game theory has been extensively used in networking research as a theoretical decision-making framework, e.g. for routing [59],[60], congestion control [61],[62], resource sharing [63-64], and heterogeneous networks [65],[66]. Based on the idea of Shapley value in the wireless relay network (WRN).The author in [67] investigated the dynamic spectrum access problem with a two-stage Stackelberg game consisting of a leader (spectrum provider) subgame and a follower (secondary user) subgame. An on-demand resource-sharing mechanism considering user's selfish characteristic and private traffic information was designed in [68]. The author proposes a centralized user-centric merge-and-split coalition formation game that users instead of FAPs participate in the game as players. Other than FAP-centric games, this user centric game makes it conceivable to estimate inter-user interfere by making use of user information (e.g., distance) so as to assist in distributing and reusing sub channels. As a consequence, a user-centric coalition formation game can achieve a preferable system performance. Finally in order to fully utilize the remaining sub channels and get over the restriction of assigning one sub channel to each player in typical coalition formation games, an additional allocation technique was finally put forth. The remaining subchannels are located by searching through each FAP's unallocated subchannels; users will only be assigned to these remaining subchannels if the aggregate throughput is increased. The spectral efficiency is greatly increased by the SAA at a minimal computational cost. Comparing simulation findings to comparable studies showed that these approaches were beneficial. The studies in [69] proposed a scheme for ICI reduction by controlling the transmit power through a non-cooperative game in which the transmit power is considered to be the action set available to the players (users). However, the author considered only a simple case of 2 users, each in different cell which are competing on 2 sub channels. Alternatively, the proposed scheme considered multiple users in multiple cells. The authors proposed a non-cooperative game where $G = (J, \{P_j\}, \{U_j\})$ represent a game with $J = \{1, 2 ... k ... J\}$ representing the set of user equipment's in adjacent cells who are using the same sub channel and $P_j = \{P_j : P_j\} \in [0, pmax]\}$ representing a continuous set of transmit power which represents the space of user's actions. $Pmax > 0$, is the maximum allowable transmit power per sub channel. The selected action (transmit power) has to be smart enough to maximize the user's utility function. A mathematical expression known as the utility function measues the degree of satisfaction a user experiences when utilizing system resources. Delay and clarity are two elements that impact the quality of multimedia services. Low data rates and frequent retransmissions, which are essentially caused by low SINR levels, are the primary reasons of delay. Furthermore, low SINR raises the bit error rate (BER), which deteriorates clarity, particularly for voice services. Thus, the primary causes of service degradation are interference and a poor received signal.

Fixing an application-based BER while increasing the throughput—which ought to be flexible and variable—is one method to handle such a scenario. When the primary goal is to maximize spectral efficiency, a concave growing function of the user's SINR should be used to determine the utility of the user [70–73]. In light of this, the logarithmic Shannon capacity function or a function proportional to it immediately springs to mind. However, broadcasting with the maximum power is the optimal approach for a user to maximize such utility function in a non-cooperative game, given a fixed interference I and fixed desired channel power. Instead of increasing the system's spectral efficiency, such conduct will raise the network's degree of interference. Consequently, this kind of function isn't a full utility function to complete it, a pricing term (or cost) should be incorporated to it so that it prevents the users from always transmitting at full power. Thus, If SINR is fixed, the utility function should be a decreasing function with respect to the transmit power. These unplanned and unmanaged wireless networks are collectively referred to by the authors in [74] as chaotic networks or chaotic deployments. They do, however, highlight certain benefits of such chaotic networks, such as making it simple for new methods to determine locations [75] and offering nearly universal wireless connectivity [76]. The main disadvantage of these disorganized deployments is that, despite being difficult to identify, interference can have a substantial impact on end-user performance [77]. The author of this study proposes a "virtualization" solution in which the interfering APs take turns serving each other's clients. Allowing clients to associate with APs from different owners has security problems, but these have been discussed and resolved in [78].The author focus on the *incentive* aspect, and propose a framework to ensure that the APs are indeed motivated to provide service to each other’s’ clients

II.5.2 Dynamic Resource Allocation Method

Dynamic channel allocation systems have attracted a lot of interest as ways to achieve effective system resource use. There have been several suggestions for permanent channel assignment, channel borrowing, shared channel pools, channel ordering, channel reassignment, and dynamic parameter adjustment. An effective resource allocation method that can lessen the impact of uplink interference in a two-tier femtocell was proposed by the authors in [79]. These writers employ an integer programming (IP) approach to achieve the goal. Despite the scheme’s complexity and intricacy, the outcomes were effective. The authors suggested using a heuristic method wherein resources were distributed collaboratively between femtocells and macrocells. The femtocell-macrocell network in this study was subjected to interference control during uplink transmission using Single Carrier Frequency Division Multiple Access (SC-FDMA), particularly in the macrocell’s cell edge area, which frequently encounters high interference levels. When the number of femtocells increases, the study’s femtocell utilizes the radio resources of nearby macrocells by taking into account the least amount of interference from users stationed in the nearby 12icrocell area. Three 12icrocell-based multi-cell cellular communication layouts are taken into consideration in this study. A growing number of femtocells are installed in 12icrocell 1. Assuming a frequency reuse factor of 3, the initial femtocell chooses radio resources from either 12icrocell 2 or 3 (neighboring macrocells). Subsequent femtocells are not permitted to use the same radio resources as the first femtocell that has been allotted. Femtocells are categorized according to the radio resources that are allotted differently; macrocells and femtocells will share the radio resource allocation. Various radio resources are assigned to femicells within the same group. To mitigate the issue of femtocell interference in networks based on Orthogonal Frequency Division Multiple Access (OFDMA) [80], [81], the authors suggest using partially shared and orthogonal spectrum to prevent cross-tier interference. The authors of [82] also suggest a dynamic fractional frequency reuse strategy that places users in orthogonal sub-bands who have poor geometry in nearby femtocells. Nevertheless, co-channel femtocell installations are recommended for greater spectrum reuse because these approaches may result in low spectral efficiency. The authors of [83],[84] analyze how to reduce interference in co-channel femtocell installations by using sector antennas and multiple antenna elements at femtocells, respectively. These methods do, however, require more sophisticated technology, which raises the cost and complexity of the femtocell in the end. Thus, it has been announced that the most promising method for handling interference in co-channel femtocell deployments is Sub-channel (SC) allocation and power regulation. However, the assignment of SCs and transmit power is an intricate optimization problem, which becomes even more complex due to the existence of several Modulation and Coding Schemes (MCSs) in WiMAX and LTE standards. Moreover, multiple SCs assigned to one user must use the same MCS [85], although each user may observe different channel gains in each SC. In the OFDMA literature, dynamic SC assignments with equal transmit power per SC are typically recommended over complex joint dynamic SC and transmit power assignments due to their ease of implementation and mathematical tractability because of the availability of link adaptability in the DownLink (DL). Previous evaluations [86],[87] also showed that in circumstances where a wide range of users require varying QoS, the benefits in overall system performance generated by assigning various transmit powers to different SCs are minimal.

II.5.3 User Clustering Scheme in Ultra-Dense Network

Clustering techniques are used to divide a data set into a number of different clusters by means of specific division criteria. For clustering plans in UDN, there are generally three types of clustering: static clustering, dynamic clustering and semi-dynamic clustering. For static clustering, the deployment of BSs or access points (APs) is pre-set. Although this technique is easy to implement in reality and has the potential to reduce signaling overheads, it is not well-suited to complex and dynamic mobile communication scenarios [88]. In [89], the author provides a static clustering approach that, with the least amount of overhead, accomplishes the large advantages and significant increases of the cooperative or coordinated multi-point (CoMP) technique. A separation function is provided for assessing the effectiveness of the separation clustering technique proposed by Xiao *et al*. [90]. This approach uses high-priority BSs and ranks BS priorities in order to suppress inter-cluster interference. Through simulation, the algorithm achieved a positive interference suppression result [90]. With dynamic clustering, instantaneous channel state information (CSI) is used to dynamically alter the formation of user and BS clusters, making it suitable for a range of mobile communication scenarios. However, this technique adds to the complexity of system scheduling and the requirement for feedback overhead. The issue of dynamic clustering has been approached from a number of theoretical angles by the researchers. In [94, 95], authors apply the graph theory method. In order to reduce system interference, the authors of [91] cluster users and generate a network interference graph using a graph coloring method and user feedback. A unique low-complexity clustering approach is put forth in [92]. By merging graph theory with the interference of a specific number of nearby BSs, the suggested technique accomplishes the objective of lowering the iterative complexity of the clustering process. Several authors in UDN have enhanced and implemented the k-means algorithm to user clustering since it is a popular and simple to use iterative method for cluster analysis [93-95].

As the fundamental part of resource management, the authors in [96] distributed resources to each cluster using an enhanced k-means algorithm. Through clustering the ensuing cluster heads, the average signal-to-noise ratio (SINR) is improved. In order to cluster BSs optimally and modify the traffic load in each cluster, the author of [94] suggests a weighted dynamic k-means method within a machine learning framework that takes geographic location and traffic load into account during the clustering phase. Unlike other enhanced algorithms [95], In addition to the enhanced k-means algorithm's ability to successfully lower the complexity of the network structure and user clusters, the authors are able to modify the number of clusters depending on the SINR. Dynamic clustering approaches based on game theory and clever optimization algorithms are also available. In [96], the author through the use of an intelligent optimization technique, he optimize the parameters of the DBSCAN algorithm. By finding isolated points, the optimized algorithm not only mitigates communication resources but also achieves the purpose of clustering users. A distributed approach is presented that provides a graph coloring algorithm for resource scheduling and a game theory based clustering algorithm for user grouping. According to simulation data, the method outperforms other relevant algorithms in terms of average cell throughput [97].

The benefits and limitations of both dynamic and static clustering are balanced by semi-dynamic clustering. A semi-dynamic algorithm with respect to the backhaul capacity constraint is proposed in [98]. The algorithm's low complexity and cheap training overhead are its advantages, but its application possibilities are limited because it requires large-scale channel information. A user clustering approach based on interference vector assessment is proposed in [98],[99], by creating an interference graph, the scheme determines the interference vectors of each user and groups them according to the relative interference values between their interference vectors. Comparative simulations were used to evaluate how effective the plan was. First, a method for creating interference weights based on the Signal-to-Other cell-Interference Ratio (SOIR) is presented. This method uses the interference weights between users to get the desired user interference vector. Second, an optimization approach was used to solve the interference vector. An interference graph, which is thought to be a useful tool for managing interference, was created in this study. The interference graphs consist of interference subjects and inter-subject relationships. Assume $\{V, E\}$, where $V = \{v1, v2, \cdots, vN\}$ denotes the set of users and $E = \{Wab\ (i, j), \forall i, j \in V\}$ represents the interference relationship between users. In Figure 13, a simple user interference graph is illustrated.

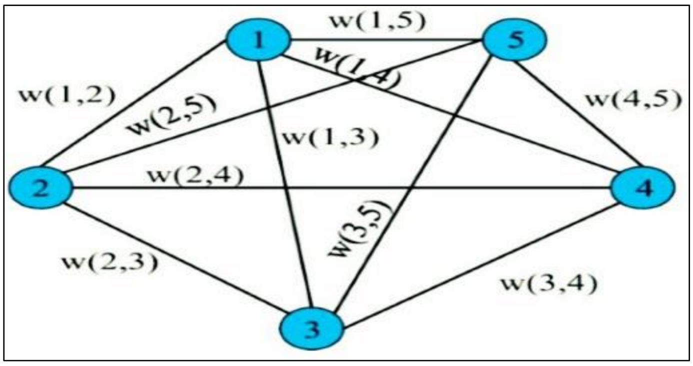

Figure 13: An interference graph.
Source: Authors, (2024).

From the graph in Figure 13, the user interference matrix W was obtained as

$$W = \begin{vmatrix} 0 & w(1,2) & w(1,5) \\ w(2,1) & 0 & w(2,5) \\ w(5,1) & w(5,2) & 0 \end{vmatrix} \quad (1)$$

The interference graph focuses on the interference weights' design. It defines the SOIR between user's u and v as follows after taking into account the impacts of both the SINR and SOIR.

$$r_{u,v} = \frac{S_v}{I_u} \quad (2)$$

where S_v is user $v's$ received signal, I_u is user u's interference signal, and $\boldsymbol{U}_{u,v}$ indicates the amount of power leaking from user v to user u. The greater the value, the greater the impact of user v on user u. (u, v) represents the interference weight between users u and v as

$$W(u,v) = \frac{1+\frac{1}{\mu V}}{1+\frac{1}{\mu U}} r_{u,v} \quad (3)$$

The SINR of users' u and v, respectively, are represented by μ_u and μ_v and μ_u. From (3), the interference weights between each pair of users can be obtained, and the interference vector for user i was set as

$$IV_i = [(i,1), W_{ab}(i,2), \ldots\ldots\ldots, W_{ab}(i,N)] \quad (4)$$

The research in [100, 101] grouped the nearby cells to study the performance of a single cluster; however, it is unclear how to build many clusters in the system. Since the system's clusters in [102] are produced by a stable Poisson process, clustering is not necessary to take into account. In those cases, clustering can be thought of as being carried out in a preset manner without taking advantage of additional system features like path-loss or location data. User partitioning has recently been taken into consideration in [103] for reduced signaling overhead where three clustering algorithms have been proposed. One potential issue is that these algorithms do not explicitly address the interference alignment feasibility constraint. Hence, transmitters must therefore modify the quantity of data streams they send in accordance with the size of the cluster. Furthermore, the clusters that are created are compelled to access the channel in a time-division fashion by the medium access control scheduling mechanism. Cluster synchronization and coordination are necessary for this.

II.5.4 Graph-Based Freqency Reuse Technique

The method for reusing frequencies in a graph is based on greedy coloring and saturation degree algorithms. In these schemes, the femtocells, or nodes in the graph, are connected by means of channel state information that is obtained from the femtocells and their users. Each base station is assigned a frequency to minimize interference through the use of graph-coloring algorithms, wherein each color corresponds to a different frequency band [104].

(i) Greedy coloring algorithm

The Greedy algorithm uses a routing technique to determine the best frequency assignment for a network by allocating the smallest color or sub-band to each available femtocell [105]. This is among the simplest techniques for coloring graphs. It gives vertices the least amount of color so that there is no conflict between them and their neighboring colored vertices, as Figure 14 illustrates. For a given graph G, the set of vertices is described as $V = \{v_1, v_2, \ldots, v_n\}$, the set of edges is described as $E = \{e_1, e_2 \ldots en\}$, the set of available frequencies is $F = \{f_1, f_2 \ldots f_n\}$ and the set of colors or sub bands for the nodes is described as $C = \{c_1, c_2 \ldots c_n\}$ where the total colors assigned in the graph network P = P +1.

Putting the greedy coloring algorithm into practice is not too difficult. Greedy coloring treats each vertex separately in order to concentrate on local optimization. This makes it ideal for situations in which global optimization is challenging or unfeasible. It is easily adaptable to many graph coloring issue variants and limitations, such as frequency assignment and scheduling. Additionally, because the algorithm only needs to keep the colors, it often uses little memory. Nevertheless, the plan assigns sub-bands arbitrarily and inefficiently. Greedy algorithms may react very quickly to modifications in the input data. There are several previous studies that are indirectly related to this research, including: implementation of the greedy algorithm on graph coloring. A map of the Deli Serdang region will be colored in this [106], minimal proof of the four-color theorem [107], and the ant algorithm [108-111].

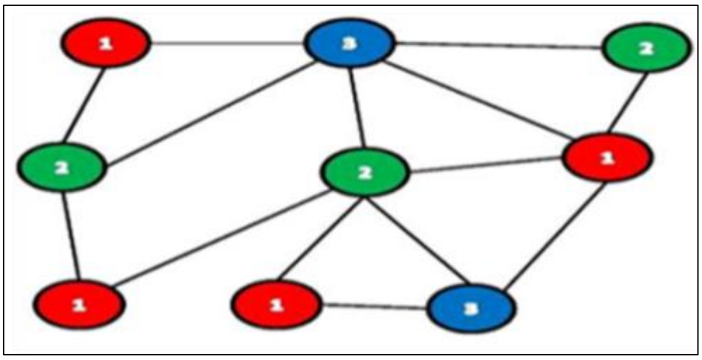

Figure 14: Greedy coloring algorithm.
Source: Authors, (2024).

(ii) Saturation degree coloring algorithm

This scheme assigns colors to a graph's vertices in a way that minimizes the number of different colors utilized throughout the graph and assigns different colors to neighboring pairs of vertices. Figure 15 shows a common saturation degree scheme with graphs colored in red, blue, and green. In fact, this is the very minimum of colors required for this specific graph. This indicates that at least three colors must be used to color this graph in order to guarantee that neighboring vertices have different color. This technique employs saturation degree (D) which is defined as the total number of adjacent colored vertices to which an uncolored femtocell or node is connected [112]. Saturated degree algorithm was proposed by author in [113] and is defined as follows. Suppose that vertices *v1, v2…vi-1* have been chosen and colored. Then at step *i*, vertex *vi* with the maximum Saturation degree is selected. The saturation degree of a vertex is defined as the number of differently colored vertices the vertex is adjacent to. Vertex v, for example, has saturation degree equal to 2 if its degree is equal to 4, one of its neighbors is uncolored, two of them are colored with color equal to 1, and the final one is colored with color equal to 3. Ties are broken in favor of the vertex with the largest degree when selecting the vertex with the maximum saturation degree. Since this heuristic colors the vertices that are most limited by earlier color selections, it seems to provide a superior coloring than Largest Degree Ordering. [113].

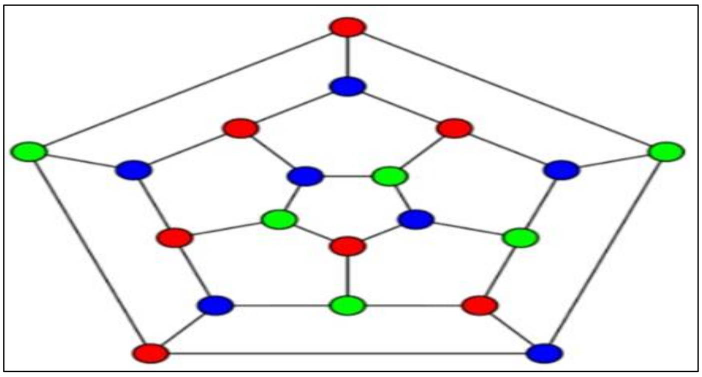

Figure 15: A typical saturation degree algorithm.
Source: Authors, (2024).

III. CHALLENGES AND FUTURE RESEEARCH DIRECTIONS

This section summarizes the current challenges identified from the research studies on the methods to reduce interference level in femtocell ultra-dense network. These challenges include:

(i) **Spectrum Efficiency in Wireless Backhaul:** Due to the numerous cell base stations in UDNs, a backhaul network with a high degree of flexibility and capacity is necessary. It is possible that the conventional wired backhaul network is no longer useful because of its high deployment, complexity, and running costs. There is a chance that the wireless backhaul network will lower infrastructure costs and increase deployment flexibility. The complexity of spectrum resource management and networking is a significant difficulty because of the enormous number of cells. Future research efforts aimed at enhancing spectrum efficiency in wireless backhaul include dynamic spectrum access (DSA) and cognitive radio. Examining cutting-edge methods for dynamically accessing and making use of available spectrum bands will be necessary to enable more effective spectrum allocation and usage.

(ii) **Dynamic environment**: One of the main disadvantages of the user-centric coalition forming game strategy is this. The coalition creation process becomes more difficult in a dynamic environment when user preferences, resources, or constraints change frequently because it necessitates ongoing updating and adjustment. Future research directions in a dynamic environment could focus on a number of topics, such as examining sophisticated spectrum management strategies to allocate spectrum resources dynamically based on interference and demand in real-time, enhancing spectrum efficiency, and supporting a variety of communication technologies. Also by developing adaptive resource allocation algorithms that can dynamically adjust network resources, such as bandwidth, power, and processing capacity, in response to changing traffic pattern, user demands, and environmental conditions.

(iii) User equipment Battery Life: The capabilities of spectrum detection, information gathering, interference cancellation, and other functions are demonstrated by the UEs equipped with sophisticated antennas. UE's battery life particularly that of smartphones, ought to be taken into account. Stated differently, a limited amount of energy will be allocated to a variety of tasks, such as signal transceiving, data roaming, and complex computing. Thus, another issue in UDN is the energy efficiency of smart devices. This is a prospective study direction that has to be pursued with continued examination. Enhancing UE battery life is anticipated to entail developing more energy-efficient processors and displays, optimizing power management systems, and making strides in battery technology. Furthermore, advancements in software optimizations, including background task management and low-power modes, will be extremely important.

(iv) Frequency Assignment: In a UDN femtocell network, frequency assignment is a crucial component that needs to be carefully considered to guarantee effective spectrum use and low interference. In order to enhance network performance overall, future research may focus on interference management and the development of strategies to reduce interference among femtocells as well as co-channel interference between femtocells and macrocells. Additionally, it is crucial to look into dynamic frequency selection algorithms that let femtocells choose the best frequency channels on their own in response to traffic and real-time interference.

(v) Security: Due to the high densification of the cells and user equipment, which offers hitherto unheard-of information interactions, security will become increasingly important in the development of UDNs. Similar to this, new channels for security compromise and privacy concerns arise from the restricted energy supply in UE devices as a result of data computing, data roaming, and other tasks. These factors must be taken into account. The vulnerability potential will unavoidably expand due to the various different networks and rising system complexity. Further research on this topic will focus on creating methods for identifying and thwarting security risks unique to femtocell UDNs. It's crucial to create secure resource allocation algorithms that take performance and security into account in order to maximize resource efficiency and minimize security risk**.**

IV. CONCLUSIONS

In this paper, we provide an overview to interference problem and reduction methods in femtocell UDN. Specifically, we first present some common architectures of femtocell UDN and issues relating to each architecture. Secondly, we provide a taxonomy to classify the UND networks. Then to alleviate the problem of interference in femtocell UDNs, some interference reduction schemes are discussed. Also, several research studies under interference reduction scheme were investigated. Finally, the challenges and open research directions are outlined in this field.

V. AUTHOR'S CONTRIBUTION

Conceptualization: Adekogba, G.V., Adedeji, K.B. and Olasoji, Y.O.
Methodology: Adekogba, G.V., Adedeji, K.B.
Investigation: Adekogba, G.V., Adedeji, K.B.
Discussion of results: Adekogba, G.V., Adedeji, K.B. and Olasoji, Y.O
Writing – Original Draft. Adekogba, G.V
Writing – Review and Editing: Adekogba, G.V., Adedeji, K.B
Resources: Adedeji, K.B
Supervision: Olasoji, Y.O and Adedeji, K.B.
Approval of the final text: Adekogba, G.V., Adedeji, K.B. and Olasoji, Y.O

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