

# Small Cell Deployment Challenges in Ultradense Networks: Architecture and Resource Management

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**Abstract**— The industries today, are undergoing transformational changes as a result of the growing demand for ubiquitous connectivity. To meet the increasing demand every day, loads of reengineering is required to achieve best-fitted architecture to accommodate more devices, ways to manage available resources, enhanced radio technologies, etc. to deliver more coverage and capacity. This paper aims to study and present different critical features of small cell and ultradense networks. The scope is to summarize various deployment scenarios and challenges. Broadly, the challenges w.r.t resource management, developing flexible architecture, managing the available spectrum and also the use of unlicensed spectrum, etc. will be addressed. The shortcomings in available resource management, interference awareness techniques, spectrum management, etc. will be summarized with different potential technologies. For small cells, it is necessary to understand its interaction with the macro network to demonstrate the overall user experience. Thus, this work will present an elaborated picture of small cell evolution followed by the radio access network (RAN) architecture to achieve a full-heterogeneous and centralized network.

**Keywords**— *Ultradense Network, Small Cells, RAN, RRM.*

## I. BACKGROUND

Ubiquitous and seamless connectivity is the stepping stone in everyone's anticipation for the current and upcoming wireless solutions to communication. Today we are in the midst of technological transformation affecting not only an individual's life but adding up a huge percentage to National economy, digital ecosystem, education, health, etc. We are in the initial phase of brewing the foundation for a sustainable solution to all our needs. ITU [1] mentioned 2019 to witness the growth of "Digital Economy" with the online participation of more than half of the world while Ericsson's [2] estimations state that by the end of 2025, 65% of world's population will be under the coverage. Cisco [4] estimated on their Global Mobile Traffic Forecast that by 2021 cellular networks' traffic will be offloaded to Wi-Fi in a ratio of 2:6. Sixty percent of total mobile data traffic was offloaded onto the fixed network through Wi-Fi or femtocell in 2016.

The imminent revolutionary fifth generation of mobile communications symbolizes a smart, connected and intelligent generation. 3GPP [3] defined various enabling technologies for 5G. 3GPP defined the concept of small cell and network densification through its various releases along with D2D, LTE TDD-FDD joint operation including Carrier Aggregation, etc. Small Cells was supported in the HSPA and LTE systems alongside macrocells. Switching to Small

cells/femtocells/picocells, strong radio evolutions [3] and advancing access technologies will complement the capacity, throughput, costs, smooth interactions with the macro coverage layer, etc.

This paper is organized as follows; Section II and III will introduce the concept of Ultradense Network and Small Cells respectively and discuss their key characteristics, and associated challenges. Section IV, will discuss some performance metrics and Section V, will cover key challenges and section VI will summarize potential technologies and research area and finally, in Section VII paper will be concluded with the findings.

## II. ULTRADENSE NETWORK

Ultradense network (UDN) is one of the preeminent solutions to support the infrastructure refurbishment to meet intensified demands. The network densification or UDN is the result of deploying small cells, within the macrocells. It is defined as the networks having a high density of access points than active users i.e. a network where the radio resources are in higher density as compared to current networks [5-7]. Considering different works of literature, UDN can be quantitatively summarized as a network with cell density greater than 1000 cells / Km squared [9]. In [5-6], it is characterized by shorter inter-site distance and sub-linear capacity growth, significantly as higher BS density causes higher interference [10]. Access nodes are placed in closest proximity to the users so provide seamless connectivity.

### A. UDN Basic Architecture

Densification refers to the addition of more sectors to macro Base Stations [14] to expand the network by deploying small cells/femtocells/picocells as fully-functional base stations. The deployed base stations are called the iBS-Individual Base Stations. These are replicas of the macrocell with reduced transmit power to provide coverage to a smaller region [9]. Some deployments have extensions to Macrocell-Access Points, referred to the Remote Radio Heads (RRH) to extend signal coverage with some or all physical layer functionalities. *Figure 1*, summaries key features of different types of small cells.

UDN is different from the traditionally deployed cellular networks in terms of footprint, active/idle mode, interference occurrence, frequency reuse pattern, backhaul connectivity, etc. [5, 8-10]. The iBS are deployed close to end-users with smaller coverage area and active sleep mode. Network densification is classified into Vertical and Horizontal

densifications depending on the cell deployment either on the elevated or the lateral planes [9]. It is also classified into Centralized and Decentralized based on the cell-interaction. Figure 2, explains the Densification classification.

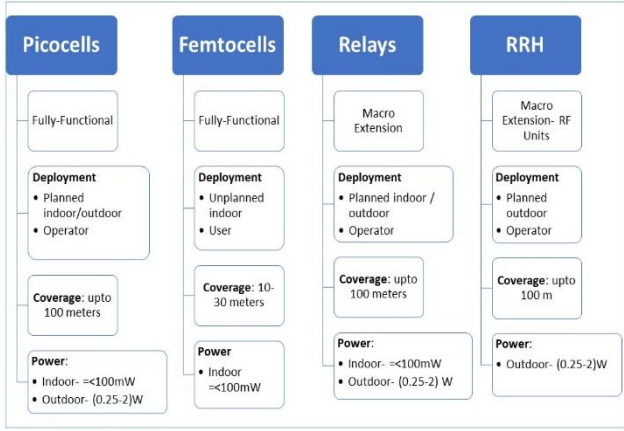


Figure 1 Types of Small Cell

The performance of the network varies with different classification and thus, it requires a different modelling approach [9]. The vertical densification provides better spectral efficiency for the same area as compared to the horizontal densification. In centralized densification, there is a central node that controls other nodes wherein the decentralized approach distributed nodes are coordinated and require D2D communication links [22].

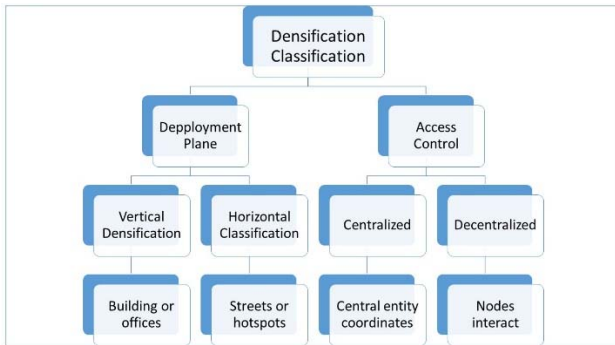


Figure 2 Densification Classification

## B. Enabling Technologies

To provide the ubiquitous connectivity and meet the 5G and beyond expectations, a plethora of technologies play a vital role. The following section discusses some of the prominent technologies and associated challenges for network densification.

### 1) Software-Defined Network (SDN)

Software-Defined Network, reformulate the network architecture to integrate 5G and beyond needs, by incorporating agility and flexibility to the existing network [23]. The ideology behind SDN is to separate the control plane from the network hardware and articulate external data controller. Network Densification through SDN deployment eliminates multiple infirmities like operational costs, energy consumption, increased signalling overheads, backhaul, etc.

by proving programmable capabilities and reconfigurability [9][23].

### 2) Massive IoT Environment

IoT services include a wide range of communication infrastructure including human-to-human (H2H), human-to-machine (H2M), machine-to-human (M2H) and machine to machine (M2M) etc. With such network demand for ubiquitous connectivity and the exponential increase in the number of smart devices, it is required to have technologies such as artificial intelligence, cloud and edge computing, information sensing, etc. to provide a platform for all interconnected services [20].

### 3) Massive MIMO Networks

Massive MIMO signifies spatial densification with hundreds of antennas equipped into the base stations. This will accommodate more users to available resource unit of a given BS and thus yield huge gains. These networks are robust and are high in reliability, throughput and Energy Efficiency [19-20].

### 4) mmWave Networks

The high-frequency bands in the have the potential to support large bandwidths and high data rates, ideal for increasing the capacity of wireless networks due to the short wavelengths. These networks provide large bandwidth, good isolation, better co-existence due to directional antennas, spatial multiplexing gains, etc. [18].

### 5) Multi-Radio Access Technologies

Multi-Radio Access Technologies (Multi-RAT) indicates the coordinated existence of different RATs to enhance the quality of service. In [24], described the technique to offload the traffic to the WiFi layer to mitigate delay using optimized RAT selection algorithms and the offloading mechanisms. WiFi nodes have delivered rates akin to cellular technology. Mobility management, data splitting and control flow across cellular and WiFi nodes is critical and is an open research area.

### 6) Proactive Caching

Proactive caching is the predictive storing of popular content in the BSs or the user equipment (UE) to serve the user demand to this content in peak traffic loads [14]. The storing of such content occurs in off-peak periods to alleviate the load on the wireless and backhaul resources [15]. Advances in context-awareness, social networks, storage, secure communications, and D2D communications have a great influence on the potential gain of content caching, and the efficient use of resources in general [16][20]. The design of caching schemes to be implemented in dense networks requires the understanding of the spatial and social structure of such networks [14].

Following are different types of UDN;

#### 1) Ultra-Dense HetNets

Ultra-dense HetNets are densified network of heterogeneous access nodes which includes the traditional high-power macrocells, low-power small cells and other non-cellular communication systems like WLAN, D2D, LPWAN, etc. to meet the high demands for coverage and connectivity. These networks have enhanced coverage, capacity and optimized exploitation of frequency resources through spatial reuse [20].

#### 2) Ultra-Dense C-RANs

Ultra-dense C-RANs are the densified network with a cluster of Remote Radio Heads (RRHs) and Radio Frequency parts. RRHs are deployed at the baseband and the RF parts are separated by connecting remote units [20]. Ultra-dense C-RAN is a cost-effective network with improved spectral and energy efficiency due to the centralized resource allocation.

### 3) Ultra-Dense D2D Networks

Ultra-Dense D2D Network is the one with a large number of D2D enabled users. The data transmission is taking place among the devices bypassing the base stations or core network. The benefits of these networks are increased Spectral and Energy Efficiency, reduced communication delay, network load and power consumption [20].

### C. Challenges

UDN is a network with sub-linear capacity growth, as the base station density increases with an increase in the impact of the interference. Interference is one of the major issues in UDN as it becomes severe with high volatility [18]. Active and idle cell states help in improving Energy Efficiency and reducing interference. Optimal resource management in UDN is critical. Failure in optimized resource allocation can lead to high interference situations, which has the potential to trigger issues like unbalanced load distributions, and higher power consumption, etc. [11, 18]. Other challenges in UDN is maintaining QoS with the mobility and handovers. In Multi RAT, QoS is challenging in the simultaneous connection in different RATs [24].

## III. SMALL CELL

With the 4G LTE and upcoming 5G networks, small cell technology has evolved as one of the critical pieces [13]. It has shown remarkable results in enhancing coverage and capacity in densely populated scenarios [3, 12]. These are low-powered Base Stations deployed at closer proximity to the user, unlike traditional macro Base Stations. Small cells intend to increase capacity, improve network performance and service quality in the areas remain in the outage [14] and complements macrocells.

The prediction is that the number of small cells deployed will grow exponentially in the coming years. The small cell technology also provides solutions for outdoor network densification. Small cell technology provides a cost-effective network solution to eliminate the outages with enhances bandwidth. They are one of the promising technology to make room for 5G and beyond networks [12].

### A. Key Characteristics

Small cell relates to a network having a dependable coverage, enhanced spectral efficiency, improved capacity, better user experience and performance. It is mainly deployed to solve network capacity issues in the outage-subsets of the macro base stations. Data transmission is improved in small cells as they are capable of transmitting at different bands of both licensed or unlicensed spectrum [11, 14]. This capability of reusing the available spectrum allows small cells to be deployed in high density, increases the overall spectral efficiency of the network in addition to the network bandwidth and speed. These are integrated into the macro networks to spread traffic loads. Few of the other advantages of small cells are that they are easy to install. Small cells draw less power, thus the mobile handsets have extended battery life [13]. Small cell ensures seamless connectivity by occupying less

space. They break down a larger site footprint to several smaller cell sites and accommodate more users per unit area.

### B. Types of Small Cells

Depending upon the decreasing transmit of the base station power, antenna position and the region, small cells are referred to as macro-, micro-, pico- and femto-cells; listed in order of decreasing base station power [14] and summarized in Figure 3.

<b>Femtocells</b>	<b>Max Range 10 metres</b>
<ul style="list-style-type: none"> <li>Capacity: Few users</li> <li>Deployment: indoor/ homes</li> </ul>	
<b>Picocells</b>	<b>Max Range 200 metres</b>
<ul style="list-style-type: none"> <li>Capacity: max 100 users</li> <li>Deployment: Large indoor/ shopping malls</li> </ul>	
<b>Microcells</b>	<b>Max Range ~ 2 kilometres</b>
<ul style="list-style-type: none"> <li>Capacity: &gt;100 users</li> <li>Deployment: Outdoor/ Street Lights</li> </ul>	

Figure 3 Types of Small Cells

### C. Basic Architecture and Deployment

Small cell hardware is discrete and energy-efficient. Small cell installation consists of small radio equipment and small antennas and is usually placed on existing infrastructures such as streetlights, the sides of buildings or poles. Small Cells can be deployed indoors and outdoors. Installation requires; Power source; Backhaul connection to the core network; and Installation place. Small cells can be deployed broadly as Passive Distributed Antenna Systems, Active Distributed Antenna Systems, Concealed integrated Metrocells or Multibeam Antennas and Sector Splitting [11, 15], summarized in Figure 4.

<b>Passive Distributed Antenna System</b>
<ul style="list-style-type: none"> <li>Inside a large Building</li> <li>Takes feed from the macrocell and then distribute it over fibre throughout a building or outside space.</li> <li>A dedicated radio base station connected to a DAS.</li> <li>Off-loads traffic from the macro network</li> </ul>
<b>Active Distributed Antenna System</b>
<ul style="list-style-type: none"> <li>Large campus areas, malls and airports</li> <li>Optical repeater which converts electrical signals into optical signals for wider reach. It then translates optical signals back into EMF waves in a selective manner.</li> </ul>
<b>Concealed Integrated Metrocells</b>
<ul style="list-style-type: none"> <li>Street lights and poles</li> <li>Mini macro sites and Easy Installation</li> <li>Flexible and scalable.</li> </ul>
<b>Multibeam Antenna and Sector Splitting</b>
<ul style="list-style-type: none"> <li>Using twin beam or multibeam antennas, a sector is splitted into two.</li> <li>Capacity doubled using single antenna.</li> </ul>

Figure 4 Small Cell Deployment

### D. Challenges

Where, small cells complement the main macro base station with extended functionalities, on the other hand, it brings additional complexity to the network design. Small cells challenges are different from those of conventional towers. Identification of potential locations for deployment is

one of the key concerns with small cells. The well-equipped network design team are responsible for identifying locations and installations taking into consideration the location of existing fibre and the physical application of the small cell itself [15, 17]. The paradigm shift from the single base station (Macro stations) approach to ubiquitous connectivity with small cells of hundreds of thousands of base stations, demands the network be transparently and securely across licensed and unlicensed spectrums [14]. Some of the key challenges for small cells are Self-organization, backhauling, handover, and interference. These challenges will be discussed in detail in the following section concerning ultra-dense deployments.

#### IV. PERFORMANCE METRICS

Following are some of the key performance metrics used in modelling Small cells in ultra-dense networks.

##### A. Coverage and Outage Probability

If the SINR (Signal-to-Interference-and-Noise-Ratio) of the randomly selected user in a network is above the threshold then it is termed as coverage probability or the success probability. The SINR value, lower than the threshold value, it is termed as Outage Probability and describes a situation of weak or no connectivity. These probabilities define the quality of the link between the user and the serving BS. This value is significantly associated with User Association [7], Propagation models [18] [26] and Estimation of the UDN Economics [9] [26] [27].

##### B. Average Spectral Efficiency

Spectral Efficiency is defined as the average number of transmitted bits per second per unit bandwidth. Spectrum Efficiency is one of the critical performance metric in 5G dense scenario as Spectrum is a scarce resource and demand is increasing exponentially. The significance of this metric is directly associated with User Associated [7] [26], Interference management [29], Backhauling issues [17], Cost Estimations [9] [27], etc.

##### C. Area Spectral Efficiency

Area Spectral Efficiency is defined as the average achievable data rate per unit bandwidth per unit area. It is an important metric to calibrate the performance of a densely packed network. It is significantly associated in User Associated [7], Propagation modelling [18] [26], Interference Management [29] and Energy Efficiency [30] [31].

##### D. Network Throughput

It is defined as the average number of successfully transmitted bits per sec. per Hz. per unit area [31]. It is closely associated with the calculation of Area spectral efficiency and outage probability. Network throughput holds significance in determining Energy efficiency [30] [31].

##### E. Energy Efficiency

The energy efficiency is a performance indicator that compares the achievable rate to energy costs. It is defined as network throughput to the power consumed per unit area [30]. Energy Efficiency is significant in Interference Management [29], Backhauling issues [17], and Propagation modelling [18] [26].

##### F. Fairness

It indicates the evaluation of a given cell association, scheduling, or resource management scheme between

different users. It determines the efficiency of any scheme implemented for resource management or allocation [17].

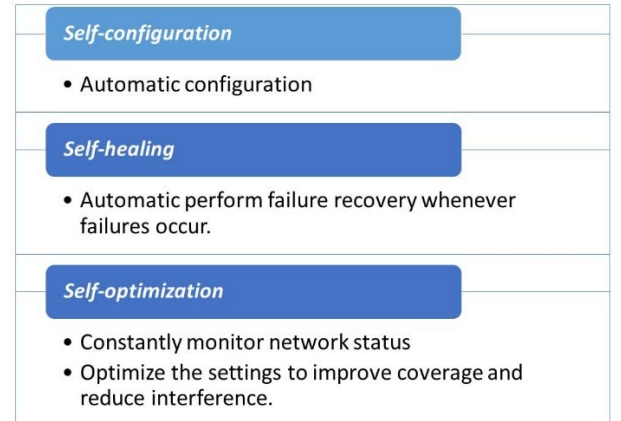
#### V. OPEN RESEARCH AREAS

##### A. Spectrum

For Mobile Operators, Spectrum is the key asset and its availability decides coverage. As the requirements are defined, 5G design has to support a wide range of spectrum from 400MHz-90GHz irrespective of spectrum bands i.e. licensed, unlicensed or shared [25]. Under mmWave, the operating frequency is 24-30 GHz with a data rate of 5Gbps and it estimated that higher frequencies will bring more spectrum. Increased spectrum allows users to have an enhanced data rate of 10Gbps. Dealing with high frequency is very critical because of the short propagation distances. Path loss is eminent in higher frequencies. Therefore, it is important to design adequate measurement devices and feasible modelling schemes.

##### B. Self-organization

The cell operations are dependant on self-organizing functionalities with picocells and femtocells, where operator supervision is not required [11]. Self-organising cells must consider various types of coexisting cells and the network parameters before deployment. The self-organizing capability of small cell networks can be generally classified into three processes, and is summarized in *Figure 5*.



*Figure 5 Self-Organizing Cell Types*

##### C. Backhauling

Backhaul network design in UDN environments is a major issue because of the coexisting cells. Operators can not guarantee an ideal high-speed low-delay backhaul for each small cell [9, 12]. For instance,

- Picocells require access to infrastructure with power supply and wired network backhauling, which may be potentially expensive.
- Femtocells, with lower backhauling costs, may face difficulties in maintaining the quality of service (QoS) since backhauls rely on consumers' broadband connections.

Therefore, network backhaul must be planned to yield benefits in terms of costs and Quality of Service. Backhaul technologies can be wireless or wired or both, with dedicated interfaces to the core network [7-9, 11].



#### D. Handover

Efficient Handover guarantees seamless uniform connectivity. It allows users' free movement within and outside of the cell coverage. The probability of handover failure increases the probability of user outage. It also helps in balancing the traffic load [9].

#### E. Interference

Interference management is very critical in context to the deployment of small cells in a dense environment. Densely populated Mobile Base Stations will cause strong inter-cell, intra-cell and inter-user interferences because of closely associated cell boundaries. This inter-cell interference degrades network performance. Interference issues are much critical in small cells UDN because of the co-existing of multi-tier cell sites. The restricted access control associated with picocells and femtocells may lead to strong interference scenarios in both uplink and downlink since users may not handover to the nearest cells [8-11].

In Release 15 [11], 5G-TDD systems at the network as well as MNO front are synchronized to mitigate Interference between the uplink and downlink. There have been many enabling technologies like permissive techniques, such as Inter-cell User-Association, Interference Coordination, Coordinated Multipoint, and Coordinated Scheduling to mitigate the challenges of Interference to enhance overall service and performance.

### VI. CONCLUSIONS AND FUTURE DIRECTION

Upcoming 5g and beyond networks are coupled together with an enormous amount of devices and data traffic. fueled by the forecasts of the imminent traffic. To meet future networks' demand, the densification of the network is the leading candidate. In this paper, we have summarized the concept of UDN, small cell and different considerations important for small cell deployment. The fundamental differences between the UDN and small cell from traditional and HetNet cellular networks. We have also listed challenges and some potential technologies and strategies.

Finally, based on the existing research efforts and other leading techniques, we have identified some potential challenges and open research directions that still need further investigation and study. One of the challenges in the accurate modelling of UDNs is the consideration of vertical densification where the small cell BSs are densified in the elevation plane. Effective network planning is essential to cope with the increasing number of mobile broadband data subscribers and bandwidth-intensive services competing for limited radio resources. To combat the increased complexity, manufacturers have built automated optimization and configuration tools into devices, and they have integrated multiple networking protocols and frequencies into a single package. Innovative frequency reuse techniques are required.

In UDN environments, there would be a need for a paradigm shift in the frequency reuse concept. Drastic interference between neighbouring cells is a limiting factor, thus strict interference management and awareness schemes are needed to mitigate the interference of neighbouring cells. With the scarce spectrum resources, one vital and long-term solution is to increase the reuse per unit area of the existing spectrum.

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## BIOGRAPHIES



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