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Network densification in 5G: A Review

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Abstract: **Network densification is an essential mechanism expected to enable next generation 5G networks to meet the 1000-fold increase in capacity. This article explores network densification as the key mechanism for wireless evolution over the next decade. Network densification includes Spectral densification (densification over space) and spatial aggregation (densification over frequency). Key enablers of network densification such as heterogeneous network, D2D, NSC are discussed. Challenges associated with network densification such as energy efficiency, interference, handoff are also discussed.**

Keywords - Network densification, D2D, NSC, Heterogeneous networks, Energy efficiency.

I. INTRODUCTION

Technological developments have led to a number of changes in the way mobile and wireless communication systems are being used. Smart gadgets are not only being used for images, voice and video transmission but also for important services such as e-banking, e-learning and e-health. These advances in the field of wireless communications are expected to flood traffic volume, which is anticipated to increase a thousand-fold over the next decade. Also, the augmentation of IoT will also contribute to the expanding traffic volume. Wireless industry foresees this trend to continue for several years to come.

Growth of wireless system capacity can be attributed to three main factors: increase in the number of wireless infrastructure nodes, increased use of radio spectrum, and improvement in link efficiency. Consider the equation based on the capacity of an additive white Gaussian noise (AWGN) channel, the throughput of a user in a cellular system is upper-bounded by

$$R<C=m\left(\frac{W}{n}\right)\log_2\left(1+\frac{S}{I+N}\right)\text{bps} \qquad (1.1)$$

where W denotes the signal bandwidth of base station, n (load factor) denotes the number of users sharing the same base station, m (spatial multiplexing factor) denotes the number of spatial streams between a base station and user device(s), and S denotes the desired signal power, while I and N denotes the receiver interference and noise power, respectively. By employing additional spectrum signal bandwidth can be increased, which leads to a linear increase in data capacity. Cell splitting can be used to decrease the load factor n ($\geq$ 1) which involves deploying a larger number of base stations, and ensuring that user traffic is distributed evenly among all the base stations. Spatial multiplexing factor m can be increased using a larger number of antennas at the base station and user devices Network densification is an essential mechanism expected to enable next generation 5G networks to meet the highly anticipated 1000-fold increase in capacity. Network densification is a combination of spatial densification (which increases the ratio m/n) and spectral aggregation (which increases W). Spatial densification is realized by increasing density of base station in a geographic area and by increasing number of antennas per node while ensuring uniform distribution of users among all base stations. Spectral aggregation refers to using larger amounts of electromagnetic spectrum, spanning from 500 MHz into the millimeter wave bands (30–300 GHz). Network densification includes densification over space and frequency

II. 5G STANDARD

5G is a packet switched wireless network standard with wide area coverage and high throughput.5G technology employs Code Division Multiple Access (CDMA) and Beam Division Multiple Access (BDMA). With 5G, data can be transmitted over wireless broadband connections at a rate of 20 Gbps and offers a latency of 1ms or lower for applications that demand real-time feedback. 5G also enable a sharp increase in the amount of data transmitted over wireless systems due to the available bandwidth and advanced antenna technology. 5G also offers network management features such as slicing in addition to features like capacity, latency. Network slicing allows mobile operators to create multiple virtual networks within a single physical 5G network.

A. 5G Architecture

5G architecture is highly advanced, its network elements and various terminals are characteristically upgraded to operate in different heterogeneous access networks.

1) Master Core: Different radio access technologies can be handled by master core. A core can be convergence of different technologies like nanotechnology, Parallel Multimode (PMM) technology, cloud computing and cognitive radio. It is based on All IP Platform and 5G-IU.
2) Master core Technologies: Different technologies that come under master core technologies are Parallel Multimode (PMM), All IP Network, Nanotechnology, Cloud computing.
3)Parallel Multimode (PMM): Master core can operate in parallel multimode i.e. it can operate both in All IP Network mode and 5G Network mode. All IP Network mode controls all network technologies of RAN and DAT (Different Access Technologies) up to 5G new technologies.5G Network mode manages all network deployment based on 5G.
4)All-IP Network: The All-IP Network (AIPN) is an evolution of the 3GPP system to meet the increasing demands of the mobile telecommunications market. wireless operators are moving to flat IP network architectures in order to meet customer demand for real-time data applications delivered over mobile broadband networks,
5)Nanotechnology: Nanotechnology is the application of Nanoscience to control process on nanometer scale. i.e. between 0.1 and100nm.The field is also known as molecular nanotechnology (MNT). It deals with control of the structure of matter based on atom-by-atom and molecule by molecule engineering.
6)Cloud Computing: Cloud computing is a technology that uses the internet and central remote server to maintain data and applications. In 5G network this central remote server will be our content provider. Cloud computing allows consumers and business to use applications without installation and access their personal files at any computer with internet access.
7)5G-IU:5G Interfacing Unit is used between new deployments and the core network so that 5G wireless can be easily manageable.

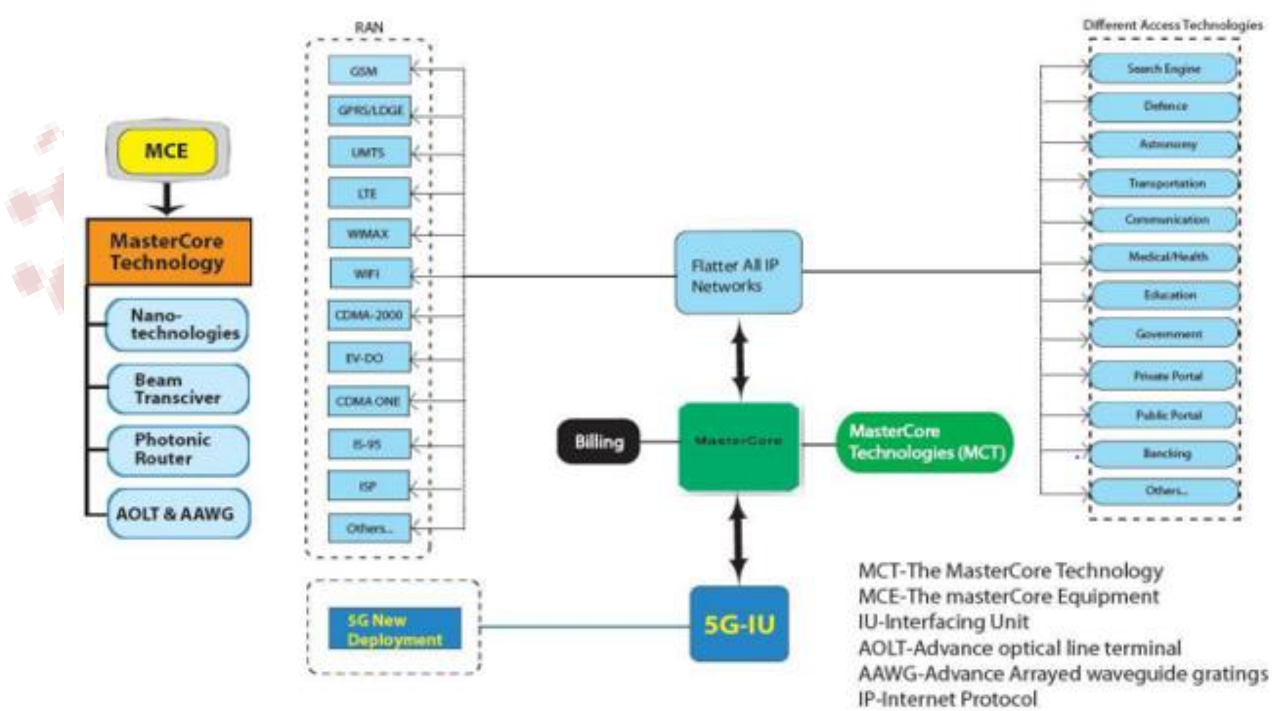

Figure1: 5G Master core Architecture

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III.SPATIAL DENSIFICATION & SPECTRAL AGGREGATION

A. Spatial densification

Spatial densification can be implemented either by increasing the number of antennas per node (user device and base station) or by increasing the density of base stations employed in a geographic area, while ensuring nearly uniform distribution of users among all base stations. Some of the state of art technologies for implementing spatial densification are discussed below.

1)Heterogeneous Networks: Dense deployment of infrastructure nodes is very much obligatory in reducing the load-factor n in the capacity equation, and for augmenting the signal power S. However, disposition of additional macro base station leads to an increase in cost and elaborate site planning. Conventional cell splitting can be replaced by low power nodes i.e., small cells, which may be employed indoors or outdoors. Outdoor small cells, commonly known as picocells, typically provide a transmit power of 30 dBm. Picocells have much lower capital expenditure (CAPEX) and operational expenditure (OPEX) compared to macrocells due to the small form factor and low power rating. Relay nodes may be deployed instead of picocells at locations where wireless backhaul access is required. A relay node is used not only to provide access to mobile users but also to backhaul data to anchor station with wired backhaul. It appears as a pico base station to the user equipment (UE) and UE device to its anchor base station. New network design challenges may come into picture when same carrier frequency is being shared between macrocells and small cells. If the handoff boundary between cells is based on the received signal power at the UE, many UE devices that are very close to a picocell find themselves in the service area of a macrocell. This leads to severe uplink interference at the picocells. Moreover, picocell coverage is greatly shrinked by the high-power transmission from the macrocells leading to a gross underutilization of low-power nodes. Cell range expansion (CRE) is devised to address this problem. CRE overcomes this problem by biasing handoff boundaries in favour of small cells, causing most users to be served by the cell to which they are closest. Downlink interference can be overcome by resource partitioning techniques.

2) Neighbourhood Small Cell: Picocells are mostly deployed by cellular operators in a (semi-) planned manner, incurring some cost in terms of site acquisition/rental, provisioning of backhaul, and so on. Neighbourhood small cell (NSC) provides a more cost-effective approach to spatial densification, and is a key attribute for addressing the 1000x challenge associated with 5G.

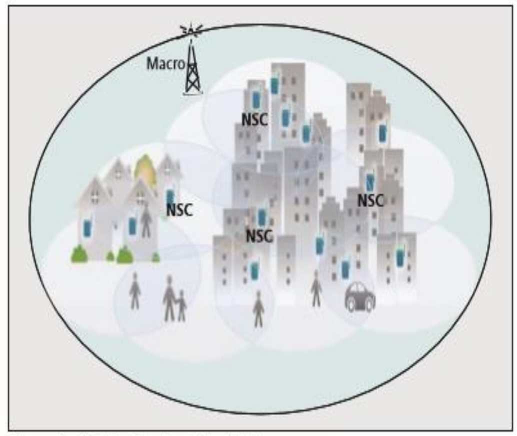

Figure2: Neighbourhood Small Cell Deployment

As illustrated in Figure 2, an NSC network consists of small cells deployed (mostly by end users) in urban/suburban homes, small offices, and enterprises. Deployment of NSC involves no site acquisition and minimal RF planning, and uses existing broadband backhaul (digital subscriber line, DSL/cable) for core network connectivity. These attributes foster the NSC network deployment with much-reduced cost compared to macro/pico deployment. Indoor-to-outdoor coverage is the key functionality of an NSC network, that is, indoor small cells providing coverage to outdoor user. Gains can be improved further using Self Organising Network (SON) techniques for interference management. SON enables spatial network densification by reducing or eliminating the need of RF planning and enabling plug-and-play deployment by end user.

Broadly, SON have the following characteristics:

• Self-configuration: Network-listening and UE feedback for neighbour-cell discovery.

· Mobility management: Robust mobility in NSC is provided by SON-optimized hand over techniques thereby coping with more challenging handover requirements.

· Backhaul load balancing: SON maintains user quality of service (QoS) through dynamic load balancing based on backhaul bandwidth availability.

3)Device to Device(D2D): Device-to-device (D2D) communication allows nearby devices to establish local links so that traffic flows directly between them thereby bypassing the base stations. D2D communication can upgrade the user experience by reducing latency, power consumption, increasing peak data rates, and creating new proximity-based services.

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Dense spectrum reuse can be made possible by D2D communication. Therefore, base station is no longer the traffic bottleneck between the source and destination.

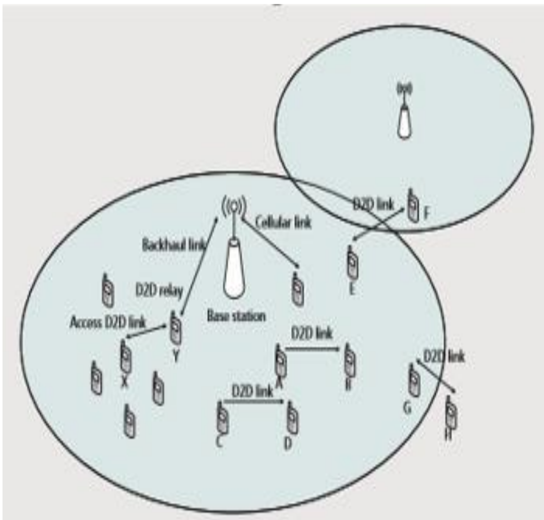

Figure 3: Illustration of D2D communication

Multiple D2D links (A-B, E-F, and G-H in Figure 3) share the same bandwidth simultaneously, thereby augmenting spectral reuse per cell beyond 1. Irregular interference topology with large signal dynamic range is a consequence of the ad hoc nature of D2D communication. In Figure 3, A transmits directly to its desired target B rather than the nearest neighbour D, although A is closer to D than to B which is referred to as restricted association. This creates significant interference at D, making its SINR much lower than 0 dB. In some scenarios the interference is notable that even OFDMA is ins to isolate interfering D2D links because of receiver desensitization. The carrier sense multiple access with collision avoidance (CSMA/CA) protocol used in the Wi-Fi system can be used in such scenarios.

An interesting use case of D2D is relay for traffic offloading, where a device with better geometry to the base station acts as a relay for another nearby device, illustrated in Figure 3. If the cellular link of X is weak, a D2D link can be established between X and Y, which has a much better cellular link.

4) C-RAN: As the mobile telecommunications industry move towards 5G, the amount of traffic traversing the network is exploding. One of the ways network operators are coping with humongous data traffic that will come with 5G is to transform the radio access network (RAN) which in essence, means centralizing it or placing it in the cloud. Spatial network densification can be enabled through the ultra-dense deployment of distributed radio antennas. Cloud-based radio access networks (C-RANs) is anticipated to be the enabler of network densification through the disposition of distributed Remote Radio Heads (RRHs).

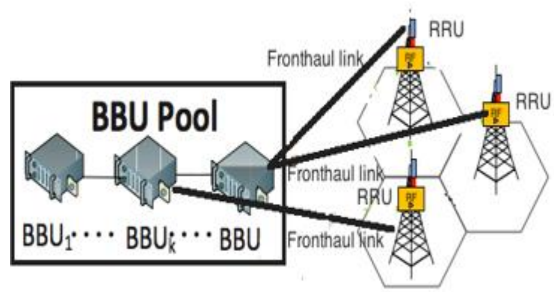

Figure 4: C-RAN Architecture

In C-RAN baseband processing unit (BBU) is decoupled from the remote radio head thereby empowering for centralized processing and assignment of radio resources. RRHs are geographically distributed and each RRH is connected with the cloud BBU pool via a front-haul which is usually a fibre optic cable which is illustrated in Figure 4.

B. Spectral aggregation

Spectral aggregation refers to using larger amounts of electromagnetic spectrum, spanning all the way from 500 MHz into the millimeter wave bands (30–300 GHz).

1)Spectrum Availability and Multiband Operation: The wireless industry is facing a spectrum crunch due to the seemingly ceaseless surge for mobile broadband data. Conventionally, spectrum has been made available for mobile broadband usage in two distinct ways:

•Bands that can be auctioned, licensed, completely cleared of incumbents, and brought online in a reasonable timeframe. This includes the cellular bands in 700 MHz, 1800 MHz, 2100 MHz, 2600 MHz, and so on.

•Unlicensed spectrum that can aid offloading traffic from licensed bands on a best effort basis. This includes the 2.4 GHz, 5 GHz, and 60 GHz bands.

Licensed or authorized shared access (LSA or ASA) is a licensed spectrum sharing paradigm that allows for network-level coordination between incumbents and licensees that use the band for augmenting cellular capacity with predictable QoS. ASA is a binary system wherein the ASA spectrum right holder has an exclusive right to use a given portion of the spectrum when and where it is not used by incumbents. At any given location and at any given time, a specific channel in the spectrum will be used by either the incumbent or a single ASA rights holder. An ASA controller provides all the information necessary for a licensee to operate within the interstices of the frequency band whenever and wherever incumbents are not using it, and to move off of the spectrum quickly when and where incumbents need to operate. ASA is completely transparent to the user device, requiring no protocol changes whatsoever. From its perspective, operating on ASA band should be no different from operating on any licensed band.

C. Caching

Majority of today's mobile network traffic is contributed by internet data and this will only continue to increase in size over the next decade. However, studies show that a significant portion of data that is accessed online are redundant, which comprise a large portion of the mobile multimedia traffic. Redundant content, such as a popular internet video, are generally small in number with large file size. Therefore, storing the redundant content onto intermediate servers will effectively reduce the amount of duplicate transmissions. Caching will also aid Internet service providers (ISPs) by diminishing the amount of inter- and intra-ISP traffic and also by reducing latency in the network. Moreover, reductions in network traffic leads to increased EE and less interference in the network. Important issues for enforcing caching mechanisms include:

- Determining caching storage location where the data has to be stored, either at the evolved packet core level (EPC) or at the radio access network (RAN) level.
- Determining what content has to be cached based on parameters such as contents popularity
- Determining how long to store cached content in memory by selecting the appropriate caching policies. Potential popularity, suitable storage size and locations are some of the factors that can be considered for caching.

D. Control and Data Plane Separation (CDPS)

Current cellular architectures are characterised by tight coupling of control and data planes. However, as network densification surges this approach proves to be problematic due to the increasing overhead of control signalling and high capacity requirements of the backhaul. Energy Efficiency (EE) also decreases as BS with no active users cannot enter idle mode, instead BS must retain control signalling. To surpass these problems, Control and Data Plane Separation (CDPS) is advocated for small cells and D2D communications. In this case macro BSs will continue providing the synchronization and control signalling to all UEs in range, whether they are served by a macro BS or by a small cell BS. Small cells BSs are accountable for providing user plane signalling to their connected UEs. Such a scheme would increase the adaptability needed to implement energy saving.

E Backhaul Densification

Network densification can enhance the data throughput between base station and wireless device. But in order to have enhanced user experience, the base stations need to be appended to the core network through high capacity, low latency backhaul. There are two main mechanism by which backhaul technologies would evolve to support the 5G wireless system. One approach is the Cloud-RAN architecture, while the second mechanism is wireless backhaul technologies. With spatial densification it is possible to deploy small cells in locations such as lampposts, building walls, and utility poles. Providing wired backhaul to these locations is found to be cost prohibitive.

Wireless backhaul provide a feasible solution by connecting the edge nodes (small cells) to aggregator nodes (called feeder links), and then to the gateway nodes (called aggregation links), which have fiber backhaul to the core network. The sub-6 GHz spectrum has often been used for LoS/NLoS feeder links, and the microwave/millimeter-wave spectrum for the LoS aggregation-links. Possible capacity improvement techniques for wireless backhaul include:

• Reducing pilot overhead and channel feedback rate by exploiting large channel coherence time and high SNR, while operating at high modulation order such as 4096-quadrature amplitude modulation (QAM).

• Implementing single-user spatial multiplexing (MIMO) on each (NLoS) feeder link, with end node locations optimized for MIMO.

· Using distributed/multi-user MIMO techniques for spatial multiplexing among LoS links extending from each gateway node to multiple aggregator nodes.

• Exploiting massive spatial processing for millimeter-wave bands, fostering large beamforming/null steering gains, and dynamic spectrum sharing between access and feeder links.

IV. CHALLENGES

Some of the major challenges associated with network densification are discussed below.

A. Interference management

Managing interference in HetNets remains one of the most challenging problems associated with network densification

A. Interference management

Managing interference in HetNets remains one of the most challenging problems associated with network densification. These problems escalate when BSs of different coverage footprints, access schemes, and transmission powers share the same licensed frequency spectrum. To illustrate this, consider a two-tier HetNet, composed of a macro base station (MBS) tier and a small cell base-stations (SCBS) tier.

A SCBS connect to the cellular network via a backhaul which is a broadband communication link such as Digital Link subscriber (DSL). Interference in such two-tier HetNet can be categorized into two types.

1)Co-tier Interference: Co-tier interference, also known as intra-tier interference, outlines the interference between BSs belonging to the same tier in the network. The main cause for this interference is due to the fact that SCBSs are deployed randomly in high density at small distances of separation. Given that no orthogonal sub-channels allocation is used, SCBSs will interfere with each other when sharing the same spectrum band as illustrated in Fig. 4. Case (1) shows uplink co-tier interference of small cell user equipment (UE) interfering with a nearby SCBS. Case (2) illustrates downlink co-tier interference of an SCBS interfering with a nearby small cell UE.

2) Cross-tier Interference: Cross-tier interference, also known as inter-tier interference, outlines the interference occurring between network elements belonging to different tiers; in this case, it is interference between MBSs and small cell UEs, and interference between SCBSs and macro UEs. Such interference arises due to mainly two factors: the large difference between transmission powers employed by each tier and the asymmetric path-loss and coverage offered by each tier. Fig.4.1 shows various case scenarios. Case (3) illustrates downlink cross-tier interference between an MBS and a nearby small cell UE. Case (4) shows downlink interference from an SCBS with a macro cell edge user. Case (5) shows uplink cross-tier interference occurs when a macro UE is at the cell edge and needs to transmit at high powers to compensate for the high path-loss and shadowing effect. Lastly, case (6) shows uplink cross-tier interference between a small cell UE and a nearby MBS.

B Energy Efficiency

Energy efficiency (EE) is defined as the ratio of area spectral efficiency to the total consumed power in a network. While network densification is seen as an effective method of increasing system capacity and coverage, such gain comes at the expense of increased power consumption. Challenges facing EE in dense networks can be categorized into three types:

- Large number of base station deployment
- Deployment strategy
- Operation mechanism

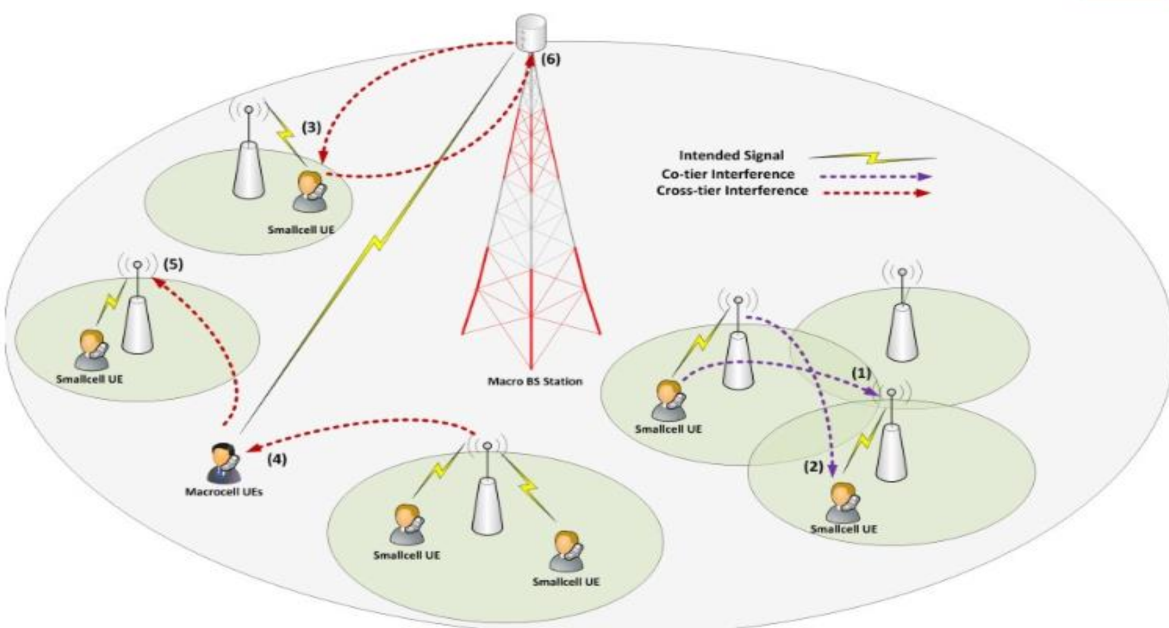

Figure 5: Different cases of intra and inter tier interference in uplink and downlink scenarios.

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C. Handover and mobility management

The handover process in cellular networks enables a UE that is already connected to a serving cell to transfer its connection to a neighbouring cell while maintaining quality of service at an acceptable level. Network densification intensifies the already existing challenges of managing handovers for mobile UEs. Since SCBS coverage is much smaller than that of MBS, handovers for mobile UEs are much more frequency. Due to the variety of coverage footprints of HetNets, a mobile UE cannot use the same set of handover parameters as those used in a homogenous network. Instead, a mobile UE must use cells specific handover parameters. Another factor aggravating the problem occurs when handover decisions are based solely on the received signal strength at the mobile UE (downlink). Since downlink transmission powers for macro and small cells are disproportionate, handovers might be unnecessary performed. Hence, it is required to simultaneously consider both downlink and uplink which could be challenging. Furthermore, the mobility of UEs traveling at different speeds is a major factor that must be considered in the presence HetNets with large dense deployments of small cells. Triggering suboptimal handovers could occur for high mobile users. Thus, consideration of mobility and received signal strength of users should be included for inter-tier handover decision.

V.CONCLUSIONS

Network densification includes densification over space (dense deployment of small cells) and frequency (utilizing larger portions of radio spectrum in diverse bands). Rapid penetration of wireless connectivity, almost exponential increase in wireless data (multimedia) usage and proliferation of feature-rich smart devices are gradually setting the stage for next major cellular evolution towards 5G. Next generation 5G wireless systems are already promising a manifold increase in data rate, connectivity and QoS. A plethora of new applications, like IoT, smart grids and IoV are expected to be supported under the umbrella of 5G systems. In this paper, master core architecture of 5G which can operate in parallel multimode (PMM) is discussed. Key enablers of spectral aggregation such as Heterogeneous networks, NSC, D2D, C- RAN are explored. Spatial aggregation can be enacted by ASA, which is a licensed spectrum sharing paradigm that allows for network-level coordination between incumbents and licensees that use the band for augmenting cellular capacity with predictable QoS. Apart from spatial and spectrum densification, there are other methods such as caching, CDPS, backhaul densification that can be used to enable network densification. Major challenges faced by network densification, such as co-tier and cross-tier interference management; energy efficiency, handover and mobility management are discussed.

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