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Enabling Key Technologies and Emerging Research Challenges Ahead of 5G Networks: An Extensive Survey

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***Abstract*— The evolution towards 5G networks is expected to slake the growing thirst of internet traffic with improved Quality of Service (QoS) and reduced energy consumption and cost. The increased penetration of smart devices and induction of arising multimedia applications, together with high quality video services are already crafting a milestone on existing cellular networks. These surging demands dictate that radical enhancements need to be made in cellular architecture to drift towards ultra-dense networks. The 5G system is envisioned to achieve improved data rate, increased capacity, decreased latency, and enhanced spectral efficiency in order to provide technical solution for the challenges behind the cellular networks. Thus, the 5G era is emerging to quench the increasing demand for network capacity, to manage explosive growth of traffic patterns and to face the challenges caused by the proliferation of versatile applications and high-end devices. In this paper, we make a broad survey on 5G cellular network architecture and some of the promising key technologies such as cloud RAN (Radio Access Network), Software-Defined Networking (SDN), Network Function Virtualization (NFV) and modulation formats. Finally, this ground-breaking survey highlights major existing research issues and possible future research directions in the next new era of mobile wireless networks.**

***Keywords*— 5G networks, cellular network architecture, key emerging technologies, technical solution**

I. INTRODUCTION

The last decade has seen the fabulous explosion of mobile data traffic, primarily influenced by ever-increasing usage of smartphone devices and flexible services such as mobile video conferencing, video streaming, e-health care, Internet of Vehicles (IoVs), Internet of Things (IoTs), and Device-to-Device (D2D) communication. The cellular network services will be exploited by more than 50 billion connected devices by the end of the year 2020 [1-2] which causes a remarkable rise in mobile data traffic according to the visual network index report from CISCO [3-4]. In addition, the number of devices could reach the hundreds of billions by the time 5G comes into reality. This exponential growth of mobile data results in several challenges, which have shifted the research focus towards 5G wireless networks [5]. Such challenges have already spawned the advent of the key technologies of the 5G systems with numerous benefits. The upcoming 5G network is expected to bind all the emerging applications like IoVs, IoTs, Cloud Computing and D2D communications in a common network, which results in new paradigm known as “socio-5G network technologies” [6].

Beyond 4G, the future pervasive communication system is envisaged to transform the way we design and use wireless networks to handle the complex operations depicted by a tenfold increase in traffic, with high mobility and interference. Supporting the exponential growth of data usage and seamless connectivity is a really deterring task for conventional cellular networks. The evolution of wireless networks has seen a transformation from traditional macro cells covering a wide area to the deployment of many small cells to fulfill the coverage and capacity requirements of future cellular systems. The intention of deploying enormous amount of small cells in 5G wireless networks is to handle the unpredictable growth of traffic caused by an increased number of powerful devices that are with internet capabilities [7]. In this context, it may not be stunning to see that the number of base stations may exceed the number of subscribers in the near future. The vision of our future is a networked society with abundant access to internet data traffic, which is reachable everywhere and every time for everyone. To fulfil this vision, the next generation 5G networks need to be a converged technology of evolved and revolved multiple RANs.

1.1 Issues in Conventional Cellular Networks

Conventional cellular networks consist of tightly coupled control and data planes in the same RAN. They are designed to guarantee the ubiquitous coverage with present wireless channel regardless of the spatial and temporal demand of service. This customary architecture satisfies the requirements of global coverage and spectral efficiency only for voice-oriented services. The explosive growth of data traffic awesomely brought a paradigm turn from voice-traffic to data-traffic. Current mobile networks are not significant enough to support massively connected devices with low latency and enhanced spectral efficiency [8-9], which will be decisive in the future 5G wireless networks. In addition, they are not able to sustain the diverse range of services with different Quality of Service (QoS) requirements and the usage of high-end portable devices efficiently. Thus, a new RAN architecture with a logical separation between control and data planes is seen as a promising approach to overcome these issues in next generation 5G systems. Conventional cellular networks lag far behind in the following aspects, thereby provoking the cellular evolution towards 5G networks [10].

- No support for exponential growth of data traffic [11]
- Inefficient for powerful devices with different quality requirements [12]
- Greater co-channel interference in full duplex radio [13-14]
- Degradation in the QoS offered to the indoor users because current cellular networks have only single base station installed at the centre of the cell irrespective of the location of the users [8].
- Lack of network solutions for a diverse range of devices with improved software services [15].

According to recent forecasts and worldwide deliberations, an incremental advancement of current cellular systems, may not be sufficient to satisfy the ambitious targets being identified for the 2020 era. Escalating capacity and coverage needs dictate that future cellular networks need to take critical steps towards ultra-dense networks. The use of highly dense networks is an encouraging way to meet the data rate demands of an emerging application [16]. However, cell densification comes with a cloud of confronts that include conceded energy efficiency, cumbrous mobility management, complicated interference management, troublesome signalling costs, and higher backhaul costs. Thus, Long Term Evolution (LTE) cellular network is currently exploring openings of different research initiatives in emerging technologies like, Massive MIMO, cell densification, millimeter wave communications, Cloud RAN, SDN, NFV, HetNets and smart antennas to enhance the system capacity and spectral efficiency [17].

1.2 Vision and Motivation towards 5G

A growing number of mobile devices, increased penetration of D2D communications and data hungry video streaming applications force the present cellular networks towards the deployment of small cells from the standard macro cells. 5G is envisioned to provide the platform to connect miscellaneous devices to the internet, thus, supporting the IoTs with decreased latency and enhanced energy efficiency [18]. In addition, it offers extra network functions to achieve extra-long battery life and scalability to connect and route signals among billions of devices. Currently, almost all wireless communications use spectrum in 300 MHz to 3 GHz band [19]. The key essence of 5G wireless networks lies in investigating the unused, high frequency mm-wave band, ranging from 3 to 300 GHz. Thus, 5G will allow utilization of any spectrum and any access technology for the best delivery of services [21, 22]. There are number of aspects that make 5G attracting, including the use of millimeter wave spectrum, virtualization in the core network, the possibility of IoTs and the software centric cellular architecture to provide a massive connectivity with cost and spectral efficiencies [20].

To adopt 5G in connection with the global market demands, 5G Public Private Partnership (PPP) focuses on communications infrastructure with a European Union budget of € 700 million for research and development of the coming decade [23]. The 5G PPP will deliver solutions, architectures, technologies and standards to successfully compete in global markets and open new innovation opportunities for the next generation communication systems. To achieve these goals, the European Commission, together with major stakeholders such as industry manufacturers, telecommunication operators, service providers and researchers, initiated the 5G Infrastructure PPP [24].

In order to understand the challenges and research issues behind 5G, it is very essential to first pinpoint the requirements of 5G system. The following items are the major requirements [25-27] identified from the research activities undertaken by industries, academia and research organizations.

The three essential requirements for developing 5G wireless networks are:

1) Capable of providing ubiquitous connectivity and huge capacity
2) Support for an increasingly diversified use cases with diverging requirements
3) Effective use of all obtainable non-contiguous spectrum

Wireless industries and research unions have initiated research activities in different factors of 5G wireless systems to meet the above requirements. 5G technologies will need to be capable of delivering 10 Gbps speed to guarantee the QoS requirements of bandwidth-intensive and delay sensitive multimedia services. With a surplus of services, devices and technologies, the focus of the network operator is offering diverse range of attractive services with strict QoS requirements while maximizing resource utilization to achieve cost and spectral efficiency. Thus, the vision of 5G networks is to meet the following requirements of subscriber and enterprises.

- High data rate: more than 1 Gb/s data rates to support high data rate demands of emerging applications
- Zero latency : less than one millisecond latency to adopt real time applications in future scenarios
- Seamless connectivity: maximum of 10 millisecond handover delay between different RANs to ensure seamless delivery of services [28].
- Massive capacity: expand to support several hundreds of billions of devices and applications.
- Energy efficiency: Decrease in energy consumption of the devices has become significant in 5G networks in order to satisfy the battery capacity and health concern of the users [29], [30].

The above- stated benefits and vision of 5G wireless networks inspired us to present this comprehensive survey. The rest of the paper is systematized as follows: Section 2 enumerates the detailed explanation of the architectural solutions for user centric 5G network such as Network densification/HetNets, cloud RAN, SDN and NFV to increase the network capacity of 5G networks. In section 3, technological solutions such as smart antenna array, massive MIMO system and modulation candidates relevant to 5G wireless networks are presented. The open research problems and future research directions are pointed out in section 4. Ultimately, section 5 concludes the survey.

II. Architectural Solutions

To meet the ever-growing demands of internet user and to surmount the challenges behind the requirements of 5G systems, a radical change in the design of cellular network architecture is needed. The vision of 5G networks forces the traditional cellular network to move from base station centric to user centric network paradigm [31]. Since the 5G technology is expected to support 1000-fold data traffic, 100 billion connected devices, and diversified use cases with different QoS multimedia applications by 2020, extensive improvements have to be made to standardize the network architecture of the next era of wireless networks. Future networks are visualized to connect miscellaneous devices with different quality requirements in different proximity.

To envision a 5G network in the market, a revolutionary action is needed in the strategy of designing the 5G cellular architecture [32]. Since the 5G cellular architecture is envisaged to be heterogeneous, it must comprise macrocells, microcells, femtocells and picocells [33- 34]. Small cell densification is a key component of next generation networks, which allows spatial reuse of spectrum by reducing the cell size. Due to the rarity of spectrum, lower power small base stations are deployed in the same band as macro base stations to reach the goals of 5G system such as massive connectivity and capacity. Naturally, the co-channel interference becomes an inevitable issue in the Ultra-Dense Networks (UDN), which will slowly make the current air interface obsolete. Configuration and maintenance of network components are a challenging issue in ultra-dense environment. SDN presents a viable solution to this complex challenge. These software components segregate the data and control planes, thereby reducing hardware constraints of 5G networks. It also requires the support of multiple BS for data transmissions. Coordinated Multi Point (CoMP) transmission ensures the cooperative data transmission, in which the amount of data and control information distributed among the transceiver nodes through the backhaul network.

In this section, we turn our attention on the technical enablers such as UDN, cloud RAN, SDN, and NFV in order to address the technical challenges and issues behind the design of network architecture for 5G. SDN allows open control interfaces and software-defined control to reconfigure and optimize the network functions. In addition, operators will be able to decrease time to adopt new services and provide an efficient provisioning of network resources. Software-defined control architecture offers the efficient utilization of spectrum and energy resources to reduce Capital Expenditure (CAPEX) and Operational Expenditure (OPEX). Cloud RAN is a key technology to meet the capacity demand of mobile data traffic and to tackle the CAPEX and OPEX burden faced by service providers in future wireless networks. In cloud RAN, data and control signals can be directed through different nodes, different spectrum and even different technologies to handle the network density and diversity efficiently. To realize the vision of 5G era, the architectural solutions based on emerging technology components such as HetNets, Cloud Radio Access Network (C-RAN), Software-Defined Networking (SDN) and NFV need to be surveyed for the advancement of surviving wireless technologies.

2.1 Network Densification / HetNets

Cell densification composes a forthright and effective approach to increase the capacity of cellular networks by reusing the spectrum across a geographical area. The network operators are trying to meet the escalating data demands of internet users by deploying number of small cells instead of utilizing a traditional macro cell alone as shown in Fig.1. Thus, a two-tier architecture is employed as a process of network densification in [35-36], where a macro cell stays in the top-tier and small-cells work under the control of macro cell in the lower tier. Since the macro cell covers the different kinds of small-cells e.g., femtocell, picocell, and microcell, they transmit the signals at a low power and serve as an essential element for the traffic offloading from the macro cells. However, low power cells can improve the QoS performance of macro cell edge users by shortening the distance between transmitter and receiver.

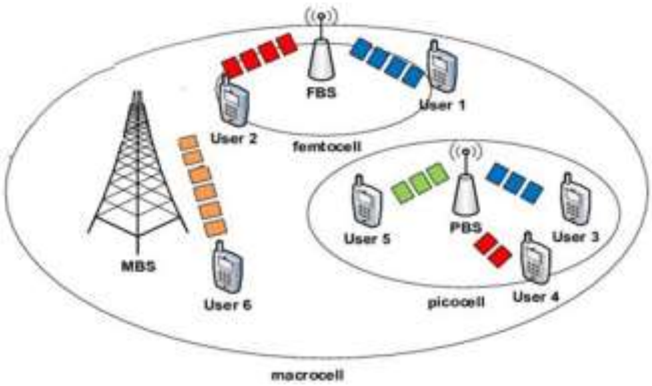

Fig.1 Cell Densification

Wireless network operators are trying to handle the wireless traffic explosion, by overlapping different kinds of small cells located within a macrocell area that is simultaneously served by one Macro Base Station (MBS), results in Heterogeneous Networks (HetNets) [37-39]. The 5G cellular networks need to be more heterogeneous to satisfy the capacity of cellular networks in dense areas with high traffic demands. HetNets are usually comprised of small cells, having low transmission power, besides the legacy macro cells. Moreover, the overlap of all small, pico and femto cells with the prevailing macro cells, leads to enhanced network capacity and spectral efficiency [40]. Smart coupling between multiple RATs guarantees the enhanced system capacity and coverage in HetNets [41]. The components of heterogeneous infrastructures should be well managed to meet the future internet requirements [42-45] by introducing intelligence that provides a solution to manage the technical and complexity issues of 5G HetNets.

Heterogeneous small cell networks have great potential to enhance network capacity and energy efficiency significantly. However, this could be drastically degraded by inter/intra-tier interference and traffic imbalance among densely-deployed small cells. Therefore, it is necessary to provide optimization between the transmission power of a macro cell and the coverage area [46]. If the transmission power of a macro cell is high, then adjacent mobile devices in the small-cell may find themselves to be connected with macro cell, and hence, the resources assigned to the small cell will be under-utilized. There are two sources of inter cell interference in HetNets: the mutual interference between a macro call and each small cell and the mutual interference among small cells. The first source of interference is due to the overlapping between a macro cell and small cells, is called inter layer interference [47]. On the other hand, the second source is called intra layer interference, which establishes when SBS coverage areas are themselves partially overlap with each other. As networks become denser, inter tier/cell interference between macro cells and small cells increases due to multitier interference.

The deployment of HetNets requires a coordinated operation between traditional macro cells and small cells for mutual interference reduction. Unfortunately, an underlaid structure in which MBSs and low power small cells reuse the same spectrum could lead to severe inter-tier interference. Hence, it is critical to suppress both intra-tier and inter-tier interference. Although intra-cell interference has been reduced by using Orthogonal Frequency Division Multiple Access (OFDMA) and efficient radio resource management techniques, establishment of an underlaid structure in an ultra-dense environment will again produce intra-cell interference in addition to inter-cell interference [48]. Interference levels and signalling overhead can be eradicated by using advanced coding and modulation schemes, successive interference cancellation techniques, advanced Inter-Cell Interference Coordination (ICIC) schemes, massive MIMO, user/control plane decoupling Coordinated Multi-Point (CoMP) transmissions and cloud processing [49,50]. Thus, cooperation and coordination are the favourable solution for interference management in an underlay system. Current interference management techniques mainly involve mitigation, cancellation, and coordination. The first two techniques are well suited for intra-cell interference, whereas for multi cell scenarios, coordination techniques are preferred. CoMP is a key feature for mitigating inter-cell interference, thereby increasing the sum rate and cell-edge performance in HetNets. However, cooperation will need to be limited to few cells only due to additional overhead required by CoMP due to Channel State Information (CSI) exchange, scheduling complexity, and additional backhaul limitation. Hence, small CoMP clusters will need to be formed in the network. This inter-cell interference has less effect on cell-centre users and severe effects on cell-edge users. In future cellular systems, interference management will be an unavoidable issue due to heterogeneity, spectrum reuse and network densification. Moreover, cloud based intelligent handoff and location management can ensure seamless connectivity by minimizing the interference levels in HetNets [51].

The second architectural revolution is the decoupling of the data and control plane due to the confined coverage of small cells in an UDN [52]. Mobile users would be crossing cell boundaries very often in a UDN. It results in an enervating signalling cost due to handovers and cell reselections. Frequent handovers and reselections can be reduced by segregating the data and control signals, thus the signalling overhead can be minimized. It is expected that macro cells will cater for the transmission of control signals while the user data is tunneled through different small cells within the macro-cell coverage. This can be achieved by using software defined networking functions and techniques. SDN is an emerging technology that decouples the control and data plane by separating control decision entities from control elements. This grants the 5G network with high data rate without incurring control signals overhead at any time and everywhere [31]. To alleviate these issues in multiple Radio Access Technologies (RAT), an efficient RAT handover decisions and interface management techniques are presented in [53].

UDN offers numerous benefits to reach the requirements of 5G networks. They are:

- Efficient reuse of spectrum across a geographical area to improve the spectral and energy efficiency [54]
- Decrease in the number of users competing for resources at each BS, which in turn increases the network capacity and enhances the cell edge users performance [55]
- Cost efficient SBS installation without any burdensome planning as compared to a MBS[35]
- Increase in data rate by decoupling the data and control planes separately[52]

Even though UDN offers prominent benefits of the 5G network as mentioned above, there are some realistic issues as follows:

- Increased costs of installation, maintenance and backhaul [56]
- Frequent authentication is required due to frequent handoff operations [57]
- Greater inter cell interference due to multitier architecture [55]
- Increased signalling overhead as the number of nodes increases dramatically [58]
- Complexity in determining appropriate associations between users and BSs across RATs [51]

Two-tier heterogeneous network, suggested in [59], assures advanced network performance by co-locating Massive MIMO BS and low-power small cells. Massive MIMO acquires traditional benefits by guaranteeing outdoor mobile coverage whereas small cells act as main capacity-drivers for indoor and outdoor low mobility users. However, backhaul is one of the major bottleneck in 5G HetNets. The ultra-dense cells should be linked to the core network through the backhaul, often with requirements in terms of capacity, energy, latency and cost efficiency. In contrast to legacy wired backhaul, densely deployed small cells are expected to be associated via wireless backhaul infrastructure [60-61]. Thus, wireless backhaul links provide a feasible and cost-effective alternative.

Wang et al. [62] proposed a method for splitting indoor and outdoor users in a wireless environment. For decoupling the indoor and outdoor users, a macro cell holds large antenna arrays with antenna elements dispensed around the macro cell and connected to the MBS using optical fibers. For indoor users, Small Base Station (SBS) with large antenna arrays are deployed inside the building to communicate with the outside MBS. All the mobile terminals inside a building can have a connection either through the SBS or by using Wi-Fi, mmWave, or Visual Light Communication. Thus, the 5G architecture guarantees improved QoS to the mobile users irrespective of the location and reduces the signalling overhead on a MBS.

Duan et al. [63] presented an authenticated handoff procedure for Cloud-RANs and multi-tier architecture of 5G networks. The control layer uses an authentication handover module to select the access network based on the measurement report of the mobile terminal. An integrated multicriteria network selection algorithm based on multiplicative utility function and Residual Residence Time (RRT) estimation is proposed in [64] to keep the probability of handover failures and unnecessary handovers within the limits in heterogeneous environment. Residence time and adaptive residence time are calculated using location information in order to provide solutions for the challenges behind the integration of network selection and mobility support in HetNets. The major requirement of 5G networks i.e., achieving ubiquitous, real-time high data rate multimedia services at anytime and anywhere will be realized through HetNets.

Three types of handoffs are possible in 5G HetNets, as follows:

- Intra-macro cell handoff: represents the handoff between small-cells working under a single macro cell [63].
- Inter-macro cell handoff: refers to handoff between macro cells. It may also cause handoff between two small-cells operating under different MBSs.
- Multi-RATs handoff: refers to handoff of a mobile terminal between two different types of RATs [65].

In future cellular systems, an efficient mobility management is needed to perform handovers in HetNets in order to meet massive capacity and connectivity needs of mobile devices. Finally, it is almost impossible for any single technology to meet all the requirements of 5G networks simultaneously.

2.2 Cloud RAN

Cloud computing plays a major role in the information technology community as it provides on demand access globally to a shared pool of configurable resources [66]-[68]. In 5G networks, inter cell interference increases due to network densification and multitier architecture. Furthermore, the higher the deployment density, the higher the chance that a Radio Access Point (RAP) will be lightly loaded due to spatially and temporally fluctuating traffic patterns. Thus, the resources of all RAPs will not be fully utilized, which in turn degrades the spectral efficiency of the system. C-RAN is a promising technique to tackle this issue, which permits selectively turn RAPs on and off to address the traffic fluctuations in an ultra-dense networks. C-RAN is based on fundamentals of centralization and virtualization. C-RAN is a centralized cellular architecture that has the power to support current and future wireless communication standards. C-RAN recently attracted researchers with a possible way to centralize RAN processing efficiently [69].

C-RAN offers several benefits compared to the conventional RANs, such as flexibility and scalability. The general architecture of C-RAN is shown in Fig. 2, which consists of three main modules, namely (i) BBU pool with centralized processors (ii) Radio Remote Heads (RRHs) with antennas located at the remote sites (iii) front haul network that connects the RRHs to the BBU pool. The baseband resources are pooled at Base Band Unit (BBU), situated at remote office [70-71]. Although centralized baseband pools are already considered for efficient radio resource management and complex multi cell algorithms, these methods do not offer the same characteristics as cloud-computing platforms, i.e., on-demand access, virtualization, elasticity, resource pooling and multi tenancy. The BBU pool is comprised of BBUs that function as virtual base stations to process baseband signals and hence, enhance the resource utilization. The RRHs transfer the signals to UEs in the downlink or forward the signals from UEs to the BBU pool in the uplink for further processing. It also includes signal amplification, filtering, up/down conversion and interface adaptation. The front haul links can be implemented by different technologies, like fiber or wireless links [72]. In C-RANs, a large number of low-cost RRHs are randomly deployed and connected through optical fiber links to the BBU pool where all baseband signal processing is done [73-75].

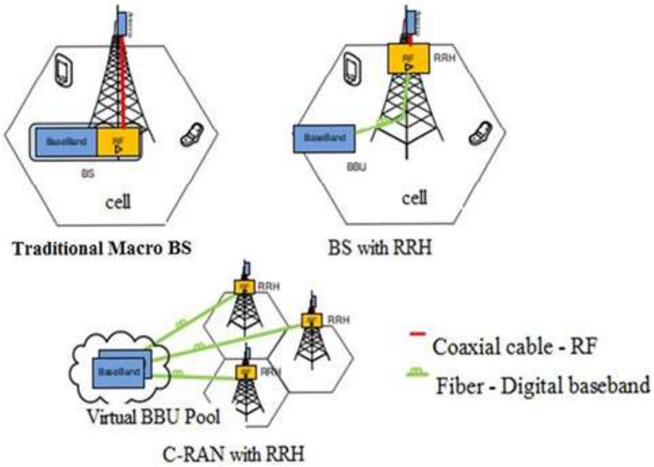

Fig.2. C-RAN Architecture

Radio signals are routed through dedicated transmission lines between RRH and data center. It requires high data rate fiber links between the RRH and the BBU. It is found to be the main drawback of C-RAN. This forces millimeter wave links a feasible option for closing the gap between wireless and fiber backhaul from RRHs to the BBU pool. They can also be used to cross obstacles like rivers or large roads, where fiber cannot be implemented because of safety or economic reasons. However, the path loss at mm Wave high frequencies is very high and the signals are attenuated further by atmospheric absorption, rain and foliage. The beam forming techniques with multi- element antenna arrays are proposed to compensate these path loss effects in mmWave radio communication.

To support cloud-RAN in 5G, it is necessary to have a system architecture that offers the required interfaces without disturbing an existing deployment. In traditional cellular networks, the cooperation among cells needs a large amount of signalling exchange, and do not perform well as expected due to backhaul delay and user mobility. However, the information exchange and central decision are able to be performed in BBU pool with minimum signalling overhead. In C-RAN architecture, the BBU pool can assess the traffic patterns of the entire network to obtain the pool of resources. It is actually calculated in terms of system performance, traffic demand, criticality of user and many other issues to determine whether the activation of the respective small cell RRH is needed or not. If some part of the macro cell covers a large number of users and the rest of the cell has a less number of users with low traffic demand, then the BBU pool can off load the users in the obstructed area by actuating the respective RRH in small cells and handle the rest of the users by macro RRH. This results in less number of handovers and thus improves the energy efficiency [76]. However, the deployment of smaller cells raises considerable challenges in energy consumption of the network. Thus, an emerging C-RAN assures energy efficient cellular operations by switching ON and OFF a subset of RRHs selectively, thus shrinking the overall energy consumption. C-RAN uses virtualization techniques to distribute the resources dynamically from the resource-pool according to the network load. Hence, the individual BBUs in C-RAN are identified as Virtual Base Station (VBS) and the whole pool is called as Virtual Base Station Cluster (VBSC).

Cloud computing offers the following benefits for 5G networks and opens the doors for new applications.

- It improves system architecture, mobility, network coverage, energy and spectral efficiency while reducing the cost of network deployment [77, 78].
- The major problems related to increasing system capacity [79] can be solved by moving RRHs closer to the users, because the signals need not to travel over a long distance to attain the users.
- With the aid of unified resource pooling, it is not necessary to worry about the availability of resources according to the individual peak load at each BS. It is more efficient in in terms of energy and cost aspects.
- The C-RAN architecture tackles the resource allocation and management issues due to spatiotemporal traffic fluctuations and hence, improves the spectral efficiency of the infrastructure [55, 80].
- Cloud based intelligent handoff and resource management can guarantee seamless connectivity in heterogeneous environment [81, 82].

2.3 SDN and Network Function Virtualization

SDN and Network Function Virtualization (NFV) are the most prominent technologies to effectively tackle the complexity issues in next generation 5G networks [83, 84]. The success of SDN is based on the systematic extraction of complex networking problems in the internet to offer unified control solutions for 5G networks. The intricacy of network management in 5G and beyond arises due to the following factors:

1) Increased data traffic, heterogeneous environment and diverse service requirements
2) The modifications in architecture and air interface due to small cell densification and added number of antennas.
3) Configuration and maintenance of many servers and routers in UDN increase the complexity of the system.

SDN offers a feasible solution for this complex challenge. The software-defined design of mobile networks could effectively tackle the complex networking problems, in order to provide optimization among heterogeneity, complexity and consistency in the network. The key ingredients of SDN are an open interface between the entities in the control and data planes, as well as programmability of the network entities by diverse requirements of applications [85].

SDN splits the overall network into overlaying control services mainly at the core network side, and the underlaying data planes mainly at the RAN side [86]. Decoupling of user and control planes, along with seamless connectivity between various diverse networks are visualized to reinforce the basis of 5G systems. SDN decouples the network control and forwarding functions, permits the network control to become directly programmable to adjust the network services dynamically [87, 88]. Increase in user data thus becomes independent of control plane resources. Consequently, the data planes will exploit the deployment of massive MIMO in order to focus energy in the desired direction to bring vast improvements in throughput and energy efficiency [89]. In addition, software-based SDN controller enables network managers to configure, manage, secure, and optimize network resources very quickly according to changing network devices and user demands via automated SDN programs. The main advantages of SDN architecture are the logical decoupling of the network intelligence to adjust the network capabilities through an application program interface, and enabling the application to manipulate services provided by the network [90].

Integration of software-defined design with RAN offers itself as a Self-Organized Network (SON) solution [91-93]. SON algorithms optimize RAN by control plane coordination at a coarse granularity, while leaving the fine granular data plane unaffected. SON can improve gain and data rate only due to the coordination of multiple BS for data transmissions. CoMP technique is used to enable cooperative data transmission in an ultra-dense environment to minimize the complexity of the system. CoMP portrays a plethora of cooperation approaches, which depends on the amount of data and control information shared by the mobile nodes through the backhaul network. Finally, SDN can be used with machine learning techniques to make the network becomes more intelligent and self-adaptive. Even though SDN represents the suitable technical solution to manage complexity issues in communication networks, several implementations and design issues such as dynamic network configuration, design of network management automation and SDN multi-tenancy [94-96] have to be addressed.

The virtualized network function allows network functions that were customarily tied to hardware appliances to run on a cloud computing platform. The separation of the network functions from the hardware setup will be the keystone of upcoming architectures. The key idea of NFV is to virtualize network functions and to make an end to-end network infrastructure in order to apply the network functions on dedicated and application specific hardware [97]. The network elements such as switches, routers, storage elements and transport resources are abstracted during network virtualization and then combined into a pool that is managed by a unified network controller. The main motivation for NFV is to decrease life cycles within communication networks through software updates rather than hardware updates, thereby to achieve cost and energy efficiency in 5G networks [98].

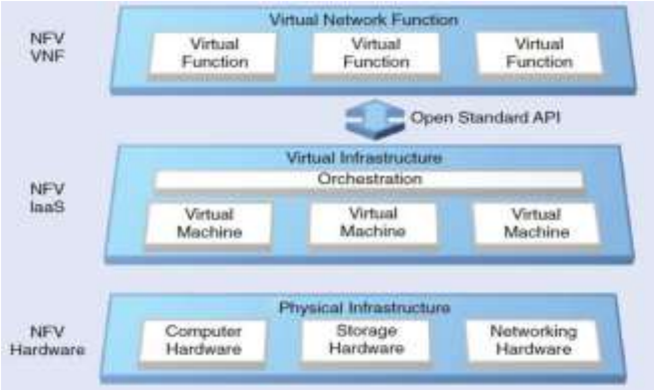

Fig.3. NFV Architecture

Fig.3 shows the NFV architecture, which allows significant agility through the creation of virtual networks and new types of network services [99]. It includes the following three components:

1) Physical infrastructure: used to separate the software that delineates the functions of network devices from generic hardware.
2) Virtual infrastructure: virtual machines are built on storage devices and generic hardware servers, connected by network switches and regulated by the orchestration. An orchestrator is hosted to allocate network resources and to assign user data and network traffic to correct locations. Thus, it supports network service lifecycle management, on-boarding of new network services, etc [83].
3) Virtual network function: automates the installation and management of the virtualized network functions on the generic hardware.

Thus, Network virtualization techniques present reduced CAPEX and OPEX costs by dynamic scaling of the network resources, improved time to market for new services, as well as extreme customizability and agility by exploiting the concept of network slicing and virtualization. Even though the combination of C-RAN, SDN and NFV bring new architectural design to future mobile networks, there are still open issues to be addressed in terms of migration from traditional infrastructures, scalability, management and security.

III. Technical Solutions

Transformation of 5G cellular architecture over present wireless system forces advancements in key technologies to make the system more effective. It is projected that wireless data traffic will rise by thousand-fold over the next decade which will be steered by the expected 50 billion devices connected to the cloud by 2020. Existing radio access solutions may not be able to satisfy these capacity demands and seem to have exhausted their potential in terms of enhancing spectral efficiency in future wireless environment. Substantial research efforts are devoted to the challenges of emerging 5G networks with the help of technical solutions such as smart antenna arrays, sectorized antenna, Massive MIMO, design of new modulation waveforms and adaptive modulation and coding techniques. Hence, it is essential to understand the physical layer concepts like the understanding of millimeter wave channel, adaptive beam forming techniques, Massive MIMO and full duplex technology. Space Division Multiple Access (SDMA) and smart antenna array are ultimately essential to mitigate the co-channel interference problem in UDN. Thus, air interface is changed from omnidirectional transmission to the concept of sectored antennas to realize the benefits of SDMA. Wireless industry is succeeding on procedures to apply MIMO techniques and multi beam antenna array with adaptive beam forming techniques to achieve the major requirements of 5G wireless networks [100]. In this section, we identify the key technologies that provide solutions to reach the requirements of 5G system, based on the concept of effective antenna array design, converting all the interference into useful signal via cooperation of surviving and new physical layer technologies suitable for 5G deployment.

3.1 Smart Antenna Array

Radio network evolution would also revolutionize the schematics of the air interface. Successful implementation of 5G networks depends on the effective antenna array design and changes in air interface to achieve reduced interference levels and improved spectral efficiency. More advanced antenna techniques are required for 5G to predict the propagation of millimeter waves at tens of GHz in ultra-dense environment. Understanding the role of beam forming techniques in the design of smart antennas is essential because it plays a vital role in effective millimeter wave communications to radiate energy in narrow and directional beams. Traditional beam forming techniques focus on maximal ratio combining and zero forcing techniques [101]. The beam-forming algorithm should provide an optimization between the desired signal maximization and interference mitigation. Large beam forming gains at the BS antenna increase the coverage, while shrinking the interference level and enhancing the link quality at the cell edges. Different configurations of antenna arrays with chosen beam forming weights control the beams to steer the energy in the desired direction. Beam forming is achievable in both analog and digital domain to make the directive beams [102]. The antenna elements in an array must be placed close together to attain the benefits of beam forming techniques. All the analog components such as phase shifters, low noise power amplifiers, etc., should be tightly packed behind the antenna elements. The coordinated beam forming solutions has been proposed in multi-antenna wireless systems to eradicate inter-cell interference with the assumption that the CSI of each mobile device is available at the BS. Beam forming can be granted on both uplink and downlink at the SBS [100]. Uplink beam forming multiplies the data received on each antenna with a weight derived from the CSI. The CSI represents the combined effect of scattering, fading and power decay with distance.

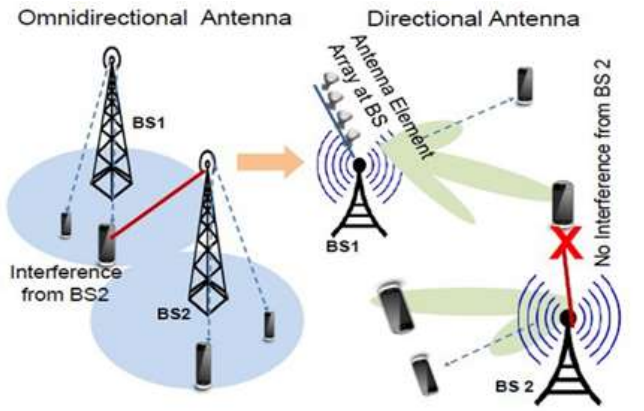

Fig.4. Beam Forming Directional Antennas [103]

Fig. 4 shows the transformation of air interface from omni-directional to directional antennas. Directional radiation patterns could be acquired by using adaptive beam forming techniques, ensuing in the introduction of SDMA [103]. Effective SDMA enhances spectral efficiency at both transmitter and receiver for beam forming antennas. Beam forming coefficients need to be trained in advance for attaining the desired spatial beam patterns, expected for effective implementation of SDMA [104]. The primary function of SDMA is empowering the adaptive antennas to steer the energy in the desired direction. Smart antennas help in interference mitigation, while retaining the optimal coverage area and transmit power reduction at both mobile device and BS [33]. Smart antenna implementation enables the same channel to be used by different beams [105-107]. This reduces the major problem of co-channel interference in 5G networks. With a multitude of antennas, it is hard to obtain the channel state information at every individual antenna element in MIMO integrated system. We present the review of MIMO concepts to the next subsection.

3.2 Massive MIMO System

The foremost and core 5G technological advancement is the millimeter wave technology, which operates on frequencies ranging from 3 to 300 GHz [108-110]. The shift towards the millimeter wave spectrum will necessitate the advanced technical concepts such as next generation antenna, massive MIMO, in order to cope up with the millimeter wave challenging problems like signal penetration, propagation loss etc. [111,112]. The current cellular architecture has a single BS installed at the middle of a cell and communicates with all the terminals irrespective of the indoor or outdoor users. Therefore, the signals will have to travel through the walls of the buildings for inside users to connect with outside BS. This is not effective in terms of data rate, energy-efficiency and spectral efficiency due to the attenuation of signals passing through walls [113]. The mobile users present outside are installed with a certain number of antenna units, together with antenna arrays of base station make virtual massive MIMO links. With overview of such an architecture, the inside users will only have to connect with inside wireless access points while larger antenna arrays remained installed outside the buildings. This will appreciably enhances the data rate, energy efficiency, average throughput and spectral efficiency of the 5G cellular system but at the sacrifice of added infrastructure cost.

Massive MIMO is based on spatial multiplexing, in which data streams from several branches are multiplexed and transmitted over spatially separated channels. Traditional MIMO is not able to attain the high multiplexing gain needed to meet the requirements of 5G, due to the limited number of antennas. Whereas, massive MIMO BS with large antenna arrays are capable of serving more number of mobile users over the same time and provide high multiplexing gain [114-115]. The uplink Multi User - MIMO system with uniform distribution of ‘K’ User Terminals (UTs) and large number of BS antennas (M) in number of cells (L) is illustrated in Fig. 5, where a BS with a few hundred antennas array serve dozens of user terminals (UTs) concurrently [116].

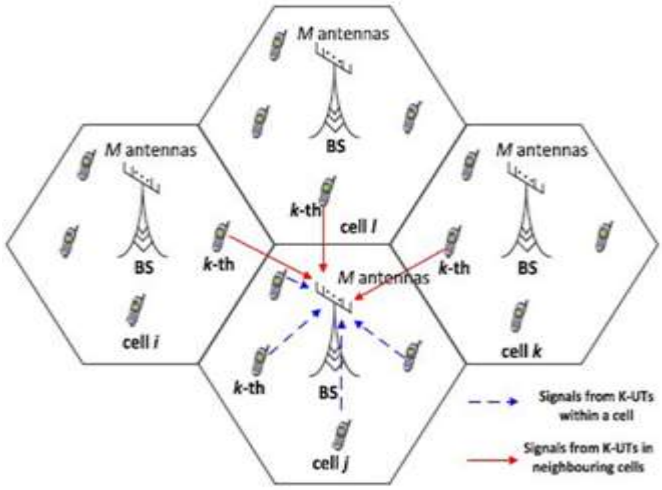

Fig.5. Illustration of Massive MIMO [116]

The BS with multiple antennas are potentially capable of sending independent data streams to multiple UTs in the same time-frequency resource. Thus, the multiuser version of MIMO is a promising technology that is expected to deliver high data rates, coverage, enhanced link quality and energy efficiency [105,106] and has therefore attracted lots of research interests. As far as energy efficiency is concerned, MU-MIMO reduces the radiated power by a factor proportional to the square root of the number of antennas deployed, while retaining the data rate unchanged [116-118]. Each BS needs accurate estimation of CSI to achieve the benefits of massive MIMO in 5G networks. Time division duplex (TDD) has been suggested as a better mode to acquire timely CSI in wireless systems over FDD because FDD requires estimation in both directions [119,120]. In a massive MIMO TDD system, the pilot signals that are used to estimate the channels can be polluted due to the reuse of non-orthogonal pilot signals in a multi-cell system [121,122]. This pilot contamination causes the inter-cell interference that is proportional to the number of BS antennas [116], which in turn reduces the achievable data rates and affects the spectrum efficiency.

Design issues to be considered for the adoption of massive MIMO system are:

- Excessive amount of signalling overhead due to coordination among different cells [57]
- Processing overhead increases as the number of antennas increases [57]
- Exploitation of different BS structure with a myriad of small antennas, operated by low-power amplifiers [123,124]
- Pilot contamination due to the reuse of same pilot signals in neighboring cells [116].

The tempting benefits offered by massive MIMO are:

- It provides high power-gain with less transmit power, hence appreciably increasing the received signal strength [51].
- It exhibits high spectral efficiency, without the need for cell densification [124].
- It allows a significant decrease in latency on the air interface [125].
- It breaks the interference barrier in future wireless networks [62]
- It mitigates the channel estimation errors and fading effects [51].

3.3 Modulation Waveforms for 5G

Orthogonal Frequency Division Multiplexing (OFDM) is one of the most prevalent multicarrier transmission techniques in wireless networks to fulfill the increasing demand for high data rate applications [126]. OFDM has been adopted in many standards such as LTE, IEEE 802.16e - WiMAX, IEEE 802.11x wireless LAN and digital video broadcasting due to their spectral efficiency and robustness to inter-symbol interference. OFDM superseded CDMA used in 3G networks due to its dominant features such as follows:

- Efficient implementation due to the use of FFT/IFFT (Fast Fourier Transform / Inverse Fast Fourier Transform) blocks at both transmitter and receiver [127].
- The ability to neutralize multipath distortion
- Robustness to inter-symbol interference and inter cell interference due to the orthogonality of subcarriers
- The ease of integration with MIMO system, since it allows for the spatial interference from multi antenna transmission
- Flexibility and simple equalizer design

This impressive list of advantages makes the OFDM as the undisputable frontrunner for 5G system. However, some limitations do exist that could become more prominent in 5G networks. It has been observed that OFDM has to tackle many confronts when it is adopted for 5G wireless networks. Actually, Cyclic Prefix (CP) is used in OFDM to reduce the inter-symbol and inter-channel interferences initiated by the multi-path propagation effects. However, the spectral efficiency of OFDM is limited by the use of a CP and by its large side lobes [128]. Since the envelope samples are nearly Gaussian due to the summation of uncorrelated inputs of the IFFT, OFDM signals may exhibit large Peak-to-Average-Power Ratio (PAPR) [129]. Therefore, it requires RF power amplifiers to be operated in the linear region. Otherwise, the signal peaks spread into a non-linear region of the power amplifier causing signal distortion. This signal distortion presents Out Of Band (OOB) radiation and intermodulation noise. Thus, it is highly desirable to reduce the PAPR in multi transmission techniques.

The difficulty in maintaining the frequency synchronization among subcarriers makes a key issue in cellular networks when base station coordination is used [130,131]. The synchronization error can affect the orthogonality and cause interference among the subcarriers. Thus, carrier and timing synchronization embodies the most exciting task in future communication systems [132,133]. Another drawback of OFDM emerges when effort is made to communicate over a set of non-contiguous frequency bands [134]. In addition, different user requirements, low latency and tangible internet demands of 5G systems make the orthogonality and synchronization issues of OFDM a big challenge. From the above contentions, it is clear that the surviving waveforms are not satisfactory to meet the vision of the 5G networks.

These drawbacks form an open and strong debate on the need to replace the commended OFDM by an efficient air interface that fulfills the challenging requirements of 5G networks successfully. At the physical layer, OFDM modulation format is not taken for granted and several alternatives with significant values of spectral efficiency are being deliberated. This section delivers a review of some of the most credited substitutes to OFDM and confers their possible interactions with the requirements of 5G networks. After a quick analysis of OFDM, the emphasis is moved on to attractive physical layer concepts such as filter bank multicarrier, generalized frequency division multiplexing, universal filtered multicarrier and OFDM with an index modulation concept.The salient features of these recently proposed modulation waveforms alternatives [155] to standard OFDM are presented in Fig.6.

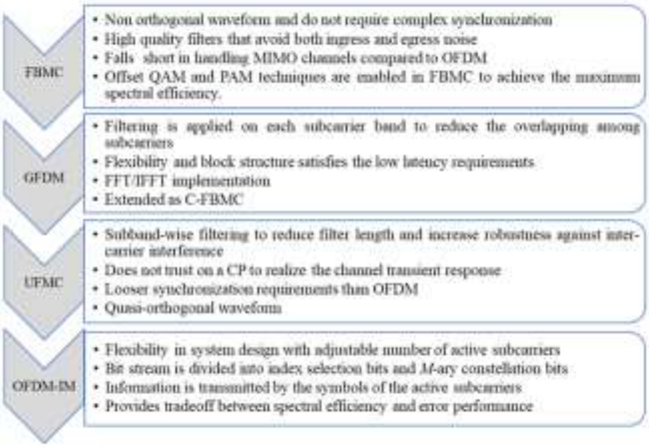

Fig.6. Modulation schemes for 5G

IV. Open Issues And Research Challenges

In this section, we discuss research issues and challenges ahead to meet the requirements of 5G networks such as high data rate, high system capacity, low latency, cost and energy efficiency.

- Interference management: In future cellular systems, interference management will be a challenge due to heterogeneity, spectrum reuse and network densification. The deployment of a large number of small cells as an overlay in a macrocell network emanates new technical challenges in terms of managing the ever increasing interference levels. Hence, it is necessary to build models and algorithms to handle the inter and intra tier interferences. Although this heterogeneity guarantees the tremendous capacity and coverage enhancements, the resulting interference will be higher as compared to existing cellular systems.

- Handoff management: The handoff process in dense HetNets may create interference to other devices and also degrade the QoS requirements. Hence, it is required to develop intelligent cloud assisted handover decision algorithms to offer a tradeoff between the number of handoffs and the level of interference in the network and to offer improved QoS to diverse range of attractive services.
- Increased antennas: The usage of multiple antennas in SBS encounter several challenges such as increased signal processing complexity, cost and physical limitations due to the implementation of small cell housings. In massive MIMO systems, channel state information linked with large number of BS antennas and coordination among different cells cause a massive amount of information exchange overhead in future wireless systems.
- Smart antenna design: Design of smart antennas is critical for effective mm-wave communications. Large beam steering antenna arrays are viewed as essential components in the 5G network design and require immediate attention from research organizations. Thus, smart antenna design depends on how efficiently beams are created, trained, steered and also computation of beam coefficients to steer the energy in the desired direction.
- Network densification: Frequency reuse is a simple and an effective way to increase system capacity in 5G networks by making cells smaller and smaller. However, there are some research challenges behind the densification of small cells: (1) High cost of installation, maintenance and backhaul (2) Greater inter cell interference due to multitier architecture, (3) Frequent authentication and signalling overhead due to frequent handovers (4) Mobility management in such a heterogeneous environment[156]. With a multitude of small cells and enormous connectivity, the limits to the deployment of small cells is the more critical issue to be solved in interference management techniques of 5G.
- Backhaul network: The backhaul is the network that links the base stations to the core network and comprises of dedicated fiber, copper, microwave, and occasionally satellite links. Even though wireless backhaul links provide a feasible and cost-effective alternative, network densification increases the complexity of the backhaul network in 5G networks. The dense deployment of small-cells requires a huge amount of data transfer and definitely, increases signalling overhead and cost of the infrastructure [157-158]. In 5G, it is expected to support often with extreme requirements in terms of capacity, latency, cost and energy efficiency. Thus, the key challenge is to offer holistic 5G backhaul solutions based on the type of technology deployed in future networks.
- Waveform design: The adoption of IM techniques into massive MU -MIMO systems and the integration of IM techniques with cooperative communication systems require further research to understand how the modulation format influences the key technologies and requirements of future 5G networks. However, more research is needed on how MIMO-OFDM-IM scheme provides an interesting trade-off between spectral efficiency, complexity and error performance compared to classical MIMO-OFDM scheme.

Technical advancements such as HetNets, C-RAN, SDN, Massive MIMO and modulation formats have attracted significant research attention from both academia and industry to meet the challenges behind aforesaid 5G network design. Key components of 5G, like network densification and user centric requirements, will enable a paradigm shift in network architecture, management and control to fulfill the expected goals of 5G networks. Thus, we believe the successful commercial roll out of 5G requires cooperation between academia and industries to uncover a plethora of new research challenge.

V. Conclusions

Rapid penetration of smart devices and the introduction of new emerging multimedia applications, together with high quality mobile video services are already daunting new requirements for 5G and gradually setting the stage for cellular evolution towards 5G in bringing emerging technologies into reality. In this survey, we provide a comprehensive review on cellular evolution towards 5G networks and essential requirements of 5G wireless systems in terms of massive capacity, high data rate, spectral efficiency, latency and QoS. This paper also pointed out the new architectural paradigm shift, associated with key technologies such as UDN, SDN, NFV, millimeter wave communication, C - RAN, HetNets, smart antennas and massive MIMO in order to understand the inherent features of enabling technologies, so as to realize the potential benefits of 5G networks. This article also provided a review of the basic principles of multi carrier transmission system, advantages and drawbacks of the popular OFDM system in wireless networks. We presented new candidate waveforms alternative to OFDM for the implementation of the air interface in future 5G communication systems. This survey will serve as a guideline to identify the major research issues and possible future research directions in 5G wireless communications. This may be offering a good foundation for the researchers to develop technical solutions for various issues in implementing the next generation networks.

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