

5G Technologies: A New Network Architectures and Design

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Abstract

To date, though promising, an existing cellular technologies deem to evolve, in the presence of great demands over the upcoming years. 5G and related technologies can address some of key objectives such as better data rate, improved capacity, reduced latency, and higher service quality. This paper introduces a novel decentralized RAN's architecture with largely dependence on LTE-A technology. The proposed design supports some prominent networking features that jointly improve the performance of both the LTE and RAN's central network. This architecture compared to that of the classic PTP backhaul design improves signaling overhead, handoff capability, overall network throughput and latency, quality of service support and data rate for users' prospect needs.

Keywords: 5G networks, Backhauling, LTE-A, Resource management, Small cell, Wifi

1 Research Background

To address the conjectures and demands of the near future, the present wireless network foundations will need to propel in different aspects. State-of-art technology principals will soon be employed as a segment of the advancement for existing technologies in wireless networks. Nevertheless, auxiliary mechanisms possibly will institute forthcoming new wireless based technologies to adjunct the advanced technologies. Specimen of these new technology constituents includes, but not limited to, advanced accessing spectrum techniques and frequency range capabilities, initiation of massive antenna configurations, unswerving device-to-device transmission, and ultra-dense utilizations [1].

From its first appearance in the late seventieth, mobile wireless communication has fallen upon from primitive technologies (e.g. analog transmissions) to present digital technologies capable of high speed and quality services that can support up to some megabits per second across large regions with mobility features [2-3]. The extensive developments with regard to a

latent power of mobile communication networks, in conjunction with the mobile device form evolution (i.e. new smart phones, PDA, and tablets), have formed a wave of novel applications with Internet-enabled ability [4], which in turn, lead to network congestion with alarming rate.

The remarkable accomplishment of current wireless mobile communication is reflected by a swift technology development. Starting with the second generation (2G) mobile communication system to the third generation (3G), the mobile wireless system has moved from a simple telephony design to a system that can support variety of multimedia content. The fourth generation (4G) wireless network system has been introduced using an IP mechanism in line with International Mobile Telecommunications-Advanced (IMT-A) requirements [5].

Employing an unconventional wireless interface in 4G systems [6] allows a comprehensive integration of existing or future mechanism such as multiple-input multiple-output (MIMO), Long-Term Evolution (LTE), LTE-Advanced systems, orthogonal frequency-division multiplexing (OFDM), and link adaptation technologies across the world. Nevertheless, there is still an outstanding number of consumers willing to utilize mobile services all around the globe each year. It seems apparent that mobile users increasingly crave for high-speed mobile Internet access, enhanced mobile devices, and, direct information access and communication. With such demand and high-tech mobile and laptops of today, wireless mobile devices and services subject to several challenges worthy of attention.

Radio frequency (RF) and its physical scarcity of spectra [7] allotted for mobile communications, for example, is one of the most fundamental challenges needed to be addressed. To enable mobile communication, ultra-high-frequency bands allocated within specific frequency range of from some hundred megahertz to some gigahertz for cellular devices. Due to limitations of available frequency spectra, service providers mainly fail to acquire an additional channel and it causes heavy network load. High energy consumption is another challenge for the utilization of

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advanced wireless technologies.

A study [8] has been stated that electricity consumption of base stations (BSs) owed by mobile operators contributes to more than 70 percent of total electricity costs. In essence, energy-efficiency of mobile communication system was neglected in an initial 4G wireless systems, yet it brought up later on as a serious challenge for mobile operators. High data rate, constant coverage, spectral efficiency, high service quality, and high mobility are to mention only a few other challenges in the field.

All of these challenges are making a heavy burden for mobile service providers who unceasingly need to respond to growing needs (i.e. higher data rates and mobility, spectral and energy efficiency, and higher network capacity) of different mobile wireless applications. This paper proposes a prospective 5G cellular architecture and argues several technologies to provide solution for demand with respect to 5G requirements.

The rest of this paper is prepared in following order. The study explains several auspicious technologies that can be implemented in 5G wireless networks. It also sheds light on a new decentralized RAN's architecture that mainly relies on LTE-A technology. Future challenges and issues of resource management in 5G small cell networks is described. Finally, conclusions are drawn.

2 Literature Review

In following sections, this paper reviews some key technologies in order to shed light on development of the future 5G wireless networks.

2.1 LTE

The pattern of perpetually expanding transmission bandwidths is arguing the current 3G system's limitation, therefore, it was chosen by the third generation partnership program (3GPP) to begin research on cutting edge wireless system design. Long Term Evolution (LTE) is the most recent standard in the mobile network technology hierarchy employed within 3GPP to make sure the 3G applicability for the next decade or so [9]. LTE supports different transmission schemes such as frequency division duplex (FDD) and time-division duplex (TDD) to allow both symmetric and asymmetric transmission [10-11].

A new base station is introduced entitles "enhanced NodeB (eNodeB)" under 3GPP standard in contrast to traditional NodeB presented by the Universal mobile telecommunication system (UMTS). By eliminating Radio Network Controller (RNC), the eNodeB base stations became more intelligent compare to the traditional NodeB by relocating the functionality to the core network gateway. LTE base stations perform

completely under IP protocol and split gateways among radio access network and core network into Serving Gateway (Serving-GW) and the Mobility Management Entity (MME). The MME is largely accountable for users' mobility, tracking mobile location, session management signaling and gateway management for mobile internet access.

2.2 LTE-Advanced

LTE-Advanced refers to the subsequent and foremost milestone in LTE development and is a fundamental solution for achieving expected growth in mobile data capacity. LTE-Advanced includes numerous scopes of data capacity improvements, including the aggregation of carriers, and advanced antenna techniques (See Figure 1 and Figure 2). However, optimizing heterogeneous networks (HetNets) gain the most which brings about superior performance using small cells.

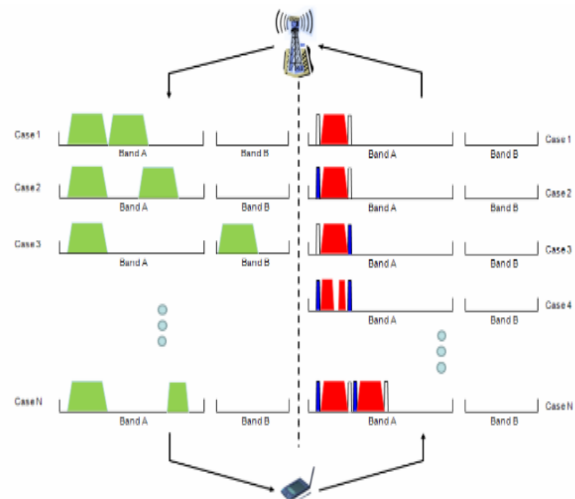


Figure 1. Carrier Aggregation Schema. The illustration shows the aggregation technique and complexity of resources allocation (e.g. determining number of Resource Blocks (RB) or identifying the HARQ process for each carrier) in the network

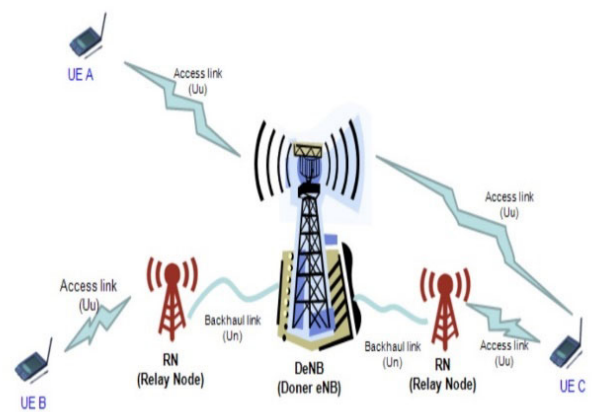


Figure 2. LTE-Advanced Network Architecture (Antenna Techniques). LTE-advanced develops a Relay Node (i.e. low power eNodeBs) to enhance data communication at cell edges

blend of low power and cost base stations and macro-cell BSs working under different bands such as licensed and unlicensed ones [20, 25].

While the placement of a large number of public access small cells (SCs) is likely to improve the radio access network’s (RAN) capacity and coverage problem [24, 26], HetNets/SCs creates a new challenge for the backhaul design. HetNets/SCs design needs to accommodate sufficient network capacity, quality of service (QoS) which is cost effective, scalable and flexible for mobile usage. To address this issue, we propose the HetNet mobile backhaul design that allows the efficient RAN incorporating core network offload techniques.

4 PON Design and Technologies

A PON is a point-to-multipoint fiber optical network with no active elements in the signal’s path [27-28]. PON involves either a single or joint optical fiber linking end users to service providers through a passive star coupler (SC), optical splitter/combiner residing at the user location. To eliminate fiber wiring cost, the SC is purposely placed close enough to the user and away from the central office (CO). A shared long fiber connects users to the CO where a short optical fiber dedicated in customer-side.

Optical Line Terminal (OLT) and Optical Network Units (ONUs) are responsible for the entire communications within a PON. All the transmissions occur from OLT to ONU are known as point-to-multipoint connection or “downstream”; and those from ONU to OLT refers to multipoint-to-point or “upstream”. The upstream transmission normally uses 1310 nm (λ_{up}) wavelength whereas downstream with 1490 nm (λ_d).

The OLT resides in CO is responsible for linking Optical Network Unit (ONU) to the backbone network. The ONU is situated at either the end-user site (Fiber to the Building (FTTB) and Fiber to the Home (FTTH) respectively) or the curb (Fiber to the Curb (FTTC) solution). A PON normally can support 16 to 64 users with employing 1: N tree, tree-and-branch, bus or ring topology.

4.1 Ring-based Architecture

The standalone architecture refers here to just the wire line segment of the hybrid architecture without incorporating the wireless segment of the small cells [29]. Figure 4 demonstrates the simple ring-based EPON design.

As shown, OLT is linked to some ONUs (N) via a 10 to 20 kilometers stem is supposed to cover one to two kilometer in diameter. There is a closed-loop point-to-point access between ONUs in a ring, which support downstream (DS) and upstream (US) signals transmission one at a time. The signals are conveyed

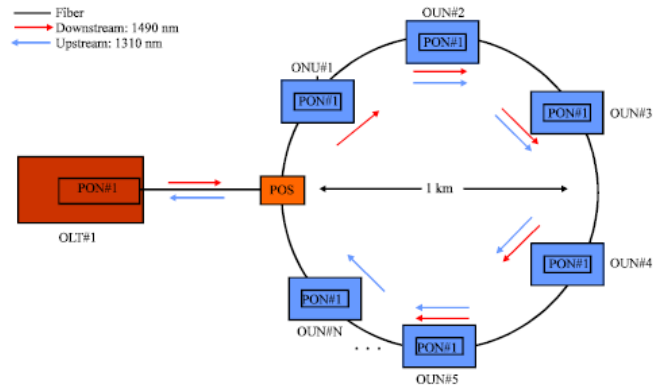


Figure 4. Simple ring-based EPON architecture

successively along the ring from one node (ONU) to another. Upstream transmission uses a time division multiple access (TDMA) system in which LAN data and control messages is transferred with upstream traffic destined to the OLT (MAN/WAN data) in a specific time frame. Therefore, additional receiver (R_x) is required aside to the conventional transceiver in ONU to handle the incoming signal.

Downstream signal is combined in optical circulator (port 2) and once joined to re-circulated US signal (via the 2x1 CWDM combiner), the joint signal, then circulates within the ring from ONU-1 to ONU-N in a Drop-and-Go mode.

There is an indefinite circulation for US signals due to the ring closed-circle till signal removal. Several stages contribute to removing, regenerating, and retransmitting of the second replica of the US signal. Firstly, the US Rx (resides at ONU) dismisses all US traffic. Later, it inspects the target MAC address of each identified Ethernet frame, and carry out one or a few of the following actions. Initially, the transmitted frames are eliminated by source node when a cycle is completed around the ring. The LAN traffic is copied and handed to the end users, after finding a match between the LAN destination address and node’s MAC address. Lastly, all remaining US traffic containing LAN and control frames (exclusive of explained LAN traffics above), is managed, regenerated, and then retransmitted to the next ONU.

5 Backhauling Structural Design

HetNet backhauling brings about different issues compare with Macro backhauling [30]. Compare to the classic integrated 2G/3G RAN structure, LTE-A/SCs-based HetNet requires profoundly unlike RAN structure. Notably, the compatibility of Coordinated Multipoint (CoMP) communication and reception methods among close macro BSs/SCs hinge greatly on the backhaul features (i.e. latency and capacity) relative to carriage medium comprising copper, optical fiber, and microwave using the RAN topology [31].

With the metro SCs being installed in large public areas [24, 27], new backhaul system can fulfill service

necessities at the lowest possible price having fiber as an optimal access technology in terms of capacity and service quality.

While fiber provides different access possibilities through Gigabit Passive Optical Network (GPON), Ethernet PON (EPON), Carrier Ethernet and dark fiber/wavelengths, it is not thoroughly accessible to all sites, and may incur more cost. Alternatively, many types of small cells with different sizes and versions exist to date. These small cells differ in terms of power, range, and number of users they can support. With their least, small cells support 3G, MIMO, LTE and Wi-Fi technologies with an ability of a backhaul connection to the cellular network and on-device power source.

Therefore, an EPON using ring-based design can be shifted to a HetNet backhaul RAN design by solely rely on existing fiber and collocating (overlying) the small cells and the macro with the ONUs using powered ONUs in relation to the PON-based FTTx residential access network [24].

Additionally, since Evolved Packet Core (EPC) is designed to be access-independent, it can support the integration of both the LTE-A SCs and WiFi access points (AP). However, the integration of WiFi APs, according to the EPC standards for 3GPP and Non-3GPP interworking, depends on whether these APs are classified as “Trusted or Un-Trusted Non-3GPP Access Networks”. Trusted Wi-Fi Networks mean that the operator install and organize the WiFi APs, in a way that user equipment can join to the WiFi network directly through the radio interface with no further security procedures.

Unlike trusted WiFi network, un-trusted WiFi neglects any trust association with the operators, in which a certain mechanism need to be applied by operators to establish a secure tunnel (i.e. IPsec tunnel) between user equipment and a trusted node in the core network. Normally, such a node is known as Evolved Packet Data Gateway (ePDG) in EPC networks. While the proposed PON-based architecture employs untrusted IP/Ethernet backhaul for both small cells (LTE-A) and WiFi APs, IPsec tunnel is required for termination/aggregation incoming connections. Figure 5 represents the ePDG location in our architecture.

Unlike the classic topology of star-based PON used in [24], we propose a ring-based PON topology utilized for fiber-based HetNet/SCs backhaul. The key features of the PON-based HetNet backhaul design is its ability of supporting an entirely dispersed panel control that allows unswerving communication ability amongst the available nodes such as SCs, BSs and ONUs. This architecture also supports scheduling scheme and signaling methods that work in a disseminated fashion (See Figure 6).

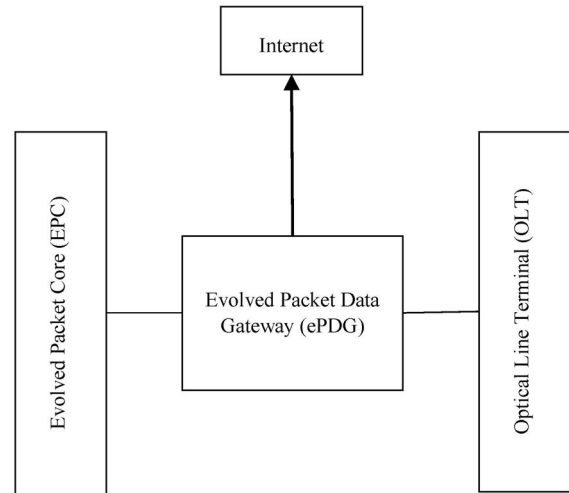


Figure 5. Evolved packet data gateway in CO site

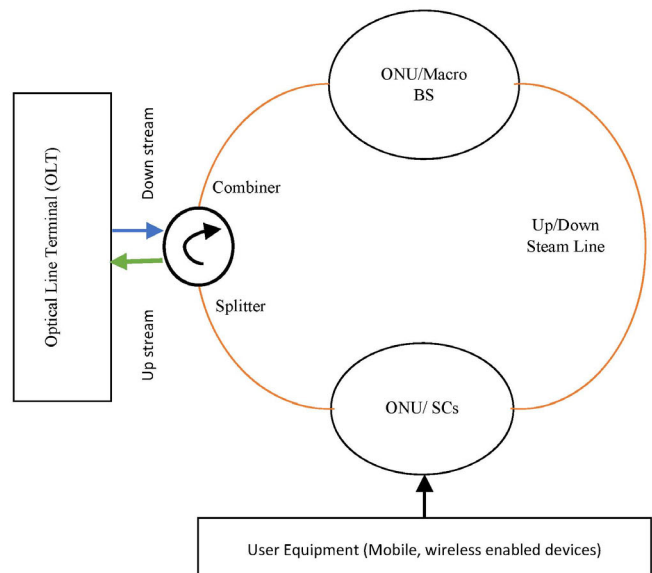


Figure 6. Decentralized RAN's architecture

It is worth to note that conventional ring design inherits several disadvantages, such as, long fiber deployment and more signal reduction as a result of longer fiber route. Moreover, due to the different distances of ONUs from the OLT, a power discrepancy is unavoidable at the OLT receiver also known as near-far problem [32-33]. Our new ring-based design, meant to address these issues using a hybrid small ring architecture, which requires less fiber and enhance the network performance.

The purposely nominated RAN using ring-based architecture enables the said design supports several prominent networking features that jointly improve the performance of both the LTE and RAN's central network. This architecture compared to that of the classic PTP backhaul design improves signaling overhead, handoff capability, overall network throughput and latency, quality of service support and data rate for users' prospect needs.

6 Backhaul Optimization Technique

Given HetNet mobile backhauling above, there are different ways to increase the data output among the wireless (mobile) devices and BS. Densification in both space and frequency is one of the key technique to enhance network performance. However, so as to transform this into an enhanced user experience, a lot need to prepare starting from connecting BSs to one another to interconnection with the core network. The researcher proposed two foremost approaches in which backhaul technologies can develop for supporting the 5G wireless systems.

The first way is to make use of the ring-based RAN architecture, which discussed earlier in this paper, and the other approach involves wireless backhaul technologies explore in this section. As it assumes in spatial densification, there are limitless possibilities to use small cells in different sites from streetlights and building walls, to industry utility rooms and silos. Given that wired backhaul to all sites may impose high cost, wireless backhaul can have a practical solution.

Wireless backhaul connects the end-nodes (small cells) to aggregator nodes or know as feeder links, and formerly to the gateway terminals named aggregation links with fiber backhaul that links to the core network. As researcher concern, some potential techniques can be used for wireless backhaul enhancement. Firstly, when performing at high modulation order (e.g. 4096-quadrature amplitude modulation (QAM)), one can employ a high signal-to-noise ratio and wide channel coherence time to moderate pilot overhead and increase the feedback rate of the channel.

Another technique that can be used is to utilize single-user spatial multiplexing (MIMO) on individual feeder link (NLoS), with end node positions adjusted for MIMO. To enhance the backhaul efficiency, a spatial multiplexing among Line-of-Site (LoS) links (in between the gateway to multiple aggregator nodes) can utilize distributed/multi-user MIMO techniques. Additionally, other techniques may include developing immense spatial processing for millimeter-wave bands, vibrant spectrum distribution among access and feeder links, and supporting wide beamforming/null steering gains.

An example of operating with high spatial multiplexing order can be seen in millimeter-wave communication in wireless backhaul context. Another example, in the lower frequency bands may be found in massive MIMO systems [34], where macro cells are furnished with two-dimensional antenna arrays, allowing multiple horizontal and vertical beamforming capabilities at the macro cells.

7 Networks Resource Management

Once optimizing the backhaul for 5G network, a

new concern would arise such as the resource management in wireless network due to the limitation of wireless resources. Studies such as in Arslan et al.'s [35] and Kuo and Liao's [36] indicated that in orthogonal frequency division multiple access (OFDMA)-based network, it is hard to achieve the optimal spectrum assignment and distribution. The first concern is about the placement of a small cell which seriously impact network performance.

Even though the SCs offload macro cell's traffic, the home evolved Node B (HeNB) cannot be installed closely. Dense deployment may result potential performance issues due to the same frequency bands usage within SCs of the traditional cellular network. While substantial number of research focused on a centralized technique to answer the deployment issue, the distributed system seems more appropriate for the small cell network.

However, using distributed method requires an effective procedure to lessen the computational complexity in relation to the spectrum assignment for achieving efficient allocation, fairness, and load balance. To address this issue, we divide the spectrum assignment technique into joint and independent modes.

Within the joint mode, SCs and the macro cell use the co-channel, where in the independent mode the different spectrum is used. As in [37], the independent mode runs algorithm on the local Small-GW with the computation complexity of $O(V \cdot E)$, in which V represents vertices and E shows the number of edges.

On the other hand, in the joint mode, the Small-GWs require information exchange among each other which needs time scheduling for the co-channel usage. The next issue is the resource allocation of 5G small cell networks. The physical technique of the small cell is the OFDMA that the incoming radios are divided into the two time and frequency fields within resource blocks (RBs).

Additionally, the assignment of resources in OFDMA is a painstaking process. A study [38] proposed an integrated downlink frequency planning across small and macro cells; yet a large number of small cells may considerably obscure the consolidated optimization procedure. To reduce the complexity of the resource management, a Lagrangian relaxation algorithm is primary presented in [39] to minimize the overall power depletion through restrictions policy used on transmission rate for users demanding for different types of services.

The study [35] developed a method for resource management named FERMI for small cell networks. FERMI offered a resource segregation technique in the frequency domain to control power pooling across cells to increase capacity. Yet, their method still requires a centralized server to uphold global information of the network.

Using plug-and-play installation and self-configuration capacity of SCs, a distributed or

hierarchical method deems more viable for the resource management problem for this study. Typically, the system inclines towards the all-out aggregation data rate and the supreme utilization. For all-out aggregation data rate [12], we assume a multiuser system with M UEs and N subcarriers. $M=[40M]$ is the set of user and $N=[40N]$ is subcarriers. We calculate D_m (data rate of the m -th user) in following:

$$D_m = \frac{B}{N} \sum_{i=1}^N C_{m,n} \log_2(1 + SNR_{m,n}) \quad (1)$$

In which B represent the entire network bandwidth available, $c_{m,n}$ represents the subcarrier assignment index signifying if the m -th inhabits the n -th subcarrier. Therefore, the objective function calculates as:

$$\text{Max}_{C_{m,n}} D_{Total} = \frac{B}{N} \sum_{m=1}^M \sum_{n=1}^N C_{m,n} \log_2(1 + SNR_{m,n}) \quad (2)$$

For maximum utilization [12], we need to understand that the utility function refers to the extent to which users are satisfied with services relative to a resource quantity given. Having different satisfaction level by the similar resource allocated, different utility functions is expected for real-time and non-realtime services in SCs and macro cell. A total of M UEs are located in a cell, including M_1 real-time users in macro cell, M_2 non-real-time users in macro cell, M_3 real-time users in small cell, and M_4 non-real-time users in small cell.

The overall source in a cell is R , r_m identifies the resource assigned to a UE m , q_m reflecting the channel quality, $0 \leq q_m \leq 1$. The resource for the user m can be specified as $r_m q_m$. The utility of the user m is $U_m(\cdot) = U(r_m q_m)$. Formerly, to maximize the aggregate utility of UEs, we calculate the optimization model for the resource allocation in following:

$$\begin{aligned} \text{Max} \sum_{m=1}^m U(r_m q_m) = & \text{Max} \left[\sum_{m1=1}^{M1} U(r_{m1} q_{m1}) \right. \\ & + \sum_{m2=1}^{M2} U(r_{m2} q_{m2}) \\ & + \sum_{m3=1}^{M3} U(r_{m3} q_{m3}) \\ & \left. + \sum_{m4=1}^{M4} U(r_{m4} q_{m4}) \right] \quad (3) \end{aligned}$$

The frequency resource allocation has been traditionally, employed to moderate the inter-cell interference in macro cellular networks [40]. Another way of reducing interference is to use the spectrum allocation policy proposed in [41] which evades cross level meddling by allocating orthogonal spectrum resources through which each SC can solely access a random subclass of the spectrum resources that are allocated to the small-tier.

In reality, small cells, may need to operate in the

same spectrum as macro cells due to infrastructure and limited spectrum availability. Further, to minimize inter-cell interference, frequency reuse [42] and inter-cell coordination [43] structures have been explored in OFDMA macro networks. The subsequent wireless network generation may also include the fractional frequency reuse (FFR) [44] system to lessen the interference issue because of the universal frequency reuse schema [45].

8 Conclusions

This work has described the main issues in relation to the transition from present Fourth-Generation (4G) cellular technology to the 5G era to explore the potential and viability of cost-effective implementation. Focusing on extra spectrum availability, extension of small-cell implementation, and evolution of backhaul infrastructure, this study has confidence in that the cellular communication industry is rightly positioned to fulfill the 1000x demand in the next ten years. This work articulates a new decentralized RAN's architecture that mainly relies on LTE-A technology. Several short-range communication technologies has been described intending to delivers a better service quality and data rate for users in future. This paper also addresses some key emerging 5G technologies that can be employed using current fiber and wireless systems for desired future performance, like MIMO, massive MIMO, and LTE Techniques. This study also addressed a new concern of the resource management in wireless network due to the limitation of wireless resources. It also formulates possible solution by introducing optimization model for the resource allocation within 5G SC networks.

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